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Excellence in Housing

conference

Innovations for Performance

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minneapolis hilton & towers
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Excellence in Housing
conference
Innovations for Performance

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A. good construction practice

THE PROCESS OF BUILDING A HEALTHIER HOUSE WITH AIR TIGHT CONSTRUCTION COMBINED WITH HYBRID MECHANICAL SYSTEMS

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ABSTRACT

A case study of building a 2,500 sq. ft. 2-story walk-out home combining the following disciplines:

1 - Healthier Building Practices
2 - Central Ventilation/A.C. Design
3 - Hydronic Heating System
4 - Duct Sealing Details
5 - Air-Sealing Details

Slide show presentation with open discussion of the following house components:

- Prioritizing the customers health concerns relating to building products.
- Building techniques for a healthier home.
- Radiant floor heating in lower level and shop.
- Fully ducted ventilation/A.C,
- The heating systems is designed for heating only.
- Ducting system is designed to operate with a heat recovery ventilator and air handler/A.C.
- Duct work in unconditioned space required unique duct sealing techniques
- Insulation/air sealing details for optimum thermal performance.

Introduction: This Paper Will Explain The Team Work And Interaction Between Builder, Indoor Air Quality/Ventilation Subcontractor And Homeowner Needed To Construct A Healthy/Comfortable Home For $100 Per Sq. Ft. We Will Cover The Following Areas:

- Customers goals/concerns relating to health and comfort
- Design/product selection
- Central ventilation/Air conditioning design
- Hydronic heating system
- Duct sealing details
- Air sealing details
- Equipment summary

Customers Goals/Concerns

The previous house that the client lived in was a super insulated 10 year old structure. This structure had the following components: Double wall construction, average vapor barrier, standard windows, no mechanical ventilation and a standard forced air heating system. Energy bills were reasonably low but there were problems with uneven heating in the lower level and severe moisture condensation on the windows in cold weather.
Because of these previous experiences their goals for a new home were to have a comfortable, healthy home that was energy efficient, low maintenance and that also would be easy to operate and quiet to function.

Design and Product Selection

We chose a two story walk-out plan for two reasons. Energy efficiency and material resources. The two story design lowers the cost of foundation and roof/truss system in proportion to total square footage thus lowering our per sq. ft. building cost. We feel it is easier to heat a structure from the bottom up and cool a structure from the top down rather that try to "push" heat or cooling air great horizontal distances.

Standard industry practices relating to foundation rim joist, wall and truss assembly would not allow us to meet our goals. The foundation should be water and air sealed, rim joists are to be insulated and air sealed. Wall assemblies need to be easy to insulate, air/vapor seal, and wire. Roof trusses must not allow wind washing, thermal bridging, i.e., ice dams.

Large amounts of glazing on the walk-out side facing south, allowing us to maximize solar gain. Formaldehyde based products were used minimally. Plywood versus particle board was used for sub flooring. The entire house sits on a 8" gravel base, to eliminate bulk water, moisture and radon concerns. Having a dry slab maximizes heat transfer of radiant floor heating (R.F.H.).

Flooring material was carefully selected, hardwood and vinyl floorings were used as much as possible as to limit an environment for airborne contaminants. Some carpeting was used.

A true air tight sealed combustion fireplace was chosen to eliminate any back drafting concerns although chosen mainly for efficiency and aesthetics this unit will provide abundant heat when called upon during the swing month of fall/spring when our local temperatures can rise and fall dramatically.

The mechanical systems were selected for health reasons as well as comfort. Independent systems were designed for ventilation, heating and cooling so that each system could be optimized.

A heat recovery ventilator (H.R.V.) was chosen for the central ventilation over the more commonly used low CFM high sone bath fan. The fresh air supply from the H.R.V. was to be ducted to the air handling duct work. Branch ducts supply fresh air to bedrooms and living spaces. The design criteria for the air handler and its ductwork was to create a hybrid means to air condition, filter and distribute ventilated air. This system design also allows for the homeowner to distribute excess heat gain from passive solar and fireplace via the air handling system.

By coupling heating and domestic hot water (D.H.W.) into one hybrid system, we eliminate one combustion appliance. This was accomplished with a high efficiency sealed combustion boiler and a side arm water heater. By the nature of this design we can achieve a healthier environment for the homeowner by eliminated back drafting potential and removing one combustion source (D.H.W.) tank. The heating system was selected because of no dust distribution, eveness of temperature, quietness of operation and energy efficiency. Heat distribution was a combination of methods; radiant slab and panel radiators.

It is a common practice with this builder and his subcontractors to install and achieve a high quality air/vapor barrier with blower door results of less than 1.75 A.C.H. at 50 P.A. Most importantly the subcontractors are to be aware of the air/vapor barrier and not disturb or destroy it. However, should this occur they must inform the job site superintendent. This practice is a key factor in insuring the homeowner a healthy, comfortable and energy efficient home.

Central Ventilation/Air Handling Design

A VanEE 2000 heat recovery ventilator was used for the central ventilation. This is a balanced system with energy recovery capabilities. It was chosen because of the need for filtered fresh air, quiet exhaust capabilities, moisture control and a solid track record as a ventilation unit. It is a 5 point exhaust system, 2 upstairs baths, 1 kitchen, 1 half bath, and rough in bath in the basement. Fresh air is directly supplied to bedrooms and living spaces.

A zone system was designed to maximize the exhaust of air from the upstairs both rooms. A control (crank timer) in these upstairs baths activates the VanEE zone damper, which closes other exhaust points in the ventilation system at that time. The .35 air change rate for this home was 120 cfm. The VanEE system balanced at 190 cfm on high, 110 on medium and 70 c.f.m. on low. Controls include one crank timer in each bathroom, a lighted switch in the kitchen and a central controller in living space for high/low operation of the ventilation unit.

Air Handling design

The reason for air handling duct work was for future air conditioning, ventilation distribution, high efficiency filtration, and distribution of excess heat from passive solar gain and fireplace. The duct work for this system was installed in the attic. The design reasons for this include: Ease of cooling and ventilating a residential structure from the top down, relating to cooling capacity and fan horsepower needed. In basement installation of ductwork ceiling heights can dictate inadequate duct sizing and location. In this application ample room was available for proper duct sizing. In this attic installation large round uninsulated (no duct board) round metal duct work for the trunk was used because of ease of applying duct sealing mastic, no custom ductwork needed, and ease of installation. The air handler ductwork was sized for a two ton air conditioning system. Various sized, flexible ducts were used in the attic for the supply runs to the ceiling diffusers. Special considerations were taken to seal ductwork in unconditioned areas which will be discussed later in this paper. Duct work was also well insulated.

Planning in the design process and coordination during rough in is important, so that as much mechanical runs (heating, cooling ventilation, plumbing wiring, etc...) are run in inside walls. This is a energy and comfort concern. A lot of the time placement of mechanical runs are determined by which sub contractor shows up to job site first. In an effort to avoid this hap-hazard placement of mechanical runs especially concerning termination points in and out of the structure (i.e., dryer, kitchen vent, furnace, hot water, ventilation, vacuum, combustion air, make up, bath fans, vents etc...), a team approach during rough in of mechanical is needed to insure proper placement for safety and efficiency reasons.

It has been our experience in the field that more planning and training could be applied to avoid mishaps such as placing furnace exhaust 12" from fresh air intake of H.R.V.

Hydronic Heating System

In a northern climate of 8500 degree days, a warm comfortable draft free home was one of our clients' goals. The best approach would be to design the heating system for heating only rather than heating, cooling, humidification and filtration. Cooling and filtration would be designed to interact with the heating system as separate systems. At this time no central humidificaton is planned. If the need arises for humidification in the future it could be added or retrofitted on to the ventilation and filtration system. During the preliminary heating system design hydronic radiant floor was our first choice however budget constraints gave us an opportunity to try something unique. The system we decided on after receiving considerable help from homeowner regarding design, heatloss calculations and equipment configuration is as follows:

- **Lower level walk-out** - hydronic radiant floor in 4" concrete slab on top of 1 1/2" of sealed foam and 8" gravel.
- **First Floor** - Wall-mount hydronic panel radiators piped with 3/8" Pex (which was very easy to install)
- **Second Floor** - Same as first floor

The electronic heating control uses an outdoor air temperature sensor to set the buffer storage tank temperature (radiator supply) and the electric mixing valve outlet temperature (floor supply). The circulatory pumps are on the entire heating season for a continuous circulation system. Running the circulator pumps continuously has a self balancing effect by supplying heat to cooler rooms and receiving heat from warmer rooms. Mechanical thermostats are included on one radiator in each loop to further regulate the temperature.

Duct Sealing

In recent years duct sealing has become a hot topic. Special attention should be given to ductwork running in unconditioned areas. Looking at the house as a "system" and how it functions or not functions leaky ducting can adversely affect its performance in the energy, comfort, health related, and mechanical aspects. Here is a brief explanation of the problems associated with leaky attic ductwork:

- Ex-filtration from the house through ductwork i.e., stack effect condensation in ductwork.
- Infiltration from duct system through diffusers and grills, i.e., introduction of air born contaminants from attic into house causing cold drafts and energy issues.
- When the air handler is running leaks in the ducts work can supply conditioned air into attic leading to a higher cost in operation and causing pressure related problems.
- Leaks in the return side of duct work can draw unwanted attic air into the system leading to potential introduction of particulate biological contaminants, insulation fibers as well as adding considerably to the cooling load during the summer operation.
- A Duct Blaster test will be performed to analyze the effectiveness of sealing techniques used.

Duct sealing mastic was applied on all joints longitudinally and the circumference joints of the duct. Trunk work was wrapped in 1" fiberglass. No duct liner or duct board was used. Cellulose insulation was blown over all duct work to an insulating value of R-18 or more.

Air Tightening Details

- Walk-out floor - 1 1/2" foam joints taped with 2" of gravel above, 6" of gravel below. At cold joints between foundation wall and basement floor slab were insulated with 3/4" foil faced foam.
- Foundation walls - 8" poured concrete with warm and dry tuff and dry waterproofing applied to exterior.
- Rim joist - A fire rated expanding formaldehyde-free spray in place foam was used for both insulating and sealing capabilities.

- Standard 8" strapped wall built as follows:
  1/2" O.S.B. exterior sheathing
  2 x 6 stud's 16" O.C.
  High density R-21 fiberglass batt
  Tu-tuff #3 air/vapor barrier sealed with Tremco
  sealant to floor, window and door perimeters, and to top plate.
  2 x 3 horizontal strapping 16" O.C. off of floor.
  Wiring and other mechanical is installed on warm side of air/vapor barrier.
  1/2" drywall
- Ceiling - Lessco boxes, Tutuff with taped joints and Tremco acoustical sealant.
- Bypass penetrations, i.e., any plumbing, electrical, heating, ventilating, structural penetrations from conditioned to unconditioned areas were sealed.

Equipment Summary

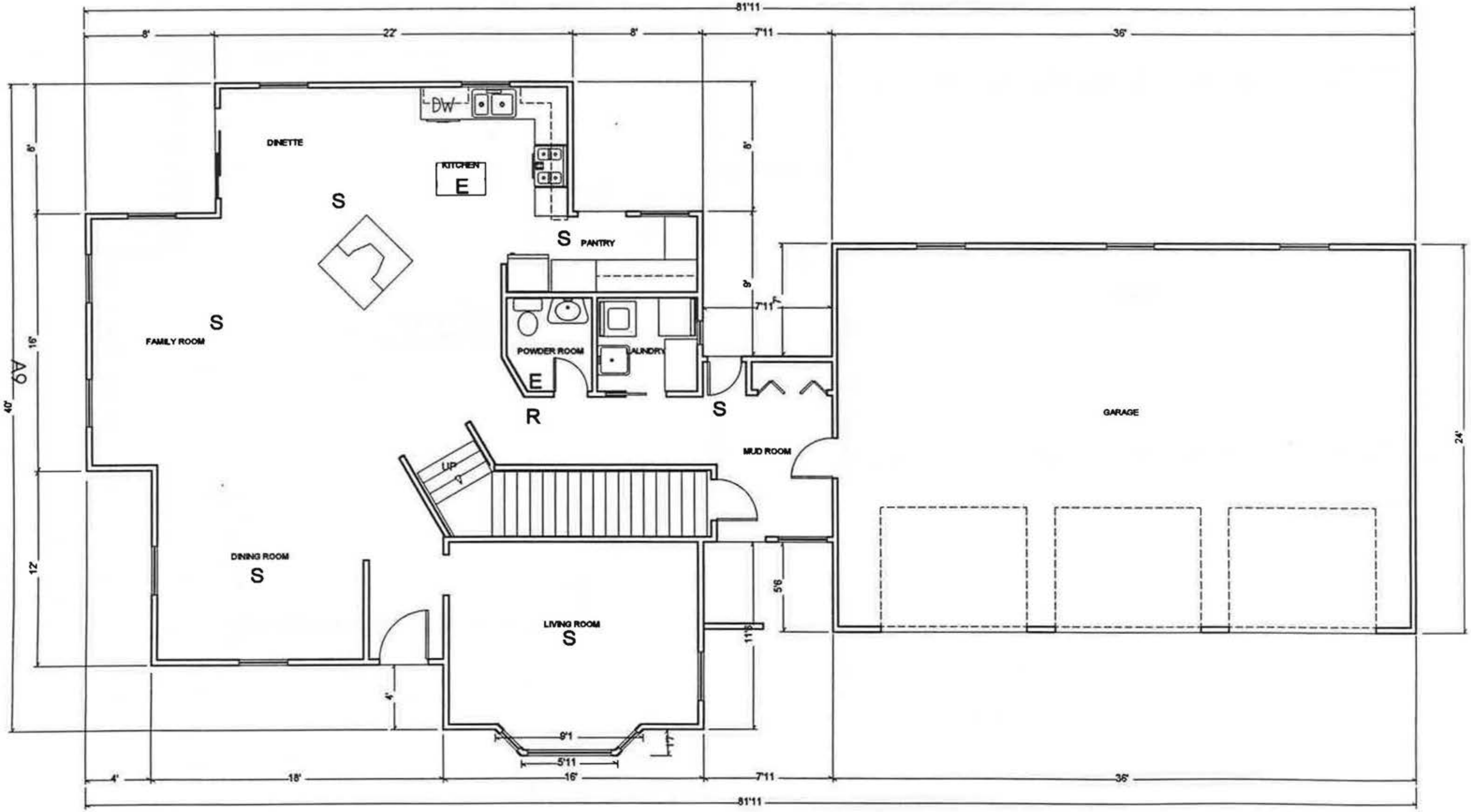
Fireplace	Opel 2000 sealed combustion
Ventilator	VanEE 2000 with 1 zone
Boiler	For both heating and domestic hot water 90,000 BTU Glowcore sealed combustion boiler with side arm water heater and 30 gallon buffer tank for heating.
Radiant Floor Heating	Stadler 1/2" Pex tubing, 6" O.C. on perimeter, 12" O.C. in field
Radiators	Thermotek hydronic panel radiators
Controls	Stadler with outdoor reset control
Thermostat	None used!!
Kitchen exhaust	Vent-a-Hood 300 c.f.m. blower

Conclusion: As of this writing the homeowners have occupied the home for 3 months and feel we have achieved our main goals of comfort and health. It is too early to access energy efficiency, however we feel the home will perform well over time. The blower door and infra- red scan along with Duct Blaster analysis will validate our goals.

R - Return air

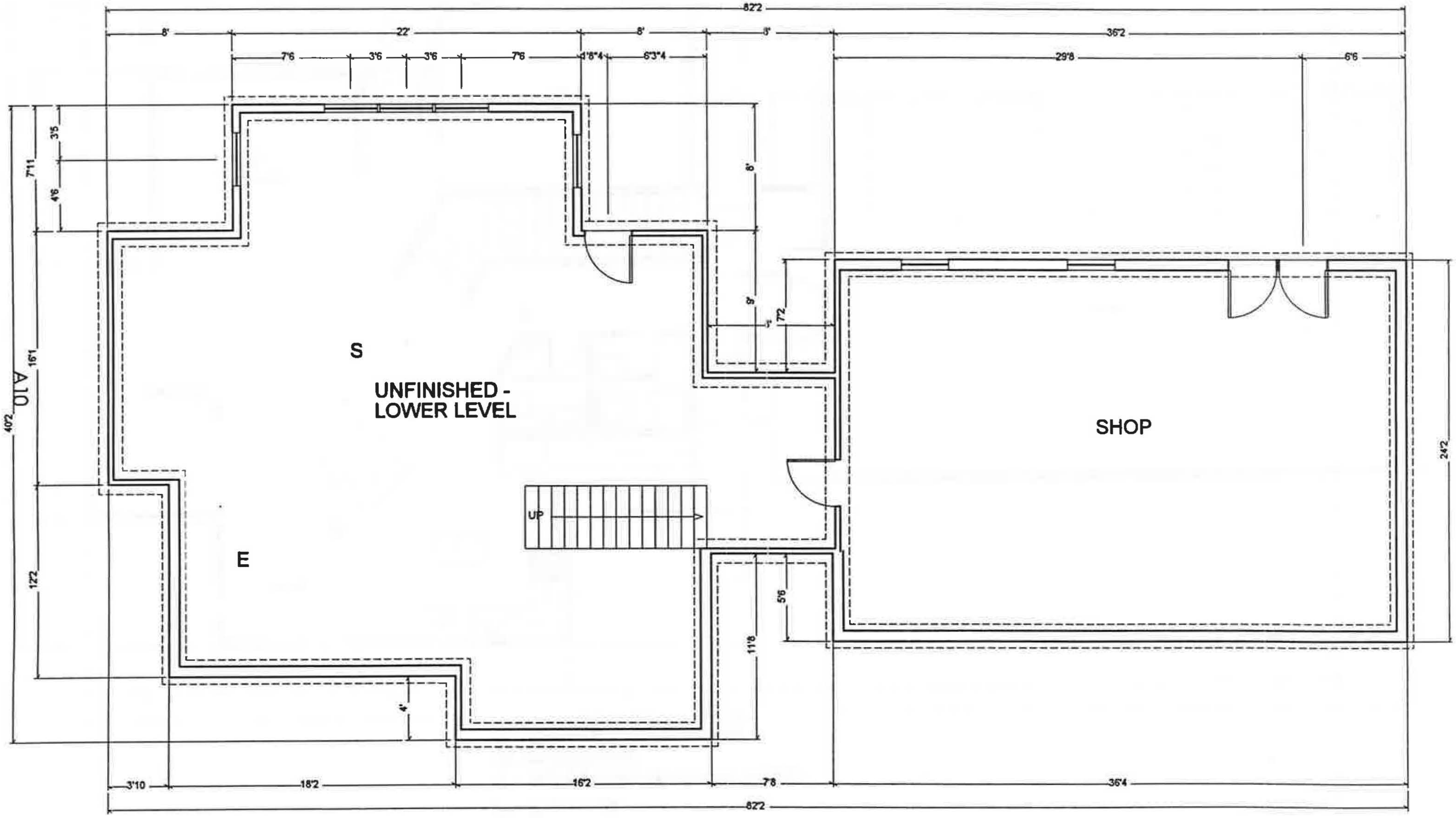
S - Supply from ventilation and/or air conditioning

E - Exhaust from ventilator



S - Supply from H.R.V.

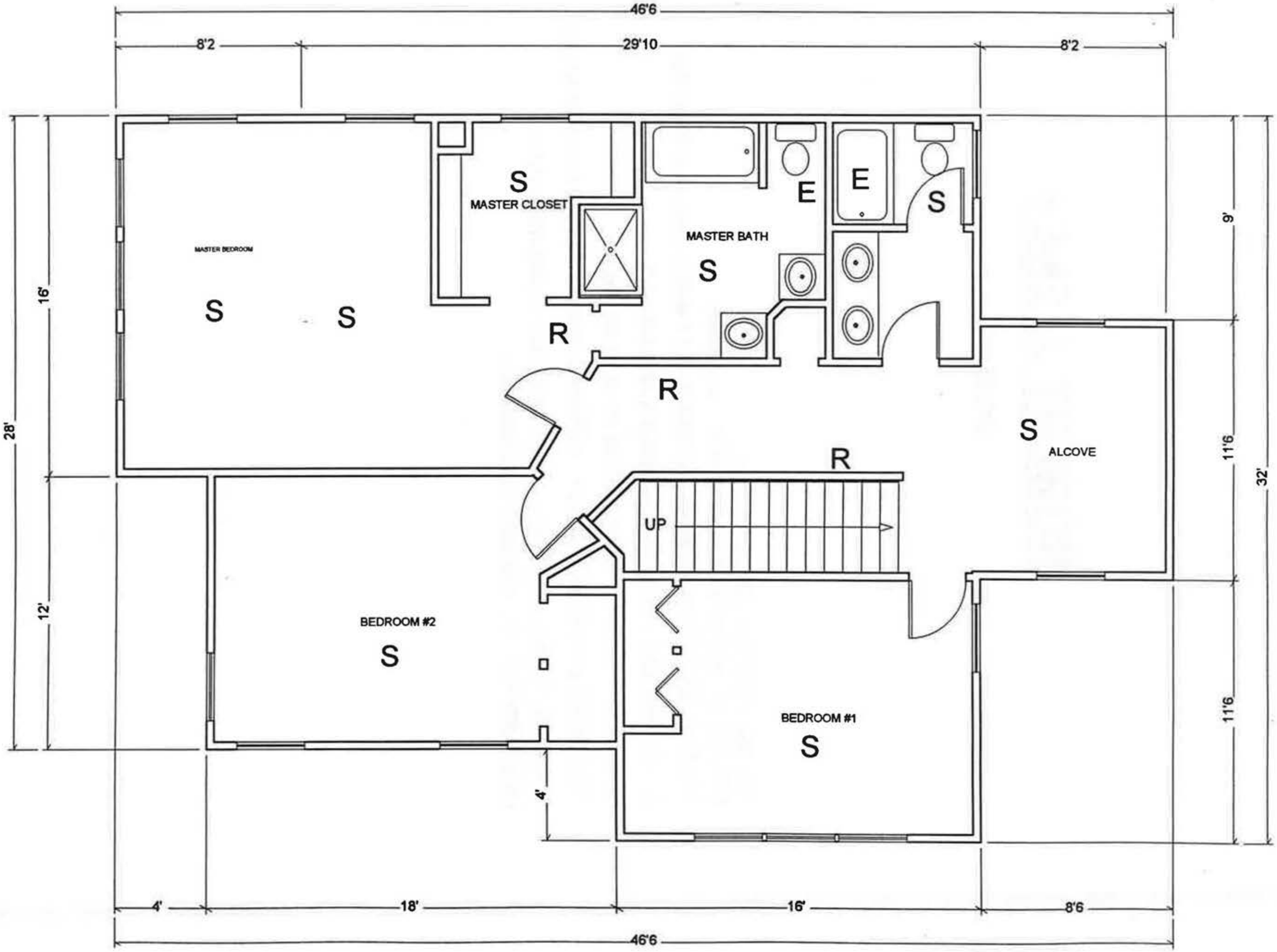
E - Exhaust from ventilator



R - Return air

S - Supply of ventilation and/or air conditioned fresh air

E - Exhaust from ventilator



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ROBERT J. ENES

BIOGRAPHY

CUSTOM HOME BUILDER SINCE 1981
BUILDER OF ENERGY EFFIECIENT HOMES SINCE 1986
CHAIR OF BUILDERS ASSOCIATION OF MINNESOTA ENERGY CODE SUBCOMMITTEE
BOARD MEMBER OF STILLWATER CHAMBER OF COMMERCE
MEMBER OF NATIONAL ASSOCIATION OF HOME BUILDERS
PARTICIPANT IN GRADUATE BUILDER INSTITUTE (ONE CLASS LEFT TO GRADUATION)
MEMBER OF E.E.B.A. (ENERGY EFFICIENT BUILDERS ASSOCIATION, INC.)
LAKE ELMO PLANNING AND ZONING COMMISSION

notes

AFFORDABLE ENERGY EFFICIENT HOUSING
EEBA CONFERENCE 1995

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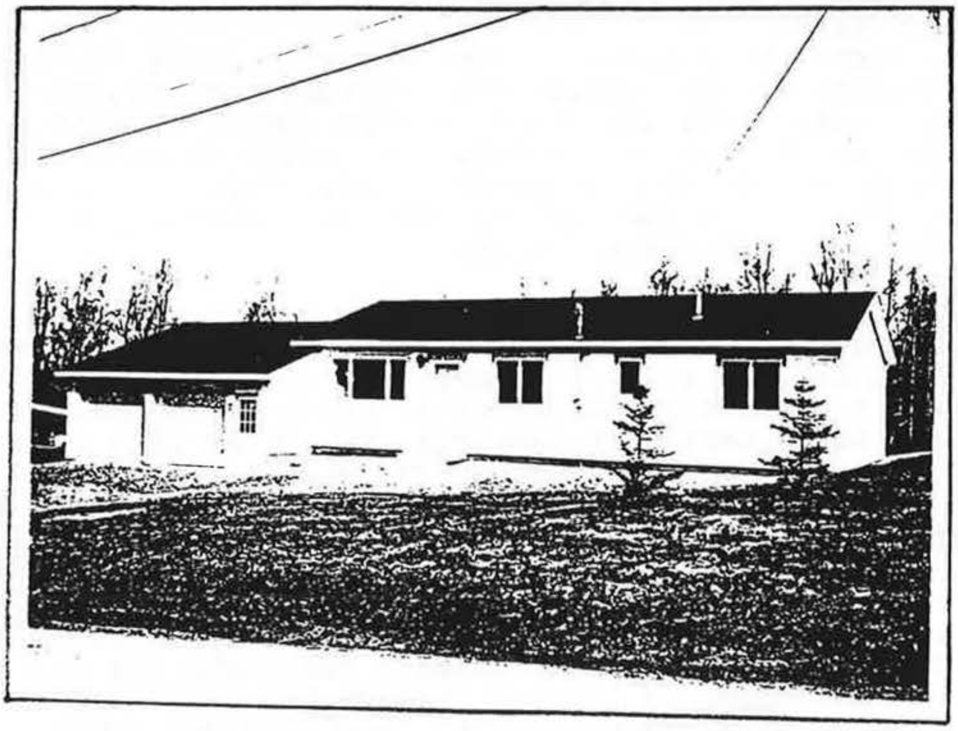


JOHNSON HOUSE
PRESQUE ISLE, ME.

AFFORDABLE ENERGY EFFICIENT HOUSING
TECHNICAL PAPER ABSTRACT
By Allan A. Bennett

This presentation discusses the construction of a single family residence located in a 10,000 degree day climate. The article explains the construction processes and design using pictures, diagrams of pertinent details, energy design studies, and the use of relatively new structural, insulation, and foundation strategies to produce a home with a reasonable budget.

This house was originally designed for construction as a slab on grade structure using insulation between the slab foundation and the ground and incorporating an in-floor radiant heating system. The early plans were to construct the wood frame building using the stick built approach.

Early discussion with the local technical college led to a proposal where the building trades students would construct the main structure as two modules and transfer the modules to the site where final trim and finishes were applied. Their goal was to accomplish as much of the work, including electrical, plumbing and heating, in the modules prior to transporting the modules to the site. The garage and utility room was stick built after the module delivery and installation.

Foundation System
The building was placed on a foundation composed of a trench filled with ballast stone to a depth of five feet. The trench was installed in the entire perimeter of the building and included a drainage tile extending to daylight. On top of this a minimum concrete footing was constructed and this in turn was topped by a 24 inch high all weather wood wall. This left a 30 inch high crawl space required to facilitate placement of the modules.

Crawl Space Ventilation
The crawl space provided a plennum for the supply side of an air to air exchanger used to continuously ventilate the conditioned space with a minimum of 1/2 air changes per hour when operated in the unoccupied mode. Three booster fans provided optional additional ventilation exhausting from the kitchen and the two baths.

Wall Framing System
The framed walls used a system of 2 x 6 studs and 2 X 4 girts to provide R-30 insulation value. This was found to be the easiest and least expensive option to achieve this desired value and to allow much of the piping to be run horizontally in the inner cavity of exterior walls without risk of freezing. The vapor barrier was placed 1/3 way through the insulation from the inside face of the exterior wall and installed as a single continuous sheet brought out onto the ceiling and onto the subfloor prior to installation of the second layer of flooring. All electrical was carefully controlled to minimize cable penetrations of the vapor

barrier except for the service entrance to the panel and for the required exterior lighting and outlets.

Floor Framing
The floor frame was conventional wood joist construction with a sub floor of 1 x 6 boards spaced such that hydronic radiant heat piping could be installed above the joists, between every other board and below the second layer of underlayment plywood. The plywood was glued to the boards with gun grade adhesives, providing a prepared base for carpet, sheet flooring, and pre-finished hardwood flooring. The joists were insulated with R-24 fiberglass and supported by poultry netting secured to the bottom of the joists. The drainage piping, domestic water, and radiant systems were installed prior to delivery and mounted completely inside the floor and within the insulation.

Heat Loss Calculations
This building is located in a 10,000 degree day area and each room or area was calculated to design a balanced heating system. The system uses 1/2 inch plastic piping on 12 inch centers or approximately one lineal foot of piping for each square foot. The total design heating load, using a 100 degree inside to outside temperature, is 18,000 BTU per hour, not including intrinsic heat from the occupants.

Roof Insulation
The roof is framed with special trusses that can be partially lowered during transportation of the modules. Gypsum board ceilings were installed prior to interior partitions, including a continuous plastic vapor barrier. R-38 fiberglass covered by a layer blown cellulose (R-10) complete the ceiling insulation system.

Fuel Consumption
Fuel used for the 1990-91 heating season was 112 gallons of number two fuel oil with the thermostat at 68 degrees and no occupants, as the house was not sold until December of 1991. The air to air exchanger was in unoccupied mode with 1/2 ACPH.

Solar Gains
The south facing windows have 64 sf. of high performance Low E glazing, and the north facing windows have 44 sf. The west side has an attached garage acting as a buffer, and the east side has no windows. This window configuration did not create an appreciable net solar gain.

Utility Room
A 10 x 12 ft utility room is located inside the garage and adjacent to the west wall. An oil fired boiler installed to act a direct vent system. Care was taken to isolate the utility space from any other living space. With the boiler in an isolated room, the sound of operation is low and any smell or other noxious fumes are kept out of the living and crawl space by the insulated wall and vapor barrier.

LOW COST ENERGY EFFICIENT HOUSING
ALLAN A. BENNETT
PRESQUE ISLE, MAINE
JANUARY, 1995

Background:

My interest in low cost housing that is economically viable for families with incomes near the poverty line has been high in my priorities since the early 1950's when I worked as a designer-draftsman for one of the first precut log home manufacturers. Most of the structures we were selling at that time were for cottages and small homes in an area that had been traditionally economically depressed. These home buyers were looking for a "step-up" from living in older and sometimes substandard housing of that time.

In the 1960's, I began working with pre-engineered metal buildings contractors using the design-build concept. I was also involved with the use of commercial and industrial construction methods and materials. At the same time, I became a project manager constructing climate controlled crop storage facilities and large industrial freezers for the agricultural and frozen food industry. These buildings required high R values and humidity control. The crop storages were located in a 10,000 degree day climate and required extremely tight vapor barriers, as the desired relative humidity within the structures was near 94%, with interior temperatures maintaining 38 to 40 degrees. Careful ventilation control was necessary to maintain the cooler surfaces above the dew point. This experience with vapor barriers, high insulation values, and controlled ventilation provided early experiences in the new construction technology that would be required for the residential construction of the 80's.

Prior to the late 1960's, almost all buildings built in the northern areas of the US had full depth perimeter foundation walls. In Maine, simple slab on grade construction was assumed to be unacceptable because they would "heave" with the frost acting on them. This notion was only partly correct, and the technology was easily available to make quality slab on grade construction feasible. The pre-engineered building dealers soon found that the easiest way to substantially reduce costs was to create a dry base for a monolithic slab on grade and perimeter grade beam foundation system instead of the traditional perimeter foundation wall extending down below the frost line for their industrial and agricultural buildings.

With these structures, the minimum required R values of roof and walls would be near R-40 and adequate ventilation would be necessary if condensation was to be controlled on the walls and ceilings. Now this was **SUPER INSULATION** before the rest of the country even considered such high values desirable.

In the late 1970's came the energy crunch, and with it, the growth of higher energy efficiency requirements to be used in the construction of homes and other buildings. At this point, I began to design and build homes using combinations of traditional home construction methods and materials as well as borrowing materials from my experiences in past industrial projects whenever these concepts could be combined to produce a better design for less cost.

Earlier Projects:

One of these first projects was to design and build a new home for my family. The use of industrial-commercial techniques to achieve economical and aesthetically acceptable features was foremost in it's design. At that period in time (the 1980's) such features as passive and active solar, high mass, bermed structures were the "thing to do" and this project had them all and more including suspended precast concrete slab second floors, interior first floor concrete tromb walls that were turned 90 degrees to the south facing sliding glass doors, cold rolled steel zee purlins for primary roof framing, exterior double wall framing and lots of insulation.

The second project was a duplex house to be used as a rental investment that had to compete in costs against government subsidized rentals. Special construction features in this project include the use of a rubble stone filled trench as part of the foundation system. The ballast stone filled trench extends from exterior grade level to a depth of five feet in order to go below the frost line. A drain tile at the bottom of the trench extends to the storm sewer. From grade to first floor framing, an all weather wood foundation system was employed. Open web wood floor trusses on 24" centers were covered by 3/4" OSB sub floor sheathing, and the use of underlayment only where sheet vinyl flooring was to be laid. Carpet was laid directly over the OSB sheathing. The exterior walls were framed with two by four double wall construction with eight inches of blown cellulose and 3 1/2" of fiberglass. Ceilings were 12" of blown cellulose insulation.

In late December, work was halted and the building was left unheated. The temperature was monitored and the temperature inside did not drop below freezing. The solar gain and the geothermal radiation below the crawl space was responsible for enough gains to balance the radiation losses due to cold outside temperatures at a point above the freezing point.

Presentation Project:

The project used in this presentation was originally envisioned as being built on an insulated slab with a gas fired hot water heater producing domestic hot water and low temperature water for the floor radiation.

This plan as conceived was changed from a slab on grade foundation to a crawl space type in order to take advantage of the availability of two custom made building modules. The modules would have a structural wood framed floor with a hot water radiant floor system installed mostly at the manufacturing location. A crawl space was necessary to facilitate placement of the modules at the site.

The foundation was constructed using a five foot deep ballast stone filled trench to grade level and with a two foot high stub wall constructed of treated wood and insulated to R-24. A 24 inch wide layer of R-7 insulating foam was installed horizontally outward adjacent to the foundation perimeter and a depth of about 6 inches below the final grade to prevent frost from occurring near the foundation. (frost protected foundation) A ground covering vapor barrier in the crawl space was composed of one layer of polyethylene covered with a large "poly tarp" to protect the poly vapor barrier from abuse.

The main living area was constructed of two modules that were fabricated at Northern Main Technical College by the building trade students. Each module was 14 feet wide and 46 feet long. The exterior walls of the modules used the strapped wall system to achieve R-30. The walls were framed with 2 X 6's at 24" oc, exterior sheathed with 7/16" OSB, insulated with 6" friction fit fiberglass, and covered with a 8 mill poly vapor barrier. On the inside of this wall, 2 x 4 horizontal strapping installed with the 3 1/2" face perpendicular to the studs so as to create a total wall cavity thickness of 9 inches. Only after the electrical and short runs of drainage piping were installed within this wall cavity was the second layer of 3 1/2" R-11 fiberglass, gypsum board, and interior trim installed.

The additional 650 lf. of 2 x 4 horizontal strapping took about 8 man hours to install. The additional 950 sf. fiberglass insulation required 5 man hours to install. Each door to window required an additional cost of 40 dollars worth of labor and materials for additional framing and interior trim.

The floor of each module was framed with 2 x 10's at 16" oc, sheathed using 1 x 6 boards with spaces between every other board into which plastic radiant floor piping was installed. Then 1/2" underlayment grade plywood was glued down over the boards. This enclosed the radiant piping within the wood floor system. The radiant heating zones were terminated at a common location in the common wall between each module. Toilet and bath fixtures were installed with piping terminating at common locations to reduce on site labor to a minimum. The entire floor was insulated with R-24 fiberglass suspended on poultry netting secured to the bottom of the joists. This was partly necessary to maintain the insulation in place while being moved over the road.

The roof was constructed using pre-engineered wood trusses at 24" oc covered with 5/8" CDX plywood and standard asphalt shingles. Soffit and ridge vents provide each space between trusses with clear unobstructed air flow. Ventilation baffles prevent air flow from washing the insulation at the eaves. The ceiling joists (lower truss chords) were covered with six mill poly vapor barrier to the installation of the gypsum board. The ceiling was insulated with two layers of R-19 fiberglass prior to site delivery and a layer of R-10 cellulose was later blown on top after the modules were fitted together on site.

Each module was delivered to the site on low flat trailers and rolled onto the prepared foundation.

Because homes with "full foundations" are traditional to the area, and this home would have no basement, other amenities would be included to compensate for the lack of a "cellar". Our trade off would be a large two car garage with workshop, storage space, and a separate enclosed utility room with access for servicing only through the garage, instead of a cellar, stairs, longer chimney, and related site and foundation drainage work. This trade off was accomplished with only a total additional cost of $1,500.

The garage structure and it's associated spaces was built on site. The garage was designed deeper than the width of the house and located on the west end of the house to shelter the house from the prevailing northwest winds. An unheated tightly built attached garage will generally have interior winter temperatures near the average of the month instead of the extremes of the exterior daily temperature high and the lows, thus reducing the extreme difference between inside and outside temperatures (Delta-T) across the common wall to about 60 degrees instead of an exterior wall Delta-T of 95 degrees. In this case, 37% lower heat loss through the common wall.

The utility room contains the oil fired hot water boiler installed with a power vent through the exterior wall system. This location for the utility room would isolate the boiler for sound, vibrations, odors, and other gasses from the living areas. The utility room is insulated the same way as the remainder of the project except that it has a reinforced concrete slab floor over R-10 foam insulation. The utility-garage floors are down three steps from the main floor. This was done to provide straight access through the common wall for heating and plumbing from the crawl space to the utility area and partly due to the topography of the lot.

As this house has a low infiltration rate, an air to air heat recovery system was installed to provide assured ventilation to both the crawl space and living areas. The ventilation system provides a minimum of about one half air change per hour in the "unoccupied mode" and one air change per hour when desired by the needs of the occupants. The actual rates can be adjusted according to the owners life style. The system uses four inch schedule twenty PVC pipe to provide duct work between the three exhausting locations, the heat recovery equipment, and the three supply locations for fresh conditioned air to be introduced into the living areas. Each bath and the kitchen area has a switch used to increase the ventilation rate from the minimum set by the owner, through the use of booster fans located in the room exhaust grills and by simultaneously increasing the volume of the intake and exhaust fans in the heat recovery device. The crawl space is used as a supply plenum under slight positive pressure. This provides adequate humidity and ventilation control of this tightly closed space. Air supplies enter the living space have grilles high up in the wall of each bedroom. A temperature probe monitors the temperature of the outside supply air and can shut down the outside air supply fan if the temperature of the core is in danger of freeze up. This system replaces a defrost heater within the heat exchanger. With the probe switch set so that when the incoming air is below minus 5 degrees, the supply fan would not operate. This occurs for less then five percent of the heating season. This is not a long enough time to create a problem considering all the possible other variables.

This building was heated for one season with no one living in the home. The temperature was set at sixty eight degrees and the ventilation at "unoccupied". Total oil consumption for space heating only for a full year was 112 gallons.

When the new owner (family of three) had lived in the home for a full year, we found that domestic hot water consumed more than twice the fuel than space heating.

When this project was conceived, we believed that the temperature in the crawl space would be near 40 degrees in winter, but found that the actual temperature was nearer to 53 degrees. This reinforced the data that frost protected foundations are more than adequate even in areas of 10,000 degree day climates or more.

After analyzing the costs, this project if built as originally envisioned on an insulated slab on grade and with a perimeter ballast stone foundation to below frost line, and depending upon if stick built or if factory modular panels were used there would be additional cost savings. There were additional costs to build upon this lot because a five percent slope across the width of the lot requiring a retaining wall and an adjustment in the floor levels between garage and living areas. If the frost protected slab on grade would not require a perimeter ballast stone trench wall to extend below the frost line, then this would also decrease the final costs.

Much consideration was placed upon various methods to construct the exterior walls and the cost of these various methods. A typical wall section was priced out (8 x 24) for each possible wall design. The additional cost per square foot along with the cost per total R value was determined. The "R S Means" costing system was used to provide comparable solutions along with my past experiences with estimating labor and having actually installed each system in actual buildings. Because the same data base was used for all the systems reviewed, the ratio of costs is more significant then a precise cost for any of the systems.

Each of the selected wall systems were reviewed to compare the additional cost to payback.

The best payback might not be the best solution depending upon a prospective owner's feelings on energy use, environmental concerns, and length of time of ownership.

Conclusion:

In 1985, I designed and received prices for a home with nearly the same floor plan but with an alternate to build the home with and without a usable basement suitable for future living expansion. The pricing can be compared by reviewing the contractors summation of basic assemblies for a full basement and for an insulated slab on grade alternate. The resultant cost saving were significant, however, the owner elected to pay for the higher cost basement due more to a tradition then any other reason. I believe the change from the traditional in any given area to another technology is difficult for owners to accept. But, if they move to another area where these techniques are common, they readily accept, but if they move to another area where these techniques are common they readily accept them. Perhaps to be different is too much to deal with. However, more and more residential customers are moving from one area to another and these "traditional" considerations will slowly fade away. In my observation, there will be more homes with either crawl spaces or on frost protected slabs in the northern states just as the slab on grade for commercial buildings has become the normal situation for those structures for which these types of technologies are appropriate.

COMPARING A FULL BASEMENT TO A SLAB ON GRADE FOUNDATION

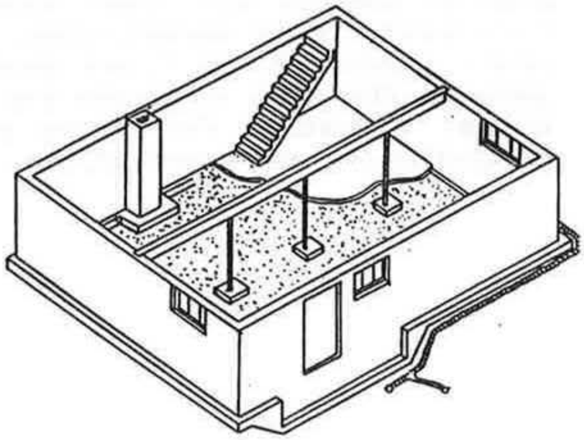
When comparing one system against another it is important to take into consideration all of the factors that are **different** between the two assemblies being compared. It is not necessary to consider any item that does not change.

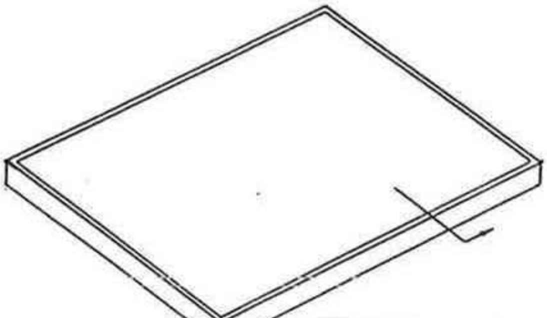
Before considering the difference in cost of a basement and a slab on grade, compare the following sketches to become familiar with those things that do change.

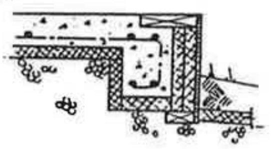
The basement cost must include everything for the entire building that do change when the basement is compared to the slab on grade.

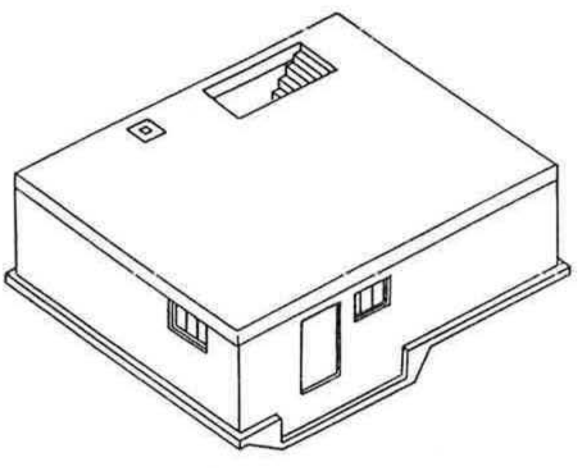
Consider that in much of the US many homes and commercial buildings are built on slabs. There is a logical reason for this and the cost is a large factor in this decision.

Housing is becoming more unaffordable to the average potential home owner and new schemes must be considered to reduce the final costs so more people can afford adequate homes.









COMPARISON COST SUMMARY

Scope of work:

Full basement with quality and conditions acceptable for future expansion to living space.

Included:

- Earthwork
- Structural drainage system
- Footings, walls, and floor slab
- Rough framed stairs
- Foundation dampproofing
- Foundation and slab insulation
- Column footings and columns
- Three windows and outside entrance
- First floor framed complete and ready for floor finishes
- Chimney to first floor
- Minimum electrical per code

As compared to a monolithic slab on grade

Included:

- Earthwork
- Complete reinforced monolithic slab
- Vapor barrier and under slab insulation
- Floor prepared for floor finishes

COST SUMMARY FULL BASEMENT

Excavation	330 cy	$720
Stone under floor slab	19 cy	305
Footings	4.5 cy	500
8" found. walls x 130'	27 cy	4860
Reinforcing steel in place		320
Found wall insulation R-10	1088 sf	1100
Under slab insulation R-7.5	1100 sf	920
Above grade insulation protector	272 sf	272
Damp proof found wall		280
Drain tile	210 lf	180
Backfill of foundation wall	120 cy	240
Floor slab	13.5 cy	1060
Vapor barrier under slab	1200 sf	156
Footings for columns and chimney	1 cy	120
Structural beam for floor joists	46 lf	220
Lally columns	4 ea	240
Box sill and plates		220
2 x 12 joists at 16" oc.inc. bridging	1100 sf	1600
Sub floor sheathing and underlayment	1100 sf	1390
Basement entrance and 3 windows		860
Stairs to basement	1 ea	400
Chimney to first floor	9 lf	240
TOTAL FOR BASEMENT TO ROUGH FIRST FLOOR		16203

COST SUMMARY SLAB ON GRADE

Crushed stone base	40 cy	$656
Perimeter grade beam	2.25 cy	242
Slab floor and chinney base	14 cy	1150
Reinforcing steel		475
Slab insulation R-10 + perimeter edge R-20		2300
Vapor barrier under floor	1200 sf	165
Insulation protector at edge		275
Backfill		120
TOTAL FOR SLAB ON GRADE FOUNDATION		$5383
Cost savings for slab on grade compared to full basement		$10,820
Contractors mark up of 10%		1082
		$11902

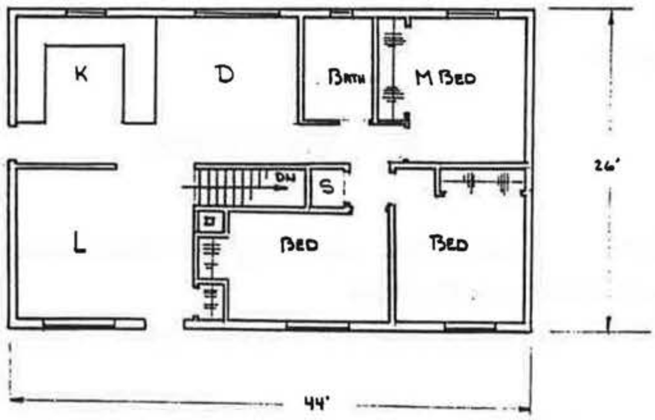
COST DIFFERENTIAL OF A HOME ON A SLAB OR WITH A FULL BASEMENT

Interest at 8 percent	$950 per year
Payment on $11,900	$630 per year
Taxes at 30 mills	$360 per year
	$ 1940

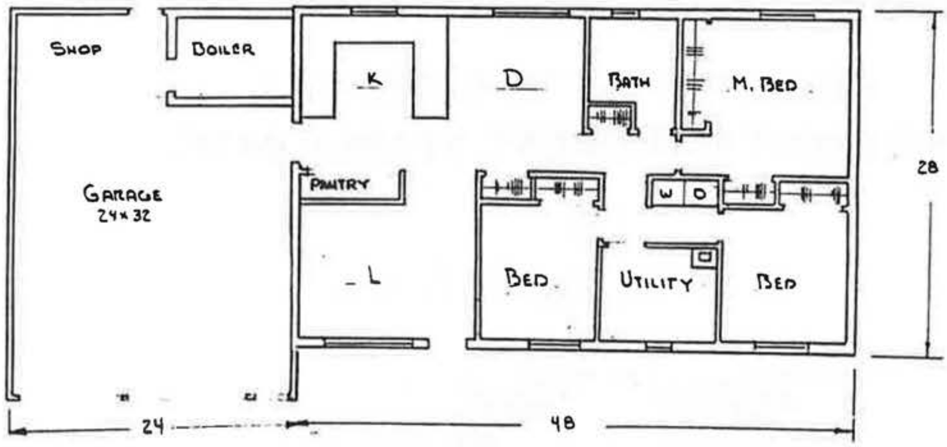
or

$161 per month

$161 per month for 20 year morgage = $38,640



1144 sq.ft. with basement



1344 sq. ft. Slab on Grade with garage and storage

APPROXIMATE EQUAL COSTS

BALLAST STONE FOUNDATION SYSTEM

A ballast stone foundation system uses sized clean stone to fill a container, (trench) instead of constructing a wall the depth of the trench. Because a container of sized stone, (max. size not to exceed twice the minimum size) has imperceptible reduction of volume due to normal soil settlement, and a large percentage of the volume of the stone is air spaces, ice crystals, if present will not expand the material unless the entire volume of air is replaced by standing water. For this reason it is necessary that a positive drain be provided at the bottom of the trench to daylight or other permanent drainage systems.

Filling a trench with sized stone without the need for mechanical compaction is far less expensive than the materials and labor of constructing a wall and then backfilling and compaction. For many structures this method will reduce the projects cost dramatically.

Properly constructed ballast stone foundations will not settle under loads or expand due to frost action. This system provides all the requirements necessary for a adequate foundation below grade.

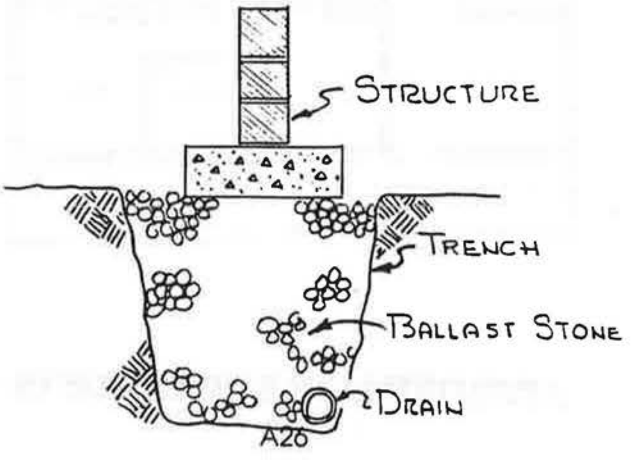
FOUNDATIONS

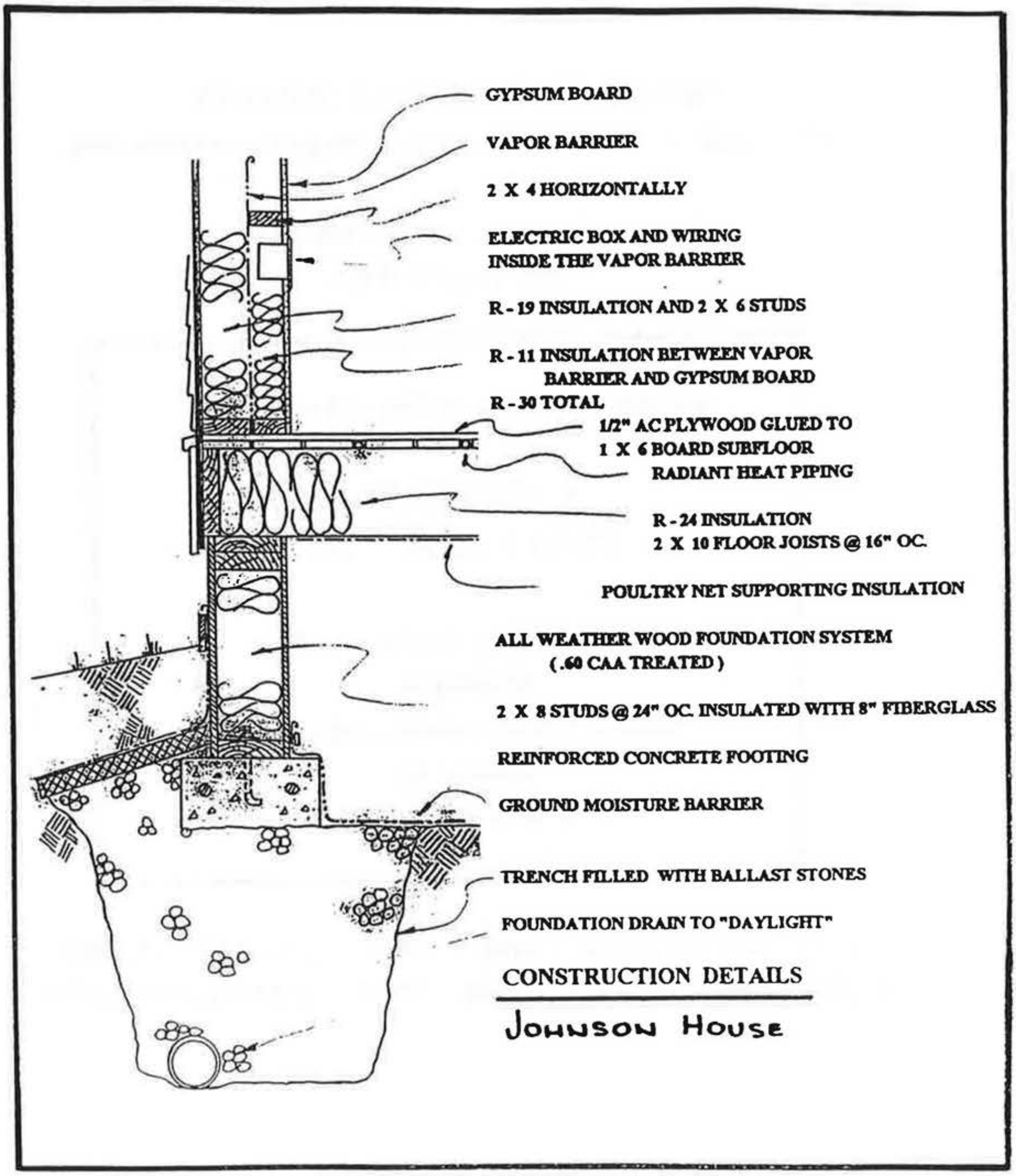
Ballast stone: **One of the earliest types of foundations and still used in many construction projects today.**

A ballast stone foundation works because:

The depth of the trench is below the frost line.
The spaces between the stones provide excellent drainage.
The uniformity of stone size create maximum density. (compaction)
Lowering the stone below freezing doesn't cause expansion. (movement)

STAYS DRY, AT MAX. DENSITY, NO FROST MOVEMENT, STABLE BASE.




GYPSUM BOARD
VAPOR BARRIER
2 X 4 HORIZONTALLY
ELECTRIC BOX AND WIRING INSIDE THE VAPOR BARRIER
R-19 INSULATION AND 2 X 6 STUDS
R-11 INSULATION BETWEEN VAPOR BARRIER AND GYPSUM BOARD
R-30 TOTAL
1/2" AC PLYWOOD GLUED TO 1 X 6 BOARD SUBFLOOR
RADIANT HEAT PIPING
R-24 INSULATION
2 X 10 FLOOR JOISTS @ 16" OC.
POULTRY NET SUPPORTING INSULATION
ALL WEATHER WOOD FOUNDATION SYSTEM (.60 CAA TREATED)
2 X 8 STUDS @ 24" OC. INSULATED WITH 8" FIBERGLASS
REINFORCED CONCRETE FOOTING
GROUND MOISTURE BARRIER
TRENCH FILLED WITH BALLAST STONES
FOUNDATION DRAIN TO "DAYLIGHT"
CONSTRUCTION DETAILS
JOHNSON HOUSE

OPTIMUM BUILDING DESIGN

OPTIMUM - The most favorable design for a given end.

Johnson house - Presque Isle, Maine
9500 Degree Days

Energy efficiency rating of buildings

CALCULATE
BTUs / sq. ft. / DD

Total yearly heating load
divided by
Square feet of conditioned space
divided by
local area Degree Days

11,710,000 btu yearly / 1196 / 9500 = 1.51 BTU / sf. / DD
58,396,500 watts yearly / 1196 / 9500 = 5.16 watts / sf. / DD

A: 14-19

HEAT LOSS STUDY
HOME
7 SKYVIEW DRIVE

Room	"R"	"U"	Sf.	DT	Total Component	% Bldg.	% Room
LIVING							
Ceiling	48	.021	230	100	480		17
Walls	30	.033	177	100	584		20
Window	3	.34	32	100	1065		37
Door	8	.125	21	100	263		9
Floor	30	.033	230	32	243		8
Perim.	24	.042	90	70	265		9
					2900	21%	
KITCHEN & DINE							
Ceiling	48	.021	336	100	705		22
Walls	30	.033	174	100	574		18
Window	3	.34	27	100	900		29
Door	8	.125	21	100	263		8
Floor	30	.033	336	32	355		11
Perim.	24	.042	120	70	353		11
					3150	23.5%	
BATHS AND LAUNDRY							
Ceiling	48	.021	220	100	462		30
Walls	30	.033	112	100	370		24
windows	3	.33	10	100	330		21
Floor	30	.033	220	32	232		15
Perim.	24	.042	45	70	133		9
					1527	11.4%	
MASTER BED ROOM							
Ceiling	48	.021	230	100	483		23
Walls	30	.033	220	100	733		35
Window	3	.33	18	100	370		18
Floor	30	.033	230	32	243		12
Perim.	24	.042	90	70	265		13
					2094	15.7%	
CORNER BED ROOM							
Ceiling	48	.021	168	100	353		18
Walls	30	,033	190	100	627		32
Window	3	.33	18	100	600		30
Floor	30	.033	168	32	177		9
Perim.	24	.042	76	70	223		11
					1980	14.8%	
INTERIOR BED ROOM							
Ceiling	48	.021	140	100	294		22
Walls	30	.033	62	100	205		15
Window	3	.33	18	100	600		45
Floor	30	.033	140	32	148		11
Perim.	24	.042	30	70	88		7
					1335	10%	

INFILTRATION = 0.3 ACPH
10,750 Cu Ft x .018 x 100 x 0.3 = 5080
18066 BTU total

Closet and hall included in appropriate rooms.

ASSEMBLIES COST COMPARISONS

Using 1994 Bare Costs from "MEANS"

Use this process for comparing costs for any type of assemblies.

Step One

Determine the basic assembly and the alternate assembly.

Step Two

List only those materials, quantities, and costs including labor that differ from the proposed alternate assembly.

Step Three

List the materials, quantities, and costs including labor that is different than in the base assembly

Step Four

Calculate the difference in cost, Cost per sq. ft, and cost per R value.

EXAMPLE

R-11 WALL ASSEMBLY

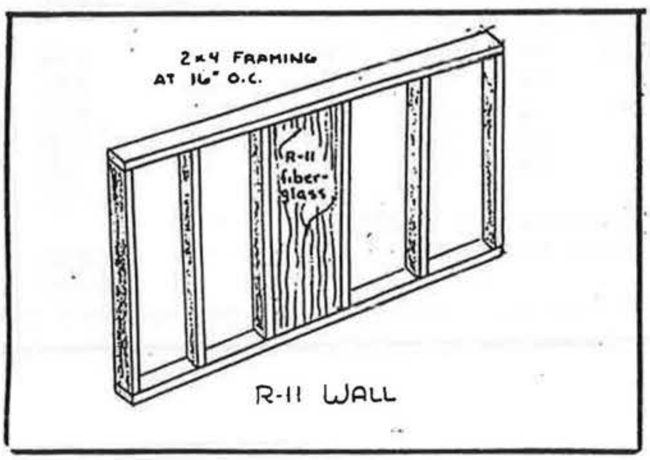
This basic wall assembly is a 2 x 4 stud at 16" oc, 8' high x 24' long, insulated with 3 1/2" R-11 fiberglass

2 x 4 plates	72 lf	\$.70	\$46
2 x 4 studs	192 lf	.63	121
R-11 insul.	192 sf	.25	48
			\$218

Note: Since all the other materials in all alternate assemblies are the same in each comparison it is not necessary to use them.

Cost per R-value = total cost / sq. ft. / R value = \$0.104

Cost per sq. ft. = \$1.14



ALTERNATE ONE R-16 WALL ASSEMBLY
USING 2 X 4 SRUDS, R-11
INSULATION AND A LAYER OF R-5 FOAM

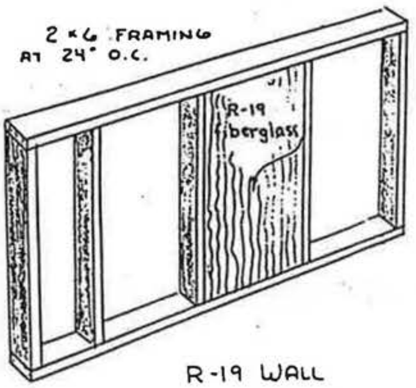
2 x 4 studs	192 lf.	$.70	$131
2 x 4 plates	72 lf.	.63	45
R- 11 insul.	192 sf.	.25	48
R-5 foam insul.	192 sf.	.47	90
			$314

Cost per R value =	$0.102
Cost per sq. ft. =	$1.64
Cost per additional Sq. ft.	$0.47

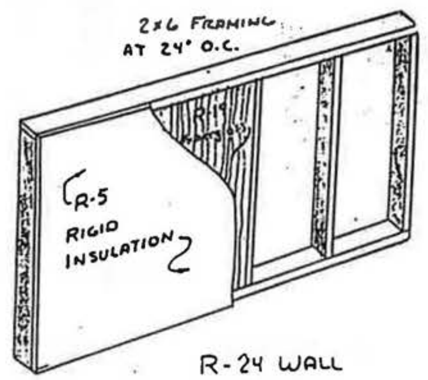
ALTERNATE TWO R-19 ASSEMBLY
Use 2 x 6 studs @ 24" oc with R-19 insulation

2 x 6 studs	114 lf.	$.86	$98
2 x 6 plates	72 lf.`	.87	63
R-19 fiber insul.	192 sf.	.37	71
			$232

Cost per R value =	$0.062
Cost per sq. ft. =	$1.21
Additional cost / sq. ft. =	$.068



R-19 WALL



R-24 WALL

ALTERNATE THREE - R-24 ASSEMBLY
Use 2 x 6 studs @ 24' oc, R-19 insul, and R-5 foam

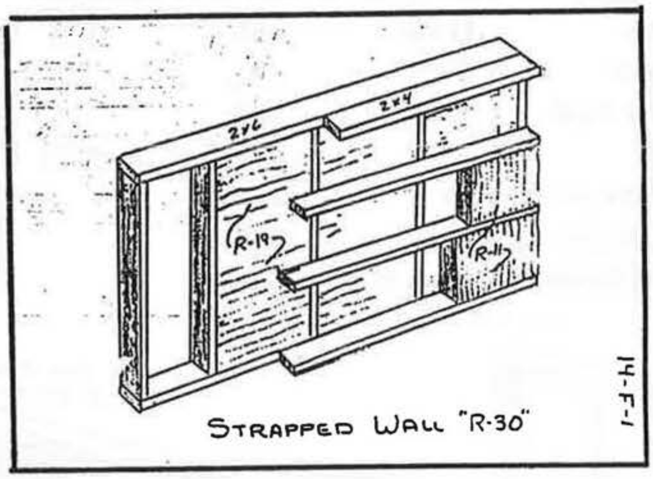
2 x 6 studs	114 lf	$.86	$98
2 x 6 plates	72 lf.	.87	63
R-19 fiber insul.	192 sf.	.37	71
R-5 foam sheet	192 sf.	.47	90
			$322

Cost per R value =	$.069
Cost per sq. ft. =	$1.68
Additional cost / sq.ft.	$0.54

ALTERNATE ASSEMBLY 4
USING
2 X 6 STUDS @ 24"oc. with 5 1/2" R-19 insulation
and
2 x 4 horizontal 'GIRTS' @ 24" vertical cpacing with R-11 insulation.

2 x 6 plates	72 lf.	$.87 / lf.	$63
2 x 6 studs	114 lf	.86 / lf.	98
R-19 insulation	192 sf.	.37 / sf.	71
2 x 4 girts	120 lf.	.63 / lf.	76
R-11 Insulation	192 sf.	.25 / sf.	48
			$356

Cost per R value =	$0.062
Cost per sq. ft. =	$1.85
Cost per additional sq.ft	$0.71.



ALTERNATE 4A
USING 2 X 8 STUDS AND 1 X 3 STRAPING

2 x 8 plates	72 lf.	1.08 / lf.	$78
2 x 8 studs @ 24"	114 lf	1.08 / lf	123
9" R-30 fiberglass	192 sf	.58 / sf	111
1 x 3 strapping	120 lf	.47 / sf	56
			$ 368

Cost per R value =	$.064
Cost per sq. ft. =	$1.92
Cost per additional sq. ft.	$0.78

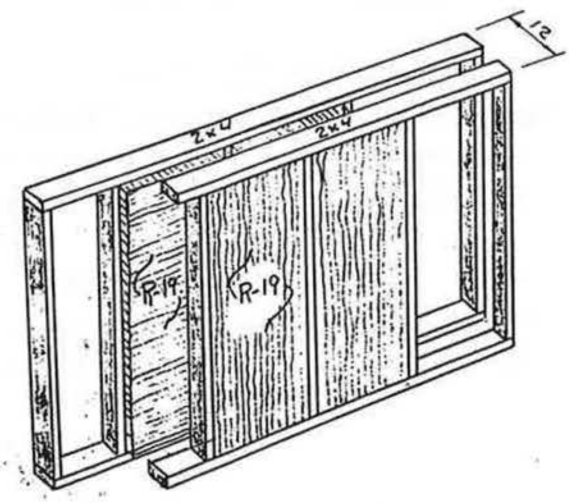
ALTERNATE FIVE R-38 ASSEMBLY
(DOUBLE WALL)

Use two walls composed of 2 x 4 @ 24"oc. with two layers of R-19.

2 x 4 plates	**144 lf.**	**$.70**	**$100**
2 x 4 studs	**208 lf.**	**.63**	**131**
R-19 fiber insul.	**384 sf.**	**.37**	**142**
			$373

Cost per R value = $0.051
Cost per sq. ft. = $1.94
Additional cost per sq. ft. = $0.80

A:10-13



– DOUBLE WALL R-38

ANALYSIS OF INSULATING STRATEGIES OF FRAME WALLS

CONCLUSIONS

Insualtion and framing assemblies in cost per square foot and in cost per R value.

R-11 wall with 2 x 4 @ 16" oc.	**$1.14 / sf.**	**$0.103 / R**
R-16 wall - 2 x 4 @ 16" w/ R-5 foam	**$1.77 / sf.**	**$0.110 / R**
R-19 wall with 2 x 6 @ 24" oc.	**$1.21 / sf.**	**$0.063 / R**
R-24 wall - 2 x 6 @ 24" w/ R-5 foam	**$1.68 / sf.**	**$0.069 / R**
R-30 wall - 2 x 6 + 2 x 4 horiz straping	**$1.85 / sf.**	**$0.062 / R**
R-30 wall - 2 x 8 studs + 1 x 3 straping	**$1.92 / sf.**	**$0.064 / R**
R-39 wall - 2 x 4 double wall x 12"	**$1.95 / sf.**	**$0.044 / R**
R-50 wall - 2 x 4 double wall x 15"	**$2.11 / sf.**	**$0.043 / R**

Costs based on 1994 "means pricing" without profit.

CALCULATING ENERGY SAVING IN DOLLARS AND SIMPLE PAYBACKS FOR BUILDING ASSEMBLIES

ASSUMPTIONS
BASED ON 1000 SQUARE FOOT OF ASSEMBLY
FUEL OIL AT \$.80 PER GALLON
9500 DEGREE DAY CLIMATE
HEATING INDEX OF 16.1

HEATING INDEX =

$$1000 \times \frac{\text{Degree Days} \times \text{24 hours}}{\text{Delta T}} \times \frac{\text{cost of fuel used}}{\text{BTU / fuel unit} \times \text{efficiency}}$$

$$1000 \times \frac{9500 \times 24}{95} \times \frac{\$.80}{140{,}000 \times .85} = 16.1$$

PAYBACKS ON ALTERNATE ASSEMBLIES

Savings per year = Change in "U" value x area x Delta T x Heting index / 1000

Change wall from R-11 to R-19
R-11 = U of .091
R-19 = U of .053
Change in U = .037

.037 x 1000sf. x 95(Delta T) x 16.1 / 1000 = \$57 savings (first year)
Cost of this change = \$70
Simple payback = \$70 / \$57 = 1.3 years

Change wall from R-19 to R-30 assembly
R-19 = U of .053
R-30 = U of .033
change in "U" = .020

.020 x 1000sf. x (Delta T) 95 x (HI) 16.1 / 1000 = $31 savings (first year)
Cost of this change is $.64/sf. x 1000 sf = $640
Simple payback is $640 / $31 = 20 years

This does not factor in fuel cost increases or savings comp.

Change wall from R-19 to a R-38 assembly
R-19 = "U" of .053
R-38 = "U" of .026
Change in "U" = .026

.026 x 1000 x 95 x 16.1 / 1000 = $40 savings
Cost of this change is $730
Simple payback is 730 / 40 = 18 years

Change windows (R-2) to (R-3.6)
Area of windows = 92 sq. ft.
R-2 = "U" of .500
R-3.9 = "U" of .277
Change in "U" is .223

.223 x 92 x 95 x 16.1 / 1000 = $31
without even calculating the cost of the windows it indicates that
upgrading windows based on just R values is not necessarily a good deal.
Please consider the infiltration rate in this problem
as this may be much more important!
Susposing that the better windows cost $210 more
210 / 31 = 6.8 years simple payback
A:14-1

THEORY VERSUS REALTY:

MAINSTREAMING

ENERGY EFFICIENT BUILDING AND DESIGN

Michael Uniacke

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(602)* 717-2879
***Area code changes to (520) on 3/19/95**

ABSTRACT

Tens of millions of dollars are being spent annually on efficiency and research programs that are having little or no impact on the way homes are being built in terms of energy efficiency. A trip into most new homes under construction in many parts of the country will reveal that builders are often not even utilizing the most basic energy efficient building and design details. This paper raises the question, "why are the same basic mistakes in terms of energy efficiency being made over and over again?" and then attempts to answer it.

The intent of this paper is to draw attention to problems that I believe are not discussed often enough in the building science community. The motivation stems forth from my growing bewilderment and frustration with the lack of progress in terms of building more energy efficient homes in this country. The paper explores the failure in technical transfer in this country and what measures can be taken to mainstream energy efficient building and design.

PREFACE

I'd like to begin my paper by acknowledging the fact that I have been a direct benefactor of the excellent work done by many individuals and several organizations throughout the country. These individuals and agencies have set a high standard which I use as a basis for comparison in this paper.

This paper represents a practitioner's perspective of the field. Over the past ten years I have worked ten years working as a carpenter, construction superintendent, contractor, teacher, and energy consultant. I currently perform building diagnostics, (with a blower door & duct blaster™), teach a building science course at the local community college, and occasionally teach workshops.

This paper is subjective and largely based on my work in Arizona. It also expresses "*my observations and opinions*" and not those of any other organizations. I have not worked closely with government, the utility culture, or the research community. Having made this acknowledgment, I will say that this does not mean my experience and opinions are any less valid, in fact they may be more valid since the end product is being evaluated

The scope of this paper is obviously very broad. Yet the last one hundred and fifty houses I inspected and tested had major problems in either the insulation system, air distribution system, crawl space with moisture, or some combination of all three. I feel compelled to express my observations and opinions in this paper due to the complete lack of quality control I encounter.

INTRODUCTION

The real challenge is not to squeeze more efficiency out of an energy efficient home, but to transfer our current understanding of home performance to the building community. If an individual knows how to design and build a home, then it is relatively simple and inexpensive to build an energy efficient house. If you accept this premise, then you have to raise the following question, "if it is simple to design and build an energy efficient home - why aren't the most basic techniques being used in the field?

Many people make the mistake of assuming that builders are getting the basics right. Unfortunately this is not the case. There is a complete absence of quality control for both the insulation and air distribution systems. In almost every attic I've inspected during the past two years, an estimated 15% to 45% of the attic insulation is missing. All the duct systems leak and an estimated one in three have major duct leakage. Why is this situation so bad?

The traditional explanations for why we are not building energy efficient homes do not ring true: energy efficiency costs too much, home owners aren't asking for them, and builders aren't interested. When 15% to 45% of the insulation is missing in an attic and the rest is poorly installed, the builders are not getting what they paid for. The traditional explanations for why we are not building more energy efficient homes in this country are as excuses for failed policy and programs.

The real problem is the failure in technical transfer and the misappropriation of resources. The vast majority of the people who need current information are not getting it. How can we expect builders and HVAC contractors to do good work if they've never been educated? The building science community needs to be asking the question, "why isn't the information getting to the people who need it the most?"

A general explanation for this failure in technical transfer is that people who are responsible for the implementation of energy efficiency programs suffer from a preoccupation with building science theory and not the reality of the construction site. This is evident in many current utility and educational programs, building science texts, and many construction details.

One of the keys to creating energy efficiency programs that deliver is simply making more effort to understanding what contractors are up against and work with this reality. A contractor's reality is based on production, appearance, and price. If energy performance standards, construction details, and training programs were more in tune with this reality, the chances of mainstreaming energy efficient building and design would increase dramatically.

REALITY - A PRACTITIONER'S PERSPECTIVE OF THE FIELD

The situation look very bad from my perspective in the field - perhaps disaster would be a more accurate way to describe what I find while performing advanced energy audits. There is a complete absence of quality control in terms of the insulation and air distribution systems in the last 150 homes I have inspected. A high quality insulation system, duct sealing, energy efficient framing details, . . . take a complete back seat in the appearance driven construction process.

I have inspected very few attics that have even come close to achieving the specified R-value. My inspections reveal 15% to 45% of the insulation is missing, never installed. The insulation, that is installed, is installed poorly with low spots regularly measuring less than one inch deep. I've also found "major" problems with installation of insulation in crawl spaces, walls, knee-walls in attics, and slab on grade foundations.

The majority of homes I inspect suffer from duct leakage. Three of the last four duct systems I measured for leakage in both Arizona and New Jersey had 600 + cfm of leakage. One of these systems had mastic on most sheet metal connections and was "considered" airtight, yet both return cavities were open to the attic as a result of this ill informed duct sealing. Leaky framed return cavities and disconnected supply ducts are the rule and not the exception.

A recent walk through of two homes under construction in New Jersey made it clear to me that many of the basic mistakes that are common to homes in Arizona are the same ones being made in New Jersey. Several local builders, who recently moved to Prescott from other parts of the country, have told me the situation in terms of energy efficiency is just as bad or worse where they came from. I also get similar reports from many nationally recognized building science experts.

The lack of quality control I encounter no longer surprises me. I have gotten to know the insulators and HVAC contractors who are responsible for the poor quality work I continually find. These people work in an industry that values speed, price, and response time - which is often at the expense of quality work. Many of the insulators do not know how insulation works - thus the importance of a thorough installation. The HVAC contractors are not getting the message about duct leakage through established channels.

The only way to get a clear picture of the quality of construction in a particular region is to test and inspect many homes. Tests need to be performed with blower doors and duct testers. Insulation needs to be inspected by someone who understands framing and the effect of thermal defects on heat loss. Sophisticated technology, computer modeling, and prescriptive standards are secondary. What matters is what actually happens in each house under construction.

THE TRADITIONAL EXPLANATIONS FOR WHY WE AREN'T BUILDING ENERGY EFFICIENT HOMES

Many people genuinely believe that we are not building more energy homes because (1) energy efficiency costs too much, (2) the public isn't asking for energy efficient homes (3) builders and architects aren't interested. These arguments simply do not hold up in the field. They are excuses for programs that are not working.

Since the building process is driven by costs, the first argument deserves the most attention. Many energy efficient construction details are free or extremely inexpensive considering the total cost of a typical home. When 15% to 45% of the attic insulation is missing, the issue simply becomes one of getting what the contractor paid for. How much does it cost to send a person up into the attic to inspect the insulation - one hour of labor? In this case it is not an issue of cost, but of quality control.

There are many framing details that reduce the amount of lumber used in a house and permit the insulators to do a better job. Twenty-four inch on center framing, three stud corners, ladder back blocking, insulated headers, are a few of the details that can save money and increase the quality of the insulation system. These details are simple, yet many builders are still using conventionally framed channels at exterior corners and the intersection of interior and exterior walls which do not permit proper installation of insulation? Why are we still using these inefficient framing details twenty years after the energy crisis?

Suntempering is a wonderful strategy to produce a more comfortable and energy efficient home that simply involves taking advantage of the sun. This design strategy has no cost. A designer simply has to be aware of how to correctly orient the house and utilize the free mass in the house. I have often asked myself, why is passive solar design being ignored in the sun rich state of Arizona?

There are the inexpensive upgrades that pay big dividends in terms of efficiency, enhanced comfort, and indoor air quality. An airtight duct system that costs approximately $300 is a minor expense that will pay for itself in one to three years. What homeowner would not want an airtight duct system if they were aware of the benefits?

Many homeowners are never presented with the choice of making these upgrades and builders assume since they are not asking they obviously aren't interested. The truth is the public does not know what to ask for. The public would be outraged if they knew how much insulation is missing in their attics or that their return duct system is sucking air out of the crawl space or attic.

Few builders have a clear picture of what is an energy efficient home. How can we expect them to sell the benefits? It is incorrectly assumed that builders have received training and are aware of these important issues. By and large, it is safe to say that the majority of builders have little or on understanding of building science issues.

The argument that builders and architects are not interested in these issues - does not hold up under scrutiny either. I have discovered in my community that there is a significant amount of latent interest in building science issues. What the building science community has failed to do is overcome the initial resistance and tap into this latent interest in building science issues with high quality training programs.

The traditional explanations do not offer a satisfactory explanation for why we are not getting the basics right. Many energy efficient details are free or extremely inexpensive considering the total cost of a typical home - yet more often than not they are not being utilized. The traditional approaches to energy efficient building and design programs are obviously not working.

TRADITIONAL APPROACHES TO THE OLD PROBLEM THAT AREN'T WORKING

Prescriptive programs, demonstration homes, and promotional campaigns are poor substitutes for rigorous training programs and performance standards. If builders and subcontractors are not given the benefit of high quality building science training and follow up testing, then real quality control will not exist in the field where it is needed the most.

If you examine many of the current approaches to fostering energy efficient building and design, it is obvious to me why they are not having much impact. Simply giving a builder a checklist of measures does not work. If an air distribution system is not tested, there is no guarantee it correctly sealed.

I think it's fairly safe to say that prescriptive systems do not yield returns. I believe prescriptive systems and demonstration homes are simply marketing tools to project an environmentally friendly image. If the program's intent is to conserve energy it will be reflected in its commitment to high quality education and testing programs, not complicated demonstration houses.

So why do we continue to build demonstration houses? To prove insulation and duct sealing works? I just visited the electric utility's demonstration house in Phoenix. This $800,000 dollar project is being built in a sea of homes that are inadequately insulated and suffer from major duct leakage. What is the real intent of these types of programs?

A good way to evaluate the intent of a program is to measure the ratio of money spent on marketing as compared to substantive training and field inspections performed by qualified personnel with blower doors and duct testers. If there is not a strong educational and quality control component, the program becomes a corporate image builder and has little or no impact on the housing stock.

The problem with all these traditional approaches is that the battle is being waged in offices and not out in the field. When utilities are committed to capturing real savings rather than image building it will be evident in the quality of the training and follow up testing in the field.

OBSTACLES TO EFFICIENCY

There is a host of genuine obstacles to incorporating efficiency into home building. They need to be identified and dealt with before substantive progress can be made. With the exception of a temperate climate and low fuel costs, most of the obstacles are a result of the failure of programs to focus on the builder and the construction site.

A major obstacle is accessibility to good information. Emphasis must be placed on "good," because good information is hard to come by if you don't know where to look. There are plenty of conscientious builders and architects, who would build and design better homes if they realized the impact of their decisions during the design and construction process.

This lack of access to current information has kept most builders and designers in the dark. There is a staggering amount of confusion surrounding home performance issues. Many builders think that indoor air quality problems are a result of house air sealing. They are not at all familiar with source control and ventilation strategies. A direct result of this type of confusion is that nothing is done to raise the level of efficiency in the homes that are being built today.

Building science is a way of thinking and understanding home performance and few people are successfully communicating this concept to the people who really need this it. Poor quality training is worse than no training at all because it only serves to compound the confusion. The building science community needs to raise the expectations for quality training and also reexamine the message.

By placing too much emphasis on super insulation details like double walls, strapped walls, and the airtight drywall approach the vast majority of builders feel alienated by this process and overlooked the basics. Labor and material intensive construction details also reflect this lack of connection with the field. Builders need to learn the basics of building science before they can be expected to undertake more challenging building details.

The building science community needs to work closer with the contractor's reality. If we were, it would be evident in the simplicity of the construction details and the emphasis of the training and testing. Contracting is a competition driven business and the building science community appears to have lost sight of this fact.

THE CONTRACTOR'S AND SUPERINTENDENT'S REALITY

Since we are leaving the mainstream builder out of the picture the most basic energy efficient building and design details will not be incorporated. The mainstream builder is an individual who would rather spend their winter vacation boating, golfing, deer hunting, or in Hawaii, rather than attending a building science conference. The building science community needs to better understand this individual's reality if energy efficient building and design is ever going to be mainstreamed.

I have focused on both the contractor and the superintendent for two important reasons. The contractor or owner of the business needs the vision and commitment to do the right thing. The superintendent oversees the jobs on a daily basis, so this person needs the knowledge to see that details are correctly executed in the field.

Construction supervision on a custom or tract subdivision is an appearance and schedule driven process. Details such as the quality of the sheetrock finish, paint, cabinets, and how presentable the house looks after final cleanup, define quality in a home. It is very easy for a supervisor to skip an insulation inspection and duct leakage test when they've got a hectic schedule and when few people are asking for the results.

Subcontractors make money by doing the same thing day in and day out. Every time a step is added to the process there is a greater risk that something will be missed. New equipment takes time to install. Many insulators are not paid enough to install batts correctly. Job performance is often evaluated in terms of production speed. All the pressure is toward getting the home built quickly, not built correctly.

Building quality into homes will only begin to happen in a consistent fashion when we acknowledge the difficulties and obstacles in the construction process and begin to show more empathy with the mainstream builder. The building science community should be championing products that are easy to install and have inherent quality control .

SOLUTIONS

The sad irony of this problem is that the solution is rather mundane. A major step in the right direction would be made by simply transferring the building science basics to the people who need this information the most. By implementing quality control in both the installation of insulation and the air distribution system a phenomenal amount of energy would be saved.

If a builder can be successfully taught the basics, then there is the real possibility of builders selling energy upgrade packages. To be able to sell an energy upgrade package the Realtor and builder have to know what they are talking about in order to convey the benefits to potential home buyers. This scenario will only occur if the builders and Realtors receive high quality education.

The more progressive builders could incorporate insulation inspections, leakage standards and testing for duct systems, air sealing, efficient framing details, controlled ventilation . . . and then exploit the fact that their competitors are deficient in these areas. Realtors could then sell both appearance and performance.

The time to ensure that quality will be built into the home is prior to breaking ground on a new house or subdivision. A subcontractor is most open minded when they are vying to get your work. Once you are locked in on a bid and the project is underway, it is much harder to get a subcontractor to change their ways. A real quality control program will lock a subcontractor in with clear specifications and testing procedures.

Testing is the only way to really know if the job is done correctly. Insulators and HVAC contractors should be held to the same standards as all other subs. Telling someone to seal up a duct system as opposed to training them to do the job correctly and following up with a test is an entirely different approach. HVAC contractors need numbers generated by a blower door or duct tester that give them feedback to how well they are doing.

QUALITY TRAINING

The main strategy for combating the failure of technical transfer in this country will be through high quality training and testing programs. Education is critical because true quality control arises from an understanding of basic building science principles.

Builders need to be instructed so they can be held accountable and perform more of their own quality control work.

Builders and architects also need to learn how to think independently in terms of home performance issues. They need to learn the how and why of the systems approach to energy efficient building and design. Plans will never anticipate all potential problems that crop up in the field, so the construction superintendent, HVAC contractor, and insulator in the field have to be able to independently work through problems.

Training the building community about the systems approach is a very tall order due to the multidisciplinary nature of the systems approach to energy efficient building and design. Ideally high quality building science training will, like a switch being flipped, create real understanding. The education must be grounded in the reality of the field because that is where the success of the training has to be measured.

If the success of the education will be measured in the field, then there must be a strong field component to the education. This is the genius of what FSEC and AEC have done with their duct doctoring programs. They completely understood the reality of the field and the challenges that contractors face in their businesses. They worked with this reality and successful training occurred as evidenced by contractors ability to meet strict duct sealing performance standards.

An effective trainer will also appeal to a worker's sense of pride. I recently pressurized a duct system with my duct blaster™ and then filled it with smoke from a theatrical smoke machine. Seeing the smoke blow through the cracks and leaks in their supposedly airtight duct system created a paradigm shift - they suddenly understood what we were after. After this experience one of the workers told me that his next system would be so airtight that it would be a feature article in an industry magazine.

And finally, we test HVAC contractor's work with a blower door or duct tester to make sure they got it right. Building science educators should be held to a similar standard. Did the training change the way builders and architects build and design as a result of the education - yes or no? If the education is not working, it must be changed because poor quality training is worse than no training at all.

CONCLUSION

The building science community faces major opportunities and obstacles. The business as usual approach to energy efficient building and design is not working in many parts of the country. The main problem is that our current understanding of home performance is not filtering down to the builders, architects, HVAC contractors, . .

A preoccupation with building science theory or corporate image and not the reality of the contractor and the jobsite explain why so many programs are having little or no impact on current building practices. The problem with all these traditional approaches is that the battle is being waged in offices and not in the field. This approach needs to be challenged before the mediocre programs begin to tarnish the excellent programs.

A successful energy conservation program will have the following elements. First and foremost, it will be grounded in the reality of the jobsite. Participants in the program will be educated in building science theory. Construction details will be builder friendly in terms of the amount of labor and material used in their execution. All duct systems will be tested with a duct tester. These measures will ensure we get the basics correct.

High quality builder and architect education will play a crucial role in programs that truly want to impact current building practices. The effectiveness of training will be defined by the builder's success in the field. If the educational process does not create substantive change in building practices, then it will need to be overhauled. The building science community can no longer take quality training.

PERMANENT
WOOD
FOUNDATION
INC.

P. O.BOX 819 FLINT, MICHIGAN 40501
PHONE (810) 232-5099

TECHNICAL SERVICES DIVISION

NOVEMBER 1994

1994 PERMANENT WOOD FOUNDATION SYSTEM DESIGN, INSTALLATION & INSPECTION CHECK-LIST

Provisions of the 1994 Permanent Wood Foundation Check-list (DII) have been developed in accordance with the 1986 National Design Specification for Wood Construction (NDS) and the 1986 NDS Supplement Design Values for Wood Construction.

Design aids provided in the Check-List have been developed for common design conditions. The use of these aids for high wind, snow, or seismic regions or areas with special soil condition should be reviewed by a qualified design professional.

The history of construction shows constant advancement and improvement in design, materials and methods, such that much of today's building practive differs significantiy of one, two decades ago. The Permanent Wood Foundation system illustrates just such an evolutionary progression. Developed two and a haft decades ago to provide an economical and dry construction method for foundations, the present system reflects the many years of field experience obtained since the early prototype were first built. Experience with these and with the thousands of PWF units has refined the system into its current highly developed form.

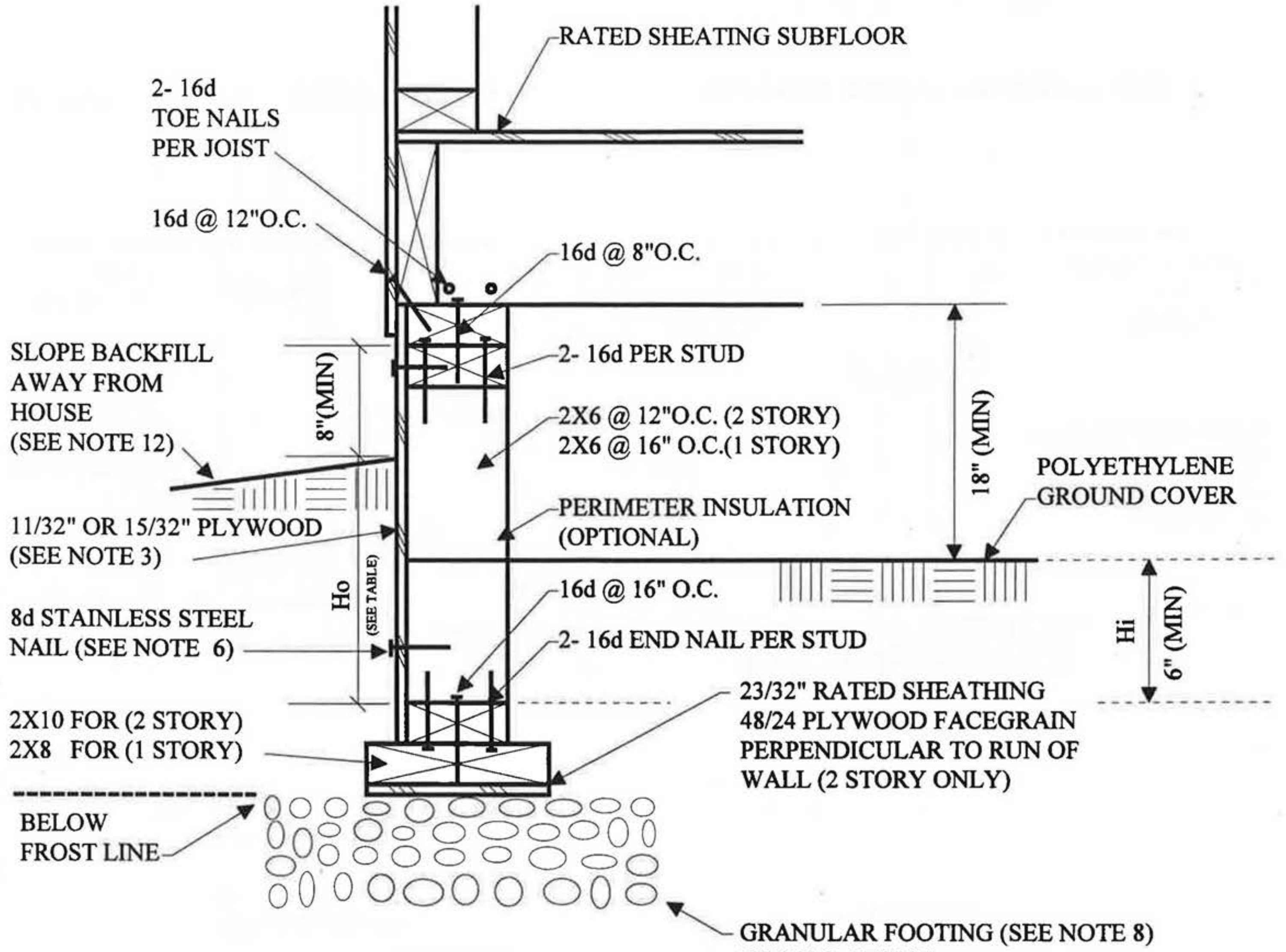
This technical paper, case study, or workshops will share ideas, experiences and research about the Permanent Wood Foundation system and Check-List.

Technical Services Division
Roscoe J. Clark

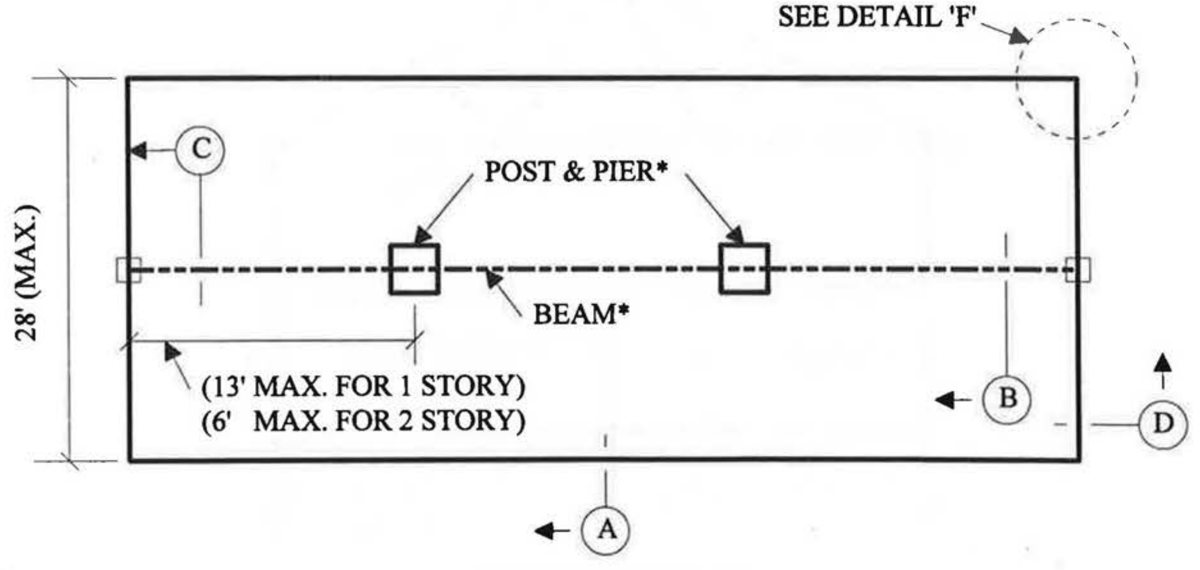
Permanent Wood Foundation Details for 28' Wide, 1-or 2- Story Crawl Space House

Permanent Wood Foundation, Inc.
Flint, Michigan

Plan 2.



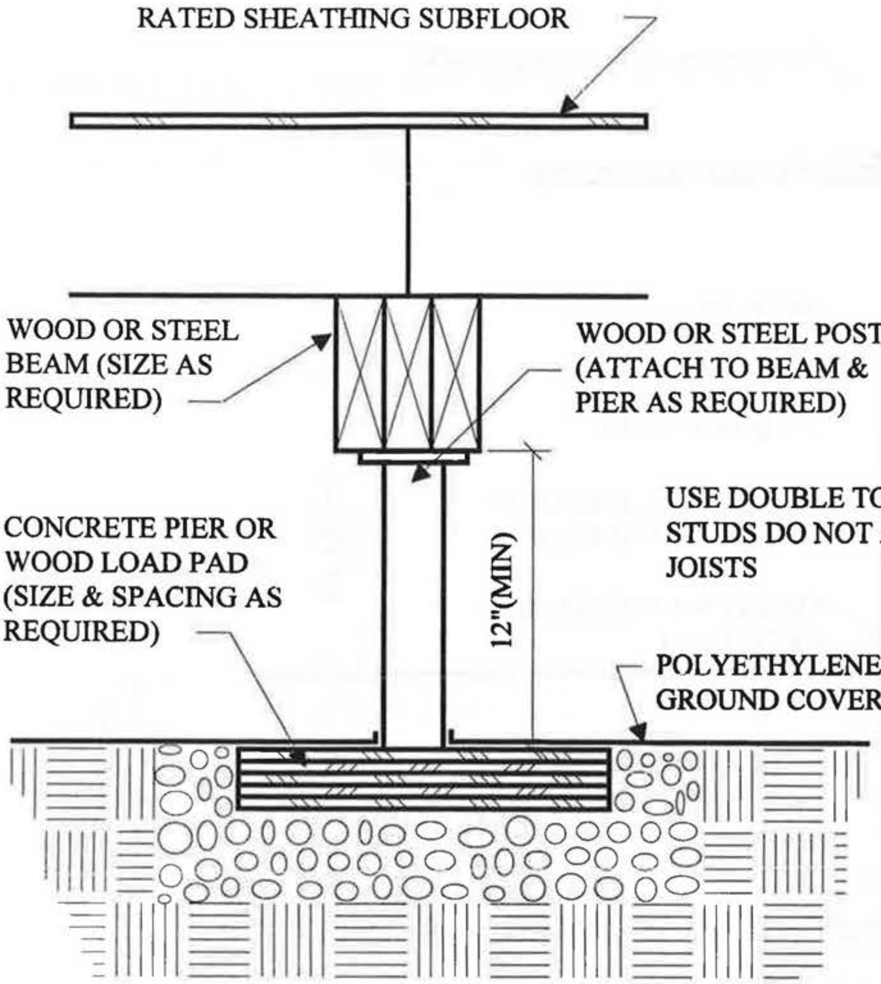
SIDE WALL (A)



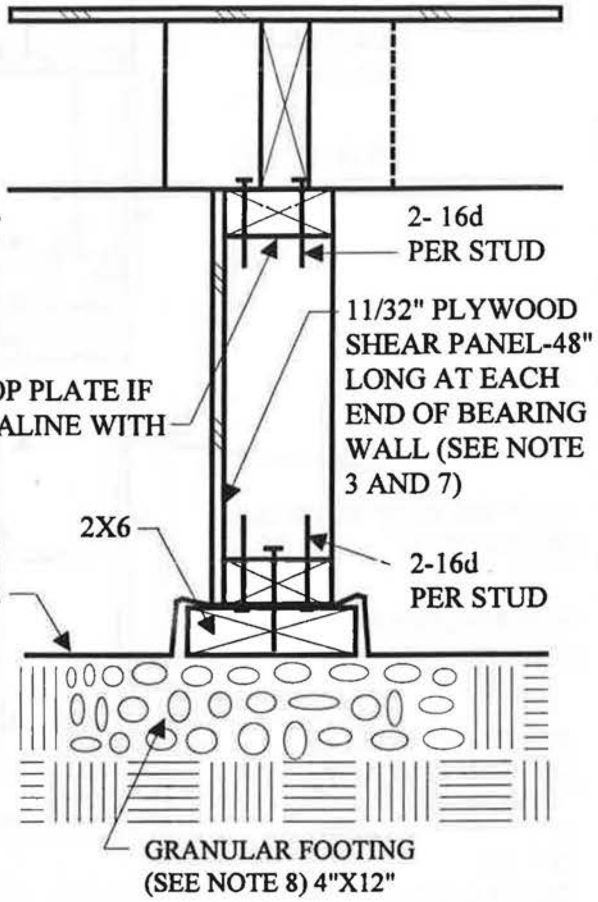
FOUNDATION PLAN

*SEE ALTERNATE DETAILS FOR TREATED WOOD BEARING WALL

Permanent Wood Foundation, Inc.
Flint, Michigan

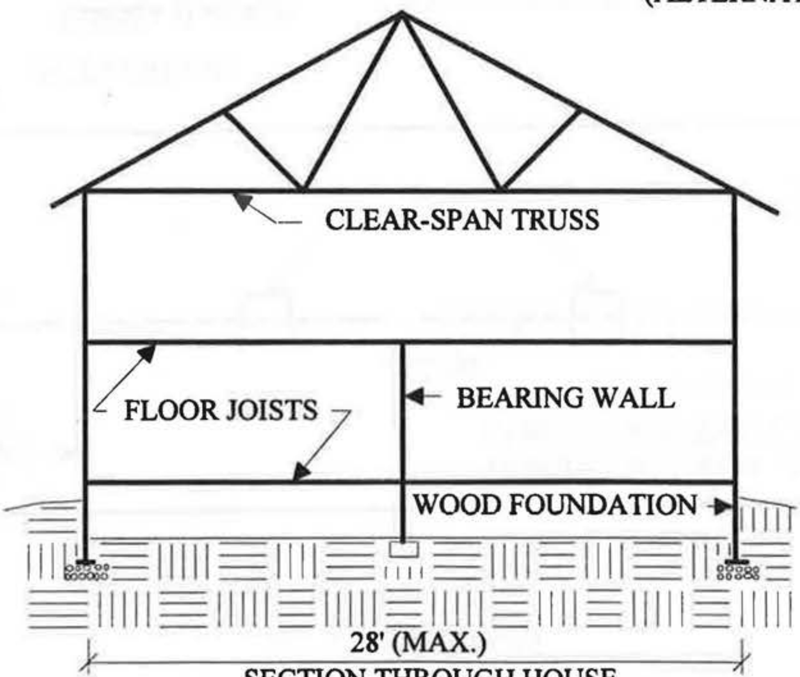


POST & PIER (B)



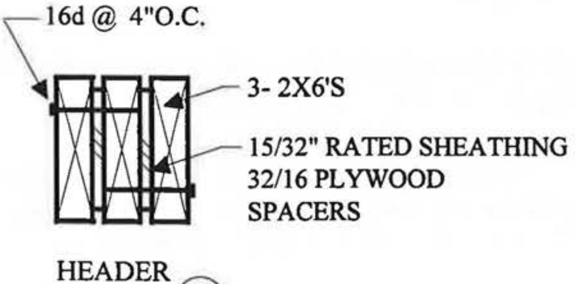
TREATED WOOD BEARING WALL

(ALTERNATE TO (B))

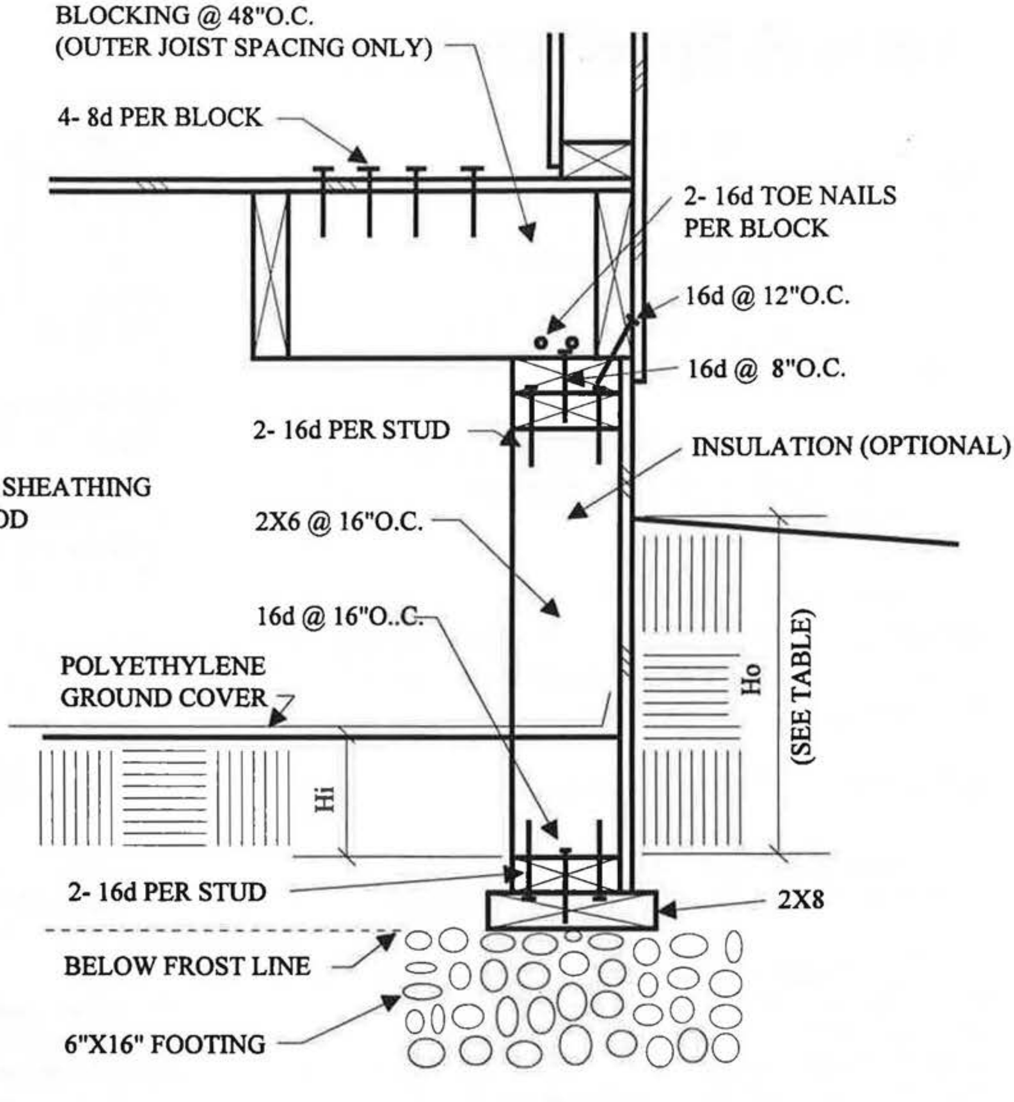


SECTION THROUGH HOUSE

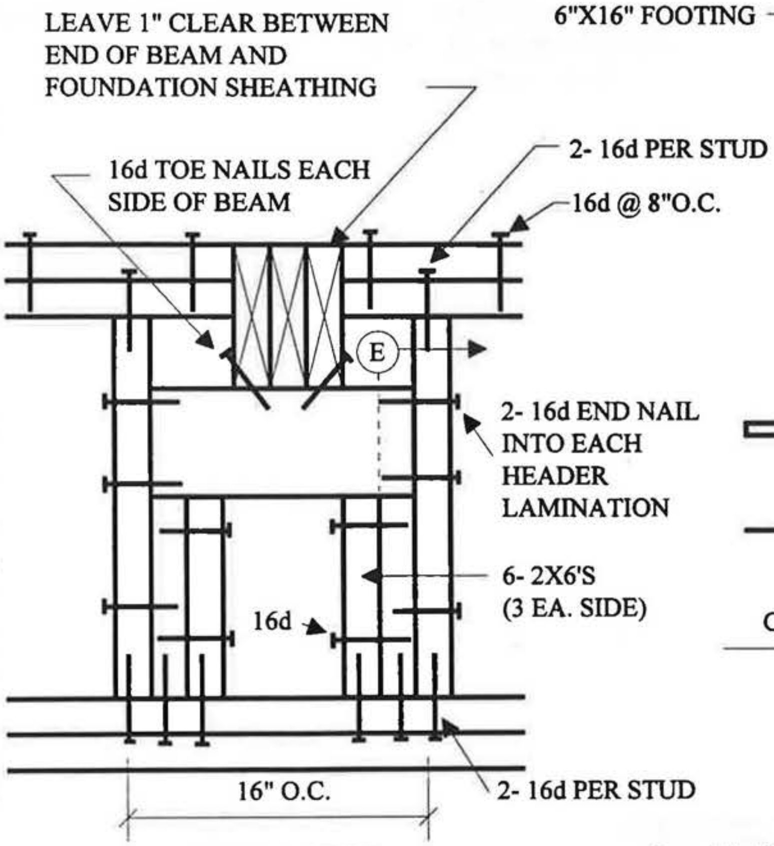
Hi (inch.)	MAX. Ho (inch.)
6	17
8	22
10	27
12	32
14	37
INSIDE FILL	OUTSIDE FILL



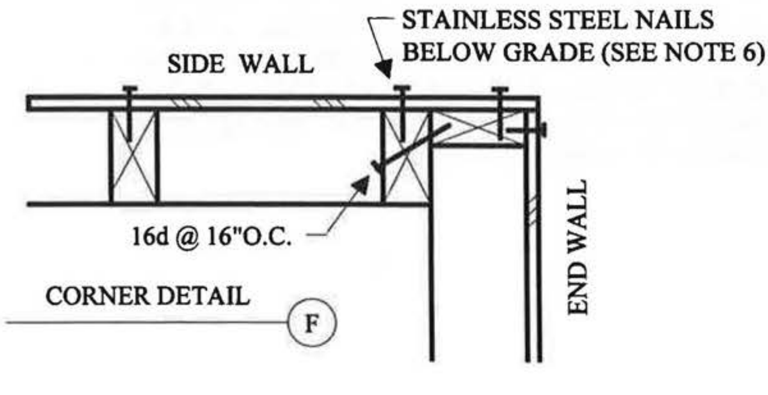
HEADER (E)



END WALL (D)



BEAM POCKET (C)



CORNER DETAIL (F)

Notes & Specifications:

1) Design loads and pressures
Roof: 40 psf snow load
Floor: 40 psf live load
Soil: 30 pcf equivalent fluid density
2000 psf allowable bearing
pressure (Soil Group 1, 2 and 3)
Gravel: 3000 psf allowable bearing pressure

2) All material sizes, grades and construction details should be verified by the user and adapted to meet his job conditions.

3) Plywood shall be identified with the marking indicating compliance with U.S. Product Standard PS 1. marked Exposure 1 is recommended for treated wood basement foundation sheathing.

4) Lumber to be Southern pine No. 2.

5) All lumber and plywood within 8" of soil to be preservative treated per AWPA-FDN Standard.

6) All plywood-to-lumber fasteners below grade shall be 8d Type 304 or 316 stainless steel nails @ 6" o.c. edges and 12" o.c. intermediate. Provide one additional plywood fasterner within 1" of base of each stud if galvanized framing nails are use for plate to stud connection.

7) Hot-tumbled or hot-dipped galvanized nails may be used for above-grade plywood connections and all lumber-to-lumber connections.

8) Footings to be gravel (3/4" max.) or crushed stone (1/2" maximum). When interior ground level is below outside finish grade, provide granuler drainage trenches or drain pipe from sump crock to drain by gravity to daylight, storm sewer or other approved stormwater drainage system.

9) Lumber cut or drilled after treatment must be field-treated by repeated brushing, dipping or soaking untill the wood absorbs no more preservative. Copper Naphthenate is recommended for this purpose. Treated lumber must never be ripped parallel to grain. Plywood does not require edge coating after cutting.

10) Stagger joints in lower plate and footing plate. Stagger joints in upper plates.

11) Provide gutters, downspouts, and splash blocks or laterals to carry water away from building. Do not connect downspout to perimeter drains.

12) Do not backfill untill wall is adeqately braced and Rated subfloor is installed on deck.

13) Where a termite hazard exists, treat soil at ground contact points, inside and outside of building.

14) Where perimeter foundation wall insulation is provided rather than floor insulation, closeable screened vents must be used.

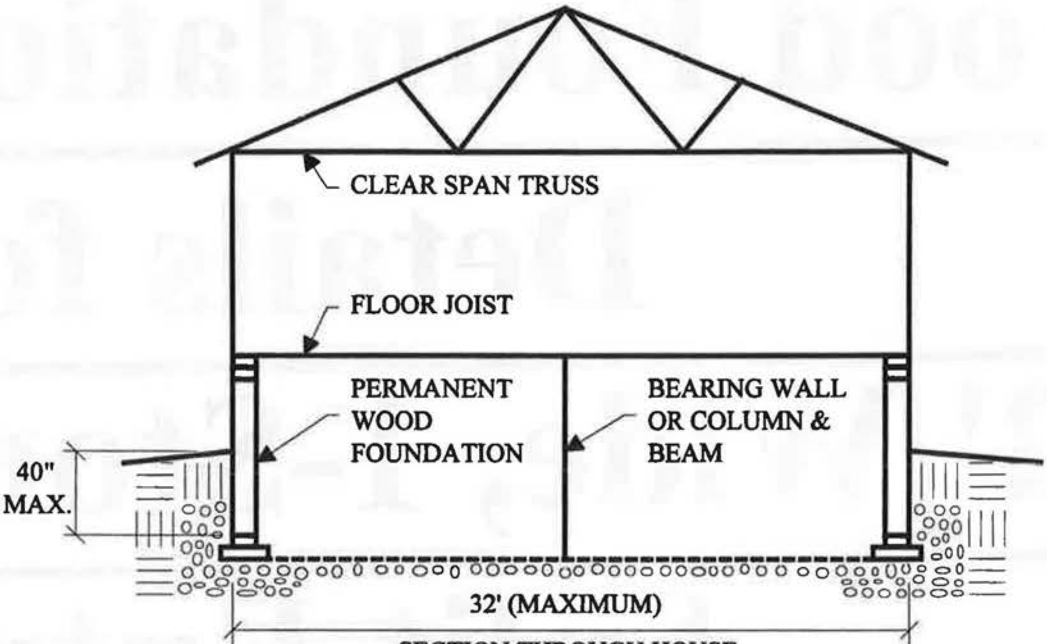
15) For a complete custom design and construction plan, write to Permanent Wood Foundation, Inc. P.O. Box 819 Flint, Michigan 48501 (810)232-5099.

Permanent Wood Foundation Details for 32' Wide, 1-Story Split-Entry House

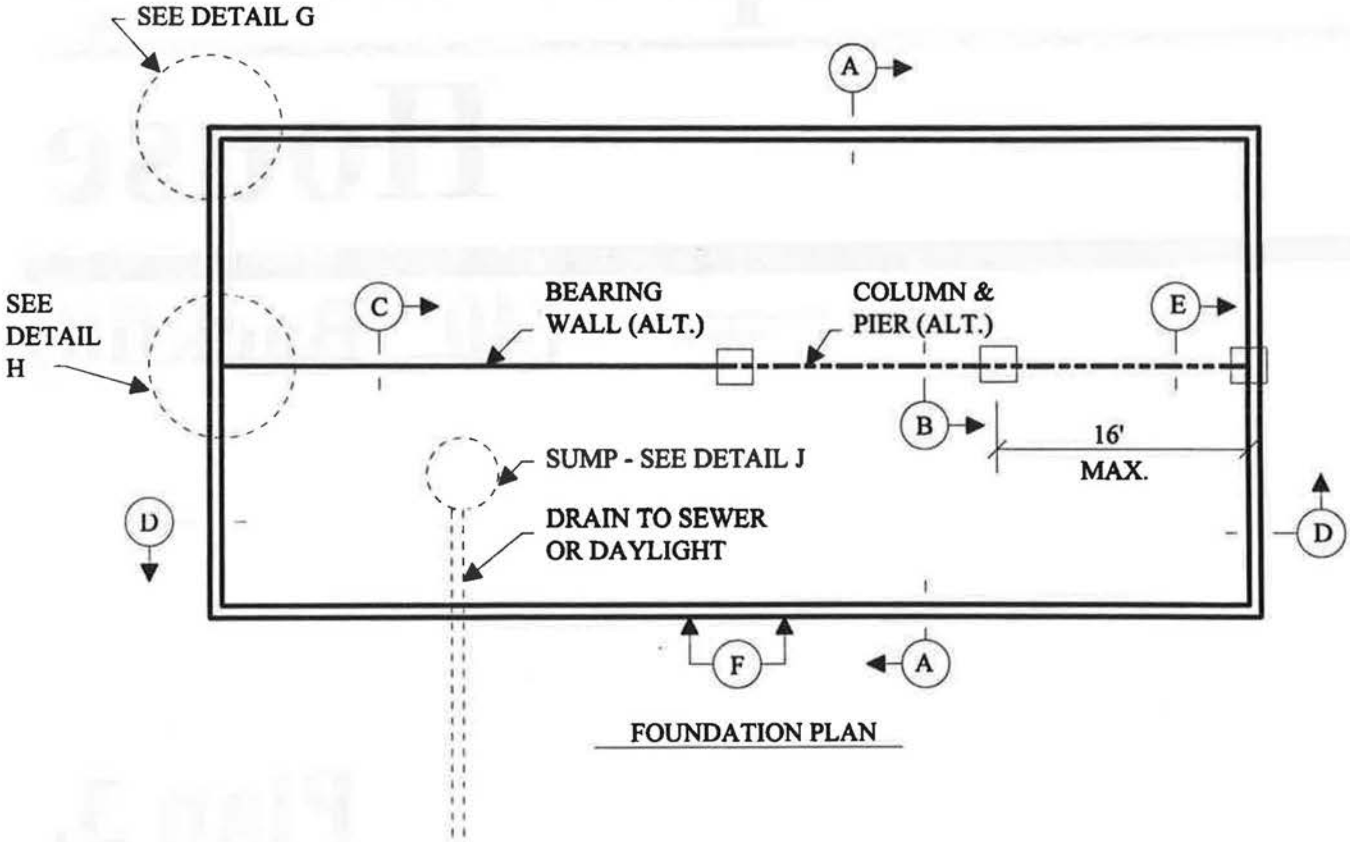
Permanent Wood Foundation, Inc.
Flint, Michigan

(40" Backfill)

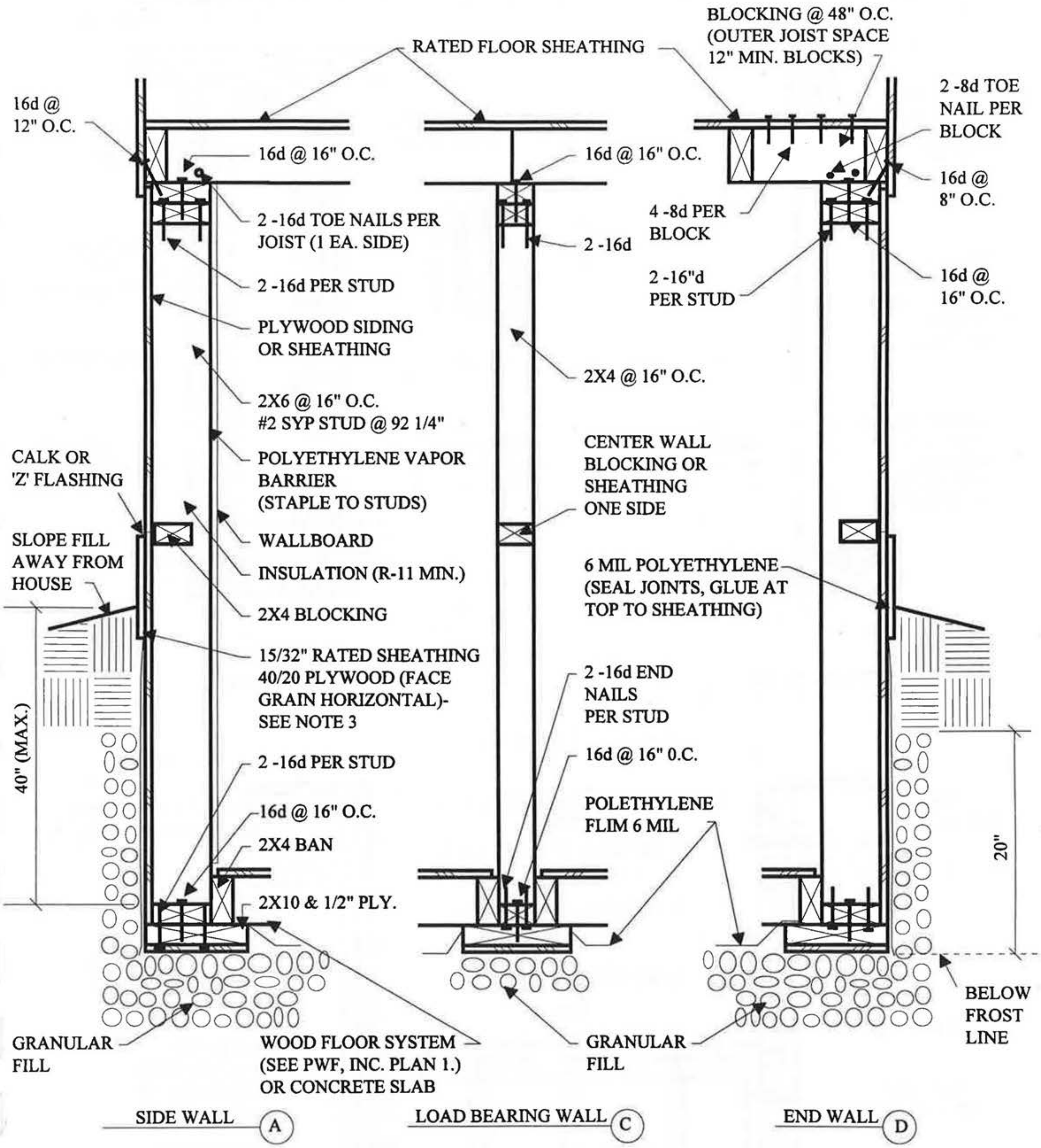
Plan 3.

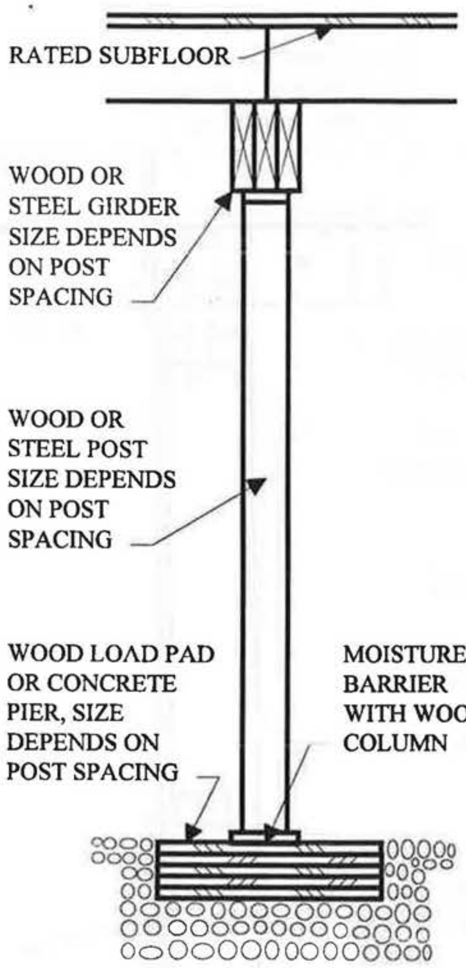


SECTION THROUGH HOUSE

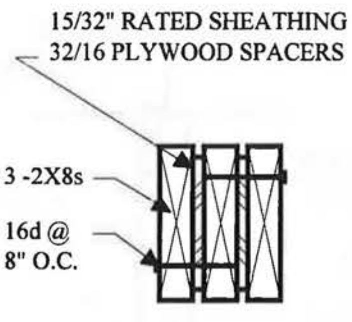


FOUNDATION PLAN

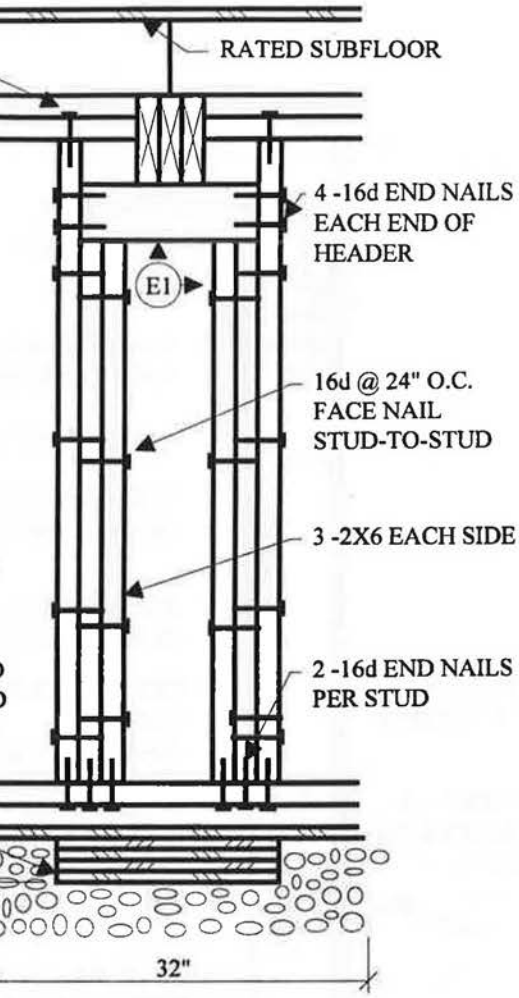

RATED FLOOR SHEATHING
BLOCKING @ 48" O.C. (OUTER JOIST SPACE 12" MIN. BLOCKS)
16d @ 12" O.C.
16d @ 16" O.C.
2 -16d TOE NAILS PER JOIST (1 EA. SIDE)
2 -16d PER STUD
PLYWOOD SIDING OR SHEATHING
2X6 @ 16" O.C. #2 SYP STUD @ 92 1/4"
CALK OR 'Z' FLASHING
POLYETHYLENE VAPOR BARRIER (STAPLE TO STUDS)
SLOPE FILL AWAY FROM HOUSE
WALLBOARD
INSULATION (R-11 MIN.)
2X4 BLOCKING
15/32" RATED SHEATHING 40/20 PLYWOOD (FACE GRAIN HORIZONTAL)- SEE NOTE 3
40" (MAX.)
2 -16d PER STUD
16d @ 16" O.C.
2X4 BAN
2X10 & 1/2" PLY.
GRANULAR FILL
WOOD FLOOR SYSTEM (SEE PWF, INC. PLAN 1.) OR CONCRETE SLAB
16d @ 16" O.C.
2 -16d
2X4 @ 16" O.C.
CENTER WALL BLOCKING OR SHEATHING ONE SIDE
2 -16d END NAILS PER STUD
16d @ 16" 0.C.
POLETHYLENE FLIM 6 MIL
GRANULAR FILL
2 -8d TOE NAIL PER BLOCK
16d @ 8" O.C.
4 -8d PER BLOCK
2 -16"d PER STUD
16d @ 16" O.C.
6 MIL POLYETHYLENE (SEAL JOINTS, GLUE AT TOP TO SHEATHING)
20"
BELOW FROST LINE
SIDE WALL A
LOAD BEARING WALL C
END WALL D



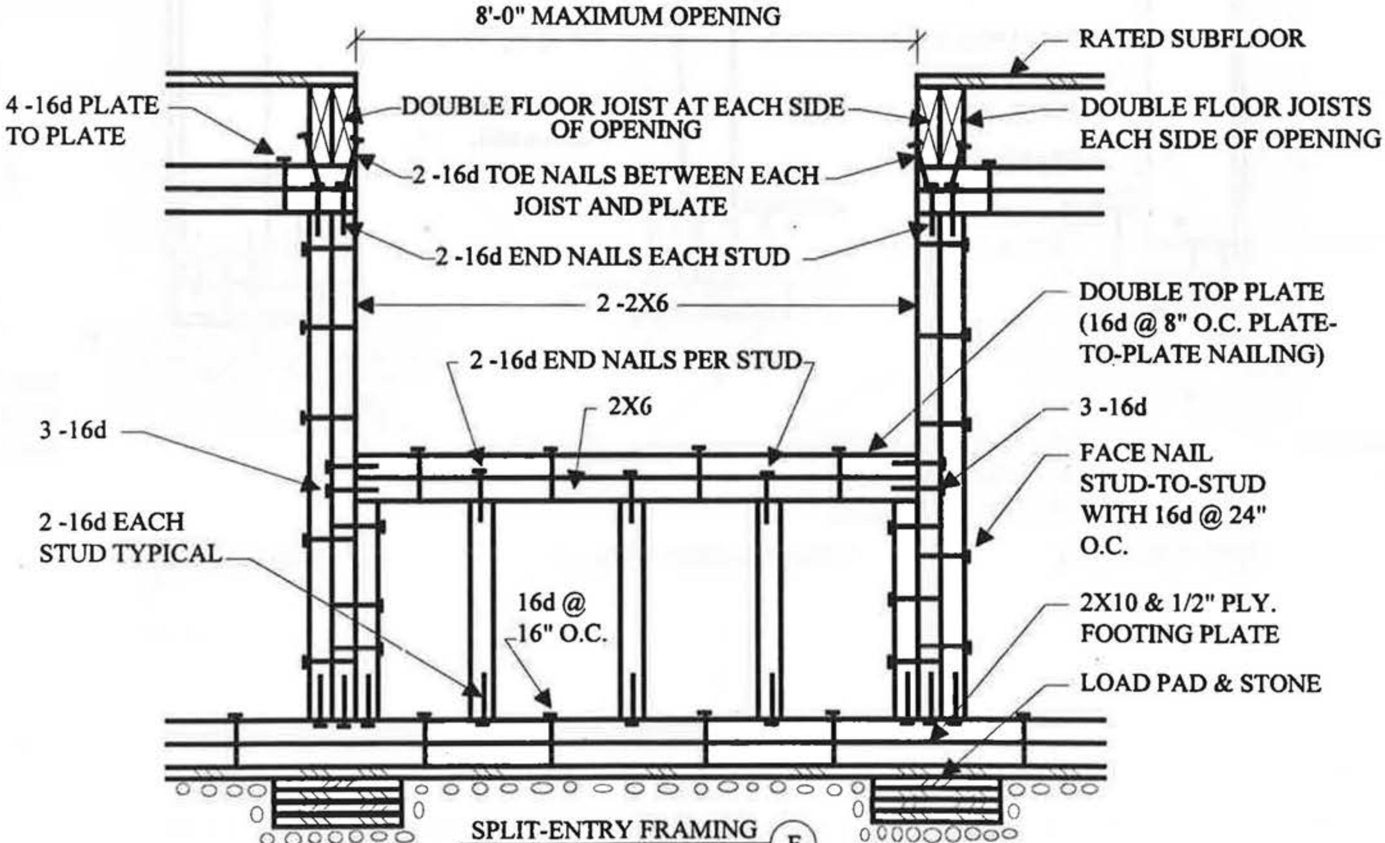
COLUMN & PIER (B)



HEADER (E1)



BEAM POCKET (E)



SPLIT-ENTRY FRAMING (F)

Permanent Wood Foundation, Inc.
Flint, Michigan

Notes & Specifications:

1) Design loads and pressure
   Roof: 40 psf snow load
   Floor: 40 psf live load
   Soil: 30 pcf equivalent fluid density
   2000 psf allowadle bearing
   pressure (Soil Group 1, 2 and 3)
   Granular Footings:
   3000 psf allowable bearing pressure.

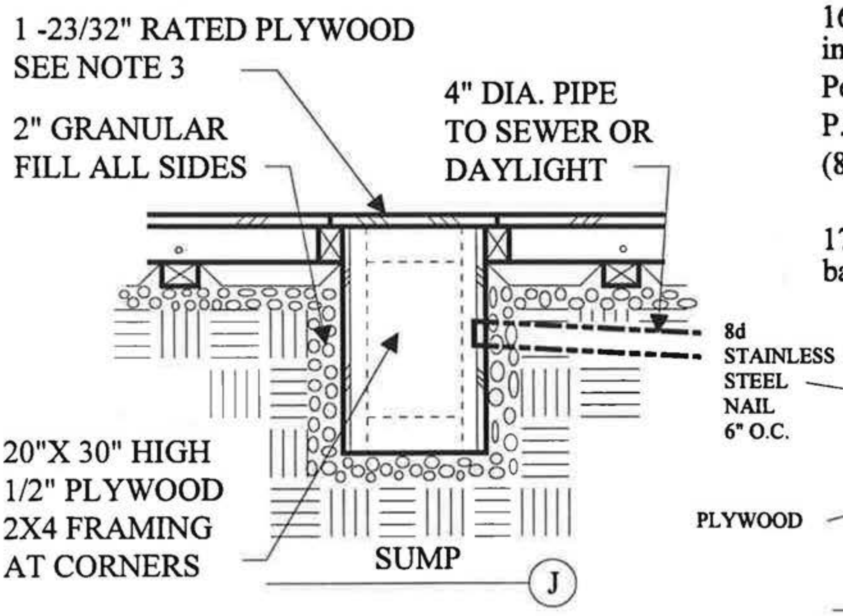
2) All material sizes, grades and construction details should be verified by the user and adapted to meet it job conditions.

3) Plywood shall be identified with the marking indicating compliance with U.S. Product Standard PS 1. marking Exposure 1 is recommended for treated wood basement foundation sheathing.

4) All lumber and plywood within 8" of soil shall be preservative treated per AWPA-FDN Standard or equivalent code-approved preservative-treating and quality control requirements.
Each piece shall bear the quality mark of an approved inspection agency certified to inspect preservative-treated wood.

5) Lumber to be Southern pine No. 2 Dry FDN or equal.

6) All plywood-to-lumber fasteners below grade shall be 8d Type 304 or 316 stainless steel nails @ 6" o.c. edges and 12" o.c. intermediate. Electro-plated galvanized nails are prohibited.



7) Hot-tumbled or hot-dip galvanized nails may be used for above-grade plywood connections and all lumber-to-lumber connections.

8) Footings and granular fill under wood floor system or slab shall be gravel (3/4" maximum), or crushed stone (1/2" maximum). Grandular fill under wood floor system or slab to be 4" for Group 1 and 2 soils, and 6" for Group 3.

9) Lumber cut or drilled after treatment must be field-treated by repeated brushing, dipping or soaking until the wood absorbs no more preservative. Copper Naphthenate is recommended for this purpose. Treated lumber must never be ripped parallel to grain. Plywood does not require edge coating after cutting.

10) Caulk all plywood joints in foundation.

11) Stagger joints in lower plates and footing plate. Stagger joints in upper plates.

12) Provide gutters, downspouts, and splash blocks or laterals to carry water away from building. Do not drain into foundation sump system.

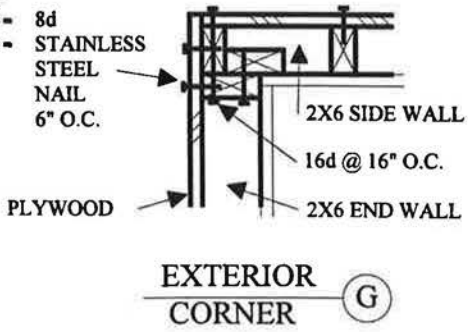
13) Do not backfill until basement wood floor system or slab has be installed and cured, and a rated first floor system is installed.

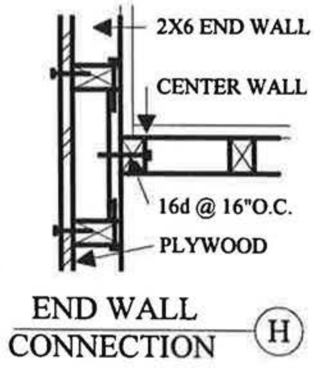
14) Sump pump required when sewer inlet is above bottom of sump.

15) Where a termite hazard exists treat soil under basement floor and around foundation.

16) For complete design and construction information, write
Permanent Wood Foundation, Inc.
P.O. Box 819 Flint, Michigan 48501
(810) 232-5099

17) For alternate construction with treated wood basement floor, write for PWF Plan 1.





notes

DRY BASEMENTS THROUGH THE SELECTIVE USE OF THERMAL INSULATION AND MOISTURE-RESISTANT MATERIALS

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Abstract

There are many building science problems related to basements including problems associated with heat and moisture movement. This paper examines the soil thermal and moisture regimes which vary with the season and depth below grade. Considering these changes, this paper proposes straightforward solutions involving the selective use of basement thermal insulation and moisture-resistant materials. In addition, solutions to insulating crawl spaces are presented together with a discussion of the potential for frost-heave and adhesion freezing problems. The proposed solutions offer the promise of lower building and operating costs while improving the indoor environment.

Introduction

In spite of all of the work that has been done to develop appropriate materials and assemblies for the foundations of houses and to separate the indoor basement climate from the outdoor soil climate, basement problems are the leading cause of warranty claims. Leaky basements, damp basements, cracked walls, frost-heaved walls, the smell of mould and mildew, cracked floors, dust, Radon gas, and now termites are just some of the problems.

Moisture is the cause of some of the leading problems associated with basements. The building of a dry basement is not always a simple task, and most problems are rectified by resorting to brute force: re-excavating the soil around leaky basements, using humidifiers during the winter and dehumidifiers during the summer to maintain an acceptable indoor relative humidity, and in extreme cases rebuilding a basement. In the end, the cost of these defects is passed on to the homeowners.

Basement moisture problems are complicated by the environment surrounding the basement. Basement walls and floors are usually surrounded by soils that are damp, and at times, the water table can move above the level of the basement floor. Also, the soil is always cool and its temperature is out of phase with the outdoor air temperature. At times moisture flows from the soil into the basement, while at other times, moisture moves in the opposite direction. There are even times when moisture flows in different directions at different wall depths, owing to the thermal lag associated with the huge soil mass around the basement. Basement walls and floors are climatic partitions that provide a transition from an acceptable indoor climate to the variable soil climate. If the forces at work are understood, the effective control of indoor climate is not difficult to achieve.

When basement moisture problems are analyzed, it becomes evident that many of these problems can be solved by considering the following variables: water vapour pressure gradients, water vapour permeability, temperature, temperature gradients, and time. It is relatively easy to predict the movement of moisture through a given basement wall assembly, providing time and temperature effects are taken into consideration.

In this paper, the influence of these variables on basement performance will be discussed. Solutions which attempt to solve many of the problems related to basements through the selective use of thermal insulation and moisture-resistant materials will be presented. These rather straightforward solutions hold the promise of reducing both building costs and operating costs while improving the indoor environment.

The Basement Regime: Cold Climate

The basement thermal and moisture 'regimes' vary both in time and depth below grade. Since it is the combination of the movement of heat and moisture that leads to most basement problems, an examination of basement moisture problems requires that both of these regimes and their interaction be understood.

The following kinds of water comprise the basement moisture regime: bulk water, capillary water, adsorbed water, water vapour, and chemically-combined water.

Bulk water or, for the lack of a better term, "gravity water" is water which is moved by the force of gravity acting on it. It will flow above ground or within the pores in both soils and building materials seeking the lowest position, that of least potential energy. In static equilibrium, its surface will be horizontal, and if this surface is below the ground surface it is known as the water table. Owing to the continual flow of water from the ground surface (rain, snow) and resistance to flow below the ground surface ground water is seldom stationary, nor is its surface horizontal. At the water surface, the pressure in the water is equal to atmospheric pressure. Below the surface, pressure increases in proportion to the distance below the water surface or water table. If standing water against the basement walls or floor can be eliminated, then water leakage through the inevitable openings in the basement enclosure will also be eliminated.

Capillary water, unlike bulk water which flows by gravity, is water that is sucked into porous materials by a combination of the affinity of the porous material for water, and meniscus forces at the water-air interface. In portland cement paste, the tension developed in capillary water can theoretically lift water to a height of 10 kilometres! However, a coating of grease on the material surfaces will completely halt this capillary suction.

Capillary water is responsible for a host of basement problems: frost heave, adhesion freezing, freeze-thaw damage, decay of organic and inorganic materials, and the support of mould and mildew. Generally, dampness is attributable to capillary water.

Adsorbed water is related to capillary phenomena and is water that is relatively firmly held by surface forces developed between the polar water molecules and hydrophilic (water-loving) materials. It is of interest since it is responsible for a part of the water diffusion through building materials, including damage due to subflorescence. "Subflorescence" is a term used to describe efflorescence which occurs within the pores of a material, causing disintegration of the material.

The air in the soil, building materials and the air in the basement also contain water in the form of vapour. Water vapour is water in the gaseous state. This is probably the most troublesome water in the basement context, since the ability of air to hold moisture is dependent on its temperature: when moist air comes in contact with a cool surface, it may reach its dewpoint, and condensation may occur on the surface. The relative amount of moisture in the air not only plays a part in condensation but also affects drying.

The final type of water found in some building materials and in some soil minerals is chemically-combined water. Chemically-combined water can be defined as the water that can not be removed from a material by drying at room temperature. This kind of water is present in concrete basement walls. It is of considerable interest to us since "chemical drying" of concrete can be used as a strategy for "locking up" some of the "water of workability" in concrete which would otherwise be dealt with as with all other "water of construction"; the removal of the water of construction is possible by providing a suitable environment and sufficient time for curing to be completed.

In addition to the moisture regime, the thermal regime also influences basement performance. Temperatures surrounding a basement are influenced by many factors, including outdoor air temperature. The outdoor air temperature changes from day to night (diurnal temperature fluctuations), from day to day, and from season to season in a cold climate. In Toronto, Ontario, which is situated in a relatively cold climate, the air temperature is usually outside the human comfort range. Figure 1 depicts the seasonal mean air temperature variation in Toronto. Included in this figure are mean values of outdoor vapour pressure, which will be referred to later in this paper.

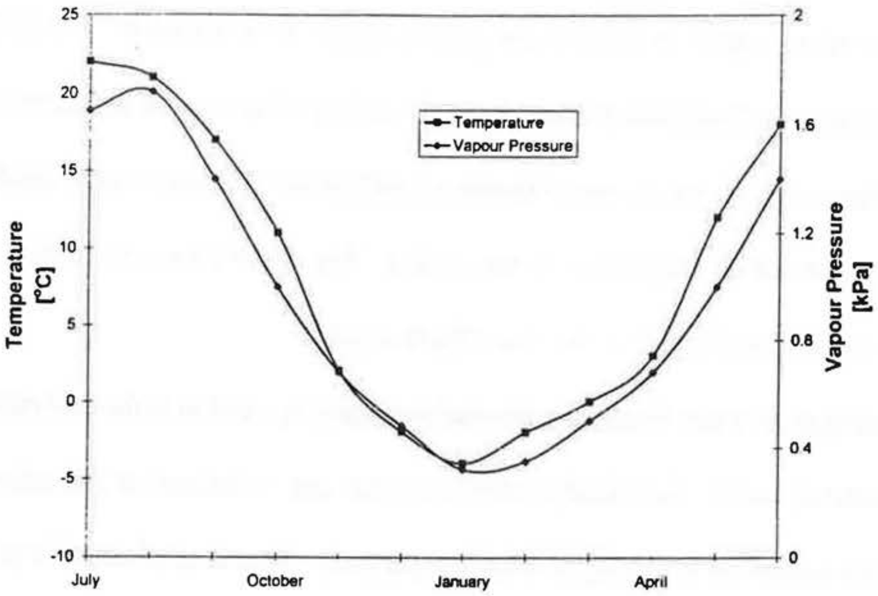

Figure 1 - Seasonal variation of air temperature and water vapour pressure.

In response to changes in the air temperature, soil temperatures surrounding basements also change. However, the rate of change is slower. With depth, the amplitude of the temperature as well as the absolute soil temperature change. Figure 2 depicts variations in soil temperature with depth by month for an open field in Ottawa, Ontario (no basement heat source and no systematic snow removal). When basement walls and floors are thermally insulated, then the soil thermal conditions will be similar to those depicted in Figure 2. It is interesting to note that at 2.5m below grade, the coldest soil conditions occur in May and June. Similarly, the July heat wave does not reach the soil under the basement floor until December and January. This 'lag' is due to the thermal inertia of the soil and its water. The lag is further increased by the existence of ice in the soil, since the latent heat of fusion must be extracted before the temperature of the thawing soil can rise above 0°C. Finally, in Figure 2 it can be seen that the seasonal temperature variation diminishes as depth increases.

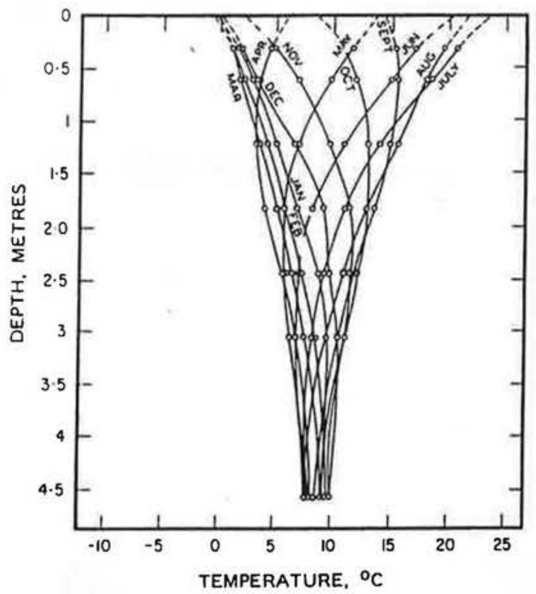

Figure 2 - Variation of soil temperature with depth. From Hutcheon & Handegord, Building Science for a Cold Climate.

Since most of the basement wall and floor areas are heat sinks throughout the year, the soil temperature is usually less than the basement air temperature. However, it is the presence of moisture in the soil and in the basement air coupled with the thermal inertia of the soil, that leads to problems. Since soil temperatures are usually out of phase with the air temperature, in the summer warm, moist air often condenses on cold wall and floor surfaces. Further, in the winter, water vapour in the relatively warm moist soil tries to enter the basement in response to a vapour pressure gradient which is in the opposite direction to the summer gradient.

To understand this seasonal movement of water vapour, it is useful to examine the psychrometric chart shown in Figure 3. In this figure, the thermal and moisture conditions of the outdoor air are represented for both winter and summer conditions. In addition, the temperature and moisture conditions of an uninsulated basement wall between the footing and 1m below grade have been represented. In determining these wall conditions, it has been assumed that the temperature of the uninsulated basement wall will approach the temperature of the soil next to it. This approach is reasonable, since there is good thermal coupling between the soil and the wall and the insulating value of the concrete is roughly the same as that of the adjacent soil.

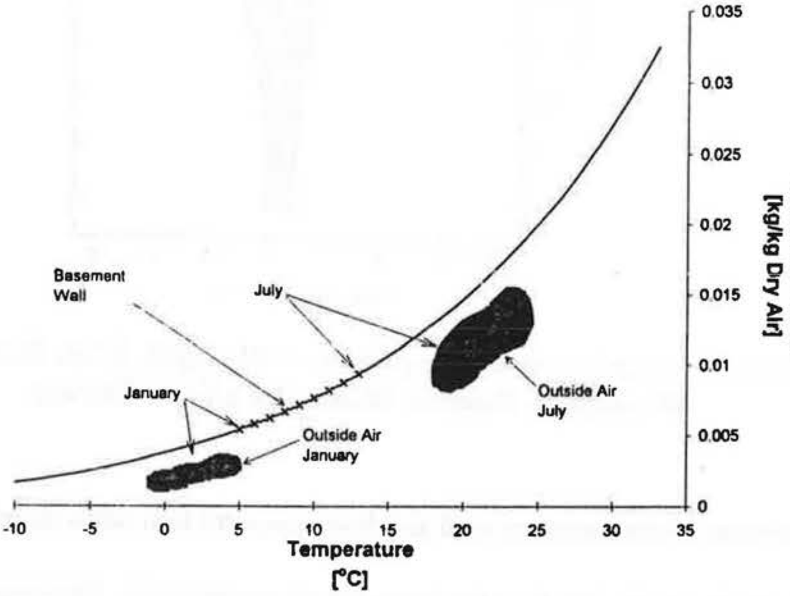

Figure 3 - Psychrometric chart with summer and winter conditions for outdoor air and the lower portion of an uninsulated basement wall.

During the summer, the soil temperature is below the dewpoint temperature of the outdoor air. If this air enters the basement and penetrates behind the insulation to come in contact with the basement wall, condensation will occur. Similarly, in the winter, when the outside air is warmed to a comfortable temperature, water vapour will tend to move from the soil into the basement.

The conditions depicted in Figure 3 which lead to the movement of water vapour have been presented a different way in Figure 4.

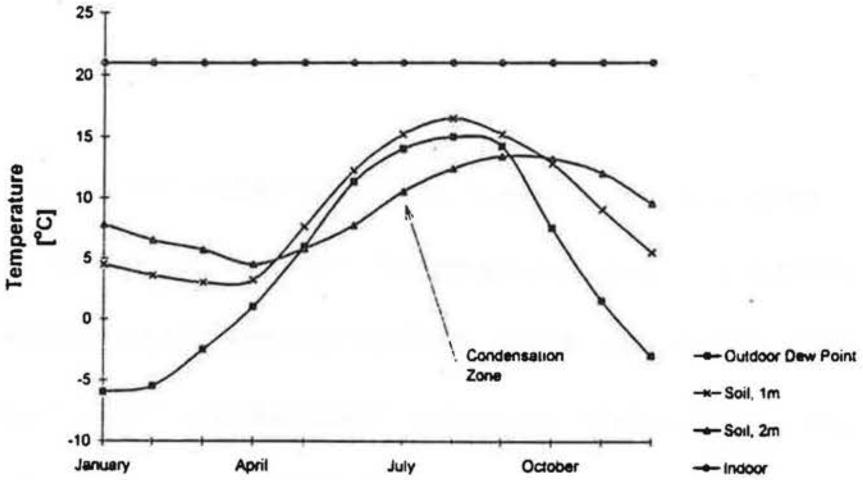

Figure 4 - Outside air temperature (below which moisture starts to condense from the air), soil temperature 1m and 2m below grade, and living space air temperature.

In this figure, the soil temperature 1m below grade roughly follows the outdoor air dewpoint temperature from May to September. However, in the same period, the soil temperature 2m below grade is lower than the outdoor dewpoint temperature. This indicates that from mid-April to the end of September, moist outside air will condense if it is cooled to the temperature of the soil 2m below grade. In contrast, room temperature is well above the dewpoint temperature for outside air throughout the year.

The curves depicted in Figure 4 are very conservative. During periods of high outdoor temperature and humidity, the air dewpoint curve will certainly be higher than the statistical mean curve above. Room air moisture content will also be higher during the winter and during the first year, when moisture of construction has to be dried out. Hence, it is worthwhile considering procedures which do one or more of the following: minimize moisture of construction; enhance drying of materials prior to moisture being trapped between layers of dampproofing and vapour retarders; and allow other means of removing unwanted moisture.

Design Solutions

It has been shown that the basement moisture and thermal regimes vary throughout the year. Further, it has also been shown that these regimes vary with depth below grade. It follows that sound envelope design practice should account for these variations. Above-grade building envelope design accounts for climatic variations: buildings in predominantly cold climates are not designed the same way as buildings in hot climates. Similarly, there are different climates at different soil depths. Therefore, it follows that basement wall design should consider these different climate variations in the moisture and thermal regime.

Traditional approaches of internal basement wall insulation coupled with a dampproof coating on the exterior lead to several problems. Figure 5 shows the temperature and relative humidity profiles for an uninsulated and an internally insulated basement wall. By placing insulation on the interior face, the relative humidity of the wall increases to a sufficiently high level to support the corrosion of steel and the decay of organic materials. As well, the dampproofing is on the "wrong side" of the insulation. Moisture that enters the space between the room-side of the vapour retarder and the dampproofing by vapour diffusion or air leakage cannot escape, nor can "built-in" moisture of construction. Mould, mildew, decay and corrosion problems may result.

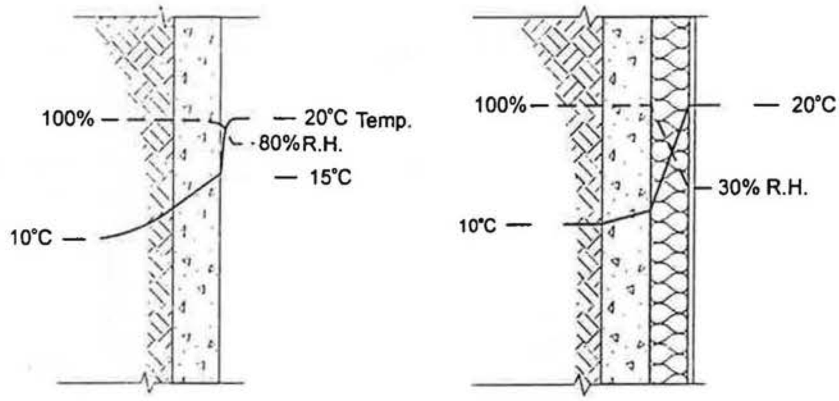

Figure 5 - Temperature and relative humidity gradients in an uninsulated and an internally insulated basement wall.

There are other problems associated with internal insulation. The performance of the wall is sensitive to workership; a poorly-installed air barrier will lead to air leakage into the insulated space. If there is an interior finish, wall leaks of bulk water from the soil or ground surface may be difficult to locate and expensive to repair. Finally, building codes often require internally insulated basements to be finished, including electrical servicing and fire protection. This adds to the initial cost of the house; a finished basement becomes compulsory, rather than being completed when funds become available.

Some of the problems associated with internal insulation can be remedied by placing rigid insulation (extruded polystyrene) between wood members and the moist basement wall, as shown in Figure 6. This will keep wood members warmer and drier, and less likely to experience prolonged periods of decay. By moving the moisture-sensitive materials away from the wall and the concrete floor, and by providing a capillary-breaking material, the wall materials will perform

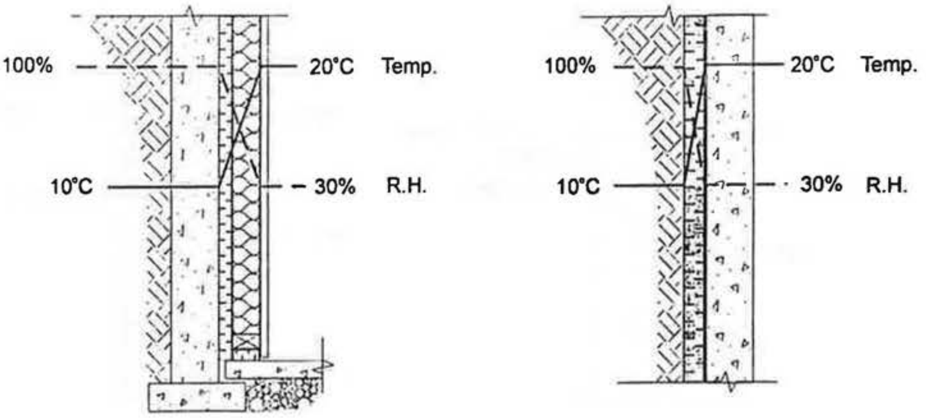

Figure 6 - Temperature and relative humidity gradients in an externally insulated and an internally insulated (with protected studs) basement wall.

better. However, this 'improved' internal insulation is still subject to the problems associated with concealed condensation and damaging leakage of bulk water.

The basement wall can be kept drier by providing exterior insulation as depicted in Figure 6. This approach can be coupled with a drainage layer or a draining fibre insulation to reduce the likelihood of leakage of bulk water into the basement. Unfortunately, the need to protect the above-grade portion of the external insulation is a major drawback of this approach. Further, providing support for brick veneer becomes difficult and expensive.

To avoid problems inherent in the internal as well as external basement insulation approaches, a compromise can be made. The below-grade portion of the wall can be externally insulated and the insulation terminated at grade. The above-grade portion of the basement wall can be insulated internally, with the insulation terminated 0.6m below grade. This 'hybrid' approach bypasses the disadvantages of both insulation approaches. At a later stage, when the

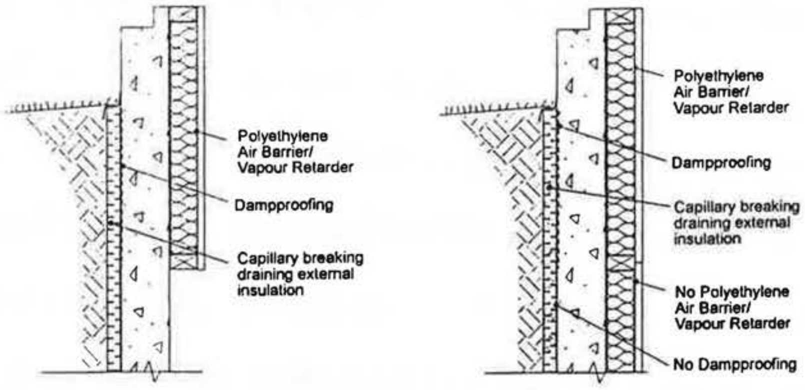

Figure 7 - Schematic of 'hybrid' design combining interior and exterior insulation.

moisture of construction has dried out and when funds become available, electrical services can be installed and the interior wall insulated to the basement floor as shown in Figure 7.

By sandwiching the wall between two insulating layers, virtually all of the objections to both internal and external insulation can be bypassed. If draining glass fibre insulation is used, it provides the necessary capillary break and eliminates the need for dampproofing the exterior face of the wall. That the outer wythe of the wall will be essentially saturated would, however, call for a higher-quality concrete than the current CAN A438 requires in order to have the necessary freeze-thaw durability.

Physics suggests that if the basement is externally insulated and if the insulation is itself capillary-breaking, then the dampproofing can be left off the wall from the footing to about 1m below grade. During the summer months, the vapour pressure gradient is directed toward the soil, promoting drying of moisture from the basement air into the soil. In the same manner, moisture of construction would dry into the soil, making it possible to finish the inside of the wall before the moisture of construction has dried out. During the winter, when the soil vapour pressure is higher than in the basement, the direction of moisture diffusion would be reversed, bringing moisture into the basement. If a vapour retarder is not installed on the lower portion of the wall, the upper portion may have to be isolated from the lower, since it will require a vapour retarder in order to satisfy winter requirements. Since most Canadian basements have to be dehumidified during the summer and humidified during winter, this form of passive moisture control becomes an added bonus to the wall without requiring vapour retarders and dampproofing.

This mixed-mode approach should be acceptable to the home building industry because only two changes have been made to standard practice:

1. Dampproofing has been left out between the footing and 1m below grade, and
2. Rigid capillary-breaking, draining insulation has been added to the external face of the below-grade portion of the wall.

Many building codes, including the Ontario Building Code, already require the provision of a drainage layer. The simple payback period for the external insulating layer is less than one year if the savings realized by not having to go back and fix a leaking basement are considered. This approach reduces conditions leading to health problems, while reducing the cost of home ownership. The approach is sound and applies equally well to other types of basements, including preserved wood basements.

Frost Damage

A final question is often raised, "will insulating basements lead to frost-heave problems?" To answer this question, it is important to understand how frost-heave can damage basement walls.

Unheated basements can be damaged by frost pushing in walls through frost heave or by walls lifting through a combination of adhesion freezing and frost heave. Frost heave causes movement in the soil due to the formation of ice lenses which expand in the direction of heat flow. Adhesion freezing is the result of freezing soil adhering to wall materials in contact with the soil; this adhesion will occur as long as the temperature of the material itself is also below the freezing point.

It has been predicted that insulated basements will behave like unheated basements, being susceptible to damage from adhesion freezing. Yet despite an extensive, cross-Canada survey [1], no evidence has been produced documenting damage to insulated basements due to frost-heave. Sweden also has no documented cases, and has been building homes with insulated basements since 1945.

Work at the University of Toronto has supported an hypothesis that explains why insulated basements do not experience the same adhesion freezing and frost-heave problems that affect unheated basements [2]. It has been shown that heat flowing into the soil surrounding a heated basement affects the adfreezing bond between the soil and the wall. Progressive desiccation of the ice forming the adhesion bond leads to an increase in creep of the ice. While the soil adjacent to the basement heaves, these displacements are not transferred to the wall. Therefore, insulated basements which are heated perform differently than unheated basements.

Accordingly, the provision of thermal insulation should not, by itself, lead to frost-heave problems.

Crawl Spaces

Crawl spaces are exposed to the same thermal and moisture regimes as basements. If the crawl space is unheated and the floor joist spaces are insulated, the joist assembly can be viewed as a special case of a wood foundation. Surfaces in this crawl space will be close to the dewpoint temperature of the air, and even below it, for a large part of the summer. Attempts to carry the moisture away through ventilation aggravate the problem, since ventilation draws in even more moisture which becomes available for condensation on cold surfaces. One solution, therefore, is to seal all ventilation openings, and operate a dehumidifier in the crawl space throughout the summer.

A method of overcoming the high humidity in the lower portion of the joist assembly is similar to the methods used for basement walls. An insulating layer can be applied over the underside of the joists, thereby raising the temperature at this critical location above the dewpoint temperature for outside air. In effect, this is equivalent to externally insulating the basement wall. The placement of the vapour retarder is also a concern. To avoid facing the double vapour retarder dilemma, a vapour-permeable insulation with a vapour-permeable spun-bonded polyolephin air barrier can be used. An SBPO membrane lacks capillary continuity; thus, if water were to condense under extreme conditions, it would be kept away from the joist faces, and the relative humidity of the joists would be kept below 80%. With the moisture problem addressed, the need to ventilate the crawl space should be re-examined. Dehumidification coupled with sealed ventilation openings may be a sound strategy. Finally, a word of caution: unheated crawl spaces start to look like unheated basements. Adhesion freezing damage may occur if the crawl space is cooled below freezing by ventilation.

The Basement Floor

What has been stated about basement walls applies equally to basement floors. Removing the dampproofing layer by leaving out the polyethylene under the floor slab makes it easier to place and finish the concrete, while offering the bonus of passive humidification-dehumidification. Radon and soil gas control are effectively achieved by either depressurizing or pressurizing the space under the floor slab. In more advanced active solar heating applications, the below-slab soil, crushed stone and the slab itself are used for both soil gas control and solar heat storage. However, if the soil is sufficiently air-permeable, excessively high air flow rates may be necessary to maintain the required pressure difference. These could lead to excessive heat losses.

The advantages and disadvantages of insulating basement floor slabs warrant further consideration. Thermal insulation not only reduces energy losses, but also assists in the management of moisture and the resulting health risks associated with moist environments. Swedish experience with uninsulated floor slabs has demonstrated the need to lower the relative humidity of the slab in order to reduce the potential for decay of organic floor coverings or adhesives. Placing insulation below the floor slab raises its temperature and reduces the relative humidity of the slab; hence materials placed on top of the slab, such as carpeting, remain drier and are less susceptible to decay.

This becomes especially important in houses without basements where the slab-on-grade forms the floor.

While insulating on the exterior is preferable from a materials performance point of view, thermal comfort is enhanced if the floor cover has little thermal mass and is insulated on the warm side. In such cases, part of the insulation could be installed below the slab and part on top of it.

Heat Loss and Thermal Insulation

Two questions remain to be answered. First, how much of the basement should be insulated? Second, how much resistance to heat flow should the thermal insulation provide?

To answer the first question, it is useful to realize that below-grade wall and floor areas act as heat sinks throughout the year. This is particularly true for these areas that are farthest from the influence of the outside air. Furthermore, depending upon the climate and the thermal properties of the surrounding soil, in the basement there is a line below which the placement of insulation will actually lead to an increase in the annual energy consumption. Below this line, more energy is expended on summer air-conditioning than is saved by reducing winter heating. For most areas in Canada, this line lies somewhere under the basement floor slab.

The extent of basement insulation, however, is not necessarily determined by net energy costs. Material performance, health and comfort often influence the designer's decisions concerning the extent of thermal insulation. While placement of insulation under the entire slab may lead to an increase in the summer cooling load, the basement will be more comfortable, the relative humidity will be lower, and the likelihood of material durability problems will be reduced.

Next, the question of quantity of insulation must be addressed. When considering basement heat-loss problems, the thermal properties of the surrounding soil are often included. Unfortunately, soil thermal properties vary widely and are expensive to determine. Also, soil thermal properties are rarely uniform and vary at a given site depending on the presence of rain or melt-water seeping through the soil. Therefore, it is rarely cost-effective to determine the contribution of the soil to the thermal resistance of a basement.

Often the thermal resistance of the soil can be neglected. Once some thermal insulation is incorporated into a design, the relative contribution of the soil to thermal resistance is small compared to the resistance provided by the insulation. Thus, the expense of determining the thermal properties of the soil can be saved once thermal insulation is used. In the case of insulated basements, it is ultimately climatic and economic factors that will determine insulation levels.

In any cold climate, as each increment of basement insulation is added, the law of diminishing returns takes effect and the corresponding reduction in heat loss becomes smaller. With increasing amounts of thermal insulation, the corresponding energy savings lessen, as shown in Figure 8. In this figure, heat loss or heating costs has been plotted along the vertical axis and the thermal resistance have been plotted along the horizontal axis. It can be noted that the first few inches of insulation result in the greatest heat savings. Increased insulation levels lead to diminishing energy savings. If the thermal resistance of the soil is then considered, the effect of diminishing return is even more pronounced.

Figure 8 reveals only the influence of thermal insulation on heat losses or heating costs. The number of heating degree days declines with depth below the soil surface, so heat savings from added insulation also decline with depth. It must be remembered, however, that the placement of thermal insulation, particularly at depths between 1m and 2m, significantly adds to the summer cooling load.

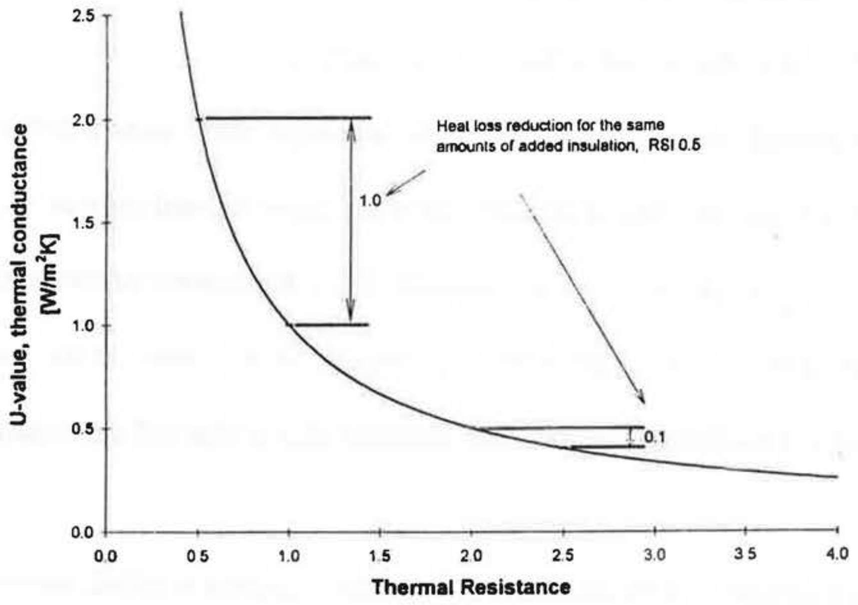

Figure 8 - The overall heat transfer coefficient plotted against thermal resistance, demonstrating the law of diminishing returns

In the end, the quantity of thermal insulation placed around a basement depends on many factors. However, when all factors are considered, the cost of design refinement usually exceeds the cost of a little extra insulation.

Conclusions

Appropriate use of thermal insulation can do much more than just save energy. When combined with moisture-resistant materials, thermal insulation can play a significant role in making basements comfortable and free of moisture problems. Since thermal insulation influences the movement of both heat and moisture, it is essential to understand the moisture and thermal regimes surrounding the basement when designing the basement insulation system.

It has been shown that soil temperature varies with depth. To better manage the movement of moisture around the basement, it follows that the dampproofing layer should be placed in a position where it does not trap water within the wall. When coupled with a drainage layer to help divert bulk water, the selective use of dampproofing can provide a drier basement that is passively humidified in winter and dehumidified in summer.

Selective use of thermal insulation can also improve basement enclosure performance. The preferred placement of insulation is on the exterior of the basement wall. Materials on the inside of the insulating layer are generally warmer and drier. As well, the relative humidity of the basement is reduced. This reduction, in turn, leads to a reduction in a number of health problems due to mould and mildew. Often, it is not energy-efficiency but health and thermal comfort considerations that influence the design of basements.

While it has been predicted that insulated heated basements may be susceptible to frost damage, experience has shown that this is not the case. It seems that the flow of heat away from the foundation wall in an insulated heated basement causes the ice bond between the soil and the wall to be highly deformable, preventing frost damage from occurring.

In cold climates, such as the climate of most of Canada, insulation should ideally extend the full height of the basement wall and continue under the slab. The extent of insulation should be determined primarily by climatic conditions and economic factors. Refinement of heat loss calculations to include the contribution of the soil to thermal resistance may not be cost-effective, as such refinements often cost more than the cost of a little extra insulation.

Crawl spaces experience the same thermal and moisture regimes as basements, enabling a similar approach to insulating them. The recommended practice is to insulate the exposed surfaces of the floor joists. The effects of this approach are similar to the effects of exterior insulation of basements, keeping the floor joists warmer and drier.

Through the careful design and detailing of an insulated basement and through the selective use of thermal and moisture-resistant materials, the basement can be a problem-free, healthy and comfortable addition to the normal living space of a home.

Acknowledgements

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2. Pressnail, K.D., Timusk, J., "Adfreezing of Insulated Residential Basements: An Hypothesis", Canadian Journal of Civil Engineering, Vol. 14, 1987.

List of Figures

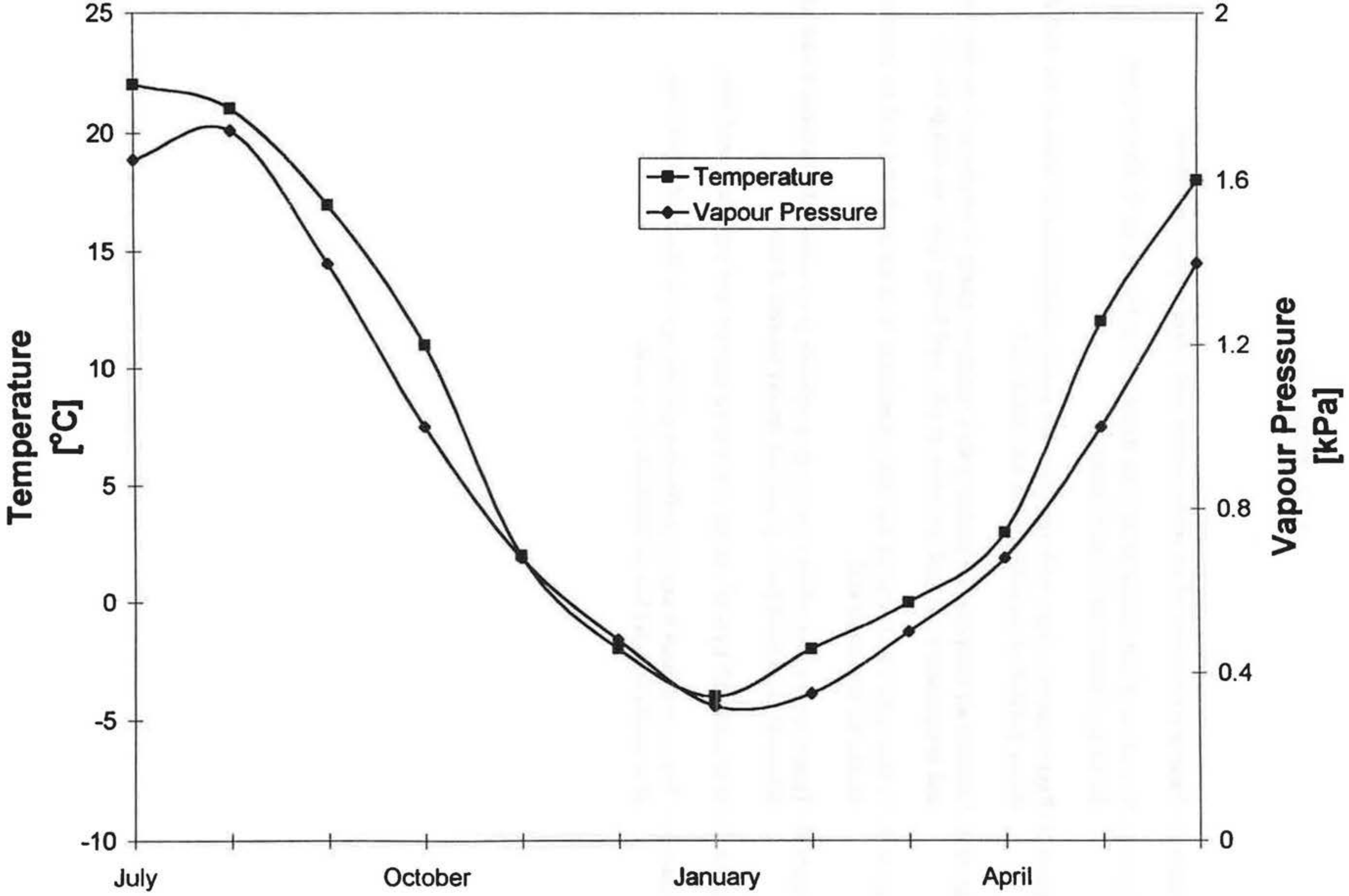

Figure 1 - J. Timusk, K.D.Pressnail, P. Eisenbach Chisholm

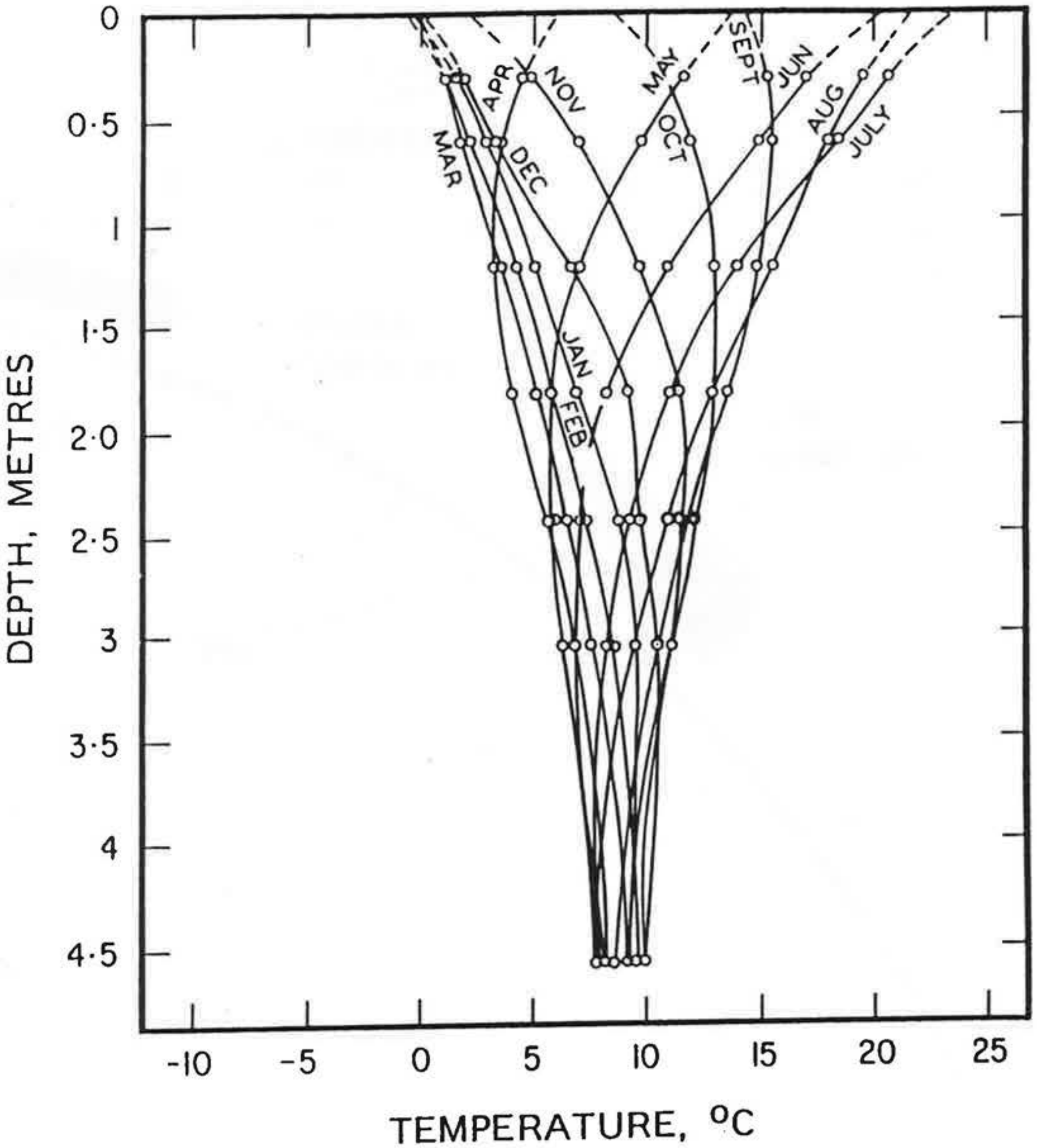

Figure 2 - J. Timusk, K.D. Pressnail, P. Eisenbach Chisholm

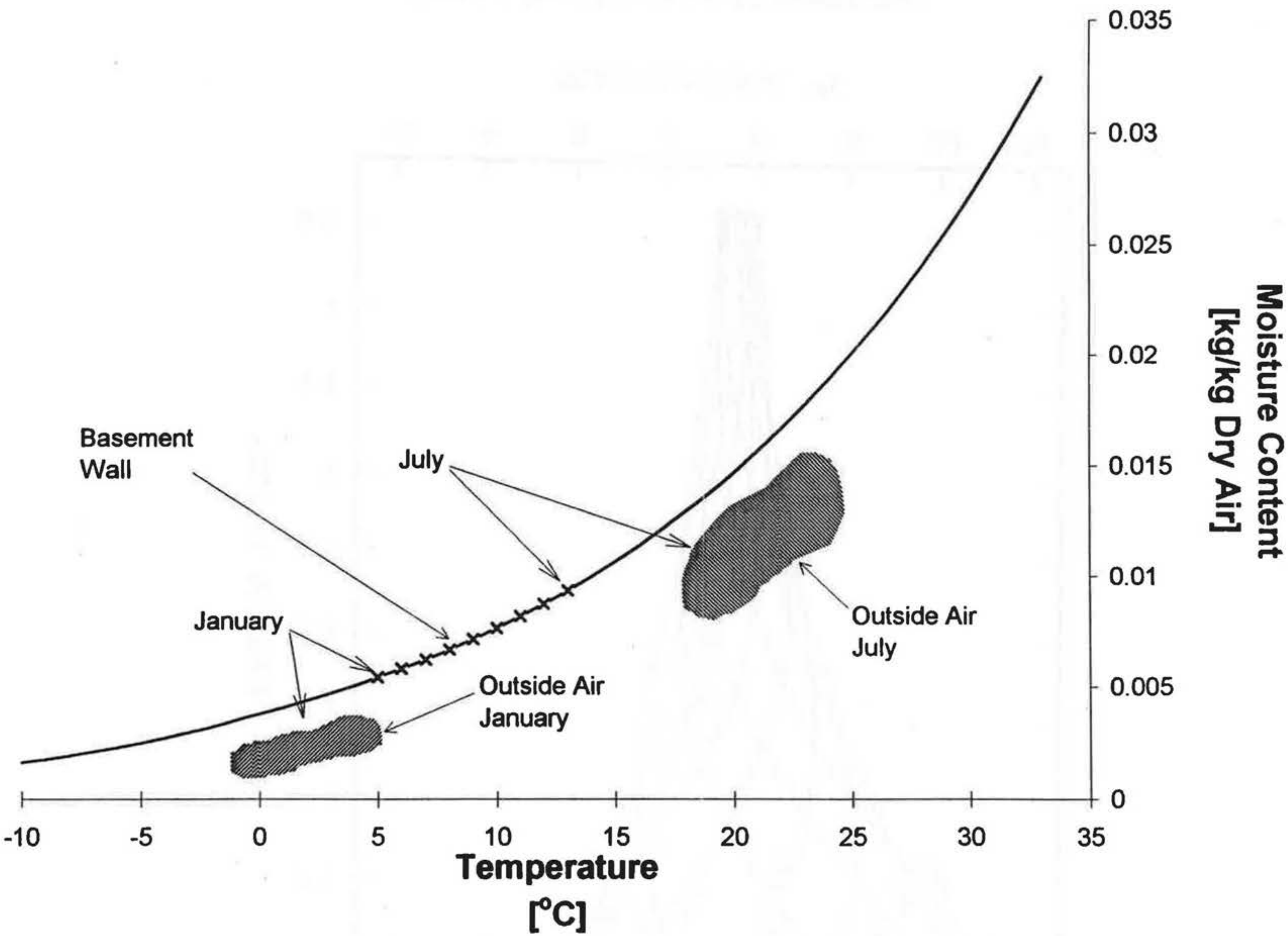

Figure 3 - J. Timusk, K.D. Pressnail, P. Eisenbach Chisholm

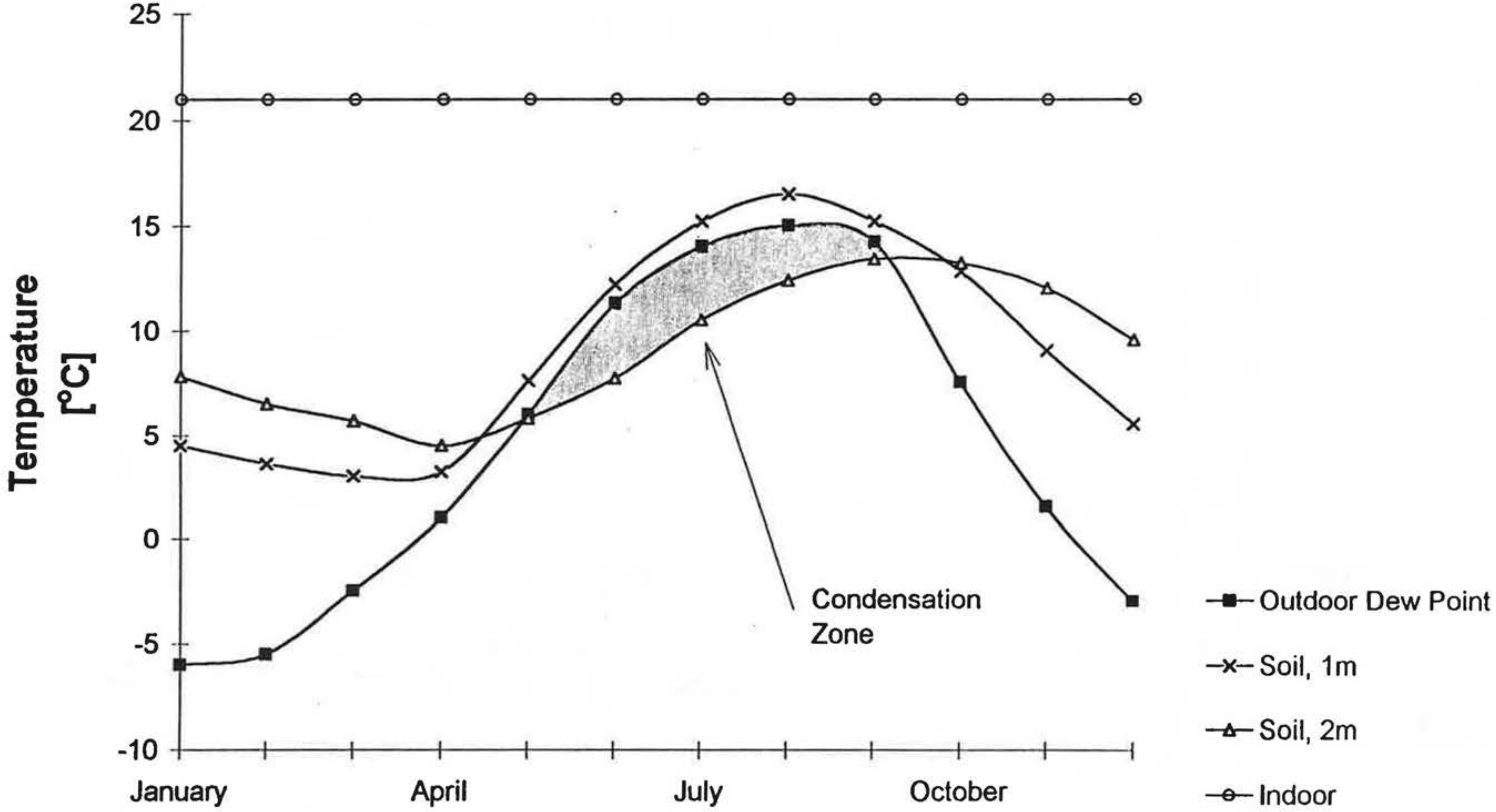

Figure 4 - J. Timusk, K.D. Pressnail, P. Eisenbach Chisholm

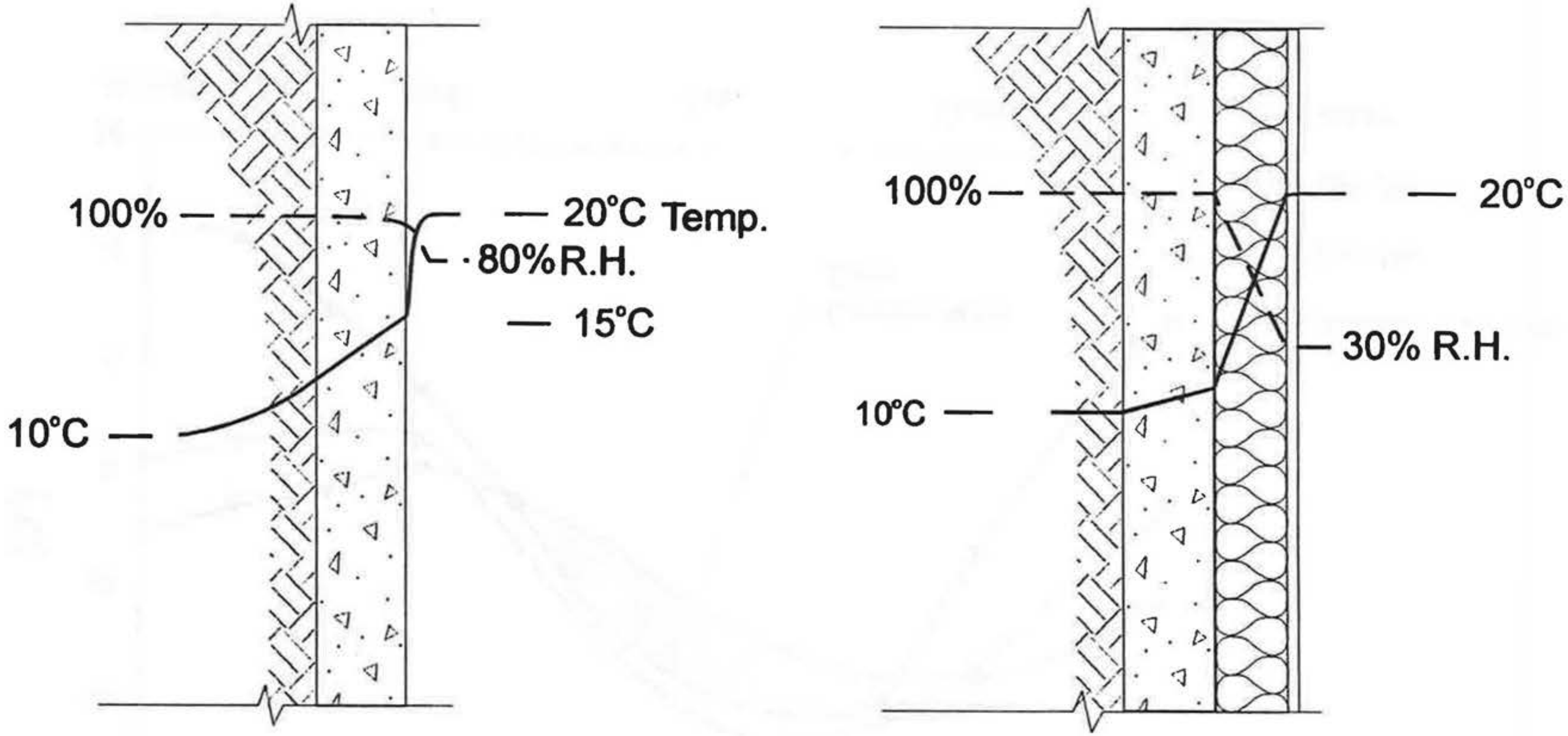

Figure 5 - J. Timusk, K.D. Pressnail, P. Eisenbach Chisholm

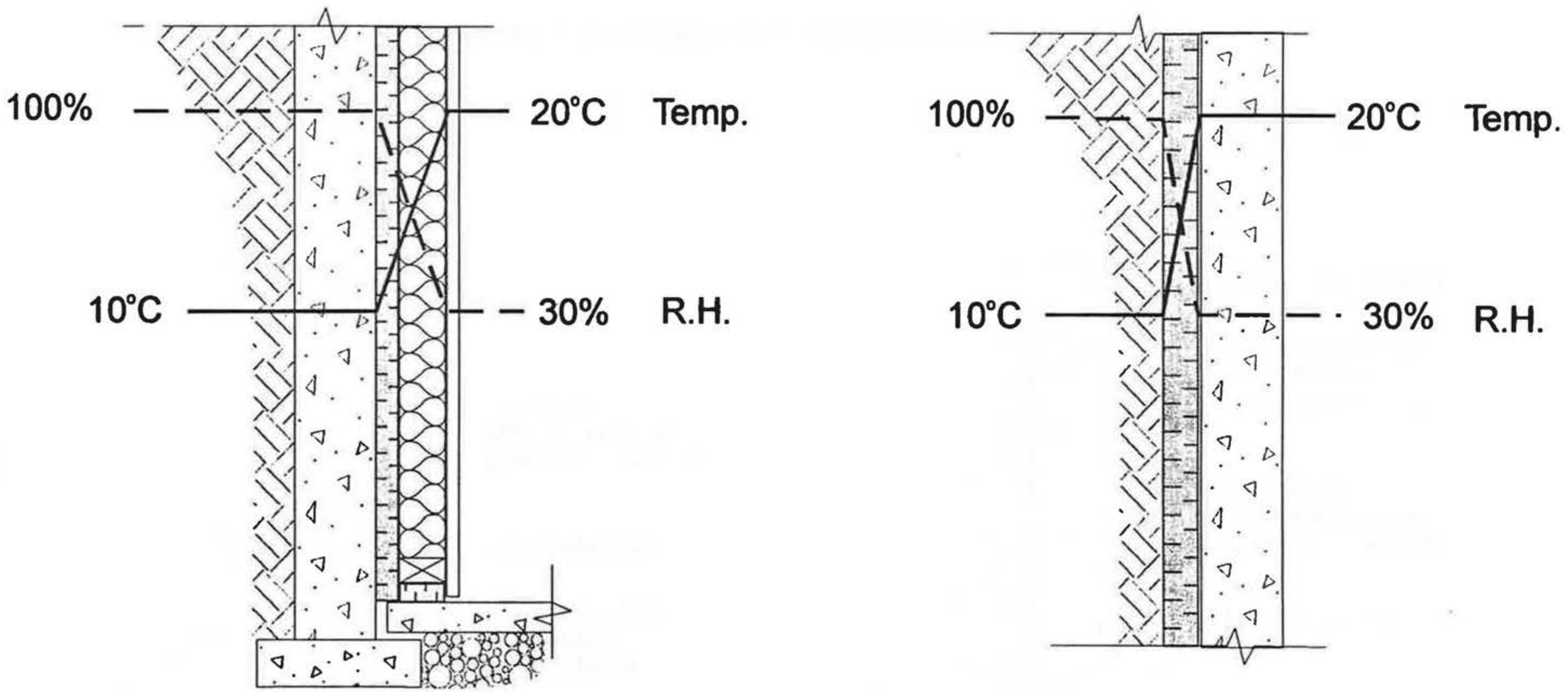

Figure 6 - J. Timusk, K.D. Pressnail, P. Eisenbach Chisholm

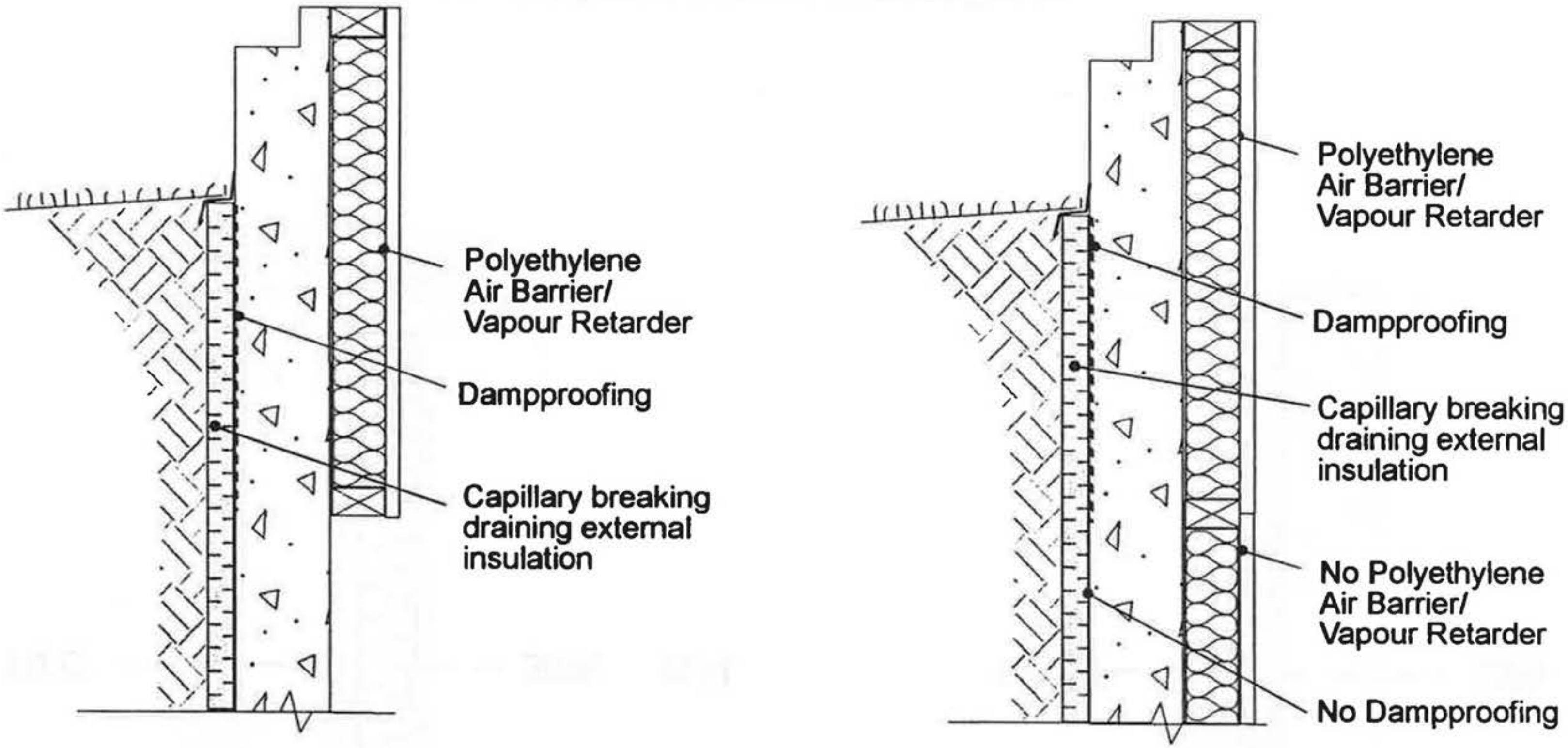

Figure 7 - J. Timusk, K.D. Pressnail, P. Eisenbach Chisholm

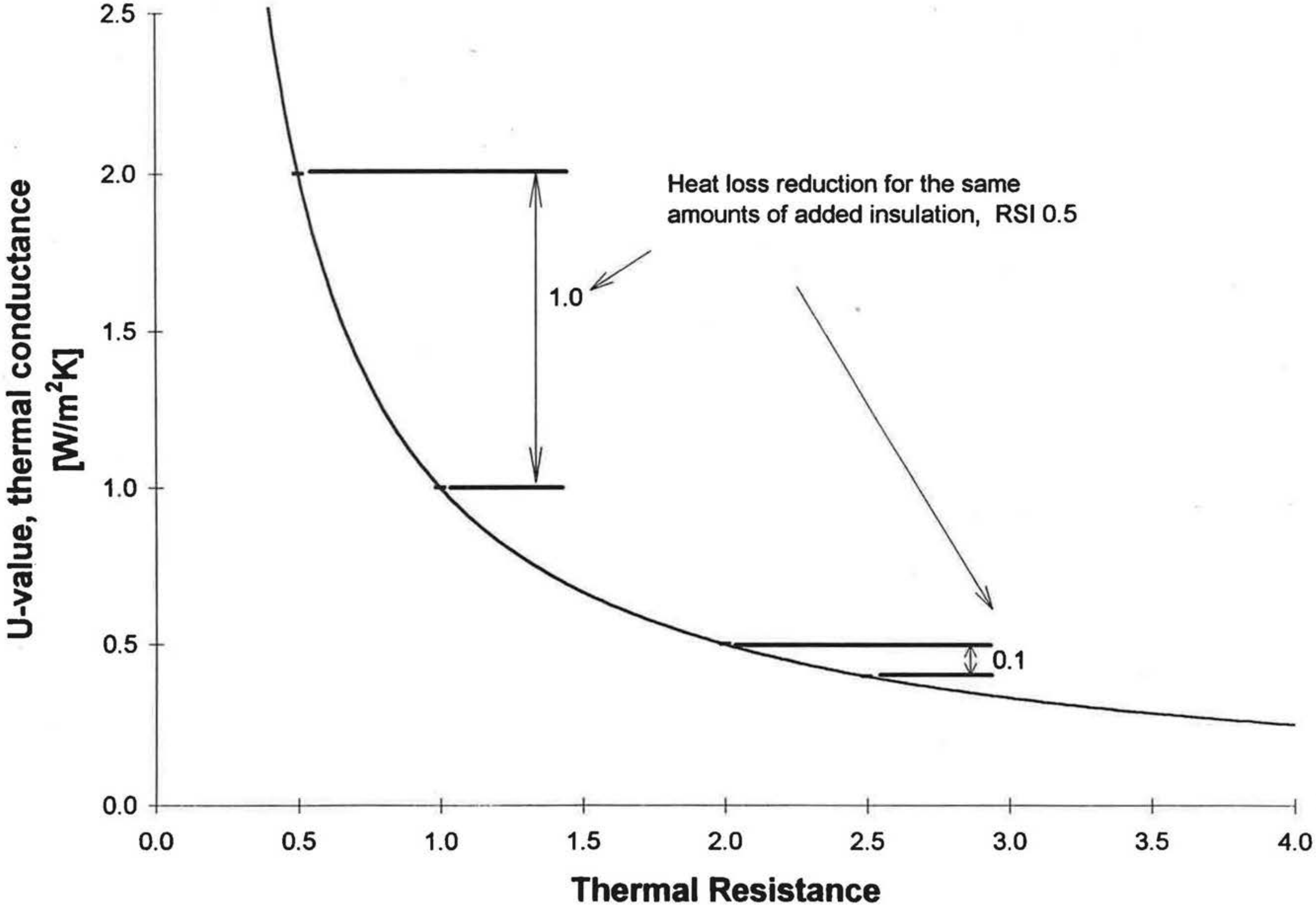

Figure 8 - J. Timusk, K.D. Pressnail, P. Eisenbach Chisholm

notes

A CASE STUDY: ENERGY CONSUMPTION PATTERNS IN A MANUFACTURED HOUSING COMMUNITY

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ABSTRACT

Manufactured housing provides an opportunity for families and individuals with low or fixed incomes to satisfy the great American dream of owning a home. Originally, the low cost of buying a mobile home was misleading due to the high energy costs associated with these structures. Since then, advances have been made by the industry, but energy consumption and bills fluctuate widely. Variations in energy used of up to 4 to 1 were seen to exist between homes built by the same manufacturer, at the same time, and subject to the same weather conditions. These observations were obtained from actual data gathered via two surveys. An enhanced computer model was developed which dissects the energy consumption into the following five components: infiltration, weather effects, solar radiation, home construction, and consumer habits. The model accurately predicts the consumption patterns of the surveyed homes. Individual lifestyle parameters are considered and modeled. Improvements in energy consumption are shown to be easily achievable which ultimately yields more money for the consumer.

Nomenclature

A	Area	(m^2)
CLF_t	Cooling load factor	
c_p	Specific heat	(J/K)
h_{fg}	Heat of vaporization	(J/K)
k	Thermal resistance	(W/K)
Q	Total heat transfer	(W)
ρ	Density	(kg/m^3)
SC	Shading coefficient	
$SHGF_{max}$	Solar heat gain factor	(W/m^2)
T	Temperature	(K)
U	Overall heat transfer coefficient	(W/m^2-K)
V	Volumetric air exchange	(m^3/s)
ω	Air humidity ratio	

Subscripts

al	Latent air heat gain
as	Sensible air heat gain
c	Ceiling
co	Conduction
d	Door
f	Floor
i	Inside
o	Outside
sg	Solar gain
t	Total
w	Wall
wi	Window
ws	Wall structure

Introduction

Owning a home is the great American dream. Manufactured housing provides an opportunity for families and individuals with low or fixed incomes to satisfy this dream. Over the past three decades there has been a great evolution in the quality of manufactured housing construction. Originally, these houses were called trailers, and they were generally moved from town to town. Gradually, mobile home parks began to develop, centralizing similarly built houses. Manufacturers started building houses which, although they were mobile, were designed to stay in one location. At this time, the low cost of purchasing a mobile home was misleading due to the high energy costs associated with these structures. This has been changing.

Manufacturers, in cooperation with the Office of Housing and Urban Development, developed new guidelines and began manufacturing more energy conscious houses. Over the past few years, energy efficient manufactured houses have been built. It is now easy to find manufactured (or factory-built) houses with large amounts of insulation, low infiltration rates and energy conserving designs. Still, studies have shown that there are wide variations in the amount of energy consumed by these homes.

Nationwide, approximately 5 million homes are "manufactured homes." The Southeast region of the United States has the greatest concentration of these housing units - in South Carolina approximately 17% of all homes are manufactured houses. In some regions of the State over 50% of new electrical hookups are manufactured houses.

Research Incentives

The South Carolina Energy Research and Development Center (SCERDC) developed a research strategy to determine the energy efficiency in manufactured houses. The reasoning behind this research is four fold. The first reason is that energy efficient houses reduce customer energy bills as well as the demand on utilities. Second, lower energy bills provide more disposable income for homeowners. Knowledge of energy efficiency allows consumers to select design variables that produce an efficient and comfortable environment inside the home. Finally, savings of up to 40% have been shown to be possible without a need for major structural changes to the manufactured house.

Early Work

The SCERDC has conducted two different energy surveys in the past five years. The first was a random survey of ninety-two manufactured homes in four cities across the state of South Carolina. Even though the houses were generally similar in size and construction, the amount of the energy bills varied tremendously; 35 to 1 in some cases. It was believed that the variations are attributable to a combination of the efficiency of the homes and the lifestyle of the residents.

Results from this random survey of homes are shown in Figure 1. The months of January and July are depicted because they represent the months with the highest heating and cooling bills, respectively. The question was raised, "Why does house A spend $271 and house B spend $7 per month in electricity bills?"

Current Work

In 1991, the SCERDC conducted its second survey; focusing on 500 manufactured houses centrally located at Jensen's retirement community, in Garden City, SC. This was an ideal site for a comparison of energy usage in manufactured houses. There are homes built as early as the late-1960's and as recent as 1990. The houses range in size from a stereotypical trailer to large double-wide (or multi-sectional) homes. Unique about Jensen's is that all of the homes are subject to essentially the same weather conditions and are generally occupied by retired couples. This micro-environment allows for the minimization of weather effects when comparing different houses.

Over 180 Jensen's residents responded to the survey with sufficient information for an in-depth analysis of their energy consumption patterns. The staff of the SCERDC also observed the homes, and took note of unusual aspects (shading, structural damage, etc.). The residents also signed release forms allowing the Energy Center to acquire two-years worth of energy bills. Figure 2 shows a comparison of energy bills for a sample of the most recently built houses for a single month. It is clear that although the houses are similarly built, there are huge variations in energy consumption. A simple computer model was developed to predict these energy consumption patterns [Mueller].

Numerical Procedure

Upon receiving the completed surveys and the energy consumption information from the residents and utility, respectively, analysis of the houses began. The survey information was entered into a spreadsheet program from which it could be easily manipulated. Average values for amounts of insulation, size of house, types of windows and doors, as well as thermostat and air conditioner settings were determined. From these average values, a "typical" manufactured house was designed.

An improved computer model was developed which dissects the energy consumption into the following five components: infiltration, weather effects, solar radiation, home construction, and consumer habits. The model also considers the three modes of heat transfer to/from a house: radiation, convection, and conduction. When applying the five components of energy consumption, a knowledge of which heat transfer component contributes to the heat gain or loss is necessary. Radiation is included in the solar radiation, weather effects, and home construction components. Convection heat transfer is included in the infiltration, weather effects, and home construction components. Conduction heat transfer is modeled in the solar radiation and home construction components of energy consumption. Figure 3 shows the typical loads on a manufactured house.

Solar radiation is composed of direct, diffuse sky, and reflected radiation. It contributes to the load on a house by 1) heating of the roofing and siding construction materials causing conduction heat transfer to the house, and 2) heating of the house interior through the windows. Obviously, solar radiation is an asset during the winter (heating) months and a debit during the summer (cooling) months. The solar gain of a house is modeled using the following equation [Kreider]:

$$Q_{sg} = A*SC*SHGF_{max}*CLF_t \tag{1}$$

The shading coefficient, solar heat gain factors, and cooling load factors are selected for the model house located at Garden City, SC.

Infiltration is a major factor in the energy consumption of a house. It is caused by differences in temperature, density, and pressure between the inside and the outside of the house. These differences are exchange by air flows through cracks around windows and doors, spaces between joints, as well as leaks in the heating, ventilating, and air-conditioning system. The following equation [Kreider] is used to determine the sensible gain via air infiltration.

$$Q_{as} = V*\rho*c_p*(T_i - T_o) \tag{2}$$

The latent heat gain due to infiltration is calculated from the following [Kreider]:

$$Q_{al} = V*\rho*h_{fg}*(\omega_i - \omega_o) \tag{3}$$

It is very important, especially in the Southeast, to consider the humidity differences due to the load applied to the HVAC system.

Conduction heat transfer occurs between the house and its surroundings due to temperature differences. The building material as well as the house's framing are factors in this heat exchange. Equations 4 through 6 are used to determine this component of energy consumption.

$$Q_{co} = k_t*(T_o - T_i) \tag{4}$$

$$k_t = k_f + k_w + k_c \tag{5}$$

$$k = U*A \tag{6}$$

Conduction heat transfer through the walls includes the heat transfer through the doors and windows. A weighted average of the U-values is calculated using Equation 7.

$$U_w = (U_d * A_d + U_{ws} * A_{ws} + U_{wi} * A_{wi}) / A_t \tag{7}$$

In all of the above equations, the indoor temperature is either the thermostat or air-conditioning setting, depending on the month. These temperatures are assumed to be constant throughout the day (no setback). Indoor humidity values are based on comfort conditions [McQuiston]. Outdoor temperatures and humidity values are monthly averages, and based on actual weather data.

Heat gains due to appliances, equipment, and the residents are included in the model and are derived from design conditions [ASHRAE,McQuiston]. Both the latent and sensible heat gains are considered. Construction and lifestyle parameters were varied to determine the optimum design for a manufactured house in the Southeast.

Results and Discussion

The computer model discussed predicts the average monthly energy consumption for manufactured houses using actual construction and weather information. Figure 4 compares the actual and predicted energy consumption patterns for the manufactured houses. It can be seen for the yearly pattern of energy usage, the difference between the model and the actual average consumption ranges from less than 1 percent to approximately 30 percent, with the largest variations found in the winter months. These winter variations are possible, since winter temperature fluctuations are much greater than those in the summer.

Figure 5 shows the decrease in energy consumption when the air infiltration rate is cut in half. The nominal value for air changes per hour (ach) is 0.5; by decreasing the infiltration to 0.25 ach, the energy consumption is improved by 7 to 48 percent. It is very clear that the greatest effects occur during the months with high humidity. Obviously, if the infiltration rate is decreased, the indoor humidity is lowered, thus the air conditioner does not have to work as hard.

It was found that the typical manufactured house has insulation values of R-11 in the walls and R-19 in the floor and ceiling. Figure 6 shows how increasing the insulation decreases the energy consumption in the house. It is clear that insulation increases result in decreases of heat loss/gain for the house. If the insulation is increased to R-14 in the walls and R-30 in the floor and ceiling, up to $26 per month can be saved (based on 7 cents/kilowatt-hour). The model predicts annual savings of nearly $200. By improving the infiltration rates from 0.5 to 0.25 ach, up to $40 per month can be saved, during the summer months. Annual savings can exceed $230 for a typical manufactured house.

It is important to note that the insulation and infiltration rate improvements complement each other. The insulation increases decrease the energy bills during the cold, low-humidity months; while, the infiltration rate decreases lower the energy bills during the warm, high-humidity months. Lower energy bills result in more spendable income for the consumer and thus improve the economy. Also, energy efficient houses decrease the electrical demand on the utility, thereby, reducing the harmful effects on the environment.

It is a common belief that controlling the settings on the thermostat and air conditioner will reduce energy demand. This is only partially true. Figures 7 and 8 show the energy usage in each home with a superposition of their thermostat and air conditioner settings, respectively. It can be seen that while the trend is for energy usage to vary with the settings, there are cases in which the energy usage is opposite of what is expected. This can be attributed to poor construction or lifestyle characteristics (leaving a window open in the winter, for example). Further examination of these homes is necessary to determine the causes of these abnormalities.

Conclusions and Recommendations

This research has proven that increasing the amount of insulation in the walls, floor, and ceiling is important; however, it is not the most critical improvement for constructing an energy efficient manufactured house. Air infiltration is the major contributor to energy inefficiency, especially in the Southeast, due to the high humidity levels. Although the insulation levels should be maximized, major structural changes should not be made (do not increase wall size to 2X6 stud construction).

Consumer information publications have been prepared to educate the consumer on how to select a comfortable and energy efficient manufactured house. The following is a list of recommendations for a manufactured house that optimizes the 3 E's -- energy, environment, and economy.

1. Caulk and seal air gaps around windows and door frames.

2. Insure that the marriage line and all the duct work are tightly sealed.

3. Install the maximum allowable amounts of insulation and make sure there are no empty spaces.

4. Properly insulate the duct work beneath the floor.

5. Install low emissivity, low U-value windows.

6. Allow for passive heating and cooling of the house when selecting a site.

7. Install energy efficient appliances.

Acknowledgments

The South Carolina Energy Research and Development Center would like to thank the residents of Jensen's, Inc. retirement community for their assistance in this research. Dr. Larry Golan and Brian Mueller would also like to express their sincere appreciation to the staff of the SCERDC for the aid in collecting the surveys.

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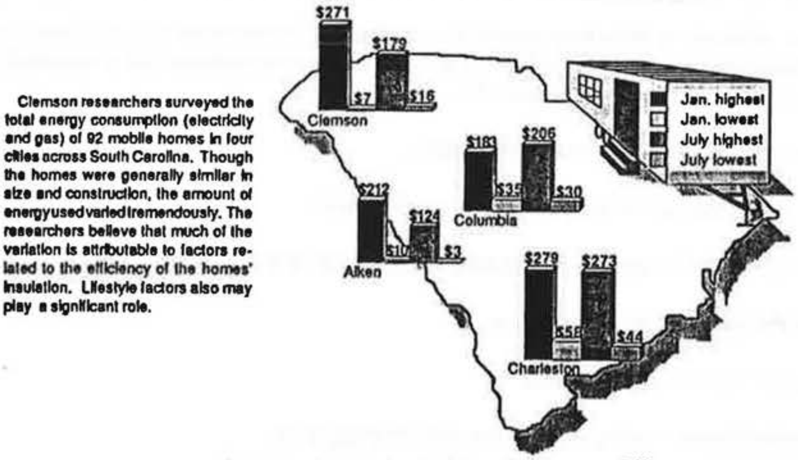

Figure 1. Comparison of Monthly Energy Bills.

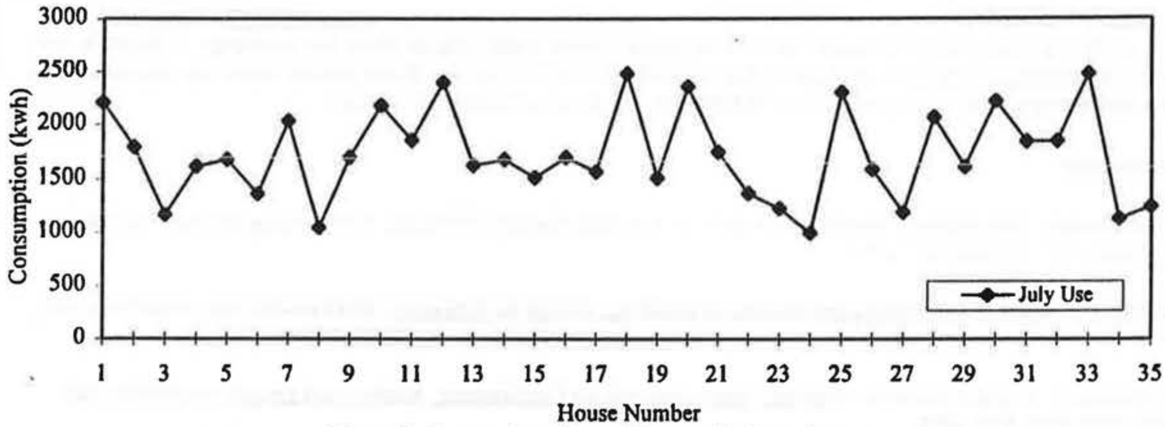

Figure 2. Comparison of monthly usage between houses.

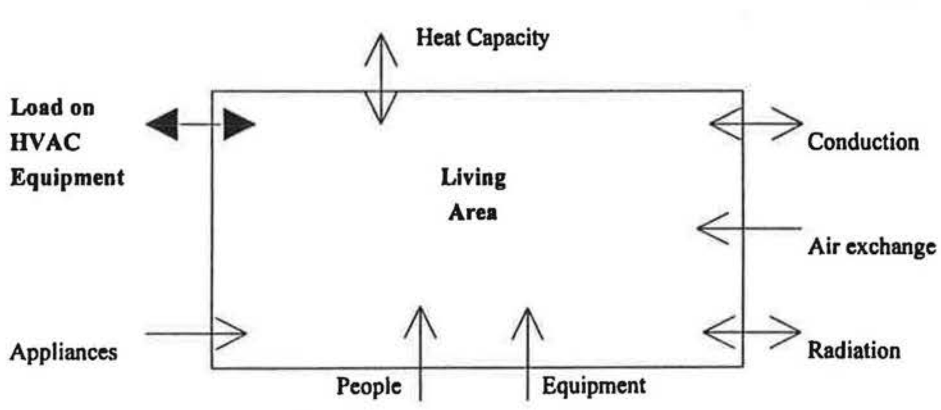

Figure 3. Typical loads on a house.

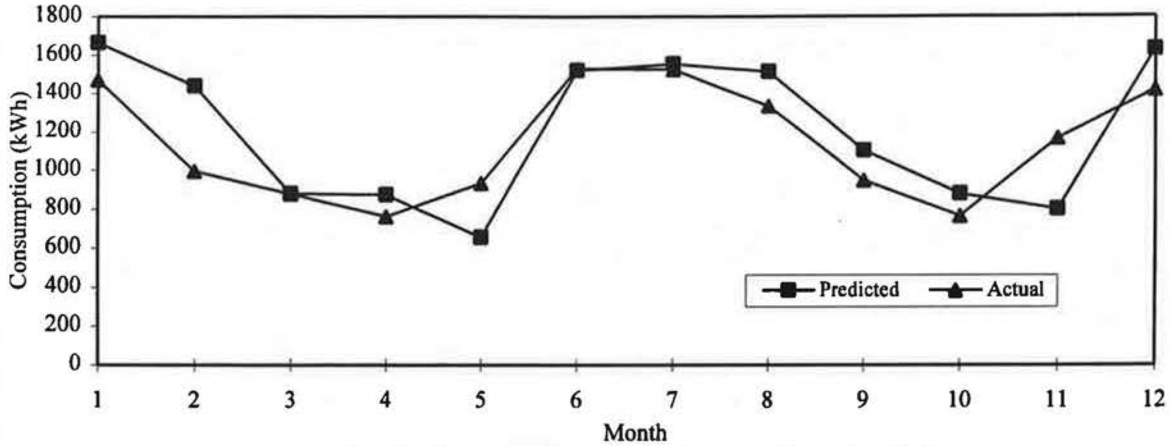

Figure 4. Comparison between actual usage and model prediction.

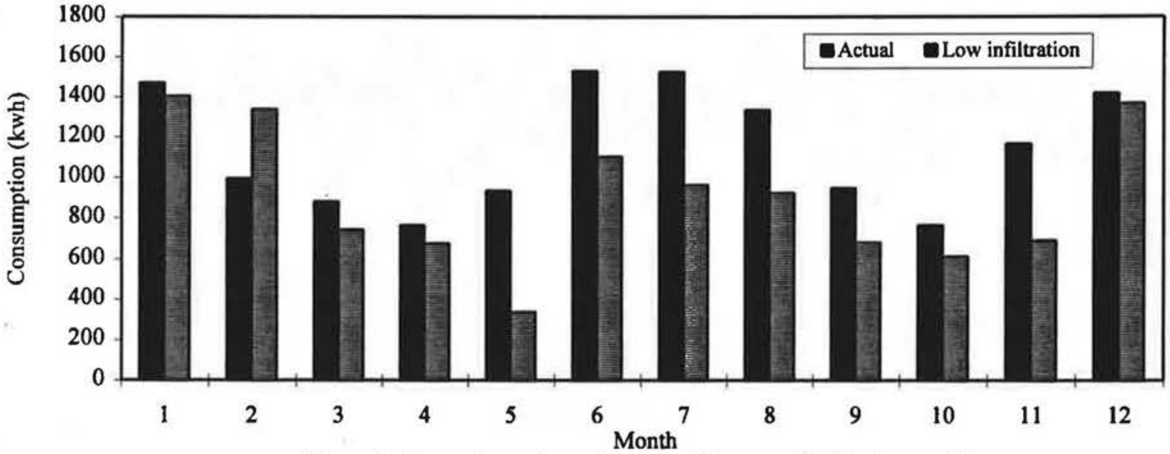

Figure 5. Comparison of actual usage and decreased infiltration model.

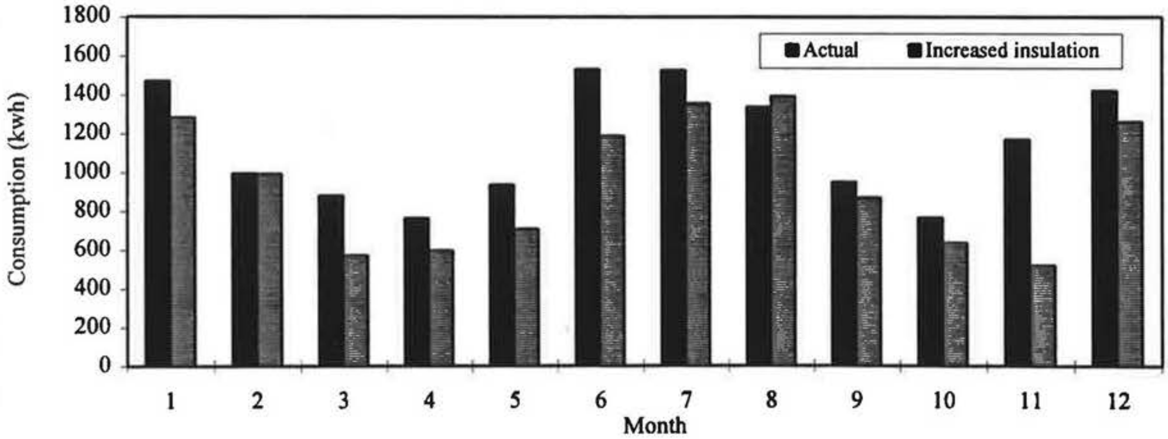

Figure 6. Comparison between actual usage and increased insulation model.

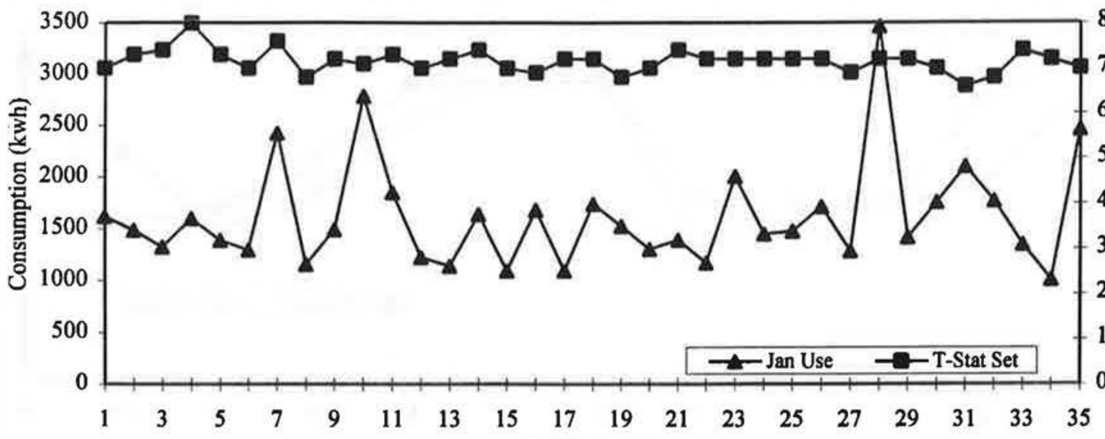

Figure 7. Comparison of actual usage with thermostat setting.

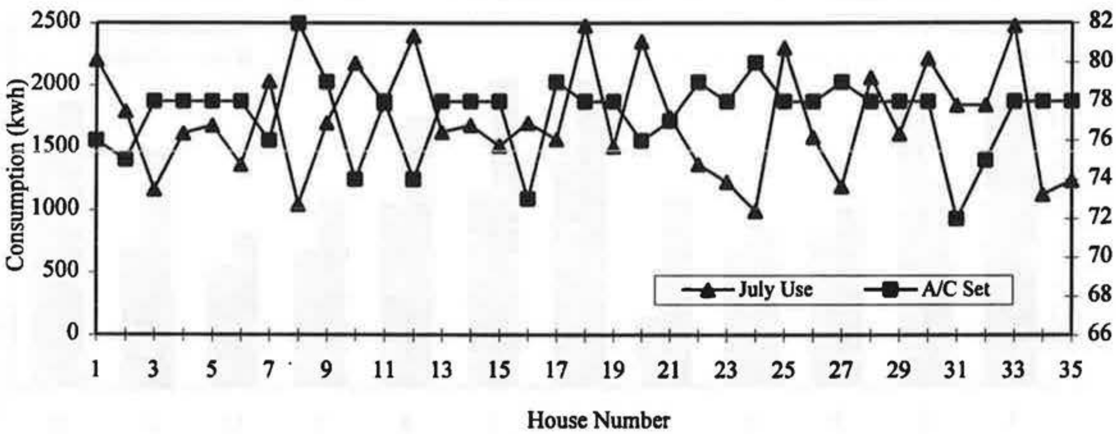

Figure 8. Comparison of actual usage with air-conditioner setting.

ELECTRONIC MONITORING OF BUILDING PERFORMANCE AND INDOOR AIR QUALITY

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ABSTRACT

We provide a general overview of our experiences using electronic sensing and datalogging systems in residential monitoring applications, and discuss some other potential applications, hardware and software options, technical challenges and possible solutions. We report on two current projects:

- A building performance/indoor air quality monitoring project sponsored by our local electric utility's energy conservation program.
- A new US EPA and MN Department of Health-funded project to investigate the interactve influences of various environmental factors on indoor radon levels.

INTRODUCTION

In our efforts to improve the performance of homes and other buildings, we often need quantitative evaluation of our achievements and failures. Occasionally the need arises to diagnose indoor air quality problems in existing homes where occupants are experiencing health, comfort or maintenance problems. Utility energy conservation programs have a clear need to document and track their projects to justify expenditures, diagnose problems, and design enhancements.

Many of these evaluations can be made quickly and simply using spot measurements with the appropriate instruments in addition to direct observation. Sometimes, however, we need more information than can be obtained with spot or grab samples, which provide only a snapshot of a particular moment in time. Many of the things that we wish to monitor in buildings are cyclical in nature and a longer sampling period is necessary to make a more accurate evaluation of the situation. We also now understand that ***buildings are systems of interacting parts***. Building design, construction techniques, materials choices, thermal insulation, air-tightness, mechanical system design and operation, occupant activities, building maintenance, and other factors interact to create complex and variable indoor environmental responses. In order to get a more meaningful measurement of certain factors or to try to develop a cause and effect relationship between factors, we need to use other methods. One method we have used successfully consists of an array of electronic sensors linked to dataloggers.

ELECTRONIC SENSORS AND DATALOGGERS

Electronic sensors are available to monitor a wide variety of environmental, mechanical and other physical factors. We have used or investigated sensors for: temperature, relative humidity, carbon monoxide, carbon dioxide, radon, formaldehyde, combustible gases, differential pressure, wind speed and direction, mechanical system status, soil moisture, rain gauge, solar radiation, electrical current and power consumption.

The electronic monitoring requires running small wires from each sensor to a datalogger which is usually in the basement or mechanical area. We have to choose compatible sensors, dataloggers, and appropriate cabling to carry the signal without unwanted electrical noise. The dataloggers we have been using can be programmed to sample the sensors' outputs and record data at intervals ranging from hundreds of times per second to once every several hours. Depending on the amount of memory the logger has and the logging interval selected, our loggers can operate unattended for a few days to several months.

Stand-alone loggers can be linked to a computer running the appropriate uploading, conversion and analysis software. The monitored data can be observed on the computer screen in real-time, and the data uploaded onto the computer's disk drive. Logged data can be reviewed as individual readings, graphed, or loaded in a spreadsheet or statistics program for experimentation and analysis.

We use loggers that will support up to 14 analog and 8 digital channels. These loggers also have output channels that, with the appropriate programming, can be used to control external devices based on sensed data—for example to increase ventilation rates when the level of a monitored indoor pollutant exceeds a predetermined level. Some of our loggers are modem compatible so that data can be retrieved and problems diagnosed remotely. The recorded data points are time and date stamped so that the sensor data can be correlated to weather, occupant activities or other external factors that are not monitored as part of the datalog.

In several houses where sensor wiring was impractical because of house layout, we have experimented with installing sensors within the appropriate air streams of heat recovery ventilation systems (HRVs). This appears promising as a technique to streamline installations, standardize measurement parameters, and minimize disruption to occupants. This technique also provides us with information about the performance and defrost cycling of the HRV.

Electronic sensors and dataloggers are only appropriate for certain types of information. In our work, we supplement the logged data streams using visual inspections, blower doors tests, infrared thermography, spot pressure measurements, alpha track radon monitors, and homeowner interviews. In combination with these tools, electronic monitoring provides an important tool for building performance and indoor air quality analysis.

notes

The Unplanned Impacts On Houses By Powered Attic Ventilators

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ABSTRACT

It is important that Building Scientists become aware of the potential for many unplanned impacts on houses by powered attic ventilators. As plans are developed for new structures, as diagnosticians examine existing buildings to determine the causes of failures and as researchers try to divine recommendations for the houses of the future, an awareness of the influence of these ventilators on houses must be maintained. By introducing this information now, others can begin to add their efforts to further map and understand these interacting relationships.

The conventional wisdom for using powered attic ventilators is listed as well as some of the opposing arguments. That information is followed by a few anecdotal cases that are reviewed to explain the origin of our interest in this phenomena. To provide some direct field measurement of this issue, additional measurements were taken in houses containing powered attic ventilators that were part of a larger group of houses receiving extensive diagnostic examination. The measurements were taken to determine how many unplanned cubic feet per minute of air the ventilator could draw from the house. Problems such as combustion safety, moisture issues, higher utility bills and discomfort were listed when they could be associated with the action of the ventilator drawing air from the house rather than from outside as intended.

For this exploratory sample of houses, it was determined that, on average, powered attic ventilators draw 231 cfm of conditioned air out of the house and cause by themselves .72 air changes per hour. This loss along with the resulting problems need further documentation.

INTRODUCTION

In several regions of the United States, powered attic ventilators enjoy the pleasures of a positive reputation. They are promoted by builders, shingle manufactures, roofers, HVAC contractors, utilities, weekender material retailers, ventilation manufactures, consultants and others. Extending shingle life, protecting shingle warrantee, removing moisture from attics and reducing the air conditioning load by the removal of attic heat are their believed benefits. These regional cultures accept and sometimes expect the use of powered attic ventilators. Cash flow in their regional economic systems is saturated with their use. Those who manufacture, sell or install powered attic ventilators in these regional cultures could experience financial hardships should it be suggested that powered roof ventilators should not be used. However, that is our central theme as a result of our measurement of some of their unplanned impacts on houses.

Background

Discussions have been ongoing for years around the issue of venting attics. Debates try to determine if we should ventilate an attic, how much to vent, where to vent,and what materials or equipment should be used. That topic will not be addressed directly. What is addressed, is an unplanned outcome for one of the attic venting strategies. Powered attic ventilation is the strategy that concerns us. It is the position of some (Wolfert and Hinrichs 1974) who happen to be in favor of attic venting, that if a powered ventilator is used, more energy will be consumed by the motor than will be saved on the air conditioning bill. Our measurements will identify an additional cost penalty that could be included in their future calculations. Others have demonstrated that increased attic ventilation does not necessarily reduce the transfer of heat across ceiling insulation into the house (Fairey 1985).

Motivation

Three years ago the issue of the unplanned impacts of powered attic ventilators was first brought to our attention by Jim Fitzgerald (personal communication Summer, 1991). Since that time we have continued to discuss the topic and recently, we reviewed the topic at length for inclusion in this report (personal communication March, 1994).

Case #1, July 1991, Nebraska: Following the installation of a sub-slab radon suction system, a house worst case test was performed. This test uses exhaust fans, the furnace blower and closing interior doors to create the greatest possible negative pressure in the house with reference to outside. Under this condition the sub-slab suction system worked and kept that area at a -5.0 Pascals with reference to the house. It was then noticed that they had failed to include the powered attic ventilator in the test. When it was added to the test, the sub slab area became +1.0 Pascal with reference to the house and radon could once again enter the house.

Case #2, November, 1991, Minnesota: A client requested assistance because of a moisture problem. They had recently purchased a new roof and the roofing contractor had installed a powered attic ventilator as part of the package. The client mentioned that they had disconnected the unit because when it operated, it pulled the wood smoke from the fireplace into the house. The house was a 2 story over a basement. The combustion appliance zone containing the furnace and water heater was in the basement. When only the powered attic ventilator was turned on, the combustion zone became -8.0 Pascals with reference to outside.

Case #3, Minnesota: A 20,000 cubic feet house has a ventilator that by itself causes the combustion appliance zone to become -3.5 Pascals. The water heater is producing 900 ppm carbon monoxide. While testing the water heater, the door to the combustion appliance zone was closed causing a furnace duct system return leak to further depressurize the zone to a total of -6.5 Pascals. The whole house became saturated to 75 ppm carbon monoxide within 10 minutes. Based on calculations that included volume, time and concentration, it is estimated that the carbon monoxide production spilling out into the house jumped to between 10,000 and 20,000 ppm.

In a recent discussion with Rob DeKeiffer I received a report from Colorado similar to case #3 above. A family of three died when their ventilator caused backdrafting, creating high carbon monoxide production and their furnace delivered the combustion products throughout the house. At the time that they were discovered there was still 1000 ppm carbon monoxide ambient in the house (personal communication, Spring, 1994).

The above cases along with our continual diagnostic testing and recording of similar phenomena lead us to set up a more formal measuring process for the eight houses reported here. By introducing our initial measurements to other Building Scientists now, others can begin to add their efforts to further document, map and understand these interacting relationships.

METHODOLOGY

To expand the building diagnostic skills of a group of HVAC contractors, a dispersed sample of available houses in the Research Triangle Park area of North Carolina were being used to demonstrate a variety of pressure and flow measurement procedures. A subset of those houses contained powered attic ventilators. For that subset, specific pressure and flow measurements were taken and observations were made to characterize the impacts that resulted from operation of the powered attic ventilator. Attics of the sample houses contained various combinations of passive ventilation in addition to the ventilator. The measurements were taken during the period from July, 1993 through September, 1993.

Each house was prepared for a standard depressurization blower door test. The volume of each house was calculated and recorded. Using an Energy Conservatory digital manometer to measure pressure, the ventilator was turned on and off several times. A measurement could then be made of the magnitude of the pressure impact on the house caused by the ventilator. House pressure with reference to (WRT) outside was recorded with the digital manometer set on the 1/10 Pascal scale. A minimum of a five point blower door depressurization test was then performed. A calculation was completed to establish, for each house, what cubic feet per minute (cfm) flow would be necessary to cause the pressure difference that was recorded when the ventilator was operated. A calculation was also completed to represent the flow at each house in air changes per hour.

RESULTS

All the houses experienced some level of depressurization when the ventilator was operated. The magnitude of negative pressure, house WRT outside, ranged from -0.5 to -2.5 Pascals. The flow from the house to the attic averaged 231 cfm and measured from a low of 104 to a high of 646 cfm. The high cfm flow occurred in a house that had two ventilators and contained several noticeable air leakage paths between the house and the attic. For the sample, an average of 0.72 air changes per hour resulted from the air flow to the attic.

All the houses are listed as having the problem of wasted energy because of the volume of flow of treated air into the attic. Two houses are listed as having combustion safety problems resulting from the operation of the ventilator in conjunction with other mechanical equipment. In particular, at Site #1 the water heater stayed in a complete backdraft mode when the ventilators were operated in conjunction with the other mechanical equipment. The water heater was located inside the conditioned space of the house. During the seven minutes of the testing cycle the area containing the water heater reached 40 ppm carbon monoxide and at five minutes the water heater flue strength of carbon monoxide was 700 ppm.

Two houses were identified as having moisture problems resulting from the ventilator induced negative pressures. At Site #4 an interesting chain of events occurred. Prior to our visit, HVAC contractors had determined that the existing duct system had a large return leak. They very successfully repaired the return side air leakage. A large portion on the sheet metal supply duct was located in the framing cavity between the first and second floors and was uninsulated. The temperature of the supply air was now colder because hot, outside air was no longer entering the system. Following the repairs, the owner complained that moisture stains were starting to appear in the ceiling sheetrock of the first floor. The advice given was to increase the powered attic ventilation and turn on bath fans to remove moisture from the structure. In a short time span after complying with the instructions, a large section of ceiling sheetrock became saturated with moisture and fell to the floor. At this point in time our site visit occurred and we made the following conclusions. The increased pressure caused by using more fans, continually, simply moved more humid, outside air through the building cavities and into contact with the colder sheet metal resulting in a flood of water onto the sheetrock. Once the sheetrock was saturated by the condensation dripping from the duct, it fell. The problem was solved by sealing air pathways between the duct cavity and the outside that were accessible, turning off the powered ventilators and using the bath fans as normal spot ventilation. Follow up contact confirmed that the problem was not reoccurring. Discomfort was noted in two houses that were listed previously, one each under safety and moisture.

CONCLUSIONS

Confirming the hypothesis that powered attic ventilators draw conditioned air from houses is important to applied building science. Once that is well established, it is important to fully describe the multiple impacts of ventilators on the house system. The interactions cover combustion safety, occupant health, building durability, space conditioning equipment operation, occupant comfort and house thermal efficiency. To gain some perspective on what it means for a ventilator to, on average, draw 231 cfm from a house the following calculation is offered. A ventilator is typically activated by attic temperature. In general they will turn on around 10:00 A.M. and will run until 7:00 P.M., a total of 9 hours of operation during the Summer and shoulder season months. The calculation is 231 cfm times 60 minutes times 9 hours equals 124,740 cubic feet of conditioned air each day drawn from the house. What does that do? What does that cost?

A review of some of the important issues includes the following:

1. Ventilators can cause negative pressures in combustion appliance zones. By themselves or in conjunction with other negative pressures they can cause backdrafting.

2. Ventilators run during electric utilities peak demand period and can become a peak demand problem.

3. Ventilators can draw conditioned air out of houses and cause the air conditioner to run more.

A. They can cause increased latent load that air conditioners must remove.

B. They can increase the cost for air conditioning for the homeowner.

C. They can cause temperature discomfort, hot areas, that homeowners try to solve by increasing cooling through closing some supply registers which can cause additional problems.

4. Ventilators can be an unexpected and undocumented source of increased infiltration rates in houses.

5. Examination of this unplanned, exhaust only ventilation, which is occurring in many houses during air conditioning, may give an indication of how much intentional exhaust Southeastern houses can tolerate without developing moisture problems. This information will be very useful when an exhaust only ventilation system is chosen as the approach to ventilate conditioned space in the Southeastern region.

At a minimum, it is recommended that if a powered attic ventilator is chosen as part of an attic ventilation strategy, the following guidelines should be provided. The installer should provide a good air barrier between the house and the attic and adequate, net free, vent area should be provided. Confirmation of safe operation is provided by measuring not by ignoring, guessing, or hoping.

ACKNOWLEDGEMENTS

The Duct Diagnostics and Repair Training Program budget of the Applied Building Science Center which is part of the North Carolina Alternative Energy Corporation is the primary source of funds that made it possible for these field measurements to be acquired.

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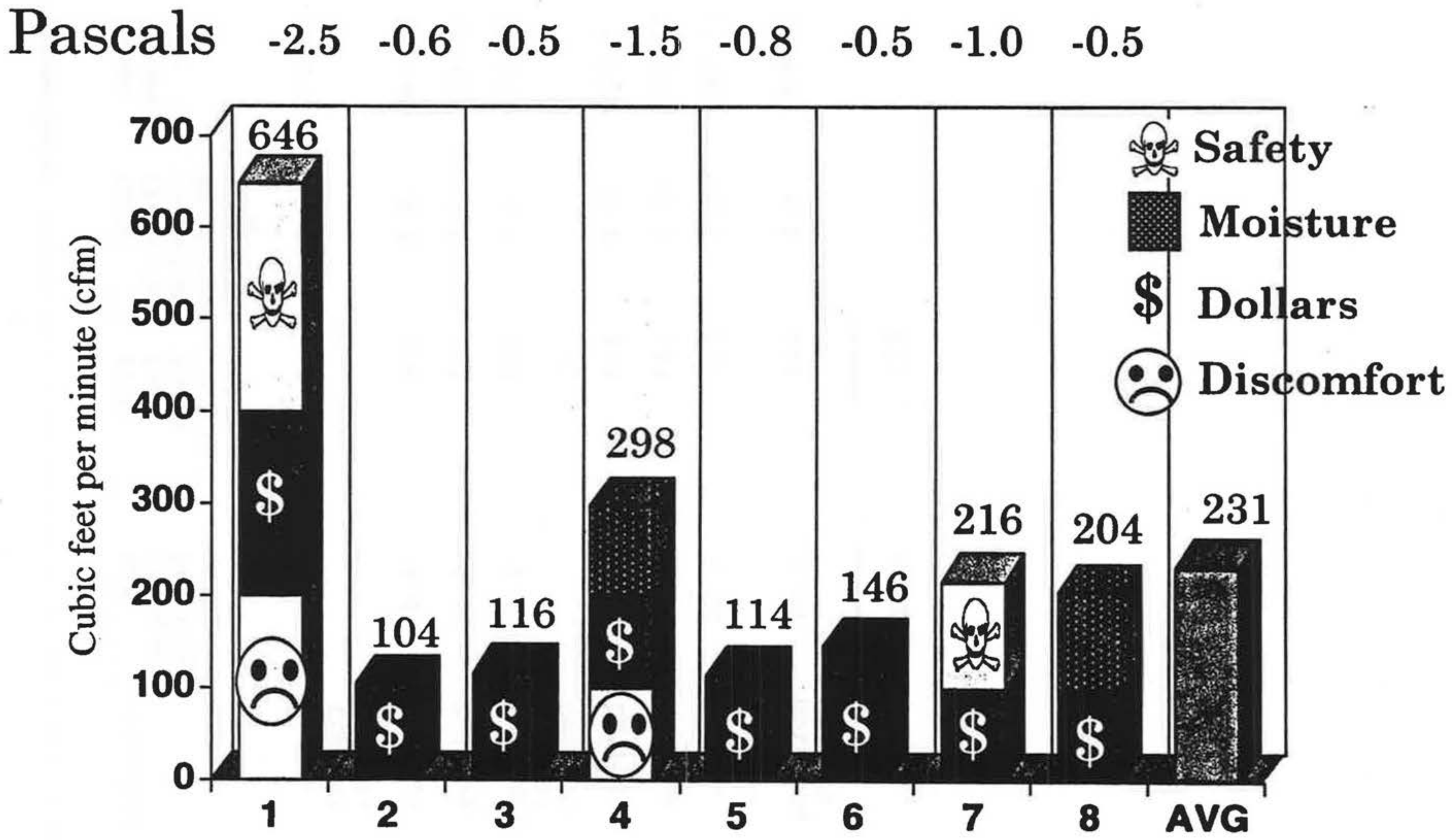
Table 1. House Data

Site #	House Volume (cu. ft.)	House Pressure Caused By Ventilator (Pascals)	Flow From House To Attic (cfm)	Air Changes Per Hour	Problems
1	32,258	-2.5	646	1.2	Safety Comfort Dollars
2	13,184	-0.6	104	0.47	Dollars
3	15,000	-0.5	116	0.46	Dollars
4	18,000	-1.5	298	0.99	Moisture Comfort Dollars
5	18,000	-0.8	114	0.38	Dollars
6	14,000	-0.5	147	0.63	Dollars
7	18,688	-1.0	216	0.69	Safety Dollars
8	13,600	-0.5	204	0.90	Moisture Dollars
Average			231	0.72	

Powered Attic Ventilators
8 NC Houses



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Affordable Housing in the South--
Barriers to Making It Energy Efficient

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In the South, there has been considerable effort to develop affordable housing. However, an informal survey of energy professionals in the region indicates that much of this effort ignores proven energy efficiency techniques. The lack of proper attention to energy efficiency results in energy costs being higher for families who can least afford them. Poor energy details often cause problems with comfort, building durability, and indoor air quality.

As a private, nonprofit corporation, the Southface Energy Institute provides research, education, and technical assistance on energy and building science issues. In 1994, Southface, working with support from the U.S. Department of Energy, the Environmental Protection Agency, and the Georgia Housing and Finance Authority, initiated a program to provide technical assistance to nonprofit organizations developing affordable housing in metropolitan Atlanta.

A variety of nonprofit organizations provide affordable housing services, both new construction and renovation, in the Atlanta area. The program models for these organizations are varied, ranging from groups that construct new homes using paid staff serving as construction leaders for weekend volunteer work parties to organizations that rely completely on paid management and construction labor for housing rehab.

Regardless of the program model, all nonprofit organizations face the following barriers to improving the energy efficiency of affordable housing in the region:

Belief that Energy Is Not An Important Issue in Affordability
The relatively mild winters of the South lead some housing professionals to believe that energy costs are not significant enough to be a factor in a home's affordability. Some organizations do not monitor energy bills for their clients, and those that do may have a misconception about the level of energy waste. One construction coordinator claimed that winter heating bills for a one thousand-square-foot design were only about $50 a month. A review of the energy bills for that organization's homes showed some homes with bills three times that amount.

Many low income home owners participate in utility budget billing programs where the projected yearly energy costs are divided into even monthly payments. While this practice helps limited income families budget against a high monthly bill, it hides the true cost of energy waste. Organizations are lulled into accepting $70 per month utility bills as affordable, rather than seeing that yearly energy costs for the family are over $800.

Somc affordable housing programs in the South do not provide air conditioning in the homes they construct. Calculating potential savings from increased efficiency does not show a dollar savings on cooling costs. However, home owners often add room or central air conditioning systems. These systems frequently have low efficiency and cooling bills can exceed those for heating.

Low First Cost and Fast Construction Schedule

All nonprofit organizations have inadequate resources to meet the need for affordable housing. Many groups are masters at stretching dollars to build as many homes as possible. Improving the energy efficiency adds to the construction costs of their homes. While the cost savings to home owners and other benefits from improved efficiency are significant, most program managers use initial construction cost as the overriding priority.

In addition to increasing the cost of construction materials, program managers fear that energy efficient measures will burden labor forces. Many nonprofits rely on weekend workparties where twenty or more volunteers work simultaneously to construct a house. These groups have perfected a construction schedule that allows unskilled volunteers to complete houses within a couple of months. Adding extra tasks or changing the established protocol can pose scheduling and training problems.

Acceptable Building Practices

Across the region, field studies of the energy efficiency of new home construction show that acceptable building practices often create energy problems. These poor building practices occur in housing of all price ranges. For example, standard corner and partition wall framing creates areas that are difficult to insulate and airseal. Poor duct sizing and layout lead to uneven air distribution-- a problem often compounded by unsealed seams in ductwork.

The lack of energy codes for several states in the region, and the poor enforcement by those that do have codes, adds to this barrier. Some affordable housing organizations believe that because their homes are "code approved" they are providing reasonable levels of energy efficiency.

Lack of Energy Expertise Within the Affordable Housing Community

Nonprofit affordable housing program managers may have little construction experience. They often rely on building professionals to serve as mentors or to actually construct the houses. Since the program managers are not aware of the problems with "building as usual" they do not demand efficiency beyond standard practices.

While the people who serve as mentors may be experienced professionals, many are not aware of advances in energy efficient design and techniques. If they are aware, they face the pressure of keeping first costs low and working with untrained crews.

Frequently there is poor communication between those making design and construction decisions and those knowledgeable of energy problems. Few agencies monitor energy costs or evaluate the performance of their buildings. Home owner complaints can provide some insights, but it is often difficult for the nonprofit organizations to identify the source of the problem that leads to the complaint.

For example, recently a home owner complained to a nonprofit organization about a mildew problem at the junction of an outside wall and ceiling. The staff initially diagnosed the problem as a leaky roof, but a closer inspection showed the roof was weathertight. The culprit was inadequate ceiling insulation that caused the ceiling to drop below the dew point temperature of room air leading to condensation and the resulting mildew.

Most organizations do not have a defined process to communicate to all those responsible for the ceiling insulation, including the home designer, framing crew, insulation installer, and final quality control inspector, that the inadequate insulation led to a moisture problem.

Inadequate Technical Assistance on Energy Issues

Even if a nonprofit organization recognizes the need for improved energy efficiency, they often do not have access to training, design assistance, in-field testing or other forms of technical assistance critical to making improvements. Where technical assistance is available, it must be delivered at a time and in a format that recognizes the unique nature of the nonprofit affordable housing community. Training one group of volunteers on energy improvements may help lower costs for one home, but has little continuing impact.

Few affordable housing organizations commit significant resources to training construction supervisors, especially on energy efficiency detailing. Burnout of construction supervisors is also a barrier to energy efficiency. Many professionals who work in the affordable housing arena are committed to helping low income families. However pay scales are frequently low, hours long, and pressure high so turnover can be quick.

The energy efficiency knowledge must be "institutionalized" in the construction program. Technical assistance programs must develop educational materials that will be useful after current staff have left. The educational tools must suit audiences with vastly different building expertise.

Developing complicated energy specifications for a new program manager who lacks the construction experience to ensure subcontractor compliance will not save energy. The manager must be trained in why energy efficiency is important; what specifications are critical to ensuring safe, efficient, affordable housing; and in how to monitor compliance with the specifications.

The traditional sources of technical information, such as trade associations, product vendors and utilities, have had limited success in increasing the energy efficiency of affordable housing in the Southeast.

Overcoming the Barriers to Energy Efficient Affordable Housing

To help nonprofits overcome these barriers to making affordable housing more energy efficient, Southface has developed several technical assistance tools. The first is a simple brochure targeted towards nonprofit affordable housing decisionmakers that outlines the economic impact of energy waste on low income families. The brochure illustrates common energy problems in affordable housing in the South.

While the brochure is helpful in informing decisionmakers of the problem, few of these people will seek out information on their own to change the problem. The burden of keeping their programs on course overwhelms many. To get programs to adopt substantial energy saving measures usually requires a series of meetings with the decisionmakers.

Our goal is to walk through a house with the decisionmaker to point out simple, yet effective measures that can be adopted for little additional cost. We also conduct a series of diagnostic tests on a completed house, including air leakage measurements of the building envelope and duct systems.

Once the commitment is made by a program's leadership, we conduct a review of the construction plans and provide a list of cost effective energy measures. Programs may not agree to change house plans, so the review may only identify opportunities for saving energy by avoiding common problems. For example, if bath tubs are located on exterior walls, then a construction note identifies the need to insulate the wall and install an air barrier material before the tub is set. A plan review usually takes several hours due to the need to discuss basic building science and energy principles with the organization's staff. In effect, the review is often a training workshop.

We have prepared a detailed energy specifications package that addresses cost effective energy recommendations, ranging from foundation insulation to selecting heating and cooling equipment. However, some groups are interested only in modifying their current approach.

We provide a simple checklist of energy measures for the standard single story affordable home design built in our region. While these recommendations are not as comprehensive as we would like, they at least get groups beginning to improve the efficiency of their housing. The checklist recommends insulation levels and identifies major sources of air leakage, such as rough openings, penetrations for utilities, attic access openings and whole house fans. It also emphasizes the need for airsealing the duct system, especially the high pressure areas, and for isolating combustion appliances from the conditioned space.

Ideally, the nonprofit will commit to hosting a training workshop for its construction staff. The approach we use on these programs varies according to the needs and availability of the staff. We blend classroom theory with hands-on training in the field. Sealing a duct system so that it passes a pressure test is more effective than viewing a hundred slides.

We have also worked with organizations in providing field training on energy measures to volunteers. One approach is to staple brightly colored illustrations of the energy measures to be completed throughout the house. One volunteer seeks out and repairs damaged insulated sheathing, another seals wiring penetrations, while others apply duct mastic.

It is still too early to measure success from our technical assistance efforts. We are currently working with over a dozen groups. One organization conducting affordable housing rehab has made a strong commitment to energy efficiency and is fast becoming a leader in its field. Predictably, others have started, stalled, and re-started on improving the efficiency of their programs.

It is clear from these initial efforts that improving the energy efficiency of affordable housing takes a strong commitment on the part of the organization. It does not come easily. It requires hard work and extra time and materials cost. However, the benefits to the families who live in these homes are significant.

notes

THE ENVIROHOME INITIATIVE

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INTRODUCTION

The Canadian Home Builders' Association has launched EnviroHome, a commercial promotion of new housing incorporating a wide array of environmental features. The EnviroHome initiative is made possible through the sponsorship of Canada Trust and receives support from the Canada Mortgage and Housing Corporation and the R-2000 Program of Natural Resources Canada.

EnviroHome is a promotional event, not a specific product, intended to show home buyers that environmental and healthy housing features are commercially available and affordable now. As part of the process for the initiative, two pilot EnviroHome events were mounted, involving the construction of demonstration homes - one in Edmonton, Alberta and one in Saint John, New Brunswick in order to "test" the initiative.

This paper elaborates on the technical and environmental features incorporated in homes built in the EnviroHome pilot program and discusses plans for future EnviroHome events.

THE EVENT

The key aspect of EnviroHome showcase homes is that they present environmentally improved homes that are affordable and available today to consumers. They use only proven, "here and now" products and innovations that deliver a lot of benefit at little additional cost.

Each EnviroHome project undertook a local promotional campaign which highlighted the benefit of environmental housing technology to homeowners and builders in the community. Local media, community organizations and others in the building industry were familiarized with the EnviroHome event and provided support and/or sponsorship to the projects in varying degrees. Each showcase home has been opened to the public and properly "labelled" so that consumers touring it understand the environmental and health features included and their benefits.

Builders are required to offer the environmental features included in the showcase home as available features or upgrades in their other projects.

THE TECHNICAL REQUIREMENTS

All EnviroHome showcase homes must be built according to the upgraded R-2000 technical standard and become registered as R-2000 units. The R-2000 standard requires builders to achieve high levels of energy efficiency in new homes. The standard also requires the home to be continuously ventilated, optimize solar contributions wherever possible and incorporate a number of indoor air quality and material conservation features.

In addition, homes built under the EnviroHome initiative must go beyond the "standard" R-2000 requirements. The projects must:

- incorporate a greater number of R-2000 indoor air quality and materials conservation features
- demonstrate environmentally sound lot treatment practices (for single units as well as the entire development)
- demonstrate enhanced water usage (ie. use low flush toilets & low flow shower heads)
- use energy efficient lighting (ie. use at least four high efficiency, 40 lumen/watt, light fixtures)
- have a site waste management plan

In large part these EnviroHome requirements are the "offspring" of requirements that came out of CMHC's Healthy Housing Competition and NRCan/CANMET's Advanced Houses Program.

THE PILOT PROJECTS

In the spring of 1994 CHBA's local home builder associations were invited to submit proposals to stage an EnviroHome pilot project event in their community. The idea was to "trial" two events in order to develop experience and information about this new initiative. After an intensive two stage selection process, the EnviroHome Selection Committee decided that two pilot project showcase homes would be constructed - one in Edmonton, Alberta, and one in Saint John, New Brunswick.

EDMONTON ENVIROHOME EVENT

The first EnviroHome showcase home to be opened to the public was in Edmonton. The project is situated in a 40-acre development which is considered as Edmonton's first sustainable nature preserve. Houses in the development will surround natural greenspace where native plant and aquatic life is protected.

The builder, Challenger Homes, looked at every material and product and asked what was the best and most cost-effective environmental option. Emphasis was placed on using recycled products wherever possible. The builder found that this resulted in several new ways of doing things.

The Edmonton home has the following features and characteristics:

■ An integrated gas space and hot water heating unit working at an efficiency of 90%. This home was the first in Canada to have the Lennox "Complete Heat" ™ system. The system is priced less than comparable separate systems of less efficiency.

■ Double glazed, Low-E coated, argon filled windows are on most south oriented windows to optimize solar gains while providing a level of energy performance. Windows in other orientations have triple glazing, a Low-E coating, and are argon filled.

■ Heating provided by solar gains accounted for over 25% of the space heating load.

■ A heat recovery ventilator provides a continuous stream of fresh air while removing odours, humidity etc. from indoors.

■ Low flush (6 litre) toilets, water-conserving showerheads and bathroom faucets that could save the homeowners 125,000 litres of fresh water each year are included.

■ Efficient compact fluorescent fixtures are installed throughout.

■ "Clean air" kitchen cabinets having components which minimize chemical off-gassing are used. For example the counter-tops use formaldehyde-free bonding agents.

■ Finger-jointed wall studs are in the wall assemblies.

■ The concrete in the polystyrene form foundation system contains fly-ash, from coal-burning power plants, which reduces the amount of cement in the concrete.

■ The wall sheathing is composed of 95% recycled paper & cardboard.

■ The outdoor deck is made of recycled beverage containers and plastic bags.

■ The rubber pavers are made from recycled tires.

■ Drought-resistant plants native to Alberta result in a landscape that requires less watering and fertilizing.

■ Wood waste from construction was shredded to provide mulching for the landscape. Construction waste was kept at a minimum.

■ A 1,000 litre cistern that captures rainwater for gardening needs is included.

SAINT JOHN ENVIROHOME EVENT

The Envirohome event in Saint John takes place in a 44-unit condominium garden home development built by Moore Homes of Saint John. About 40% of the development site will be designated as public parkland. One of the units in the development will be the EnviroHome showcase home although all the homes are being built to R-2000 specifications.

Moore Homes, a family-owned homebuilding firm, is a strong believer in providing a healthier living environment for its customers at an affordable price. All materials used were carefully selected in order to maximize the indoor air quality in the home while also providing environmental benefits.

The Saint John home has the following features and characteristics:

■ Double glazed, Low-E coated, argon filled windows with insulated spacers are used. South facing orientations receive as much glazing as possible and cost effective.

■ Heating provided by solar gains accounted for about 25% of the space heating load.

■ The interior has been finished using only water-based paints and varnishes. Items requiring solvent based finishing for reasons of cost effectiveness and performance were pre-finished in order to protect indoor air quality.

■ High quality kitchen cabinets made of solid wood and low off-gassing wood products are used. Glues used in the cabinetry contain reduced levels of chemicals such as formaldehyde.

■ Hardwood flooring covers the main floor and was pre-finished. This flooring surface also helps to reduce the amount of dust in the house.

■ A heat recovery ventilator provides a continuous stream of fresh air while removing odours, humidity etc. from indoors. A high efficiency air filter aids this process.

■ Low flush (6 litre) toilets, water-conserving showerheads and bathroom faucets installed could cut the home's water requirements as much as 35%.

■ The foundation system consists of hollow polystyrene forms which contain the poured concrete. Instead of being stripped-off, these highly insulating forms are left in place, providing a complete & fully insulated basement wall. The concrete contains some fly-ash as a partial replacement for cement.

■ The wall sheathing is composed of 95% recycled paper & cardboard.

■ Roof shingles are made of long-life fibreglass containing recycled aggregate.

■ Waste from construction was minimized and materials were recycled wherever possible.

PROMOTIONAL ACTIVITIES

A major thrust of EnviroHome events is to undertake a local promotional campaign which highlights the benefits of environmental housing technology to both homeowners and the community. Very successful opening ceremonies were held in Edmonton and Saint John, attracting a great deal of media interest and interest from the building community. In addition, local subtrades and suppliers donated time and materials to help make the events successful.

Also, each showcase home is required to be open to the public for a period of time after their official opening. To help promote the homes and the initiative, the builders' sales staff were trained in the presenting and selling of the homes' environmental features. As an example of an open house event, some local schools and Canada Trust branch offices in Edmonton will be having an "EnviroHome Day".

FUTURE ENVIROHOME EVENTS

With the successful experience drawn from the pilot project Envirohome events in Edmonton and Saint John, the EnviroHome initiative is in excellent position to be broadened in 1995. Local home builder associations throughout Canada will be invited to mount an EnviroHome event in 1995.

As shown in this year's pilot project's showcase homes, EnviroHome events will display a wide range of features and products that can help protect the quality of the environment. Best of all, these benefits can be offered to consumers at an affordable price. For consumers the result is housing which is "good for you, good for your community, and good for your environment".

Mold, Moisture, and Indoor Air Quality
A Cold Climate Perspective

McGregor Pearce, Pat Huelman, and Wanda Olson

Introduction:

People in the developed world are estimated to spend about 90% of their lives indoors. Therefore the quality of the air in homes and buildings is a topic of much interest. Molds are responsible for many indoor air symptoms and complaints. Unlike chemical contaminants, air borne mold spore levels can rise and fall dramatically in response to environmental factors, such as temperature and moisture. Once established, mold colonies can be very difficult to eradicate. The best way to provide mold free indoor environments is to build out conditions that favor their growth. While this paper is based on experiences in Minnesota, much should be relevant to homes and buildings in other locations as well.

What are Molds?

In order to avoid building related mold problems, it is important to understand a bit of mold biology and ecology. Molds play a vital role in the recycling of organic material. They degrade dead plant and animal matter into bioavailable nutrients, thereby promoting the growth of new life. While they have left little fossil record, it is assumed that molds are ancient life forms that have adapted to almost every environment on earth.

The whole planet is subjected to a constant "rain" of mold spores. When a spore lands in favorable habitat, it secretes digestive enzymes into its immediate environment. These enzymes degrade the surrounding material into nutrients which the mold absorbs and uses to grow. Molds can survive on almost any organic material. Damp masonry can support enormous colonies of mold, thriving in an invisibly thin layer. From the initial spore, fine filaments extend to form a fibrous mat called a mycelium. These filaments secrete more digestive enzymes, and the colony continues to grow by digesting the substrate around it. If appropriate moisture and temperature conditions are maintained, a mold colony will continue to thrive until all of the digestible material is gone.

Once established, the colony begins to produce reproductive structures which generate spores. Each of these spores is identical to the one that began the colony, and is potentially capable of initiating another. Healthy mold colonies generate astronomical numbers of spores. These spores are usually less than ten microns in diameter (the period at the end of this sentence is about 100 microns in diameter). They become airborne at the slightest disturbance, and may ride air currents for thousands of miles from their point of origin. Mold spores are found at both poles as well as several miles above the earth

Mold spores can present indoor air quality problems for building occupants. Because of their small size, they are capable of being inhaled into the deepest recesses of the lung. Allergic reactions are triggered by complex organic molecules on the spores cell surface which react with and irritate the immune system. Large doses of inhaled mold spores can create health problems for non-allergic people as well By overtaxing the immune system, in its efforts to clear the invading particles, hypersensitization can occur with a host of unpleasant symptoms. In addition to causing immune system problems, some molds produce toxic substances that can be either acute or chronic poisons. While mold related health problems are poorly characterized, it is generally agreed that people should not live in moldy buildings.

Mold in buildings:

The single most important design feature of a mold free building is rigorous moisture control. Moisture measured as water vapor in air is referred to as relative humidity. Liquid water in solid material is referred to as water activity. Both are measured as percents. Molds usually require moisture levels, measured either as relative humidity or water activity, of at least 70% in order to establish themselves.

It is important to understand that an indoor space with an average relative humidity of 30% can still harbor local environments where moisture levels are much higher. A good example would be a window in a home in January, in a cold climate such as Minnesota. The temperature might be 70° F., and the relative humidity under 30%, yet liquid water can be observed condensing on a cold window pane, and the wood at the bottom of the pane may stained black from mold growth.

One important method of moisture-mold control is to balance indoor humidity levels against the insulating qualities of the exterior sheath to prevent local condensation conditions from occurring. Although window condensation can create visible problems, it is unlikely to cause a wide spread mold problem. Once the moisture flows down the glass onto the window frame, it becomes exposed to 30% humid indoor air, and is rapidly evaporated. More serious condensation problems can occur in areas hidden from view, such insulated exterior wall cavities. In such areas, protected from the drying effect of building or home ventilation systems, moisture can accumulate, and create ideal mold growing conditions.

Although water vapor condensation frequently plays a role, bulk water intrusion probably causes the most severe indoor mold problems. Flooding events, plumbing failures, envelope leaks and fire related water damage can rapidly generate astronomical mold levels, that persist long after the building is cleaned and dried. Mold contamination is capable of becoming serious within less than seven days. Therefore it is vital that water soaked building materials be either cleaned and dried, or gutted out, before the mold can gain a foothold. But remedial measures can only be taken when the water problem becomes apparent. Certain features that are commonly built into modern homes can cause hidden moisture/mold problems of the most severe sort.

Mold and the modern basement

Older homes usually have what might be referred to as furnace-laundry tub basements. The masonry floor and walls are exposed to view. Although these basements may be dank and dusty, they are unlikely to harbor thriving mold growth. Foundation water leaks are readily apparent, and the water introduced by them either evaporates, or can be mopped up with a bit of dilute bleach to kill off any mold growth. When leaks persist, the homeowner can have the landscape drainage modified, or install drain tile to deal with the problem.

The high square foot cost of modern housing has made finishing and occupying of underground space seem desirable. Cold climate building codes dictate that foundation walls be insulated. The builders choice is often to fir out the walls with wooden studs, fill the cavities with fiberglass insulation, then cover the wall with a plastic vapor barrier. It is a logical next step for the homeowners to cover the wall with painted gypsum board or paneling. To complete the project, the slab is covered with carpeting. They now have finished space, which is used for bedrooms, play areas, or office space. Unfortunately, unless the foundation walls and slab have been properly designed and installed, capillary moisture migration through these masonry surfaces can initiate extensive mold problems.

The Hoover dam holds back the Colorado river, yet the downstream side of the dam is wet to the touch. Water readily moves though tiny pores in the cement, migrating from the wet side to the dry. When damp soil presses against concrete foundation walls or slab, the drier air inside creates a gradient and the water begins to move into the basement. In an unfinished basement, the water evaporates, and makes the basement feel damper than the rest of the house. In a finished basement, moisture can accumulate behind dry wall or under carpeting. This soil water is full of mold spores and nutrients, and mold thrives under such conditions. Such conditions can persist without visible staining or odors in the interior space, and often the first sign of the problem is occupant health complaints. To compound the problem, the commonly installed forced air HVAC system readily distributes the mold from the basement to the rest of the building.

In addition to distributing contamination, HVAC systems utilizing sub-slab duct work may actually become sources of mold/moisture problems. These systems are installed by digging a perimeter trench before pouring the concrete floor. Large diameter PVC pipe is then laid in the trench, with supply boots extending up above the level of the cement. After the slab is poured, the boots are cut flush with the floor and fitted with supply grills. A down draft furnace then feeds air into the sub-slab duct work to warm or cool the space. This approach is popular in slab-on-grade construction, such as town home and condominium projects.

If such a system were professionally installed by licensed personnel, with all seams chemically welded, and a manometer test performed before pouring the slab, it is possible that they could be acceptable. Unfortunately, cost considerations tempt builders to cut corners. While the ten foot sticks of PVC duct are inexpensive, the elbows and other fittings are costly, and galvanized metal fittings are often substituted. Such fittings are then press fit, or at best fastened with a few sheet metal screws. Instead of welded, air tight PVC supply boots, fabrications of galvanized metal are crudely fastened to the top of the truck lines to extend through the slab.

Such systems constitute a recipe for trouble. Wet soil can rapidly corrode holes in metal fittings, allowing water to leak directly into the duct work. Once the system is inoculated with muddy water, the mold problems follow close behind. Cleaning the system has little effect, as it is still wide open to the soil in which it is installed. One can often observe braided chain patterns of sand and mud on the bottom of sub-slab ducts by looking down through the supply openings. A mirror and flashlight can be used to reveal the metal fittings.

In addition to providing a microbiological breeding ground, these leaky sub-slab systems can supply enormous quantities of moisture to the home, on a four season basis. The heaviest mold contamination is sometimes found in the attic When the builder is called to task for a sub-slab system half full of water, the quick fix is to install exterior drain tile below the level of the duct work, in order to channel water away from the house. But it is virtually impossible to repair existing holes in the system, and the exposure of the forced air in the ventilating system to the soil persists and gives a new dimension to the term "air conditioning". It is important to weigh installation cost savings against the expense required to excavate and repair underground foundation moisture problems.

What to do:

1. The exterior shell of the building should be wrapped with an effective air barrier to prevent cold air from intruding into the envelope and creating cold temperature surfaces capable of promoting moisture condensation.
2. The Building envelope should contain an air tight, consistent layer of insulation, free of voids or gaps.
3. A warm face vapor barrier should be installed in as air tight a manor as possible. Great care should be taken to prevent anyone from cutting holes in the vapor barrier once it is installed. Electric outlets, recessed light fixtures, and plumbing penetrations are common culprits. Warm, moist indoor air must be kept out of the building envelope.
4. Buyers and builders should select simple building shapes, to permit easy installation of air and vapor barriers and insulation. Electrical and plumbing penetrations should be avoided in exterior walls.
5. Anyone wishing to finish below ground space should take care to insure that the foundation is waterproofed. Traditional "mastic and plastic" foundation treatments are prone to failure. For keeping the foundation dry, exterior drain tile is superior to interior, and both is better. A capillary break should be fitted to prevent soil moisture from contacting the slab and underground portion of the foundation. A capillary break can be achieved by a number of methods. The underside of the slab should be sealed with a continuous sheet of cross laminated polyethylene. The footings should be covered with a strip of plastic, or a brushed on coating of water impervious material. The exterior foundation wall should be waterproofed with a polymer spray on coating that maintains flexibility, then covered with insulating drain board or back filled with pea gravel. Remember that sand does not provide a capillary break.

7. If a sub-slab duct system cannot be avoided, the system must pass a plumbers manometer test to guarantee that it is going to be leak free. No metal parts may be used.
8. Laundry areas in upper levels of the home must be disaster panned. Overflowing or leaking washing machines can readily do thousands of dollars in damage to finished space below, and can be the cause of very severe mold problems. Upstairs laundry rooms must have floor drains, and overflow containment pans.

Conclusion:

Homes are often built and purchased on the basis of dollar cost per square foot. Extra money in the budget is dedicated to imported tile or luxury appliances. Moisture/mold problems usually don't show up until the house is sold and occupied. Mold problems are much easier to prevent than to fix. If water damage occurs in buildings, it is vital that they be dried immediately. Owners reluctant to shoulder the expense of radical gutting of water damaged walls and carpet are in danger of facing much more significant medical care in treating mold related health problems. It is hoped that consideration of some of the issues addressed here can spare builders and owners the harm and expense associated with moldy homes.

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Healthy Indoor Environments Thru Passive Ventilation Using Integral Window Ventilating Systems/Devices

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It is hard to pick up a newspaper or magazine these days without reading something about the environment, indoor air quality, tight buildings, stale air, and spotted owls. You ask, 'What have spotted owls got to do with our session today?' Spotted owls are the concern of the citizens of Washington State and Oregon where the leadership to combat poor ventilation by the Department of Energy thru the Bonneville Power Administration originated. Over the past few years the Building Codes of these two states as well as parts of other states in the Pacific Northwest have included the introduction of pure fresh air ventilation into both residential and commercial construction by various methods. These codes are working their way across the lower 48 states and Alaska. Most of the codes are patterned after those building codes existing in United Kingdom for over ten years. The concern of indoor air quality worldwide is a hot topic of the general public. Indoor air pollution has been referred to by some IAQ experts as the "asbestos of the 90s".

Additional natural or background or passive ventilation into a tightly constructed house or building originated in Scandinavia. Of course, it is logical that those countries in Scandinavia would need additional ventilation because of their climate as well as construction methods. The window manufacturers from Sweden, Norway, and Denmark introduced what became known as "trickle" ventilators into their products. Trickle ventilators are manually operated air-inlets fitted to windows (preferably at the top) to allow a **controlled** flow of air to trickle in. The amount of air flow is usually sufficient to improve indoor air quality without significantly affecting energy costs.

Trickle ventilation has become the system most people in the window industry recognize when talking about passive air-inlets and/or integral ventilation systems. I could go into great detail about the causes of poor indoor air quality but suffice it to say that many new materials commonly found in homes and buildings such as carpeting, furniture, paint, wood, drywall, etc. emit certain characteristics that pollute the indoor air. Tight construction to save energy produces unhealthy indoor conditions. To put it simply, emphasis on energy conservation has created a monster. The fact remains that we are indoors too much of the time- it's unavoidable. We also live and work as creatures of habit. We demand modern living conditions and a good quality of life. I don't see us reverting to past times when only a Saturday night bath was the norm. We are not going to change the way we live. We will continue to use our dishwashers, computers, washing machines, stereos, TVs, etc., etc., etc.,- those items that consume energy. But we will not be subjected to the illnesses and conditions caused by bad indoor air.

Another reason for trickle ventilators-reduce condensation. We all know what causes condensation. No window manufacturer or supplier is spared complaints about condensation. Andersen Corporation publishes a pamphlet entitled "Understanding Condensation" which indicates they openly admit that condensation is a problem. Trickle ventilation reduces condensation by allowing a flow of air around the surface of the glass where condensation forms. When it's dry and cold in the winter in certain climates, people introduce humidity into their living atmospheres without realizing the result- condensation. We human beings are constantly using bathrooms, kitchens, and various appliances that emit moisture. (Seeing your breath) The small flow of air through a trickle ventilator is like a defroster in your car, a little slower but equally as effective.

Integral window ventilator systems can be broken into three basic types. There are some specialty types that I will mention but are not presently marketed in the US. Types: Glazed-in, slot, and surface mounted. I will discuss each one pointing out the application, advantages, features, and benefits of each. A number of manufacturers offer similar systems in the USA- most of which are manufactured in a European country. You can see samples of typical integral window ventilator systems displayed in the exhibit hall.

IMPORTANT FACT: TITON TRICKLE VENTILATORS OFFER VENTILATION WITH SECURITY!!

There is a move in the state of California to eliminate the use of night latches, secondary opening positions for windows, limit stops- whatever you want to call them. That action may effect the use of these devices in other parts of the country also. Integral window ventilation systems offer a way to get controlled ventilation without opening windows- one of the unique benefits of these devices. To express this concept another way: With the use of window trickle ventilators, fresh air is introduced in the controlled manner without concern for security even at night or when structures are unoccupied.

A discussion of the impact of integral window ventilating systems/devices on voluntary standards, code body deliberations and certain individual states within the US is in order.
The California Energy Commission has published a new study entitled Energy Efficiency Standards and Indoor Air Quality dated December 1994. A movement within the state of California has already been mentioned as it relates to ventilating windows with security. The Ventilation Task Force for the state of Minnesota has included indoor air quality as it relates to energy conservation in their ongoing proceedings. Alaskan builders are frantically searching for alternatives to energy consuming mechanical systems that include testing of integral window ventilating systems/devices. The National Fenestration Rating Council has included the consideration of using window ventilation in their rating procedures. NFRC is a non-profit public/private collaboration of manufacturers, builders, designers, specifiers, code officials, consumer, utilities and regulators that is establishing a national energy performance rating system for fenestration products. Sanctioned by the federal government under the Energy Policy Act of 1992, NFRC will, over the next several years, establish a program where many factors are rated, including solar heat gain, optical properties, air infiltration, condensation resistance, long term and annual energy performance in addition to "U" value which determines the energy performance of fenestration products. ASHRAE is presently revising Standard 62- Ventilation for Acceptable Indoor Air Quality. The 1989 version only mentions operable windows as a source for natural ventilation. The revised standard will include passive ventilation through windows. The American Architectural Manufacturers' Association also has recognized the

need for passive ventilation through fenestration products in their voluntary standards and Window Selection Guide soon to be published revised. AAMA is a trade association of firms engaged in the manufacture and sale of architectural building components and related products to include windows, sliding glass doors, storm windows and doors, curtain walls, store fronts, skylight and space enclosures, and siding. AAMA relates to the residential, commercial, manufactured housing, and institutional building industry. The New York State Builders Association,Inc., the New York State Energy Office, the New York State Energy Research and Development Authority and public utilities through New York State have joined forces to create NY-STAR. This comprehensive, independent, not-for-profit certification program will save energy in New York State. Of course, the Pacific Northwest, as mentioned earlier is the leader in combining energy conservation and proper ventilation. The movement to improve indoor air quality along with energy conservation is snowballing. It is highly recommended that energy efficient builders climb aboard the snowball rather than being in its path. Contact your fenestration product suppliers to encourage them to include integral ventilating systems/devices in their sales and marketing programs.

REMEMBER: ENERGY CONSERVATION WITH PROPER PASSIVE VENTILATION EQUALS SMART HEALTHY CONSTRUCTION.

notes

RADON REDUCTION THROUGH SOLAR VENTILATION: DESIGN & EVALUATION

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ABSTRACT

Conventional residential energy conservation measures that limit air exchange rates between the indoors and outdoors have been shown to increase concentrations of radioactive radon decay products as well as other indoor air contaminants such as combustion by-products and off-gases from carpeting, furnishings, appliances, cleaning products, and building materials. The ventilation system under investigation seeks to combine the goals of energy efficiency and conservation with low-cost radon reduction and indoor air quality management. Drawing on established radon mitigation techniques of ventilation, air supply and pressurization, the Solar Radon Reduction System (SRRS) provides radon reduction at low energy costs due solar pre-heating of supply air. Installation costs for the SRRS are also lower than conventional air-to-air heat exchanger and sub-slab suction radon mitigation options. Radon reduction and indoor air quality improvement are accomplished through dilution, reduced infiltration, and slight pressurization of the dwelling through the induced-draft solar-heated outdoor air and the supply of combustion appliance make-up air. Installed in six test homes in Waterloo and Cedar Falls, Iowa, the SRRS was found to achieve significant radon reductions in all houses with elevated levels of up to 73% from background levels as high as 21.0 pCi/L.

INTRODUCTION

Increased insulation and weatherization, intended to reduce home energy demands and heating bills, have been found to have detrimental effects on the quality of indoor air. The U.S. Environmental Protection Agency (EPA) now warns that improper ventilation can concentrate contaminants that would otherwise escape through leaks and cracks, and many indoor environments may be dangerously polluted by these toxic chemicals and gases. Tightened to conserve energy, a growing number of homes, buildings and schools are plagued by "sick building syndrome" (Dulley, 1994). The broad array of indoor pollutants includes molds, airborne fungal spores and bacteria, pesticides, solvents, respirable dust, carbon monoxide, nitrogen dioxide, formaldehyde, and other volatile organic compounds (VOCs), but the most insidious may be radon gas and its byproducts. Radon is harder to detect and reduce at the source than other airborne pollutants, and difficult to filter. Still, high levels of radon as well as the many other air pollutants can be prevented from accumulating indoors (Turner and Brennan, 1985). Since U.S. residents spend on average 75-90% of their time indoors, the health of many people may greatly depend on the quality of air in the indoor environment.

An invisible, odorless radioactive gas produced from the natural decay of uranium-238 and radium-226, radon-222 is found in nearly all soils and occurs in low concentrations almost everywhere on earth. High concentrations of radon gas have been traced to large deposits of granite or sillimanite rock, as well as to granitic sand and gravel. Radon is readily soluble in water, so groundwater that has recently reached the surface, including well water, may also carry high levels of radon.

Radon can enter the indoor environment via several paths, including emission from building materials. In both the U.S. and Sweden high radon levels have been attributed to radioactive shales and mine tailings inadvertently used for residential construction (Turner and Brennan, 1985). More typically, radon originates as gas in soil beneath homes and buildings and infiltrates inside through floor drains, hollow-block walls, cracks in concrete walls and floors, gaps and joints in building materials, or direct exposures to soil. It can also outgas from the water supply, when water is exposed to air during showering and other household or industrial uses. Because radon is inert and does not chemically bind or attach to other materials, it can easily pass through all gas-permeable materials including concrete (Renken, 1994). Due to pressure differentials created by the "stack effect" of convection indoors, particularly in cold seasons or during rainy weather conditions, radon can infiltrate indoors and accumulate to hazardous levels.

The major health concern associated with elevated radon levels is an increased risk of contracting lung cancer. Although radon is one of the few *known* (Group A) carcinogens, the level of lung cancer risk associated with residential radon exposure is still controversial. Two short-lived radon decay products, both alpha-emitting polonium isotopes, are solids which can attach to dust particles and, upon inhalation, become lodged in airways near some of the most cancer-sensitive cells in the human body. As the decay process continues, the radioactive particles release bursts of energy that ionize lung tissue. Damaged cells can then multiply rapidly, resulting in lung cancer. Research is currently underway to find out if radon causes other kinds of cancer as well. The EPA reports that swallowing water with high radon levels may pose risks, though hazards from ingesting radon-laden water are believed to be much lower than those from breathing air containing radon. The National Cancer Institute has declared radon exposure the leading cause of cancer among non-smokers, accounting for an estimated 7,000 to 30,000 deaths per year. The EPA has set a recommended "action level" for remediation at the radon concentration of 4 picoCuries per liter of air (pCi/L), which is comparable to having more than 250 chest x-rays per year. The ubiquitous problem of radon accumulation has prompted senior EPA officials to label radon the "highest cancer risk of any single environmental problem" (Freije, 1990).

A 1988 EPA survey found that nearly one in three homes have elevated radon levels, prompting the Surgeon General to urge testing for all houses and apartments below the third floor. The EPA now estimates that 1 out of every 15 homes throughout the U.S. are estimated to have radon levels of 4 pCi/L or more (US EPA, 1993). In Iowa, an estimated 70-75 percent of homes have radon levels above 4 pCi/L (Eckoff, 1990). An EPA survey of 130 schools among 16 states found that 54 percent of the schools had at least one unsafe room, while 19 percent of the 3,000 classrooms measured high. It is now believed that the radon danger in schools and most other types of non-residential buildings is at least as severe and widespread as it is in homes (Freije, 1990). The average indoor radon level is estimated to be about 1.3 pCi/L, compared to an average of 0.4 pCi/L outdoors. The U.S. Congress has set a long-term goal that indoor radon levels be no more than outdoor levels (US EPA, 1993).

Usual radon mitigation methods attempt to prevent naturally-occurring radon gas from entering a building by keeping the living space at a higher pressure than that of the contiguous soil. The EPA currently recommends the following approaches to reduce radon infiltration and accumulation in existing structures:

- Natural ventilation,
- Forced ventilation,
- Sealing foundation cracks and openings,
- Sub-slab suction,
- Air supply, and
- Heat-recovery ventilation (US EPA, 1986).

Sealing cracks and other openings in the foundation is a basic part of most approaches to radon reduction, although the use of sealing alone is not recommened as it does not lower radon levels significantly or consistently. The most heavily marketed system at present, sub-slab depressurization (SSD), uses fans oriented upward to apply suction beneath the foundation and vent exhaust air above the roof. Creating a pressure differential large enough to lower radon below the EPA action level often requires drilling several holes into the concrete slab and installing associated piping as well as sealing cracks, holes, and drains (Freije, 1990). This can result in considerable expense to homeowners and may also worsen other common indoor air pollutants, such as carbon monoxide from combustion appliances.

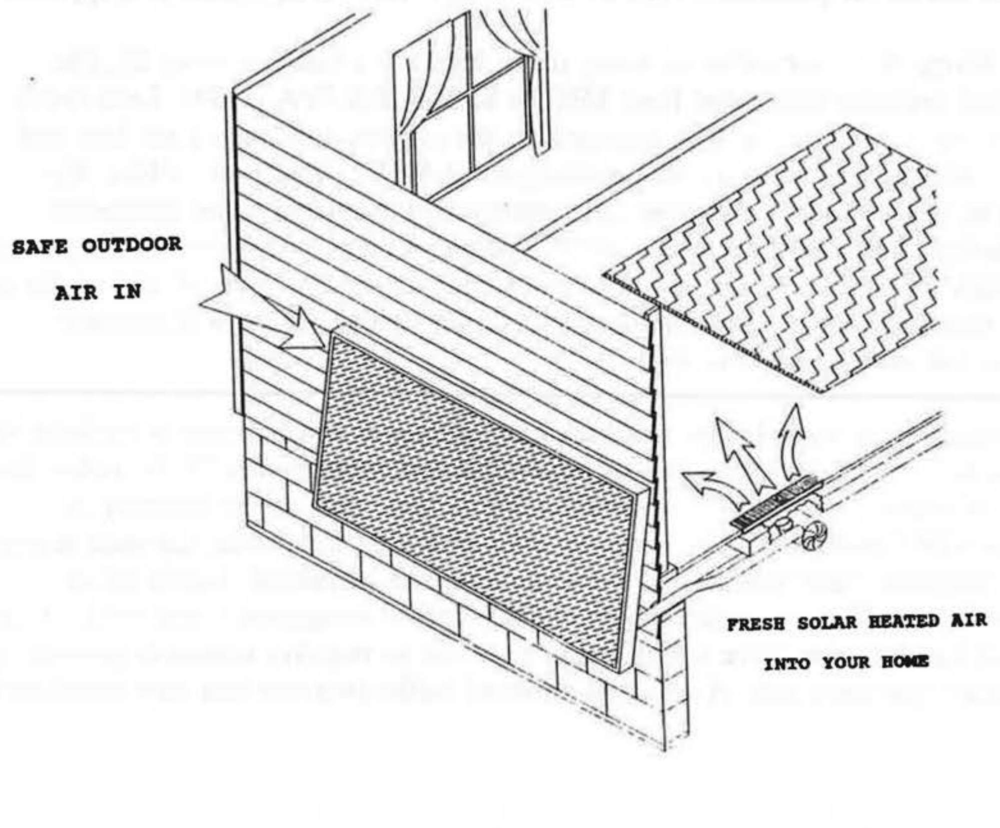
The average charge for a contractor to lower radon levels in a home is about $1,200, although repairs required may range from $500 to $2,500 (US EPA, 1993). Less costly approaches to radon reduction include pressurizing the indoors with supply-air fans and increasing ventilation with air-to-air heat exchangers (AAHX), which help dilute other contaminants as well as radon. However, all commercially available radon mitigation systems, including those equipped with AAHX, operate at a net energy loss in temperate climates through the direct introduction of outdoor-temperature air. Thus these popular air management strategies can be quite energy intensive and counteract steps to increase weatherization and energy conservation.

Controlled evaluation of varied radon mitigation techniques at specific sites is difficult due to the numerous factors that determine indoor radon concentrations, primarily the radon source strength and infiltration rate. Effects of construction factors, such as the integrity of basement slabs and foundation walls, characteristics of sumps and drains, crevices at pipe entry points, unpaved crawl spaces, and the infiltration rate of natural outside air or "tightness" of the dwelling, are often indeterminable before mitigation is attempted. Even a well-ventilated building may have a high radon level due to negative basement pressure and thus an increased gas entry rate. A structure's natural infiltration rate can vary seasonally due to changes in soil moisture and frost level or even hourly based on barometric pressure, convection, and effects of wind direction and velocity (Fleischer, 1988). Given the number of radon mitigation options, the range of factors that affect radon levels in a dwelling, and the fact that no single system can guarantee acceptable indoor radon levels, homeowners and radon mitigation contractors must weigh several variables when developing a mitigation approach. Installation and operating costs associated with each mitigation step often compound the selection of optimum systems.

PROJECT HISTORY

In attempt to address both elevated radon levels and heating costs, one of the authors (R. J. Klein) devised and installed an original solar ventilation system to introduce fresh, pre-heated air indoors at a test home in Waterloo, Iowa in 1990. The Solar Radon Reduction System (SRRS), initially comprised of a 4' x 8' flat-plate solar air collector, ductwork into the central heating system, and a 0.59 Amp, 75 cfm (cubic feet per minute) mechanical blower, was designed to both pressurize the indoors and improve air quality in an energy-efficient manner (Fig. 1). The supply of outdoor make-up air for combustion appliances and stack effect losses reduces indoor radon levels through reduced infiltration and dilution. During cold seasons, the SRRS introduces solar-heated outdoor air into the home, augmenting its existing heating system to produce a net energy gain. In the summer months, the system's blower provides low-energy cooling by ventilating the structure when outdoor air temperatures drop below indoor comfort levels.

Fig. 1 Diagram of Solar Radon Reduction System



Based on charcoal canister readings, the initial radon concentration of 8.8 pCi/L in the basement of the first test home was reduced to 2.5 pCi/L, a reduction of more than 70 percent. Energy costs were reduced and the general indoor comfort level was reportedly improved by the addition of solar heated outside air. In 1991 the system was chosen as an award recipient in the Innovative Radon Mitigation Design Contest sponsored by the U.S. EPA, the Association of Energy Engineers, and Environmental Engineers & Managers Institute. The EPA requested that further research be conducted on the technique according to EPA Protocols for Diagnostic Measurements in Radon Mitigation Demonstration Projects.

An additional solar collector, which heats domestic water in tubes inside the panel as well as vents solar-heated air indoors, was then installed in conjunction with the first SRRS to further extend heat gain and energy savings throughout the year. This homemade panel was constructed from debris recycled from a home improvement project, as the glazing was previously used as sliding glass doors. A second complete SRRS was installed in 1991 at a test home in Cedar Falls, Iowa which originally exhibited a charcoal canister radon reading of 19.9 pCi/L in the basement. Construction and installation was accomplished at about 10% of the cost of comparable commercially available radon mitigation systems. In 1993, the SRRS design was issued U.S. Patent 5,186,160 and awarded funds by the University of Northern Iowa's Reuse & Recycling Technology Transfer Center to continue research. A detailed instruction manual was developed for homeowners or contractors to build an SRRS — a solar panel installed on a south-facing wall, roof or as free-standing unit together with a fan, wiring, and ductwork into the building's central heating system — for about $200, or even less if constructed with recycled materials.

SRRS efficiency evaluations were first conducted in the winter of 1992/1993 at test home North, a 960 ft^2, 1½-story wood-frame home equipped with a natural gas water heater, clothes dryer and forced-draft furnace; and test home Lovejoy, a single story, 1270 ft^2 wood-frame home with only electric appliances including a resistant heat forced-draft furnace. Both homes have partial basements and crawl spaces under the living area. Initial data collection included radon levels, hours of system operation, air flow rates, structure pressure differentials, temperature differentials, and estimated energy used. Radon data were collected in both homes as the mean of 4-hour intervals with two continuous radon data loggers (Honeywell Model 05-418) operated in accordance with EPA protocol (US EPA, 1993). The duration of SRRS and furnace operation was measured and recorded daily using elapsed time hour meters. The volume of air the SRRS induced-draft fans introduced into the homes was based on manufacturer data confirmed with pitot tube velocity and duct area measurements. The SRRS at North produced an air flow of either 65 or 130 cubic feet per minute (cfm), based on whether one or two solar panel fans were in operation, resulting in 0.6 or 1.2 air changes per hour (ACH). Single SRRS panel operation at Lovejoy produced an air flow of 75 cfm, adding 0.4 ACH. Dwelling pressures were determined with manometers and blower door tests, and utility meters along with temperature/relative humidity strip charts were used to calculate energy usage.

The two Honeywell radon monitors were initially operated side-by-side simultaneously with a carbon canister test at Lovejoy to evaluate the precision of the instruments. Based on ten day monitor means of 8.4 and 8.3 pCi/L and the canister result of 8.1 pCi/L, both instruments were determined to be statistically calibrated at a 96% confidence interval. Monitors were then installed on the first floor at both of the test homes, maintained in "closed house conditions" with the SRRS deactivated and sealed, to establish background radon levels according to EPA protocol (US EPA, 1993). Data indicated 1st floor background radon concentrations of 4.3 pCi/L for North and 8.0 pCi/L for Lovejoy.

The SRRS was tested in a variety of operational modes to evaluate individual effectiveness of the system as well as system effectiveness when used in conjunction with other EPA recommended mitigation methods. The initial evaluation was conducted with the SRRS operating in a solar thermostat-driven mode, which achieves maximum energy benefits by introducing solar heated air inside only during times when adequate solar energy is available to heat outdoor air above the ambient indoor temperature, to a minimum of 25°C and often as high as 50°C. The thermostat located on the inside surface of the solar collector typically triggered the induced-draft fan to operate in this mode between 9 am and 4 pm.

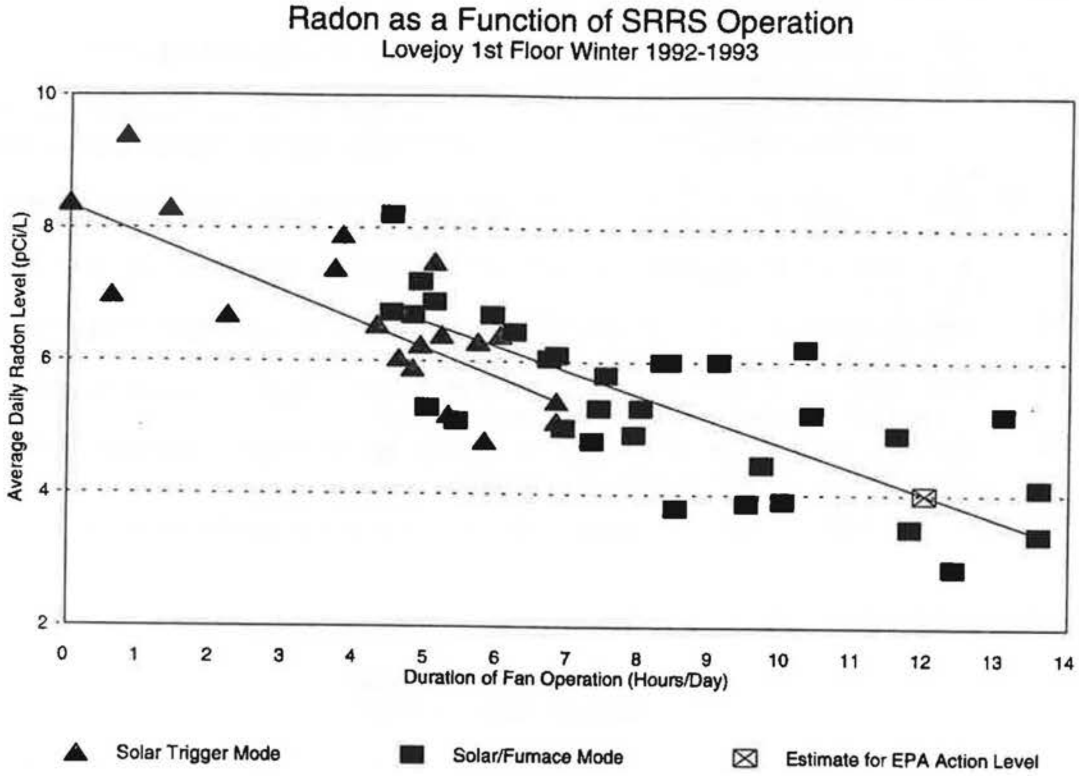
Compared to background radon concentrations, SRRS solar thermostat-driven operation was found to lower mid-day radon levels by an average of 29% at North and by 24% at Lovejoy. The general indoor air quality and comfort levels were reported to be improved by the addition of solar-heated outdoor air. The initial research revealed that over the 6-week test period, cloudiness and adverse weather conditions limited SRRS operation to less than 1 hour for about 15 days. Due to continued radon infiltration when the mitigation fans were off, night-time and early morning radon levels returned to near background levels.

The second operational mode evaluated the effect of the SRRS when allowed to operate for additional periods of time than could be achieved in the solar thermostat-driven mode, when home heating demands required furnace operation. A "solar/furnace-driven mode" was achieved by wiring the SRRS to trigger its induced-draft fan both by the solar thermostat and an electrical relay circuit from the central furnace fan. In addition to providing longer SRRS operation, this mode allowed operation of the system at intervals throughout the day and night as well as during times of solar insolation.

As would be expected for a ventilation/pressurization mitigation system, SRRS radon reduction effectiveness was found to be related to the duration and volume of air introduced into the dwelling. Data collected during the extended furnace-driven mode showed mixed results: North showed little correlation between radon concentration and hours of SRRS operation, which may be attributed to the rate in which radon resumed infiltration during non-operational periods; yet Lovejoy showed a direct correlation between reduced radon and hours of system operation (Fig. 2). Extended solar/furnace-driven SRRS operation accomplished maximum radon reductions of 53% (North) and 56% (Lovejoy) compared to background levels.

Through graphical interpolation of the data obtained, 12 hours of SRRS operation (with a 75 cfm flow rate) was predicted to keep first floor radon levels below EPA's action level of 4.0 pCi/L at Lovejoy. Even in this mode, the solar heating aspect of the SRRS still provided a net conventional energy gain by introducing pre-heated air indoors several hours per day. Based on BTU heat gain and loss calculations, energy savings for the 6-week period were estimated to be 1.1 MBTU at North and 0.2 MBTU at Lovejoy, verifying that the SRRS yielded a net, albeit small, energy savings in both test homes. Long-term energy savings were predicted to be greater, as solar insolation received during the test period was approximately half the average available in the region for January through March.

Fig 2. Effect of thermostat-driven and increased hours solar/furnace-trigger SRRS operation on radon concentration for test home Lovejoy



MODIFICATION & EVALUATION

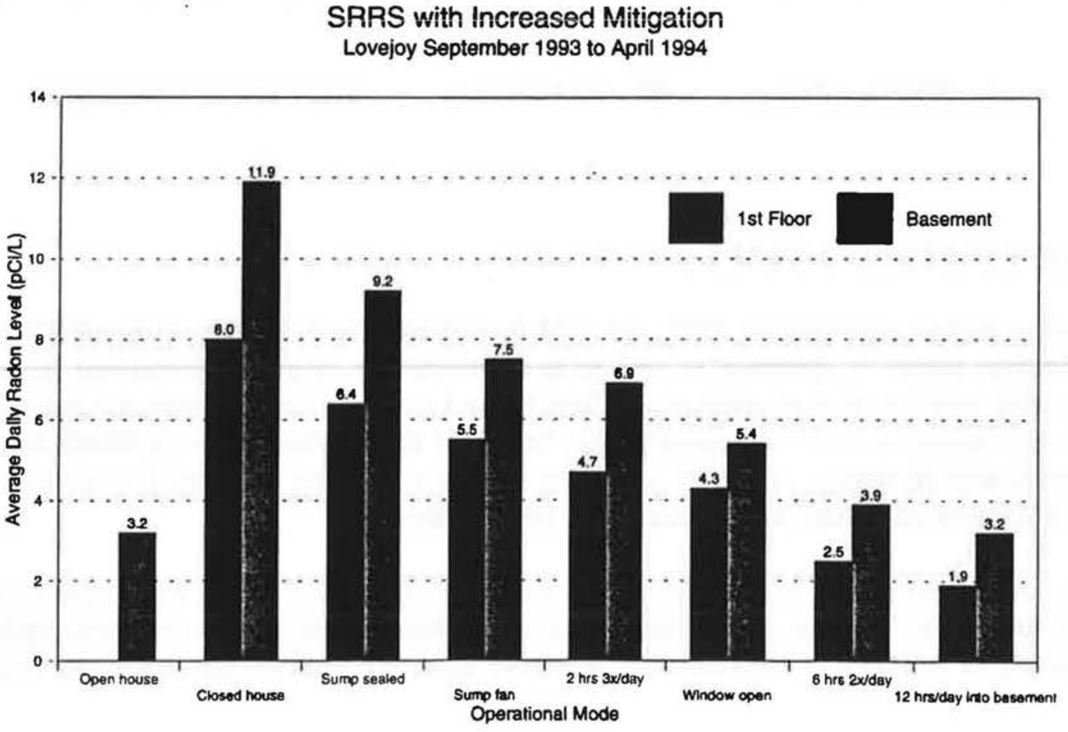
Further testing continued in 1993 and 1994 to evaluate the flexibility of the SRRS in additional modes of operation as well as to determine the optimum operational mode and resulting radon reduction efficiencies. Test home Lovejoy, equipped with the two continuous radon monitors in both the basement and first floor living areas, was monitored over seven months with increasing levels of mitigation as shown in Table 1, selected to coincide with EPA's radon mitigation action steps (US EPA, 1986).

Data collected reveals an incremental reduction levels for each of the test modes (Fig. 3). The first mode, with the SRRS deactivated and basement and upstairs windows open a majority of the time to accommodate relatively mild fall weather, resulted in an average basement radon concentration of 3.2 pCi/L, which represents the minimum radon level expected utilizing natural ventilation as the sole form of mitigation. While this most simple method achieved a radon concentration below the EPA action level, such open house conditions are impractical for most temperate climates.

Table 1. Increased radon mitigation steps with Lovejoy SRRS

Time Interval	SRRS/Dwelling Conditions
9/10 - 10/7/93	SRRS deactivated; periodic open house conditions including basement windows open.
10/8 - 11/8/93	SRRS deactivated; closed house conditions.
11/9 - 11/26/93	SRRS 75 CFM fan discharging through central heating system to 1st floor during adequate solar insolation (solar thermostat-trigger mode); foundation sump pump pit sealed and passively vented outdoors.
11/27 - 12/29/93	SRRS discharging upstairs during adequate solar insolation; sump pit vented outdoors with 45 CFM fan.
1/1 - 1/9/94	SRRS discharging upstairs triggered by timer set for 2 hours, 3 times per day; continued sump pit forced venting.
1/10 - 2/6/94	SRRS discharging upstairs during times of adequate solar insolation; one basement window slightly opened; continued sump pit forced venting.
2/7 - 2/22/94	SRRS discharging upstairs with timer trigger set for 6 hours, 2 times per day; one basement window slightly opened; continued sump pit forced venting.
3/25 - 4/17/94	SRRS discharging directly into basement with timer trigger set 6 hours, 2 times per day; basement window closed; continued sump pit forced venting.

Fig. 3 Incremental radon reduction at Lovejoy



The second test period established closed house background radon concentration levels of 8.0 pCi/L upstairs and 11.9 pCi/l downstairs, used as baselines to establish radon reduction efficiencies for subsequent SRRS test modes. Lovejoy had visually sound basement concrete slab and foundation walls, but an open foundation drain tile sump pit was identified as a possible direct radon entry point. During the third test period, the SRRS was activated to discharge air through the home's ductwork into the 1st floor living area with solar thermostat-driven operation. In addition, the foundation drain tile sump pump pit was sealed and passively vented to the outdoors. The combined SRRS solar thermostat operational mode in conjunction with basement sealing lowered radon levels an average 20% upstairs and 23% downstairs. These values are consistent with first year solar-thermostat mode reduction of 24%, suggesting the mitigation achieved during this test mode was primarily due to the operation of the SRRS; basement sealing appeared negligibly effective.

In the fourth test mode, the SRRS remained in the solar-thermostat operation while the sump pit ventilation system was modified to include a 45 cfm forced-draft fan, a variation of the popular subslab depressurization mitigation technique. Given constant SRRS operation, this more aggressive radon mitigation technique resulted in radon reduction improvements of 11% upstairs and 14% downstairs as compared to natural sump pit ventilation, yet EPA action levels were still not obtained.

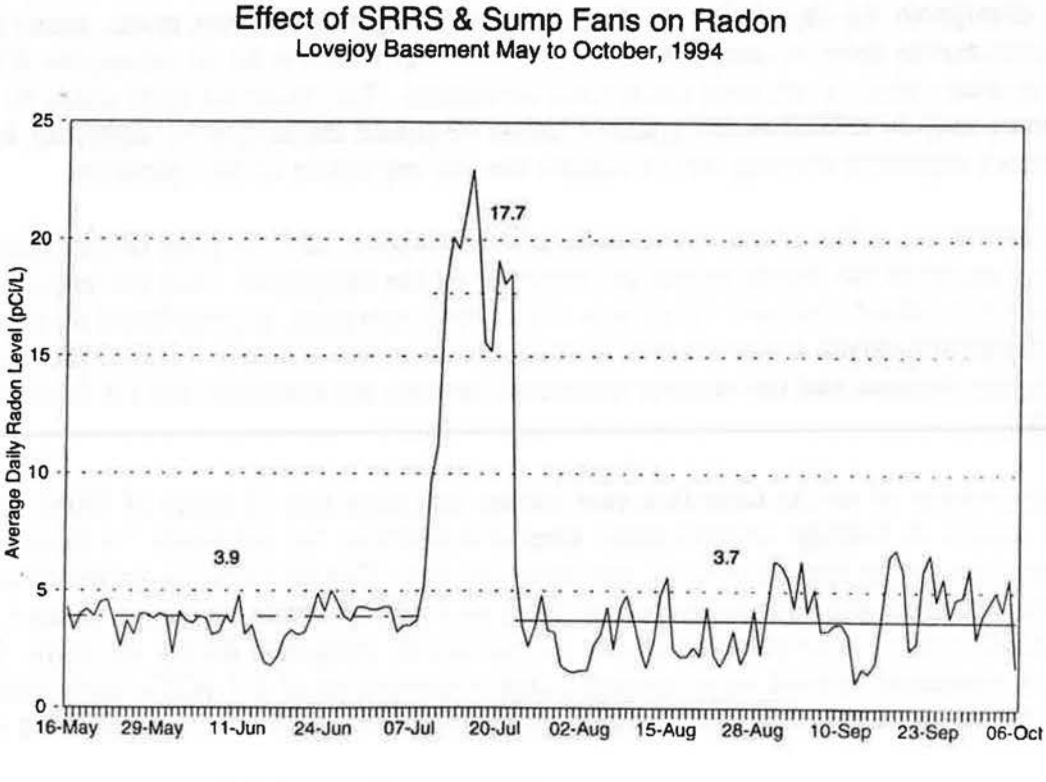
During optimum solar insolation conditions (i.e. non-cloudy days), the SRRS operates for approximately 6 hours, typically between 9 am and 3 pm. To evaluate the effect of the SRRS during ideal weather conditions as compared to actual weather related operation, the SRRS was wired to a timer set to operate the system for two-hour intervals evenly spaced three times throughout the day. From the data obtained during this fifth test mode, actual SRRS operation during times of adequate solar insolation was found to be an impressive 85% to 92% of what could be assumed under ideal conditions. This relatively high actual to ideal efficiency may be related to the system's ability to reduce infiltration by supplying low impedance appliance makeup air throughout the day regardless of fan operation.

Since downstairs radon levels remained consistently higher than 1st floor levels, increased air supply directly to the basement was predicted to aid the mitigation. Thus test period 6 incorporated natural basement ventilation with SRRS operation, accomplished by returning to solar thermostat-driven operation and opening one basement window. Lower radon levels were again obtained and the relative difference between the basement and 1st floor levels was reduced.

In consideration of results from first year testing indicating that 12 hours of SRRS operation could achieve an average upstairs radon level of 4.0 pCi/L, for test mode 7 a timer was set to trigger the fan to operate 6 hours two times per day. This timer-based operation coincided with the optimum solar insolation period (9 am to 3 pm) to obtain maximum energy gain, and an additional 6-hour period provided evenly-spaced mitigation during the night. This mode of operation resulted in an upstairs radon concentration of 2.5 pCi/L (69% reduction) and a downstairs level of 3.9 pCi/L (67% reduction). The SRRS was next modified to discharge fresh air directly into the downstairs area of the dwelling rather than through the home's central heating system, and the basement window was closed. With the fan still operating for a timer-based 12 hours per day, this approach achieved a maximum reduction of 76% upstairs and 73% downstairs.

Longer-term evaluations of the 12-hour timer-based SRRS operational mode were continued at Lovejoy over the summer of 1994 to evaluate the effect of both the SRRS intake fan and the sump pit exhaust fan (Fig. 4). The three-month basement radon concentrations from May to July during operation with both fans running averaged 3.9 pCi/L. A two-week period in July when both fans were deactivated and the house was maintained in closed house conditions while the homeowners were on vacation graphically illustrates how quickly the house returns to high background radon levels of 17.7 pCi/L without mitigation, which is even higher than the winter-time baseline obtained the previous year (11.9 pCi/L). The following three-month test was conducted with only the SRRS fan in operation and revealed larger daily average radon ranges but a long-term average almost equivalent to the test with both the SRRS and sump fans, 3.7 pCi/L. This demonstration documents the stronger mitigation influence of SRRS ventilation and positive pressuration relative to the sub-slab suction achieved by the sump fan in this case. It also indicates that the lowest expected long-term basement radon levels at Lovejoy even with combined mitigation methods are in the 4 pCi/L range.

Fig. 4. Relative importance of SRRS and sump pit fan operation on radon mitigation



The improvements developed and successful results obtained during the second year of research established that the SRRS is a promising radon reduction technique, but additional evaluations on a larger number of test houses were desired to more fully document the effectiveness of the system. While radon reduction effectiveness and energy efficiency will undoubtedly vary from installation to installation, improved indoor air quality and energy benefits are expected in all cases.

ENERGY CONSIDERATIONS

A major advantage of the Solar Radon Reduction System over other radon mitigation methods is its ability to introduce solar-heated air into the home during cold seasons as well as to provide low-energy cooling during warm weather. This energy gain is optimized when system operation is limited to periods of adequate solar isolation during the heating season and when outdoor temperatures drop below ambient indoor levels in the summer. A drawback of SRRS operation in other modes is the introduction of wintertime cold outside air during cloudy days and nighttime operation as well as overly warm and humid outdoor air during the cooling season. The net energy efficiency of the SRRS can be compared to sub-slab depressurization systems, which introduce no external air into the house.

Such heat gains and losses can be calculated for the 12-hour timer-based operational mode (6 hours twice/day) for the month of March, 1994, which included 10 clear days, 11 partly cloudy days, and 10 cloudy days; an average outside temperature of 2°C; and an estimated average relative humidity of 50%. Outlet temperature monitoring indicates that average SRRS outlet air can be assumed to be:

- 38°C for 4 hours and 20°C for 2 hours on clear days;
- 20°C for 6 hours on partly cloudy days;
- 2°C for 6 hours on cloudy days; and
- 2°C for all 6 hour nighttime operation intervals.

The net energy content or enthalpy of SRRS outlet air was therefore estimated to be 1.7 MBTU for the month of March, and the enthalpy of indoor air at an average 22°C and 25% relative humidity replaced by SRRS air was about 2.7 MBTU. Thus approximately 1.0 MBTU of extra heating energy (300 KWH with an electric furnace) was required to accommodate SRRS input air to indoor ambient levels. Additionally, operating the 115 Volt, 0.59 Amp induced-draft fan for 12 hours per day for 31 days required 25 KWH of electricity. At the volume-discounted rate of $0.03/KWH in Cedar Falls, IA, the energy expense attributable to SRRS operation for March 1994 was about $9.75. The solar collector's heat input saved 510 KWH or $15.30.

If each month of operation resulted a similar net expense due to a heavier demand on either heating or air conditioning, the annual SRRS operating bill would be around $117. Complete installation of the SRRS was estimated to be $500 versus a typical $2,500 for sub-slab mitigation, which operating 24 hours per day with the same type of fan would cost 50

KWH/month or $42/year. Negating the time value of money, the energy payback of the SRRS toward the sub-slab system would be about 27 years, most likely beyond the working life of the system and the time most people reside in a home.

CURRENT RESEARCH

Initial SRRS evaluation involved progressively more aggressive system operation and intervention to obtain below action-level radon concentrations. In other dwellings, similar trials and radon recording instrumentation would likely be necessary to determine optimal system operation. In order to simplify subsequent SRRS installations, newly available and affordable continuous radon alarms equipped with start/stop electrical relays (EnvirAlert Model MTL-102 with MTL-106 mitigation controllers), which trigger fans to operate above pre-programmable radon levels, have been incorporated into the SRRS strategy.

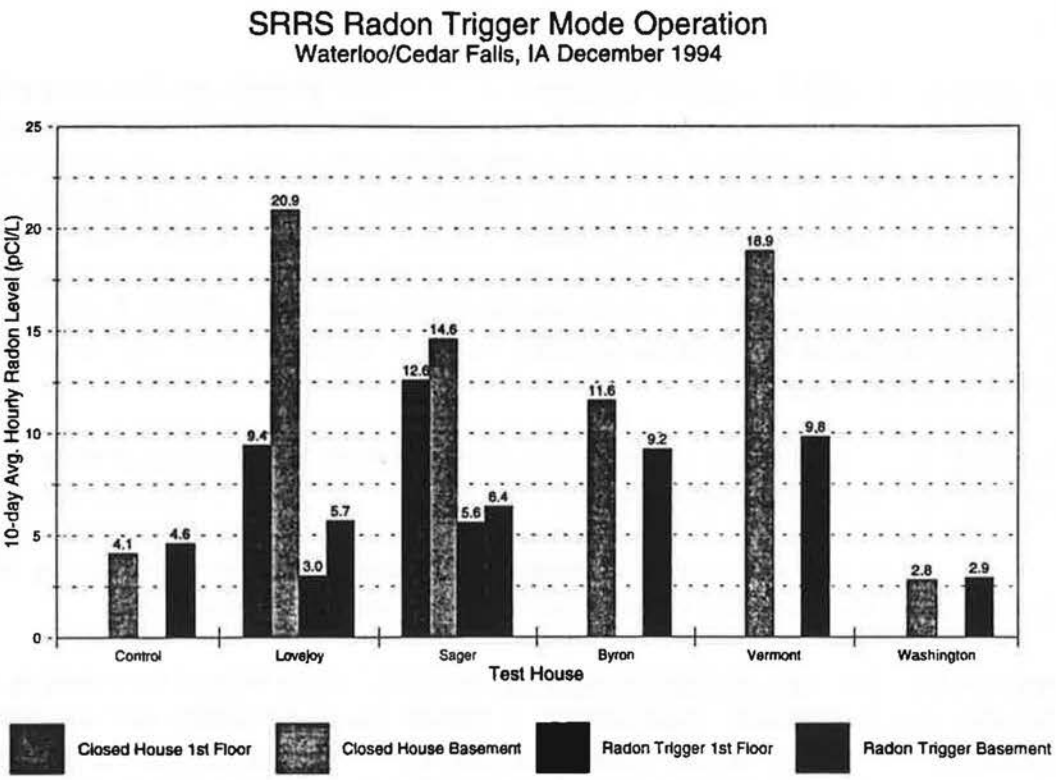
In the summer and fall of 1994, modified SRRS systems were installed at four additional test sites with elevated radon levels. Each house was equipped with EnvirAlert radon-trigger mitigation control devices as well as computer data acquisition systems for continuous datalogging. These "radon-stats" activate the SRRS when radon levels reach 3.0 pCi/L, and to maximize energy benefits, are wired in conjunction with electronic temperature sensors that additionally activate the fan either above (heating mode) or below (cooling mode) a preset intake temperature. The sites were monitored to determine the most suitable operational mode at each to maximize energy savings for desired radon reduction levels. Data collected include radon levels, solar radiation, inlet and outlet temperatures and humidity, air speed, and indoor/outdoor pressure differentials at hourly intervals to assess radon infiltration and energy gains under varying conditions.

Based on initial side-by-side operation for several days, the six EnvirAlert radon monitors were determined to be calibrated at a 90% confidence interval. Preliminary data was collected in December 1994 for closed house conditions and radon-trigger operation (at 3.0 pCi/L mitigation level) at the four new sites Sager, Byron, Vermont, and Washington as well as Lovejoy and a "control" house which had no radon mitigation installed. The two Honeywell monitors were used to record 1st floor radon levels at Lovejoy and Sager, and Air Chek mail-in charcoal radon testers were used to determine 1st floor levels at Byron, Vermont, Washington, and the control.

During the 10-day test periods, SRRS operation significantly reduced the average basement radon concentrations at every house with elevated radon levels for the "radon trigger mode" test period compared to closed house conditions (Fig. 5). The maximum response was seen at Lovejoy, which was the only house which sump pump pit and foundation sealing was included, from a background level of 9.4 pCi/L to 3.0 pCi/L on the first floor (a 68% reduction) and from 20.9 pCi/L to 5.7 in the basement (a 73% reduction). Since the EnvirAlert monitors output a value which is an average of the previous 22 hours, the lag time between the start of an upward radon trend and the electrical activation of the SRRS fan be a limiting factor; additional testing during combined radon-trigger and solar temperature-trigger operation has shown improved reductions.

Based on mail-in testers, below-EPA action level results were also achieved on the first floor at both Byron (3.9 pCi/L) and Washington (3.5 pCi/L) during this operational mode. Foundation sealing and improved weatherization as well as higher capacity fans may achieve even greater reductions at these houses. A further modification of activating the SRRS from RadonAlarms on the first floor radon is also under evaluation to provide a tighter control on living space radon levels, which may be required for houses such as Washington that have higher radon levels upstairs than in the basement.

Fig. 5 Preliminary results of expanded SRRS testing with fans activated when radon levels reach 3.0 pCi/L



CONCLUSIONS

This research has shown that the Solar Radon Reduction System is effective in reducing indoor radon concentrations. Due to the ventilation, air supply, and pressurization principles incorporated in SRRS operation, radon reduction efficiency was found to be related to the duration the system and the volume of fresh air introduced into the dwelling.

In order to meet the EPA action level of 4.0 pCi/L, modified modes of SRRS operation were tested in conjunction other radon mitigation techniques including natural ventilation, sealing foundation cracks and openings, and a variation of sub-slab suction. Compared to SRRS operation before sump sealing at Lovejoy, only a 4% greater radon reduction was achieved, indicating that in this case, the sealing effort had little effect on living space radon concentrations. Installing a forced-draft exhaust fan to the sump pit, a low-cost type of sub-slab suction, showed an additional 11% to 14% radon reduction compared to sump sealing alone, yet later research on the 12-hour SRRS timer-based operation showed the sump fan had little effect. Increased natural basement ventilation with an open basement window had drawbacks in reducing control over ambient basement temperature, and evaluation of SRRS direct basement discharge found that this tactic was not necessary to achieve low radon levels.

Operation of the SRRS system at Lovejoy for two 6-hour periods per day exceeded the prediction based on interpolation of first year data with an average living space radon yield of 2.5 pCi/L; this timer-based mode also maximized energy benefit. The modification to discharge SRRS input air directly into the basement air was a significant optimization in terms of radon reduction, energy efficiency, and indoor comfort levels. This configuration achieved a reduction efficiency of 76%, and this mode renders fan operation during less than ideal temperature conditions less noticeable to homeowners. In addition, basement walls, usually well-insulated by surrounding earth, may provide a heat sink to prolong energy benefits and buffer losses.

The SRRS shows promise as a radon mitigation technique that can reduce radon in almost all cases and can obtain concentrations below the EPA action levels in existing dwellings with elevated background radon levels. While this study was limited in the number of dwellings evaluated, the proven and referenced mitigation techniques incorporated into the SRRS project satisfactory radon reduction results in other "problem" dwellings.

Compared to other radon mitigation options, the SRRS offers control over system operation to balance energy demands, improvement in overall indoor air quality and comfort, low installation costs and the lowest annual operating costs. These advantages suggest more home owners may be likely to install a mitigation system and, once installed, be less likely to discontinue its operation.

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HOUSE DEPRESSURIZATION/BACKDRAFTING/CARBON MONOXIDE POISONING

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ABSTRACT

Four separate families were poisoned by carbon monoxide in North Central Iowa in a seven day period during the winter of 1993-1994, resulting in ten hospitalizations and two deaths. An investigative team consisting of an Iowa State University associate professor and the owner/operator/president of an environmental consulting/mitigation firm investigated three of the cases. The first case involved a relatively new house with two natural gas natural draft furnaces and a water heater. The family had been subjected to elevated carbon monoxide levels several times. The owner/occupant was frustrated with local heating contractors who were unable to correct the carbon monoxide problem, and was frightened when carbon monoxide episodes continued after being told the problem had been fixed. Investigation showed depressurization from furnaces, water heaters, fireplaces, and/or exhaust fans caused reverse flow from the water heater, the two furnaces, and/or the gas fireplace. The owner installed sealed combustion a water heater and furnaces.

In two other two cases numerous design and maintenance problems contributed to the poisonings. These problems were not recognized by local utility employees, the fire department, local authorities, or heating contractors.

THREE CASE STUDIES

Case One

Background, Case 1

The family moved into the house in June 1993, purchasing the house from a retired couple. In October all five family members were hospitalized, with dangerous carboxyhemoglobin levels of 13 to 30 percent. The family was treated with oxygen, and released. A heating contractor determined the problem was an improperly installed thermally-actuated flue damper on the water heater. The 4-inch flue damper was installed over a 3-inch vent pipe, which entered the damper and blocked operation.

After the poisoning, the family purchased 4 carbon monoxide detectors, which sounded intermittently, even after removal of the damper. The detectors required frequent fresh air rejuvenation, and replacement of the sensing cells. A carbon monoxide chemical card also turned black. The heating contractor made repeated calls, but with gas indicator tubes failed to detect any carbon monoxide. Neither did the utility company or the building inspector. A member of the family again experienced poisoning, with carboxyhemoglobin levels in excess of 33 percent.

The heating contractor informed the homeowner the poisonings resulted from three independent problems, all of which he had solved.

1. The water heater damper had been blocked.
2. The gas fireplace left on overnight had backdrafted.
3. Fresh air intakes had frozen shut.

The heating contractor made the following changes and suggestions:

1. Extended the main 7-inch vertical vent an additional 5 feet above the flat roof.
2. Added an elbow above the roof to the existing 9-inch vertical fresh air intake.
3. Added an additional 6-inch combustion air intake, connected it to the return of both furnaces, and advised the homeowner to operate the furnace blower continuously.
4. Advised the homeowner to install glass doors on the gas fireplace, keep the doors closed, and only operate the fireplace during waking hours.
5. Replaced the 1/8 inch screen on the fresh air intakes with a larger screen after frosting occurred (Code requires 1/4 inch mesh.)

With the above steps completed, the alarms continued to intermittently sound. The contractor no longer had solutions and advised the homeowner to monitor the carbon monoxide levels herself, using gas detection tubes furnished by the contractor. The homeowner, by now frustrated and scared, believed her concerns were no longer taken seriously. She asked Iowa State University for assistance, and after a telephone consultation, was given the name of several contractors for further evaluation. She selected Dr. Wiggers, who, after initial evaluation, requested further extension technical assistance.

Physical Characteristics, Case 1

House: 5600 square feet, approximately 10 years old, two story, designer home, well-designed, well constructed, and well maintained.

Heating: Two furnaces, natural gas, natural draft, common vented with water heater, 68,000 Btu/hr and 90,000 Btu/hr, gas log in masonry fireplace (added by current residents), and hanging heater in garage.

Water Heaters: One 40,000 Btu/hr natural gas and one electric water heater.

Venting: A 7-inch diameter vertical double wall gas vent 17 feet in height and a 7-inch horizontal manifold shared by all three gas appliances. Connectors: 3-inch water heater, 4-inch furnace, and 5-inch furnace. The 7-inch vent and manifold met NFPA54-1992 vent tables. The 3-inch water heater vent was undersized, with a 4-inch required. The 4-inch furnace connector was undersized, with a 5-inch required. The 5-inch connector met requirements. These, although contributing to the problem, were not the primary problem.

Venting Pressures:

At less than 4.0 Pascals negative, water heater and furnaces drafted.
Above 4.0 Pascals venting was sporadic.
Above 5.0 Pascals backdrafting occurred continuously.

Exhaust:	Kitchen Exhaust	500. cfm
	South Bathroom #1	44.
	South Bathroom #2	44.
	North East Bathroom #1	82.
	North East Bathroom #2	66.
	Entry Bath	52.
	Basement Bath #1	29.
	Basement Bath #2	50.
	Clothes Dryer	104.
	Subtotal, Mechanical	1035. cfm installed
	Fireplace, gas	535.
	Water Heater	25.
	68,000 Furnace	40.
	90,000 Furnace	50.
	Subtotal, Gas Appliance Vents	650.
	TOTAL EXHAUST	1685. cfm
Outside Air Provided: (maximum flows observed)		
	9-inch fresh air to utility	110. cfm
	6-inch combustion air furnace	138.
	4 -inch combustion air fireplace	86.
	TOTAL OUTSIDE AIR	334. cfm
	SHORTAGE OF COMBUSTION AIR	**1,351. cfm**
Envelope: Blower Door Results		
	Air Changes Per Hour, 50 Pa	3.56 ACH50
	Effective Leakage Area (LBL)	114. square inches
	Equivalent Leakage Area (CANADA)	215. square inches
	Air flow @ 5 Pascals (Pa)	464. cfm

Depressurization:

Under some wind conditions, as high as 6 Pa with no exhaust appliances.

No exhaust flows	2 Pa
Fireplace, doors closed	2
Two bathroom fans	2
Four bathroom fans	3
Six bathroom fans	4
Seven bathroom fans	5
Seven fans and clothes dryer	5
Fireplace alone, doors open	10
Seven fans, dryer, and kitchen vent	11

Carbon Monoxide Levels:

The high CO blood levels in family indicate high CO levels had occurred.
Occurred, as indicated by First Alert detectors.
Occurred, as indicated by Gas Alert chemical sensors
Intermittent, with no readings at times.
Various, 8 to 12 to 18 ppm by Drager 190 recorded by Wiggers.
Present, as indicated during rapid build up during backdrafting tests.

<u>**Analysis, Case 1**</u>

Multiple problems were identified. First, the water heater vent was blocked. Second, the gas fireplace backdrafted. Third, the gas fireplace caused backdrafting of the water heater and furnaces. Fourth, the venting was undersized. Fifth, the house depressurized when various combinations of exhaust appliances operated. Sixth, originally the vent did not extend sufficiently above the flat roof. Seventh, the vertical combustion air intake was prone to being covered with snow and icing. Eighth, the units were producing carbon monoxide. Two additional possibilities that were not investigated were depressurization of the house caused by winds over the attic ridge ventilator and the possibility that combustion products were being reintroduced back into the house from the combustion air intake located on the flat roof next to the vent termination.

Providing sufficient combustion and make-up air was not adequately considered. The single combustion air opening was not large enough to satisfy Uniform Mechanical Code requirements of one square inch per 5,000 Btu/hr. Addition of the 6 inch combustion air opening did meet these requirements, but the requirement of two openings of 100 square inches each freely communicating with the interior spaces was still not met. This, however, was not the primary problem in the house.

Section 607 of the Uniform Mechanical Code, which states "Operation of exhaust fans, kitchen ventilation systems, clothes dryers or fireplaces shall be considered in determining combustion air requirements to avoid unsatisfactory operation of installed gas appliances" was not applied. As noted in <u>Physical Characteristics</u>, 1,685 cfm of exhaust appliances existed in the house. Only 334 cfm of outside air, plus natural infiltration, was provided. This, as evidenced by operation of the gas appliances, was insufficient, resulting in the primary problem.

To provide sufficient combustion and make-up air would require either large openings to the outdoors, or powered intake fans operating in conjunction with exhaust and heating appliances. Our experience shows that even though combustion air openings are added and meet code they do not always function adequately. Adding powered intake fans, with safety interlocks, alos did not seem the best solution.

It is likely the previous owners, a retired couple, did not experience severe problems because of differing lifestyles. The present occupants used many of the exhaust appliances concurrently and often: the range hood, the bathroom fans, the clothes dryer, and the gas fireplace. The retired couple did not use all four bathrooms concurrently, or the wood-burning fireplace often. Their risk increased when they had guests and used all exhaust appliances.

Heating contractors failed to reduce carbon monoxide production levels from the heating appliances. Carbon monoxide levels rose to over 35 ppm after only 7 minutes of backdrafting combustion products from the furnaces and water heater into the utility room, even with utility room door open. The test was discontinued. The production was most likely caused by either a dirty burner, poorly adjusted burners, inadequate primary air, or overgassing.

Recommendations and Action, Case 1

Homeowner was advised to replace both furnaces with high efficiency sealed combustion units. The water heater should be upgraded by adding draft induction or it should be replaced. She was advised to discontinue use of the gas log, or replace it with a direct vent, sealed combustion gas fireplace insert.

The homeowner was initially unable to secure bids for new, sealed combustion heating units for two reasons: 1) Contractors stated sealed units did not work in the north central Iowa climate, and 2) Contractors were unwilling to risk the liability of working where there was a known carbon monoxide problem. We suspect the female homeowner, a pleasant, well-educated individual who was forced to become knowledgeable about carbon monoxide, intimidated the local contractors and was "blacklisted" in the local community.

Regional representatives of furnace manufacturers were notified. They located dealers willing to install sealed combustion units in the house. The homeowner replaced the water heater and both furnaces with high efficiency sealed combustion units.

The gas log was not replaced and remains as potential carbon monoxide source. Eighteen (18) ppm of carbon monoxide was recorded in the living room when the gas log was operated under backdrafting conditions.

Case Two

Background, Case 2

The family lived in the house for several years. In 1988 they hired a contractor to remodel the basement. The furnace location was changed, and the return air disconnected at ceiling level. The furnace, water heater and water softener were enclosed in a small utility room with solid walls and door. Basement ceilings were finished with drywall. Return air to the furnace was supplied by ducts in the upstairs floor open to the floor joist area which was left open in the utility room.

During the winter of 1992-93 the family noticed a number of flu-like illnesses, which increased in winter of 93-94. In February of 94, after an especially difficult period of flu-like symptoms in the family, the 9-year-old daughter suffered seizures of an undetermined origin. She was evaluated, given medication, and released.

The family continued to be ill, and a week after the daughter's seizures they all become very ill. The father suspected carbon monoxide, and checked the carbon monoxide chemical dot indicator located near the furnace. It indicated no carbon monoxide. Early the next morning the children lost consciousness, the father called for emergency help, and then collapsed over the phone.

They were taken by ambulance to the hospital, where they were treated with oxygen. Carboxyhemoglobin levels were from 25 to 31. All recovered and were released that day.

Physical Characteristics, Case 2

House: 2500 square feet, 10 years old, one story, full finished basement, well-maintained.

Heating:

Natural gas natural draft furnace and water heater, common vent. Wood-burning fireplace in living room not used. Both the furnace and the water heater had a large amount of soot and dirt around the draft diverter, around the burners, and on the floor in front of the units.

Venting:

A 6-inch diameter vertical double wall gas vent approximately 13 feet high. An additional 5 feet was added by a heating contractor after the poisoning. Although there were several elbows, reducing capacity, the vent systems appears to meet NFPA54-1992 requirements.

Exhaust:	Kitchen Exhaust	- Not connected to outdoors
	Basement bath	- Reversed, not connected, and blowing into house
	Upstairs bath	- Yes
	Fireplace, wood	- not used.
	Furnace	- not measured
	Water heater	- not measured.

Outside air provided: One 1 -1/2 plastic pipe to outdoors, negligible flow.

Depressurization:

The utility room operated under a strong negative pressure, caused by the furnace blower. When operated with the utility door and other openings shut (the typical mode of operation for the family), both the water heater and the furnace backdrafted continuously. When operated with an additional two vents installed after the poisoning, both the water heater and furnace vented.

CO Levels:

None indicated on Chemical Dot Carbon Monoxide Sensor. Sensor was several years old, and had expired. No carbon monoxide was present when we inspected the house. Carboxyhemoglobin levels in family indicate high levels had occurred.

Analysis, Case 2

Depressurization, the primary cause of the carbon monoxide poisoning, resulted from non separated combustion and return air which in turn led to dirty burners. The Uniform Mechanical Code, Section 317.2, states that "..there shall be a positive separation between combustion air and outside or return air for blower-type heating systems. The combustion-chamber opening shall be separated from a fan plenum by an airtight separation without openings therein..." Section 703.3 of the code states "Openings and ducts shall not connect appliance enclosures with space in which the operation of a fan may adversely affect the flow of combustion air."

The negative pressure developed by the air circulation fan is more than ten times as great as the natural draft of a furnace or water heater. The furnace blower, when running, backdrafted the furnace and water heater. The original remodeling, which enclosed the furnace in a small utility room without combustion air, caused the dangerous situation when the furnace return air pulled air from the space. No one inspecting the furnace since the remodeling told the owner of the obvious, and dangerous, situation.

The daughter was not checked for carbon monoxide after her seizures. Seizures are one of the many symptoms of carbon monoxide poisoning. Reliance on an expired chemical dot carbon monoxide indicator nearly led to the death of the family. As the father pointed out, the front of the indicator has a line "Date Installed", but the instructions on the front do not point out that the useful life is only one heating season.

Heating contractors who visited the house after the poisoning incident increased the height of the vent above the roof another 5 feet, and installed two combustion air openings communicating with the interior of the house. They did not address the problem caused by the return air from the utility room, and the potential problems that could still arise.

Recommendations and Action, Case 2.

The homeowner was advised to take the following steps:

1. Have the burners and burning chambers thoroughly cleaned.
2. Have the furnace and water heater adjusted and inspected.
3. Provide return air ducting to the furnace and separate the combustion air from the return air.
4. Provide combustion air.
5. Consider new, sealed combustion heating appliances.
6. Purchase backdraft indicators and carbon monoxide detectors.

The failure of persons involved with the case to identify and remedy the basic causes is a major concern.

Case Three

Background, Case 3

In the spring of 1994 the co-owners of a motel were found dead in their living quarters connected to the motel office. Their blood was more than 60 percent saturated with carbon monoxide, a fatal saturation. Investigators were "99 percent sure" the carbon monoxide came from a propane boiler or water heater. Officials were also quoted as suspecting a down draft, caused by high winds and worsened by snow, trapped gas exhaust fumes in the dwelling. Investigators noted the living quarters were "sealed airtight" and the water heater and boiler were venting "almost perfectly."

Physical Characteristics, Case 3

Dwelling: Living quarters at the north end of a one-story wing of a motel with 14-16 units. A small basement area under the living quarters contains a hot-water boiler (for space heating) and water heater.

Space heating:

Natural draft gas-fired boiler, 245,000 BTUH input capacity, relatively new. 8-inch connector to an 8-inch manifold.

Water Heating:

Older 95,200 BTUH 67 gallon water heater. Immediately from the top a 5-inch elbow connects to a draft diverter box, then to the shared 8-inch manifold. Only the rise of the elbow before connector is horizontal.

Exterior Venting:

Exterior double wall 8-inch pipe, approximate length 12 feet. Two 45 degree offsets were used to clear the roof edge. Offset had an area of approximate 1.5 x 5 inch area of outer pipe corroded away. It showed signs of brown and white streaking and was in generally poor condition.

Clothes dryer:

A commercial clothes dryer on the main floor vented through a six inch galvanized pipe out the back wall.

Additional Heating (non-functioning):

64,000 Btu/hr furnace in attic connected to ceiling registers.

Other exhausts:

One kitchen exhaust fan venting through a 6-inch diameter galvanized pipe.

Attic Space: Entire attic open and connected. 12 x 12 inch gable vent on the west end and three 8 x 8 inch roof vents on the south roof face (in the attic above the living quarters). No soffit vents. Cupolas used for high vents.

Envelope: Blower Door Results	
Air Changes Per Hour, 50 Pa	7.16 ACH50
Effective Leakage Area (LBL)	126. Square Inches
Equivalent Leakage Area (CANADA)	221. Square Inches
Est. Exhaust Depressurization	7.2 Pascals
Air Flow @ 5 Pascals	503.7 Cubic feet per minute
Estimated Natural Infiltration	106. Cubic feet per minute
	0.40 Air Changes per hour
Minimum Ventilation Guideline	1350. CFM50

Blower door tests indicate a structure of fairly typical construction and is not "air tight".

Pressure Differences:

Living Area to Outdoors	-5.6 Pascals
Attic to Living Area	-0.6 Pascals

Analysis, Case 3

Measurements were made to determine why flue gases remained in the dwelling. Conclusions:

1. The 5 inch pipe between the water heater draft diverter and the common vent for the water heater is nearly horizontal, with less than 1 foot of rise. A rise is needed to exhaust the gases. With no rise proper venting can not be assured.
2. The 8 inch horizontal manifold is undersized.
3. The 8 inch vertical common vent on the outside of the building is undersized.
4. The vertical common vent is in poor condition, with a rust hole at an elbow.
5. The vertical vent is poorly located on the side of the building, and likely to cool, leading to poor draft, condensation, and rust. The location at the edge of the roof does not take full advantage of wind induced draft and is more likely to experience downdrafts.
6. The boiler and water heater are sized to supply hot water for the entire wing of the motel, yet they are located, and draw their combustion air, from only the residential quarters of the motel.
7. The Uniform Building Code requires one-hour fire rated construction (doors and walls) separating the boiler and water heater from the living quarters and the remainder of the motel. The introduction of combustion air into the utility room is also required.
8. No provision for combustion air was made in the basement utility room, other than removal of the basement door. Windows had been covered with plywood and insulated.
9. The structure was operating under negative pressures. The causes of depressurization include:
   a. Attic depressurizes when the wind pulls air out of roof vent cupolas. There were no soffit vents to allow air into the attic.
   b. Attic depressurization was communicated to the living quarters through a leaky ceiling and attic duct system.
   c. There was no make-up air provided, as required by code, for the commercial clothes dryer.
   d. Inadequate combustion air for the water heater and furnace.
10. The furnace, water heater, and venting appeared poorly maintained. Vents were rusty, and the general appearance was of minimal expenditure maintenance. There were no inspection stickers, and no records could be found showing annual maintenance.

Recommendations and Action, Case 3

Corrections needed include:

1. The utility room be constructed to meet the Uniform Building Code requirements of one-hour fire rating.
2. Both the boiler and water heater be checked for proper combustion, including a check of combustion products to insure compliance with CO emissions.
3. Replacement water heater be considered. If not replaced, it should be completely maintained. The burner must be cleaned, and proper operation assured. The existing draft diverter must be replaced, and the needed rise established in the water heater vent pipe. There is insufficient space in the low basement room to establish sufficient rise, so major remodeling and re-venting will be needed.
4. That all venting be redesigned and all existing vent pipes be replaced. The vertical vent pipe should be routed within the structure and exit near the center ridge.
5. That sufficient combustion air be introduced into the utility room.
6. That sealed combustion units, power vented units, or electrical units be considered as

alternatives.

7. That make-up air be supplied to the clothes dryer and kitchen exhaust vent as required by codes.
8. That additional vents be installed in the attic.
9. That firewalls be installed in the attic between units as recommended by code.
10. The furnace in the attic should inspected before operating.
11. That a professional with experience in meeting Uniform Building Code requirements and in heating system design and installation be consulted to inspect the building and to determine the changes needed to insure safety.

CONCLUSIONS

Several problems contributed to the carbon monoxide problems in the three cases investigated. These problems included a blocked damper, a backdrafting gas fireplace, fresh air intakes frozen shut, insufficient combustion air, insufficient make-up air, lack of glass doors on a gas fireplace, burners producing excessive carbon monoxide, undersized venting, utility room without combustion air, return air not connected to furnace, expired carbon monoxide detector sensors, lack of maintenance, insufficient rise on water heater connector, holes in vent pipes, poor location of common vent, commercial boiler and water heater located in basement without combustion air, and depressurization of structure by attic ventilation.

The long list of problems found in these three dwellings is frightening, made more so since carpenters, homeowners, utility representatives, medical personnel, heating contractors, and building inspectors determined and corrected only a few of the causes of the carbon monoxide.

Interactions between structures and heating systems are numerous and complex. The buoyant forces that carry combustion products up the vent are extremely small and easily overpowered by exhaust fans, fireplaces, and wind forces. For carbon monoxide poisoning to occur there must be a source of carbon monoxide and the venting system must fail, allowing the products of combustion to remain in the structure. These three cases highlight several types of vent failure. There are many others.

More recent studies conducted by the authors, using gas meters, combustion gas analyzers, carbon monoxide detectors, and manometers found over-gassing is often overlooked as a source of carbon monoxide. Over-gassed appliances produce high levels of carbon monoxide (over 4500 ppm) and are prone to sooting and soot blockage.

These three case studies along with others conducted by the authors indicate heating appliances create carbon monoxide problems. To correct these problems requires cooperation of all people involved: including builders, remodelers, heating contractors, firefighters, local authorities, gas utilities, building inspectors, homeowners, appliance manufacturers, medical personnel, and extension educators.

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SUMMER HUMIDITY = YEAR-AROUND POOR INDOOR AIR QUALITY

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The prevailing wisdom is that maintaining indoor air quality is simply a matter of supplying fresh air and using a good furnace filter. Builders and home owners are primarily motivated to use ventilation to prevent condensation on windows. Typically, ventilation is discontinued when the temperature rises. Natural ventilation declines as the temperature rises. Monitoring of carbon dioxide levels show that the highest levels (+ 2,500 parts per million, PPM) occur when air-conditioning without mechanical ventilation. Ideal carbon dioxide levels are 700-800 PPM. Fresh air ventilation should occur anytime the windows are closed and is most critical during the non-heating season.

Fresh air ventilation and filtration are only two elements of indoor air quality. Humidity control is also a critical element. During the warm humid periods, open windows or mechanical ventilation produce high indoor humidity. Two or three months of +60% indoor relative humidity will permanently maintain a year-round dust mite population. Only a couple weeks of high indoor humidity will grow large quantities of mold and mildew. During the summer months, enough allergens can accumulate in the home to cause a serious indoor air quality problem for the entire year. Source control of the allergens inside the home is important. This problem is eliminated by maintaining the proper humidity level and providing controlled fresh air throughout the entire year.

The paper cites a study of ten modern homes with serious allergy problems and indoor air quality problems. A team of allergists, hygienists, engineers, and technicians studied these homes and the occupants for two years. All of the homes were monitored for six months for temperature, relative humidity, carbon dioxide, allergens, and occupant's health to identify the problems. The source of the allergens was the mold in the basements and the dust mites in the furniture, carpets, and beds. Then five of the homes were modified to provide fresh air and humidity control. The other five were used as a control. The mold and live dust mites in the humidity controlled are gone and the allergens are declining. After an additional year of monitoring and testing, the control homes were also modified and the study is ongoing.

Promises of Indoor Air Quality
A national company advertises that air filtering eliminates indoor quality problems. Another company announces that air filters reduce the need for fresh air and save money. Several companies touted by national celebrities claim the solution to indoor air quality is a simple electrostatic air filter. Many companies say fresh air means indoor air quality. Hundreds of companies advertise cleaning air ducts will cure your indoor air quality problems. Truth or fiction? This would be humorous except many people part with their hard-earned money and do not improve their indoor air quality. Indoor air quality products are a several billion dollar market. Most of the concepts are unable to provide indoor quality. What are the facts about Indoor Air Quality?

What Is Good Indoor Air Quality?
An environment free of the contaminants that adversely effect people's health or comfort is the simple answer. Environment is the space we occupy and the air we breathe. If "people" are to include 95% of the population, the presence of the common allergens produced by mold and dust mites must be considered a pollutant.

Fresh Air
Provide an adequate supply of fresh filtered, dry outdoor air to flush out indoor pollutants and an adequate supply of oxygen. The indoor space should be free of recognized pollutants. The quantity of fresh air is debatable. Currently the American Society of Heating, Refrigeration, And Air/Conditioning Engineers (ASHRAE) recommend fifteen cubic feet per minute per person or one third air change per hour of living space, whichever is more. . Because the cost of fresh air is low, most people prefer a little extra.

Air Filtering
Air filtering is a built-in accessory to every human being. It's the nose with those ugly hairs protruding. The air filtering efficiency of a nose is about the same as a low cost furnace filter. That's nothing special. The spectrum of filters available is from the cheap furnace filter up to the air flow restricting High Efficiency Particle Arresting Filter (HEPA) that removes many things including larger air-borne viruses.

The basic spun fiberglass filters are 10% efficient. All filter efficiency is stated using ASHRAE 52 Standard. Electrostatic air filters are 20% efficient (called allergy filter). That's two times more efficient than cheap furnace filters but are not adequate to keep heating/cooling equipment clear of dust. The extended media pleated cloth filters are 30%-40% efficient. They keep equipment and furniture clear of dust and remove all the recognized polluting nongasous airborne particles from the recirculating air. The next level is the premium extended media filter that requires filter paper insertion into a molded frame. It is 65% efficient and will keep equipment and home dust free.

Electronic filters are 65%-95% efficient immediately after washing. The efficiency depends on the amount of turbulence of the air stream. The efficiency of the electronic filters deteriorates rapidly as they collect dust. Manufacturers recommend washing once per month for optimum performance. How good should the filter be? Its important to keep mechanical equipment clean and good to reduce the dust that settles on furniture.

The findings of a review of all the air filter research by Roger M. Fox MD, Tampa, FL are that very little medically sound documentation exist on the benefits of air filtering. Filters do not substitute for fresh air or source control of pollutants. Air filters should not be the primary means of improving indoor air quality. My personal opinion is that unless you are undergoing open surgery or are immunologically impaired, the 30%-40% efficient extended media filter may be acceptable.

Humidity

Regarding "Indoor Air Quality" that's about it, right? Wrong! What's left? Everyone understands the importance of controlling humidity in the winter to stop windows from sweating . In fact those sweaty windows are the motivation that sells 90% of fresh air ventilation systems. When the snow melts, we stop being concerned about ventilation and humidity control. The key is source control of pollutants. Allergens are a pollutant.

What Causes Poor Indoor Air Quality In Wisconsin Study Homes?

An ongoing Wisconsin study headed by Physicians Plus, a local HMO, involves 10 families with serious allergy problems. Most of the patients were ill sporadically throughout the year. The temperature and relative humidity has been monitored constantly for two years. The dust mite, mold/mildew spore count, carbon dioxide, and organic biologicals are being sample every quarter.

Found Mold And Dust Mites

Mold/mildew and/or dust mites were present at some level in all of them. Sixty percent of the homes have the high quality electronic or high grade pleated cloth air filters. All of the homes had residential dehumidifiers. The typical winter humidity of these homes was 35%-40% RH which caused minor moisture condensation on the windows. One home had 50%-55% RH and had mold growth during winter. In the rest of the homes, little or no mold growth occurred during the winter months.

Found Summer Humidity High

Summer humidity repeatedly exceeded 80% for several weeks in seven of the ten homes. The highest relative humidity was recorded when the windows were open during humid cool evenings. Typical summer humidity was 60%-75%, when the air conditioners were operating. Mold presence is best detected by a musty odor associated with basements. A strong musty odor was present in most of these homes. Clearly the majority of mold growth occurred during the humid summer months. Just a couple of weeks of high humidity caused mold/mildew to grow and load the home with allergens. Mold/mildew was usually found in areas where carpeting was on concrete or in basements. Mold/mildew growth is caused by the normal 75°F, 60% RH air infiltrating under the carpet or other material on cool concrete. When the 75°F, 60% RH air is cooled to 50°F-60°F the RH rises to +90% RH. Mold grows rapidly at this condition.

Two of the homes had little or no evidence of mold. The windows of these homes were seldom opened when it was humid outside and the air-conditioner was usually on. The relative humidity in these homes was lower, and seldom exceeded 65%. These homes had no mechanical ventilation except bath fans and kitchen hoods. Cooking, pet, and other odors lingered in these homes. These homes exhibited high carbon dioxide levels, commonly over 2,000 PPM in the summer and approximately 1,500 PPM in the winter. Our meter max outs at 2,000 PPM. High carbon dioxide levels indicates that other indoor pollutants are probably also high, indicating low ventilation rates. Carbon dioxide levels of 1,000 PPM are considered an upper limit. The windows had moisture problems during the heating season. The homes had no carpeting in the basements.

It is critical to stay below 50% RH to prevent mold growth on any concrete surface that is covered by carpeting or storage boxes. After the structure is loaded with mold, extensive ventilation and air filtering are unable to rid the home of these allergens.

Dust Mites

Dust mites require longer periods of plus 50% RH to establish themselves. In addition to several months of the plus 50% RH, dust mites must have a food supply of skin scales, and an upholstered surface to live in. When the relative humidity is below 50%, the adult dust mites desiccate and die in 2-3 weeks, The dormant adolescent dust mites can survive for up to six-eight months below 40% RH. The usual location for dust mites are commonly occupied upholstered chairs, carpets and mattresses. The allergen from the dust mite is its fecal excrement. The allergen is potent for six-eight months after excretion. Tracking the temperature and relative humidity in these homes through a year illustrates that +55%-RH exists during the 3-4 summer months. This environment allows dust mites to thrive and reproduce. The homes had low to high levels of dust mite population. The drier homes had fewer dust mites with two exceptions. The house with highest levels of year-round mold had few mites. One of the homes with minor mold had the highest levels of dust mites. High levels of mold may inhibit dust mite growth.

Identifying Causes Of The Indoor Air Quality Problems

After collecting data for six months, the homes were paired for similar problems and mechanical system. One of each pair was randomly selected for resolution of the indoor air quality problems. Our team of experts agreed all the homes were grossly under-ventilated during the air-conditioning season and marginal during the heating season. We also agreed that the homes had a source of allergens produced by mold and dust mites. To control the source of these allergens, it was necessary to keep the relative humidity below 50% during summer.

Ventilating/Humidity Control Equipment

To control the homes' high summer humidity and the moisture summer ventilation adds, a ventilation system with 100 pint/day of dehumidification was used. A 35% efficient pleated cloth, extended media air filter was used to keep the equipment clean and remove allergens from the fresh air. Five of these homes had the Sahara whole house ventilation/humidity control system installed during Nov.-Dec. 1993. The 100 pint per day dehumidifier blends fresh air with air from the home and draws it through the air filter. The filtered air passes through the dehumidifier and is routed to cause air circulation in the home. During times of low outside humidity, the fresh ventilation air is adequate to keep the home below 50% RH. If the indoor humidity exceeds 50% RH, the dehumidifier dries the combined air stream. The following table shows the amount of moisture added or removed per day from the home by 100 CFM of ventilation air. Ventilation with 60°F,80% Rh to 80°F, 40% RH outdoor air removes 13 lbs. of water per day if the home is maintained at 78°F, 50% RH. Each person adds 3-5 lbs. water per day. Some water is probably diffusing through the concrete into the home. Forty to fifty pints per day of dehumidification is required when the outdoor moisture is at this level.

Monitoring continued in all the homes during 1994. In the modified homes, the relative humidity during the winter months averaged 30%, compared to 40% in the unventilated homes. The summer humidity was maintained at or below 50% RH in the mitigated homes compared to 60%-80% in the control homes. The occupants of the modified homes reported an immediate improvement in the freshness of the air and the moisture on the windows. The musty odor did not return the following summer. No evidence of Mold/mildew was present in the modified homes.

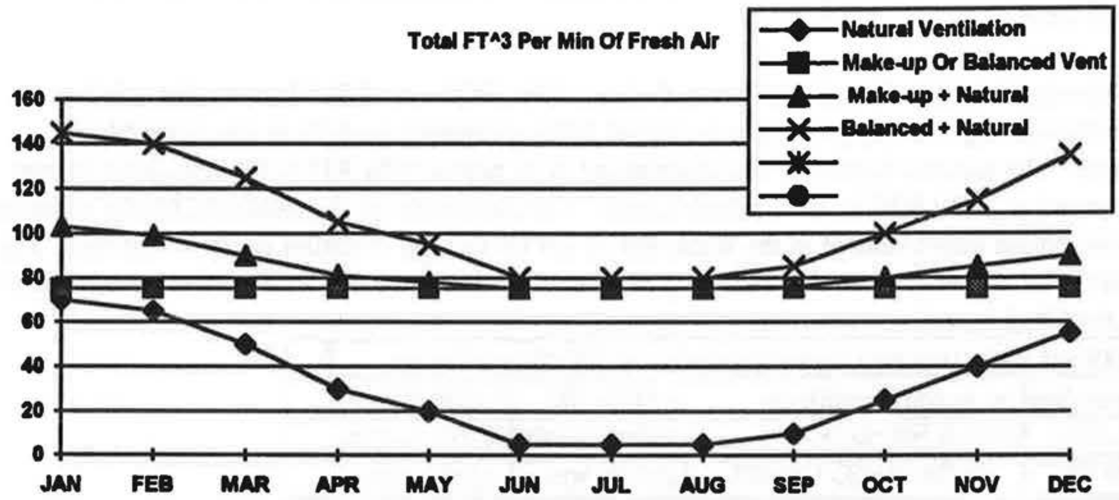
Pounds of water removed or added per day by 100 cfm ventilation			
Depending	on inside conditions	+ -LBS.H2O	+ -LBS.H20
Lbs.H2O	Temp.& Rel.Humidity	24hrs,100cfm	24hrs,100cfm
Per# Air	@ Same H2O Content	@70°F,30%rh	@78°F,50%rh
0.0006	0°f,80rh-15°f,40%rh	-45	
0.003	32°f,80rh–50°f,50%rh	-19	
0.006	50°f,80rh–75°f,35%rh	13	
0.009	60°f,80rh–80°f,42%rh		-13
0.0126	70°f,80rh–85°f,48%rh		26
0.0178	80°f,80rh–100°f,43%rh		81
	Condition Inside The Home	Winter	Summer

No live mites were found in the modified homes. The level of dust mite allergens is dramatically decreasing. The other five homes continued to have indoor quality problems proportional to their level of high humidity.

On a very humid day in Wisconsin, 60-80 pints of water are removed from the combined air streams to keep the home below 50% RH. The moisture comes from the fresh air, the occupants, and moisture entering by diffusion from concrete in contact with earth. The unit, dehumidifying continuously, uses twelve kilowatts per day or about $30/month. The dehumidifier operates continuously only during the most humid days. The amount of electricity to operate the Sahara Dehumidifier is similar to a conventional 35 pint dehumidifier. The Sahara removes 3-4 times more moisture per KWH.

Cost Of Winter Fresh Air

The following graph illustrates the effect of seasonal outdoor temperatures on the natural ventilation rates that were observed in these homes. As the outside temperature dropped during winter, the warmer inside air creates pressure on the homes causing an increase in natural ventilation. On the coldest winter days, this home has adequate natural ventilation (75 CFM). During the summer, natural ventilation rates drop to 5 CFM. Adding 75 CFM of make-up air ventilation increases the total winter ventilation to 105 CFM and the summer ventilation to 80 CFM. Adding 75 CFM of balanced ventilation increase the total winter ventilation to 140 CFM and the summer ventilation to 80 CFM.



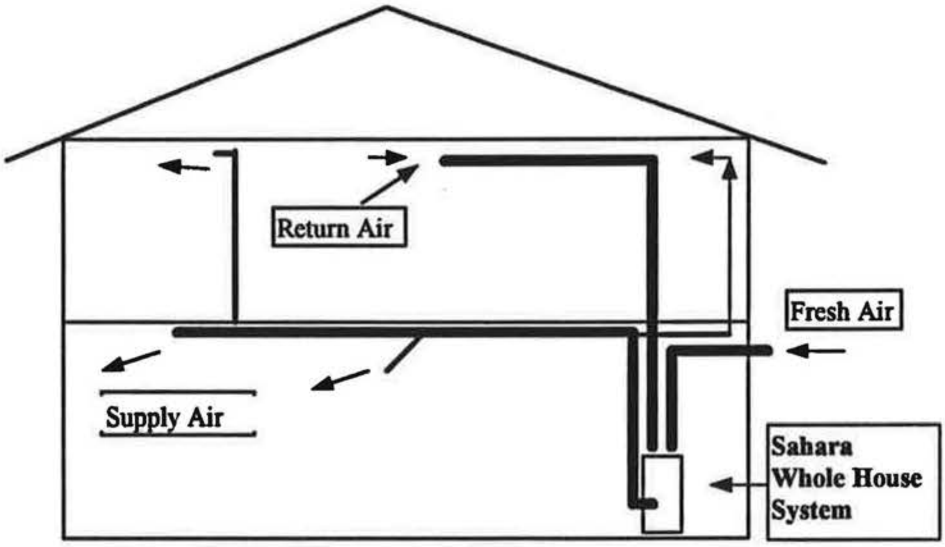
Providing a constant amount of fresh air (75 CFM) as make-up air compared to balance air ventilation causes a more consistent ventilation rate during the coldest months. Because of this difference, the make-up air ventilation system pays a smaller heating penalty than thought. The above example shows the additional ventilation on the coldest month being only 40 CFM and 70 CFM during the warmest month. If ventilated for 12 hours a day, heating with a high efficiency natural gas furnace, the increased heating bill is approximately $50/year.

Cost Of Controlling Summer Humidity
Operating the typical 30-40 pint residential dehumidifier is approximately $30-$40 per month. Because of high efficiency, the cost operating the whole house system is comparable. Total operating cost of heating the fresh air during the winter and dehumidifying during the summer is approximately $150 per year.

Introduction Of Fresh Air Into The Home
Blending 75 CFM of 0oF fresh outside air with 175 CFM of 70oF inside air from the cold air return combines for a temperature of 50oF. Introducing the fresh cool air into the home requires careful planning. Discharging the fresh air into the supply duct of the furnace or a utility room with a boiler in the basement is acceptable. In a home without a furnace, its necessary to duct the fresh air to the bedrooms and the open part of the home. The fresh air inlets are located high and avoid discharging the cool air on people. In some situations, a heat recovery ventilator and Sahara are recommended to conserve energy and decrease cool drafts. Exhaust ventilation can also be used in conjunction with the Sahara System.

Mitigation Of The Control Homes
During Nov. 1994, the remaining five homes were modified with ventilation/humidity control equipment. The monitoring is continuing. The Physicians Plus Allergists are tabulating the results of a quarterly health questionnaire and examination of the families. The initial appraisal of the medical impact is good. Several other studies are in progress to verify this concept. The American Lung Assoc. "Health Home" and the National Assoc. Of Home Builders are among those testing the concept.

Cost Of Whole House Indoor Air Quality System
A simple ducted system may have a retail installed cost of $1500.



Summary
Most homes are humid enough during the summer months to grow mold and dust mites. Their allergens last through the winter. Family members, pets, plants, and moisture diffusion are the primary sources of moisture in a home. Indoor pollution levels are also high during the summer. Summer ventilation is more important than winter because of the dramatic decrease in natural ventilation. Ventilation flushes the pollutants and controls moisture when it's cold outside, but adds to the summer humidity. To control the summer humidity, a large dehumidifier that is capable of removing 70-80 pints of water per day is necessary. If the home is kept below 50% RH, the home is more comfortable, mold, and dust mites are controlled. In addition, the system is capable of providing air filtering, and circulation of the fresh air throughout the year. This is an ongoing study and a more complete report is being compiled.

The Environmental Protection Agency recently published "Indoor Air Pollution, An Introduction For Health Professionals" Catalogue NO. US Government Printing Office: 1994-523-217/81322. The recommendations of the publication are well documented and similar to the modifications we made on this group of homes

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Household Contaminants and Household Exhaust and Ventilation Device Usage

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ABSTRACT

This paper identifies a) the pattern of usage of kitchen and bath fans and clothes dryers in a pilot study of twenty-three households with these three appliances and b) the level of contaminants measured in four Minnesota homes when tests were performed as part of a homeowner requested diagnosis of indoor air.

BACKGROUND

The home building industry has undergone changes in construction methods during the last fifteen years. These changes, due in part to consumer demand for comfort and in part to concern for energy efficiency, have led to tighter building envelopes. Unless provided with mechanical ventilation these tighter homes will likely experience a decrease in the number of natural air changes per hour. This condition can, and studies show, has led to problems that include moisture damage in structures and poor indoor air quality. As these problems become more prevalent building scientists are devoting more attention to air flows in homes and to changes in building pressures. Exhaust and ventilation devices directly affect house pressures, making the use of such equipment a timely topic.

During the recent development of the Minnesota Voluntary Residential Mechanical Ventilation Standards many discussions took place regarding how exhaust and ventilation devices affect pressures in homes. If this equipment is included in determining total exhaust capacity in homes, the typical use of that device or the combined use of more than one device being used at one time is an important factor in determining what the standard should be.

Studies done in Canada and the United States have concluded that exhaust and ventilation devices are able to provide the amount of ventilation that manufacturers indicate they will provide if they are installed properly. (Energy Design Update, 1989). When determining total exhaust capacities of residential buildings, it should be assumed that this equipment will perform as rated. The Home Ventilating Institute of America (HVI) tests and rates over thirty brands and models of ventilation and exhaust equipment. In the 1994 Home Ventilating Products Directory, HVI reports that cubic feet per minute (cfm) output ratings for over the range hood type kitchen fans are from140 to 1200 cfm. Bath fan output is from 50 to 410 cfm. If combined with a typical clothes dryer that produces a conservatively estimated150 cfm, these three fans together could be responsible for total exhaustion of from of 340 to 1760 cfm.

As homes become tighter, and they inevitably will, more thought must be given to the interaction between exhaust and ventilation devices and the environment they serve. We need to be concerned with all aspects of negative pressures, from their influence on combustion product venting to soil gas entry. The industry will need to evaluate ventilation and exhaust devices based on several site conditions including, but not limited to, backdrafting, biological and bacterial potential, as well as radon and other soil gas potential.

INTRODUCTION

The paper is presented in two parts. The first part presents findings from a pilot study that recorded the use of fans in twenty-three Minnesota homes. The fans studied are kitchen exhaust fans, bath fans and clothes dryers. Kitchen and bath fans are designed to remove contaminants generated during bathing and grooming and during cooking; clothes dryers are designed to remove the moisture released during the clothes drying process. These appliances are considered in mechanical ventilation standards for family dwellings because their use affects building pressures and can contribute to backdrafting of any natural draft combustion appliance.

The second part of the paper presents case studies of four Minnesota homes. In each case, the investigator was called to the home because of problems perceived by the homeowner. Levels of contaminants found in each home documented.

PART I. THE FAN STUDY

Methodology. Contacts for participants of the study were made from posted notices and through community meetings. Criteria for participation was limited to the presence of the following devices in the participant's home: a clothes dryer, kitchen fan and at least one bath fan in a bath that included a shower and/or tub. It was required that all three appliances be exhausted to the outside.

Participants were asked to complete a survey which included five questions about their household. They were also asked to complete a daily equipment record sheet for each device for a period of seven days. They did so by indicating use of each device during any part of any hour during these seven days. Completed surveys were returned by mail. The five questions were designed to give a profile of the household, clothes drying practices, the facilities provided in the baths, the type of kitchen exhaust in the home and the satisfaction of the sound level of the equipment surveyed.

Twenty three households participated in the study. The households ranged in size from one to five persons with two-person households (35%) being the most frequent size. There were no households with infants or persons over 64 years and four households with children under five years of age.

Results.

Clothes Drying Practices. Sixteen of the 23 households reported line drying of clothes. Six households did line drying indoors, three outdoors and seven reported line drying both indoors and outdoors. Although there were six households who used their dryers during three or less hours for the seven day recording period, all twenty-three households used the clothes dryer during at least one hour. Total use for all households was reported as use during 122 hours. See Chart 4.

Bathroom Facilities. Twelve households reported more than one bath with an exhaust fan. Of the total 30 baths reported, there were no reports of fans in baths where only a tub was present, ten reported fans in baths with showers only and 24 reported fans in baths with both tub and shower. Total use for all households was reported as use during 226 hours. See Chart 3.

Note. One household was equipped with a Van E* heat recovery ventilator which ran continuously during the reporting period. This equipment provides its own make up air and therefore was not recorded as bath fan use.

Kitchen Equipment. Two households reported that their homes were equipped with downdraft fans. The remaining 21 homes reported a hood over the range or cooktop. Total use for all households was reported as use during 43 hours.

Sound Satisfaction. The chart below indicates the results for satisfaction with sound levels of the three fans as reported by the participants.

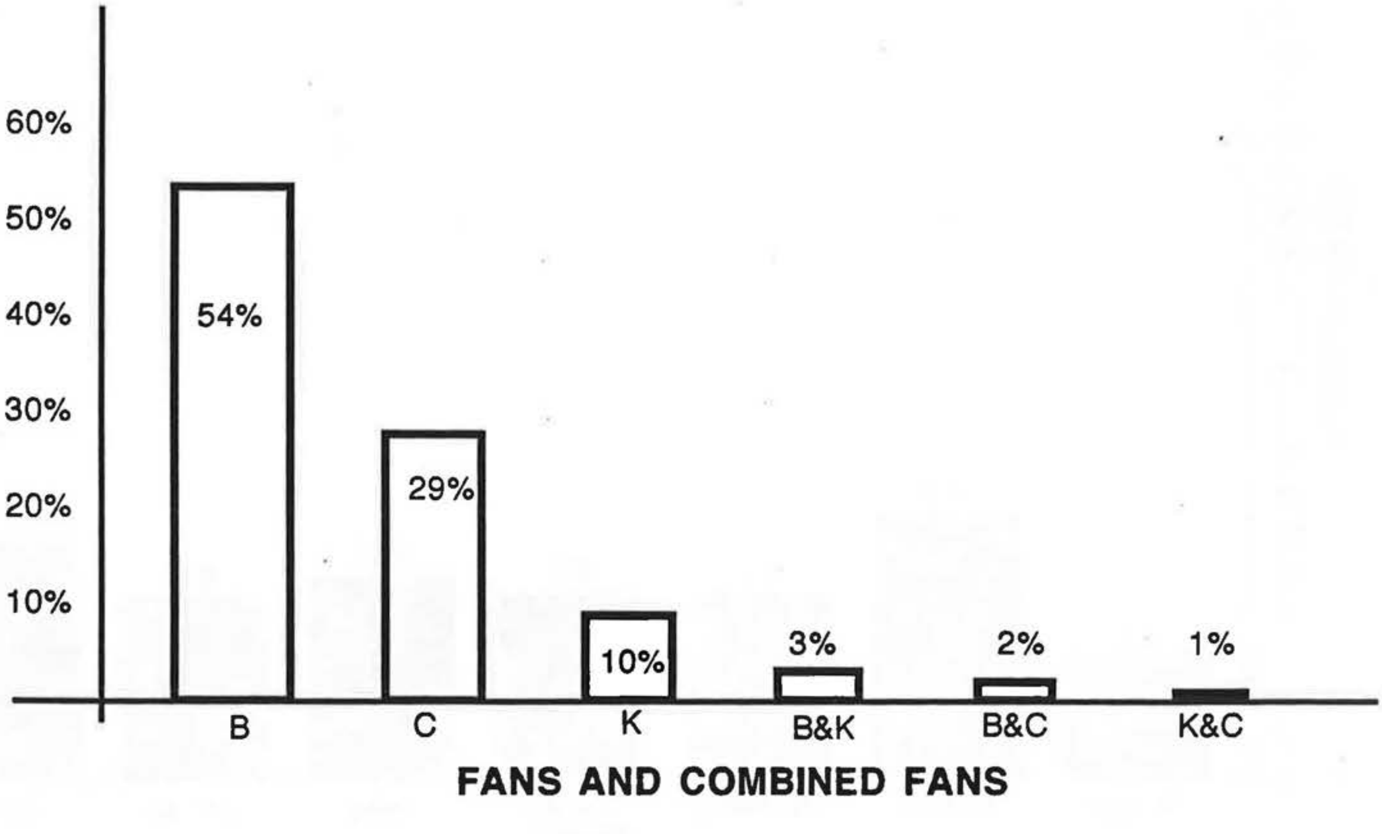
Satisfaction Level	Equipment		
	Clothes Dryer	Bath Fan	Kitchen Fan
High	20	14	5
Moderate	2	4	4
Low	1	5	14

Combined Use. During 54% of all hours during which any fan was being operated, bath fans alone were used. During 29% of all hours of use, clothes dryers alone were being operated. For 10% of the hours of any fan use, kitchen fans alone were used. The combined percentages are as follows: Bath and kitchen fan together, 3%; bath and clothes dryer together, 2%; kitchen and clothes dryer together, 1%. The percent of time that all three were operated at the same time was negligible(less than 1%). See Chart 1.

Discussion. Significant findings are the satisfaction with the sound levels and the frequency and pattern of usage. This information has implications for those building scientists who are charged with the task of determining how fan usage affects pressures in homes. The pattern of usage gives insight into the potential total cfm's that might be exhausted from the house at any one time.

An important component of the Minnesota Residential Ventilation Standards now being developed is the sone rating for exhaust and ventilation appliances. While HVI reports sone level ranges for kitchen fans to be from 3 to 12.5 sones and bath fans from 1 to 7.5 sones (a sone is approximately the sound of a quiet refrigerator in a quiet room or a quiet conversation level), the satisfaction level of the homeowner may give a more accurate indication of how much the fan will be used. The results indicate that while 20 families are satisfied with the sound level of their clothes dryers, only 5 of 23 were satisfied with the sound level of their kitchen fans. The corresponding use of these fans indicate that that kitchen fans are used much less (43 parts of hours) than clothes dryers (226 parts of hours).

CHART 1. **PERCENTAGE OF TOTAL USE-INDIVIDUAL OR COMBINED**



C - CLOTHES CRYER
K - KITCHEN FAN
B - BATH FAN

CHART 2: HOUSEHOLD USE OF KITCHEN FANS (n = 23)

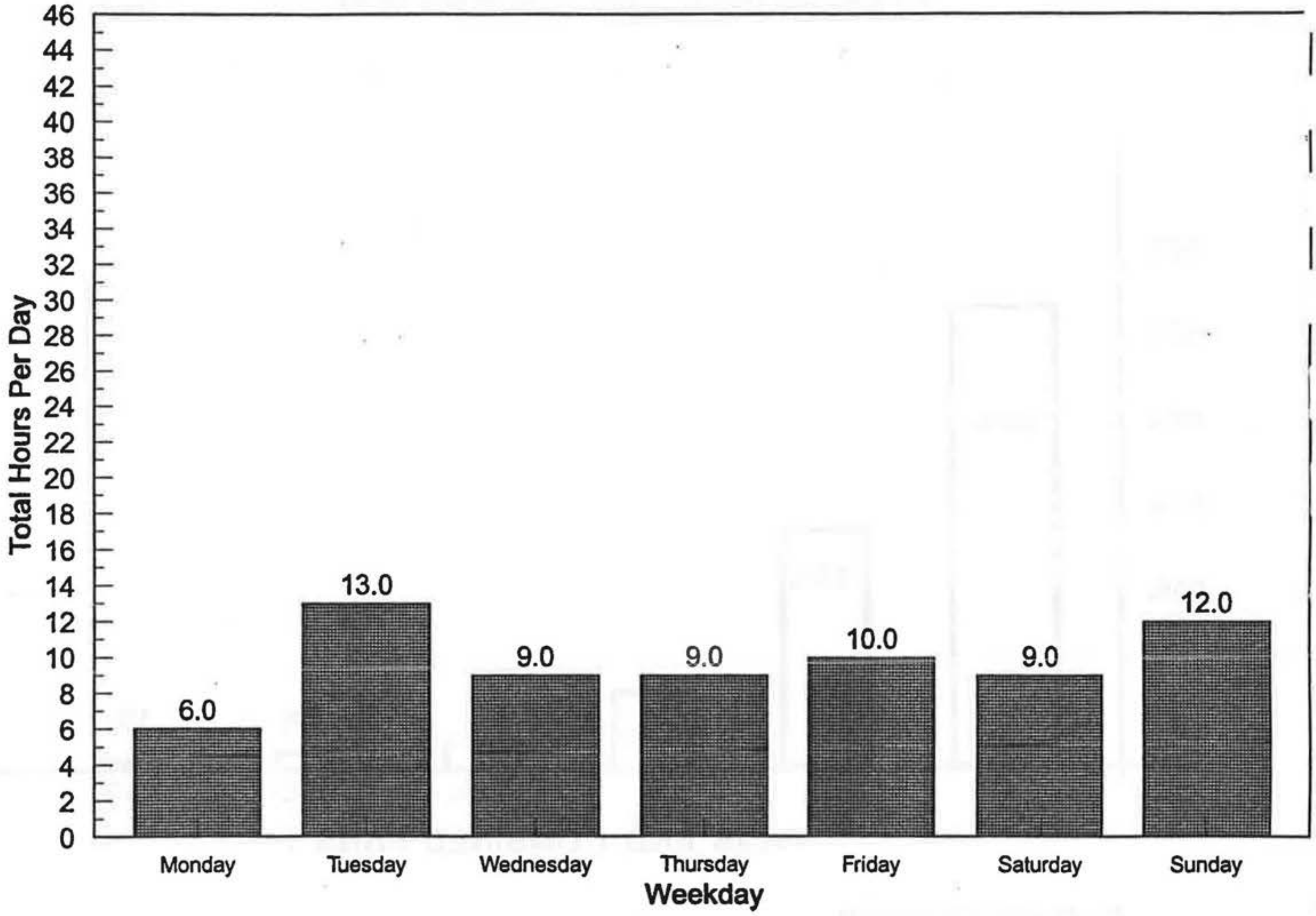


CHART 3: HOUSEHOLD USE OF BATH FANS (n = 23)

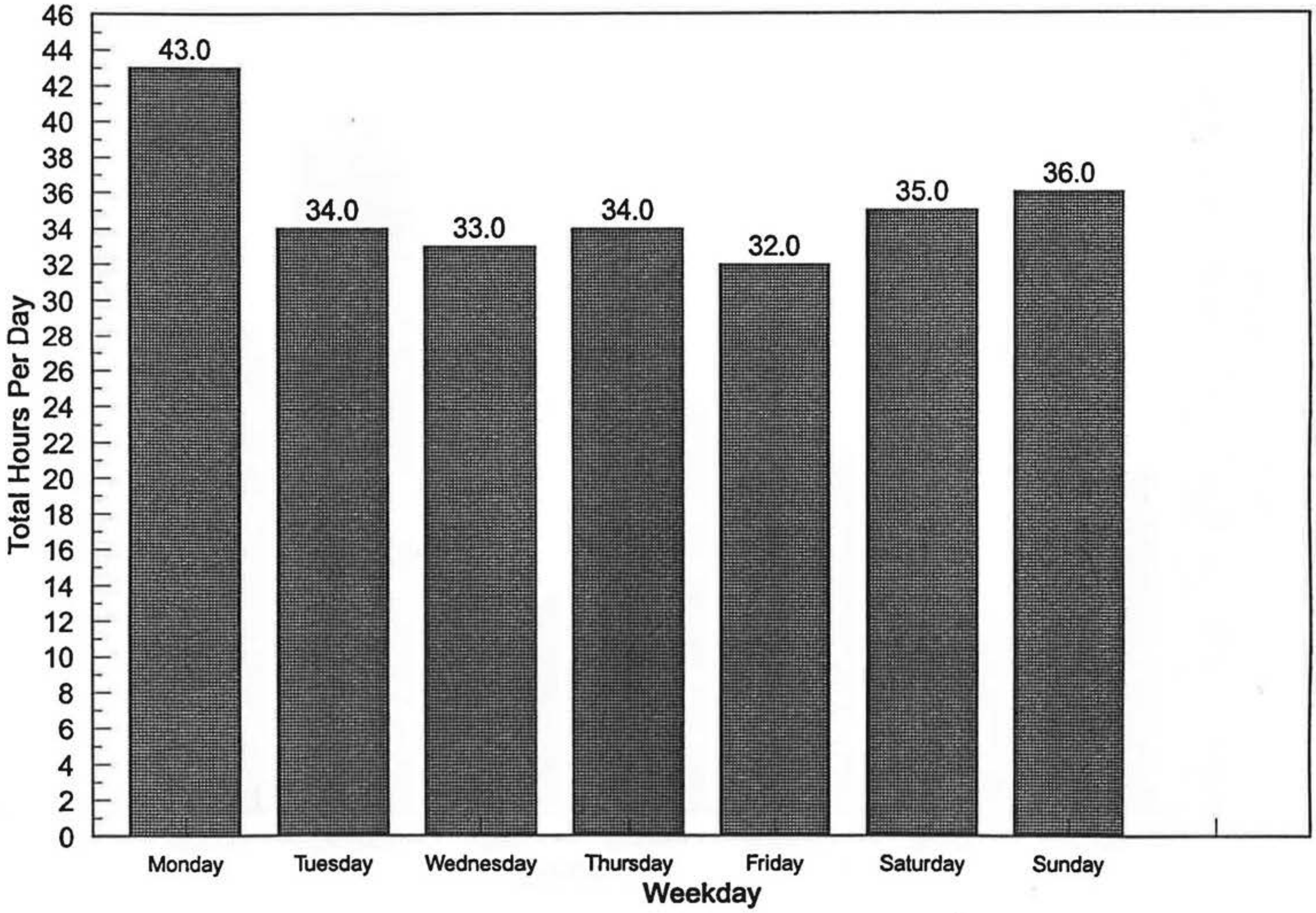
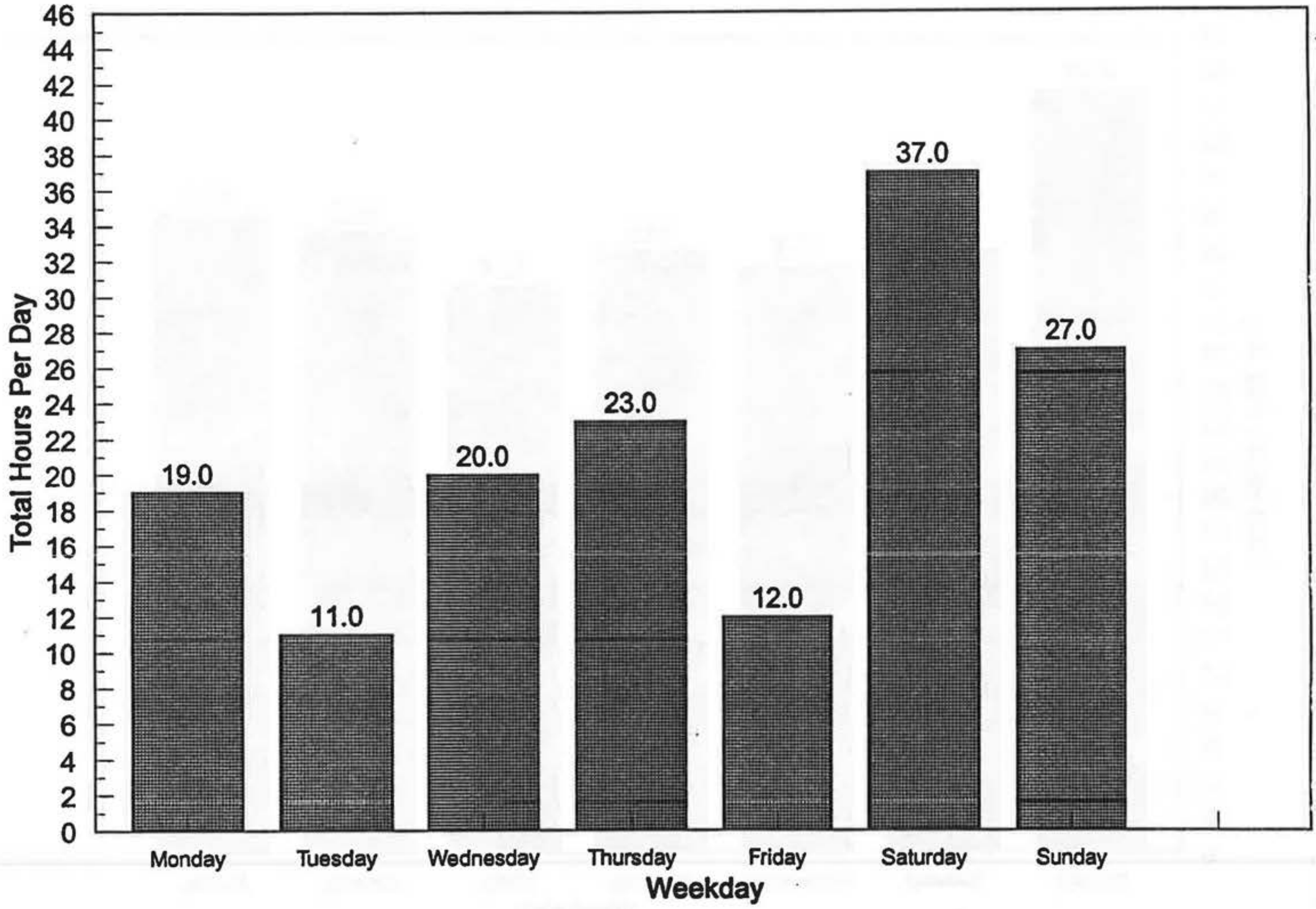


CHART 4: HOUSEHOLD USE OF CLOTHES DRYER (n = 23)



PART II. FOUR CASE STUDIES

Homes today are being equipped with progressively larger exhausting equipment. (Moffat, 1991). What can we expect when we combine bigger exhaust capacity in new and tighter homes? Should we expect a significant increase in negative pressures? Will the addition of additional combustion air lines compensate adequately for this larger exhaust capacity? The following case studies address these questions.

Each study is preceded with a description of certain conditions found in that house: the air tightness of the house as measured with a blower door, the total exhaust capacity of all exhausting equipment in the house and the negative pressure measured in the house when all exhausting equipment is operating at full capacity or worst case conditions. [A tight house would measure less than 1000 cfm; a medium tight house would measure 1000 to1600 cfm; and a leaky house would measure above 1600 cfm. All measurements at a pressure reading of 50 Pascals.]

Case Study One.

Tightness of Home: 1500 cfm
Total Exhaust Capacity: 520 cfm
Worst Case Negative Pressure: 15 Pascals

Homeowner Complaint. The four members of this household were hospitalized with carboxyhemoglobin (COHb) levels in excess of 25%. [While the Environmental Protection Agency recognizes that the length of exposure must be taken into account, a COHb level of 7-17% will statistically diminish visual perception and the ability to learn and perform sensorimotor tasks; a level of 40% will cause collapse; a level of 60% will cause unconsciousness and a level of 80% will cause death.] One of the two adults in this household was a woman in the fifth month of pregnancy.

The homeowners had complained of flu-like symptoms for over three months and at least one member had lost consciousness on more than one ocassion. Their complaints to their physicians were diagnosed as probably the flu brought home by school aged children. The homeowners requested that the utility company supplying gas to their home test the home for the presence of carbon monoxide. This test was done, but only after the furnace had been turned off and the windows left open for two hours. No carbon monoxide was measured by the gas company under these conditions. The installing mechanical contractor visited the home on more than one occasion and assured the homeowners that the furnace was functioning properly. It is not known what tests, if any, were performed by the contractor.

Investigative Findings. The house was equipped with a G20 non-induced draft furnace. It was found to backdraft at 3-4 Pascals of negative pressure, significantly lower than is typical (levels of above 5 would be acceptable). The furnace was also found to produce carbon monoxide (CO) of over 3000 parts per million (ppm) during backdraft conditions. Even when drafting properly, CO levels in the flue were measured at levels up to10 ppm. Long term monitoring showed furnace flue backdrafting for over a twelve hour period of time even though no exhaust equipment was operating. When this period was interrupted, ambient CO levels of over 1200 ppm were measured in second floor bedrooms. (See appendix for acceptable CO levels.)

Suggested Remedial Action. The homeowners were advised to vacate the house for several weeks while testing was being completed. The furnace has since been removed and replaced with a closed combustion furnace. Legal action has been initiated.

Post Test Report. None yet available.

Case Study Two.

Tightness of home: 1100 cfm
Total Exhaust Capacity: 500 cfm
Worst Case Negative Pressure: 12 Pascals

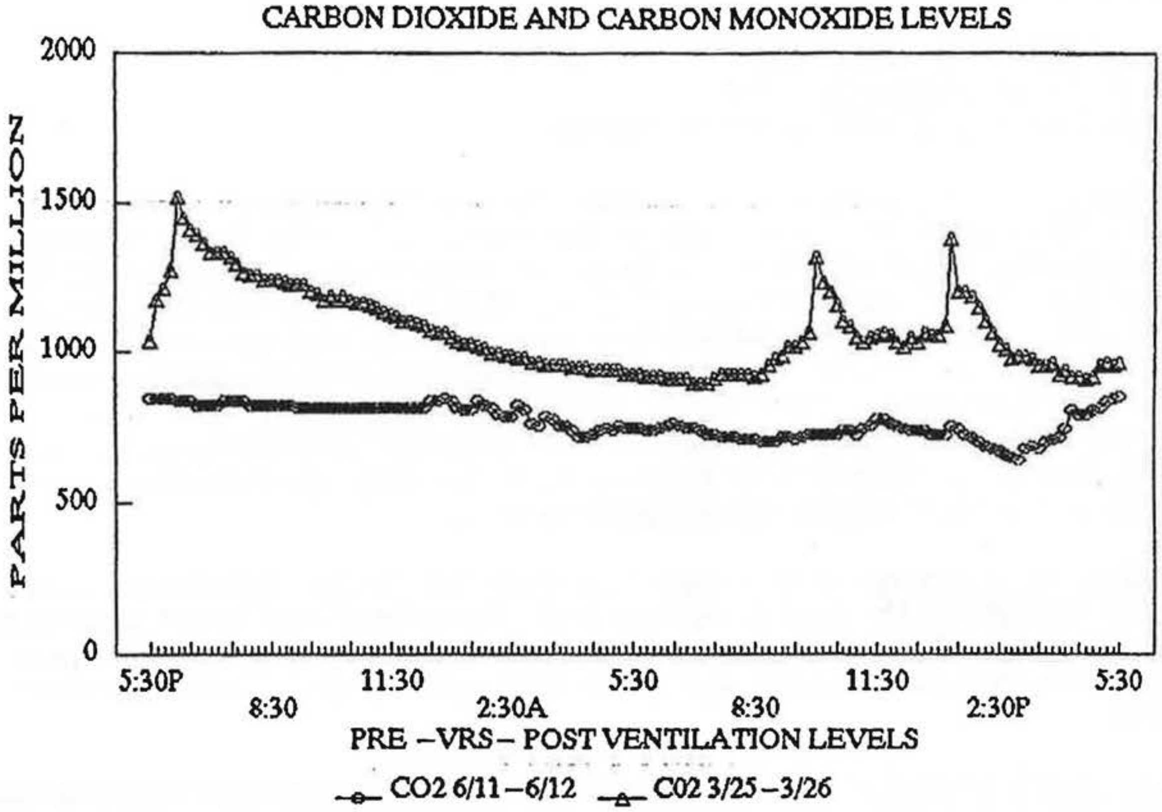
Homeowner Complaint. The homeowners, a retired couple, engaged the investigator to find the cause of excess moisture in the home. In particular, they were concerned about condensation on windows.

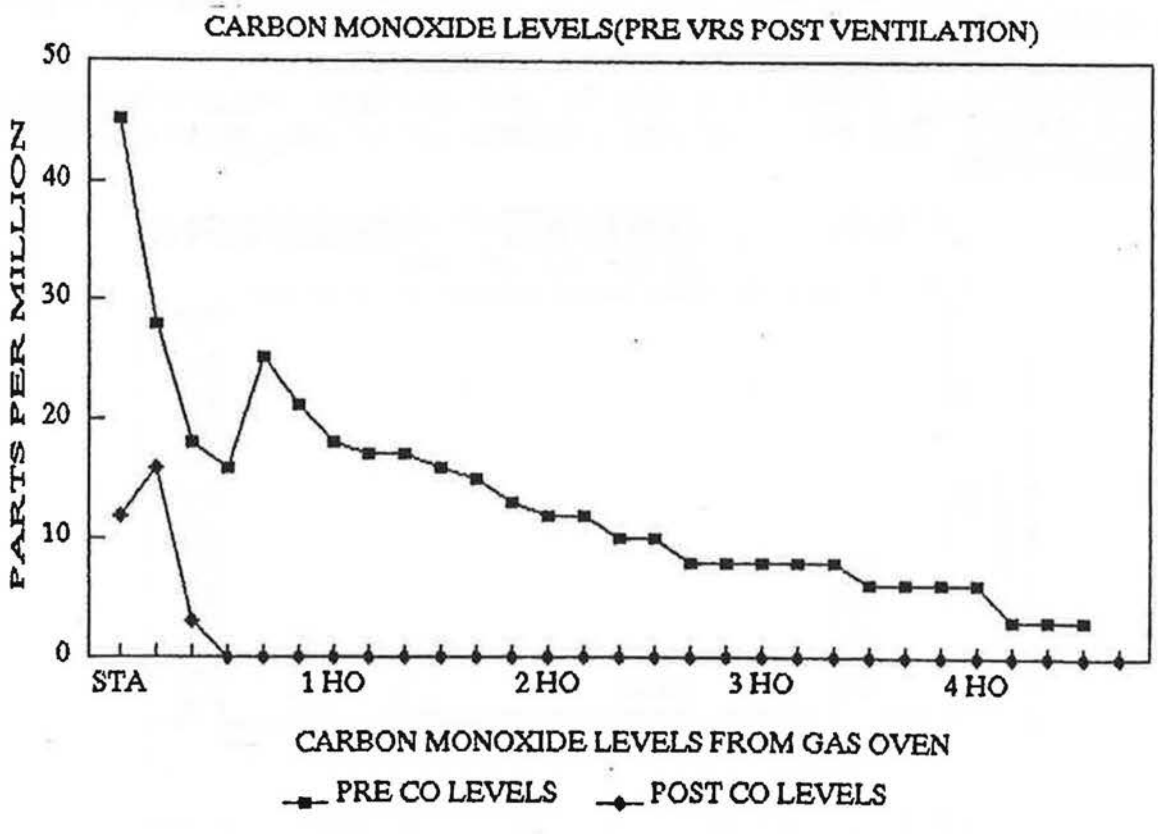
Investigative Findings. A significant problem with backdrafting was found. Operation of the gas oven produced CO levels of over 40 ppm in the kitchen. Decay was slow, with CO levels remaining at 4 ppm four hours after the oven was turned off. In an effort to reduce the CO levels in the kitchen, the kitchen fan was operated. However, the furnace and water heater were found to backdraft while the kitchen fan was operating. The water heater produced significant levels of CO only during backdrafting. Carbon Dioxide (CO^2) was logged for a three day period and was measured above 1000 ppm during this time. [EPA recommended ambient levels for CO_2 are less than 1000ppm.]

Suggested Remedial Action. A balanced heat recovery ventilation system was installed at the investigator's recommendation. Instructions of operation were presented to the homeowners and explained to them. Legal action has been initiated.

Post Test Results. See charts below.

ADVANCED CERTIFIED THERMOGRAPHY





Case Study Three

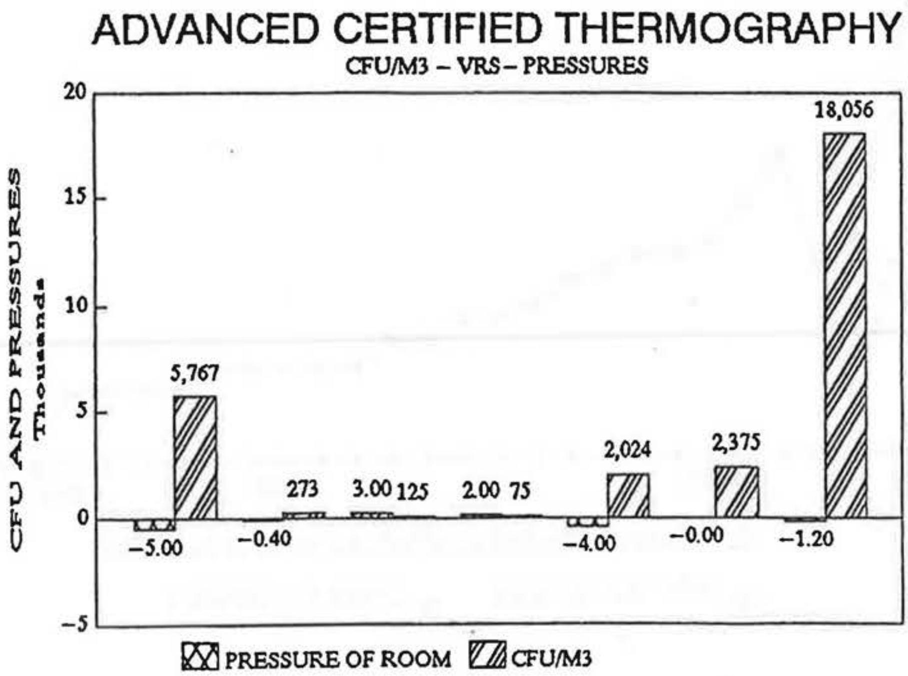
House Tightness: 2200 cfm
Total Exhaust Capacity: 300
Worst Case Negative Pressure: 5 Pascals

Homeowner Complaint. The household consists of a husband, wife and one child. The home also provides day care services. The entire family reported experiencing allergic reactions in the home. They requested testing with the belief that their symptoms were being caused by a propane leak into the house. Previous to the onset of these investigations, two separate fires had broken out in the home. The source was traced to a propane leak in gas lines to the home. The gases had leaked into the sump basket and erupted into fires. In an attempt to keep propane from entering the house, a fan blowing air into the sump basket was installed for three days. It was after this procedure that the family began experiencing the allergic reactions.

Investigator Findings. A very high level of biologicals (See definitions) were found throughout the house. Rooms in the lower level were found to have the highest levels. When exhaust equipment was operating, testing at an open block core showed extremely high levels were entering the house. See chart below.

Suggested Remedial Action. The blocks and basement were thoroughly cleaned. A radon mitigation system was installed in the sump basket and the soil and blocks were depressurized to draw the biologicals out of the building. Legal action is being considered.

Post Test Results. Follow-up testing revealed significant levels of biologicals in only one room. This was attributed to incomplete cleaning of the original contamination.



Case Study Four

House Tightness: 2500 cfm
Total Exhaust Capacity: 225 cfm
Worst Case Negative Pressure: 3 Pascal

Homeowner Complaint. The homeowner, a single woman, became alarmed when, over a five year period of time, she realized that three foster children had all developed "asthma like" symptoms.

Investigator Findings. Biological contamination levels exceeding 40,000 CFU/m^3 were found in several areas of the basement. Further investigation found that the ground under the entire basement slab had settled approximately twenty inches. Approximately twelve inches of standing water was documented in the space.

Suggested Remedial Action. On the advice of her physician, the homeowner abandoned the property. No remedial action was taken due to the cost of repairs. Legal action is being considered.

DEFINITIONS

Pascal: A unit measurement of pressure. House air tightness tests are typically conducted with a pressure difference of 50 Pascals between the inside and the outside. Fifty Pascals is equal to 0.2" of water at 55 degrees F.

Biologicals contaminants: Tiny particles that are alive, were once alive, or are part of something that is or once was alive (e.g. molds, insect parts, pollen, animal dander). These contaminants can cause health effects such as allergic reactions, Legionnaire's Disease and pneumonitis. Symptoms range from eye, nose and throat irritation to life-threatening fevers. (Source: EPA.)

Exhausting device: any device that removes air from the home as a secondary function. These devices, which use house air and direct it outdoors, include but are not limited to gas, oil or solid fuel burning equipment, clothes dryers, and central vacuum systems.

Ventilation device: any mechanical device, usually a fan, that is specifically intended to remove house air in order to reduce indoor air pollutants or moisture including, but not limited to, bath, kitchen and laundry area fans.

Parts per million: a term generally used to designate the number of particles of a substance compared to the total of all other particles present. Common unit used to measure concentrations of compounds in air.

notes

AUTOMATED BIOMASS-FIRED HEATING PLANTS - A RENEWABLE OPTION FOR MULTIFAMILY HOUSING

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ABSTRACT

The purpose of this paper is to bring to the attention of the energy-efficient building community a renewable energy option for larger facilities: automated biomass heating plants. Drawing from many examples (including the retrofit of a nine-building 50-apartment housing project converted from electric heat to a central biomass boiler plant), it will be demonstrated how wood-chip fuel can give dramatic reductions in costs for space heating and domestic hot water. The paper will focus not only on the economic and environmental benefits of biomass heating, but also on the system components and their costs. Policy issues around substitution of biomass fuels for fossil fuels will also be addressed.

INTRODUCTION

Biomass is any organic material that can be burned for energy. For the purposes of this discussion, we will look at the most commonly available forms of woody biomass: wood chips, sawdust, bark and chipped sawmill wastes. These forest products are readily available in much of North America, and are generally the lowest cost combustion fuels on the market. In some areas some forms of biomass are available as waste products, priced at the cost of trucking. But more commonly biomass is either harvested for energy or sold as a byproduct of the forest products industry. Its cost is typically 40-50% less than that of bulk-purchased no. 2 fuel oil or natural gas.

Most biomass residues are burned at sawmills to run steam kilns, sold to electric generating plants, or marketed as a feedstock to paper mills. But there are a growing number of institutional, commercial and industrial facilities that are purchasing biomass to burn for heat. These include schools and colleges, hospitals, greenhouses, municipal and state buildings, correctional facilities, hotels and district heating systems. A recent survey of installations in the northeastern U.S. and maritime Canada found over 150 such facilities.

Biomass can be an excellent fuel for large multifamily housing developments, particularly in harsh winter climates and in areas where the competing conventional fuels are very expensive. Because biomass fuel is so inexpensive, burning biomass in a central boiler plant can provide high levels of comfort at very low cost. There is an additional maintenance benefit in having a single heating plant to take care of, compared to separate heat and hot water systems for individual apartments.

This paper will examine one such installation in some detail. Green Acres is a 50-unit low-income family housing project owned by the public housing authority in Barre, Vermont. In 1992 the project was converted from individual electric heat and hot water systems to a central wood-chip system. Over the last three years, the fuel cost for supplying all heat and hot water at Green Acres has averaged $25 per apartment per month in the 8600 degree day climate of central Vermont. This represents a 76% reduction in energy costs for heat and hot water, compared to the previous electric heat. The Green Acres project will be discussed in detail later in this paper.

AUTOMATED BIOMASS HEATING

In most institutional applications biomass fuel handling systems are automated. The operator never handles the fuel, and there is no manual labor involved in running the system. The overall system consists of a storage bin, automated mechanical equipment to move the fuel from the bin to the point of combustion, a combustion chamber and a boiler to act as heat exchanger (see Figure 1).

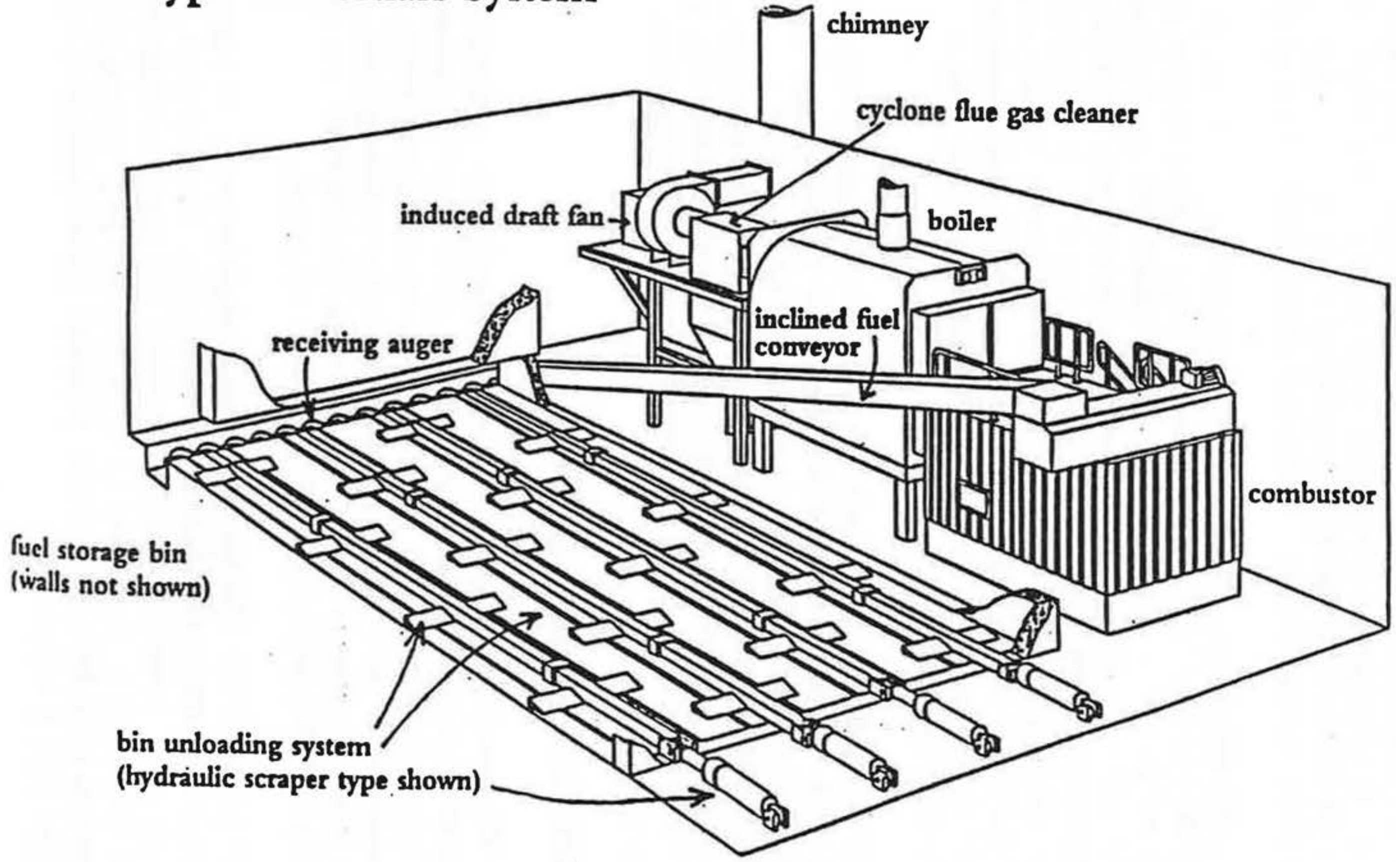
In cold climates the bin is usually a below-grade concrete bunker which can hold more than one truck load of fuel (in warmer climates, above-ground metal silos or bins are sometimes used). Fuel deliveries are made by either tractor trailer trucks, fitted with self-unloading hydraulic floor systems, or large dump trucks. The truck approaches at the top of the bin and discharges down into the bin, filling it by gravity. Tractor trailers generally deliver 25-30 tons of fuel per load, and dump trucks 15-20 tons.

Fuel is withdrawn from the base of the bin automatically, using either a hydraulic scraper system (shown in Figure 1) or a travelling auger that sweeps the base of the bin, discharging to a fixed auger outside the bin. The fuel conveying system, generally consisting of two to five motor-driven augers, moves the fuel from the bin to the combustion chamber.

Some biomass-burning facilities, such as greenhouses and industrial plants, may use small tractors or front-end loaders to handle the biomass fuel. This approach, combined with a simple roofed storage shed for the fuel, is much less costly than a fully automated system and may be used in cases where operators are willing to spend some time each day to load a small day-bin which in turn feeds the boiler.

The primary combustion chamber can either be located in the base of a large conventional solid-fuel boiler (Figure 2), or in a separate combustor which sits adjacent to the boiler (Figure 3). The biomass fuel generally burns on grates in the combustion chamber, with under-fire air blown up through holes in the grates from below and over-fire air injected above the grates.

A Typical Biomass System



Courtesy KMW Energy Systems

Figure 1

Hot combustion gases pass from the primary combustion into the heat exchanger of the boiler. Here the heat is transferred to the heat exchange medium, either hot water or steam. Cooled exhaust gases then exit via a steel stack or masonry chimney. Most systems use an induced draft fan just upstream of the chimney and a "cyclone" or particulate removal device to remove solid pollutants from the exhaust gases.

The central boiler plant supplies hot water or steam to the distribution piping, whether the plant serves a single building or multiple buildings. If there is more than one building, they will be connected back to the central plant with buried pre-insulated piping. Boiler water is used directly for heating, while domestic hot water (DHW) can be supplied using one or more heat exchangers. If there are dedicated supply and return DHW pipes originating in the boiler room, a single DHW heat exchanger and storage tank in the boiler plant can be used. Alternately, the distributed space heating medium (hot water or steam) can be run through DHW heat exchangers in each building or in other multiple locations closer to the end use.

In institutional biomass plants, it is common to have 100% backup capability using conventional fuels. If the biomass system goes down for any reason, the backup system takes over automatically and can handle the full heating load. Biomass heating plants are often shut down in the summer, when the heating load is low, with the backup system taking over to supply DHW and any heating loads. However, a biomass system which also serves the DHW load might be set up to run twelve months of the year to satisfy that load.

THE ECONOMICS OF BIOMASS HEATING

Biomass heating plants carry high capital costs for construction of the storage bin and a boiler room large enough to house the equipment, for the handling system, for the combustion system and boiler, and for the chimney system and controls. Below-grade bins might cost $50-60,000 to build and the need to build additional boiler room space will vary from project to project. Automated biomass systems in the 1-5 million Btu range generally cost $80-$250,000 for the installed equipment.

For systems to be economic, the fuel cost savings must be great. The economics works best when the conventional fuel being replaced is very expensive or when the heat load is very high. In retrofit situations, biomass can compete favorably with electric heat when the prices are $.10 per kWh or more, and with oil or natural gas when the annual heating fuel bill is $25,000 or more. Biomass systems are more economic in new construction than in retrofits.

In some situations, economics can be greatly enhanced when there is biomass available nearby at very low prices. For example, a Trappist monastery in Massachusetts purchases nearly the entire wood-chip output of a nearby hardwood sawmill at a very reasonable price. A hospital in northern Wisconsin purchases bark from a large mill a few miles away for $1 per ton plus trucking, and burns the bark for heat in the winter and to run steam absorption chillers for air conditioning in the summer.

For multifamily housing, biomass has the best chance to compete in large projects with large heating bills. One example might be electrically heated low-income housing where the tenants pay their own electric bills (such as Green Acres). High winter electric bills lead to high vacancy rates in this type of housing, so a biomass conversion can dramatically increase the project's financial stability as well as benefitting tenants directly. Another example might be high-rise urban housing with a large oil or gas bill and an aging central boiler plant. If the project were located on a site with room to add a fuel storage bin and there were a rural forested area within 50 miles, the biomass conversion might be feasible. Having a hot water or steam distribution system already in place makes the biomass conversion more likely to be economic.

For new multifamily construction, biomass heating is most likely to be viable when the project does not operate on conventional market-based economics. One example might be a fairly large co-housing project. The participants in such projects are more likely to share environmental goals which would be furthered by the use of a renewable fuel for supplying heat and hot water. The buried piping which would link individual buildings back to a central boiler facility would be less expensive than in a retrofit since it would be installed in conjunction with other buried utilities at the time of original construction. If the project participants were interested in being actively involved with the operation of the biomass system, a less automated (and less costly) system might be possible. This would bring down the threshold size of cost-effective systems and make the biomass heating technology viable for smaller projects.

ENVIRONMENTAL BENEFITS

There is an attractive common-sense appeal to burning a locally-produced renewable fuel, particularly when compared to burning fossil fuels that are imported from outside the region or outside the country. This appeal can speak eloquently to decision-makers and voters. In Vermont, 15 schools have been converted to wood-chip heating systems in the last decade. For new school construction and school conversions from electric heat, wood chips have become the fuel of choice in the state. Under conventional short-term economic analysis, these conversions would not have competed favorably with low-cost fuel oil or natural gas. However taxpayers have taken the long view and have voted to invest additional money to install biomass systems.

Automated biomass systems, because of the sophistication of their controls, are a clean-burning technology. In proper operation they produce no visible smoke - only a steam plume in cold weather. There is no associated odor or noise. The emissions test favorably compared to fossil fuels. Particulates have typically tested below air quality emission limits in all state jurisdictions. Wood fuel has no sulfur and so does not emit sulfur oxides when burned. There is some concern about the oxides of nitrogen from very large plants (utility scale), but not from the smaller plants discussed here.

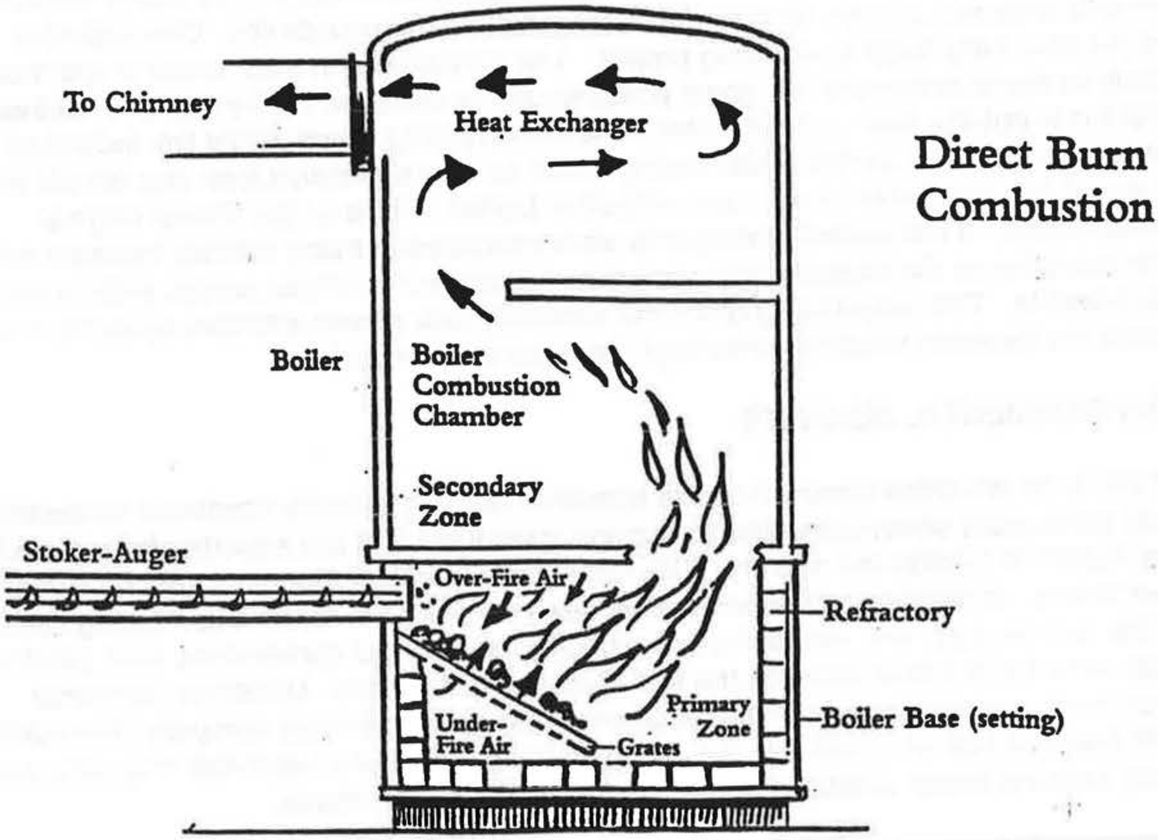

To Chimney
Heat Exchanger
Direct Burn
Combustion
Boiler
Boiler
Combustion
Chamber
Secondary
Zone
Stoker-Auger
Over-Fire Air
Refractory
Under-
Fire Air
Grates
Primary
Zone
Boiler Base (setting)

FIGURE 2

Two-Chamber Combustion

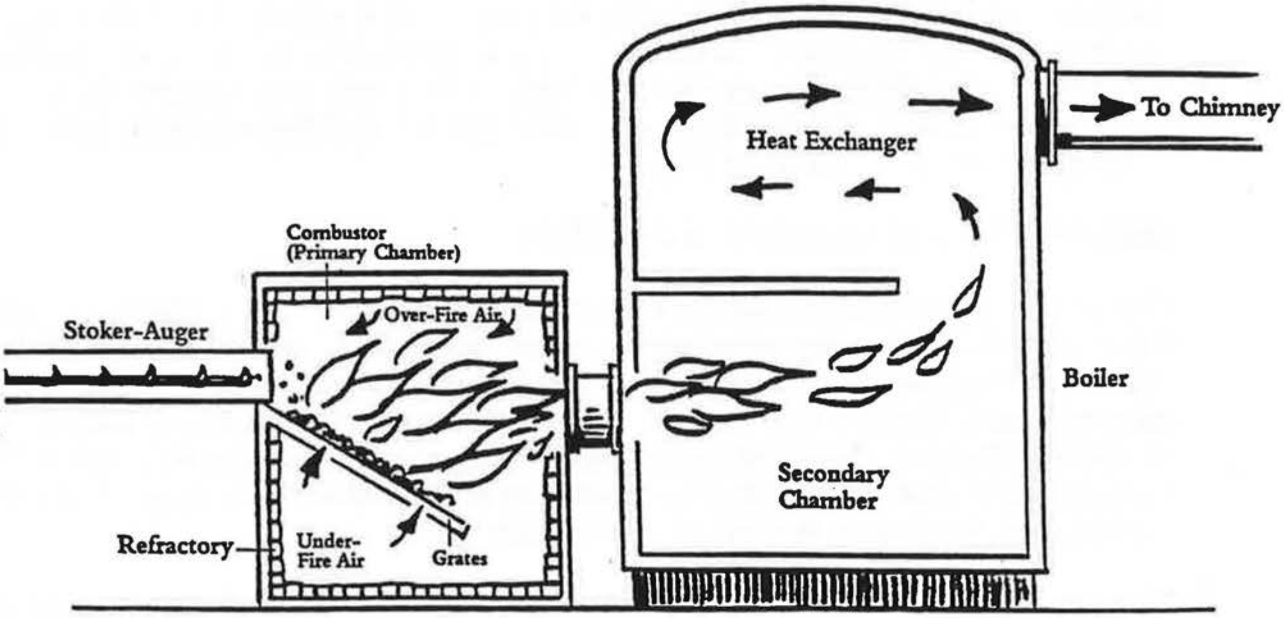


FIGURE 3

In terms of possible contributions to greenhouse gases, it is generally accepted that burning wood is carbon dioxide neutral when the fuel is harvested using sustainable forestry practices. In other words, while wood combustion does produce carbon dioxide, there is no net addition to atmospheric carbon dioxide when harvested trees are replaced with new growth.

The ash content of clean biomass fuel is generally less than 1.5%, so that for each ton of fuel burned there is no more than 30 pounds of ash produced. The ash is not toxic or harmful and in fact is a good soil additive for agricultural applications. Most plants either send the cooled ash to the landfill or give it away to local farmers or gardeners.

While the environmental benefit of burning sustainably harvested biomass or biomass from the waste stream is clear, compared to burning fossil fuels, it is difficult to monetize this benefit for combustion plants smaller than industrial or utility-scale facilities. This makes it difficult to justify the investment in conversions to biomass systems when fuel oil prices are very low, as they continue to be. However, initiatives such as the President's Climate Change Action Plan, which aims to make sharp reductions in greenhouse gas emissions, are beginning to make a positive contribution to justifying biomass-for-energy projects.

BIOMASS FUEL AVAILABILITY & DELIVERY

Biomass is readily available across the rural forested areas of the northern tier states, in the southeast, and in other areas where logging is common. A 1993 survey of the eleven northeastern states found an excess capacity of marketable biomass in every state with no indications that the resource would have trouble keeping up with an increase in demand. Most institutional heating users of biomass buy from within 50 miles of the source, whether that is a sawmill or a whole-tree chipping operation. In some cases, biomass is trucked up to 100 miles.

Biomass is a good match for energy users in rural areas, but it is also possible for it to be used in urban settings where there is a forest resource within relatively close distance. The capitol complexes of state buildings in both Concord, New Hampshire and Montpelier, Vermont are served by biomass district heating systems. The Montpelier system uses about one truckload of fuel per day; deliveries are so inconspicuous that most residents of the city are not aware of the existence of the plant.

In some markets, such as the northeast, hardwood chips are the dominant biomass fuel while in others, such as the Pacific northwest, softwood is far more common. Although systems are generally designed and tuned for one or the other, either fuel works well in automated biomass combustion systems. Green sawdust can be a good fuel, except that it can freeze in the bin in a cold climate. In some rural markets bark is very inexpensive, but is a difficult fuel to handle and burn. The costs of sawdust and bark as combustion fuels are highly dependent on competing uses. Close to urban areas, for example, bark is expensive because of high demand for landscaping mulch.

While biomass fuel is widely available, potential suppliers may not be accustomed to dealing with purchasers outside the forest products industry. A facility that wants to burn biomass may have to work hard to find and set up a relationship with a supplier, and even then delivery scheduling will not be as easy as for fuel oil.

POLICY CONSIDERATIONS

Most states have energy policies which support and promote the use of renewable energy. Yet when it comes to heating larger buildings, it is the general belief that there is no renewable option. Almost all larger buildings use the conventional fossil fuels, gas and oil, or electricity for space heating and domestic hot water. For those who are committed to promoting the use of sustainable energy, biomass provides a unique opportunity to substitute a renewable combustion fuel for non-renewable conventional fuels. Large multifamily buildings or complexes are among the many possible settings in which biomass combustion technology can be used today.

Another attractive feature of using biomass fuel is that it keeps energy dollars in the local economy, rather than exporting capital out-of-state, out of the region or out of the country. The use of biomass supports local forest products industry jobs and can help to vitalize rural economies.

Unlike most conventional forms of energy, the pricing of biomass is largely de-coupled from the national and global energy markets and so tends to be stable, promoting economic and energy security. In Vermont, which has a decade of experience with burning biomass in institutional settings, prices have risen only 5% during the ten year period, with no up-and-down fluctuations.

Only in the last two to three years have the federal government and the states begun to take aggressive steps to curtail greenhouse gas emissions. For large buildings, these initiatives generally translate into increasing the efficiency of the buildings so that they will consume less fossil energy and less electricity. Reducing fossil fuel consumption by 25% is seen as an ambitious target for energy efficiency projects. The use of biomass for heating, on the other hand, goes a quantum step beyond, providing the same level of heating while cutting fossil fuel consumption by 85-90%. As society learns to put a dollar value on greenhouse gas emissions, biomass will be likely to be incorporated into more new construction and retrofit projects.

CASE STUDY: GREEN ACRES

Green Acres is a 50-unit low-income family housing project located in central Vermont. It was built in the early 1970's when electric baseboard heat was still being vigorously promoted by utilities in the state. By the mid 1980's it was clear to the owners, the Barre Housing Authority, that the electric bills associated with electric heat at Green Acres represented a severe economic hardship to their tenants. Residents saw electric bills averaging $250 each month for the four-month winter peak period, with some bills over \$300. Even with utility allowances, the cash flow impacts of having to spend in excess of \$1,000 in electric bills over four months led to tenants getting behind on their bills. It also created a vacancy problem for the Housing Authority when tenants moved away to get out from under electric bills they could not afford.

In 1988 the Housing Authority undertook an ambitious \$1.2 million program to modernize Green Acres, using funds provided by HUD. The project included converting the individually metered electric heat and water heaters to a central hot water boiler system with wood chips as the primary fuel and oil as the backup fuel. A central boiler plant was built onto the existing maintenance building, which connected to the eight residential buildings using pre-insulated buried pipe. The constant-circulation hot water loop supplies space heat directly through hydronic baseboard radiation, and serves one domestic hot water heat exchanger tank in each building. The plumbing infrastructure (electric heat removal, installation of buried pipe, installation of hydronics, oil boilers and ancillary boiler room equipment) cost \$540,000 of HUD grant money.

The biomass portion of the project consisted of building a below-grade fuel storage bin, capable of holding one-and-a-half truck loads of wood chips, and a new boiler room with wood boiler, fuel handling equipment and controls. The wood-chip portion of the project went on line in March of 1992.

The wood-chip system was financed under a unique partnership. The building construction (for the bin and boiler room) was done out of \$100,000 in grant money supplied by the state's low-income weatherization trust fund and Vermont's multifamily housing energy conservation program. The wood-chip system cost \$95,000 and was financed by a local non-profit energy service company, Vermont Energy Investment Corporation (VEIC), using a payment-out-of savings approach. VEIC borrowed the funds from the Vermont Housing Finance Agency and is paying off the loan out of payments made to them by the Housing Authority. In effect, the Housing Authority is buying hot water from VEIC, which owns and maintains the system on the Green Acres premises, and purchases the fuel. At the heart of this arrangement is a HUD rule which allows a local housing authority to retain energy savings for a period of time, instead of having the savings revert to the federal government.

Over the first two years of operation, the system has met or exceeded all the savings and financial goals on which it was premised. Energy costs for heat and hot water have been reduced by 76%, with a monthly cost for heat and hot water of \$25 per apartment, averaged over a 12-month period. Tenant electric bills have been reduced to an average of \$34 per month.

It costs about \$1,100 per year to maintain the Green Acres wood system and about \$650 for the backup oil system. In the last year, wood has supplied 89% of heat with 11% being made up by oil. The oil system runs when the wood system is shut down for any reason, such as a late wood-chip delivery or an unplanned loss of wood fire because of an over-sized chip jamming the auger system. Although the wood system runs twelve months of the year (to supply summer DHW loads as well as heat), it is often shut down for periods of weeks in the summer due to very low loads. The Housing Authority maintenance staff spends about 20 minutes a day on the wood system, primarily in manual ash removal. The system runs untended at night and over weekends, so the Housing Authority incurs no additional labor costs or overtime in its operation.

Transforming the Market through High Performance Home Building: The U. S. EPA Energy Star Residential Buildings Program

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Abstract

This conference program presents a 15 to 20 minute overview of the recently announced EPA Energy Star Residential Buildings Program. EPA professional staff making the presentation will then use the remainder of the time to seek input, comments and ideas from home builders, sub-contractors, mortgage lenders, weatherization specialists, energy engineers, code officials, utility program managers, and other shelter industry stakeholders. EPA is interested in this input to help fine tune its vision of a true builder-oriented market driven program which results in higher market penetration of super efficient homes aimed at significant reductions in air-pollution.

Background and Significance

The EPA-Residential Energy Efficiency and Pollution Program -- which will result in pilot testing of several hundred "Energy Star Homes" nationwide has been envisioned to be entirely voluntary and market driven. Its goal is to transform the way American consumers, builders, lenders, and public officials view housing construction, remodeling, finance, marketing, material supply and its critical relationship to the environment.

Our Nation's housing is a large reservoir of untapped potential for reducing damaging air-pollution now resulting from energy waste. Significant pollution reductions through leveraging energy efficiency in profitable and cost-beneficial ways will boost the economy across a very broad spectrum, from the individual consumer's pocketbook to the health and well being of society and its institutions.

By 2010 there will be approximately 110 to 115 million built dwellings in the U.S. Authorized by Federal statutes, EPA seeks to work directly with the shelter industry to significantly reduce housing energy-related air-pollution, particularly of the gases implicated in global climate change such as CO_2, Methane, NOx, and CFC's -- through an aggressive national participatory campaign.

The EPA "Energy Star Homes" program has targeted a 50 percent reduction in new home energy use compared to the 1992 CABO Model Energy Code, to be implemented in at least 10 percent of new housing by the year 2010. This would represent an approximate 75% improvement in overall energy efficiency of housing compared to the consumption levels prevalent prior to the 1973 oil-embargo.

In addition, the program aims to foster energy efficient rehabilitation through transforming housing finance methods, in a significant portion of the approximately 60 million existing energy-inefficient homes that do not qualify for low income weatherization programs. To reach these tough goals the program will conduct analysis of existing finance, engineering, design, technical, applications, demographic, and marketing information and attempt to "learn by doing."

The EPA strongly believes that by tapping into the innovation that characterizes today's energy efficient builder and remodeler, and propagating this knowledge and dedication throughout the building industry, broader applicability of designs, techniques, products and quality assurance will transfer effectively to production housing. Such results will more fully capture the air-pollution potential and improved sustainability of development through high-performance buildings, compared to the less efficient although improved housing being built today.

Intended Audience: Home builders, sub-contractors, lenders, weatherization specialists, energy engineers, code officials, remodelers, utility program managers, consumer groups, home energy raters and inspectors, and other shelter industry stakeholders are expected to attend this session.

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	Leslie Leahy	(Super Efficient Lighting)
	Carol May	(Distribution Systems, Indoor Air)

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Mike L'Ecuyer

Global Change Division Director:

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Program Description (January 1995)
EPA Energy Star Residential Buildings Program

Goal: Transform the residential market to higher energy efficiency and reduced air-pollution emissions associated with its energy use.

Overall Objectives: Create an enhanced market pull for environmentally high performance residential development and refurbishment of existing buildings.

Strategic Approach:

- Form market pull consortiums to promote use of super efficient design, material specification, and operating strategies in new and existing homes.
- Partner directly with home builders and remodeler across the Nation to voluntarily explore together, accelerated application of the most profitable and cost effective measures.
- Conduct the necessary financial, cost, applications, marketing, and performance analysis to verify the packages selected by builders and remodelers are profitable and buildable.
- Improve financing for housing consumers, persons remodeling homes, builders, and developers with an emphasis on uniformity, simplicity, availability and security.
- Provide marketing assistance to amplify partner's position in the local marketplace with the improved product.
- Treat the building as a system, using existing popular models and features as the base line for enhancement and pilot testing.
- Engage in modest redesign during the pilot phase, emphasizing increased functionality, thermal performance, and indoor environmental quality in partner's current model new homes.
- Pilot test the most profitable packages of new construction and retrofit related energy efficiency strategies to furnish real results for the marketplace.
- Evaluate the overall performance and cost effectiveness of pilot projects together with the program partners, and communicate the successes and lessons learned to the public.
- Create and sustain industry-wide collaboration and professional alliances with the broadest spectrum of building trades, energy service providers, consumer groups, financial interests, federal agencies, product manufacturers, the dynamic utility sector, and environmental groups.

notes

FOX VALLEY WHOLE HOUSE RESEARCH PROJECT

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ABSTRACT

The intent of this paper is to review the results from a collaborative research project that assessed the effectiveness of a whole house approach to energy conservation. The objectives of the project were 1) determine how effective the whole-house system was in reducing natural gas consumption by residential customers; 2) determine what health and safety procedures must be used by contractors if the whole-house system is utilized; 3) evaluate contractor interest in adopting new techniques; 4) evaluate a pilot training effort for interested contractors; and, 5) evaluate the economic potential of the system from the customer's perspective.

INTRODUCTION

During the 93-94 heating season two Wisconsin utilities collaborated on a joint research project to determine the effectiveness of using a whole house system approach to residential energy conservation. The system involved the identification of hidden air passages and treatment work to seal them off when determined to be cost effective. A pre and post safety assessment was performed on all combustion appliances as part of the process. Differential pressure testing also was key in assessment of savings potential.

THE PROJECT

The experiment consisted of 48 treatment potential homes and 45 control homes. All structures involved in the project had previously participated in an energy conservation program. Only 16 treatment homes were found suitable based on the project assessment protocol. Savings on space heating in 11 of the 16 receiving treatment exceeded 20% on an annual basis. Treatment costs ranged from $250 to $2850. The cost associated with the assessment protocol was estimated at between $100 to $200 per house. Significant safety problems involving combustion appliances were discovered in 17 of the 93 homes participating in the project. Local contractor interest in the project was encouraging. Customer response to the treatment was extremely favorable with increased comfort often cited as one of the noticeable benefits.

BIOGRAPHICAL SKETCH FOR RANDY CHASE

Randy Chase, Residential Programs Coordinator for Wisconsin Natural Gas Company, has been involved with energy conservation programs since 1982. During his eight years with Wisconsin Natural, he has been responsible for low income weatherization, residential conservation, sales, training coordination, and technical support for customer service field personnel. Several programs he has worked on have received national awards.

Retrofitting Interior Gas Piping and Energy Systems in Existing Buildings

Robert Torbin, Foster-Miller, Inc.

1. Introduction

There are many obstacles preventing the conversion of existing multifamily buildings from centralized space and water heating to individual apartment services. The conversion from electric and/or fuel oil to natural gas for individual apartments can be cost prohibitive. Although there are significant potential energy and cost savings in undertaking these types of conversions, institutional, financial and technical obstacles have prevented wide scale implementation. Two critical issues must be addressed in the conversion of centralized heating services to individualized apartment sized natural gas systems:

- Gas Distribution: Large diameter steel pipe to a central boiler must be replaced with smaller runs of pipe to each apartment unit.
- Appliances: Small capacity apartment sized units must be introduced which require floor space, distribution ducts/baseboards, and venting.

The dual integrated appliance (DIA) combines space and water heating in a single unit which saves floor space, operates at a high efficiency, and requires only a single vent. Flexible gas piping consisting of corrugated stainless steel tubing and mechanical joints operating at 2 psi can be retrofitted for significantly lower cost than rigid steel pipe. These technologies have one thing in common: they have been developed to reduce the cost of installation and improve the utilization of natural gas.

Multifamily units have been studied in various ways to identify factors that affect fuel savings and consumption. Certain studies have concentrated on centralized versus decentralized heating in an attempt to pass the responsibility and reward for energy savings directly to the tenant. These studies range from individual unit billing allocation schemes for central heating systems to the complete changeout of centralized heating systems to individual heating units and controls.

The individual unit billing allocation study charged each building unit relative to floor area and realized 6 percent savings. It is important to note that this billing structure may not effectively maintain an overall savings. This is because one tenant's efforts/savings will be divided among all the units. Tenants may notice that their efforts do not appreciably affect their energy bill, and therefore, reduce or abandon their conservation efforts causing usage to increase.

In metering studies, where master meters are replaced by individual meters, submeters, or individual consumption monitors, savings vary from 5 to 77 percent. The savings variations are partially a result of differences in the building structures, climates, heating system types, and type and use/non-use of weatherizing. Table 1 gives a summary of the energy savings achieved through decentralization of heating. The Palermini and Hewitt 1991 study contained two buildings where the central gas-fired boiler systems were converted to individual gas space heating units. In these instances, savings of 69 percent and 77 percent were obtained. These

Table 1. ***Summary of energy savings achieved by changing from centralized heating to decentralized heating with a shift in responsibility for energy use to the tenant***

Study	Building Type	Year	Type	Savings (%)
Palermini, D. and Hewitt, D.	Multifamily building	1991	Conversion from central oil to individual electric	28
			Conversion from central gas to individual gas	69 to 77
			Central gas with allocation added	6 to 29
Scott, W.L.	Multifamily buildings, 90 units or more each. Low-rise 4 stories or less and high-rise 10 stories or more	1991	Metering	19
Bohac, et al.	Multifamily building, single and two-story	1990	Decentralized heating, DHW	13 to 19
Byrene and Fay	Multifamily building, 3-story	1989	Computer modeling	20
McClelland, L.	Multifamily buildings	1983	Metering	14

savings were directly influenced by increased tenant control of interior unit temperatures, the use of weatherizing, and the replacement of old heating systems with more efficient systems.

Use of a DIA system, where space heating and domestic hot water systems are combined, is another way savings may be realized. A study by Bohac et al. 1990 on the effects of installing DIA systems in place of conventional systems showed savings on fuel use between 13 and 19 percent. In this study, the DIA systems (with minimum AFUE values of 76 percent) replaced furnaces with AFUE values of 60.2 percent. Further analysis of these systems is needed to compare the savings of DIA systems with conventional systems of the same AFUE. Based on the information available, significant savings can be achieved by shifting from centralized to decentralized systems. In all the cited studies, energy/cost savings were realized.

2. Gas Piping Technologies

2.1 Piping Systems

Currently, steel pipe (both threaded and welded) is the most commonly used material for gas piping systems in multifamily buildings. This is a time proven system that is considered by the gas industry as being both safe and reliable. In the last few years, some plumbing contractors have taken a closer look at the benefits of installing copper tubing gas piping systems as a replacement for steel pipe in residential and commercial buildings. Primarily, the benefits are economic and ease of installation.

In large multifamily buildings, the gas piping system usually consists of two distinct portions, vertical and horizontal piping. The portion of the gas piping system in a large building that distributes gas to each floor is referred to as the "vertical riser" or "vertical main." All gas codes require that the vertical riser be constructed from Schedule 40 steel pipe. If the building is to have decentralized gas metering, a few gas utilities have assumed responsibility for the design, installation and maintenance of the vertical riser. The National Fuel Gas Code (NFPA 54) 1992 allows threaded fittings to be used on steel pipe sizes up to and including 4 in. Larger pipe sizes must be joined as welded joints. Some of the other model codes and/or utility practices are more restrictive and require welded joints for pipe sizes larger than 2-1/2 in. Most vertical risers use pipe lager than 4 in. because the systems are typically designed for low pressure service (7 in. of water) and carry large capacities of gas to service the entire building.

2.2 Semirigid Tubing Systems

The use of semirigid tubing for natural gas distribution within residential and commercial buildings has been going on for many years. Until recently, the tubing used was exclusively copper. In 1988, corrugated stainless steel tubing (CSST) was introduced to the United States plumbing industry. Corrugated stainless steel tubing is an acceptable code listed material for natural gas piping systems in the National Fuel Gas Code, Standard Gas Code, Basic/National Mechanical Code and One- and Two-Family Dwelling Code.

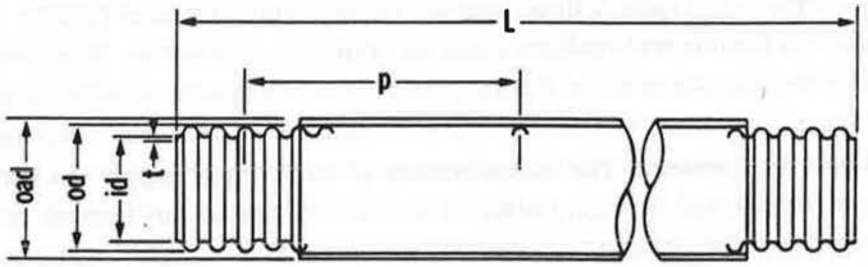
The design of corrugated stainless steel tubing used for gas piping is similar to flexible appliance connectors used by the gas industry for over 30 years. The CSST is manufactured from stainless steel and is fabricated with annular corrugations. The number of convolutions per inch and the amplitude of each convolution are both much smaller than that found on the typical appliance connector. (Table 2 describes the various dimensions of CSST.) Therefore, the CSST is much less flexible and resilient than an appliance connector. However, CSST is only intended to be flexed once or twice during installation. Unlike the appliance connector, CSST is used neither as a vibration damper, nor is it expected to be moved once installed.

CSST is sold only as a system. The manufacturer must not only supply the tubing, but also the associated mechanical fittings, multiport manifolds, special mechanical protection shields, and detailed installation instructions. In the United States, CSST systems must be certified by an independent testing organization and each component must be marked with specific information. The system is certified in accordance with the requirements of an ANSI Standard: ANSI/AGA LC-1 entitled "American National Standard for Fuel Gas Piping Systems Using Corrugated Stainless Steel Tubing." CSST is lightweight and is extremely easy to install. It has excellent corrosion resistance characteristics and is protected by an outer covering of plastic. It can be easily bundled for multiple tubing runs and can be manufactured in almost any length required. CSST uses simple mechanical fittings for joining, requiring only hand tools for assembly. CSST is currently available in four sizes: 3/8, 1/2, 3/4 and 1 in. (ID).

The use of corrugated tubing has several installation advantages over rigid steel pipe. In most installations there will be no intermediate joints between the manifold and appliance because the tubing is capable of being installed in one continuous run. This minimizes the number of potential leak sites and eliminates concealed joints. Because the tubing is bendable by hand, it can be installed more quickly and in areas that would be inaccessible to rigid pipe. This feature is especially critical in the retrofitting/remodeling of existing structures. The tubing installation requires only hand tools and, therefore, needs no heavy, electrically powered cutting/threading equipment and/or truck to carry and store piping and fitting inventories.

Table 2. Typical CSST dimensions

Effective Hydraulic Diameter	EHD	14	19	26	31
Nominal diameter	in.	3/8	1/2	3/4	1
	mm	(10)	(15)	(20)	(25)
Inside diameter (id)	in.	0.45	0.59	0.79	0.98
	mm	(11.5)	(15.0)	(20.0)	(25.0)
Outside diameter (od)	in.	0.56	0.72	0.98	1.21
	mm	(14.2)	(18.4)	(24.9)	(30.8)
Pitch/10 corrugations (p)	in.	1.34	1.50	1.97	2.36
	mm	(34)	(38)	(50)	(60)
Tube wall thickness (t)	in.	0.008	0.008	0.01	0.01
	mm	(0.20)	(0.20)	(0.25)	(0.25)
Coating thickness	in.	0.024	0.024	0.024	0.024
	mm	(0.6)	(0.6)	(0.6)	(0.6)
O.D. of coating (oad)	in.	0.61	0.77	1.03	1.26
	mm	(15.4)	(19.6)	(26.1)	(32.0)
Length (L)	ft	250	250	180	180
	m	(76.2)	(76.2)	(54.9)	(54.9)



cutting/threading equipment and/or truck to carry and store piping and fitting inventories.

Because the tubing comes in coils and is lightweight, a tubing reel can be used to expedite the running of the service and appliance lines. This technique makes it possible, in some cases, for one plumber to install the entire system. The installation is insensitive to the construction materials and structural elements. The tubing can be installed through holes drilled in the wooden floor joists, through open spaces in trusses, strapped to the sides of a floor joist, or beneath the joists. It can be run through steel studs as easily as through wooden wall studs. Since most gas piping is field run, the added flexibility of the corrugated tubing allows the installer to seek the path of least resistance around existing obstacles, either in new construction or in remodeled structures. This eliminates the repetitive measuring, cutting, threading and joint assembly common with steel pipe systems.

Mechanical fittings are used to connect the tubing with the system. Compared to steel cost. The fittings are lightweight and small enough to be easily carried around in the plumber's belt pouch. Fewer joints combined with easy, fool-proof assembly assures few, if any, problems during pressure testing of the system.

Extensive field assessments of current tubing/piping hardware and installation practices have been completed. The field tests included time and material studies in several different single family, multifamily and commercial buildings, including both new construction, retrofitting and rehabilitation. In all test buildings, both low pressure steel pipe and elevated pressure corrugated tubing systems were designed and installed. The data were analyzed for both installation labor (man-hours) and total cost (labor plus materials). The results, summarized in Table 3, have been calculated using a labor rate and material prices which have been found to reflect average costs in the United States (Torbin, Belkus, Campbell, Valentine 1989). Results from the research clearly indicate that semirigid tubing systems operated at elevated pressure are both safe and reliable, and can be installed for less cost than conventional low pressure steel piping systems.

2.3 Distribution Networks

Traditionally, when gas piping systems are installed in multifamily buildings, they are designed for low pressure service applications. This requires much larger pipe sizes than would be required if higher pressures were used to distribute natural gas within the building. As an example, if gas operating pressure was increased from 1/4 psi (~7 in. of water) to 2 psi, an increase of eightfold, the gas carrying capacity of the pipe would be increased 2.8 times. As a result of operating with increased pressure, there are large potential savings to be realized with reduced pipe sizes (both material and installation costs). Couple this with other potential savings using semirigid tubing, and the total cost savings could be substantial compared to installing low pressure all rigid steel pipe systems.

A typical advanced gas distribution network for a multifamily structure can be described as follows: Gas is supplied via a street main at a pressure up to 60 psi and reduced to a lower pressure of 5 psi by a service regulator at the building entrance (see Figure 1). Total gas supplied to the building would be monitored by a conventional gas meter, possibly equipped

Table 3. Results from piping field tests installation labor and cost comparison (CSST versus steel pipe)

Building Type	Percent Average Labor Savings Over Steel Pipe	Percent Average Total Installed Cost Savings Over Steel Pipe
Single family (all types): detached/attached wood frame/new construction	30 to 50	15 to 40
Multifamily low-rise: wood frame/new construction	10 to 70	10 to 40
Multifamily high-rise: concrete and steel frame/new construction	40 to 65	30 to 40
Multifamily rehabilitation:	70 to 80	50 to 60
Light commercial buildings: (all types)	40 to 80	30 to 60

with an automatic meter reading device. This portion of the piping system is called the gas entrance header. From that point, the gas would be distributed via a steel pipe vertical riser(s) to various upper level floors (including the roof) and/or a horizontal header to common or retail use areas on the first floor level within the building. The size of these pipes would be in the range of 2 to 4 in. The vertical piping would require chaseways and engineered floor penetrations and support devices. The horizontal piping would also require engineered supports and wall penetrations.

On each floor, gas would be distributed via a subnetwork, including another service regulator to reduce the pressure from 5 to 2 psi, compact gas meters, and semirigid distribution piping to each apartment unit. This portion of the piping system is called the gas service header. The compact gas meters, required valves, and hardware to connect the components could be installed in pre-assembled modular cubicles. Finally, the gas would be

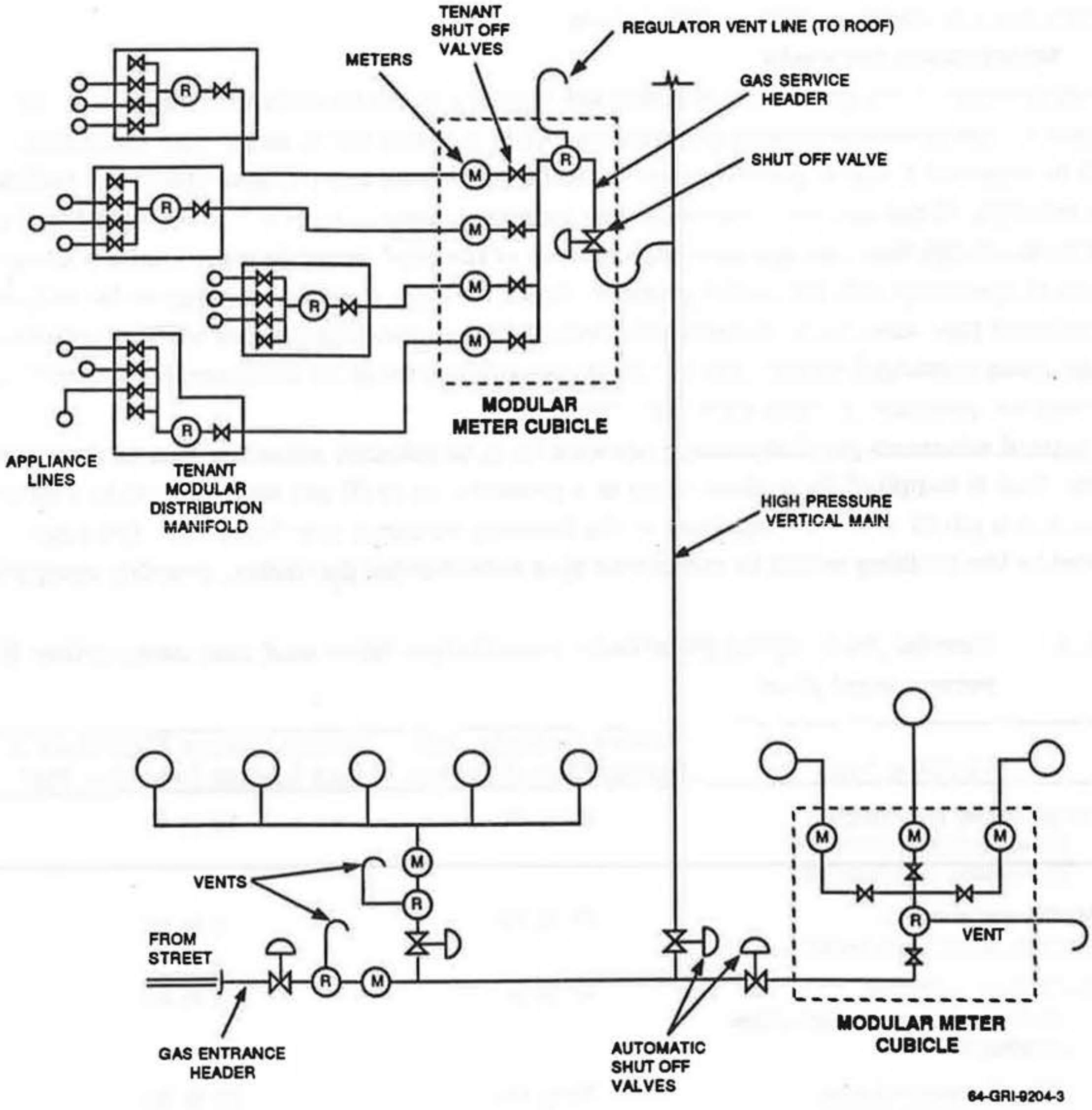
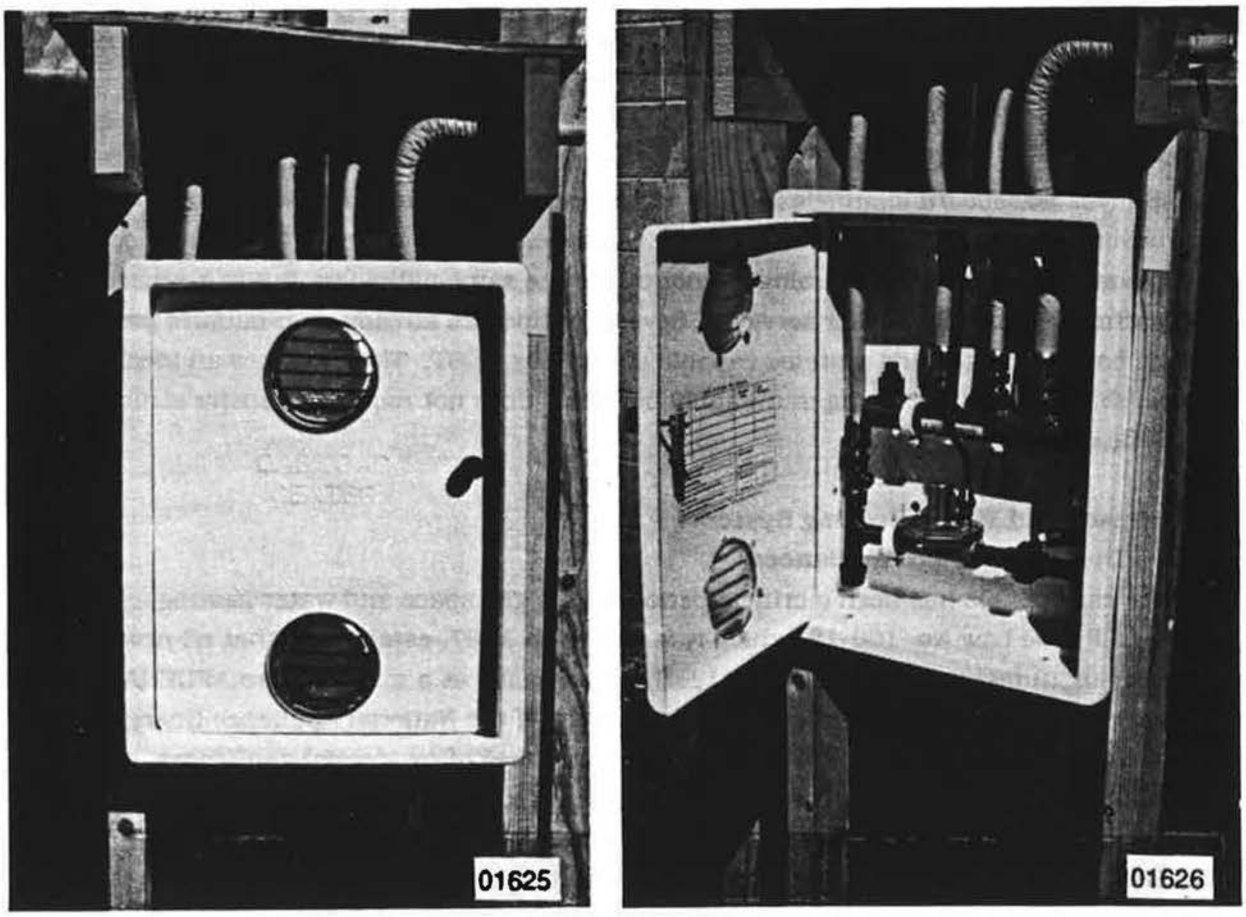


Figure 1. Gas distribution network - typical residential-commercial building

components could be installed in pre-assembled modular cubicles. Finally, the gas would be distributed within each tenant unit via the modular distribution manifold or Gas Load Center (GLC). This is essentially a second subnetwork which includes a line regulator to reduce the pressure from 2 to 1/4 psi, and a multiport manifold for delivery of the gas to each appliance or gas outlet. This approach will streamline the design and installation of the piping system by making it highly compact and efficient from a fluid dynamic standpoint, and a repetitive, common installation for each apartment.

The GLC is a fabricated plastic or steel box, designed to be installed either between two standard wall studs or on a wall surface (see Figure 2). When fully installed, the box includes a service shut-off valve, drip leg, a Maxitrol regulator (for 2 psi systems), a piping union (to facilitate regulator replacement), inspector test port, and a multi-port steel manifold with mounting bracket. The entire manifold assembly can be removed from the enclosure to



a) Door closed

b) Door open showing 4 port manifold

Figure 2. Typical gas load center

permits greater access during the tubing installation. The panel includes a hinged door which can be specified for either left or right-hand opening. The enclosure is also provided with knock-outs for five tubing runs, and can be oriented for tubing runs from above or below.

Although the manifold is designed with a standard four port configuration, it can also be customized in terms of the number and size of the ports. An optional two tier horizontal configuration is also available. All manifold components can be pre-assembled at the plumbing contractor's shop prior to field installation. Once assembled, the entire Gas Load Center can be pre-inspected and pre-tested for leakage. After the enclosure is installed between the studs, the field operation is reduced to installing the meter and appliance tubing runs, and completing the joint assembly. As an option, appliance shut-off valves can be installed at each manifold port to facilitate the servicing of the piping system, and to provide the consumer with some enhanced safety features. Each port can be numbered and recorded on a log sheet attached to the door, so that each appliance connection can be easily identified. Safety information and important telephone numbers can also be listed on a notice located on the door panel.

Chaseways are an integral part of the design of some multifamily buildings for running services between floors and along horizontal sections on each floor. These pathways are designed into some multifamily buildings for electric and water supply/drainage/fire suppression, but not necessarily for gas. It is important to minimize the size of gas piping to more easily accommodate already tight space requirements allowed for services requiring chaseways. Baseboard channels located within rooms and offices are becoming more popular for running services such as electric power, communications, and data transmission. There is no reason why semirigid gas tubing cannot utilize the same pathways, but in a separate compartment from these other services. Several companies already manufacture prefabricated plastic baseboard molding systems capable of carrying CSST. This becomes an ideal solution when rehabilitation of existing multifamily buildings does not require extensive structural or cosmetic changes.

3. Space and Water Heating Systems

3.1 Dual Integrated Appliances

The early 1990s has been a critical period for the gas space and water heating appliance market. Public Law No. 100-12, which was passed in 1987, established that all new gas furnaces manufactured after January 1, 1992 must have as a minimum an AFUE (Actual Fuel Utilization Efficiency) of 78 percent. The law is part of the National Appliance Energy Conservation Act of 1987 (NAECA) and affects 14 classes of residential appliances, of which seven classes include gas appliances. The act requires that the Department of Energy set, review and raise minimum efficiency standards over the next 15 or 20 years. Any changes in minimum efficiency standards must be "technologically feasible" and "economically justified." The law applies to appliance installations in all states, with few exceptions.

One class of gas furnaces has been devastated by the new standard. Conventional atmospherically vented furnaces cannot meet the new standard. The problem is the NAECA defines the AFUE for these appliances based on the assumption that the furnaces are installed indoors and all combustion air is supplied from the outside via ducts or grills. Any efficiency increases as a result of vent dampers are not included in the AFUE calculation. In 1991, these units accounted for approximately 65 percent of the market. The two remaining types of furnaces on the market are fan-assisted combustion systems with AFUEs of 78 to 83 percent and full condensing units with AFUEs of 90 to 95 percent. Both of these alternatives are significantly more expensive to purchase and install than the conventionally atmospherically vented furnaces. Only one manufacturer has been able to market a furnace with a 78 percent AFUE that can be conventionally vented.

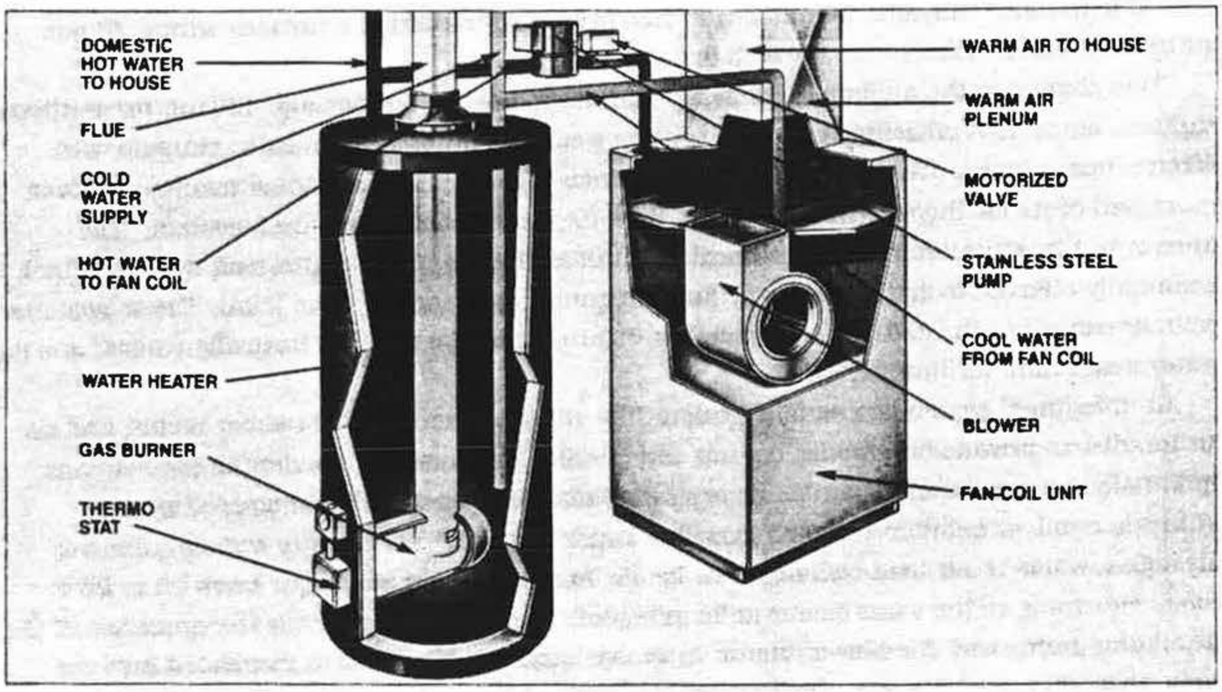
This change in the appliance efficiency standards has been especially difficult for southern utilities, since high-efficiency gas-fired heating systems cannot economically compete with electric heat pumps. The changes in the appliance efficiency standard has resulted in lower increased costs for the electric heat pump than for the equivalent gas-fired system. The answer to this situation for the southern gas utilities has been the hydro-heat system, which is commonly referred to as the combo or dual integrated appliance system (DIA). These systems were developed in the 1970s. As depicted in Figure 3, combo systems basically consist of a gas water heater and air handler.

An integrated system is a simple system that utilizes a domestic hot water heater and an air handler to provide both space heating and potable hot water for residential applications. Optionally, air conditioning can be incorporated into the system. The integrated system utilizes a small circulation pump to draw hot water from the water heater and circulates it through a water-to-air heat exchanger in the air handler. There the water loses 10 to 20°F before returning to the water heater to be reheated. A thermostat controls the operation of the circulating pump and the blower/motor in the air handler. Warm air is circulated into the home through a duct system. Cooling can be provided through the use of a split system with an evaporator coil in the air handler and a remote condensing unit (optional items).

A typical integrated system includes:

- Water Heater - A high efficiency water heater is used to satisfy both heating and space heating requirements.
- Air Handler - The air handler may be one of several configurations including a vertical unit for closet installation; a horizontal unit for ceiling installation; a wall unit for "between-the-studs" installation; or a duct coil for retrofit applications.
- Pump System - A small pump circulates hot water from the water heater to the hot water coil in the air handler. The pump may be integrally mounted in the air handler or may be mounted in the piping.
- Controls - The control system is relatively simple and includes typical controls such as a cooling/heating thermostat, pump and fan relays, 115/24V transformer.
- Water Piping - Water piping between the water heater and the air handler is field supplied. Water lines are typically 3/4 in. nominal copper or approved plastic pipe. The lines should be insulated. In addition, check valves and service valves may be required, though application varies by manufacturer.
- Condensing Units - Split system condensing units are matched to the evaporator coil in the air handler. The outdoor condensing units may be manufactured by someone other than the OEM.

Dual integrated systems are efficient, competitively priced, space saving, easy to install and maintain, and extend the life of the water heater by increasing water circulation, which reduces



How do Gas Combo-Heaters work?

The water heater operates like any conventional water heater. When space heat is needed, the sequence of operation is as follows:

1. The wall thermostat energizes a small pump which circulates hot water from the water heater through a coil in the air handler.
2. The fan in the handler comes on and blows air over the coil where it absorbs the heat.
3. This warm air is then circulated through the ducts and into the home.

Reference Source: American Gas Association

Figure 3. Combination space and water heating system

sediment buildup and corrosion. Within the United States, approximately 375,000 units have been installed in starter homes and multifamily buildings. If water heaters are properly sized, DIAs can work perfectly well in northern multifamily buildings. However three states, including New York, restrict or do not allow installation of combo units. The problem appears to be in the classification of the unit. Some state code officials have classified the water heater used in the combo unit as a boiler, thus requiring the water heater to comply with all applicable boiler codes and standards. Since boilers are pressurized, they are designed to more rigorous standards than water heaters. None of the water heaters sold currently meet the boiler standards.

Since combination space and water heating appliances are an integrated system comprised of components from several different manufacturers, a means to determine overall system efficiency was needed. To address this need, an ASHRAE Standard, ANSI/ASHRAE 124P entitled: "Method of Testing for Rating Combination Space Heating/Water Heating Appliances" was developed. The standard covers electric, gas-fired and oil-fired combination space and water heating appliances up to a rated input of 300,000 Btu/hr.

3.2 Appliance Venting

Venting systems have not changed significantly since the 1950s. What has changed, which has had a dramatic affect on venting methods, is appliance design. The products of combustion for the new classes of appliances, mid-efficiency with AFUE of 78 to 83 percent and high-efficiency with AFUE greater than 90 percent, have required that a new set of standards be developed for safe venting. To complicate matters further, many of these new appliances have fan-assisted combustion systems.

Conventional venting systems include a draft hood or diverter and an atmospheric burner. The buoyant force of the hot gas is enough to drive it from the combustion chamber, up the vent pipe and out to the atmosphere. The draft hood, among other things, allows additional indoor air to mix with the combustion products. This is called dilution. Diluted air lowers the dew point of the mixture by reducing the humidity, which also helps reduce condensation. There is a price to pay for adding indoor heated air to the combustion products. The overall efficiency of the appliance is lowered because some of the indoor air heated by the appliance goes out the vent.

To reduce off-cycle appliance losses, fan-assisted combustion systems were developed. Fan-assisted systems reduce dilution air in the vent. Unfortunately, this causes the humidity and gas dew point to rise. Also, there is less flow in the vent. With a higher dew point temperature and less gas to warm the sidewalls of the vent, the potential for condensation increases. This is true for mid-efficiency and high-efficiency appliances, which are also referred to as near-condensing and full-condensing units, respectively. Therefore, the development of a variety of more efficient appliances increased the need for different venting requirements.

On a combination pace and water heating system, there is only one vent pipe to size and install, which is an economic advantage over the separate appliance system. Multistory vents are necessary for multifamily buildings where appliances on each floor are connected via a common vertical pipe system. For rehabilitated multifamily buildings, the question is whether fan-assisted appliances can be retrofitted to replace draft-hood equipped appliances originally installed with larger vent systems. For example, the original vent system may have been sized for a 60,000 Btu/hr furnace. The replacement unit is apt to be a 40,000 to 45,000 Btu/hr mid-efficiency furnace. The smaller unit has less products of combustion. Thus, the vent system will experience a lower flow rate than with the original larger furnace. However, current research results indicate that retrofitting fan-assisted appliances into a multistory vent does not add to the risk for vent system failure.

Combination space and water heating systems require a Category 1 vent because the water heater portion of the system produces combustion products. The water heaters have efficiencies ranging from 76 to 83 percent, operate in the non-condensing range and vent under negative pressure. Therefore, no special materials or installation practices are required for the vent systems of combination space and water heating systems.

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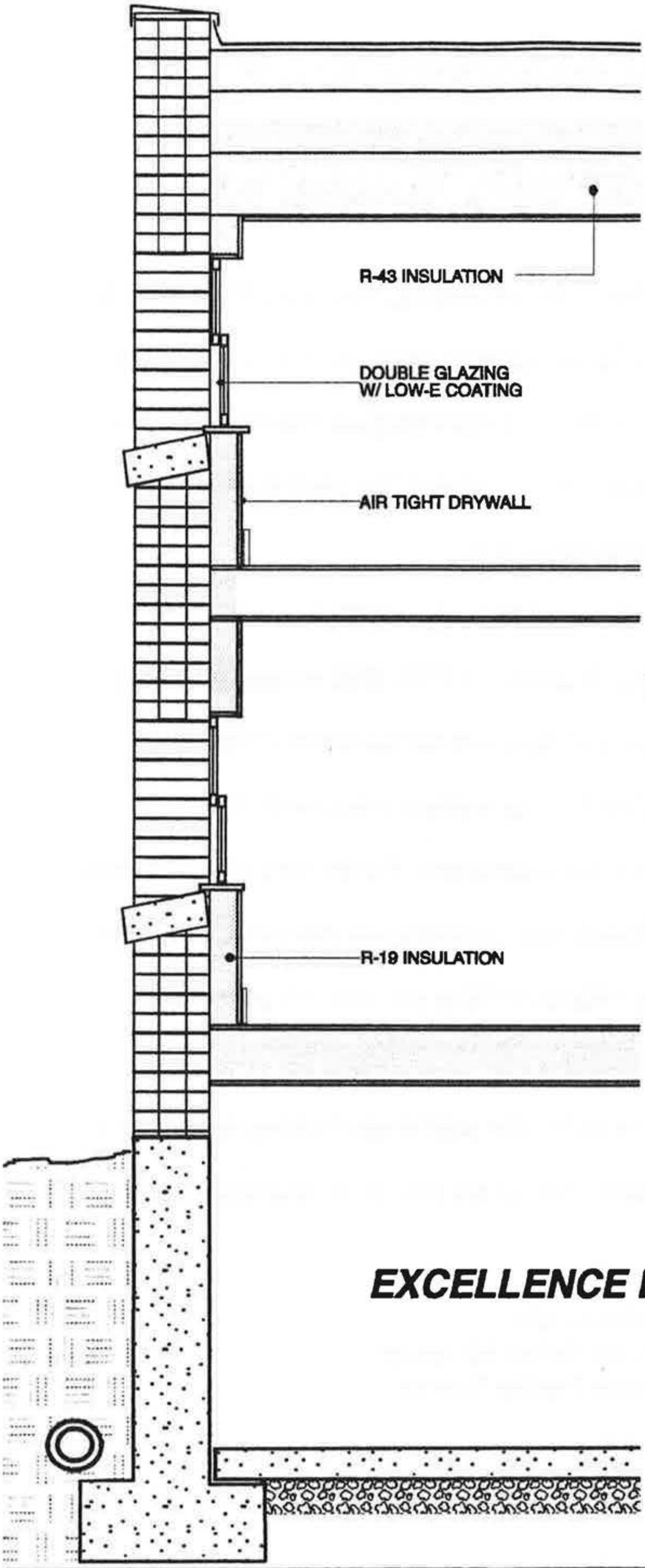
notes



SUPERINSULATION REHAB OF MULTI-FAMILY BUILDINGS

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EXCELLENCE IN HOUSING CONFERENCE

MINNEAPOLIS, MN
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ENERGY EFFICIENT AFFORDABLE HOUSING PROGRAM

MULTI-FAMILY BUILDING SUPER INSULATION REHABILITATION

I. BACKGROUND

The US Department of Housing and Urban Development defines affordable housing as a place to live that costs no more than 30% of an occupant's income, *including energy costs.* Typically, affordable rents or mortgages are achieved by minimizing construction costs. Yet, in an effort to meet this goal, energy efficiency is often excluded. The result is housing with affordable rents or mortgages, but unaffordable energy costs.

The Illinois Department of Energy and Natural Resources (ENR) has taken the lead in promoting energy efficient affordable housing. Beginning in 1988, ENR initiated the Energy Efficient Affordable Housing Program. ENR is working with Illinois non-profit affordable housing developers to integrate energy efficient building practices in both multi-family building rehabilitation and new single family home construction. The objective of the Program is to demonstrate the impact that energy efficiency has on creating and maintaining affordable housing. This paper will focus on the energy efficient building practices utilized for multi-family building rehabilitation.

The energy efficient building practices included in multi-family building rehabilitation are collectively referred to as "Super Insulation" (SI). SI is a package of measures consisting of three components;

1. High Insulation Levels
2. An Emphasis on Indoor Air Sealing
3. High Efficiency Heating Systems

ENR provides grants of up to $2,000/unit to cover the incremental costs of SI upgrades in multi-family building rehabilitation. By comparison, rehab costs in these buildings range from $50,000/unit to $80,000/unit. Energy savings range from 24% to 88% with an average savings of 70% when compared to rehab without SI measures. Monthly energy costs range from $10/unit to $42/unit in the SI rehabbed buildings.

Information about energy efficient building practices utilized in multi-family building rehabilitation are presented. Energy consumption analyzes are also given.

II. MULTI-FAMILY BUILDING REHABILITATION

The SI Multi-Family Program was initiated in 1988. Efforts were made to identify other groups from around the country who were doing similar energy efficient multi-family rehab work. No groups could be found thus SI practices originally developed for new single family home construction were modified for masonry buildings undergoing rehab.

A total of 20 buildings (192 units) have been rehabbed to date with SI building techniques. The energy efficient building practices described next are those that are typically used in SI rehab. However, methods to improve upon these practices are constantly being sought. For example, wet-spray cellulose insulation is being considered instead of batt insulation for open cavity insulation. A continuous ventilation system was used rather than individual bathroom and kitchen exhaust fans that are used as needed. Dense-pack cellulose was used where the interior finish was not removed as part of the rehab work. These variations and future plans are also explained. The practices are described in terms of **Insulation, Air Sealing** and **Mechanical/Ventilation.**

A. Insulation

Wall Insulation - Typical

Most buildings requiring substantial rehabilitation ("gut" rehab) have been abandoned for a number of years. The roof is in poor condition and all the windows are missing or beyond repair and require replacement. Electrical, plumbing and heating systems require replacement. The walls are beyond simple patching and painting.

Consequently, all plaster and lath has sustained major damage. New interior wall finishes are necessary. Original rehab plans call for removal of all plaster and lath with new furring and drywall installed over the exposed masonry. In some cases, the framing and drywall is installed over the plaster and lath given high demolition costs to remove the existing plaster and lath. Wall insulation is generally not planned.

Wall Insulation - SI

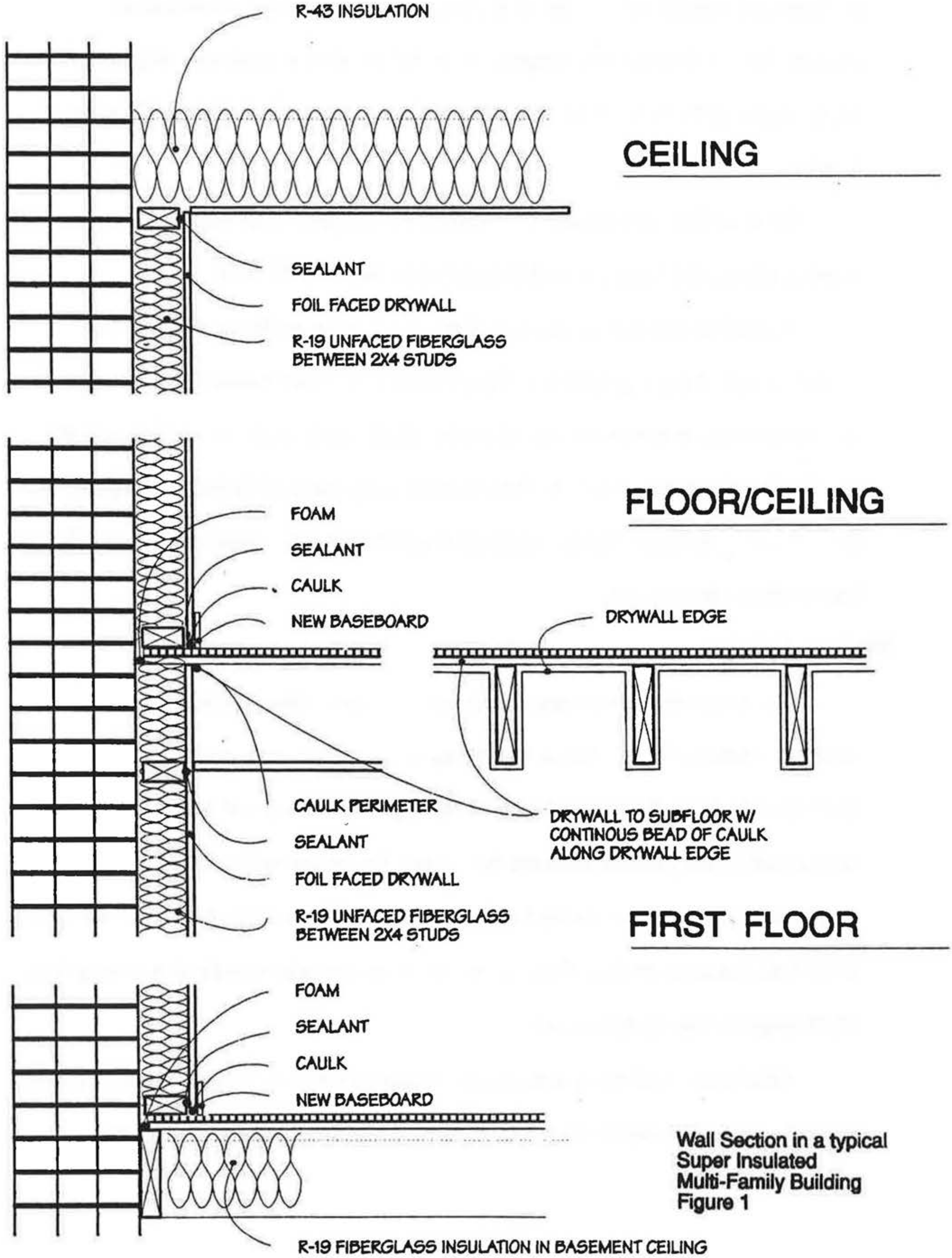
The framing system generally planned for rehab may be 3/4" metal channels or 2" x 4" framing (wood or metal studs) spaced 18" or 24" oc. SI work requires a 2"x 4" framing system.

Framing is installed on average about 1" away from the masonry wall (existing plaster/lath). This is done to move the new wall away from all irregularities that are on the surface of the masonry wall. The bottom and top plates are attached to the subfloor and ceiling joists, respectively. This is a typical framing practice where 2"x 4" framing is used in a masonry rehab project (Figure 1).

R-19 (6") insulation is used rather than 3-1/2" insulation (either R-11, 13 or 15) to completely fill the cavity. A standard 3-1/2" batt leaves a 1" air space between the

CEILING/FLOOR DETAILS

(JOIST PERPENDICULAR TO WALL) SECTION A-A



Wall Section in a typical
Super Insulated
Multi-Family Building
Figure 1

insulation and exterior wall which would allow the establishment of convective air currents. Though there is some compression of the batt, therefore not achieving the full R-19, it is believed the trade-off of completely sealing the cavity outweighs the slight loss of R-value.

Unfaced fiberglass insulation is installed. Polyethylene is not used as the vapor retarder. Rather, foil backed drywall is included as part of the SI rehab.

A problem with batt insulation in SI rehab is that the insulation is not always continuous behind framing members. Thus, there is an air space between the framing and the masonry wall. A convective current can be established in this space which lowers the effective R-value of the insulation. There is some compression of the batt as it is pushed in the wall and it was hoped that the insulation would find its way behind the framing. This has not always been the case.

Wet-Spray Cellulose

Wet-spray cellulose is being considered in lieu of unfaced batts in a number of buildings scheduled for SI rehab in the coming months. There are a number of advantages to this system. First, the space between the framing and masonry wall is filled. All spaces around conduit and junction boxes are also sealed. The insulation is installed at a higher density which acts as an air barrier but with a slightly lower R-value (R-value of cellulose drops with increased density). Cellulose is also environmentally friendly as it is made from 100% recycled material (newsprint).

Disadvantages of the system include the slight decrease in R-value of the insulation. Secondly, if installed during hot humid weather, 3 to 5 days will be needed for the insulation to dry. It is also more expensive than fiberglass batts at approximately $.65/ft^2. Air sealing measures currently required under the SI Program will be examined to determine if they are still necessary given the air sealing properties of wet-spray cellulose. Wet-spray cellulose is being considered for most buildings to receive SI rehab in the future with an open framing system.

Dense Pack Cellulose

One rehab (533 Fisher) was completed this past year where the plaster and lath was not removed because it was in good condition. This two-story, eight unit building is balloon frame construction with brick veneer. It was decided that dense pack cellulose would be used to insulate the exterior walls.

Dense pack cellulose is blown in dry at a density between 3.5 lbs/ft^3 and 4.0 lbs/ft^3 (at this density, it is very difficult to push one's finger into the insulation). Typical cellulose installation is between 2.5 lbs/ft^3 and 3.0 lbs/ft^3. Like wet-spray, increased density provides for increased air sealing but with a slightly lower R-value. 2" holes were drilled through the interior finish in each stud cavity (holes could not be drilled from the exterior because of the brick veneer). The drilled cores were retained and used to patch the walls. Pulley wells were also packed with cellulose as part of the application as the existing windows were replaced and the pulley wells were no longer needed.

Rim Insulation - Typical

The "rim" is defined as the exterior wall surface in the ceiling/floor cavity. If exterior wall insulation is planned, insulation is usually installed in the rim, although not necessarily. If built without rim insulation, heat simply bypasses the wall insulation.

Air leakage can also occur through the rim. The ceiling/floor cavity serves as a convenient path for air movement into the building via the ceiling, floor and interior walls. An effective air barrier in the rim can be created if sealed to the framing system properly. This is discussed in greater detail under "Air Sealing."

Rim Insulation - SI

R-19 unfaced fiberglass insulation is installed in the rim as part of the SI package. The insulation is cut to fit snugly between the ceiling joists and is installed concurrent with the wall insulation. Wet-spray cellulose will be installed in the rim where this insulation technique is used.

Cellulose was used to insulate the rim where dense pack was used (533 Fisher St.). This cavity was easily accessible as the wall construction was balloon frame and the rim was insulated while the walls were being insulated. Holes would have to have been drilled in the ceiling cavity between joists next to exterior wall had the building been platform construction.

Interior Masonry Bearing Wall ("fin" wall) - Typical

The objective of sidewall insulation is to provide a continuous thermal break between the interior and exterior. The key word is "continuous." Insulation can be placed behind corner studs of interior partition walls, thereby maintaining the continuity of the insulation and providing a thermal break between the interior and exterior. However, it is impossible to make this same break between an interior masonry wall and the exterior wall. These interior structural masonry walls, which are common in masonry multi-family buildings, act as "fins" by wicking heat to the outside. Addressing this problem is excluded multi-family building rehab projects.

Interior Masonry Bearing Wall ("fin" wall) - SI

Typically, the plaster/lath on fin walls is removed in a substantial rehab. The furring strips often remain on the wall and serve as a nailer for new drywall. The first 4' to 6' on the heated sides of the fin wall are insulated with 3/4" polyisocyanurate insulation following removal of the plaster and lath. The 3/4" insulation was selected for two reasons. First, it fits neatly between the existing furring strips - the fin wall does not have to be framed as the exterior walls. Secondly, it has the highest R-value per inch than other rigid insulation systems at 7.2 (Figure 2).

PLAN

TYPICAL EXTERIOR WALL WITH EXISTING BEARING WALL (FIN WALL)

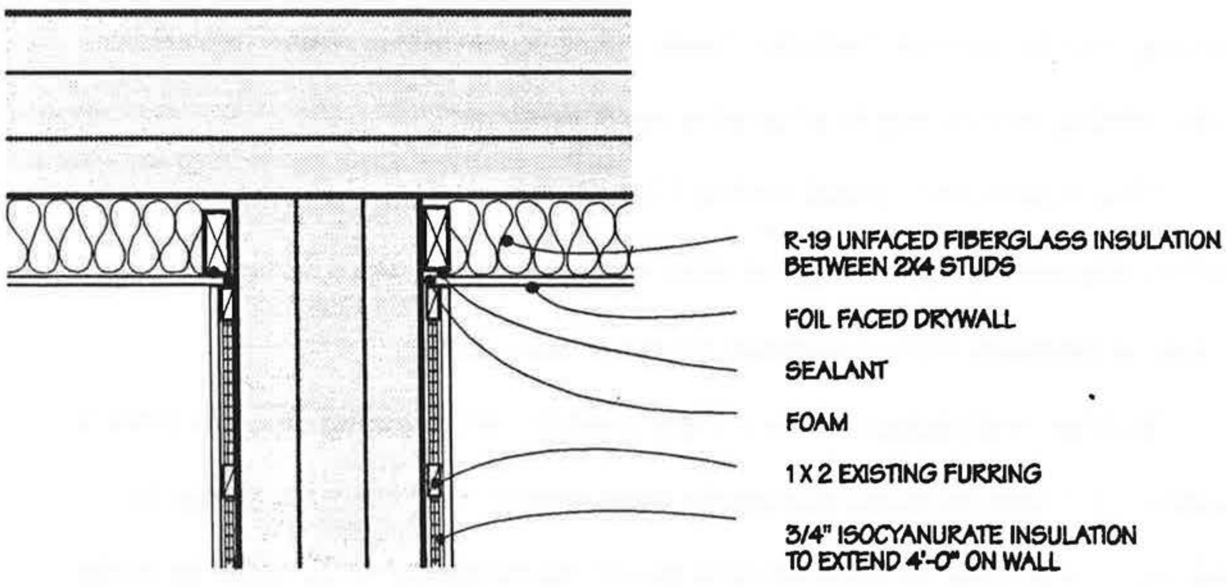


Figure 2

Attic Insulation - Typical

Older masonry multi-family buildings are often said to have a flat roof which is not entirely accurate. The roofs usually pitch front to back creating a roof crawl space of about 4' at the high end. The roof rafters are often located next to and slightly higher than the ceiling joists at the low end leaving no crawl space at all. Typical multi-family building rehab includes either R-19 or R-30 ceiling insulation where there is adequate roof crawl space. Either blown cellulose or fiberglass insulation or fiberglass batt insulation is used.

Attic Insulation - SI

Attic insulation is upgraded to R-43 under the SI Program. Where R-43 cannot be obtained given the roof /ceiling framing, the highest R-value possible with the insulation is achieved.

Windows - Typical

Windows are in such disrepair in buildings undergoing a substantial rehab that in all cases they must be replaced. Typically, double glazing is provided in window replacement. Double glazing, though, may be achieved in one of two ways.

First, a prime single glazed window is installed along with a single glazed storm window. Alternatively, a double glazed prime window (without a storm) is installed. Both are used in substantial rehab even though the second has a distinct advantage.

Both layers of glazing must be in place to achieve double glazing. If a prime/storm combination is used, the tenant must put the storm window down during the winter. In other words, it is being left to the tenant to provide double glazing. If the tenant leaves the storm up during the winter, single glazing is achieved even though the developer had "planned" for double glazing. Double glazing is achieved whenever the sash of a double glazed prime window is down - achieving double glazing is not left to the discretion of the tenant.

Little attempt is made to seal the space between the window and rough opening. In addition, pulley wells are not insulated nor are wood mullions between windows.

Windows - SI

Double glazed windows with a low-E coating are required in the SI Program. The addition of the low-E coating provides the same R-value that a triple glazed window provides at less the cost and weight of a triple glazed window.

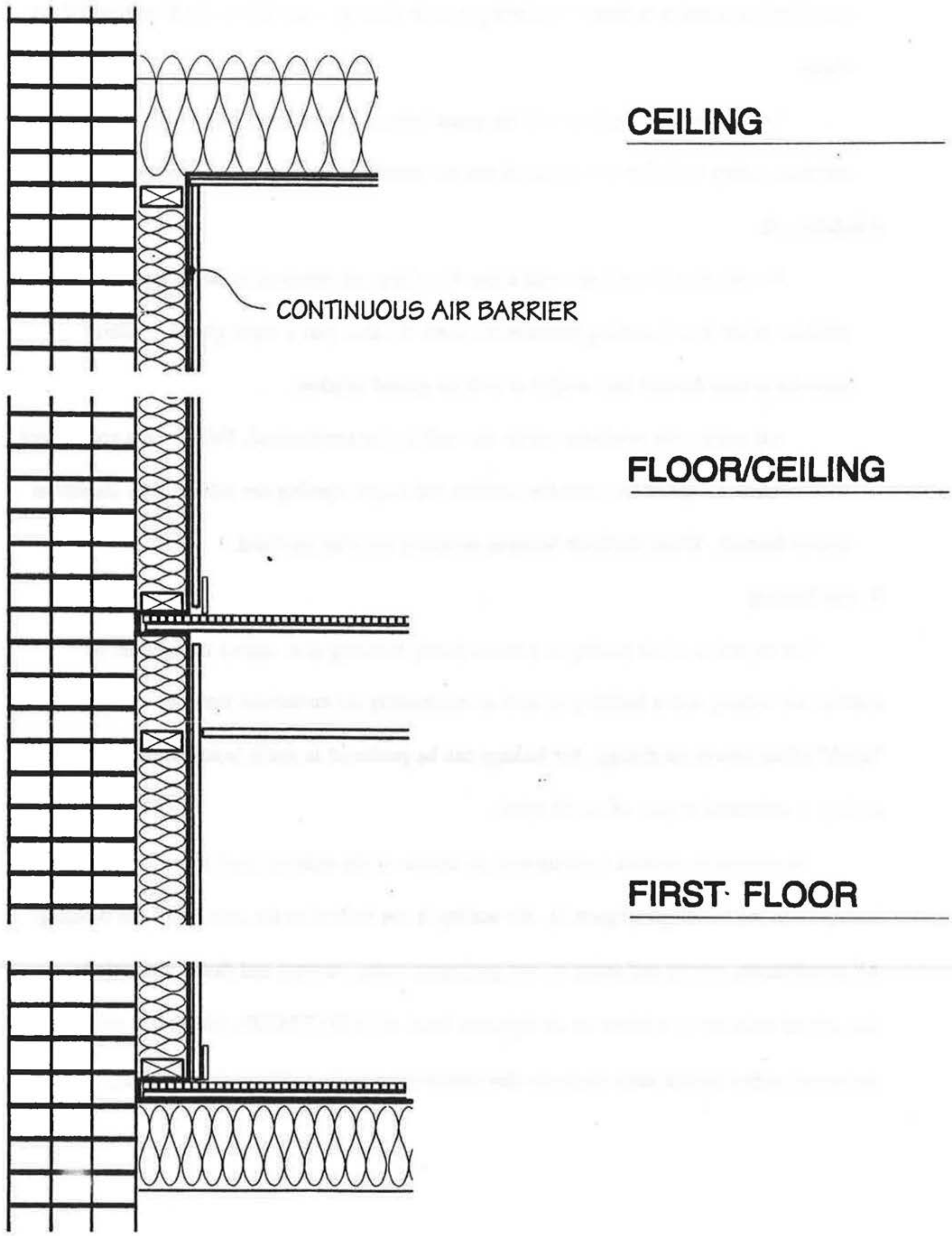
Air sealing the windows within the wall is also emphasized. Pulley wells are packed with insulation. Spaces between the window and rough opening are stuffed with insulation and/or foamed. Wood mullions between windows are also insulated.

B. Air Sealing

The objective of air sealing in a multi-family building is to reduce the amount of exterior air leaking into a building as well as minimizing air movement between units by the "stack" effect (warm air rising). Air leakage can be profound in multi-level buildings and air sealing is addressed as part of the SI rehab.

An attempt to provide a continuous air barrier at the exterior shell is made to reduce air leakage into the buildings (Figure 3). Air sealing is not limited to the exterior of the building. All penetrations, cracks and joints in unit perimeter walls, ceilings and floors are sealed. Completed units are to achieve an air tightness level of 1100 CFM50Pa (about 0.5 ACHNa) as measured with a blower door to assure that indoor air quality problems do not occur.

SECTION B-B



A conscious effort to include air sealing in a typical substantial rehab in Chicago is rarely, if ever, made. Air sealing is limited to caulking the exterior frames of windows and doors. No attempt to provide a continuous air barrier in the building shell or reduce air movement by the stack effect is made. However, including air sealing can be done at a relatively low cost utilizing inexpensive materials. Some of these same materials are often used in a typical rehab. Simply changing the manner in which they are installed, coupled with an understanding of air movement principles, can reduce air leakage.

Air Sealing the Building Shell

The Airtight Drywall Approach (ADA) is used. Drywall, coupled with sealing key joints in the wall, is used as the air barrier. The first step to air sealing the building shell is, ironically, sealing penetrations in the wall that contribute to stack effect.

Air movement by the stack effect occurs at the exterior wall and is a result of the manner in which these buildings were constructed. After the floor joists were attached to the exterior wall, furring strips were attached to masonry. The furring strips extend down past the floor joists. A subfloor was then laid across the top of the joists. However, the subfloor could not be installed up to the masonry because of the presence of the furring strips. A 3/4" gap (the width of the furring strips) exists between edge of the subfloor and the masonry wall. "Sleepers" were installed across the subfloor followed by the finished floor, usually tongue-in-groove hardwood. The 3/4" gap is maintained across this assembly due to the furring strips.

This construction is typical at each floor level and the third floor ceiling. Consequently, a continuous channel from basement to the roof crawl space is present along the masonry walls, both exterior and interior masonry walls. This cavity serves as a convenient escape path for heat moving through the wall as warm air rises.

This gap is visible when the baseboard is removed. It is especially pronounced when the plaster and lath are removed. This gap referred to as the "masonry/subfloor joint" can be sealed with expanding foam. Wide joints may be first stuffed with scraps of fiberglass or drywall and then foamed.

Sealing the joint at the first, second and third floor is necessary to cut-off the stack effect. The joint is to be sealed prior to the installation of the exterior wall framing.

Sealing this joint serves three functions. First, it eliminates the stack effect along the masonry wall. Second, it helps reduce air movement into the "sleeper" area of the subfloor where it can exit into building units from penetrations in the ceilings, floors and interior walls. Finally, it makes the airtight drywall continuous along the exterior wall from floor to floor.

Drywall is used as the major component of the exterior air barrier. An acoustical sealant is used to seal the drywall to the framing members. A continuous bead of sealant is applied to the framing members at the wall perimeter along the top and bottom plates, corner studs, and rough opening framing members. The sealant prevents air from moving into the living space from behind the drywall, for example, air moving into an interior partition wall.

In a typical rehab, drywall is installed from the subfloor to the bottom of the ceiling joists. No drywall is placed in the rim area. If the drywall is used as the air barrier, it must be continuous in the rim area. In buildings receiving SI rehab, the drywall is installed from subfloor to subfloor.

The drywall is notched to fit around ceiling joists where the joists are perpendicular to the masonry wall. The drywall is simply installed up to the subfloor where the ceiling joists are parallel to the wall.

The joint between the drywall and ceiling joists/subfloor is sealed with caulk or foam. This joint will not be seen when the ceiling drywall is installed. The bottom joint between drywall and subfloor is also sealed with caulk. This joint will be covered when baseboard is installed. The drywall is now continuous from floor to floor as can be seen in Figure 1.

There is one final advantage to this drywall system. Recall that foil back drywall is being used with the foil serving as the vapor retarder. The vapor retarder is also continuous in the rim area. A poly vapor retarder is rarely, if ever, installed in the rim area and kraft faced batts to not provide vapor seal at the framing members.

Reducing Stack Effect

A common air movement mechanism in multi-story buildings is caused by the "stack" effect; that is, warm air rises. It is quite common to have air infiltrating at the lower levels and air exfiltrating at the upper levels. Air moves up through the building through penetrations in the floor/ceiling cavities. Another objective of air sealing in SI rehab is to seal, or cut-off, these penetrations.

In essence, any penetration through the floors, ceilings and perimeter walls of a unit are sealed. Existing penetrations are exposed as part of the substantial rehab. Penetrations created as part of the rehab can also be easily sealed.

The most pronounced existing penetration found in these buildings are the plumbing stacks. These chases are open from basement to the roof cavity. The cavities are sealed at each floor level in a number of ways. If the opening around a pipe is fairly small, foam or caulk is used. Larger openings require backing with scraps of insulation or drywall followed by sealing with foam.

New penetrations that result from rehab include conduit penetrations through wall plates, panel boxes, fans and junction boxes. In all cases, caulk is usually sufficient to seal these penetrations. Caulk is also sufficient to seal the joint between drywall and panel boxes, exhaust fans and junctions boxes for lights, switches and outlets.

Air Sealing Standard

A common reaction to a discussion of the air sealing work in buildings receiving SI rehab is that they will be "too tight." This has not been the case. First, it is improbable that all holes, joints and other "nooks and crannies" found in these buildings will be sealed.

The goal of the SI Program was never to make the units as air tight as possible. Doing so would require the use of a continuous mechanical ventilation system. The cost of installing such a system has been beyond the $2,000/unit incremental cost allowed under Program guidelines needed to upgrade to SI. However, a continuous ventilation system was used in the 533 Fisher St. building. Exhaust fans are used in bathrooms and kitchens in all other buildings that received SI rehab.

An air leakage standard was set that would not require a more advanced mechanical ventilation system. That standard is 1100 CFM@50Pa, or approximately 0.5 Air Changes per Hour (ACH) natural. At this level, it is felt that sufficient ventilation air is available to prevent indoor air quality problems.

C. Mechanical/Ventilation

Buildings undergoing substantial rehab require a new heating system. Either a new central heating system is installed or forced air furnaces are installed in each living unit. The tenants usually pay the heating bills in the latter case. However, in the two Woodlawn buildings, a master meter was used with individual furnaces and the owner pays the bills.

The SI Program does not require one heating system over another. Energy consumption can be significantly reduced with either system type in the SI rehab. However, measured consumption in SI buildings has shown individual heating to generally use less energy than a central system.

The Fisher and Ellis buildings utilize a modular hot water central heating system. The Weil-McLean GV boilers (AFUE 87%) were used in both buildings. Two boilers with a rated input of 140,000 Btus (total 280,000 Btus) were installed in the Fisher building. Four boilers with a rated input of 175,000 Btus (total 700,000) were installed in the Ellis building. An outdoor reset with cutoff control was installed on each system. Weil-McLean 78% boilers were used in the Ingleside, Central Park and Van Buren buildings.

Forced air furnaces were installed in the Sunnyside, Kenmore and both Woodlawn buildings. The furnaces are direct vent sealed combustion with an AFUE of 90%. These furnaces have rated inputs of 40,000 Btus. A central domestic hot water system is used in each of these buildings.

A combination heating system was installed in each unit in the Fairfield, Washtenaw, and JP buildings. A combination heating system is simply a water heater with a fan coil that meets both space heating and domestic hot water needs. When space heating is required, water is pumped from the water heater to the fan coil. A blower then passes air over the coil where heat is exchanged. The warmed air is distributed through a standard duct system.

The Mor-Flo (now called SABH) Polaris 100,000 Btu units was used for the combination system. Though the Polaris is rated at 100,000 Btus, 40,000 Btu fan coils were installed with the units. The Polaris has an AFUE rating 90%. The appliances is direct vent sealed combustion.

Chicago building code does not require exhaust fans in bathrooms and kitchens with windows. However, exhaust fans are required in all bathrooms and kitchens receiving SI rehab to assure adequate indoor air quality. The purpose of the exhaust fans, which must be vented directly to the outdoors, is to remove moisture and pollutants from the units. The bathroom exhaust fans are rated at 75 CFM while the kitchen exhaust fans have a minimum rating of 150.

All buildings but one completed this past year have bathroom and kitchen exhaust fans that are used when needed by the occupant. The Fisher building has a continous exhaust only system manufactured by Aldes American, Two fans are used to exhaust air from the eight units. Grilles are provided in each bathroom and kitchen that exhaust 25 cfm continuously. Make-up air is provided through trickle ventilators installed on the window sash in windows in the bedrooms and living rooms.

III. ENERGY CONSUMPTION

Energy consumption was analyzed in twelve SI buildings. For comparison, energy consumption was also analyzed in eight multi-family buildings that received a "typical" rehab. In a "typical" rehab, energy efficiency improvements are generally limited to attic insulation, replacement windows and boiler replacement or repair. Energy consumption results are shown in Table 1 for the SI buildings. Energy consumption in the eight "typical" buildings is shown in Table 2..

Normalized space heating energy consumption in the SI buildings ranged from 4.22 Btus/ft^2-°FDay to 12.04 Btus/ft^2-°FDay with an average consumption of 7.58 Btus/ft^2-°FDay. Normalized space heating energy consumption in the "typical" buildings ranged from 15.91 Btus/ft^2-°FDay to in excess of 36 Btus/ft^2-°FDay with an average consumption of 25.11 Btus/ft^2-°FDay. Space heating consumption was 24% to 88% lower in the SI buildings with an average savings of 70%. Monthly heating costs/unit ranged from \$10 to \$42 in the SI buildings and \$40 to \$92 in the typical buildings.

Table 1

ENERGY CONSUMPTION - SI BUILDINGS

BUILDING	NUMBER OF UNITS	SQUARE FOOTAGE	BTU's/ SQ-FT/ DEG(F)DAY	CONSUMPTION PER UNIT (ANNUAL THERMS) MONTHLY	COST PER UNIT (ANNUAL COST) MONTHLY
JP BUILDING	20	19,500	4.31	(271) 23	($127) $11
829 W. SUNNYSIDE	12	11,400	4.22	(259) 22	($122) $10
4130 N. KENMORE	14	14,444	4.38	(292) 24	($137) $12
6138 S. WOODLAWN	10	12,531	6.11	(494) 41	($232) $19
6141 S. WOODLAWN	6	8,556	4.99	(459) 38	($215) $18
1323 S. FAIRFIELD	3	3,994	5.22	(449) 37	($211) $18
1332 S. WASHTENAW	3	3,135	9.17	(618) 52	($290) $24
533 FISHER (Rockford)	8	5,632	5.82	(284) 24	($133) $11
4119-29 S. ELLIS	23	30,234	7.40	(628) 52	($295) $25
4746 S. INGLESIDE	15	14,784	11.30	(719) 60	($338) $28
305 S. CENTRAL PARK	23	25,952	12.04	(877) 73	($412) $34
3502 W. VAN BUREN	13	19,725	10.87	(1064) 88	($500) $42

Table 2

ENERGY CONSUMPTION - TYPICAL REHABBED BUILDINGS

BUILDING	NUMBER OF UNITS	SQUARE FOOTAGE	BTU's/ SQ-FT DEG(F)/DAY	CONSUMPTION PER UNIT (ANNUAL THERMS) MONTHLY	COST PER UNIT (ANNUAL COST) MONTHLY
4740 S. INGLESIDE	6	11,700	18.58	(2339) 195	($1099) $92
4737 S. INGLESIDE	12	14,784	21.20	(1686) 140	($792) $66
400 S. LARAMIE	21	28,800	18.31	(1621) 135	($762) $63
418 S. LARAMIE	30	30,000	15.91	(1027) 86	($482) $40
500 S. LARAMIE	44	44,000	25.96	(1675) 140	($787) $66
743 N. CENTRAL	59	43,890	36.69	(1762) 147	($828) $69
541 N. PINE	50	45,182	25.07	(1462) 122	($687) $57
5700 W. RACE	43	48,978	20.14	(1480) 123	($696) $58

notes

DEVELOPING APPROPRIATE RETROFIT TRAINING PROGRAMS

BY

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THE RETROFIT PROCESS

The word "retrofit" is defined by Webster's as " ...a change in design, construction or equipment..... in order to incorporate later improvements..." Retrofit, rehabilitation, and reconstruction are all descriptions of various processes by which a building is modified, hopefully for the better. Retrofit has been the key word used to indicate an investment of time, energy and money into an existing building which might improve the building in a number of ways but which specifically targets the energy characteristics. It is the process that starts with an insightful analysis with some combination of diagnostic tools that results in a series of recommendations that are selectively prioritized based on cost benefit analysis, health and safety, personal choice and budgetary resources.

The basic challenge to the retrofit process itself, as well as to the development of a retrofit curriculum, is that it is so very site specific. Like a fingerprint, there are no identical existing situations even when two structures are identical in construction detailing, layout and dimension when first constructed. Through the aging process, and through the specific occupancy, each home develops its own unique personality, dynamic and appearance. Identifying this is key to an appropriate retrofit process. The first goal then is distinguishing that fingerprint and all of its unique characteristic. And, the first goal of any training would be to provide students with the tools to successfully identify those characteristics and to determine the dynamics of the structure and how best to rectify weaknesses in the system.

KEY ELEMENTS AND TRAINING AIDS

What are the key elements to a successful retrofit training? The first consideration of any training should be to define the purpose, goals and need for that specific training. These should be clearly defined at the outset of the training so that all participants are in agreement as to the measurable outcome of the training. There should be a trainers guide and a student manual. These do not have to be elaborate productions, but should outline all of the material to be taught, give definitions of all "concepts" discussed, describe all diagnostic equipment, provide checklists that can be used by the student in the field, and list all appropriate reference material. Also, it is important to provide a basic guide for construction management. The success of even the smallest retrofit project will hinge greatly on sane construction management principals.

In retrofit training, a great deal of emphasis is placed on audio-visual aids. Extensive slides depicting in detail all of the key construction techniques to be discussed, are vital to an effective presentation. Video tape of specific projects is also effective although harder to procure. Overheads, blackboards and/or flip charts are also required and will be used frequently throughout the presentation. Scale models, such as a plexiglass house demonstrating pressure diagnostics or air leakage, for use in the classroom are excellent tools for explaining complex concepts. Another example would be cross sections of walls, ceilings, etc. It is much easier to demonstrate the appropriate installation sequence with three dimensional models. Retrofit training automatically generates a great deal of spontaneity as individual students will draw from their experiences and specific problem resolution can become a critical part of any training.

DIAGNOSTICS

Inclusion of the full range of diagnostic equipment when possible is important to all retrofit training. This includes: the blower door; infra-red camera; combustion test kit; CO/CO2 monitors; thermometer and humidistat; pressure manometer; pressure pan; weather data charts; a bag of basic carpentry tools; safety equipment for the assessor; and, a flashlight.

The most successful retrofit classes will set up all of this in a demonstration house and spend at least a half a day conducting, discussing and interpreting the full blown assessment with all of the tools. Homes to be used for training purposes can usually be procured from volunteers, local banks, real estate agencies, housing authorities, and home lending institutions among other sources. Sometimes a trade for some basic improvements can be made for use of the house. Empty buildings are always the best when you have a number of people. Cleanup of the borrowed building is critical to ensure your reputation in the business and to encourage future cooperation from those with buildings that are perfect for training.

Many times information gleaned from this type of hands on demonstration will help the student to understand the basic dynamic of a building that will enhance assessment skills whether or not he or she can continue to bring the full array of equipment to the field in every case.

When doing diagnostics on a demonstration house during retrofit training, time is very limited. Since the training is not in the use of the diagnostic tools themselves and is simply an overview of the function of the tools and what is often found when used, there are some ways to involve the class beyond just observation. First of all, if some of the class is experienced, have them help with the tests. For those that are not, set up the blower door and give everyone a simple sketch of the floorplan of the house. Turn on the blower door and have each person (or small group) walk around the building looking for leaks which they will mark on the plan. Then bring everyone together and go over their findings in a group and take recommendations for rectifying each leakage area. There are many variations to this but it is quite effective in involving everyone in the assessment process.

Another technique is to divide the group into teams (two to four people) and assign them to different parts of the house. As diagnostics are performed, each team focuses on their particular area to bring an indepth assessment, report of unusual findings, and recommendations back to the group. If more than one demonstration house is used, the teams then switch assignments. The group then must make overall recommendations with the underlying theme that the house must be viewed as a system and that all recommendations must be looked upon in terms of their impact on the whole structure. The key is to prevent everyone standing and watching someone else demonstrate. The greater the active participation, the greater the success of the training.

RESOURCES

The more samples of commonly used products that one can bring to a training session, the better. Depending on the level of training of the participants this could include samples of all of the following: insulation, caulks and sealants, vapor barrier materials, duct sealing mastic and material, poly pans, outlet gaskets and covers, fasteners, particular types of wood products (especially trims materials used in air sealing), gaskets, siding materials, etc. Many times explaining the details of a given repair is facilitated greatly with actual material samples that might be used. Scrap lumber should be available for testing caulks and foams. Various types of caulking guns and foam applicators should be on hand so that students will have an opportunity to actually test a variety of tools. A discussion on allocated space for proper storage of materials and tools should be included. This is part of good construction management and could also be presented in a separate section.

Resource and reference materials that should be available for the class to browse includes code manuals, energy specific building manuals, general building science, basic carpentry books, and the host of excellent periodicals that are on the market today that deal with the many facets of remodel and retrofit. Brochures that describe related public programs are also appropriate, such as Energy Rated Homes, Weatherization, etc. A suggested reading list or resource directory should be compiled and given to each participant before the end of the class. Allow time for a review and discussion of the materials included. A glossary of terms is also an invaluable tool that participants can add to their own library.

PARTICIPANT CONSIDERATIONS

Controlling the size of the class is crucial to an effective training. Although there is no one correct size, a number of factors should be taken into consideration. Since retrofit does require a great deal of interaction between the trainer and the participants size of the group should be a major factor in the planning process, especially for on-site portions of training. Large groups will become easily bored and drift off if they cannot actively participate in the training. Very little is retained when people are crowded into an area where numbers of them cannot see what is happening and are not a part of the process. Keep class size to a reasonable level to maximize training. It is often difficult to limit classes to a particular level of expertise, but in teaching retrofit it is preferable to have small classes of participants with similar levels of experience and knowledge. If this is not possible, the trainer should try to discern the level of experience at the outset and mix all working groups. The more experienced students can be incorporated as training assistants.

Although it would be ideal to group class participants by experience and knowledge, this is rarely the case. Most retrofit training classes are composed of a range that begins with the inexperienced homeowner wanting to work on his own home, to the experienced builder and subcontractors, to public housing maintenance personnel, etc. All of the participants have one goal which is to learn techniques that can be applied in building to reduce energy costs, enhance comfort levels, and extend the life of their buildings. For the most part, the same curriculum can be used while varying certain aspects according to the needs of the audience.

When working with multi-cultural groups training has to be tailored to take into account some of the characteristics of the trainee group. Many of the techniques applied here are also relevant when working with groups that have a mixed experienced level as well.

One of the first rules that is basic to a good cross-cultural or mixed experience training is to realize that no one has all the answers (not even the trainer), and that often, local people will have a much better solution to a given problem than anyone else might. The oldest traditional housing was efficient, environmentally sound, maximized the use of indigenous materials, and incorporated many of the major elements of the shelter industry, i.e. sources of heat, ventilation, light, providing protection from the cold while maximizing the unique features of the site itself. It was only after the introduction of the lowest quality "modern housing" throughout the State that the quality of life degenerated to a low point creating a major crisis in these areas.

TRAINING CURRICULUM AND OUTLINE

Attached to this narrative is a section of a sample outline that is commonly used for Basic Retrofit Training. The percentage that is listed following each category is the percentage of classroom time that is spent approximately on that category. Depending on the level of training that the class has previously had, these percentages may vary some, but, a minimum of forty percent of time is spent on actual case studies. The key to producing an effective retrofit training is in gathering detailed documentation of a variety of retrofit projects from the local area. They do not all have to be successful. Those that failed in some way or another are often the greatest training tools one can use. It is critical, though, that they be well documented with slides and a narrative outline that can easily be used by a trainer who may not have been on site during the project.

A separate and specific curriculum is usually required for on-site use in the field with untrained crews. This curriculum should heavily emphasize a hands on approach throughout the training with only a minimal time is spent in the classroom. A tailored version of "Building Science" can be used as an introduction to the class. Early approaches to training on-site crews involved slight adaptations of the standard curriculum with additions of "hands-on" time. This approach was adequate but not highly effective. Much better is an approach that is centered around on-site activities with short instructional periods for the basic building sciences.

FUNDAMENTALS OF RETROFIT TRAINING

Often those that teach retrofit workshops have long histories in the construction arena but are not professional teachers. They are very good at the subject matter, but can often improve upon delivery and training technique. To ensure the long term success of any training, the following should be recognized and implemented by the trainer:

1. Before beginning the class state the rules, lay down the goals, and define the purpose and scope of the training. Be specific in what you are going to attempt to accomplish. Through

a round of introductions of class participants, try to get a feeling for the levels of experience and expectations of the group.

2. Do not talk too fast. Experienced trainers that have been giving the same curriculum over and over again, can easily breeze through the material without ever really stopping to see that the students are still actively following the class. Slow down. Ask questions that provoke a response, and wait for the response. Don't be afraid of a few moments of silence while class participants gather their thoughts. Don't just say "Does everybody understand? Okay..." and then move on. Most people will not say they do not understand. When you lose them once, you often lose them for the rest of the class. Be very specific in questions that might prompt feedback that will indicate whether or not you are being understood? You can always ask if anyone has a story that might illustrate the point you just made. If you do get back that kind of response you know that you have been understood and you can go on. Too often trainers have a "hard agenda" that they set before even meeting the class. For them success has more to do with accomplishing that agenda than making sure the curriculum is digested by the class. And, in many instances the only successful outcome of this type of approach is that the agenda was completed.

3. Do not interrupt. If someone is talking or developing a thought, let them finish. If you finish for them, you may discourage them from talking again. Allow for sufficient time for people to respond and plan your schedule accordingly. Also, be sensitive to your students and do not embarrass them in any way. Trainers who are not aware of their students feelings may lose their participation at the outset. Be positive in encouraging participation.

4. Try to limit "if this...then that" situations. This is extremely difficult in retrofit, for it is often necessary to present in terms of supposition. "If the insulation is wet and deteriorated, then we might assume that there is high moisture, no air/vapor barrier on the interior, no air barrier on the exterior, etc..." Focus on concrete examples. The best way to present all of this is through case studies where specific situations are documented and examples of retrofit strategies discussed. Do stress the immediate and long term benefits of any given measure both in potential energy savings, health and safety and increased life of the building. Focus on the practical.

5. Use a positive not a negative approach in all of your descriptions of the existing situation. Care must be given not to insult the people that you are training by criticizing their existing situation. Objectively pointing out cause and effect is essential to an effective training, but, it is wise to refrain from making judgements or acting as if there have been deficiencies on the part of local people, agencies, etc. in creating these situations. Training should strive to be non-political and positive in its approach to avoid alienation of the students. Especially in small communities, it is inevitable that someone in the class may have been involved in or responsible for the initial construction of buildings that would be good candidate for retrofit. A "let's go from here, avoid making the same mistake again, and fix what's wrong" is a great deal more productive than any kind of finger pointing.

6. If you have trouble engaging the class in actively participating, ask for their help. One of the exercises that can be done in each class is to describe the "existing situation" of a case study before reviewing what actual retrofit procedures were implemented. This exercise is a great icebreaker and will get the class actively involved and relating to each other. Break the class into small groups, give each a basic sketch of the house, describe what was found by diagnostic testing, and have each group make recommendations for retrofit. Depending on how thorough you want their recommendations to be, you can allow from fifteen to forty five minutes for this exercise. Once completed, list all of the class recommendations on a flip chart and then present the actual case study. Discussion that follows should encourage class commentary on what actually was done and why. What were the cost considerations? What code deficiencies had to be rectified? How were the results of the diagnostics given at time of the assessment incorporated into the final retrofit strategy? Were energy savings realized? If not, why? Did the class come up with recommendations that might have been better or more effective at saving energy? Were there health and safety issues to consider?

   Having the class brainstorm in small groups on case studies should be done at least twice during the class and more if possible. At some point, a case that is basically not a good candidate for retrofit should be included. For example one where the foundation is very poor and not repairable, the cost benefit just isn't there, or the framing is rotten and the structure should be condemned, and etc. Present it as a problem and let the class determine what to do. It is good to present one case that is not a good candidate to drive home the idea that there are parameters to retrofit, that cost is a big issue, that there are some things that are beyond repair, and, that sometimes it is appropriate to say "no" to a project. Since one of the biggest issues in retrofit is when to stop, and/or how far to go, this can be the most important assignment that you give your class.

7. Avoid statistics and use illustrations. Studies and compiled statistics are meaningless to many people outside of the "bureaucracy". Most points can be made much more effectively through story telling. Compiling an array of true stories to illustrate the basic principals of building science will make a mediocre training curriculum exceptional. Years after the training, these stories will be remembered and applied. This is another reason why the "case study" should be such a large part of this kind of training.

8. Be open to a different set of values that may be displayed by the class or individual students. Every culture and every economy exhibit vast differences in the style of their housing and the end use of that housing. The things that each of them consider important may not at all be what the trainer considers important. Western culture puts a high premium on space and cosmetics. Most other cultures do not. Furnishing and appliances are placed for convenience, possessions are shared, bedrooms are for sleeping, kitchens and living rooms become one, common space is often used for workshop space (especially in cold climates), and, upkeep often becomes a function of when it can be afforded. In these cases, a retrofit strategy might involve a very different set of parameters than one in an suburban neighborhood. Always keep in mind that the ultimate goal is to save energy and increase health, comfort and safety and there are many ways to get there.

9. Emphasis must be placed on the client education that is necessary to ensure continued long term energy savings after rehabilitation. It is of critical importance that anyone involved in retrofit understand that the investment in the building itself will be of minimal consequence if a long term operating and maintenance plan is not implemented and if the homeowner does not implement available low and no cost measures. Successful weatherization and retrofit programs will incorporate a client education training strategy into all aspects of their program delivery. Throughout the course of retrofit training reference should be made to client education where appropriate.

10. Develop an atmosphere of partnership with your students. You are all in this process together and their input and experience will be important in the process of discovering what the problems are in a given house and how to solve them. Stay away from the traditional teacher-student role. In every successful training the trainer as well as the students should walk away having learned something new.

FUNDAMENTALS

There is one issue that stands out as the key to a successful retrofit training. It also lies at the crux of the "retrofit dilemma" today. This is how to instill the concept of "DO NO HARM". From the world of weatherization, to HUD's moderate rehabilitation to private sector major retrofit projects, bringing a balance of energy saving measures to the house without incurring possible health and safety dangers into the dynamic of the home truly is the challenge. It is a paramount concern, especially to a retrofit trainer who may be giving a student just enough information to create dangerous situations. In most training programs, this concept should be reinforced throughout the training and specific time should be set aside separately for this issue. The role of diagnostic tools in determining the potential for health and safety problems needs to be underscored.

Emphasis must be placed on building science and viewing the house as a system. This concept must be reiterated frequently throughout training. All strategies must tie together and become accountable to their impact on the "system". Training must emphasize not only what to do, but when to walk away (even if its before beginning). Training must also stress the time, place and circumstance for calling in a professional diagnostician, such as a heating contractor, or a blower door technician, etc. This is perhaps the greatest responsibility that can be assumed by the trainer, and, the most difficult task to be accomplished through the training process.

By incorporating many of the above mentioned training techniques and by recognizing that retrofit is a most fluid science, the successful trainer will be able to help in opening up what is the most complex and challenging aspect of the construction industry today.

BUILDING ENERGY RETROFIT

A SAMPLE AGENDA

I. BUILDING SCIENCE (10%)

II. DIAGNOSTICS (15%)
- A. AIR LEAKAGE
- B. HEATING SYSTEM
- C. HEALTH AND SAFETY
- D. STRUCTURAL
- E. VENTILATION
- F. ENERGY PRIORITIES
- G. SITE CONSIDERATIONS
- H. BUILDING TRIAGE

III. METHODOLOGY (10%)
- A. COST/PAYBACK
- B. LIFE CYCLE COSTING
- C. INTERIOR
- D. EXTERIOR
- E. PROPERTY VALUES
- F. STRUCTURAL CONSIDERATIONS
- G. REQUIREMENTS ATTACHED TO $
- H. OTHER

IV. ASESSMENT STRATEGIES (20%)
- I. ON-SITE ASSESSMENT FORMS
- J. WEATHERIZATION PRIORITIES
- K. INTERPRETING THE DIAGNOSTICS
- L. COSMETIC
- M. STRUCTURAL
- N. ENERGY PRIORITIES
- O. HUD HOUSING QUALITY STANDARDS
- 8. OTHER

V. QUESTIONS OF "OPERATING AND MAINTENANCE" (5%)
- P. COST
- Q. COMPLEXITY
- R. TRAINING

VI. CASE STUDIES (40%)
- S. WEATHERIZATION
- T. LOW COST/MODERATE RETROFIT
- U. SUBSTANTIAL REHABILITATION
- V. BACK TO THE FOOTPRINT
- W. "JUST SAY NO"

HOT2000 VERSION 7 AND AUDIT2000

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ABSTRACT

HOT2000 is a comprehensive, easy-to-use energy analysis and design software, for low-rise residential buildings, that is used in the industry by builders, engineers, architects, researchers, utilities and government agencies. Utilizing current heat loss/gain and system performance models, the program aids in the simulation and design of buildings for thermal effectiveness, passive solar heating, and the operation and performance of heating and cooling systems. AUDIT2000 is a simulation software based on HOT2000 with extra features for modelling existing houses, energy conservation measures and reconciliation with utility bills.

The programs include facilities for viewing and editing weather data and fuel cost rate structures. An economics model may be used to estimate the pay-back of energy conservation measures. All reports may be viewed on screen, printed directly, or saved in ASCII files for later printing by either a built in or a separate print spooling utility. Either a mouse or keyboard may be used for navigation through the program menus and editing screens. Both HOT2000 and AUDIT2000 are available in MsDos format. A Macintosh version of HOT2000 is also available.

INTRODUCTION

HOT2000 has been used in the industry for the last ten years. Initially developed as a compliance tool for the Canadian efficient housing program, R-2000, it is now widely used as a design tool across Canada and the United States by individuals as well as for programs. However, as housing is getting older and efficiency standards are increasing the need for an auditing/retrofit tool has become apparent. Thus AUDIT2000, based on the HOT2000 program was created. AUDIT2000 was initially released in 1993 as a beta version, and has since been revised to respond to the needs of the retrofit industry.

The following report explains the technical aspects and features of both programs.

HOT2000 TECHNICAL MODELLING FEATURES

HOT2000 conducts a monthly energy balance on a house design to determine potential energy (space heating, water heating, appliances, and lighting) requirements. The monthly energy balance includes monthly and hourly bin analyses of specific building components and mechanical systems. HOT2000 contains the following technical modelling features.

Above-Grade Envelope Components

The above-grade envelope components support the following technical modelling features:

1. Areas and insulation thermal resistance values can be entered for individual building components (such as walls, floors, and ceilings). The effective thermal resistance of the assembly is calculated by the program from the construction details the user enters through pop-up lists. It takes into account thermal bridging and compression of insulation in the attic along the eaves.

2. Up to 10 entries per building component are permitted.

3. The building main wall and roof components include the solar surface heating effect of sunshine.

4. The monthly heat loss for each component is based on the area, effective insulation, and a temperature bin analysis that uses the setpoint temperature, the average monthly temperature, and the standard deviation of temperature.

Window Components

The window components support the following technical modelling features:

1. East, west, north, south, southeast, southwest, northeast, and northwest window orientations can be entered for passive solar gain calculations.

2. Based on the entry of a 6 digit code which defines the glazing type, coatings, gas fill, window type, spacer, and frame material, overall thermal resistance values and solar heat gain coefficients are calculated for each window (Enermodel Engineering, 1990).

3. Overhang geometry information is used to determine the window shading effect on passive solar gains for individual windows.

4. Shutters on individual windows on each orientation are modelled using empirically derived shutter closure periods based on latitude and solar position.

5. The window rotation feature reorients all windows by entering a new orientation for the south-facing windows. All other windows are automatically rotated to reflect the reorientation.

6. The window exchange feature exchanges all of the windows on two or more orientations without affecting the windows on the remaining orientations.

7. Monthly passive solar contribution and utilization are calculated on the basis of available solar gains, internal building mass, interior temperatures and temperature swings, house heating loads, and building mass heat storage parameters (Barakat and Sander, 1982).

Foundation and Below-Grade Building Components

The foundation and below-grade building components support the following technical modelling features:

1. Modelling of below-grade building components includes different soil and moisture characteristics to calculate heat loss rates to the surface and to the deep ground (Mitalas, 1982).

2. Open, closed (sealed), and ventilated crawl spaces are modelled, including transient heat flows to the earth.

3. Unheated crawl spaces are modelled using a derived monthly crawl space balance-point temperature.

4. Slab on grade foundations are modelled, taking into account interior, exterior or slab perimeter edge insulation.

5. Shallow-depth basements and full-depth basements are modelled, taking into account interior or exterior insulation.

6. Combination basements, including common corners, are modelled.

Infiltration and Ventilation Heat Losses

The infiltration and ventilation heat losses support the following technical modelling features:

1. Natural air infiltration rate can be determined in one of two ways; either based on fan depressurization test results (CGSB, 1985) or by choosing from a list of four air tightness types (Loose, Average, Present, Energy Tight).

2. A monthly wind-induced infiltration rate and temperature-induced infiltration rate is calculated, based on the exposure of the house to winds, wind speed, airtightness and leakage areas, and temperatures. The natural air infiltration model is based on the Alberta Air Infiltration Model (AIM-2) developed at the University of Alberta. (Wilson & Walker, 1990; Bradley, 1993).

3. Minimum continuous ventilation rates are either derived using the R-2000

ventilation guidelines, which are based on the Canadian Standards Association Preliminary Standard F326.1, *Residential Mechanical Ventilation Requirements*, or entered directly.

4. Heat recovery ventilator efficiencies are modelled using sensible heat recovery test data at 0°C and -25°C (32°F and -13°F) (CSA, 1985).

5. The heat recovery ventilator model derives an efficiency-to-temperature curve based on the test data, and derives a monthly weighted efficiency using an hourly bin analysis of temperatures against the efficiency profile curve. The effect of direct heat transfer on HRV effectiveness is accounted for (Wray, 1986; Bradley, 1993).

6. Fan and pre-heater energy consumptions are derived using a normalized temperature distribution to determine fan energy above and below the indoor setpoint temperature, so that the contribution to heating and cooling loads can be determined (Wray, 1986; Bradley, 1993).

7. The supply and exhaust ducts between the exterior of the house and the HRV are modelled to take into account the effect of heat transfer and air leakage from the duct to the space (Bradley, 1993).

Space Heating Systems

The space heating systems support the following technical modelling features:

1. HOT2000 contains default steady-state efficiencies for various types of space heating systems and calculates both monthly and seasonal efficiencies for the selected space heating system. Furnace type, fuel type, capacity, steady state efficiency, and pilot light energy consumption may be specified by the user.

2. HOT2000 calculates a design heat loss for the January 2 1/2 % temperature condition to size a heating system with or without the impact of a heat recovery ventilator (based on the National Building Code of Canada).

3. Space heating heat pumps (air, water, or ground source) are modelled using an hourly temperature and heat loss bin distribution. HOT2000 determines the heat pump capacity, coefficient of performance, and energy consumption for each hourly bin, as well as the load and part-load capacities, cycling times, and energy consumption for backup space heating systems for each hourly bin.

4. The space heating heat pump model considers various heat pump control strategies (temperature-restricted operation, unrestricted operation, or full heating load balanced operation).

Space Cooling Systems

The space cooling systems support the following technical modelling features:

1. Space cooling (air conditioning) systems are modelled using an hourly temperature and heat loss bin distribution.

2. HOT2000 models the following central air conditioning systems: conventional, ventilation, and economizer air conditioners.

3. For the purpose of determining the air conditioning size required for a house, HOT2000 can estimate the required rated capacity, indoor fan flow rate, and fan power.

4. Sensible cooling load modelling includes the effects of thermal storage and of changes due to the opening and closing of windows.

5. Latent load modelling includes the effects of outside humidity on the inside latent load (Barringer, 1991).

6. Variations in the air conditioner capacity and coefficient of performance (COP) with outdoor temperature is modelled.

7. Dehumidification by the air conditioning system is modelled.

8. Loss of efficiency due to part-load operation is modelled.

Domestic Hot Water Heating Systems

The domestic hot water (DHW) heating systems support the following technical modelling features:

1. HOT2000 calculates the contribution of a solar domestic water heating system from test data using the Canadian Solar Industries Association annual rating.

2. Primary and secondary water heating system combinations are modelled.

3. Standby losses, flue loss, hot water temperature, intake temperature, room temperature, location, and occupancy are accounted for in estimating DHW energy consumption.

Internal Heat Gains

The internal heat gains support the following technical modelling features:

1. Internal heat gain modelling includes standby losses for domestic water heating systems, interior electrical usage, pre-heater energy, and occupant heat energy.

2. A monthly internal gain utilization is derived, based on available gains, heating loads, temperatures, and utilization parameters (HOT2000 Technical Manual, 1989).

OTHER HOT2000 FEATURES

Comparing House Data Files

HOT2000 enables you to compare house data files. Entire files, as well as specific aspects such as air conditioning or above-grade components, can be compared. The comparison report may be displayed on the screen or sent to a printer.

Creating Custom Weather Data Files

HOT2000 provides Canadian and U.S. weather data files. Canadian monthly weather data, based on Atmospheric Environment Service 30-year averages, is available for 76 sites. U.S. monthly weather data, based on Typical Meteorological Year (TMY) data, is available for 200 sites. Data is also available for 10 international locations, and has been compiled from various sources and represents typical weather.

These weather data files may be edited and saved under a different name, or they can be used as the basis for creating a custom weather data file. Custom weather data files can be used in house data analyses and calculations to test designs for heat loss or gain under varied weather conditions.

From the average monthly temperatures and the standard deviation of temperatures, each month is divided into 32 bins using the EKB model (Erbs, Klein, Beckman, 1983). Calculations of heat loss and equipment operation (space heating, ventilation, infiltration) are carried out in each bin (if applicable) in order to more precisely account for temperature dependant effects.

Performing Economic and Financial Calculations

HOT2000 can do an economic analysis on the performance of energy conservation investments, or, alternatively, it can determine the energy conservation investment required to meet specific economic conditions. The program takes into account rates for data on price escalation, inflation, mortgage, savings, and taxes, and will generate an economics report.

Calculating Fuel Costs

HOT2000 enables you to select a fuel type from a number of options, and to specify a rate structure to determine the fuel cost of a particular fuel at a specified rate. These fuel cost calculations can then be included in the analysis of the proposed design.

Reporting

HOT2000 performs detailed energy efficiency calculations and provides thorough and accurate reports. The following is a list of the major features of HOT2000 reports for performing heat loss or gain analyses and comparing house data files.

1. Reports can be viewed on the screen, printed, or sent to a spool file.
2. Printed reports are available in lengths from 32 to 88 lines per page. Paper feed may be set to continuous form or single sheet.
3. All entered data can be included in a report to provide a permanent record.
4. Approximate heat loss (in megajoules or millions of British thermal units (Btu)) is reported for each building component.
5. Design heat loss results provide information for sizing space heating equipment.
6. Month-by-month summaries of gross space heating energy loads, usable passive solar and internal heat gains, net space heating energy loads, and heat recovery efficiency (if applicable) are presented in tabular form. A month-by-month summary of the below-grade heat loss, temperature, and air change rate is also provided.
7. Monthly and annual performances of heat pump and space heating systems are presented, including energy inputs, energy outputs, and coefficient of performance (COP).
8. Ventilation requirements are presented for sizing ventilation systems.
9. Annual fan use in Kilowatt (kW) hours is presented for heat recovery ventilator fans, exhaust fans, and space heating and cooling system fans.
10. Monthly and annual performances of air conditioning systems are presented, including: sensible and latent loads; air conditioner, fan, ventilator, and total fan energy; COP; and average relative humidity (RH).
11. Estimated annual fuel consumption and costs for space heating systems, domestic hot water heating, appliances, and lighting are reported.
12. The R-2000 Home Program energy consumption is reported for each house.

AUDIT2000

AUDIT2000 is an energy analysis software based on HOT2000, but targeted towards retrofit. All of the models which were mentioned previously in this report are found in AUDIT2000.

However, in order to make it more applicable towards retrofit analysis, some new features were added, including, detailed appliance and lighting entry screens, an archetype model, reconciliation against metered energy consumption, energy conservation measures (ECM), supplemental heating, a detailed indoor temperature screen, a homeowner report generator and some additional screens for making comments on the renovation history and potential of the house (structure and equipment), moisture assessment and leakage sites. Following is a description of these models.

Appliance and Lighting Screens

The appliance and lighting screens allow for either detailed entry or quick entry of the appliances and lighting in the house. The fuel type for each appliance can be specified (electricity, natural gas, propane or wood), as well as its location in the house (to account for internal gains).

For lighting, either the total load for each of the main floor, basement and exterior can be entered or a detailed summary, including the type of lightbulb used, its consumption rate and a lighting usage schedule can be entered.

Archetype Model

The archetype model allows for a quick, approximate means to generate a house file. The user inputs a minimum of details describing the house, such as its age, geographic location, length and width, number of storeys, foundation type, heating and ventilation system type and general construction of the walls and roof. The program uses these inputs to algorithmically derive wall and window areas, and to generate physical house characteristics from stored look-up-tables. The algorithms and look-up-tables were developed using an extensive database of housing characteristics. The values are then passed to the HOT2000 "core" to perform a full heat loss analysis of the house. The user can review the generated report on the house and make changes to the file through the main house editor.

Reconciliation

Actual meter readings from the utilities can be entered into AUDIT2000 (for electricity, natural gas, propane, oil or wood) for the house being analyzed. The reconciliation model will run the AUDIT2000 energy analysis and compare it to the metered readings for the specified year. A means is provided for the user to quickly assess the impact on the reconciliation of changes to three of the most error-sensitive parameters: air infiltration, amount of supplemental heating and indoor temperature.

Energy Conservation Measures

Once the house has been entered and analyzed as is, upgrades to the house can be modelled. The ECM model allows the user to specify upgrades to the envelope or to equipment (including cost) and rerun the analysis taking into account financial analysis parameters such as the inflation rate and energy escalation rate. Once the upgrade has been analyzed it can be compared against the base house or other upgrade packages to determine payback or rate of return.

Indoor Temperature Model

This is an approximate method which allows the user to account for temperature variations in different parts of the house (such as those caused by zoning) and the effect of setback thermostats. The method calculates average heating and cooling temperatures weighted by floor area and time.

Supplemental Heating

This model estimates the effect of supplemental heating systems by treating them as internal gains to the house. The types of systems that can be selected as supplemental heating systems include all primary heating systems as well as several other common secondary systems, such as gas space heaters, electric fan heaters and wood fireplaces.

Homeowner Report

AUDIT2000 passes the results and other specified information from a simulation run to a separate "WINDOWS" application which then allows the user to manipulate, preview and print a report for the homeowner. The report includes text and graphics and presents summaries of energy consumption and costs, savings potential, recommended ECMs and relevant notes of the auditor.

CONCLUSION

In order to ensure that HOT2000 and AUDIT2000 continue to be accurate and useful simulation tools, user requests, results of monitored data and the emergence of new technologies are continually being incorporated into the program.

The ongoing development of both HOT2000 and AUDIT2000 is supported by the Buildings Group of CANMET, the research and development arm of Natural Resources Canada. HOT2000 is distributed through the Canadian Home Builders Association. The basic calculation methods used for HOT2000 are derived from the National Research Council of Canada, ASHRAE and CANMET research. Validation of the program against BLAST and DOE as well as field monitoring of actual R-2000 houses built under the R-2000 Program in Canada has demonstrated the accuracy of HOT2000 as a design tool. The results from simulations of existing houses run on AUDIT2000 also correlated well with data collected in a 200 home study.

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Developing a Grassroots Political Campaign for Conservation

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ABSTRACT

The intent of this paper is to present a concept for developing a marketing campaign for conservation. The goal is to encourage support from the National Association of Homebuilders (NAHB) for a more appropriate standard of conservation in construction practices. The paper begins by discussing some of the problems builders are currently facing in the rapidly changing energy market. It then proposes some solutions that builders should consider. Finally, the paper highlights the fact that the NAHB has a gold key to unlock our environmental problems and be the new "American hero." Through education, promotion, and implementation of appropriate building techniques, the NAHB can dramatically reduce energy usage and provide a healthier and more comfortable indoor environment.

Ralph Cavanagh, Natural Resources Defense Council, states, "Marketing barriers in the residential sector are largely due to lack of information about energy use and related cost and about technologies available to reduce energy use. Energy efficiency is quite simply the most powerful engine of environmental protection ever devised..." He goes on to state," Progress remains paralyzed by inexplicable inabilities to distinguish efficiency from pain and economic stagnation..."

INTRODUCTION

In the last EEBA Newsletter, the Opinion Page addressed the fact that the NAHB has once again opposed standards that are essential to EEBA's building techniques. The greatest marketing barrier for conservation is the NAHB building industry's lack of understanding of the advantages of adopting construction techniques based on building science. The most unfortunate aspect is lack of support for mechanical ventilation. NAHB is in opposition to ASHRAE's added requirement for controlled mechanical ventilation in the proposed revision of it's Residential Ventilation Standard 62-1989. The article ended urging members to make their voices heard. Before EEBA members start writing letters and calling our local politicians to complain, let's come up with a uniform plan.

Since NAHB is the national backbone to the building industry in America and the voice for builders in Congress, it seems logical that its endorsement in appropriate energy conservation should be our highest goal. In order to achieve this goal, we must demonstrate to the NAHB that energy efficiency is indeed economic development for its industry. EEBA needs to develop a concise strategic plan that clearly demonstrates the economic development and the improvement to the final product, the house. The message that we want to deliver is that EEBA can assist NAHB on education in energy conservation so that the NAHB can ride high on a public education campaign, waving the NAHB flag.

The logical steps in developing a national grassroots campaign should be taken toward educating NAHB on why they should consider supporting conservation to its fullest. We need to set goals, define our message, and build advocacy. Most important, we need to do our research. Why don't builders support energy conservation? Why don't builders support mechanical ventilation? In order to resolve these concerns, we need to put ourselves in their shoes. We need to understand why the NAHB has not strongly adopted the new energy conservation standards, which are in line with the Canadian, Swedish and some European standards such as those set in France.

The builder sees the additional energy measures as the major threat to housing because he sees these measures as adding a higher cost to the home, often without analyzing the whole picture. We often hear from builders that energy efficiency is bad for business. If a survey was taken, the findings would show that it cannot, does not, and will not sell. It is so tough to make it in this business - all we don't need are more rules and regulations which will send us under.

I hear these myths voiced daily. They exist due to the spread of incomplete and often inaccurate information. We need to inform builders correctly by demonstrating the economic and long-term benefits of energy conservation and by giving them the tools to succeed. Education and marketing are certainly key tools in the plan. Another reason for the builders' reluctance is that all the responsibility of meeting the higher energy standards falls on their shoulders. There is so little room for financial error. If, for example, they fail to pass the blower door testing, they could lose their shirts. Builders feel that they cannot afford to take that risk. Another major hindrance is the fact that it's expensive for a builder to change his building techniques and retool his operation. If energy efficient construction is to become mainstream, incentives are needed to begin the changeover.

We must also realize that this is an industry in which the techniques have been passed on for generations. Change is typically slow and methodical. However, now we are suggesting that builders rapidly change their building techniques. Many builders are sensitive to change and feel that they are being told that they don't know how to build or are somehow at fault. This is simply not the case. Those individuals need to understand that they were following the accepted methods of the time, but now there are too many people in the world and too much fuel being used for a sustainable future. In the last 20 years dramatic changes in our understanding of how houses work have taken place. The oil shortages of the '70s and the awareness of the environmental impacts from energy usage and resource depletion has mandated the acceleration of change within the building industry. The world's appetite for energy and resources is growing exponentially. The Canadian Homebuilders Association (CHBA) has been the backbone of its energy programs. The NAHB, with EEBA's involvement, should develop an Educational Program modeled after the Canadians' successful R2000 Program. This duplication was the approach in Alaska, and with tremendous cooperation from CHBA, has been a successful national leader.

The R2000 Program refers the new building science as THE HOUSE AS A SYSTEM. Comfort and energy efficiency in these buildings are achieved by designing and constructing the structure with the understanding that the building is a combination of the various components, such as walls, floors, ceilings, windows, heating appliances, ventilation systems, and the people who use the building. A change in one component of this building "system" will affect the performance of the other parts and, therefore, the overall comfort, health, energy use and long-term durability of the building. The design and construction must account for these interactions, and most important, the effect the outdoor environment has on the building.

THE MESSAGE

The message is that EEBA would gladly assist the NAHB with a strategy to help them become successful and develop a strong marketing image at the same time. We want to help the NAHB set up a national training program. The curriculum could be developed and delivered through EEBA in conjunction with the NAHB Energy Office. We want to help them lobby for the government funding for proper training, assistance for training the crews, and on-site technical education. We want to assist in obtaining funding for professional energy education programs for the general public, as well as the industry at large, such as the architects, engineers, bankers, realtors, appraisers and inspectors.

Fortunately, energy efficient mortgages (EEMs) which recognize the added value of energy efficiency and offer financial incentives for these added measures are being set up across the country. We need to continue to make sure these programs are established for a national uniform rating system. EEMs also need to address the true cost and life of a house, as well as the energy use of the house. Through spreading the initial cost of energy efficiency across the life of the mortgage (as opposed to a 5-year payback), the added construction measures become very affordable and logical.

In Alaska a few years ago, the state funded an early adopter program through the U.S. Department of Energy (DOE) for the first Five Star Plus homes in Alaska. The financial incentives made the projects possible and successful. The builders were excited about the programs, but without the incentives (and considering tight budgets), there was not a market for these homes until recently with the new programs. All builders should have access to this fund. It is essential because it is not yet cost-effective for builders to implement a new technology in a sensitive building economy, which is especially important for small builders. They do not have extra capital, and if they do not receive assistance to retool their industry, their businesses will suffer. Financing for the NAHB/EEBA educational and incentive programs should be of highest priority for government funding.

The building industry is slowly beginning to undertake revolutionary changes, and EEBA needs to act as a catalyst by guiding the way for the industry. The NAHB has been the predominant player in the national building and energy policies; therefore, we need to set our direction to ride along with them to make the pathway for appropriate building regulations. EEBA needs to first develop a uniform building science curriculum for the building industry similar to the Canadian R-2000 Program. Then we will have the opportunity to teach the building industry the proper building techniques for a more sustainable global future. EEBA will then have a greater opportunity to be directly involved in making technical decisions on energy efficient building policy.

Energy efficiency means economic development for the building industry. It is also a key to resolving the world's environmental problems. The building industry is a logical place for launching the new public education campaign on the "Big Picture," as well as the basics of building science. The marketing message that NAHB should deliver to the public is that through housing, we can affect the environmental future by revamping the existing market and retooling the industry. The NAHB should ask for funding support from DOE and HUD for industry-wide training and public education. If the builders do not take advantage of these monies, the utilities will. Builders need to be informed about the advancing technology, have hands-on training, and receive incentive funding to assist each builder as the industry is retooled to address indoor air quality and energy conservation issues.

The NAHB should also play a major part in the energy efficient programs rather than the utilities and the government agencies. Policy on energy conservation should not be only in the hands of the local utilities who are looking at what is exclusively cost effective for their utility. The builders are the industry that has to live with the regulations, so the rules need to be understandable to them. NAHB and EEBA should be active at the local, state, and national levels. This involvement offers the NAHB the opportunity to be the recipient of the benefits from economic development and growth that the industry will experience from adoption of higher energy standards: There will be more jobs for the building industry.

Research and implementation of energy efficient building techniques have matured greatly over the last 20 years, refining super insulation technology into a building science. What is lacking is sufficient education showing the public (the demand side) and the builder (the supply side) how much energy can be saved by changing building techniques and how these techniques can improve the quality of life by making buildings more healthy, comfortable and durable - in short, better investments.

The plan will show that by investing in conservation measures, the builder can now offer a superior product. The EEBA home provides a more durable structure by eliminating moisture damage in the walls, floors, and ceilings. The indoor environment created by the EEBA house will provide improved levels of comfort and health. The energy use is typically reduced by 50-60 percent compared to conventional construction practices.

When reviewing current information on housing developments in the energy conservation field, the cost-effectiveness of the energy improvements is always carefully analyzed. Decisions are based on various formulas for payback and return on investment criteria. Included with these formulas are a variety of items, which should certainly be part of the decision process. However, in determining the appropriate expenditure for energy conserving measures, perhaps non-traditional factors should be considered.

One factor which is now receiving needed attention is the effect energy conservation has on the homeowners' quality of life. How do they feel in the house? What are the health implications of an under-ventilated house? What are the associated health care costs? Food for thought: According to The American Lung Association, asthma in the US has increased 60 percent since 1970. Weatherization efforts began to create more energy efficient buildings in a response to the energy crisis of the early '70s. Perhaps a relationship exists. Conferences and research around the world are targeting the IAQ/health issues. It seems prudent that to realistically evaluate the return on energy conserving measures, health and comfort, along with energy savings, should be factored into the equation. Future generations will benefit from this approach and the corresponding changes in building design and construction.

THE CAMPAIGN

If builders receive funding to enable them to retool their industry and funding for a public education campaign, it seems logical that the NAHB will endorse these ideas. EEBA needs to work to help builders get through this major transformation in their industry. Let's show the builders what an opportunity this change can be for their industry. We need to stress that building techniques are changing, so why not be aggressive and strong - be a leader, not a follower. By taking the bull by the horns, they can become winners in the battle to create quality homes for all Americans, have a viable economical industry and a sustainable future for generations.

Working together as a team with a uniform voice, EEBA, with cooperation from the R2000 Program and the CHBA, can develop a successful grassroots political campaign. Together we have to make a lot of noise from coast to coast - one message, loud and clear. The campaign that we want to deliver is a winner for everybody: the builders, the homeowners, and future generations. Because it's the classic WIN-WIN for all, there is no reason why we can't succeed. By following the logical steps listed on the following attachment for developing a grassroots campaign, EEBA will be successful in achieving its goals.

STEPS FOR DEVELOPING A GRASSROOTS POLITICAL CAMPAIGN

1. Join the NAHB Team:
   The goal is to have every EEBA member become actively involved with the NAHB by volunteering to sit on the regulation, energy or marketing committees. If your chapter doesn't have one, set one up.

2. Create Legislation:
   Define what you want to accomplish. Draft legislation rather than just opposing an issue.
   A. Seek legislative funding for builders for a national training program, individual assistance, hands-on training and continuing education
   B. Support a National Uniform Rating System with incentives for mechanical ventilation, sustainability, and conservation measures
   C. Seek funding for a public education campaign, as well as an education curriculum tailored to all the players in the building industry, such as Realtors, Appraisers, Architects, Engineers, Designers, and Government Agencies
   D. Shop for a sponsor and seek positive press coverage

3. Research Statistics:
   Independent research on the economic benefits and environmental implications substantiates the credibility of energy efficient building.

   A. Publicize the fact that the Canadian government has put over $50 million into research on building science, therefore, the NAHB does not have to take years to reinvent a new program.

4. Look for Advocates and Define the Audience:
   A. Identify and list potential advocates/opinion leaders. Educate and mobilize them to spread the message to target audiences.

5. Carrying the Message:
   A. Shape dialog, generate PR, host hearings, develop speakers bureaus, write letters to public officials, newspaper editors, etc.
   B. Enhance mailing lists and launch a letter writing campaign. Provide a toll free 800 number to call for more information. Follow up with phone calls to establish contacts

6. Organize & Mobilize:
   A. Create events, hold district meetings, and field hearings

7. Media Relations:
   A. Publicize success stories, create press kits, educate reporters on issues and provide independent research findings.

THE SPEAKER

Louise Palmer Nicklas

Louise Palmer Nicklas is originally from South Carolina where she studied advertising and public relations. She went on to do 2 years of graduate work in mass communications until she changed over to the fine arts for her master's degree. As a wildlife artist interested in environmental conservation, she witnessed the destruction of the shorelines on the South Carolina coast from the Savannah River nuclear power grounds and other industries. Louise was a volunteer with the Palmetto Alliance, an environmental group in the South, until she moved to Alaska in 1980. Since then she has been promoting conservation by helping establish the organization, Regroup, designed to promote recycling, reducing and reusing on the Kenai Peninsula. Watching her husband's interest in building, seeing the relationship between his work and the environment, she gave up her career as a professional potter in 1987 to devote her time to helping him start the company, HEAT Alaska, Inc., which markets energy conserving building products and services in Alaska. Her mission is to help create an awareness of how much energy can be saved by improving our buildings so that nuclear power will no longer have to be a part of the energy equation.

notes

REUSE OF MATERIALS READILY MARKETABLE WITH LITTLE OR NO PROCESSING

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Introduction

This paper presents a summary of a four-month study by SOLTERRE Design to assess the feasibility of opening a retail venture for reused building materials gained from renovation and demolition activity in the Metropolitan Halifax area.

Metropolitan Halifax, in the province of Nova Scotia, has a population of 330,000 people and an approximate construction value of $265 million in 1993 (This value includes residential, institutional, commercial and industrial activity).

Jennifer Corson, principal of SOLTERRE Design, is president the of recently established 'The Renovator's ReSource', a private retail venture marketing reused building materials from renovation and demolition activity in the Metropolitan region.

This paper will outline a proposed classification system for construction and demolition waste by the Construction Association of Nova Scotia (CANS). CANS represents those contractors who could use certain components of this waste stream, such as concrete,asphalt, bricks, other masonry, and materials associated with the demolition, roadbuilding, new construction and renovation industries.

Presented, as well from SOLTERRE's extensive survey of renovation projects, are factors which were developed for assessing reusable materials per square foot of renovation and demolition activity are presented.

Background

In September 1993, in recommendations addressed to the Nova Scotia Minister of the Environment, CANS summarized findings after conducting a four-month study regarding construction and demolition waste practices in the province.

In the letter, CANS proposes a new classification of material for easier handling, segregation, recycling and reuse of this material. To summarize, CANS recommended the following classification of materials:

- Class A materials would be those materials that do not release levels of contaminants above standard allowable limits. These materials would be classified as inert.
- Class B materials would be those materials which can be reused or recycled.
- Class C materials would be those materials that do release levels of contaminants above standard allowable limits. Such materials would be classified as non-inert.

Class A and Class C material are determined by physical characteristics alone. Class B materials would be those materials that can be recycled. These materials may be composed of both Class A and Class C materials, but are defined by economics rather than physical properties. It is important to note that a material may be both a Class A and a Class B, or a Class C and a Class B material. Identification of materials, that are sufficiently inert to be buried in a simple pit, will greatly aid municipalities in permitting and designating locations to be used for this purpose. Present lack of understanding regarding the pollution potential of these materials has contributed to a lack of municipal confidence as to the effects of such sites on the environment.

Construction and demolition debris may be classified into the three waste categories; Class A - clean, inert fill; Class B - recyclable or reusable; and Class C - waste. Much of the debris is inert material that will not decompose or release contaminants into the environment. Examples of such materials are concrete, structural brick, clean excavated material and gravel. These components of construction and demolition waste make up approximately 30-40% of the construction and demolition waste stream. Other components have the potential for reuse and recycling and make up approximately 60-70%. Such materials include asphalt pavement, roofing, wood, certain metals, plastics, paper, cardboard, etc.

There will be some overlap of Class B with Class A and Class C materials. Some Class B materials are inert and may be suitable for fill, while others may require disposal in the manner of municipal solid waste. Due to the lack of recycling efforts in Metropolitan Halifax, some of the recyclable materials have had to be disposed of as fill.

Table I. CANS Proposed Classification of Construction and Demolition Material

Material Type	Destination
Class A - Clean Fill Inert, uncontaminated material, approved by Dept. of the Environment for burial (i.e., concrete, brick, excavated material)	Private fill sites and fill on job sites. Fill sites act as a stockpile and/or permanent disposal. Such sites would be permitted by a Topsoil Permit
Class B - Reusable/Recyclable Materials that have potential for reuse on other jobs or can be recycled into new products (i.e., glass, plastic, doors, windows, fixtures, cardboard, roofing, wood, metals)	Until recycling becomes economically feasible, Class B materials will be disposed of as Class A with approval or as Class C. It is feasible to recycle Class B materials, and they should be **banned** from all landfills and private fill sites.
Class C - Waste Materials left over which must be disposed of at a special facility (i.e., contaminated fill, fibreglass, hazardous materials)	These materials are composed of municipal solid wastes and hazardous wastes that must be disposed of accordingly.

The classification of building materials, specifically the Class B materials as proposed by CANS, will lead to the flowing back of construction and demolition debris to reuse and recycling rather than to landfills. This proposed classification system is being considered as part of an extensive revision of the Nova Scotia Environment Act. It is anticipated that the new system will be tabled in the Legislature during the fall of 1994.

The Company

The Renovator's ReSource, established in August 1994, is the product of the SOLTERRE study to determine the amount of reusable building material from the construction, renovation and demolition waste streams in Metropolitan Halifax. 'The Renovator's ReSource' is a retail venture marketing retrieved, reusable construction and demolition material for the Metropolitan area. Required materials for this venture are windows, doors, lumber, fixtures (plumbing and electrical) and other valuable materials currently being landfilled. It is noted that the implementation of 'The Renovator's ReSource' will also signal to home-owners, manufacturers, and suppliers, that their unwanted items have value, and can be diverted from land fill with handling facilitated by 'The Renovator's ReSource'.

The business has three inter-related parts: the first consists of a retail location for sorting, storing and selling of inventory. An electronic inventory facilitates both the buying and selling of materials. The second part consists of the operation of a collection service for retrieving goods from smaller renovation job sites and individual home-owners. The third part will consist of a contract demolition team that will bid on and manage demolition contracts. This latter part of the operation is important for a continuing supply of goods to the retail location.

Renovation Project Site Surveys

Estimating volumes of renovation and demolition inventory for 'The Renovator's ReSource' was a difficult task. Many projects are not registered with the municipal building permit authorities, particularly residential renovation (the largest potential supplier of reusable building materials to a retail facility). This challenge was rivalled by the task of changing the mind-set of owners, contractors, renovators and demolition companies, from the waste stream approach, to the retrieval and reuse approach.

To assure the material flow and, therefore, potential sales for 'The Renovator's ReSource', an on-site survey was conducted on twenty-six renovation project sites. Sites were found with assistance of the City of Halifax Building Department. Residential projects of various sizes were also located, including additions, renovations and replacements. As well, eleven demolition contractors were interviewed by telephone as to their interests in a dismantling approach.

Contractor Attitudes Towards Recycling, Reuse and Landfill

Interest level tended to be high for smaller renovators and builders. The cost of buying new materials and disposing of wastes encourages reuse, but the lack of storage space does not allow these firms to keep useful materials. These are superb potential clients for 'The Renovator's ReSource'. Interest level is increased by the free pick-up of materials. The removal costs and ease of removal, are prime considerations for this user group.

Types of Debris Generated in Metropolitan Halifax

Types and quantities of waste materials were determined by interview or observation. Plaster and lath were a large portion of the waste generated from interior renovation projects. Wood waste was by far the largest debris component. Most of this was deemed not reusable because of size or condition (rot or nails), but possibly recyclable. Asphalt shingles and vinyl siding were universally scrapped. Fixtures, doors and windows were seldom saved unless requested.

As noted previously, many residential contractors lack the space to store materials. Some materials were reused in the same project where applicable (windows, doors and plumbing fixtures being the most common). Many items were given away when requested by clients or passers-by. Recyclable items such as copper or aluminum, if in sufficient quantity, were most commonly sold.

Volume of Debris Generated

The estimated waste generated per square foot of residential renovations and additions was 0.1 yd^3. This volume is about the size of a toilet tank. Volumes of waste for replacement repairs tended to be smaller as many items were reused.

Expenditures on residential construction were obtained from Canada Mortgage and Housing Corporation (CMHC), and from the City of Halifax. A basis of structural square footage, to determine material volumes, has been developed, against which survey factors/square foot are applied. Industrial, commercial and institutional (ICI) expenditures were obtained from the City of Halifax, and from Statistics Canada for the entire Metropolitan area.

Table II. Square Footage - Construction and Demolition, Metropolitan Halifax, 1993

		Expenditure (million) $	Average Value/ Square Foot $	Square Feet
New Construction				
-Residential	2,419 units	189.4	70	2,706,000
-ICI		75.6	100	756,000
Renovations, Repairs, Additions	1,850 permits	335.1	70	4,787,000
Demolitions	98 permits	n/a	-	147,000

New Construction Debris

While new construction accounts for substantial activity, waste generated is a fraction (perhaps 10%) of renovation activity. No new construction sites were surveyed for this project. In Table III, no values for debris retrieval were recorded, although opportunities do exist.

Renovation - Factor per Dollar Spent

Survey data was summarised and factors developed which are applied against structural square footage in Table III.

Table III. Estimated Retrieved Construction and Demolition Materials - Annual Supply for Metropolitan Halifax.

	Area ft^2/yr	Lumber (bd. ft.)	Doors (units)	Windows (units)	Cabinets (lin. ft.)	Plumbing Fixtures (units)(1)
Factor/ Sq. Ft.		1.439	.00207	.00196	.01174	.00204
New Construction(2)						
-Residential	2,706,000	0	0	0	0	0
-ICI(3)	756,000	0	0	0	0	0
Res. Renovations (4)	1,596,000	2,297,000	3,304	3,128	18,737	3,256
Demolition						
Residential	48,000	69,072	99	94	564	98
Other	99,000	142,461	205	194	-	-
Total		2,508,533	3,608	3,416	19,301	3,354

(1) Plumbing fixtures are assumed to be 50% sinks and 50% toilets.

(2) New Construction was not surveyed for waste retrieval. While some materials would be retrieved, to be conservative no values are recorded.

(3) Industrial, Commercial and Institutional.

(4) A large value for square feet (4.787 million s.f., Table III) is based upon retail sales and owner surveys. It is deemed more realistic to reduce this value by two-thirds so that repairs, which produce little valuable waste, are excluded. The remainder, as shown, represents additions and renovations, a likely generator of material supply.

Demolition

In 1993, 98 demolition permits were issued in Metropolitan Halifax. No information on structural square footage was available, however, about one-third were residential and an estimate of 1,500 sq. ft. per structure demolished, is used.

Demolition contractors tend to use machinery which precludes the careful separation of materials necessary for salvage. Tender specifications indicate the method used and time period allowed. Contacts are found prior to demolition, when materials are saved, since most contractors do not have storage space available.

Business Potential

Once 'The Renovator's ReSource' is operating at full capacity, it is estimated, with means of the survey material volumes that the outlet will have annual estimated sales as listed in Table IV. The prices for the reused materials will be generally from 10-30% of their market value.

Table IV. Estimated Annual Supply

($ Dollar Value of Sales)

Product	Potential Supply	Price	Sales
Lumber	2,508,533 bd. ft.	$ 0.10/bd.ft	$250,853
Doors	3,608 units	$ 5.00 / unit	18,040
Windows	3,416 units	$ 5.00 / unit	17,080
Cabinets	18,737 lin. ft.	$ 5.00/lin.ft	93,685
Plumbing Fixtures	1,677 toilets	$15.00/toilet	25,155
	1,677 sinks	$25.00/ sink	41,925
	POTENTIAL SALES		$446,738
	TOTAL SALES (1)		$893,476
	ESTIMATED NET ANNUAL TOTAL(2)		**$223,369**

(1)On the basis of the Winnipeg ReStore experience it is estimated that the above items will be approximately 50% of total annual sales of 'The Renovator's ReSource', therefore, the potential annual sales from all renovation, construction and demolition activity is expected to be $893,476.

(2)It is anticipated that 'The Renovator's ReSource' will have involvement with 1 in 4 projects, or 25%, which generate saleable materials, therefore, the expected sales from the first year of operations is expected to be $223,369.

Conclusion

Progress has been slow in achieving tangible gains in the reuse or recycling of valuable waste. Long standing beliefs and attitudes by owners, engineers and contractors are giving way to recycling initiatives and to public demand for improved environmental protection. A recent hike in tipping fees, from $43 to $74/metric tonne, will continue to put pressure on the owner and contractor to separate their building materials prior to general disposal.

There is great opportunity to expand the entire retrieval system of materials from construction, renovation and demolition waste stream in Metropolitan Halifax. SOLTERRE is expanding its' business opportunities by initiating a pre-demolition audit consulting service and an electronic materials exchange. Other companies are currently looking at the feasibility of opening construction and demolition disposal sites for the Metropolitan region. It is recognized that the lack of legislation pertaining to construction and demolition disposal is retarding progress for these sites.

A review of this legislation at all levels of government pertaining to the management of construction and demolition debris within Nova Scotia is needed. Recommendations with respect to controlling all aspects of construction and demolition debris, specifically, the defining (classification system) and handling processes must be clarified.

The above mentioned projects, specifically the establishment of 'The Renovator's ReSource' will result in reduced amounts of construction and demolition debris going to landfill sites and increased amounts being reused and recycled. This will extend the life of all municipal landfills which now receive construction and demolition debris, and will reduce the amount of virgin material being used in construction. This certainly supports a sustainable construction future for Nova Scotia.

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Current Problems in Construction and Demolition Materials Disposal in Metropolitan Halifax Region, Construction Association of Nova Scotia.

Habitat for Humanity ReStore, Winnipeg, 1992 Annual Sales and Expenditures.

notes

ENVIRONMENTAL AND ECONOMIC IMPACTS OF VARIOUS RESIDENTIAL BUILDING PRODUCTS, CONSTRUCTION METHODS, AND DESIGN CHOICES

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ABSTRACT

This study demonstrates the use of an environmental audit for three model houses. The impacts of house size, material selection, and level of energy efficiency on raw material consumption, energy use, and building and maintenance expenses are examined. A baseline house serves as the model for comparison. Choices of building products for this house are based on a survey of home builders in a three-county area of New York State. The two alternative models are designed using advanced technology for decreasing raw material inputs.

INTRODUCTION

Humans have manipulated and consequently have had an impact on the natural environment for thousands of years (Wagner, 1974). The first Earth Day which occurred on April 22, 1970 was perhaps the beginning of the heightening of public awareness of the negative impacts that human activities often have on the planet (Kneese, 1990).

With the evidence of environmental problems such as erosion of farmland, deforestation, the continuing problem of ozone depletion, and signs of global warming mounting (Worldwatch Institute, 1992), the concern for environmental problems has grown, and the realization of the need to take action is becoming apparent throughout the global community. In the decade of the 90's even American industry is concerned about environmental issues and is cooperating to begin to address environmental problems (Kneese, 1990).

With the global population continuing to increase and as the economies of the world become globally linked, the demand for energy and raw material inputs is expanding at a brisk rate. In the span of 40 years, global per capita consumption of copper, energy, steel, and wood has doubled (Durning, 1991).

Statistics collected by the U.S. Government illustrate that increasing demands upon natural resources also continue within the United States. In 1975, 32.6 billion board feet of lumber were consumed in the U.S. In 1985, this figure had increased to 36.4 billion board feet and by 1989 had further increased to 43.6 billion board feet, (Agricultural and Forestry Statistics reported by Statistical Record of the Environment, 1991). Modern industrial economies require a vast amount of natural resources to provide the varied raw materials from which to manufacture products, devices, machines, and structures (Material and Mans Needs, 1974).

The U.S. economy is a giant consumer of natural resources to convert to raw materials and to supply the energy that the economy requires. The rate of domestic output in the U.S. has been especially dramatic since late in the decade of the 1940's, with total goods and services doubling every fifteen years since that time (Stephenson, 1981).

The US construction industry, comprising 8.4% of national GNP in 1988, is one of the largest industries within the US economy (R&D in the Construction Industry, 1989). As a major industry, construction places high demands upon existing natural resources to supply raw materials for the manufacture of building components. In addition, many waste products are generated from the manufacture and installation of these products, to the extent that the building industry is currently responsible for approximately 35% of emitted chlorofluorocarbons into the atmosphere, 30% of carbon dioxide emissions, 35% of solid waste, 35% of annual energy consumption and vast quantities of natural resource consumption (Wilson, 1992).

The United States housing industry, as a significant proportion of the nation's total construction industry, consumes a vast amount of natural resources, by both type and volume. In 1987, the National Association of Home Builders (NAHB) estimated that a typical 1,700 square foot single family home required 9,726 board feet of lumber, 55 cubic yards of concrete, 2,500 square feet of insulation, 3,016 square feet of aluminum, brick, or wood siding; 1,992 square feet of asphalt roofing shingles; 3016 square feet of roof, wall, and floor sheathing, 750 linear feet of copper wiring; 280 linear feet of copper tubing; 302 pounds of nails, and 55 gallons of paint (NAHB, 1987). In addition, the average size single family home produced in the US has been steadily increasing for the past 40 years. In 1963 the average size home constructed was 1,365 square feet; 1,660 square feet in 1973, 1,740 square feet in 1983 (Prowler, 1985) and 1,966 square feet in 1991 (F.W. Dodge Statistical Services, 1993). The raw material and energy inputs required to manufacture the products for and to construct housing have a significant impact upon the natural environment.

GREEN BUILDING

The impact that buildings place upon the environment has been gaining attention within the construction industry. Articles have started to appear in professional and trade publications on the subject of "green buildings." These articles illustrate designers', builders', and engineers' concern about the environmental impact of the erection and operation of buildings . "Building Green," an article in Civil Engineering (1991), reviews the work of several groups attempting to answer questions such as "is it possible to choose construction materials made from renewable, safe resources?...(and)...must they require an excessive amount of energy to produce or transport?" (Austin, 1991; p. 52). The American Institute of Architects (AIA) has been working to encourage designers to design environmentally responsible buildings by publishing the Environmental Resource Guide, a quarterly journal that attempts to provide design professionals in the construction industry with information."about how design choices affect the environment" (Crosbie, 1992, p.99).

In addition to the increasing number of articles appearing in professional and trade journals in the construction industry, conferences on the subject of "green buildings" are being held around the world. The Royal Institute of British Architects (RIBA) held a conference for its members in 1989 entitled, "Towards Green Buildings." This conference presented "an overview of what the current environmental issues are from a number of perspectives...(and)...raised the question of how environmental issues are likely to affect the commissioning, design, operation, and maintenance of buildings within the next 10 years" (Lorch, 1990; p.58). The United States National Institute of Standards and Technology (NIST) recently held a conference entitled, "US Green Building Conference." Papers were presented at this conference which examined methodologies for determining criteria for "green buildings" as well as on new technologies currently being explored in the areas of building materials, lighting, and indoor air quality (NIST Publication 863, 1994).

Typical criteria for determining which material, method or design to choose when building or renovating are "aesthetics, budget, performance, codes, and availability" (ERG; 1992, p.I.1). Currently emerging in the design and construction industry is the idea of including criteria that take into account the environmental impact associated with different material, method and design choices. Green Building is the term that has emerged to describe buildings that do include environmental criteria when making these decisions. However, the term "Green" is cause for confusion within the building industry (Crosbie, 1991). As Wardell (1993) states: "There's no definitive meaning of the term 'green' and no widely accepted way to measure or quantify it" (p.54).

Market Failures and Environmental Impacts of Buildings

One of the factors that make it necessary to define and attempt to determine what the environmental impacts of various building choices are (or what is a 'green' building) originate with the way national economic accounting systems are structured. External costs cause resources to be poorly allocated in an economy. That is, the optimal combination of goods are not being produced with the lowest cost combination of inputs (Wonnacott & Wonnacott, 1990).

Inadequate Pricing of Natural Resources

Currently the environmental costs to society associated with building construction and operation are external from the economic accounting system (Reppetto,1992). Price acts as a signal to a society that its members are consuming resource 'A' at levels that are severely increasing its scarcity. Thus increasing price works as an economic incentive to conserve resource 'A' and to search for substitutes. However, current methods of counting national income fail to count natural resources as assets. Reppetto (1992) illustrates this point well when he observes that...

"Buildings, equipment and other manufactured assets are valued as income producing capital, and their depreciation is written off as a charge against the value of production. This practice recognizes that consumption cannot be maintained indefinitely simply by drawing down the stock of capital without replenishing it. Natural resource assets, however, are not so valued. Their loss, even though it may lead to a significant decrease in future production, entails no charge against future income." (p.96) For example, the dollar cost of building a house under the present system of economic accounting methods does not reflect the true cost incurred by society to construct that house. If the economic accounting system were structured in a way that accounted for depletion of natural resources, then the environmental impacts of constructing buildings upon the natural environment would become more clear (Cole & Rousseau, 1992).

Market Barriers to Energy Efficiency

Rosenfeld and Hafemeister (1989) list two market barriers that work against the adoption of energy efficient practices and technologies in US buildings. The first barrier is identified as "different time horizons (that) the various principles consider when making decisions" (Rosenfeld and Hafemeister,1989; p. 84). To illustrate this principle, the example of a utility company's investment in a new electrical generating facility is given. The company expects to pay for this investment over a ten to twenty year period. However, homeowners typically do not invest in energy efficiency if the payback period is longer than two years (Rosenfeld and Hafemeister,1989).

Public and private institutions typically do not invest in efficiency if the pay-back period is longer than three years (Rosenfeld and Hafemeister, 1989). The second barrier arises from the fact that utility companies are usually required to set their rates to cover their average costs plus a small return on investment. This causes another distortion. If consumers were paying the replacement cost of additional energy, that is if they were paying the amount of money per unit of electricity which would be required to produce more energy generating plants, then consumers would have a stronger economic incentive to invest in energy efficiency improvements (Rosenfeld & Hafemeister, 1989).

Discounting

Discounting devalues money that is expected to be received in the future (Pezzey, 1992, p.336). Norgaard and Howarth (1991) illustrate this point when they note that For example one million dollars invested at a 5% rate of interest for 100 years has a present value of only $7,604. Some studies have shown that lowering effective discount rates will decrease consumptive pressures bearing upon natural resources (Pezzey, 1992). However in an economic model developed by Farzin (1984), he determined that lowering the discount rate will increase "investment demands on environmental resources and thus speed rather than slow their decline" (Pezzey, 1992, p.366). Daly and Cobb (1989), maintain that when the discount rate is higher than the reproductive rate of any renewable resources asset, then that asset will be threatened with consumption levels higher than it can sustain.

Ackerman (1994) applies this principle to forests when he notes that private owners of timber look to maximize the net present value of their asset. If the discount rate is increasing at a higher rate than the forests' rate of growth, then it becomes more profitable to harvest than to allow the forest to continue to grow (Ackerman, 1994). However, forests must be held at some minimum level to be able to sustain yields over indefinite periods of time (Ackerman, 1994). Pezzey (1992) points out that further research into the problem of discount rates and natural resource consumption is needed.

Hidden Costs of Energy

The 1992 issue of the Environmental Resource Guide identifies The ill-effects of acid rain, produced as a by-product from the burning of coal to produce electrical energy, as another market failure which causes the price paid for energy to not reflect its true cost. These costs include air and water pollution which are often difficult to assign a value to. However, these costs are real. The by-products of generating energy from fossil fuels subtract real value from the economy. Mount Mitchell, N.C. provides an excellent example. Researches determined that in that area, over a two year period, 43% of the fir trees died as a result of high levels of acid rain produced by coal fired electrical generating plants (Nicklas, 1992, p.IV. A1). Pimentel *et al.* (1994) cite a 1989 Worldwatch report which estimated a per gallon cost for oil of over $4.00 if price also reflected environmental and social costs associated with oil consumption.

Additional factors responsible for market failure with respect to environmentally responsible design include resistance to innovation in the construction industry, industry fragmentation, institutional roadblocks such as resistance to unfamiliar practices and products from local code officials and building inspectors and from builders themselves. All of these issues are compounded by the paradox of price. Price may deter many builders and contractors from using innovative products and methods. However, the price of these products cannot drop until they are used widely enough in the industry so that manufacturers can realize production efficiencies (Jones, 1992).

Environmental Auditing for Building Construction

Crosbie (1992) notes that no agreement has yet been reached on what qualifies as a "truly green building" Cole and Rousseau (1992) suggest that in response to this problem the building industry needs to develop methods that allow analysis of the impact upon the natural environment that different material, construction method, and design choices have and that the way to achieve this is by developing a method for conducting environmental audits for buildings, which are defined as:

> "... an accounting of the quantifiable environmental factors that will be incurred in building production and use, reducing them to equivalent terms and presenting them in meaningful categories. The purpose of the audit is to add an environmental dimension to design decisions."
>
> (Cole & Rousseau, 1992; p. 23)

This definition goes beyond traditional economic measures such as cost-benefit analysis and life cycle cost analysis, which have demonstrated significant limitations as methods for assigning monetary values to environmental costs.

Embodied Energy

Embodied energy is the amount of energy consumed to actually build a structure (Malin, 1993). It is a "hypothetical construct used to audit the energy expenditures required for a product's manufacture" ERG, year, p.). according to Malin (1993) embodied energy research is typically divided into three areas:

- "First order energy: fuel use for mining, transporting raw material, energy use at manufacturing facility (p. 8)"
- "Second order: energy used to produce the equipment and machinery that does the work, and to transport workers to and from the site" (p.8).
- " Third order: general support services and social services for workers. second order energy for machinery, equipment and infrastructure" (p.8).

A study conducted for The Committee on the Renewable Resources for Industrial Materials (CORRIM) by Boyd, Koch, McKean, Morschauser, Preston and Wanagaard (1970) contains significant information on the embodied energy of solid wood dimension lumber. Included in this report were comparison embodied energy figures for frequently substituted materials for wood in construction projects; aluminum, steel, concrete, and plastic. The CORRIM report investigated the process of cutting trees and then converting them to dimension lumber. The amount of energy required to complete this process was recorded at each step. Information was also gathered and analyzed for the energy requirements "...from source to end commodity for steel, aluminum, concrete, bricks, and petro chemical derivatives" (Boyd et al p.3).

The advantage of embodied energy analysis is that it provides a common measure from which to rate the environmental impact of different building materials (ERG, IV.D2). Consumption of energy to do work, in this instance to produce building products, requires the burning of limited reserves of fossil fuels and emissions of the by-products of this consumption process.

However, there are currently some major problems with studies that have been conducted. Malin points out that the durability differences that exist between similar products can "offset or reinforce conclusions based on embodied energy" (p.9). In addition, no generally agreed upon set of methods is used or available to researchers, so that comparisons between studies are of limited usefulness. Access to detailed and reliable data is also often a problem in conducting an energy analysis of building materials production. Current commonly accepted "system boundaries are "extraction, transportation and processing, which account for about 90% of energy used" (Cole & Rousseau,1992, p.24).

BREAM is a system developed by Bartlett & Baldwin (1993) to provide environmental labeling of buildings if they meet the set of criteria .The system awards points based on the degree to which a building minimizes environmental impacts in three broad areas; "global issues and resources, local issues, and indoor issues" (Bartlett & Baldwin, 1993, p.6). Global issues consider such criteria as amounts of carbon dioxide emitted in the process of maintaining the building; local issues are categories such as water conservation, and indoor issues are such factors as lighting and indoor air quality. The more points awarded to a building, the better it is judged to be at minimizing environmental impacts. However, this rating system does not actually quantify pollutant levels that each building may be emitting. For example actual levels of carbon dioxide emissions are not measured or calculated, but instead, points are awarded to a building based on factors that would tend to decrease it's output of carbon dioxide. For example if the building has higher than average levels of thermal insulation, or makes use of highly efficient appliances, then the more points the building would be awarded for decreasing its level of carbon dioxide emissions.

Building Environmental Performance Assessment Criteria (BEPAC) is a building rating system developed in Canada. This assessment system was modeled after BREAM (Cole, 1994). BEPAC evaluates the environmental impact of buildings in five areas: ozone layer protection, environmental impacts of energy use, indoor environmental quality, resource conservation, and site and transportation (Cole, 1994).

Environmental Value Engineering

Environmental value engineering (EVE) is a method developed by Roudebush (1992) that combines methods from standard value engineering techniques with a method called "EMERGY," a term used by Odum (1991) to describe the method he developed for assigning a single unit of measure to all inputs of a project in a economy. This single unit of measure is solar emjoules. Basically, the methodology of EVE is to determine all inputs for a given project; raw materials required, fuel energy and money used to pay for human labor, and then using Odum's EMERGY analysis. These various inputs are all converted to solar energy, a form of energy common to inputs of production. Roudebush (1992) maintains that by using EVE analysis, alternative materials and construction methods for a project can be evaluated. A determination of which inputs to a project will minimize environmental impacts while maximizing economic value can then be made.

Challenges facing the construction industry in implementing an understandable and manageable environmental auditing system on a widespread basis are substantial. But studies reviewed here demonstrate that there may be movement to a consensus. The development of a manageable method for conducting environmental audits for buildings would be useful for designers, builders, other housing professionals, and consumers and would be invaluable in the growing market of environmentally conscious design.

ANALYTICAL METHODS

The central concern of this study is with the tensions and balances between environmental and economic costs in new home construction. As a specific case exploring these tensions and balances, this investigation focuses on new home construction in the northern United States, in the counties of Cortland, Schuyler and Tompkins in what is generally termed "Upstate" New York. The peculiarities of climate in this area set certain parameters for building construction. In this setting, the investigation poses and seeks answers to three questions.

> What are the environmental impacts of different building product, construction method, and house size choices?
>
> What effect does each of the following--building product choice, construction method and house size have upon the economic cost of operating a house?
>
> What is the relationship between the initial house construction dollar cost and the long term dollar costs of maintaining and operating the structure?

These three questions are explored and answered by developing four simulation models of four types of new home construction that might be done in these areas. These simulation models consist of three independent variables: namely building product choice, construction method and house size. The independent variable of building product choice is examined for five component areas, those being the foundation, structural framing, roofing, siding, insulation. The structural framing component is further divided into four sub-components, those being the floor framing, exterior wall framing, interior wall framing and roof framing.

Two major component areas, mechanical/electrical and interior finishes are not included in this study, as the large number of sub-component areas that exist within these two components put them beyond the scope of this study.

Construction method, within the context of this study, is defined as the way in which the house is built. Choices such as structure type, one story versus two story; and construction system choice: full basement versus slab on grade, are examples of different construction methods.

House size in this study is determined from standards set by professional appraisal systems. The Marshall system, being the most widely followed in the United States, was used to measure the size of each simulation model. The Marshall system calculates square footage from measurements taken at the outside of exterior walls and includes only enclosed finished living space: not porches or garages (Carlson, 1991). Only above grade stories are included in this calculation of square footage of primary living space. In addition, nothing is deducted for thickness of exterior walls, interior partitions or stairwells.

Overview of Each Simulation Model

Four simulation models were created as a technique for answering the questions posed in this study. Each model was chosen to represent various combinations of each of the three independent variables: house size, building product choice, and construction method.

Simulation model H-1 is representative of the size, building products and construction methods typically selected by home builders in Cortland, Schuyler and Tompkins Counties, New York. To determine what choices are typically made in this three-county area, a builder survey was conducted. Builders' names and addresses were obtained from local yellow page, cross street, and trade association directories. Each builder so located in Cortland, Schuyler and Tompkins County of New York State was then mailed an eight-page questionnaire about the number and size of houses built in 1993, as well as the building products and construction methods most often used in five major component areas of a house. Those five component areas were the foundation, structural frame, thermal insulation, roofing and siding. These five components were selected because they are the components which require the greatest amount of materials when a house is built. The results of this survey informed the size, building product selection and construction methods of H-1. The study area was limited to a three-county geographical area to keep the data collection and analysis at manageable levels.

The products selected for H-2, the second simulation model, were chosen as being representative of technologically advanced and green products. Identification of these products was determined by examining each issue of four residential building trade journals published between 1990 and 1993: Fine Homebuilding, Builder, The Journal of Light Construction and Professional Building and Remodeling Magazine. The number of advertisements and/or articles mentioning or promoting an alternative product were counted. The product with the highest number of advertisements/articles within each of the eight component areas, foundation, floor framing, exterior wall framing, interior wall framing, roof framing, roofing material, siding and thermal insulation was the one chosen for the H-2 model.

Simulation model H-2 is matched with H-1 on the variable of size. H-1 and H-2 are also matched on the variable of construction method in seven of the eight component areas. Models H-1 and H-2 are not matched and differ on the variables of construction method and materials used for the exterior wall framing component. The exterior wall framing component of H-1 uses the stick built method, while the exterior framing component of H-2 uses a series of pre-manufactured foam-core panels that are assembled on site. Thus, for the exterior wall framing component, H-1 and H-2 vary on both materials and construction method.

Simulation model H-3 also has 2,000 square feet of finished floor area and uses typical construction products for each component area except for insulation. H-3 uses cellulose insulation in the exterior walls and ceilings rather than the fiberglass insulation used in the H-1 walls and ceilings. The construction method used for the H-3 foundation and the exterior wall framing component also differ from those used in model H-1. The H-3 foundation uses the Scandinavian technique of a slab on grade shallow foundation system. That is, an eight wide by 20" deep continuous foundation wall that rests on a piece of two inch thick extruded polystyrene foam. The perimeter of the foundation wall is further protected from frost by the addition of more extruded polystyrene insulation. The exterior wall framing component of H-3 consists of a double studded wall that is 12" thick. The outer portion of this wall is framed by using 2x4 studs placed at 16" centers with built up headers over window and door openings using double 2x10s: a typical framing method. The inner portion of this double studded wall uses 2x3 studs placed at 24" centers. The exterior wall cavity is insulated with 12" thick cellulose insulation and the attic is insulated with 16" of cellulose insulation. H-3 is identical to H-1 except for the factors just mentioned. In summary, those factors are: a shallow foundation system rather than a full basement, 12" thick double studded walls rather than 5-1/2" thick single studded walls, cellulose wall and attic insulation rather than fiberglass insulation, and R-44 thermal resistance in the exterior walls and R-60 thermal resistance in the attic rather than R-19 and R-38 in simulation model H-1.

The fourth simulation model (H-4) uses the same products and construction methods as those used for simulation model H-3 However, it is 25% smaller than models H-1, H-2, or H-3. Simulation model H-4 is based on a simple thesis: the best way to minimize environmental and economic costs of house construction is to consume less. That is, build smaller houses and use construction methods to minimize consumption of raw materials and energy. Thus H-4 is 25% smaller than H-1, H-2, or H-3. It has 50% higher levels of built in thermal efficiency than H-1 and uses construction methods that further reduce this structures demand for raw material inputs compared to those used for H-1. For example the Scandinavian shallow foundation system reduces the amount of raw materials and energy required to construct a typical full basement.

Measures

Three environmental and three economic measures were used in this study in an effort to quantify the effects of building product choice, construction method and house size upon the environmental impacts and economic costs of house construction.

Given current understanding of the impact of human development upon the natural environment, a clear, concise operationalized definition of a "green" or "sustainable" house is not possible. For example it cannot be said that a green or sustainable house consumes less than 30 million BTUs of embodied energy and no more than 100,000 BTUs of annual operational energy, or that it consumes no more than 10 trees per 1,000 sq. ft of living space. However, we can say that a house that uses less embodied and operational energy and consumes fewer resources to build is greener than a similar structure that uses more. Thus green becomes a comparative or relative term.

The environmental measurement techniques listed here are very basic indicators. They illustrate only the amounts of raw material, embodied and operational energy requirements of various house design and building decisions. A description of each measure and reasons it was selected as an indicator of the environmental cost of house construction is included here.

Environmental Measures

The volume of raw material inputs consumed to manufacture each building product quantified the volume of raw materials that would need to be mined, pumped, or harvested from the earth to manufacture each building product. Using concrete as example, how much sand and stone would have to be dug from the ground for to produce the aggregate for each cubic yard of concrete? To produce the Portland cement required to make concrete, how much limestone, sand, bauxite, gypsum and iron ore had to be dug out of the ground to produce the cement required for each cubic yard of concrete?

As noted in the above definition given for a green house, a structure that consumes fewer resources to build has a lower environmental impact than a similar structure that consumes more. Thus this measure gives a relatively accurate indication of how green a house is based on the consumption of natural resources required to build it.

Energy consumed to operate the structure over a twenty year period was computed as follows: the amount of heating fuel: oil, natural gas, electric k.w. hours, required to supply heat for each of the three sample house's for a typical heating season was calculated. In addition the annual energy required to supply domestic hot water was also calculated. Using this annual figure as a basis, the costs of supplying energy to the structure were calculated for a time period of twenty years into the future. Dollars were held constant to 1994 values, that is no adjustment for future inflation was made.

This measure was selected as an indication of the environmental impact of a home construction for two reasons. First, the consumption of fossil fuels depletes finite reserves of this vital resource. Secondly, combustion by-products from fossil fuel use contributes to the build up of carbon dioxide in the atmosphere, a factor which may contribute to global warming. Thus it is maintained that a house that requires less energy will have a lesser impact upon the environment than a house that needs more.

In this study embodied energy figures were included for products when that information was available. For example the Portland Cement Association has conducted an analysis on amounts of energy consumed to produce cement and concrete (Wilson, 1993). This study served as the information source on the energy consumed in the production of concrete for each of the three simulation models.

PROCEDURE

Once the building products and construction methods of the eight component areas of each model were determined, a set of construction drawings for each simulation model was drawn. A meticulous estimate of building materials was then executed to determine the amount of product required for each of the five component areas within each of the three models. Information required to quantify each of the environmental and economic measures was collected from various sources, with much of the material coming from forestry, engineering and architectural texts, journal articles, reports from federal government agencies, published conference proceedings, direct conversations with individuals from various building product manufactures, researchers within industry and academia, and local building product suppliers.

Procedure to quantify raw material inputs

Two basic items determined in this section of the analysis were:

> What are the raw material inputs required to produce each building product?
>
> How much of each raw material input is required to produce each unit of building product?

For the first step, collected information sources (listed previously) were searched to determine what the basic raw material inputs to each building product are. For example, concrete is produced from sand, stone, Portland cement and water, and Portland cement is produced from calcium (usually limestone), silicon (clay or sand), bauxite and iron ore. Thus the raw material inputs required to produce concrete are sand, stone, water, limestone, clay, bauxite, gypsum and iron ore.

The second step, determining how much of each raw material input is required to produce each unit of building product, was much more involved and requires a more detailed explanation. Using solid sawn dimension lumber as an illustrative example, the method used to quantify the volume of raw material inputs (trees) that would be required by each model is described here. A similar method was followed for each building product.

Lumber producers, sawmills, must obtain sawlogs as the raw material inputs required to produce wood building products. Sawmills typically purchase the sawlogs they need to produce lumber from timber growers. This being so, the forest products industry has developed techniques for determining the amount of finished product that can be obtained from each unit of raw material input, that is the amount of lumber that can be produced from each sawlog. The unit of measure used to determine wood volumes in the forest products industry is the board foot, one board foot being equal to a piece of wood one inch thick by twelve inches square. Within the forest products industry, log rules, also called log scales, exist which closely estimate the amount of lumber, in board feet that can be obtained from logs of various diameter, length, and form class. Form class is the amount of taper that exists over the length of the log (Holland *et al.*., 1982). Log rules also factor in a deduction for the amount of waste that occurs from making square and rectangular shapes from cylindrical objects, and also make adjustments for waste due to saw kerf. Saw kerf is the amount of material lost due to the thickness of the saw blade as it cuts through the log.

The next step in this analysis was to estimate the number of trees required to produce the sawlogs needed to manufacture the lumber for each simulation model. Following visits to several retail lumber yards in the study area a determination was made that much of the lumber sold in this area originates from forests in the southern portion of the US. Continuing to trace the lumber manufacturing process backwards, Interviews were conducted with a forester and a statistician from the Southern Forest Products Association. To increase the accuracy of the estimate concerning the amount of sawlogs produced from a single tree, it was necessary to narrow the point of origin of these trees to a specific forest in South Alabama. Frank Stewart, a forester with the Southern Forest Products Association noted that an intensively managed private industrial forest in South Alabama has a typical tree rotation time of 40 years. During that time period, trees have commonly grown to be 14 to 16 inches in "diameter at breast height" (DBH). DBH is a term used in the forest industry to denote the diameter of a tree, measured at four and one-half feet above the ground. Using International Log Rule volume tables, allowing for a saw kerf of 1/4" and a log taper allowance of 1/2" per four lineal feet of log length, a 14" tree (DBH) will produce approximately 335 board feet of lumber.

Returning back to the four simulation models, the number and size of each piece of lumber required to construct each model was noted. (i.e.. the number of 16' long 2x10s, 16' long 2x6, etc.). These figures were then converted to board footage figures using the following formula:

$$N = P \, \frac{T(W)}{12} \, L$$

where

N= number of board feet,
P= number of pieces,
T= thickness of the piece in inches,
W= width of the piece in inches,
L= length of the piece in feet.

Thus, the total pieces of lumber for each model were converted to a total board footage figure. Then by dividing the volume of lumber required to produce each model by the amount of board feet of lumber produced by a 14" DBH tree, a determination could be made of the number of trees that would be consumed to produce each model.

To summarize: there was a basic method followed to quantify the raw material inputs for each of the building products included in H-1, H-2, H-3 and H-4. That is, first a meticulous materials takeoff of the product was executed. Next, these amounts converted into standard units used within each building product manufacturing industry. Then through information obtained from forestry, engineering and architectural texts, journal articles, reports from federal government agencies, published conference proceedings, direct conversations with individuals from various building product manufactures, researchers within industry and academia and local building product suppliers, the amount and type of each raw material input per unit of building product was determined. Through calculations it was then possible to quantify the amounts of raw material inputs required to produce each building product.

<u>Procedure followed to quantify embodied energy</u>

Several studies have been conducted within the building products industry to determine the amounts of energy required to produce various building products. (See, for example, the report done by the Committee on Renewable Resources for Industrial Materials sponsored by the National Academy of Sciences and the National Resource Council, reported in Wood and Fiber, 1976). These studies served as the information source to quantify the energy required, in BTUs, to produce each building product. Again, using wood as an example, approximately 30,000 BTUs are required to produce one 8' 2x4 (ERG, 1993, p.I.V). With this basic piece of information, calculations were used to convert this one 8' 2x4 into a board footage measure. At this point it was possible to calculate the number of BTUs per board foot of solid sawn lumber. This figure was then multiplied by the number of board feet of solid dimension lumber required by each simulation model. The results of these calculations give the total amount of BTUs of energy embodied within the solid lumber of each of the three simulation models. Similar techniques were followed to calculate the embodied energy of each building product for each of the three simulation models.

Procedure followed to calculate operational energy

Operational in this study is defined as the amount of energy required to supply the annual space heating needs of each simulation model. The calculations of annual energy consumption and dollar cost was performed using the degree-day method as outlined by Nisson and Dutt (1985). Calculations are included in Appendix G.

Procedure followed to calculate price

To quantify this measure, material take-off lists from each simulation model were taken to sample retail building supply outlets in Tompkins, Cortland and Schuyler Counties. Prices obtained from each establishment were then averaged to obtain a representative price for each product that was typical for this three county area.

ORGANIZATION OF THE DATA AND SELECTED RESULTS

When calculations were completed the data were arranged into tables. One table for each of the five component areas analyzed: the foundation, structural framing, roofing, siding, and thermal insulation components. The environmental and economic measures of each building component within the three simulation models are listed in these tables. In addition, a summary table was constructed to present overall findings for each environmental and economic measure for each simulation model.

SIMULATION MODELS

Table 1 shows amounts of product, natural resource inputs, and energy required to produce the foundation for each of the four simulation models. The use of polystyrene blocks filled with concrete to produce the H-2 foundation wall decreases the amount of concrete required to produce the same foundation as that produced with the more typical method used for the H-1 foundation. In addition the use of foam block forms decreases the amount of energy embodied within the foundation of H-2 compared to the foundation of H-1. H-3 consumes the least amount of concrete, 20 cubic yards compared to 36 cubic yards for H-2, 51 cubic yards for H-1, and 21 cubic yards for H-4. Thus H-3 consumes a smaller amount of natural resources and embodied energy than H-1, H-2, or H-4. In addition, the dollar cost of the products required for the H-3 foundation are less than that required for the H-1, H-2, or H-4 foundation.

Table 1. Foundation Component

FOUNDATION COMPONENT					
	H - 1	H - 2		H - 3	H - 4
Product	Concrete	Concrete	Polystyrene blocks	Concrete	Concrete
Amount of product	51 cubic yards	36 cubic yards	298 blocks, 898lbs. polystyrene	20 cubic yards	21 cubic yards
Raw materials consumed for concrete manufacture					
Stone	26.8 cu. yds.	18 cu. yds.		10 cu. yds.	6.5 cu. yds.
Sand	16.5 cu. yds.	12 cu. yds.		6.65 cu. yds.	4.3 cu. yds.
Portland Cement	7.7 cu. yds.	6 cu. yds.		3.35 cu. yds.	3.2 cu. yds.
Energy embodied within product	571 million BTU	446 million BTU		224 million BTU	235 million BTU
Gallons of oil equivalent	4,134 gallons	3,231 gallons		1,622 gallons	1,702 gallons
Dollar cost of product	$2,907	$5,109		$1,140	$1,197

Table 2. Floor Framing Sub-Component 1

Floor Framing Component				
	H - 1	H - 2	H - 3	H - 4
Material	wood	wood	wood	wood
Product	solid sawn lumber and plywood	Engineered wood products	solid sawn lumber and plywood	solid sawn lumber and plywood
Amount of product	5,445 board feet	4,289 board feet	1,677 board feet	1,328 board feet
Trees consumed	16 trees	11 trees	5 trees	4 trees
Energy embodied within product	47.2 million BTU	72 million BTU	17 million BTU	11.8 million BTU
Dollar cost of product	$4,744	$8,100	$2,123	$1,089.00

The floor framing component of simulation model H-1, with 2,200 square feet of floor framing constructed with 2x10 floor joists at 16 inch centers and covered with 3/4" thick plywood would consume 5,445 board feet of lumber, or 16 trees (assuming a yield of 335 board feet of lumber per tree). H-2 contains the same amount of floor framing area as H-1, however the use of engineered wood products instead of solid wood lumber decreases the amount of trees required to construct the same floor area from 16 trees to 11 trees. The manufacture of the floor framing products for H-2 would consume larger amounts of energy than the floor framing products required by H-1 or H-3. In addition the dollar cost of the framing products required by model H-2 is the highest. H-3, with 531 square feet of floor framing, requires the smallest number of trees, embodied energy and money to produce the floor framing products it would require.

Table 3. Exterior Wall Framing Sub-Component 2

Exterior Wall Framing Component					
	H - 1	H - 2		H - 3	H - 4
Products	WOOD: solid sawn lumber and plywood R-19 fiberglass insulation	ENGINEERED WOOD: 7/16" osb wall sheathing,	Polystrene: Foam core panels; expanded foam (R-22 insulation) btw. 2 sheets osb	WOOD: solid sawn lumber and plywood, R-44 cellulose insulation	WOOD: solid sawn lumber and plywood, R-44 cellulose insulation
Amount of lumber	5,128 board feet	2,592 board feet	73 panels: 1,022 lbs. polystyrene	5,448 board feet	4,380 board feet
Trees consumed	15 Trees	7 Trees			13 Trees
Energy embodied within structural component	43 million BTU	49 million BTU	51.1 million BTU	47 million BTU	39 million BTU
Insulation EE	7.2 million BTU			2.7 million BTU	2.4 million BTU
Total EE	50.2 million BTU	TOTAL FOR H-2: 100.1 million BTU		49.7 million BTU	41.4 million BTU
Dollar cost of structural component	$3,738	$5,723		$3,753	$3,037.00
Dollar cost of wall insulation	$460			$616	$552.00
Total dollar cost	$4,198	$5,723		$4,369	$3,589.00

The exterior wall framing for H-1 requires 15 trees compared to seven trees for H-2. H-1 uses the typical exterior wall framing method of stick built walls using individual pieces of 2x6 solid wood members placed at 16" centers. H-2 uses foam-core panels, 5-1/2" thick expanded polystyrene, sandwiched between two pieces of 7/16" thick OSB. The OSB skins account for the 2,592 board feet of lumber used by the H-2 exterior wall framing sub-component. The H-3 exterior wall framing sub-component consists of double studded wall constructed from solid wood 2x4 members placed at 16" centers for the outer portion and 2x3 solid wood members placed at 24" inch centers for the inner portion.

The H-4 exterior wall framing consumes two fewer trees than the H-1 exterior wall framing, and six more trees than the H-2 exterior wall framing. The H-2 exterior wall framing requires 100 million BTUs of embodied energy, while H-1 requires 43 million and H-3 39 million. The dollar cost required to purchase the products for the H-2 exterior framing is greatest: $5,723 compared with $3,738 for H-1 and $3,037.

Table 4. Interior Wall Framing Sub-Component 3

INTERIOR PARTITION FRAMING COMPONENT					
	H - 1	H - 2		H - 3	H - 4
Product	WOOD: 2x4 wood studs @ 16" o.c.	STEEL:8'x1-1/2" x3-1/2" 25 ga. steel studs		WOOD: 2x4 wood studs @ 16" o.c.	WOOD: 2x4 wood studs @ 16" o.c.
Amount of product	1,903 board feet	1,006 pounds of steel	If recycled steel is used	1,903 board feet	1,214 board feet
Natural resources consumed					
Trees	15 Trees			15 Trees	4 trees
Iron ore		1,600 lbs.	0		
Limestone		150 lbs.	0		
Coke		450 lbs.	0		
Energy embodied within product	10.8 million BTU	19.3 million BTU	7.5 million BTU	10.8 million BTU	6.9 million BTU
Gallons of oil equivalent	78 gallons	140 gallons	54 gallons	78 gallons	50 gallons
Dollar cost of product	$1,067	$1,659		$1,067	$684

H-2, using steel studs rather than wood, consumes no trees. It does consume 8.5 million more BTUs than H-1 to produce the same linear feet of interior partitions with the same number of openings. If 100% recycled steel were used to produce the steel studs the embodied energy would be reduced from 19.3 million BTUs to ?? BTUs. The H-3 interior partitions consume 1,214 board feet of lumber compared to 1,903 board feet for H-1. H-3 consumes 1,214 board feet of lumber to produce the interior partitions compared to 1,903 board feet for H-1. Thus producing the lumber required for the H-3 interior partitions would consume two fewer trees than those required for the H-1 interior partitions.

Table 5. Roof Framing Sub-Component 4

Roof framing component					
	H - 1	H - 2	H - 3	H - 4	
Product	WOOD: 2x4 wood trusses @ 24" o.c.	WOOD: 2x4 wood trusses @ 24" o.c.	WOOD: 2x4 wood trusses @ 24" o.c.	WOOD: 2x4 wood trusses @ 24" o.c.	WOOD: 2x10 rafters with 2x4 firring over eating and entrance areas
Amount of product	2,344 board feet	2,344 board feet	2,344 board feet	2,648 board feet	
Natural resources consumed					
Trees	7 trees	7 trees	7 trees	8 trees	
Energy embodied within product	21.7 million BTU	22.6 million BTU	21.7 million BTU	23.4 million BTU	
Gallons of oil equivalent	157 gallons	164 gallons	157 gallons	170 gallons	
Dollar cost of product	$2,857	$2,690.87	$2,857	$2,525.5 8	

The products and construction methods used for the roof-framing sub component vary little between models H-1, H-2 and H-3. All three use 2x4 wood trusses placed at an incremental spacing of two feet. However, H-1 uses 1/2" cdx plywood as roof sheathing while H-2 uses 7/16" oriented strand board (OSB). This difference accounts for the additional .9 million BTUs of embodied energy required to produce the building materials for the H-2 roof-framing component. H-3, although having 25% less floor area than H-1 or H-2, requires the greatest amount of product to construct, 2,648 board feet of lumber compared to 2,344 board feet for H-1 and H-2. H-3, although having 25% less floor area than H-1 or H-2 (1,122 square feet compared to 1,142 square feet) has only a 20 square feet smaller foot print (the square feet of land area covered by the house structure) than H-1 or H-2. In addition, H-3 joins a large one-story area with a smaller two-story area, while H-1 and H-2 join a large two-story area with a smaller one-story area. The H-3 roof framing also contains several roof breaks (different roof heights joined together) and also has a section of cathedral ceiling over the entrance and eating areas. The H-1 and H-2 roof framing components have no roof breaks or areas of cathedral ceiling.

Table 6. Structural Framing Component

	Summary framing component			
	H - 1	H - 2	H - 3	H - 4
Products	WOOD: solid sawn lumber and plywood	ENGINEERED WOOD STEEL EXPANDED POLYSTYRENE	WOOD: solid sawn lumber and plywood	WOOD:solid sawn lumber and plywood
Amount of product	14, 820 board feet lumber	10,231 board feet lumber 1,022 lbs. polystyrene	11,372 board feet of lumber	9570 board feet lumber
Natural resources consumed				
Trees	53 trees	25 trees	43 trees	29 trees
Iron ore Limestone Coke		1,600 lbs. iron ore 150 lbs. limestone 450 lbs. coke		
Energy embodied within products	123 million BTU	214 million BTU	96 million BTU	81 million BTU
Dollar cost of products	$12,421.00	$18172.00	$7900.00	$7,335.00

Table 6 lists the amounts of product, natural resources and dollars required to construct the structural framing for models H-1, H-2 and H-3. This table combines the information contained in preceding tables. Simulation model H-3 consumes the most trees: 53, while H-2 consumes the least: 25. The structural framing component H-2 consumes the most embodied energy: 214 million BTUs, while H-3 consumes the least: 81 million BTUs. The dollar cost to purchase the building products necessary to construct the structural frame of H-2 is highest: $18,172 and lowest for H-3: $7,336.

Table 7. Roofing Component

Roof Shingle Comparison			
Shingle durability	20 year organic asphalt shingle	25 year organic asphalt shingle	30 year organic asphalt shingle
Amount of material			
Squares	17 square	17 square	17 square
Weight	3,980 lbs.	4,028 lbs.	5,100 lbs.
Embodied energy	17.7 million BTU	14.3 million BTU	15.12 million BTU
Initial dollar cost of shingles	$374.00	$493.00	$935.00
Annual costs	$31.47	$24.83	$31.16
Total cost of maintaining the roof for a period of 30 years*	$944	$745	$935

This table illustrates the durability and cost comparisons of 20, 25 and 30 year organic asphalt roofing shingles. It uses simulation model H-1 as the method for comparing each shingle type, so that these three comparisons assume the same size and type of roof.

Table 8. Annual Space Heating Cost Comparisons

HEAT LOSS AND ANNUAL FUEL COST COMPARISONS				
Conduction	H - 1	H - 2	H - 3	H - 4
WALLS	R-19 fiberglass 17.4 million BTU	R-22 polystyrene 12.5 million BTU	R-44 cellulose 7.6 million BTU	R-44 cellulose 8 million BTU
CEILING	R-38 fiberglass 4.5 million BTU	R-49 fiberglass 3.5 million BTU	R-60 cellulose 2.9 million BTU	R-60 cellulose 3.5 million BTU
GLASS R-3.3	17.8 million BTU	17.8 million BTU	17.8 million BTU	10.7 million BTU
DOORS R-15	.7 mllion BTU	.7 mllion BTU	.7 million BTU	.46 million BTU
HEAT LOSS DUE TO INFILTRATION	16.2 million BTU	3 million BTU	3 million BTU	2.2 million BTU
HEAT LOSS DUE TO VENTILATION	ventilation supplied by infiltration	7 million BTU	7 million BTU	5.5 million BTU
TOTAL	56.6 million BTU	44.5 million BTU	39 million BTU	30.4 million BTU
AMOUNT OF HEATING OIL REQUIRED PER HEATING SEASON	410 gallons	322 gallons	285 gallons	220 gallons
Dollar cost of fuel at curent price ($.80/gal.)	$328	$258	$228	$176
Asumes a typical upstate New Yok heating season: base 65- 6,983 heating degree days. Also assumes a furnace AFUE of 85%				

DISCUSSION

The primary aims of this study were to determine the effects that various building product, construction method and house size choices have upon the natural environment. In addition the monetary cost of maintaining a house for a twenty year period and the initial dollar cost of the building materials as affected by building product, construction method and house size choice was examined.

Table 9. Space Heating Costs

Space heating fuel costs and net present value comparisons				
	Baseline H-1	H-2	H-3	H-4
Annual dollar cost of fuel oil for space heating	$328	$258	$228	$176
Total dollar cost for heat at end of seven year period	$2461	$1,935	$1710	$1,320
Total dollar cost for heat at end of 20 year period	$8,212	$6,459	$5,708	$4,406
Dollar cost of thermal insulation investment over baseline	$4,835 (Baseline)	+$1618	-$37	-$313
Net present value 7 years into the future		-$1125	+$745	+$1388
Net present value 20 years into the future		+$34	+$2399	+$3913

* Assumes an annual fuel escalation rate of 2.3%
** NPV calculations assumed an alternative return on investment of 6% annually.

The results of this study indicate that the independent variables of building product choice, construction method and house size each have an impact, although in varying amounts, on the environmental impact of new home construction. The three independent variables also effect the monetary expense of constructing a house, and then of maintaining it over a twenty year period.

The results show that building product choice does have an impact upon the environment, at least when measured in terms of the amount of raw-materials consumed. The two different products used for the H-1 and H-2 exterior wall framing component demonstrate this. Although the linear feet of exterior wall framing and the size and number of openings are identical , the exterior wall of model H-2 would consume seven trees, compared to 15 for H-1. A reduction of eight trees to construct the exterior walls of the same size and style house. The only lumber required for the exterior walls of H-2 s is contained in the interior and exterior OSB skins that sandwich the foam-core. In addition, the total weight of the expanded polystyrene foam contained in 73-4'x8' foam-core panels is 1,022 pounds: which certainly represents a much smaller amount of raw material consumption than that of eight trees, each with a diameter of 14" at 4'-6" from the ground, and each producing four-16' sawlogs.

Although polystyrene foam is manufactured from petroleum, the material it uses as its major raw material input is ethylene or ethane: a by-product from the refining process used to produce gasoline and fuel oil. Thus the petroleum by-product used to manufacture polystyrene does not increase demand for crude-oil, but actually works to allow fuller utilization of crude-oil reserves.

Building product choice does have a significant environmental impact when that impact is measured in terms of the amount of energy embodied within the products. The results of this study indicate that typical building products, as represented by those selected for model H-1, would produce a house with lower amounts of embodied energy than those selected for H-2. However, at the house-to-house comparison level, H-1 used only 17 million fewer BTUs of embodied energy than H-2, an amount equivalent to just 123 gallons of oil. Comparing the embodied energy requirements of H-1 and H-2 at the component level does show significantly greater differences. Using the exterior wall framing component as an illustration, the foam core panels used for H-2 compared with the typical method of stick built walls represented in model H-1, used considerably larger amounts of embodied energy. The H-1 exterior wall framing component consumes 43 million BTUs of embodied energy while H-2 consumes 100 million BTUs of embodied energy to produce the same amount of exterior wall. However, the foam-core panels combine two components into one. Those being the structural element of the exterior wall framing and the thermal insulation component for the exterior walls. If the embodied energy of the 5-1/2" fiberglass insulation required by the H-1 exterior walls is included with the embodied energy of the structural component, the total energy embodied within the exterior walls of H-1 becomes 57.7 million BTUs. The difference between the embodied energy of the H-1 exterior wall component compared to the H-2 exterior wall component then becomes 42. 3 million BTUs, or an equivalent of 306 gallons of oil.

The much smaller amount of concrete that would be required for the H-3 basement illustrates that a shallow foundation system can conserve natural resources. Although the footprint of the H-3 foundation is just 22 square feet smaller than the foundation footprint of H-1 and H-2 (1,120 square feet for H-3 compared to 1,142 square feet for H-1 and H-2) H-3 consumes 42% less concrete than H-2 and 59% less concrete than H-1. This reduced consumption of concrete is reflected by the reduced amount of aggregate (sand and stone) required to produce H-3 compared to H-1 and H-2.

Other impacts examined in this study show how choices in the design and construction of homes and the materials used to implement those choices can have significant environmental and economic impacts. Further research in this area may focus on methods to convert such quantitative information into easily understandable indices that would be useful to designers, builders, other housing professionals, and consumers.

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SUSTAINABILITY AND THE ROCKY MOUNTAIN REGION OF THE NATIONAL PARK SERVICE

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INTRODUCTION

The National Park Service has made a commitment to environmental sustainability. The Rocky Mountain Region of the National Park Service (NPS) has addressed this commitment through the design and construction of employee housing and visitor centers which incorporate sustainable practices. A significant opportunity to integrate sustainability and affordability is now being realized through a program to design and construct over 500 units of prototypical housing to replace trailer housing in national parks throughout the country. The program intends to create housing that conserves resources and improves livability with cost conscious design and construction processes.

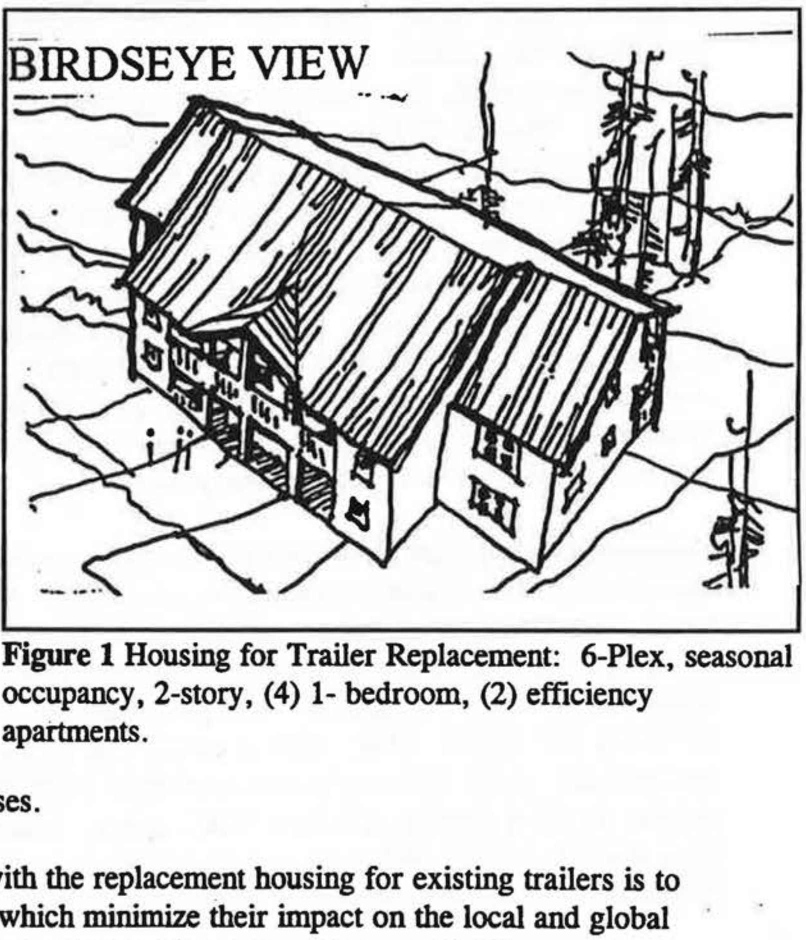

Figure 1 Housing for Trailer Replacement: 6-Plex, seasonal occupancy, 2-story, (4) 1- bedroom, (2) efficiency apartments.

One of the design team's primary goals with the replacement housing for existing trailers is to design high quality, durable, living units which minimize their impact on the local and global environment. While we have the advantage of being able to learn from and build upon the experience with recently constructed housing, the time available for design and construction of the trailer replacement housing is very tight. The design and documentation process resulting in prototypical drawings and specifications for over 20 unit types and a variety of multi-unit building designs will be completed in less than a year. Additional resource information to allow the designs to be adapted to historical, climatic and other site-specific constraints will also be created by the design team.

The design of the first housing units under this program is detailed here. We also present plans for subsequent housing which will benefit from the research performed on systems and products for the first units.

BACKGROUND

The National Park Service has approached sustainability by emphasizing energy conservation through the use of passive solar design, well-insulated and tight structures, high-performance windows, and high efficiency mechanical and electrical systems. Recently constructed modular units at Capitol Reef National Park in south-central Utah took the next step by addressing material and equipment selection relative to sustainable principals.

The modular, 2- and 3-bedroom housing units at Capitol Reef were completed in 1994. The homes are single-family, ranch-style residences with basements. Outside of the fact that they provide shelter, warmth, light, and water there is very little else that can be said about them that is conventional. They have an east/west aspect ratio which allows for greater southern exposure. There is 18% of windows per square foot in the homes with an average of 55%of the window area facing south. Along with the high-performance, low-E windows, full-height waterwalls have been incorporated into the south facade behind high-transmitting, low-iron, insulating glazing. Active living spaces are positioned to the south while the kitchen, bathrooms, and closets provide a buffer to the north. Clerestories provide sunlight as well as daylight to the north spaces. In addition, large, southerly window wells allow sunlight and daylight into the basements. The walls are structural insulated panels (SIP) and the houses were dimensioned to accommodate the SIP production sizes. This energy-conserving design resulted in 50% lower energy use last winter on a square foot basis as compared to a conventionally constructed unit in this park .

Material and equipment selection for these units was based on affordability as well as life-cycle costs, resource impact, and indoor air quality. For example, the wood skins on the SIP panels are oriented strand board which is made from small diameter, fast growing trees. The adhesives in the board are an exterior-grade, phenol formaldehyde which off-gas less than interior glues which are typically urea formaldehyde. The rigid insulation in the SIP is expanded polystyrene (EPS). EPS is blown with pentane which has an ozone depletion potential and global warming potential of zero. Carpeting is made from recycled pop bottles and the specified finishes have low VOC ratings. Water conservation is addressed in these units through fixtures which meet current federal standards, and the piping runs are all minimized. A detailed description of the units is given in Lobato 1994.

TRAILER REPLACEMENT HOUSING

Design Team Roles

The Rocky Mountain Region of the National Park Service is managing the trailer replacement housing project. They hired the Denver-based architectural firm of Barker Rinker Seacat & Partners, Architects to provide architectural and engineering services. The firm's principle responsibilities are to provide leadership to research and define housing needs and priorities; develop housing design concepts; prepare prototypical documents (drawings and specifications) for housing designs; and develop processes and resources to enable other design teams within or serving the Park Service to complete site-specific final bid documents. Enermodal Engineering is serving as the sustainable design consultant on the project. They are responsible for ensuring compliance with the 1992 Model Energy Code and NPS 76 Housing Design and Rehabilitation Guidelines, and identifying sustainable alternatives that meet structural, thermal, acoustic, regional, affordability and aesthetic criteria for the design.

Project Design Requirements

The design program requirements are established by various sources: NPS 76, national and local codes and laws regarding construction, life safety and accessibility, and specific criteria developed by the Design Team. In addition, the designs must address the following issues:

- The designs must be able to be constructed by either pre-manufactured (modular) or site-built methods.

- The designs must be adaptable to a wide variety of constraints including cultural and historical context, climatic, physical site and occupant characteristics. The sites for housing in many instances will be in-fill sites, where the building's orientation and other design parameters are pre-established.

- The designs will reflect recent NPS sustainable design criteria for energy and natural resource conservation and material choices for life cycle and environmental impact.

- The designs will be affordable.

- All housing will be constructed within the next two years.

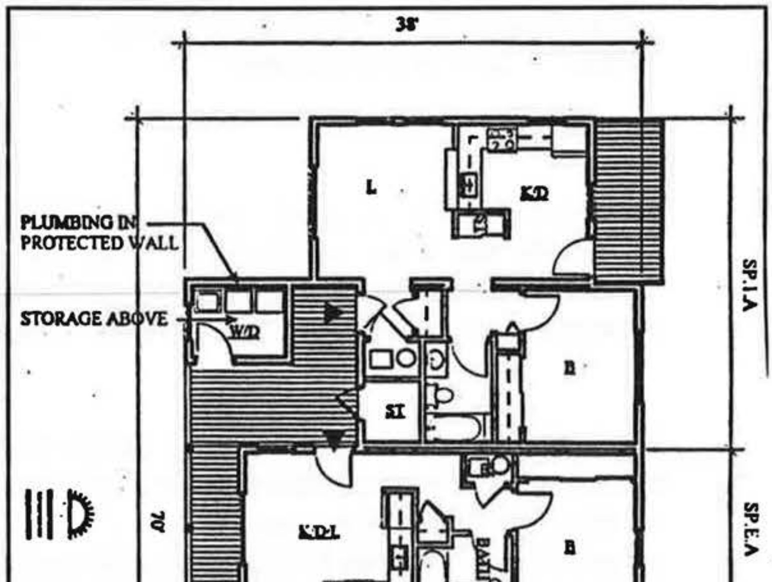

Figure 2 Floor plan of 6-plex.

The First Prototypes

The first housing units to be designed under the Trailer Housing Replacement Program are a 6-plex (see Figures 1 and 2) and a 4-plex in Yellowstone National Park. The 6-plex is comprised of one-bedroom units with a total of 4200 square feet. The 4-plex is comprised of 2-bedroom units with a total of 4630 square feet. The Yellowstone housing has an east-west orientation; however, the 4-plex has a 100-ft high stand of trees to the south which obstructs the sun. The 6-plex has a road to the south and takes advantage of the solar exposure. The units have 11% window area as a percentage of the conditioned floor area and 40% of the glazing faces south.

Federal housing is required to meet the energy efficient standards set forth in the 1992 Model Energy Code (MEC). Cooling is not an issue with the Yellowstone housing, so the MEC should be adequate for setting minimum insulation levels. In southern locations where cooling loads are an issue the MEC is not sufficient for addressing cooling loads. In these locations more attention will be given to glazing selection and minimizing cooling loads. NPS 76 will be met in instances where its requirements exceed the MEC.

Yellowstone sees 9125 °F-days annually and the MEC specifies a total wall U-value of 0.148 Btu/hr-ft2-°F (R-7), a ceiling U-value of 0.026 Btu/hr-ft^2-°F(R-38), and a floor U-value of 0.05 Btu/hr-ft^2-°F (R-20) over the unheated basement, or basement wall insulation with a U-value of 0.06 Btu/hr-ft^2-°F (R-17). (The basement will be heated to protect piping and items in storage from freezing. See discussion below.) The wall U-values include the windows. NPS 76 requires a ceiling R-value of 48 which will be met. Incidently, each additional R-value is worth about $0.6 per square foot annually, so we can easily show that increasing wall and ceiling R-values is cost effective.

Foundation

All concrete will be specified with 20% of the portland cement replaced with flyash. This reduces the cost of the concrete by $1-$2 per square yard although it is questionable whether or not the savings are always passed on. The flyash does retard the setting time which gives the concrete greater strength, but care must be taken when pouring in cold weather conditions.

The Yellowstone housing will have basements for storage, and will be heated to keep piping and items from freezing. Based on the MEC requirements, the floor over the basement and the basement walls will be insulated to a U-value of 0.09 Btu/hr-ft^2-°F (R-11). Because these are remote sites, the cost to deliver concrete is exorbitant so we are considering stay-in-place insulating formwork. Such systems reduce concrete requirements by 10-50%, but typically require more reinforcement than conventional concrete foundations. The cost of the forms varies between $2 and $3 per square foot and the finished wall system costs on the order of $6 per square foot (not including the interior finish). There are some outstanding issues which need to be resolved including moisture protection given that there is solid insulation between the concrete beams and a cost comparison given the low-heating requirements in the basement. With conventional construction, the floor joists and the basement walls would be insulated with fiberglass batts which is less expensive than rigid board insulation and has a substantially lower embodied energy.

Much of the housing that will be built will have a crawl space. For units which will be occupied year around we will propose a frost-protected shallow foundation. Frost-protected shallow foundations reduce excavation and concrete requirements, are simpler, and can save money. The National Association of Home Builders has developed design guidelines (NAHB 1994) for heated buildings which have recently been adopted into the 1995 CABO One-and Two Family Dwelling Code. These guidelines also cover unheated buildings. (As an aside, the Denver Building Department has recently approved frost-protected shallow foundations. The technology is being used for a residential addition and is proposed for a large public housing project. Initial estimates show savings of $300,000 from use of the shallow foundations on the housing project.)

Envelope

The walls will be 2x6 construction, 24 inches on center with 5/8 inches of oriented strand board (OSB) sheathing. We considered using sheathing made from 100% recycled paper products. The sheathing has an R-value of 1 greater than OSB and the additional cost is paid for in one year of reduced propane use. However, the sheathing does not meet lateral loading requirements so OSB will be used. A 6 mm polyethylene vapor barrier will be installed on the interior. If cellulose insulation is used, no air barrier is required around the exterior; if batt insulation is installed, an air barrier will be required. The siding is a fiber-cement product which is fire resistant and carries a 50-year, limited, transferrable product warranty. The installed cost of the product is on the order of $1/square foot.

The windows are aluminum clad wood with low-E coated glass and have a U-value of 0.4 Btu/hr-ft2-F, rated in accordance with the National Fenestration Rating Council's 100-91 U-value procedure. The ceiling is an R-48 which also proved to be very cost effective given a less than $0.1/square foot installed cost for an additional R-10 of blown-in cellulose insulation. A standing-seam metal (hot-dipped galvanized steel) roof will be used. The roof deck will be oriented strand board. The floors will be constructed with I-joists and have OSB floor decking. For the porches, wood-plastic composite lumber will be used for the decking and con-heart redwood will be used for the columns. The composite lumber costs 50% more than construction-grade redwood but it requires no maintenance and carries a 10-year warranty. With the extreme weather conditions in Yellowstone, the composite lumber should pay for itself well within 10 years.

While this is all simply stated, multiple discussions took place as to whether to build 24 inches or 16 inches on center, which sheathing and wallboard to use, the higher first cost of blown-in cellulose in the walls, how tight to build the structures, and differences in site-built and modular construction. Seismic considerations in the Yellowstone area drove structural decisions, and the requirement to design for either modular or site-built construction lead us to specify alternative products and construction methods.

For example, with the specification of cellulose insulation, the fact that modular manufacturers are not set up to install cellulose in the walls forced us to reconsider the use of cellulose. Cellulose was our first choice because it provides tighter construction and it has the highest recycled content of the available insulation materials. Modular manufacturers use a spray-on cellulose in the ceilings, but they use batt insulation in the walls. The assembly line is not set up to use spray-on insulation in the walls, so the question arose as to whether a dry-pack, blown-in system would work. Concerns over the insulation settling, especially during transportation, and over the flexibility of a modular manufacturer to switch to the dry-pack system lead us to the decision to specify either spray-on cellulose or fiberglass batt insulation.

Heating and Ventilation

As to the tightness of construction, this was one of the more difficult areas to discern. Using the MEC requirement of 0.65 ACH, we determined that we could reduce energy costs by $230 annually at the 6-plex and $250 annually at the 4-plex by reducing infiltration to 0.3 ACH. ANSI/ASHRAE 62-1989, the standard for Ventilation for Acceptable Indoor Air Quality, specifies 0.35 ACH for residences. With 0.3 ACH we would need mechanical ventilation. Baseboard heating is planned for the units with a gas-fired boiler with an AFUE of 87%, so the mechanical ventilation would require that ductwork also be installed. We estimated the cost to install 6 separate, heat recovery ventilation units in the 6-plex to be $6000. Taking into account energy savings and energy use to run the fans, the payback on the heat recovery ventilation units is more than 20 years.

What is lost from this calculation are the comfort advantages and the real cost of energy and pollution emissions. Offsetting these considerations somewhat is the fact that the units may not be occupied year around so a lower level of energy savings would be realized. Also, the installed cost for the heat recovery ventilators in the 6-plex is greater than that for the 4-plex even though the overall square footage of the 6-plex is less than the 4-plex. The calculations were done assuming $0.13 per kWh cost for electricity, $0.55 per gallon of propane, and a 9% discount rate. If we were to consider a 1800 square foot, 3-bedroom house in the same location the payback would be less than 10 years. In homes with forced-air systems the payback is even faster because there are no additional costs for ducting. In locations within the Park Service where forced-air systems will be used we will be proposing combination units which integrate a heat recovery unit with the domestic hot water heater to heat the home. No furnaces will be required and the payback will be less than 5 years.

We did not abandon tight construction completely for the Yellowstone housing. There are potential energy savings by achieving an 0.4 to 0.5 ACH level. The reduction in peak heating energy use from 0.65 to 0.45 ACH is 10,000 Btu/hr. This reduction along with the savings from the higher insulation levels reduces the peak heating load from 89,400 Btu/hr to 60,000 Btu/hr. This reduction in peak load allows us to downsize the boiler from one that has an 106,000 Btu/hr rated output to one which has an 80,000 Btu/hr rated output. The cost difference is $200. In addition, annual savings of $150 could be achieved with the tighter construction.

Interior Finishes

For wallboard we simply specified sheet rock so the contractor will purchase what is locally available. The material cost for sheet rock is a strong function of transportation costs. The closest gypboard manufacturer essentially sets the price and manufacturers only sell into an area where they can compete. There are products on the market with higher than average recycled content; however, they are either not locally available or are cost prohibitive in Yellowstone. In other locations they may be competitive.

Low VOC, water-based paints, sealers, and stains will be used on interior surfaces. Our challenge with paints was to identify the most durable, low VOC paint. Consumer Reports (1994) published an article on interior paints that ranked products relative to cost, application, and durability. Based on this information and product Material Safety Data Sheets, we chose products which meet California VOC requirements of less than 250 grams per liter.

There are alternatives for cabinetry that are formaldehyde-free, although we found that they are currently cost prohibitive for these projects. We have instead specified that all particle board be sealed, including all edges, with a water-based polyurethane.

Linoleum will be installed in the kitchens, bathrooms, and utility rooms. All living areas and bedrooms will be carpeted. Carpet with fibers made from 100% recycled PET (plastic pop bottles) has been used on park service projects and is being considered for this project. Of the more sustainable options for carpeting, there is still no clear winner. Cost-wise it is clear that either a nylon carpet will be used or the carpet made from recycled pop bottles. Installation will be a tackless system which is common for residential applications.

Water Conservation

All plumbing fixtures will meet current federal standards of 1.6 gallons per flush for the toilets, 2.5 gallons per minute for the showers and faucets. We looked at options for lower flow devices and concluded that for the toilets we would stay with the more common 1.6 gallon/flush models because of complaints with the lower flow devices. Consumer Reports (1995) covers the performance of various products on the market today to help in selecting fixtures. All landscaping will be developed to support NPS criteria of minimum impact, no irrigation, and native material only.

CONCLUSIONS

In the design of the trailer replacement housing, any new design element must meet the approval of the Rocky Mountain Region and the region in which the housing is being constructed. Early on it became apparent to the design team that our efforts had to be focused in terms of sustainable alternatives that were being presented. We chose to focus on building elements which have the most intense resource requirements, such as siding, sheathing, insulation, roofing, wallboard, paints, and heating and ventilation. Federal standards for water and NPS 76 requirements for landscaping addressed water conservation for us. We are not involved in the specification of appliances although we will make recommendations along the way.

TABLE 1 - Standard Practice and Affordable Sustainable Alternatives for the Trailer Replacement Housing

Element	Standard	Yellowstone	Next Housing Projects
Energy Design	1992 MEC; NPS 76; 0.65 ACH	1992 MEC; NPS 76; 0.45 ACH	1992 MEC; NPS 76; 0.3-0.45 ACH; Passive Solar
Foundation	Crawl Space -conventional	Basement - flyash in concrete mix; insulate with batt insulation	Crawl Space - flyash in concrete mix; frost-protected shallow foundation, stay-in-place insulated formwork
Walls	2x6 - 16" O.C.	2x6 - 24" O.C.	2x6 - 24" O.C.
Insulation	Batts	Blown-in Cellulose & Batts	Blown-in Cellulose & Batts
Sheathing	Oriented Strand Board	Oriented Strand Board	OSB; 100% recycled paper product
Siding	Varies with region	Fiber-cement	Fiber-cement
Windows	Al Clad Wood with Low-E	Al Clad Wood with Low-E	Low-E selected for climate; Frame alternatives (wood and fiberglass; vinyl)
Wallboard	Locally available product	Locally available product	Locally available product - cost effective alternatives with high recycled content
Paint / Sealers	Water and oil based	Water-based	Water-based
Floor Covering	Vinyl flooring and carpet	Linoleum and carpet	Linoleum and recycled-content or recyclable carpet
Flooring	2x10 - 16" O.C.; oriented strand board	I-joist; oriented strand board	I-joists; oriented strand board
Roofing	Regional with oriented strand board deck	Regional: Metal with oriented strand board deck	Regional with oriented strand board deck
Outside Decking	Con-heart Redwood	Wood-plastic composite for non-structural	Wood-plastic composite for non-structural; ACQ treated lumber for structural
Heating and Ventilation	Forced-air or baseboard heating	Baseboard heating; Downsized due to energy-efficiency measures	Baseboard, or Forced-Air with heat recovery ventilator - combo unit: water heater used for heating
Lighting	Incandescent	Compact Fluorescent and Incandescent	Compact Fluorescent and Incandescent
Water Conservation	1993 Federal Stds; NPS 76	1993 Federal Stds; NPS 76	1993 Federal Stds; NPS 76

Table 1 documents building practices that were standard in the national parks, what sustainable features are being incorporated at Yellowstone, and what we plan to follow-up with on the subsequent housing projects.

Relative to some of the "sustainable indicators," we achieved the following:

- Heating energy is reduced by over 30% (primarily through tighter construction) as compared to the MEC which translates into resource conservation, reduction in pollution emissions, and operational cost savings;

- Embodied energy is reduced by going to 24 inches on-center stud spacing, specifying soft insulation (cellulose or fiberglass batts) rather than rigid board insulation, and specifying flyash in the concrete mix;

- Detrimental indoor air quality effects are minimized by sealing all wood products with the potential for outgassing VOC's with water-based polyurethane, specifying water-based paints and stains; locating boilers outside the living space;

- Housing is made durable through specification of materials such as fiber-cement siding, metal roof, high-performance windows, and linoleum; and

- Affordable housing is ensured through first-cost and life-cycle analyses.

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notes

EXPLORING ALTERNATIVES TO THE DISPOSAL OF RESIDENTIAL CONSTRUCTION WASTE[1]

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ABSTRACT

The National Association of Home Builders (NAHB) Research Center has just completed the first year of a two and a half year construction waste management project funded by the EPA Office of Solid Waste. The project was designed to investigate and evaluate cost-effective, voluntary alternatives to the disposal of residential construction waste. The first year tasks included waste assessments and workshops. The waste assessments were conducted on two homes to establish baseline generation rates. The workshops, conducted in three different areas, were designed to explore obstacles and opportunities in source reduction, re-use of materials, and recycling. In subsequent work, results of the waste assessments and workshops will be used to develop and evaluate alternative waste management programs in two pilot communities. A builder's field guide and video tape will be produced to disseminate the most successful approaches to the reduction and recovery of construction waste. This paper describes the results of the project to date and the alternative management strategies proposed for the two pilot communities.

INTRODUCTION

Waste generated in the building or demolition of a home, office, road, dock, or bridge is commonly referred to as construction and demolition (C&D) waste. Estimates of total C&D waste for the United States vary considerably but center around 40 million tons per year, which constitutes approximately 20 percent of the 225 million tons of waste generated annually in the United States.[2] In the past, open burning and job-site burial of C&D waste were common and acceptable methods of disposal. When clean air and waste regulations largely reduced these means of disposal, C&D waste was taken to either municipal solid waste (MSW) or C&D landfills, depending on the tipping fees and availability of each. Rapidly diminishing MSW capacity, however, has led to reductions or elimination of this disposal option in many areas.

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[1]This paper includes information from a report being prepared for the U.S. Environmental Protection Agency. All data and conclusions are preliminary.

[2]This is a rough approximation of construction and waste totals and is used for illustrative purposes only. Reliable national estimates of C&D waste are not available. Source: Peter A. Yost, "A Feasibility Study and Cost Analysis of Recycling Construction Site Gypsum Wallboard Waste", thesis submitted to University of New Hampshire (September 1993).

Additionally, many states have adopted or are considering stricter design and operation requirements for C&D landfills. These changes may result in sharply increased waste disposal costs for builders.

The construction of an average single-family home typically yields four tons of debris, and many of these materials have the potential for recovery or recycling. Although much effort is being devoted by federal, state and local governments to developing markets for recyclable MSW, little comparable time and money is focused on recovering, recycling, and improving markets for C&D waste materials. While some localities have attempted to create reclamation incentives, little or no guidance has been provided to builders and remodelers on alternatives to traditional landfilling.

In cooperation with the United States Environmental Protection Agency, the NAHB Research Center has initiated a project to demonstrate and evaluate environmentally sound and cost-effective waste reduction and recycling methods for residential and light commercial construction. This paper summarizes the key tasks of the project performed thus far, including: 1) the results of detailed waste audits of typical residential construction in three regions of the United States; and 2) the key points from workshops in the same three regions, which included discussions of waste reduction, on-site reuse, and recycling measures with representatives of local and state governments, the building and building materials industries, and private sector waste haulers.[3]

CHARACTERIZATION OF CONSTRUCTION WASTE

The first step in managing a waste stream is identifying its components and quantifying their contribution to the total stream. Only with an accurate assessment of construction waste can new waste recovery industries and channels of distribution be developed. Relatively little work has been done to assess light-frame construction waste and comparison among studies is complicated by variation in measuring units (volume or mass) and categorization. While waste volumes are important because the capacity of landfills is based on available space, weight is also important as it determines the costs of handling and transporting construction waste. The lack of standard units of measure makes extrapolation for regional or national estimates difficult.

Baseline construction waste assessments were conducted in Grand Rapids, Michigan; Bowie, Maryland; and Portland, Oregon.[4] The sites were selected based on their high level of residential construction activity, interest from a local home builders association (HBA), and an atmosphere of

[3]An additional task still in progress focuses on strategies to increase the development and ultimately the use of recycled content and/or recyclable building materials.

[4]The waste assessment in Portland was conducted for Metro Regional Services by Eco+Tech Construction Co. in 1992. The NAHB Research Center acknowledges Metro Solid Waste Department in Portland for access to all of their waste assessment data and participation in the first year of this project.

cooperation among local solid waste officials, builders, waste management firms, and building product manufacturers.

During the assessments, all construction waste was collected, separated, and weighed. One home from each site was chosen to be representative of the region based on design, size, and construction materials and practices. The results of the Bowie, Maryland assessment are presented in figures 1 and 2 below. (Detailed results from all three assessments are included in Appendix A).

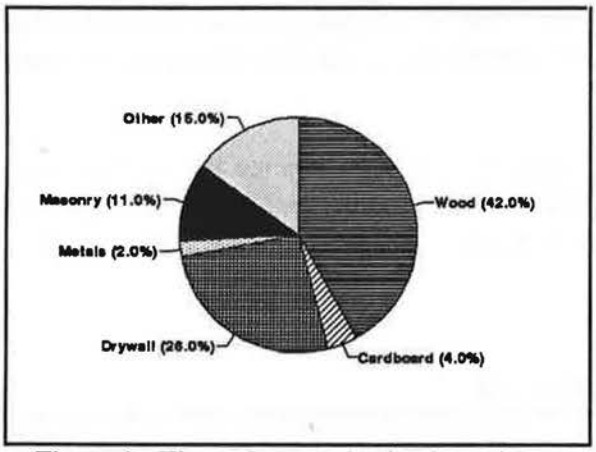

Figure 1. Waste characterization by weight - Bowie, Maryland.

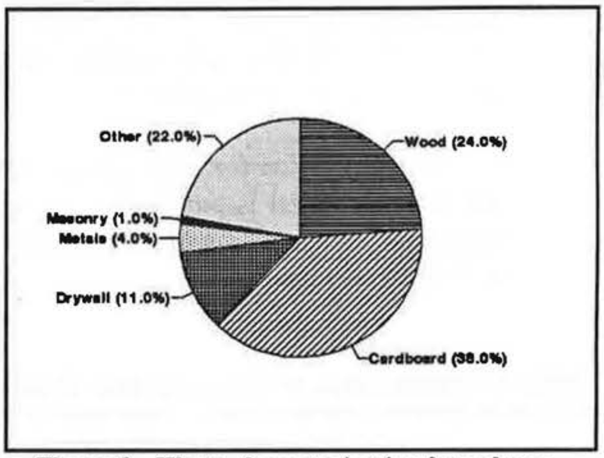

Figure 2. Waste characterization by volume - Bowie, Maryland

The results from all three sites were similar enough to extract some general conclusions:

- At all three sites, regardless of the units of measure, wood, drywall, and corrugated cardboard comprised 70-80 percent of the total waste generated.

- Despite significant differences in methods of construction and the builders' production volume, results from all three sites were somewhat similar. For example, variations in waste composition due to differences in regional building practices (a brick front facade in Maryland, wood siding in Portland, and vinyl siding in Grand Rapids) were notable, but as a percentage of the total were relatively minor. Similarly, the fact that the Maryland builder was a large production builder, and the Grand Rapids and Portland builders were small custom builders had relatively little impact on the results.

- Drywall waste at all three sites was similar to the industry rule of thumb of one pound of waste per square foot of living space.

- Engineered wood products (containing adhesives) can make up as much as 50 percent of total wood waste, an important consideration as recycling opportunities for wood are explored.

- Generation rates of corrugated cardboard waste can vary, depending on the selection of certain materials, and the proximity of suppliers. For example, local millworks (doors, windows, and cabinets) reduce the need and hence the volume of packaging; and the choice of exterior finish material (wood or brick versus vinyl or aluminum) also affects the volume of cardboard generated.

- Builders often are unaware of their *total* waste disposal cost and its breakdown. The most significant portion of total disposal costs are not tipping fees but rather the costs associated with the handling, containment, and transport of waste materials. Table 1 illustrates that the total cost of construction waste disposal at the Maryland site was essentially the same as Portland ($136.00/ton), despite a tipping/pickup fee more than twice as high in Portland. Builders need to understand their total waste management costs as they consider alternatives to disposal.

- Builders pay twice for usable construction materials that end up in the waste pile - once when the material is purchased and again when it is hauled away. Decisions regarding source reduction of construction waste must include the cost savings of avoided purchase and disposal costs.

Table 1. Translation of Construction Waste Assessment

	Bowie, Maryland	**Portland, Oregon**
Total Waste	5.1 tons	6.8 tons
Container/Hauling fee	$570.00 (2 pulls @ $285.00/pull)	$255.00 (3 pulls @ $85.00/pull) +
Tipping fee	Does not apply**	$510.00 (6.8 tons @ $75.00/ton)
Labor	$122.40 (5.1 tons @ 2.4 hours/ton* @ $10.00/hr)	$163.20 (6.8 tons @ 2.4 hours/ton* @ $10.00/hr)
Total Waste Disposal Costs	$692.40	$928.20
Total Cost Waste Disposal (per ton)	$136.00	$136.50

* national average per waste analyses from Metro, Solid Waste Department, Portland, Oregon
** $35.00/ton charged at landfill but not directly charged to builder by hauler

WASTE REDUCTION, RE-USE, & RECYCLING WORKSHOPS

In addition to the waste assessments, workshops were conducted at each of the selected sites. The workshops consisted of discussions of waste reduction measures with members from the building industry, and discussions of on-site reuse and recycling measures with representatives of local and state governments, building and building materials industries, and private sector waste haulers. The workshops were a guided discussion of: opportunities for waste reduction and the recovery of individual construction waste materials; methods of containing, collecting, transporting, and processing the materials; and development by manufacturers and use by builders of recycled content building materials.

Some key points from the workshop sessions focusing on waste reduction included:

- Although numerous waste reduction methods were discussed with building industry members, those present did not see any of the methods resulting in significant waste reduction. Design-oriented opportunities, such as overall dimensions, house configuration and the layout of doors, windows and stairs, raised concerns among some builders regarding the marketability of "value-engineered" houses which can be labeled by competitors as inferior. The consensus was that effective reduction of waste could only be achieved through a comprehensive re-education process involving architects, engineers, builders, and inspectors.

- Although the builders were skeptical that waste could be reduced via hands-on, technically-based construction techniques, many added that structuring subcontracts to include a supply-install concept (i.e., create a direct link between material purchaser and installer) resulted in the generation of less waste.

- Many builders are interested in alternatives to disposal, as long as the alternatives do not result in increases in their costs, i.e., disposal options are usually pursued for economic gain before environmental gain. In many cases, recycling is driven not by the value of the materials (a market pull), but rather by the avoided cost of disposal (a market push). In fact, perhaps the most significant impediment to the development of recovery opportunities is the low value of many construction site recoverables.

The workshop sessions focusing on the on-site re-use and recovery of waste materials included both a material-specific discussion and a general discussion on methods of recovery. Some key points included:

- ***Wood*** - Recycled wood, without market structures in place and with significant processing costs, can not compete with sources of virgin wood fiber in the production of building materials. Nonetheless, some counties currently accept source-separated wood waste at a reduced tipping fee (A facility in Prince George's County, Maryland for example accepts pallets, brush, and "untreated" wood for eventual sale to mulching operations). However, because there is some controversy as to the acceptability of engineered wood products for mulch because of adhesive content, and a significant portion of the wood waste generated in residential construction is engineered wood (see Appendix A), the possibility of topsoil-applied new-construction wood waste is uncertain. Research needs and opportunities regarding the suitability of glue-containing wood products for various agricultural uses from an environmental, health and safety standpoint were discussed at the Prince George's County workshop.

- ***Drywall*** - Recycling of drywall into new wallboard is only feasible in areas of the country close to certain wallboard manufacturing plants that have or can easily add the technology required to handle waste wallboard processing. One manufacturer, for example, has 140 building product distribution centers nationwide that could become involved in the recovery of waste gypsum wallboard if cost-effective methods of handling the materials can be established. Additionally, some research on agricultural and/or topsoil application of ground gypsum has been done, but no studies to date have addressed any potential hazards from trace organic compounds such as heavy metals or dioxin from the paper content in waste gypsum wallboard. The Gypsum Association is just embarking on a research effort to address this issue with the USDA Agricultural Research Service. Depending on the results of this investigation, certain agricultural and topsoil uses of waste gypsum wallboard may become formally acceptable as an alternative to disposal of this material.

- ***Corrugated cardboard*** - The market value of cardboard is changing this material from a waste to a good. With a current market value (baled) of approximately $100/ton, and strong interest among waste hauling firms, this material is a likely candidate for cost-effective recovery.

- ***PVC Building Materials*** - Although plastic wastes have relatively high value and well-established market structures, the amount typically generated during the construction of one home (see Appendix A) would not by itself justify the processing and transporting costs for this material's recovery. If, however, this material can be accumulated into large enough amounts, arrangements could be made to recover the material, via either intermittent pickup, or collection containers at building supply centers.

Specific methods of recovery presented and discussed at the workshop included:

- ***Commingled Processing*** - Commingled recovery processes involve separation and recovery of the materials off the construction job site. The waste is generally contained and collected in the same roll-off containers used for construction waste disposal. Materials are recovered by mechanical or manual separation. If markets exist for cardboard, drywall, and all uncontaminated wood waste, then conceivably 70 - 80% recovery rates are obtainable. The advantage to this approach is that no change in operation is required for the builder - construction waste is handled in the same manner as for disposal. The disadvantage to this approach is that separation costs reduce the net value of the recovered materials, and contamination resulting from commingling (dirt, dust, spilled paint, etc.) can render some materials unrecoverable or not worth separation. Additionally, significant capital investment is required to initiate and operate such a facility.

- ***Source Separation*** - Source separation involves individual containers on the construction job site with materials identified for recovery going into designated containers. This approach involves the greatest change in waste management practices for builders and all of their subcontractors. Prior experience has shown that the general contractor must aggressively educate all job site workers, with requirements to separate the materials written into subcontracts. A commitment is required not only of upper management, but of the supervisors as well to make the separation effort work. Prior experience has also shown that the educational and retraining efforts must be ongoing for up to a year before the system begins to be self-managing. The advantage to this approach is that easily separated materials are kept so and contamination from commingling is eliminated.

- ***Passive Time Separation*** - Passive time separation of materials takes advantage of the fact that certain construction materials - wood, drywall, cardboard (to some extent), and siding materials - are generated during specific and discrete stages of construction. If job site service by the waste hauler can be coordinated with the construction cycle, waste materials can be passively separated over time. This method is used by an increasing number of builders in both Portland, Oregon and surrounding areas of Chicago. Because this method is significantly less expensive than other waste management approaches, charges for the service can be determined up front on a square foot basis, and an employee (laborer to clean up job sites and place construction waste in the roll-off) can be eliminated from the general contractor payroll. The disadvantages of this approach may be that: 1) this approach is not likely to interest large, well-established waste hauling firms and, hence, require new entrants to the business of waste management; and 2) building and OSHA inspectors may adversely react to a container-less approach to on-site waste management.

- ***Re-use of Construction Waste Materials*** - Non-profit building materials recycling operations recover used building products and rejected building materials for discounted sale to low-income homeowners. For example, The Loading Dock in Baltimore, Maryland is the oldest retail business of its kind in the nation and has served as a model for the establishment of numerous similar operations around the country. Any material given to the Loading Dock, whether picked up by The Loading Dock or delivered by the builder to the Baltimore warehouse, represents a tax-deductible donation. Similar operations were identified in Portland and Grand Rapids.

  On-site re-use of wood, drywall, and possibly cardboard may be possible after the materials have been processed in a mobile grinder. At least one manufacturer markets a low-speed, low-noise, mobile grinder well-suited for this method. The acceptability of on-site application with state and local sold waste officials can vary and may depend on research into the suitability of individual waste components for on-site application as noted above.

FUTURE WORK

A primary objective of this phase of this EPA-funded project has been to identify barriers and opportunities related to voluntary and cost-effective residential construction waste management. This has led to: 1) a detailed characterization of the waste materials generated on typical residential construction sites, 2) an understanding of the importance of involving *all* of the potential players in construction waste management, and 3) an understanding of strategies that could be used to reduce construction waste from these sites.

With this information, pilot programs designed to test and evaluate selected techniques will be conducted during 1995. Elements of the programs will include:

- A focus on wood, cardboard, and drywall recovery opportunities

- Supply-and-install contractual relationships with subcontractors, creating a direct link between material purchaser and installer

- Continued investigation of on-site re-use of both clean wood waste and drywall as a soil amendment

- Assistance to waste haulers/processors and builders in determining the costs and feasibility of commingled processing, source separation, and passive time separation methods of waste management

- Fenced or other container-less designated areas for construction waste on job sites and issues related to this waste management technique

More definitively, discussions with waste processors and product manufacturers at the workshops in Michigan and Maryland have led to several region-specific developments:

- Through funding from the Gypsum Association, research by the USDA Agricultural Research Service should formally determine the acceptability of waste gypsum wallboard for certain agricultural and topsoil uses.

- The Research Center is working with the American Plywood Association (APA) to determine the nature and need for research on the suitability of engineered wood products for topical application either on-site or in mulching/landscaping operations.

- United States Gypsum has a plant in Baltimore, Maryland which will accept drywall cut-off waste from new construction sites as part of the Prince George's County, MD pilot program.

- Certainteed will be working with the Research Center in the Grand Rapids, Michigan pilot program on the potential for recovery of vinyl siding cut-off waste.

- Alcoa Building Products will be working with the Research Center on the potential for metal and vinyl siding cut-off waste recovery in the Prince George's County pilot program.

- Local builders, waste haulers, and waste processors in both communities will participate in the pilots and be an integral part of the evaluation process.

The results of the pilot programs will be used in the development of both a builder's field guide and a video tape on construction waste management.

`THE IDEAL HOUSE: INTEGRATING AFFORDABILITY, ENERGY AND ENVIRONMENTAL EFFICIENCY, AIR QUALITY AND DISASTER RESISTANCE

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ABSTRACT

Much has been researched and written about the individual qualities of good home design and construction in terms of energy efficiency, affordability, indoor air quality, sustainability and wind, fire, and flood resistance. The real challenge is to integrate all these characteristics into the ideal house. The purpose of this paper is to review the characteristics of each of the above features and explore the integration of them into the ideal residential structure. The house would take the shape of a compact two-story structure. The first floor would be constructed using an insulated, strong, high thermal mass masonry system resistant to flood, wind, fire, and termite damage. The second story would be constructed using a lighter reinforced wood frame system with between stud insulation coupled with exterior insulated sheathing to minimize thermal bridging across studs. A geometrically compact structure uses less construction materials per floor area, presents less area for improved thermal efficiency, and less profile for wind and flood resistance. Optimizing floor plan living and sleeping areas present opportunities for efficient split HVAC zoning, natural ventilation, and solar passive adaptation. The design would emphasize the 4, 8, and 12 foot dimensioning for waste reduction, selection of environmentally friendly building materials, such cellulose insulation, and efficient lighting and appliances. Features providing improved indoor air quality such as duct selection, design and location; radon barriers, omission of carpeting, ventilation, and control of moisture would be addressed. The design philosophy, concepts, and rationale for the integration of these and many other features of the ideal residence will be addressed in this paper.

INTRODUCTION

Once upon a time in the near future, there was a house that was everything a house could be. It was energy efficient, comfortable, affordable, easily maintained, contributed favorably to the environmental quality of the area, strong, and durable; capable of withstanding violent winds and floods. Although it may sound like the beginning of a fairy tale, the design and construction of such a house is feasible. Integrating affordability, energy and environmental efficiency, air quality and disaster resistance in a building is no small task. Often one factor impacts other factors in a building design.

DISCUSSION

When designing the ideal house the major concept boils down to simple geometry. The emphasis should be to maximize the living area and minimize the external surface areas. The concept of geometry impacts on all factors under consideration. By using a compact design we present a smaller profile to fires, insect damage and most natural disasters such as hurricanes, tornadoes, and floods. We also use less building materials, energy and natural resources for construction which improves the affordability and environmental impact. Let's examine the concept of geometry a little closer.

Geometry: When looking at energy efficiency in a building, geometry has an impact on a lot of the current formulas used for conduction, convection and radiation. Heat is transferred from hot to cold by conduction, convection and radiation which may be expressed by the following formulas:

Conductive heat transfer can be expressed as: $Qcd = A \times 1/Rt \times (T_2 - T_1)$; Where QCd = Quantity of Conductive Heat Transferred (Btu/hr); A = Area of Surface (ft^2); Rt = Resistance to Heat Flow, Total (ft^2 OF hr/Btu); and $(T_2 - T_1)$ = Temperature Difference Across Surface (°F).

Convective heat transfer (sensible) can be expressed as: $QS = V \times Sh \times DA \times (T_2 - T_1)$; Where Qs = Quantity of Convective Heat Transferred (Btu/hr); V = L x W x H = Volume of Air Movement (ft^3/hr); Sh = Specific Heat for Air (0.24 Btu/lb); $(T_2 - T_1)$ = Temperature Difference of Air Masses (°F); so $Qs = 1.06 \times CFM \times (T_2 - T_1)$ sensible heat transfer (Btu/hr).

Radiant heat transfer can be expressed as: $Qr = A_1/A_2 \times a_1 \times e_2 \times (T_2 - T_1)^4$; Where QR = Quantity of Radiant Heat Transferred (Btu/hr); A_1/A_2 = Ratio of Apparent Areas; a_1 = Absorption Factor of Receiving Surface; e_2 = Emissivity Factor of Transmitting Surface; and $(T_2 - T_1)^4$ = Temperature Difference Between Surfaces (°F).

Homes of compound shapes, that is with courtyards, different angles, and a long length-to-width ratio will inherently use more energy and generally cost more to purchase than homes with simple shapes. A two-story home that is relatively square may have 28 percent less surface area for heat transfer and less exterior construction materials than a long, narrow ranch home of the same square footage. A two-story offers more opportunities for cross-ventilation and zone air conditioning. We also make better land use and have less environmental impact. There are many relatively compact two-story shapes that have nice architectural lines provided by positioning of unconditioned porches, garage, workshops, etc. So by reducing the area component of the building, particularly the surface area (walls, and roof), we impact favorably on the energy use in the building.

Affordability: A definition of affordability is now in order. Too often we think of the affordability or cost of home ownership as equal to the principle interest and taxes. Other factors need to be entered into the affordability equation which could be expressed:

$A = (P+I+In+t) + O + M+SI (E) + T$; where

A = affordability; P = principle; I = interest; I = insurance; t = taxes; O = operational costs, such as utilities; M = maintenance costs; SI = societal impacts (environment);
T = transportation to and from work, entertainment, shopping, etc.

Owners are obligated to pay off the interest, taxes and principle on a residential buildings and it is prudent or required by the mortgage company to have insurance. Then there are maintenance costs. Many of us fail to consider the operational or energy costs and the other utilities to operate the house. Even fewer of us consider the societal impacts or the externalities, which is the latest buzz word for environmental consequences. We must not overlook the cost of transportation to and from homes, schools, entertainment centers and so forth. During the middle ages in Europe, transportation costs was not a factor. Most people could walk to their business, entertainment and shopping within ten minutes. Proprietors often lived above the stores that they operated. Modern Americans, on the other hand, often travel tens of miles to their places of employment, places where they shop or entertainment centers. Many people now live in what is called the urban fringe. Too often people spend more for transportation to and from business, shopping, schools and entertainment than they pay for energy to operate their homes. Therefore, constructing the ideal home would include selecting a site that is convenient and presents a good passive solar orientation.

Energy Efficiency: Referring to our affordability equation: Considering the (O) portion of the affordability equation, A = (P+I+In+t) + O + M+SI (E) + T, it is possible to spend more for utility bills over a typical 30 year mortgage life than for the principle and interest on the loan. Lower utility costs place the buyer in a better position to make mortgage payments, a factor some banks will consider when qualifying a buyer.

The purchase of an energy-guzzling home can lead to startling expenditures, especially when considered over a 30 year mortgage period. For example, such a home might cost $85,000. If a conventional 30 year mortgage is secured with 20 percent down, $68,000 would need to be financed. At 10 percent interest, monthly payments would amount to approximately $1,025 for 360 months, totally about $369,000. Adding this to the $17,000 down payment, results in a grand total of $386,000 for principle and interest over the 30 year mortgage period. Owners of less energy efficient homes in this price range may pay an average of $195 per month or more for utilities. Assuming $0.08 per kilowatt hour and $0.65 per therm for natural gas, if the cost of utilities escalates at seven percent a year, as some experts estimate, the owner could pay about $221,000 for utilities during the 30 year mortgage period. Therefore, the owner could pay almost 60 percent of the principle and interest on the mortgage loan for utilities. If the designer or the contractor has wisely chosen energy-conserving measures, a significant reduction in energy costs could be achieved with little or no extra investment. Even if a builder makes a $2,500 investment in energy-conserving features, this will only add about $38 a month to the mortgage payment, but may actually reduce the utility bill by as much as $60 per month. Considering the escalation of utility costs over a 30 year mortgage life, this could lead to a savings of $54,320. Another factor to consider is that money saved through energy conservation is after tax dollars; that is, a savings of $1,000 a year in energy costs equates to $1,200 a year before taxes if one is in the 20 percent tax bracket.

Disaster Resistance: Building strength into a building can save resources and reduce environmental impact. It could be said that Hurricanes Hugo and Andrew devastated thousands of acres of forests in the northwest and southeast. This was the indirect destruction caused by the cutting of replacement timber necessary to rebuild coastal South Carolina and south Florida homes. Many construction professionals conclude that good design and construction could have reduced much of the damage caused by Hurricanes Hugo and Andrew. In some cases, the extra costs would have been limited to a few dollars if extra nails had been used or more attention paid to details. The cost of these omissions has been placed over 30 billion dollars and includes loss of valuable natural resources.

In addition to using valuable forest resources, the rebuilding effort takes a tremendous amount of energy to transport and process raw timber into finished products such as concrete block, steel, aluminum, glass and other materials used in construction.

The approximate energy needed to produce various building materials ranges from 17.4 million Btu/ton (MBtu/T) glass for windows to 219 MBtu/T for the aluminum used to manufacture their frames. So when we build strong, durable buildings, we save energy and reduce the impact on the environment.

The energy needed to produce the construction materials in a 1960 square foot residential building (exclusive of furnishings and appliances) is approximately 271.7 M BTU (Table 1). This is equivalent in energy to almost 47 barrels of oil, or about two years of energy used to generate the electricity needed to operate appliances and lighting in the average house.

There is an expression in the construction trade: "measure twice, cut once." It is important that the job be done correctly the first time. It takes energy to manufacture, transport and install almost every building material such as aluminum frame windows, asphalt shingles, 2x4s and plywood.

Table 1
Approximate Energy Used in Construction Materials for a 1960 Square Foot Residential Building*

System	Materials	MJ	BTUs
Exterior Walls	4" face brick 2"x4" stud, 4" insulating sheathing	126,200	119,620,000
Glass Windows	17.5% wall area, 1/4" single pane	3,400	3,223,000
Interior Walls	3/8" gypsum, 2"x4" studs, 1/4" plywood panels	12,300	11,659,000
Floor (off grade)	1-3/16" hardwood, 3/4" subfloor, joists, w.f. beam	60,000	56,872,000
Foundation, 30" stemwall	30" concrete block with 12"x12" concrete footer	14,860	14,085,000
Roof	asphalt shingles on 1/2" plywood, rafters, joists	69,900	66,256,000
Total Energy in the	building materials =	286,660	271,715,000

*Adapted from Wong and Sauer, 1983.

Energy resources are finite and costly. It is important to conserve and use them wisely, saving our money in the process.

As the saying goes, it doesn't take a rocket scientist to understand structural integrity. The concepts of a strong home or building are simple:

- a strong foundation firmly bonded to the ground
- strong walls bonded to the foundation
- a strong roof bonded to the walls.

A weak link in any of these three areas could cause the home to be severely damaged or destroyed. Most of the damage caused by Hurricanes Hugo and Andrew was not caused by weaknesses in the building code, but by omissions of the builders and inspectors.

Wind Force Phenomena: Hurricane winds start at 75 mph. At this speed, winds can produce a direct force of almost 15 pounds per square foot on a perpendicular surface. So theoretically, a 2,514 pound force could be exerted on an 8-foot x 20-foot (160 square foot) wall by a 75 mph wind blowing directly on it. But the pressure exerted by wind increases exponentially so that a 150 mph wind could exert a pressure of 60 lbs/sq. ft. or 9,600 pounds of force on the same wall. Consequently, it would be extremely difficult to protect a home or any building from major damage against winds in excess of 150 mph. The direct force of wind on a vertical component of a building (p), in pounds per square foot (lbs/sq. ft.), can be expressed by the formula:

$p = (\partial\ V^2)/2g_c$; where p = pressure in lb/ft^2; ∂ = density of air = 0.077 lb/ft^3; g_c = gravity constant or 32.17 ft./sec^2; V = velocity of air in ft/sec

So at 60 mph, $p = \dfrac{(0.077)\ (88)^2}{2\ x 32.174} = 9.2$ lb/ft^2

at 75 mph, $p = 14.4$; at 120 mph, $p = 36.8$ lbs/ft^2; and at 180 mph, $p = 82.8$ lbs/ft^2.

As the wind passes around a building, a vacuum is produced on the leeward side which pulls the building. So on the windward side the wind produces a force trying to push the building over, and on the opposite side a vacuum tries to pull the building over. Another interesting phenomenon is that wind can be deflected by trees and other buildings so that wind forces are rarely direct Wind directions constantly change, which produces constant tugging, twisting and bending forces on a building. These are called **dynamic forces**, or forces associated with motion. All these forces and directions should be addressed in a building that has good structural integrity.

If, during high winds, a window breaks or a wall is penetrated by debris, pressurization of the home can occur. An opening as little as 2% of the wall area on the windward side of an enclosed building can result in full pressurization of the home. This could be analogous to blowing up a balloon. Theoretically, the force tending to blow the house apart due to pressurization could reach as high as 34 lbs/sq ft with hurricane force winds of 120 mph blowing directing through a broken window. The converse is true with an opening on the leeward side of the building. This will tend to create a vacuum on the interior. By the way, experts recommend windows be kept tightly closed at all times during high winds. This contradicts a well-established myth suggesting windows on the lee side be opened during a tornado.

Minimizing the profile will reduce the pressure on the building from wind and flood and risk of being hit by flying debris.

Thermal Mass: Massive buildings, such as those built with concrete block, have the capacity to store great quantities of heat, thereby delaying heat transfer in or out. Heavy buildings with thermal mass or thermal inertia have good thermal stability and resist temperature change. Thermal mass can be defined as the characteristic of a material to resist temperature change due to its own capacity to store heat. Concrete, concrete block, building brick, steel and water have this characteristic in varying amounts. Thermal mass can effectively dampen or average outside temperature extremes.

In construction, thermal mass is generally measured by its heat capacity, that is, its ability to store heat per unit volume. For example, one pound of dry air has about the same net heat storage capacity as one pound of concrete, but one pound of solid concrete occupies less than 1/100th of a cubic foot while a pound of air occupies about 14 cubic feet.

Concrete is extensively used in both commercial and residential construction. Theoretically, warm air at 90°F inside a 1,500 square foot super-insulated home could be cooled to 75°F with just 27 concrete blocks at 60°F. There could be as many as 2,160 blocks in such a home representing tremendous thermal storage capacity.

Properly enhanced with shading and outside insulation of R-6 or more in cold climates, thermal mass can make a building more energy efficient than its lightweight frame counterpart because:

1. Air conditioning and heating loads can be deferred to off-peak rates. (Thermal lags as long as 12 hours can be obtained.)
2. Heating and cooling systems can be sized smaller (temperatures of massive materials never reach outside design extremes.)
3. By preheating or cooling, the heat storage capacity of the thermal mass can provide extra conditioning to carry over peak conditions.
4. The seasonal efficiency if air-cooled air condition systems can be improved through a reduction of operating hours during high daytime temperatures.
5. The non-heating and cooling seasons can be extended from three to eight months due to the temperature damping effect of thermal mass.
6. In some cases the phenomenon known as "thermal wicking" of stable ground temperatures can be effective.

Many Florida homes were built in the 1950's and 60's using concrete block systems (CBS) without insulation. From an energy performance standpoint, they often did better than frame homes without insulation. Midway through the 1970's we found it imperative to use insulation in Florida buildings because of soaring energy costs. The questions is not to use insulation but where to apply it and in what quantity?

1. For buildings with long occupancy profiles (homes, apartments, hotels and most commercial buildings), placing at least R-6 rigid closed cell insulation on the outside of the thermal mass is the best option. A 1,500 square foot CBS home could have 2,160 blocks weighing more than 70,000 pounds. Add another 60,000 for a 4" slab.

This concrete mass equates to about 31,000 BTUs per degree Fahrenheit of thermal capacity. Precooling the walls to 73°F, for example, and then letting the temperature rise to 78°F could provide the equivalent of over 10-ton hours of cooling. This capacity paves the way to be used as a load management tool to get over peak periods. By extending the outside insulation 3' or more below grade, thermal storage can be maximized even further. In many Florida locations ground temperatures below 3' tend to stabilize between 69°F - 76°F. Extending insulation several feet below grade traps this heat sink and, in some cases, a favorable heat transfer can be wicked up in the winter and down in the summer through the slab and walls.

2. For buildings with short occupancy profiles (auditoriums, churches), placing R-8 to R-11 rigid or batt insulation on the inside is the better option. Temperatures of massive structures tend toward Florida's mild average temperatures allowing better discrimination of heat and cooling. For example, the average temperature in Miami and Tampa during the hottest month (August) is only 83°F. With the temperature in the structure approaching this average, most of the cooling capacity can be dedicated to cooling the internal load (occupants) instead of heat gained through the building envelope.

3. To further enhance the benefits of thermal mass in Florida, for example, it is necessary to minimize direct solar heat gain by shading the proper building orientation. Overhangs, landscaping, sun screens, and Bahama shutters are effective ways to employ shade. If possible, orient the long sides of the building to face south and north instead of east and west. Not all locations in the country are as well suited for thermal mass as Florida. Florida's mild ground and average temperatures contributes to its success.

IAQ Checklist for Building Professionals: There are many causes of poor indoor air quality in buildings and there are many techniques that can mitigate the problems. The list presented is by no means complete, but does address the more common problems associated with sick buildings. If these suggestions are followed, it may save a considerable amount of natural resources, energy, litigation, and could improve the reputation of any building professional.

Building Envelope Design and Construction Considerations:

1. Emphasis should be placed on elimination of pollution sources rather than relying on ventilation air dilution intended by ASHRAE 62-89 proposed standard.
2. Design the building to provide maximum usable area with minimum surface areas (squares and cubes) translates to better IAQ, less building materials, and less heat transfer surface.
3. Tight building construction practices should be employed. Roofing and wall system should prevent water intrusion and provide for water exit from building. Weather strip and caulk around windows, doors, plumbing and wiring accesses through the building envelope. The exterior structure should be tight enough to prevent the outside air entry.
4. Vapor retarders, including vinyl wall coverings, important for preventing moisture problems in stud spaces in cold climates, should never be used on the inside of exterior walls in hot humid climates such as Florida otherwise mildew growth and wetting of the insulation result.

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5. The plastic vapor seal under concrete floor slabs should be installed with holes or tears sealed before the concrete is poured. Use a 6 mil black plastic sheet for ground cover below off-grade structures (seal seams and to stem wall as appropriate) to prevent moisture and toxic soil gas entry.
6. For high radon areas to prevent entry: use crushed rock or course sand to provide gas communication under building and foundation, then use high density plastic gas retarder between this fill and building.
7. Allow drying of construction materials and the structure prior to sealing and painting.
8. Use guttering and down spouts to carry rainwater away from building to reduce the opportunity for rain to seep under and enter building.
9. Consider installing a central vacuum system with an outside exhaust .
10. To minimize hydrocarbon and other VOC transfer prevent air from garage and workshop areas from entering occupied areas of house and building.

Heating, Ventilation and Air Conditioning (HVAC) Design, Operation and Care:

11. In general, a positive air pressure should be maintained within a building, particularly commercial buildings. Portions of a building identified to have potential indoor air pollution problems (i.e., copy rooms, garage, etc.) should be kept under negative pressure, exhausting well away from other portions of the building.
12. Carefully control ventilation which should be conditioned and filtrated such that the indoor air is maintained at a temperature between 70 to 78°F and 30 to 60%. Ventilation should be kept to the absolute minimum necessary to provide proper indoor air quality and a uniform carbon dioxide level below 1,000 parts per million.
13. The HVAC system should be sized for the expected sensible and latent load.
14. For residential and other applications having a fan selection on the cooling thermostat, the fan should be kept in the automatic position.
15. Bathroom exhaust fans should have humidity sensors or 20 minute timers to best remove moisture from the tub and shower area.
16. When moisture problems in a building are recurrent, consider the use of innovative heat pipes, hot gas bypass, or desiccant moisture exchange technologies. First, make sure major moisture sources have been addressed. Dehumidifiers are costly and not energy efficient.
17. Be skeptical of ozone generators as a method of reducing indoor air pollution.
18. Smokers should only be allowed to smoke outside or in designated areas with dedicated HVAC systems and under negative pressure with respect to adjacent spaces.
19. Air conditioning filters should be changed regularly. Treating filters with germicides, fungicides or deodorizers should be done with caution and only with EPA approved substances. In general, HVAC filters are designed to protect equipment, not people. High efficiency particulate air filters (HEPA) may restrict air flow if used as a retrofit on existing equipment. Using medium efficiency filters or room air cleaners with HEPA filters and activated charcoal may be a better option.
20. Periodically examine the air conditioner drip pan to make sure that the drain is not clogged. Also, drip pans should be treated with the proper air conditioning germicides to prevent bacterial growth.

Duct Design and Installation Considerations:

21. Return air and ventilation air intakes should be placed well away from moisture and potential pollution sources such as garbage dumpsters, cooling towers and loading docks. Roof intakes should be placed well above the roof mildew prone surface.
22. Unlined or uncoated fiberglass ducts are a potential source of mold and air quality problems and should be avoided. Galvanized steel ducts insulated and wrapped with a vapor retarder on the outside are preferred.
23. Avoid fiberglass insulation where the fiberglass particles may come in contact with humans either from ventilation carrying the particles or by direct contact.
24. Use air doors and smoke sticks to identify leaks, and then seal leaks in AC duct work with approved acoustical sealing or mastic.

25. For residential applications, consider return air ducts or doors with proper undercutting or lovers for bedroom areas.
26. For residential applications, provide air circulation into and throughout closets with such things as louvered doors, open shelving and AC registers.

Interior Design Considerations:

27. Avoid indoor water fountains and pools and water-guzzling indoor plants (cactus okay). Fountain water evaporates to increase humidity.
28. Avoid deep pile carpets particularly those imported which may contain formaldehyde as fix for dyes. Deep pile carpeting tends to be a haven for dust mites, fleas, human dander and other irritants which can never be totally removed. Fabrics suspected of containing formaldehyde should be washed and dried for an extended period of time before installation.
29. Avoid furniture and paneling containing particle board and plywood constructed with interior glue or urea resins which contain formaldehyde.
30. Select furnishings that have low moisture absorption capability, such as wicker, cane, glass, steel and ceramic tile.
32. Schedule painting (Low or no VOC's) and heavy cleaning during periods of low occupancy.
33. Use insect baits instead of chemically treating with insect poisons.

Landscape Considerations:

34. Do not locate hedges or shrubbery too near the building which can create a micro climate much more severe in terms of humidity than reported by the weather bureau.
35. Consider low maintenance landscaping and drip irrigation systems

Integrating the Concepts:

Floor Plan: As mentioned the floor plan should take advantage of maximizing the floor (living) area while minimizing the surface (wall, roof) area. In addition precut studs and standard 4', 8', and 12' dimensioning should be used to minimize waste and environmental impact.

In hot climate regions the kitchen should be located on the northeast or east side of the home, if practical. The reason for this is that most of the heat-producing type of cooking is done for the evening meal, and this internal heat build-up tends to become quite localized in the kitchen. If the kitchen is placed on the west side of the home, the afternoon heat contribution from the sun can worsen the problem, making the kitchen and adjacent dining room very hot. This tends to force the occupant to turn the thermostat to a lower setting to compensate for the heat build-up. In the process, the whole house will be excessively cooled just to satisfy the required comfort level in the kitchen and dining room areas. If the kitchen and dining room are located on the east or northeast side of the home, the sun's impact will be minimized as those areas tend to be the coolest portion of the house in the late afternoon. If the house is two-story and the bedrooms are located upstairs, this offers an opportunity for nighttime cooling, cross-ventilation and zone air conditioning where the upstairs bedrooms could be cooled or heated only in the evening and the downstairs unit turned off. In the daytime the upstairs air conditioning unit could be turned off, while the downstairs unit is turned on. This strategy is effective during periods of low humidity if mildew is not a problem.

Foundations: The recommendation to "build your home on solid rock" is thousands of years old. Million dollar homes have slid down California hills because of foundation undermining. In Florida, the author's residence, there is little rock on which to build, but a solid foundation can be built with steel reinforced concrete or heavy treated piers to form a good bond to the earth. A good foundation is especially important to prevent damage during hurricane tidal surges and flooding. Moving water can undermine a foundation, causing the building to collapse and break up. A well constructed foundation can minimize this damage.

Concrete block walls. Concrete block wall structures generally have been shown to be stronger and more resistant to hurricane winds than wood frame walls. Although there was damage to block walls from Hurricanes Hugo and Andrew, the frequency of damage appeared to be much less than homes with wood framing. This was shown to be true even if the blocks were poorly laid. However, the strength of wood framing was severely compromised by poor design and craftsmanship.

Wood frame walls. Although wood frame walls are not generally as strong as block walls, they can be made hurricane resistant with proper design and construction. Stud walls are normally attached to the foundation through the sole plate which is bolted to the foundation with J-bolts imbedded in the foundation/slab. Studs are secured to the sole and top plates with hurricane clips, metal straps and toe nailing, and proper corner bracing should be used.

The capability of high mass masonry construction to possess thermal inertia, be strong, wind, flood, fire and insect resistant; and the capability of frame home to hold more insulation and be resistant to earthquakes leads the writer to consider both wood and masonry for construction of the ideal house. The first floor was selected to masonry for strength and the other characteristics above. It will be built three feet below grade, water table permitting, for the dual benefit of presenting a lower profile to wind and flood, and capability for geothermal wicking (stable temperate ground temperatures) . The first floor would contain the living areas: the kitchen, dining room and living room. The second floor would be frame using good strong construction bonding to the first floor's masonry walls, The frame walls would contain R-13 insulation between the studs and R-6 insulation board on the outside which would serve to insulate any thermal short circuits from studs and gaps in the wall insulation. In the summer evenings, with the windows open to receive the cool night breezes, this light mass component would cool rapidly often providing comfort with out mechanical cooling. It would also shade the high mass first floor and serve as a second zone for a split zone HVAC system. In the evening the HVAC equipment could be turned on to and dedicated only to the upstairs sleeping areas (if needed at all); in the daytime the HVAC system would be dedicated to the downstairs living areas. Thus only half of house would need to be heated and cooled at one time.

Windows: Poorly installed windows can blow out in high winds. Unprotected windows can also be broken by flying debris. Large bay windows, fixed glass picture windows and sliding glass doors are particularly vulnerable to flying debris and are hard to protect. Windows should be made as small as practical consistent with providing appropriate viewing and natural lighting. It is suggested that a properly designed window should start no lower than 3 feet from the floor and end no higher than 6 1/2 feet from the floor. This allows a view of the outside while sitting down or standing up. Large vertically oriented windows should be avoided unless called for by Code for possible egress during fires. Reduced window area is also consistent with energy efficient home design. In disaster prone regions, glass used for architectural or aesthetic purposes should be avoided because of risk of damage during high winds; also excessive energy use will be avoided. Installed skylights generally weaken the roof system and should be avoided or made as small as possible using extra reinforcement.

Use of Bahama shutters will provide both shading and good viewing through windows, but can also protect the windows from flying debris during high winds. Solid wood or metal awnings will also provide shade on the windows and serve to protect the windows during high winds, if properly closed. Solid wood or metal shutters will also protect windows but will not provide shading.

Windows that face south under a one or two foot overhang will have much better energy performance than windows facing east or west, and moderately better performance than windows facing north, especially in hot climate regions. Consequently, two homes with identical floor plans may have considerably different energy usages if one home faces west and the other home faces south. The reason for this difference is the natural migration of the sun from a high altitude in the summer to a low altitude in the winter. Also, the unshaded east and west windows allow entry of morning and afternoon sunlight. In the summer the sunlight is restricted from coming in the windows by the overhang. However, in the winter when heat is needed, the sun is low enough to provide direct solar heating. For example, in south Florida the noontime sun in late June will be almost directly overhead or about 87 degrees from the south horizon. However, in late December the noon sun will only be about 40 degrees above the horizon.

Windows should allow cross-ventilation and functional viewing without using excessive glass. On a hot summer day with the sun shining directly on a glass window, an extremely small one-square foot pane of clear glass will allow more heat to enter a room than would enter from conduction through the rest of the wall. For the best functional viewing, the window height should start at about the three foot level and end at about six to six and one-half feet from the floor. That way comfortable viewing can take place whether a person is sitting or standing. In addition, horizontally-oriented glass will provide much better panoramic viewing than vertically-oriented glass of the same square footage. Horizontal windows provide more ventilation than vertical windows of the same type and area. Relatively long spring and fall seasons in Florida provide excellent opportunities for cross-ventilation. Casement windows provide the largest open aperture, almost 100 percent of the window area. Awning windows generally provide about 70 percent, and single- or double-hung windows approximately 40 percent of the area. The window system should be properly sealed with caulk or weather-stripping.

While double-paned or insulated glass is a necessity in the northern states, in many cases they will not prove cost effective in regions with mild weather such as Florida, southern California and Texas. Since double-paned windows address conductive heat loss or gain, they only become cost effective when the average temperature difference between inside and outside is over 20°F. However, insulated glass should be considered anywhere if street or airport noise is a problem.

Roofs: While a foundation is important to prevent water and flood damage, a strong roof is the key to preventing wind damage caused by hurricanes and tornadoes. A poorly designed or constructed roof that has not been properly attached to the walls with steel hurricane clips or straps will be most susceptible to damage during high winds. Many homes damaged during hurricane Andrew had nails missing in the metal clips or straps (usually eight are required) or the straps were too short for the application (18- inch straps are stronger than 12-inch straps for tying down roof trusses or rafters).

From observations in the aftermath of Hurricanes Hugo and Andrew, it appears that most structural failure occurred first at the roof. Failure was also common when the sheathing was improperly nailed to the roof trusses or rafters. All too often when the roof system fails, wall system failure follows, especially in frame construction. The strongest roof systems are flat and the hip roofs. Flat roofs present a very small profile. Hip roofs are structurally stronger and deflect winds better than gable designs.

Our ideal home will have a low slope or flat roof that will use triple dip galvanized steel for durability, low maintenance and a low profile for possible wind damage. In addition, galvanized (zinc-coated) metals acts as a fungicide which will not permit molds to grow, presenting a healthier microclimate around the building. It also provides an opportunity to use of cisterns or water collection from the roof to flush toilets or other greywater applications.

Landscaping: In some cases during Hurricanes Andrew and Hugo, and even during the more current March 13, 1993 winter storm of the century, homes escaped damage from the high winds only to be damaged by falling trees or limbs blown from trees. No tree is wind proof and given enough velocity, any tree will fall or break. Investigation made after these hurricanes and storms revealed that some trees resist wind damage better than others.

One of the most durable trees was the Florida state tree--the Sabal palm. Palm trees in general are very resistant to high winds. Other wind resistant trees were shown to be hickory, pecan, live oak, bluff oak, bald cypress and American ash. Trees that do not do well in high winds and could cause damage to homes and buildings were identified to be laurel oak, water oak, sweet gum, sugarberry, cherry laurel and pine trees.

In addition to providing aesthetic and environmental stability, trees can also make homes more energy efficient. If you are able to choose your site or choose your landscaping that will be near the home, it is suggested that wind resistant trees be selected. The less wind resistant trees should be placed at a considerable distance from the home, if practical. Prior to hurricane season, all trees and shrubs should be pruned and trimmed to minimize potential damage.

Placing the home between shade trees, particularly those that may be on the east or west side of the home, can be to an owner's advantage. These trees are particularly effective if they are deciduous trees; that is, trees that lose their leaves in the wintertime. They provide shade in the summer and allow the sun to pass through in the winter. Pine trees and evergreen trees located on the north and northwest sides of the home will provide a barrier against cold winter winds. Landscaping can also be used to effectively channel prevailing summer breezes into the home.

Landscaping should make use of native plants and ground cover. Plants and ground cover native to the area tend to be low maintenance, self-perpetuating and drought tolerant. There are a number of attractive bushes, flowering plants and ivies that make excellent landscaping, requiring little effort on the part of the homeowner to maintain and thereby saving energy and contributing to a more favorable environment. Use of mulches from bark and wood chips for driveways is much more energy-saving than use of concrete and asphalt which absorb the sun's energy and re-radiate this heat to the house. Use of natural cover also provides better drainage.

Insulation and Infiltration Control: Installation is just as important as the level of insulation (R-value). Avoid gaps and compressing; use the proper density. A frame house generally offers opportunity for a greater degree of insulation, and performs exceptionally well if an insulated sheathing placed on the outside of the home coupled with batt insulation in the stud wall cavity. Attics should be insulated according to geography/weather considerations; R-28 for Florida, R-38 to R-50 for Minnesota.

Joe Lstiburek emphasizes that buildings should be built using a map. Climate conditions vary significantly between regions of the United States. There are hot dry regions, cold, damp regions, cold dry regions and there are hot humid regions. A house built in one area is not necessarily a good house for another area. Constructing our ideal home, the weather map should be taken into consideration. Placement of the vapor barrier, vapor retarder on the inside or next to the conditioned space in a hot, humid climate can lead to disaster. Conversely, placing a vapor retarder on the exterior of a cold climate could lead to disaster. So the rules change from locality to locality. In cold climates vapor retarders should be on the interior heated side of a building, while in hot humid climates they should either be omitted or an infiltration barrier placed on the exterior of the building.

Vapor barriers, such as polyethylene sheeting, are not recommended for installation in Florida residences. However, infiltration barriers or house wraps are recommended. Vapor barriers do not breathe or allow moisture to pass, and could cause problems with moisture condensing in the insulation and forming mildew. House wraps or infiltration barriers do breathe and do allow moisture to pass while keeping air infiltration out of the house. It is prudent to make sure the house has been properly caulked and sealed, particularly under the sole plates and wiring and piping through the top plate.

Installation of a radiant heat barrier in the attic is also an attractive option in terms of providing a greater degree of comfort to the occupants and lowering energy bills. A radiant heat barrier is basically aluminum foil on paper backing. Radiant barriers are effective in keeping the sun's radiant heat out, especially if there is no external shading on the home. Keep in mind that insulation such as fiberglass batts and cellulose reduces conductive heat transfer, whereas a radiant barrier reduces radiant heat transfer. In the summertime radiant energy might account for as much as 40 percent of the heat energy coming into the home.

HVAC: Generally, the heating and air conditioning ventilation systems are employed into one system. The most efficient form of heating is generally natural gas, with the heat pump following a close second. The most inefficient form of heating is electric strip heating. This can be very expensive to use for heating in northern Florida. If a heat pump is used, the efficiency is normally referred to the "coefficient of performance" or COP. The higher the number the better. Heating equipment may also be rated with a heating system performance factor or HSPF. For natural gas, the system efficiency usually is 70 percent or greater. There are some impulse-type of furnaces that are over 90 percent efficient. These may be very expensive.

For cooling systems, a measurement of efficiency is termed the SEER or seasonal energy efficiency ratio. The higher the SEER, the greater the efficiency. There are some with efficiencies as high as 14 or 15, particularly those referred to as ground or water coupled (geothermal) heat pump systems. These usually employ a closed-loop water recirculating system that exchanges heat directly with the ground or a body of water such as a swimming pool. There are other open-loop systems called water source heat pumps that require a pump, pumping water from the ground and then returning it to the ground. Some of the these may be counterproductive in terms of water conservation and some efficiency is lost due to scaling and water impurities. Some air-to-air systems may lose some of their moisture removing capabilities at very high efficiencies. There are exceptions and these should be verified with the contractor.

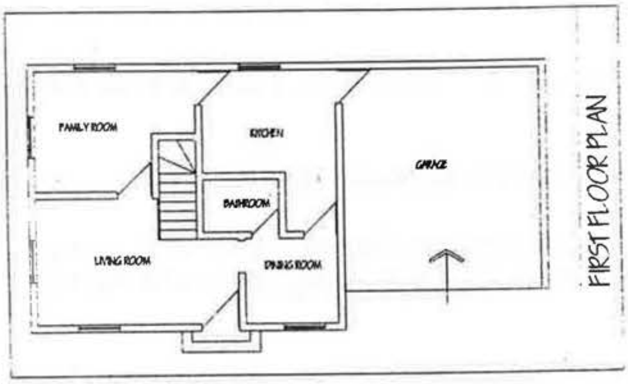
The moisture-removing capability of an air conditioner is very important in Florida because of potential for mildew problems. It is therefore especially important to have the air conditioning system sized properly using Manual "J" or other load calculating procedures. If the air conditioning unit is oversized, which is a real problem in Florida, then the air conditioning system will not run long enough to remove the moisture and the humidity in the home will be high, creating an excellent environment for mildew growth.

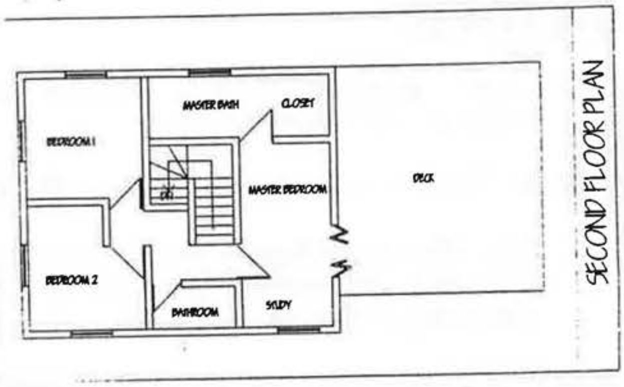
Water Heating: Next to heating and air conditioning, water heating is usually the next largest consumer of energy in a home. Here again, natural gas is the most efficient for water heating, and electric strip heating is the least efficient. Generally speaking, an electric water heater will cost about three times as much to operate as a natural gas water heater. There are also accessories, such as heat recovery units (HRU), that reclaim heat normally wasted in an air conditioning system to heat water. These HRU's can be cost effective especially if used with a heat pump. A solar preheating system may also be effective.

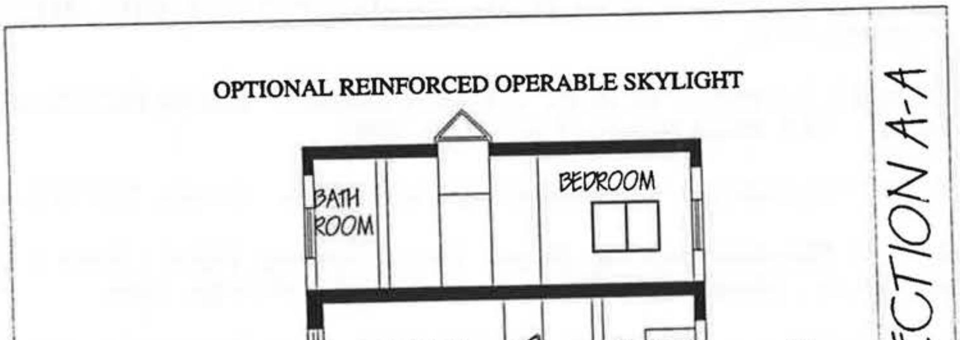
Efficient Lighting: Fluorescent lighting is about three times more efficient than normally used incandescent lighting. In many cases, compact fluorescent lighting can be used in place of incandescent bulbs used in lamps, and strip-tube fluorescent lighting can be effectively used for general overhead lighting. High pressure sodium lighting should be considered for outside and security lighting purposes. Although it has a slight orange cast, it is about three times more efficient than mercury vapor lighting or incandescent lighting.

SUMMARY

Ideal house description: Our ideal home would be located in a hot, humid climate such as Florida or southern Texas, will be a two-story split zoned structure, with sleeping (bedroom) areas upstairs, living areas downstairs, would emphasis 4, 8 and 12 foot standard dimensioning to accommodate sheetrock and minimizing construction waste. Construction of the masonry first floor will have exterior R-6 rigid insulation, be three foot below grade, steel reinforced; and with exception of structural corners etc., all other cores will be filled with inexpensive fly ash low-grade concrete for higher thermal mass. If located on radon-bearing soil, a high density plastic ground gas barrier will be installed under the slab with high communications soils beneath this gas barrier. The second floor will be wood frame with R-13 in the exterior walls and R-6 exterior rigid insulation. The structure will have low sloped galvanized metal roof with installed radiant heat barrier and R-19 cellulose insulation. The HVAC system would be a high efficiency geothermal heat pump with heat recovery water heating unit, or combination high efficiency air conditioner with natural gas heating and water heating. All ducts will be galvanized sheet metal and located in the conditioned space.







Home buying can represent an exceptionally high investment. Most builders and buyers tend to be preoccupied with the principle, interest and taxes on the home with much less consideration given to the operational costs, which over a 30 year mortgage life could, in some cases, amount to more than the principle and interest paid on the mortgage. If the questions addressed earlier are asked and satisfactorily answered, it could mean a considerable dollar savings for the buyer, not to mention the favorable environmental consequences associated with energy conservation.

By using a good foundation and securely attaching the walls to the foundation and the roof to the walls, most homes can be made wind resistant to wind forces of 110 mph or more. It is important that good construction techniques and materials be used. It is important that metal straps be used to anchor the roof trusses and the top plate to the wall studs. Inspections should be made that all the nails through the roof sheathing are anchored to the truss and that extra nails be used on the gable end of the roof. Metal cross-bracing or plywood sheathing should be used on the corners of the walls and lateral bracing should be used to give extra support to the roof trusses. In general, masonry homes are inherently stronger than wood-frame homes. Even so, proper techniques should be used to reinforce block and concrete with the proper steel reinforcement rods or rebar. Prudent design, construction and inspection of your home will give you extra security during hurricanes and other high wind conditions and save energy and natural resources at the same time.

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BUILDING SUSTAINABLE COMMUNITIES:
Habitat for Humanity's Environment Initiative

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ABSTRACT

Habitat for Humanity builds houses in partnership with low-income families through 1100 affiliates in the United States. The Department of Environment of HFH seeks to make Habitat houses examples of decent, sustainable living conditions by focusing on: (1) resource efficiency in house designs, (2) recycling of construction and other waste, and (3) permaculture applications for homeowners.

INTRODUCTION

Habitat for Humanity International (HFH) builds houses in partnership with low-income families. Its Department of Environment, begun in the Spring of 1993, serves as a resource center offering technical advice to 1300 affiliates in 36 countries, 1100 of which are in the United States. It endeavors to conserve the earth's resources through learning, teaching and example. The Department seeks to insure that HFH provides decent, sustainable housing, which will have a minimal environmental impact, while fostering wholesome communities which can be sustained in perpetuity.

In order to effectively focus its environmental program, the HFH Environment Initiative has been established. It has three interconnected components:
1. Resource Efficiency: This is the major emphasis which applies to both the building materials used and to the performance of the houses. Designs are being developed and implemented to make Habitat houses highly appropriate to local climates and traditions.
2. Recycling: This includes three main features: (a) the use of viable local building materials with a high content of recycled products, (b) a program for construction waste, and (c) raising funds through HFH stores that sell used and surplus building materials.
3. Permaculture: HFH is beginning to serve as a facilitator for other organizations which have the knowledge and experience to benefit Habitat homeowners in this area. Permaculture incorporates arborculture, organic agriculture, and xeriscaping in a holistic stewardship of natural resources.

Through adoption and implementation of this program, HFH affiliates are becoming true stewards of the gifts of Creation, examples worthy of emulation in hundreds of communities.

PROGRESS TOWARD IMPLEMENTATION

The Problem.

If one is a responsible adult he or she must be concerned for future generations. To put it in the most basic human terms, if we care for our children, the children of this generation, we must leave them a good earth. We must all become stewards of this gift of creation.

Never before in history have the two most prestigious scientific organizations on the planet given a joint declaration on any subject. In 1992, The Royal Society of London and The National Academy of Sciences issued just such a joint statement. In summary, it said if mankind does not change his ways dramatically, he may well become extinct in the near future. In modern society with all the great successes of advanced science, most of us have come to believe that science could solve just about any physical problem that came up. And now the best minds on the planet are telling us that this time they can't bail us out. We have no choice but to do it the hard way...to roll up our sleeves and help ourselves. The planet's brightest minds agree. Science cannot bail us out.

As rapidly as the fabric of life is unraveling about us, it apparently has not been quick enough to make the environment the number one priority of world leaders. Despite this apparent lapse of attention, it is heartening that the alarm is beginning to be heard. The threat of a rapid loss of our ozone shield was the first crisis to raise global environmental awareness. Nations are meeting and making decisions and taking action: Montreal (ozone), Rio (general) and in September '94, Cairo (population and sustainable development). We have a long and challenging way to go toward getting our collective house in order. You must have asked yourselves as individuals and as members of this organization: "What can we do now?" We at Habitat for Humanity have been asking that very question and we have the audacity to think that, with the help of people like you, we can indeed... make a difference. In fact, we have a fantastic opportunity if we can marshal the fortitude and resources to seize the initiative. Let's get specific.

Construction Waste and Saving Trees.

In upscale housing, golf course developments are becoming increasingly popular, even though as many as 75 percent of the people who live in such developments do not play golf. Golf course grasses use an inordinate amount of water and harmful chemicals. Since many of the people are really buying the view, not the golf, let's give them the beautiful natural expanse without the golf. In the past, civil engineers have laid out building lots cookie cutter style on paper in their offices. Finally they site the houses on the lots, and send workers out to cut down trees.

That is traditional but it is absolutely backwards environmentally. In the past you would build 200 houses on 100 acres on 200 half acre lots. You could still build 200 houses, but designate half the land as common area with 50 acres of wetland, woods and trails, perhaps even a stream. Let all the houses have a view of the wild area. In addition, planners should steer away from wide boulevards and adopt rustic roads just wide enough for two cars to pass. Keep wild areas intact. Professional arborists or urban foresters must be employed so that as the houses are sited on the lots and then built as many good trees as possible are saved. Establishing the actual property lines should be the last step.

WHAT CAN BE DONE ON SMALL PROJECTS?

PROTECT TREES

- Site houses to save trees on individual lots.
- Learn techniques for protecting trees during construction.
- Network with organizations that plant trees, then assure that a tree is planted to replace each tree cut or used in construction.

RECYCLE CONSTRUCTION WASTE.

- Recycle cardboard. Grocery and department stores make good money selling their baled cardboard. Habitat affiliates are encouraged to work out a partnership with them.
- Chipped lumber and trees can be used in the fabrication of oriented strand board, parallel strand lumber, and Faswall building blocks. And, if these aren't viable options in a given community, the wood chips can be composted.
- Scrap lumber can be finger-jointed and reused or given away to handymen or high school wood-working classes.
- Gypsum scraps can be shredded and used to make new wallboard or used as a soil amendment where clay content is high.
- Scraps of foam sheathing and fiberglass insulation batts can be shredded and used for loose fill insulation.
- Concrete overpours can be used on the next worksite or carried back to the plant and poured into forms for stopping blocks. As manufacturers of builders and building materials become more environmentally aware, virtually all building "waste" should be reused or recycled.

Education.

Habitat for Humanity is completing over 30 houses a day in 1600 communities throughout much of the world. A number of HFH affiliates are already taking leadership in resource efficiency. We believe in leadership by example, and we depend upon them to give us good field-tested examples. As outstanding examples of resource efficiency are brought to our attention we are committed to having them published in the popular press and our own newsletters. Habitat World, our flagship publication, has a circulation of 800,000.

Each year Habitat holds numerous training conferences and staff meetings across North America and throughout the world. Serious efforts are being made to have various aspects of our Habitat Environment Initiative as a prominent part of each of these meetings. Environmental stewardship and concerns are rapidly becoming an integral part of the fabric of our organization. Some examples are in order. You will see us moving to two-by-sixes on 24" centers instead of two-by-fours on 16" centers. That will improve R (i.e. insulation) values by close to 60%. In some of our states that produce the most lumber, the size of trees cut for lumber is falling dramatically. In a recent 10 year period the cross section of saw timber fell by an astonishing 50 percent. We find that traditional dimensional lumber wastes half the tree, while manufactured lumber, such as laminated veneer lumber, parallel strand lumber, and oriented strand board, consume over 80 percent of a tree. We encourage our affiliates to try such products taking care that they contain a minimum of volatile organic compounds such as formaldehyde. There are numerous applications for using waste and recycled materials in building. As our resources permit we are monitoring an increasing variety of innovative building materials. We interact with the manufactor's researchers and developers and find that many of them share our interest in sustainable building practices.

Steel studs and beams from recycled automobiles present a unique challenge. In many places they are cheaper than dimensional lumber. However, depending upon their fabrication, they can conduct heat as much as hundreds of times better than wood and that negates energy efficiency measures. Methods are now being developed to thwart this problem. But the procedures involved must be kept simple in order for volunteers to use them. Steel framing is an effective approach for rafters and interior walls just about anywhere. For now, we do not recommend this material for exterior walls in areas that require significant heating in the winter. The total cost of termite damage in Florida is one half of that for the whole country. If for no other reason than damage control, some of our most successful Florida affiliates are embracing steel framing.

Permaculture.

In the yard we want to get away from ornamentals which are fertilizer and water intensive. We want to move toward bio-diverse indigenous species of grasses, shrubs, and wild flowers, which flourish under existing natural conditions. We want to facilitate the work of gardening organizations. Some have offered to help us with indigenous ornamentals while others intend to help Habitat homeowners establish bio-intensive organic vegetable gardens. Such gardening practices recycle household waste by using compost and gray water.

Bio-intensive organic gardens can produce abundant vegetables from small, extremely fertile beds. This technique recycles kitchen and yard waste through composting. Facilities for recycling kitchen and other household waste should be integrated into the house design. If local code allows, the plumbing can be designed so that household gray water can be recycled as well.

Traditional organic gardening is a daunting challenge, especially in developing the soil to full productivity. There was some thought that it may be too much of a challenge until we discovered the work of Dan Barker of Portland, OR. He has placed more than 1000 gardens with low-income families with 85 per cent retention after the second year. Dan has been advising us on his methods. They seem to be tailor-made for Habitat, and we have already experienced dramatic success in trying them out.

Some of our first individual, raised-bed organic gardens were provided to Habitat homeowners this past June in Americus, Georgia. This summer in Cleveland, Ohio, existing residents and new HFH homeowners cooperated to establish 20 raised bed organic gardens. Rather than detract from what Habitat does best, which is building houses, these projects have been accomplished with the enthusiastic support of avid professional gardeners. The results have exceeded all expectations, and have enhanced the quality of life of Habitat homeowners. They will serve as effective examples to all HFH affiliates.

Greg Sandor, a great Habitat leader, has dozens of the homeless people of Washington, DC, gardening, and they love it. They are connected, they are productive and fulfilled, and it is spreading to other cities. Eventually we hope that some of these gardeners will become Habitat homeowners.

Recycling and Waste.

Dozens of Habitat stores are recycling everything from clothes to paint, from furniture to light fixtures and windows. Several of these operations are called Habitat ReStores. They trade in surplus and recycled building materials. Through them, needy people can afford to buy the materials to keep their houses in good repair, thus reducing the demand for new housing. Besides serving as an outstanding resource for low income people, some of our stores are providing over 40 percent of the funds that affiliates raise for building houses. They are recycling and they are reducing the demand on our precious resources. Such stores are environmentally correct and they help people to help themselves, the Habitat way. They are an exciting and growing part of our work.

Some affiliates are already taking the lead with special projects. Last year the Lynchburg, VA. Habitat built our first earthwise house, and our second such environmental concept house was completed in Austin, Texas, this past spring. Recycled materials were used throughout and after occupancy they have proven to be very high in their resource efficiencies.

Turning traditional waste into superior building material is a real bonanza. When grains are harvested the waste straw is usually burned, creating darkening skies and contributing to greenhouse gasses.

Our affiliate in Silver City, New Mexico broke ground for our first plastered straw bale house on Sunday, September 18, 1994. The walls of most of our houses carry an R-value of 11 or 12. The walls of this house will be four times that value... cool in the summer, warm in the winter. Super insulated and certified passive solar at a cost comparable to traditional construction.

One option that we are finding increasingly attractive is plastered straw bale with steel post and beam framing. The steel penetrates only a fraction of the straw bale walls. The thermal conduction problem is completely negated.

We are working with two U.S. government agencies toward providing electrification for Habitat built houses in India, Uganda, and Kenya. Using the Solar Electric Light Fund, initially hundreds and later possibly thousands of photovoltaic units will be installed and homeowners will be trained in the utilization of these systems and service personnel will be trained in their upkeep. This project promises to be our most productive excursion into the renewable energy arena and should serve as a prototype for future applications.

<u>Resource Efficiency and Climate Specific Design.</u>

Canadian affiliates are building super resource efficient houses. Most of them are coming quite close to the very high R-2000 Canadian standard, which provides guidance in building houses that use a minimum of energy and water. The Homestead, Florida affiliate is providing an example for the sunny south. They are well on their way to raising the funds to build a model ecological community of 200 houses. The guidelines which are being used are Cool Community, which have been specifically formulated for hot climates. In addition to guidelines for resource efficient housing for Canada at one extreme and South Florida at the other, we also have available for our affiliates, guidelines for some intermediate climates. A research professor of architecture at UCLA and a Habitat volunteer, has developed computer software that assists in the custom design of very resource efficient houses. The designs are specifically matched to climates and traditions, as they occur across the continent. We intend to vigorously pursue this approach and develop such a resource for low-income housing. Within a few short years we should have a multi-media program assisting in the design of houses appropriate to local conditions wherever Habitat builds houses.

The design program will be experience based. For example the Texas low-cost housing project will build thirty houses stretching across three climate zones. The performance of each house will be monitored for a year after its completion. Based upon the data gathered, user friendly homeowner's manuals will be published. Eventually we want to develop such manuals for every climate. It is our ambition to help everyone we can reach, to get the most benefit from their houses with the least damage to this precious planet.

During a week in July of 1994, Jimmy and Rosalynn Carter, Habitat co-founders Millard and Linda Fuller, and 1200 volunteers joined together to build 30 houses with a Sioux Indian tribe. The location was Eagle Butte, South Dakota. Eventually there will be 105 houses in the community. Due to the severe winters of the area the houses are super insulated. Special and thoughtful efforts were made to have the dwellings and the community at large conform to characteristics in keeping tribal customs. An outstanding environmental feature is the wetlands area which was created to provide sewage treatment by natural processes. This particular system has already proven its effectiveness in Minnesota and Canada. In 1995 the Tijuana-San Diego affiliate will install a similar system suitable for hot climates as part of their comprehensive environmental project. The seeds of environmental stewardship are being planted. Habitat is beginning to make a difference, but there is much to be done.

CONCLUSION

Our generation is unique in history. No generation in the past has faced this problem. Common sense applies to common occurrences. It corresponds to how it happened before. The unraveling of the fabric of life has no precedent and it makes no common sense. That is why so few really accept what is happening. No generation in the future will have the luxury of this responsibility. We alone must solve it. It is our fervent hope that we have the wisdom and the time . As we build houses in each community we can make them that bright and shining light. A beacon for all to see. Habitat staff and volunteers, as well as energy efficient builders like you, can make an example of environmental sustainability for the world to follow. No other group has such a great opportunity and responsibility. Habitat for Humanity is accepting the challenge, and with the commitment of builders like you, we can do it!

Mold, Moisture, and Indoor Air Quality
A Cold Climate Perspective

McGregor Pearce, Pat Huelman, and Wanda Olson

Introduction:

People in the developed world are estimated to spend about 90% of their lives indoors. Therefore the quality of the air in homes and buildings is a topic of much interest. Molds are responsible for many indoor air symptoms and complaints. Unlike chemical contaminants, air borne mold spore levels can rise and fall dramatically in response to environmental factors, such as temperature and moisture. Once established, mold colonies can be very difficult to eradicate. The best way to provide mold free indoor environments is to build out conditions that favor their growth. While this paper is based on experiences in Minnesota, much should be relevant to homes and buildings in other locations as well.

What are Molds?

In order to avoid building related mold problems, it is important to understand a bit of mold biology and ecology. Molds play a vital role in the recycling of organic material. They degrade dead plant and animal matter into bioavailable nutrients, thereby promoting the growth of new life. While they have left little fossil record, it is assumed that molds are ancient life forms that have adapted to almost every environment on earth.

The whole planet is subjected to a constant "rain" of mold spores. When a spore lands in favorable habitat, it secretes digestive enzymes into its immediate environment. These enzymes degrade the surrounding material into nutrients which the mold absorbs and uses to grow. Molds can survive on almost any organic material. Damp masonry can support enormous colonies of mold, thriving in an invisibly thin layer. From the initial spore, fine filaments extend to form a fibrous mat called a mycelium. These filaments secrete more digestive enzymes, and the colony continues to grow by digesting the substrate around it. If appropriate moisture and temperature conditions are maintained, a mold colony will continue to thrive until all of the digestible material is gone.

Once established, the colony begins to produce reproductive structures which generate spores. Each of these spores is identical to the one that began the colony, and is potentially capable of initiating another. Healthy mold colonies generate astronomical numbers of spores. These spores are usually less than ten microns in diameter (the period at the end of this sentence is about 100 microns in diameter). They become airborne at the slightest disturbance, and may ride air currents for thousands of miles from their point of origin. Mold spores are found at both poles as well as several miles above the earth

Mold spores can present indoor air quality problems for building occupants. Because of their small size, they are capable of being inhaled into the deepest recesses of the lung. Allergic reactions are triggered by complex organic molecules on the spores cell surface which react with and irritate the immune system. Large doses of inhaled mold spores can create health problems for non-allergic people as well By overtaxing the immune system, in its efforts to clear the invading particles, hypersensitization can occur with a host of unpleasant symptoms. In addition to causing immune system problems, some molds produce toxic substances that can be either acute or chronic poisons. While mold related health problems are poorly characterized, it is generally agreed that people should not live in moldy buildings.

Mold in buildings:

The single most important design feature of a mold free building is rigorous moisture control. Moisture measured as water vapor in air is referred to as relative humidity. Liquid water in solid material is referred to as water activity. Both are measured as percents. Molds usually require moisture levels, measured either as relative humidity or water activity, of at least 70% in order to establish themselves.

It is important to understand that an indoor space with an average relative humidity of 30% can still harbor local environments where moisture levels are much higher. A good example would be a window in a home in January, in a cold climate such as Minnesota. The temperature might be 70° F., and the relative humidity under 30%, yet liquid water can be observed condensing on a cold window pane, and the wood at the bottom of the pane may stained black from mold growth.

One important method of moisture-mold control is to balance indoor humidity levels against the insulating qualities of the exterior sheath to prevent local condensation conditions from occurring. Although window condensation can create visible problems, it is unlikely to cause a wide spread mold problem. Once the moisture flows down the glass onto the window frame, it becomes exposed to 30% humid indoor air, and is rapidly evaporated. More serious condensation problems can occur in areas hidden from view, such insulated exterior wall cavities. In such areas, protected from the drying effect of building or home ventilation systems, moisture can accumulate, and create ideal mold growing conditions.

Although water vapor condensation frequently plays a role, bulk water intrusion probably causes the most severe indoor mold problems. Flooding events, plumbing failures, envelope leaks and fire related water damage can rapidly generate astronomical mold levels, that persist long after the building is cleaned and dried. Mold contamination is capable of becoming serious within less than seven days. Therefore it is vital that water soaked building materials be either cleaned and dried, or gutted out, before the mold can gain a foothold. But remedial measures can only be taken when the water problem becomes apparent. Certain features that are commonly built into modern homes can cause hidden moisture/mold problems of the most severe sort.

Mold and the modern basement

Older homes usually have what might be referred to as furnace-laundry tub basements. The masonry floor and walls are exposed to view. Although these basements may be dank and dusty, they are unlikely to harbor thriving mold growth. Foundation water leaks are readily apparent, and the water introduced by them either evaporates, or can be mopped up with a bit of dilute bleach to kill off any mold growth. When leaks persist, the homeowner can have the landscape drainage modified, or install drain tile to deal with the problem.

The high square foot cost of modern housing has made finishing and occupying of underground space seem desirable. Cold climate building codes dictate that foundation walls be insulated. The builders choice is often to fir out the walls with wooden studs, fill the cavities with fiberglass insulation, then cover the wall with a plastic vapor barrier. It is a logical next step for the homeowners to cover the wall with painted gypsum board or paneling. To complete the project, the slab is covered with carpeting. They now have finished space, which is used for bedrooms, play areas, or office space. Unfortunately, unless the foundation walls and slab have been properly designed and installed, capillary moisture migration through these masonry surfaces can initiate extensive mold problems.

The Hoover dam holds back the Colorado river, yet the downstream side of the dam is wet to the touch. Water readily moves though tiny pores in the cement, migrating from the wet side to the dry. When damp soil presses against concrete foundation walls or slab, the drier air inside creates a gradient and the water begins to move into the basement. In an unfinished basement, the water evaporates, and makes the basement feel damper than the rest of the house. In a finished basement, moisture can accumulate behind dry wall or under carpeting. This soil water is full of mold spores and nutrients, and mold thrives under such conditions. Such conditions can persist without visible staining or odors in the interior space, and often the first sign of the problem is occupant health complaints. To compound the problem, the commonly installed forced air HVAC system readily distributes the mold from the basement to the rest of the building.

In addition to distributing contamination, HVAC systems utilizing sub-slab duct work may actually become sources of mold/moisture problems. These systems are installed by digging a perimeter trench before pouring the concrete floor. Large diameter PVC pipe is then laid in the trench, with supply boots extending up above the level of the cement. After the slab is poured, the boots are cut flush with the floor and fitted with supply grills. A down draft furnace then feeds air into the sub-slab duct work to warm or cool the space. This approach is popular in slab-on-grade construction, such as town home and condominium projects.

If such a system were professionally installed by licensed personnel, with all seams chemically welded, and a manometer test performed before pouring the slab, it is possible that they could be acceptable. Unfortunately, cost considerations tempt builders to cut corners. While the ten foot sticks of PVC duct are inexpensive, the elbows and other fittings are costly, and galvanized metal fittings are often substituted. Such fittings are then press fit, or at best fastened with a few sheet metal screws. Instead of welded, air tight PVC supply boots, fabrications of galvanized metal are crudely fastened to the top of the truck lines to extend through the slab.

Such systems constitute a recipe for trouble. Wet soil can rapidly corrode holes in metal fittings, allowing water to leak directly into the duct work. Once the system is inoculated with muddy water, the mold problems follow close behind. Cleaning the system has little effect, as it is still wide open to the soil in which it is installed. One can often observe braided chain patterns of sand and mud on the bottom of sub-slab ducts by looking down through the supply openings. A mirror and flashlight can be used to reveal the metal fittings.

In addition to providing a microbiological breeding ground, these leaky sub-slab systems can supply enormous quantities of moisture to the home, on a four season basis. The heaviest mold contamination is sometimes found in the attic When the builder is called to task for a sub-slab system half full of water, the quick fix is to install exterior drain tile below the level of the duct work, in order to channel water away from the house. But it is virtually impossible to repair existing holes in the system, and the exposure of the forced air in the ventilating system to the soil persists and gives a new dimension to the term "air conditioning". It is important to weigh installation cost savings against the expense required to excavate and repair underground foundation moisture problems.

What to do:

1. The exterior shell of the building should be wrapped with an effective air barrier to prevent cold air from intruding into the envelope and creating cold temperature surfaces capable of promoting moisture condensation.
2. The Building envelope should contain an air tight, consistent layer of insulation, free of voids or gaps.
3. A warm face vapor barrier should be installed in as air tight a manor as possible. Great care should be taken to prevent anyone from cutting holes in the vapor barrier once it is installed. Electric outlets, recessed light fixtures, and plumbing penetrations are common culprits. Warm, moist indoor air must be kept out of the building envelope.
4. Buyers and builders should select simple building shapes, to permit easy installation of air and vapor barriers and insulation. Electrical and plumbing penetrations should be avoided in exterior walls.
5. Anyone wishing to finish below ground space should take care to insure that the foundation is waterproofed. Traditional "mastic and plastic" foundation treatments are prone to failure. For keeping the foundation dry, exterior drain tile is superior to interior, and both is better. A capillary break should be fitted to prevent soil moisture from contacting the slab and underground portion of the foundation. A capillary break can be achieved by a number of methods. The underside of the slab should be sealed with a continuous sheet of cross laminated polyethylene. The footings should be covered with a strip of plastic, or a brushed on coating of water impervious material. The exterior foundation wall should be waterproofed with a polymer spray on coating that maintains flexibility, then covered with insulating drain board or back filled with pea gravel. Remember that sand does not provide a capillary break.

7. If a sub-slab duct system cannot be avoided, the system must pass a plumbers manometer test to guarantee that it is going to be leak free. No metal parts may be used.
8. Laundry areas in upper levels of the home must be disaster panned. Overflowing or leaking washing machines can readily do thousands of dollars in damage to finished space below, and can be the cause of very severe mold problems. Upstairs laundry rooms must have floor drains, and overflow containment pans.

Conclusion:

Homes are often built and purchased on the basis of dollar cost per square foot. Extra money in the budget is dedicated to imported tile or luxury appliances. Moisture/mold problems usually don't show up until the house is sold and occupied. Mold problems are much easier to prevent than to fix. If water damage occurs in buildings, it is vital that they be dried immediately. Owners reluctant to shoulder the expense of radical gutting of water damaged walls and carpet are in danger of facing much more significant medical care in treating mold related health problems. It is hoped that consideration of some of the issues addressed here can spare builders and owners the harm and expense associated with moldy homes.

Recommended Reading:

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THE 1995 EXCELLENCE IN HOUSING CONFERENCE

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Healthy Indoor Environments Thru Passive Ventilation Using Integral Window Ventilating Systems/Devices

By: Stuart Fishman, Vice President, Sales & Marketing, Titon Inc., South Bend, Indiana

It is hard to pick up a newspaper or magazine these days without reading something about the environment, indoor air quality, tight buildings, stale air, and spotted owls. You ask, 'What have spotted owls got to do with our session today?' Spotted owls are the concern of the citizens of Washington State and Oregon where the leadership to combat poor ventilation by the Department of Energy thru the Bonneville Power Administration originated. Over the past few years the Building Codes of these two states as well as parts of other states in the Pacific Northwest have included the introduction of pure fresh air ventilation into both residential and commercial construction by various methods. These codes are working their way across the lower 48 states and Alaska. Most of the codes are patterned after those building codes existing in United Kingdom for over ten years. The concern of indoor air quality worldwide is a hot topic of the general public. Indoor air pollution has been referred to by some IAQ experts as the "asbestos of the 90s".

Additional natural or background or passive ventilation into a tightly constructed house or building originated in Scandinavia. Of course, it is logical that those countries in Scandinavia would need additional ventilation because of their climate as well as construction methods. The window manufacturers from Sweden, Norway, and Denmark introduced what became known as "trickle" ventilators into their products. Trickle ventilators are manually operated air-inlets fitted to windows (preferably at the top) to allow a **controlled** flow of air to trickle in. The amount of air flow is usually sufficient to improve indoor air quality without significantly affecting energy costs.

Trickle ventilation has become the system most people in the window industry recognize when talking about passive air-inlets and/or integral ventilation systems. I could go into great detail about the causes of poor indoor air quality but suffice it to say that many new materials commonly found in homes and buildings such as carpeting, furniture, paint, wood, drywall, etc. emit certain characteristics that pollute the indoor air. Tight construction to save energy produces unhealthy indoor conditions. To put it simply, emphasis on energy conservation has created a monster. The fact remains that we are indoors too much of the time- it's unavoidable. We also live and work as creatures of habit. We demand modern living conditions and a good quality of life. I don't see us reverting to past times when only a Saturday night bath was the norm. We are not going to change the way we live. We will continue to use our dishwashers, computers, washing machines, stereos, TVs, etc., etc., etc.,- those items that consume energy. But we will not be subjected to the illnesses and conditions caused by bad indoor air.

Another reason for trickle ventilators-reduce condensation. We all know what causes condensation. No window manufacturer or supplier is spared complaints about condensation. Andersen Corporation publishes a pamphlet entitled "Understanding Condensation" which indicates they openly admit that condensation is a problem. Trickle ventilation reduces condensation by allowing a flow of air around the surface of the glass where condensation forms. When it's dry and cold in the winter in certain climates, people introduce humidity into their living atmospheres without realizing the result- condensation. We human beings are constantly using bathrooms, kitchens, and various appliances that emit moisture. (Seeing your breath) The small flow of air through a trickle ventilator is like a defroster in your car, a little slower but equally as effective.

Integral window ventilator systems can be broken into three basic types. There are some specialty types that I will mention but are not presently marketed in the US. Types: Glazed-in, slot, and surface mounted. I will discuss each one pointing out the application, advantages, features, and benefits of each. A number of manufacturers offer similar systems in the USA- most of which are manufactured in a European country. You can see samples of typical integral window ventilator systems displayed in the exhibit hall.

IMPORTANT FACT: TITON TRICKLE VENTILATORS OFFER VENTILATION WITH SECURITY!!

There is a move in the state of California to eliminate the use of night latches, secondary opening positions for windows, limit stops- whatever you want to call them. That action may effect the use of these devices in other parts of the country also. Integral window ventilation systems offer a way to get controlled ventilation without opening windows- one of the unique benefits of these devices. To express this concept another way: With the use of window trickle ventilators, fresh air is introduced in the controlled manner without concern for security even at night or when structures are unoccupied.

A discussion of the impact of integral window ventilating systems/devices on voluntary standards, code body deliberations and certain individual states within the US is in order.
The California Energy Commission has published a new study entitled Energy Efficiency Standards and Indoor Air Quality dated December 1994. A movement within the state of California has already been mentioned as it relates to ventilating windows with security. The Ventilation Task Force for the state of Minnesota has included indoor air quality as it relates to energy conservation in their ongoing proceedings. Alaskan builders are frantically searching for alternatives to energy consuming mechanical systems that include testing of integral window ventilating systems/devices. The National Fenestration Rating Council has included the consideration of using window ventilation in their rating procedures. NFRC is a non-profit public/private collaboration of manufacturers, builders, designers, specifiers, code officials, consumer, utilities and regulators that is establishing a national energy performance rating system for fenestration products. Sanctioned by the federal government under the Energy Policy Act of 1992, NFRC will, over the next several years, establish a program where many factors are rated, including solar heat gain, optical properties, air infiltration, condensation resistance, long term and annual energy performance in addition to "U" value which determines the energy performance of fenestration products. ASHRAE is presently revising Standard 62- Ventilation for Acceptable Indoor Air Quality. The 1989 version only mentions operable windows as a source for natural ventilation. The revised standard will include passive ventilation through windows. The American Architectural Manufacturers' Association also has recognized the

need for passive ventilation through fenestration products in their voluntary standards and Window Selection Guide soon to be published revised. AAMA is a trade association of firms engaged in the manufacture and sale of architectural building components and related products to include windows, sliding glass doors, storm windows and doors, curtain walls, store fronts, skylight and space enclosures, and siding. AAMA relates to the residential, commercial, manufactured housing, and institutional building industry. The New York State Builders Association,Inc., the New York State Energy Office, the New York State Energy Research and Development Authority and public utilities through New York State have joined forces to create NY-STAR. This comprehensive, independent, not-for-profit certification program will save energy in New York State. Of course, the Pacific Northwest, as mentioned earlier is the leader in combining energy conservation and proper ventilation. The movement to improve indoor air quality along with energy conservation is snowballing. It is highly recommended that energy efficient builders climb aboard the snowball rather than being in its path. Contact your fenestration product suppliers to encourage them to include integral ventilating systems/devices in their sales and marketing programs.

REMEMBER: ENERGY CONSERVATION WITH PROPER PASSIVE VENTILATION EQUALS SMART HEALTHY CONSTRUCTION.

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RADON REDUCTION THROUGH SOLAR VENTILATION: DESIGN & EVALUATION

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ABSTRACT

Conventional residential energy conservation measures that limit air exchange rates between the indoors and outdoors have been shown to increase concentrations of radioactive radon decay products as well as other indoor air contaminants such as combustion by-products and off-gases from carpeting, furnishings, appliances, cleaning products, and building materials. The ventilation system under investigation seeks to combine the goals of energy efficiency and conservation with low-cost radon reduction and indoor air quality management. Drawing on established radon mitigation techniques of ventilation, air supply and pressurization, the Solar Radon Reduction System (SRRS) provides radon reduction at low energy costs due solar pre-heating of supply air. Installation costs for the SRRS are also lower than conventional air-to-air heat exchanger and sub-slab suction radon mitigation options. Radon reduction and indoor air quality improvement are accomplished through dilution, reduced infiltration, and slight pressurization of the dwelling through the induced-draft solar-heated outdoor air and the supply of combustion appliance make-up air. Installed in six test homes in Waterloo and Cedar Falls, Iowa, the SRRS was found to achieve significant radon reductions in all houses with elevated levels of up to 73% from background levels as high as 21.0 pCi/L.

INTRODUCTION

Increased insulation and weatherization, intended to reduce home energy demands and heating bills, have been found to have detrimental effects on the quality of indoor air. The U.S. Environmental Protection Agency (EPA) now warns that improper ventilation can concentrate contaminants that would otherwise escape through leaks and cracks, and many indoor environments may be dangerously polluted by these toxic chemicals and gases. Tightened to conserve energy, a growing number of homes, buildings and schools are plagued by "sick building syndrome" (Dulley, 1994). The broad array of indoor pollutants includes molds, airborne fungal spores and bacteria, pesticides, solvents, respirable dust, carbon monoxide, nitrogen dioxide, formaldehyde, and other volatile organic compounds (VOCs), but the most insidious may be radon gas and its byproducts. Radon is harder to detect and reduce at the source than other airborne pollutants, and difficult to filter. Still, high levels of radon as well as the many other air pollutants can be prevented from accumulating indoors (Turner and Brennan, 1985). Since U.S. residents spend on average 75-90% of their time indoors, the health of many people may greatly depend on the quality of air in the indoor environment.

An invisible, odorless radioactive gas produced from the natural decay of uranium-238 and radium-226, radon-222 is found in nearly all soils and occurs in low concentrations almost everywhere on earth. High concentrations of radon gas have been traced to large deposits of granite or sillimanite rock, as well as to granitic sand and gravel. Radon is readily soluble in water, so groundwater that has recently reached the surface, including well water, may also carry high levels of radon.

Radon can enter the indoor environment via several paths, including emission from building materials. In both the U.S. and Sweden high radon levels have been attributed to radioactive shales and mine tailings inadvertently used for residential construction (Turner and Brennan, 1985). More typically, radon originates as gas in soil beneath homes and buildings and infiltrates inside through floor drains, hollow-block walls, cracks in concrete walls and floors, gaps and joints in building materials, or direct exposures to soil. It can also outgas from the water supply, when water is exposed to air during showering and other household or industrial uses. Because radon is inert and does not chemically bind or attach to other materials, it can easily pass through all gas-permeable materials including concrete (Renken, 1994). Due to pressure differentials created by the "stack effect" of convection indoors, particularly in cold seasons or during rainy weather conditions, radon can infiltrate indoors and accumulate to hazardous levels.

The major health concern associated with elevated radon levels is an increased risk of contracting lung cancer. Although radon is one of the few *known* (Group A) carcinogens, the level of lung cancer risk associated with residential radon exposure is still controversial. Two short-lived radon decay products, both alpha-emitting polonium isotopes, are solids which can attach to dust particles and, upon inhalation, become lodged in airways near some of the most cancer-sensitive cells in the human body. As the decay process continues, the radioactive particles release bursts of energy that ionize lung tissue. Damaged cells can then multiply rapidly, resulting in lung cancer. Research is currently underway to find out if radon causes other kinds of cancer as well. The EPA reports that swallowing water with high radon levels may pose risks, though hazards from ingesting radon-laden water are believed to be much lower than those from breathing air containing radon. The National Cancer Institute has declared radon exposure the leading cause of cancer among non-smokers, accounting for an estimated 7,000 to 30,000 deaths per year. The EPA has set a recommended "action level" for remediation at the radon concentration of 4 picoCuries per liter of air (pCi/L), which is comparable to having more than 250 chest x-rays per year. The ubiquitous problem of radon accumulation has prompted senior EPA officials to label radon the "highest cancer risk of any single environmental problem" (Freije, 1990).

A 1988 EPA survey found that nearly one in three homes have elevated radon levels, prompting the Surgeon General to urge testing for all houses and apartments below the third floor. The EPA now estimates that 1 out of every 15 homes throughout the U.S. are estimated to have radon levels of 4 pCi/L or more (US EPA, 1993). In Iowa, an estimated 70-75 percent of homes have radon levels above 4 pCi/L (Eckoff, 1990). An EPA survey of 130 schools among 16 states found that 54 percent of the schools had at least one unsafe room, while 19 percent of the 3,000 classrooms measured high. It is now believed that the radon danger in schools and most other types of non-residential buildings is at least as severe and widespread as it is in homes (Freije, 1990). The average indoor radon level is estimated to be about 1.3 pCi/L, compared to an average of 0.4 pCi/L outdoors. The U.S. Congress has set a long-term goal that indoor radon levels be no more than outdoor levels (US EPA, 1993).

Usual radon mitigation methods attempt to prevent naturally-occurring radon gas from entering a building by keeping the living space at a higher pressure than that of the contiguous soil. The EPA currently recommends the following approaches to reduce radon infiltration and accumulation in existing structures:

- Natural ventilation,
- Forced ventilation,
- Sealing foundation cracks and openings,
- Sub-slab suction,
- Air supply, and
- Heat-recovery ventilation (US EPA, 1986).

Sealing cracks and other openings in the foundation is a basic part of most approaches to radon reduction, although the use of sealing alone is not recommened as it does not lower radon levels significantly or consistently. The most heavily marketed system at present, sub-slab depressurization (SSD), uses fans oriented upward to apply suction beneath the foundation and vent exhaust air above the roof. Creating a pressure differential large enough to lower radon below the EPA action level often requires drilling several holes into the concrete slab and installing associated piping as well as sealing cracks, holes, and drains (Freije, 1990). This can result in considerable expense to homeowners and may also worsen other common indoor air pollutants, such as carbon monoxide from combustion appliances.

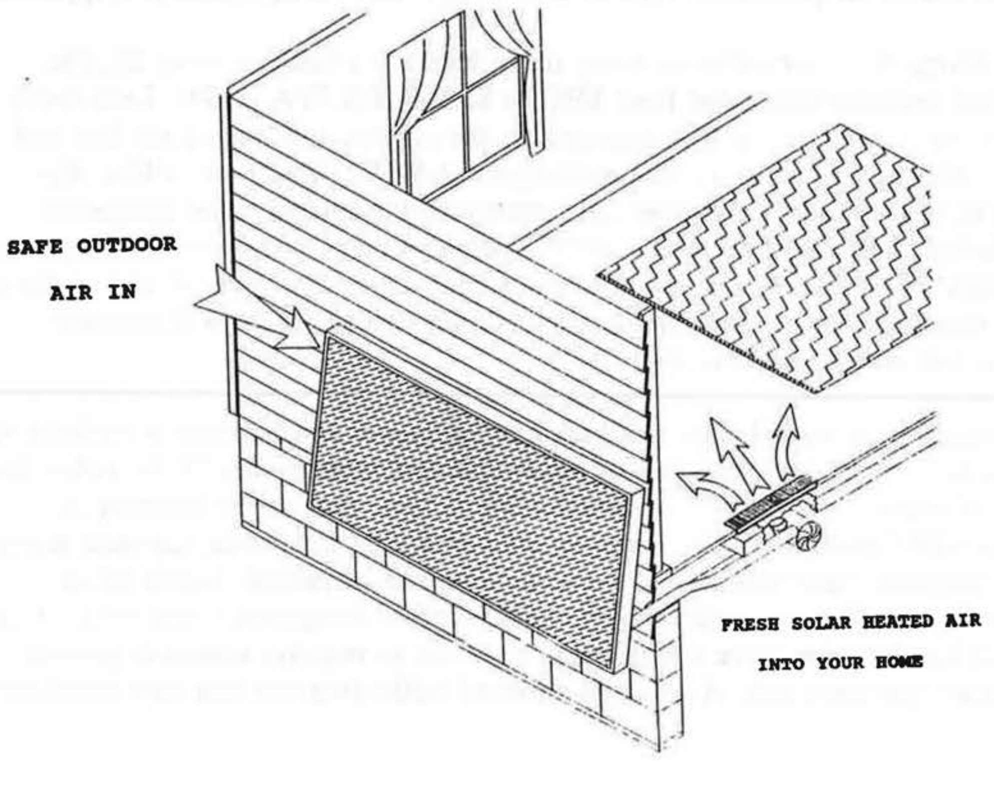
The average charge for a contractor to lower radon levels in a home is about $1,200, although repairs required may range from $500 to $2,500 (US EPA, 1993). Less costly approaches to radon reduction include pressurizing the indoors with supply-air fans and increasing ventilation with air-to-air heat exchangers (AAHX), which help dilute other contaminants as well as radon. However, all commercially available radon mitigation systems, including those equipped with AAHX, operate at a net energy loss in temperate climates through the direct introduction of outdoor-temperature air. Thus these popular air management strategies can be quite energy intensive and counteract steps to increase weatherization and energy conservation.

Controlled evaluation of varied radon mitigation techniques at specific sites is difficult due to the numerous factors that determine indoor radon concentrations, primarily the radon source strength and infiltration rate. Effects of construction factors, such as the integrity of basement slabs and foundation walls, characteristics of sumps and drains, crevices at pipe entry points, unpaved crawl spaces, and the infiltration rate of natural outside air or "tightness" of the dwelling, are often indeterminable before mitigation is attempted. Even a well-ventilated building may have a high radon level due to negative basement pressure and thus an increased gas entry rate. A structure's natural infiltration rate can vary seasonally due to changes in soil moisture and frost level or even hourly based on barometric pressure, convection, and effects of wind direction and velocity (Fleischer, 1988). Given the number of radon mitigation options, the range of factors that affect radon levels in a dwelling, and the fact that no single system can guarantee acceptable indoor radon levels, homeowners and radon mitigation contractors must weigh several variables when developing a mitigation approach. Installation and operating costs associated with each mitigation step often compound the selection of optimum systems.

PROJECT HISTORY

In attempt to address both elevated radon levels and heating costs, one of the authors (R. J. Klein) devised and installed an original solar ventilation system to introduce fresh, pre-heated air indoors at a test home in Waterloo, Iowa in 1990. The Solar Radon Reduction System (SRRS), initially comprised of a 4' x 8' flat-plate solar air collector, ductwork into the central heating system, and a 0.59 Amp, 75 cfm (cubic feet per minute) mechanical blower, was designed to both pressurize the indoors and improve air quality in an energy-efficient manner (Fig. 1). The supply of outdoor make-up air for combustion appliances and stack effect losses reduces indoor radon levels through reduced infiltration and dilution. During cold seasons, the SRRS introduces solar-heated outdoor air into the home, augmenting its existing heating system to produce a net energy gain. In the summer months, the system's blower provides low-energy cooling by ventilating the structure when outdoor air temperatures drop below indoor comfort levels.

Fig. 1 Diagram of Solar Radon Reduction System



Based on charcoal canister readings, the initial radon concentration of 8.8 pCi/L in the basement of the first test home was reduced to 2.5 pCi/L, a reduction of more than 70 percent. Energy costs were reduced and the general indoor comfort level was reportedly improved by the addition of solar heated outside air. In 1991 the system was chosen as an award recipient in the Innovative Radon Mitigation Design Contest sponsored by the U.S. EPA, the Association of Energy Engineers, and Environmental Engineers & Managers Institute. The EPA requested that further research be conducted on the technique according to EPA Protocols for Diagnostic Measurements in Radon Mitigation Demonstration Projects.

An additional solar collector, which heats domestic water in tubes inside the panel as well as vents solar-heated air indoors, was then installed in conjunction with the first SRRS to further extend heat gain and energy savings throughout the year. This homemade panel was constructed from debris recycled from a home improvement project, as the glazing was previously used as sliding glass doors. A second complete SRRS was installed in 1991 at a test home in Cedar Falls, Iowa which originally exhibited a charcoal canister radon reading of 19.9 pCi/L in the basement. Construction and installation was accomplished at about 10% of the cost of comparable commercially available radon mitigation systems. In 1993, the SRRS design was issued U.S. Patent 5,186,160 and awarded funds by the University of Northern Iowa's Reuse & Recycling Technology Transfer Center to continue research. A detailed instruction manual was developed for homeowners or contractors to build an SRRS — a solar panel installed on a south-facing wall, roof or as free-standing unit together with a fan, wiring, and ductwork into the building's central heating system — for about $200, or even less if constructed with recycled materials.

SRRS efficiency evaluations were first conducted in the winter of 1992/1993 at test home North, a 960 ft^2, 1½-story wood-frame home equipped with a natural gas water heater, clothes dryer and forced-draft furnace; and test home Lovejoy, a single story, 1270 ft^2 wood-frame home with only electric appliances including a resistant heat forced-draft furnace. Both homes have partial basements and crawl spaces under the living area. Initial data collection included radon levels, hours of system operation, air flow rates, structure pressure differentials, temperature differentials, and estimated energy used. Radon data were collected in both homes as the mean of 4-hour intervals with two continuous radon data loggers (Honeywell Model 05-418) operated in accordance with EPA protocol (US EPA, 1993). The duration of SRRS and furnace operation was measured and recorded daily using elapsed time hour meters. The volume of air the SRRS induced-draft fans introduced into the homes was based on manufacturer data confirmed with pitot tube velocity and duct area measurements. The SRRS at North produced an air flow of either 65 or 130 cubic feet per minute (cfm), based on whether one or two solar panel fans were in operation, resulting in 0.6 or 1.2 air changes per hour (ACH). Single SRRS panel operation at Lovejoy produced an air flow of 75 cfm, adding 0.4 ACH. Dwelling pressures were determined with manometers and blower door tests, and utility meters along with temperature/relative humidity strip charts were used to calculate energy usage.

The two Honeywell radon monitors were initially operated side-by-side simultaneously with a carbon canister test at Lovejoy to evaluate the precision of the instruments. Based on ten day monitor means of 8.4 and 8.3 pCi/L and the canister result of 8.1 pCi/L, both instruments were determined to be statistically calibrated at a 96% confidence interval. Monitors were then installed on the first floor at both of the test homes, maintained in "closed house conditions" with the SRRS deactivated and sealed, to establish background radon levels according to EPA protocol (US EPA, 1993). Data indicated 1st floor background radon concentrations of 4.3 pCi/L for North and 8.0 pCi/L for Lovejoy.

The SRRS was tested in a variety of operational modes to evaluate individual effectiveness of the system as well as system effectiveness when used in conjunction with other EPA recommended mitigation methods. The initial evaluation was conducted with the SRRS operating in a solar thermostat-driven mode, which achieves maximum energy benefits by introducing solar heated air inside only during times when adequate solar energy is available to heat outdoor air above the ambient indoor temperature, to a minimum of 25°C and often as high as 50°C. The thermostat located on the inside surface of the solar collector typically triggered the induced-draft fan to operate in this mode between 9 am and 4 pm.

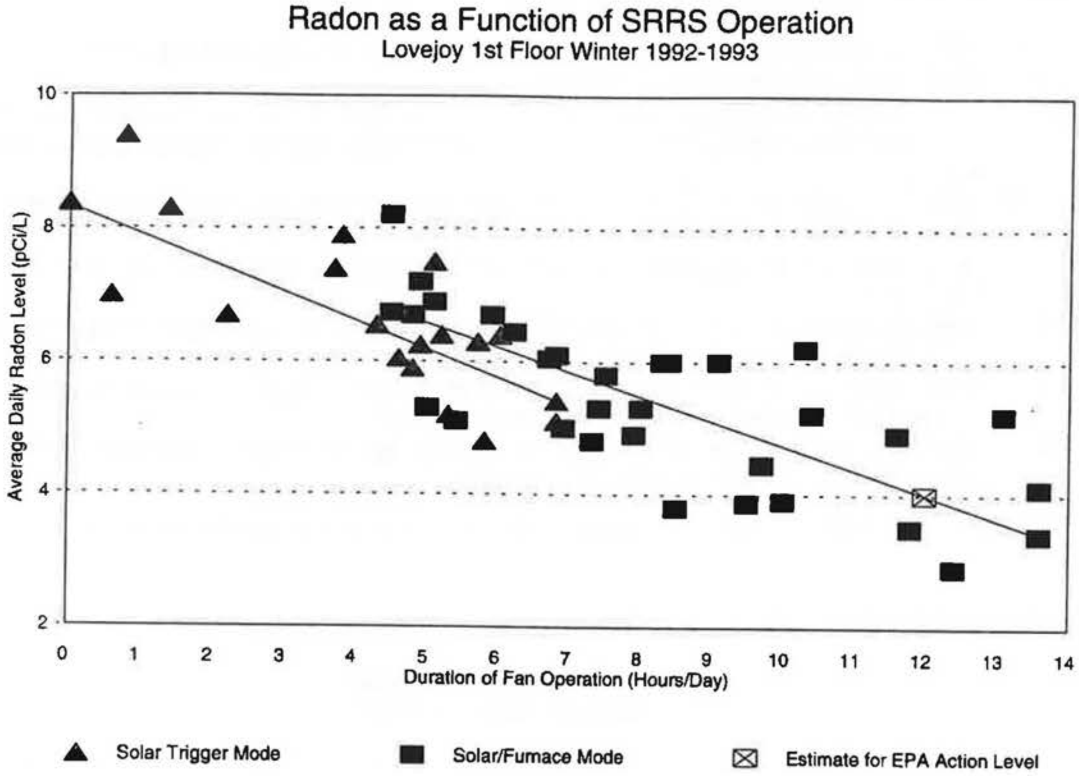
Compared to background radon concentrations, SRRS solar thermostat-driven operation was found to lower mid-day radon levels by an average of 29% at North and by 24% at Lovejoy. The general indoor air quality and comfort levels were reported to be improved by the addition of solar-heated outdoor air. The initial research revealed that over the 6-week test period, cloudiness and adverse weather conditions limited SRRS operation to less than 1 hour for about 15 days. Due to continued radon infiltration when the mitigation fans were off, night-time and early morning radon levels returned to near background levels.

The second operational mode evaluated the effect of the SRRS when allowed to operate for additional periods of time than could be achieved in the solar thermostat-driven mode, when home heating demands required furnace operation. A "solar/furnace-driven mode" was achieved by wiring the SRRS to trigger its induced-draft fan both by the solar thermostat and an electrical relay circuit from the central furnace fan. In addition to providing longer SRRS operation, this mode allowed operation of the system at intervals throughout the day and night as well as during times of solar insolation.

As would be expected for a ventilation/pressurization mitigation system, SRRS radon reduction effectiveness was found to be related to the duration and volume of air introduced into the dwelling. Data collected during the extended furnace-driven mode showed mixed results: North showed little correlation between radon concentration and hours of SRRS operation, which may be attributed to the rate in which radon resumed infiltration during non-operational periods; yet Lovejoy showed a direct correlation between reduced radon and hours of system operation (Fig. 2). Extended solar/furnace-driven SRRS operation accomplished maximum radon reductions of 53% (North) and 56% (Lovejoy) compared to background levels.

Through graphical interpolation of the data obtained, 12 hours of SRRS operation (with a 75 cfm flow rate) was predicted to keep first floor radon levels below EPA's action level of 4.0 pCi/L at Lovejoy. Even in this mode, the solar heating aspect of the SRRS still provided a net conventional energy gain by introducing pre-heated air indoors several hours per day. Based on BTU heat gain and loss calculations, energy savings for the 6-week period were estimated to be 1.1 MBTU at North and 0.2 MBTU at Lovejoy, verifying that the SRRS yielded a net, albeit small, energy savings in both test homes. Long-term energy savings were predicted to be greater, as solar insolation received during the test period was approximately half the average available in the region for January through March.

Fig 2. Effect of thermostat-driven and increased hours solar/furnace-trigger SRRS operation on radon concentration for test home Lovejoy



MODIFICATION & EVALUATION

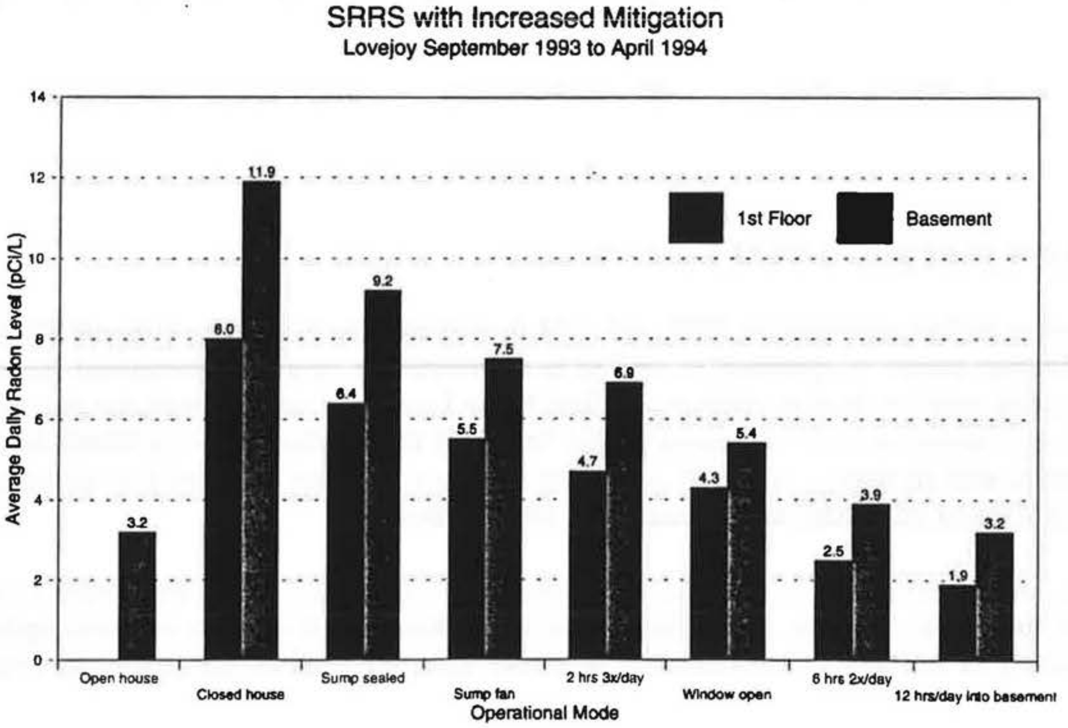
Further testing continued in 1993 and 1994 to evaluate the flexibility of the SRRS in additional modes of operation as well as to determine the optimum operational mode and resulting radon reduction efficiencies. Test home Lovejoy, equipped with the two continuous radon monitors in both the basement and first floor living areas, was monitored over seven months with increasing levels of mitigation as shown in Table 1, selected to coincide with EPA's radon mitigation action steps (US EPA, 1986).

Data collected reveals an incremental reduction levels for each of the test modes (Fig. 3). The first mode, with the SRRS deactivated and basement and upstairs windows open a majority of the time to accommodate relatively mild fall weather, resulted in an average basement radon concentration of 3.2 pCi/L, which represents the minimum radon level expected utilizing natural ventilation as the sole form of mitigation. While this most simple method achieved a radon concentration below the EPA action level, such open house conditions are impractical for most temperate climates.

Table 1. Increased radon mitigation steps with Lovejoy SRRS

Time Interval	SRRS/Dwelling Conditions
9/10 - 10/7/93	SRRS deactivated; periodic open house conditions including basement windows open.
10/8 - 11/8/93	SRRS deactivated; closed house conditions.
11/9 - 11/26/93	SRRS 75 CFM fan discharging through central heating system to 1st floor during adequate solar insolation (solar thermostat-trigger mode); foundation sump pump pit sealed and passively vented outdoors.
11/27 - 12/29/93	SRRS discharging upstairs during adequate solar insolation; sump pit vented outdoors with 45 CFM fan.
1/1 - 1/9/94	SRRS discharging upstairs triggered by timer set for 2 hours, 3 times per day; continued sump pit forced venting.
1/10 - 2/6/94	SRRS discharging upstairs during times of adequate solar insolation; one basement window slightly opened; continued sump pit forced venting.
2/7 - 2/22/94	SRRS discharging upstairs with timer trigger set for 6 hours, 2 times per day; one basement window slightly opened; continued sump pit forced venting.
3/25 - 4/17/94	SRRS discharging directly into basement with timer trigger set 6 hours, 2 times per day; basement window closed; continued sump pit forced venting.

Fig. 3 Incremental radon reduction at Lovejoy



The second test period established closed house background radon concentration levels of 8.0 pCi/L upstairs and 11.9 pCi/l downstairs, used as baselines to establish radon reduction efficiencies for subsequent SRRS test modes. Lovejoy had visually sound basement concrete slab and foundation walls, but an open foundation drain tile sump pit was identified as a possible direct radon entry point. During the third test period, the SRRS was activated to discharge air through the home's ductwork into the 1st floor living area with solar thermostat-driven operation. In addition, the foundation drain tile sump pump pit was sealed and passively vented to the outdoors. The combined SRRS solar thermostat operational mode in conjunction with basement sealing lowered radon levels an average 20% upstairs and 23% downstairs. These values are consistent with first year solar-thermostat mode reduction of 24%, suggesting the mitigation achieved during this test mode was primarily due to the operation of the SRRS; basement sealing appeared negligibly effective.

In the fourth test mode, the SRRS remained in the solar-thermostat operation while the sump pit ventilation system was modified to include a 45 cfm forced-draft fan, a variation of the popular subslab depressurization mitigation technique. Given constant SRRS operation, this more aggressive radon mitigation technique resulted in radon reduction improvements of 11% upstairs and 14% downstairs as compared to natural sump pit ventilation, yet EPA action levels were still not obtained.

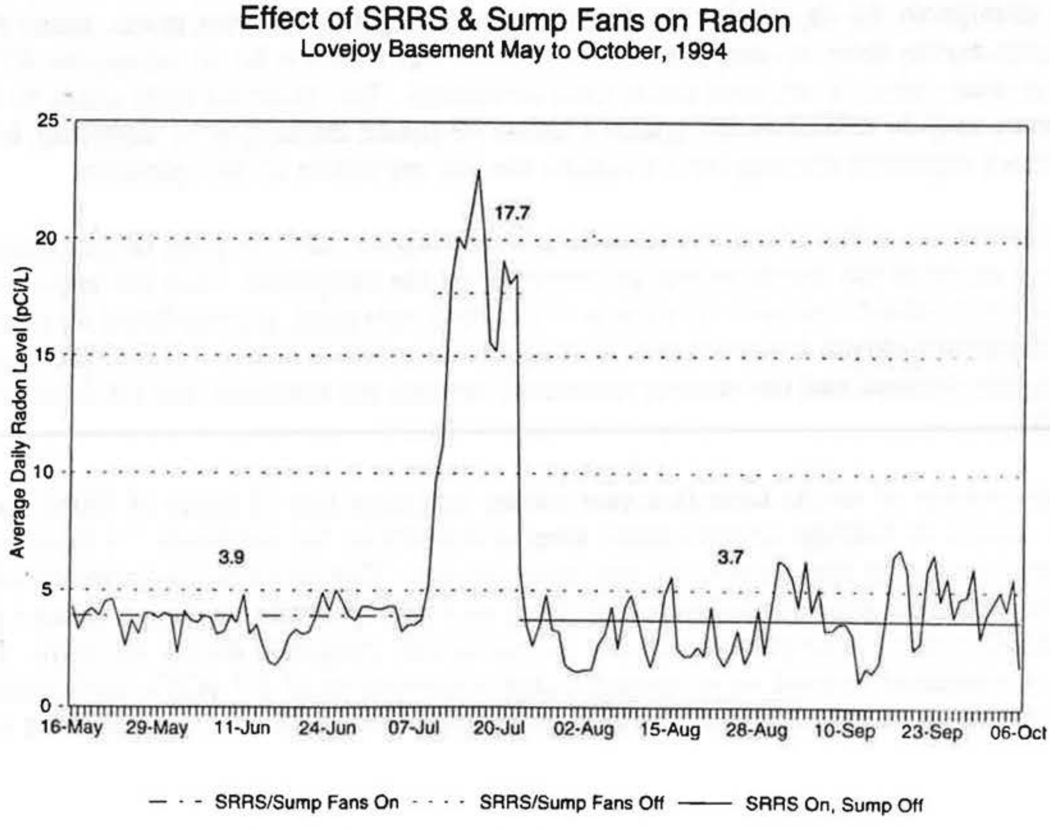
During optimum solar insolation conditions (i.e. non-cloudy days), the SRRS operates for approximately 6 hours, typically between 9 am and 3 pm. To evaluate the effect of the SRRS during ideal weather conditions as compared to actual weather related operation, the SRRS was wired to a timer set to operate the system for two-hour intervals evenly spaced three times throughout the day. From the data obtained during this fifth test mode, actual SRRS operation during times of adequate solar insolation was found to be an impressive 85% to 92% of what could be assumed under ideal conditions. This relatively high actual to ideal efficiency may be related to the system's ability to reduce infiltration by supplying low impedance appliance makeup air throughout the day regardless of fan operation.

Since downstairs radon levels remained consistently higher than 1st floor levels, increased air supply directly to the basement was predicted to aid the mitigation. Thus test period 6 incorporated natural basement ventilation with SRRS operation, accomplished by returning to solar thermostat-driven operation and opening one basement window. Lower radon levels were again obtained and the relative difference between the basement and 1st floor levels was reduced.

In consideration of results from first year testing indicating that 12 hours of SRRS operation could achieve an average upstairs radon level of 4.0 pCi/L, for test mode 7 a timer was set to trigger the fan to operate 6 hours two times per day. This timer-based operation coincided with the optimum solar insolation period (9 am to 3 pm) to obtain maximum energy gain, and an additional 6-hour period provided evenly-spaced mitigation during the night. This mode of operation resulted in an upstairs radon concentration of 2.5 pCi/L (69% reduction) and a downstairs level of 3.9 pCi/L (67% reduction). The SRRS was next modified to discharge fresh air directly into the downstairs area of the dwelling rather than through the home's central heating system, and the basement window was closed. With the fan still operating for a timer-based 12 hours per day, this approach achieved a maximum reduction of 76% upstairs and 73% downstairs.

Longer-term evaluations of the 12-hour timer-based SRRS operational mode were continued at Lovejoy over the summer of 1994 to evaluate the effect of both the SRRS intake fan and the sump pit exhaust fan (Fig. 4). The three-month basement radon concentrations from May to July during operation with both fans running averaged 3.9 pCi/L. A two-week period in July when both fans were deactivated and the house was maintained in closed house conditions while the homeowners were on vacation graphically illustrates how quickly the house returns to high background radon levels of 17.7 pCi/L without mitigation, which is even higher than the winter-time baseline obtained the previous year (11.9 pCi/L). The following three-month test was conducted with only the SRRS fan in operation and revealed larger daily average radon ranges but a long-term average almost equivalent to the test with both the SRRS and sump fans, 3.7 pCi/L. This demonstration documents the stronger mitigation influence of SRRS ventilation and positive pressuration relative to the sub-slab suction achieved by the sump fan in this case. It also indicates that the lowest expected long-term basement radon levels at Lovejoy even with combined mitigation methods are in the 4 pCi/L range.

Fig. 4. Relative importance of SRRS and sump pit fan operation on radon mitigation



The improvements developed and successful results obtained during the second year of research established that the SRRS is a promising radon reduction technique, but additional evaluations on a larger number of test houses were desired to more fully document the effectiveness of the system. While radon reduction effectiveness and energy efficiency will undoubtedly vary from installation to installation, improved indoor air quality and energy benefits are expected in all cases.

ENERGY CONSIDERATIONS

A major advantage of the Solar Radon Reduction System over other radon mitigation methods is its ability to introduce solar-heated air into the home during cold seasons as well as to provide low-energy cooling during warm weather. This energy gain is optimized when system operation is limited to periods of adequate solar isolation during the heating season and when outdoor temperatures drop below ambient indoor levels in the summer. A drawback of SRRS operation in other modes is the introduction of wintertime cold outside air during cloudy days and nighttime operation as well as overly warm and humid outdoor air during the cooling season. The net energy efficiency of the SRRS can be compared to sub-slab depressurization systems, which introduce no external air into the house.

Such heat gains and losses can be calculated for the 12-hour timer-based operational mode (6 hours twice/day) for the month of March, 1994, which included 10 clear days, 11 partly cloudy days, and 10 cloudy days; an average outside temperature of 2°C; and an estimated average relative humidity of 50%. Outlet temperature monitoring indicates that average SRRS outlet air can be assumed to be:

- 38°C for 4 hours and 20°C for 2 hours on clear days;
- 20°C for 6 hours on partly cloudy days;
- 2°C for 6 hours on cloudy days; and
- 2°C for all 6 hour nighttime operation intervals.

The net energy content or enthalpy of SRRS outlet air was therefore estimated to be 1.7 MBTU for the month of March, and the enthalpy of indoor air at an average 22°C and 25% relative humidity replaced by SRRS air was about 2.7 MBTU. Thus approximately 1.0 MBTU of extra heating energy (300 KWH with an electric furnace) was required to accommodate SRRS input air to indoor ambient levels. Additionally, operating the 115 Volt, 0.59 Amp induced-draft fan for 12 hours per day for 31 days required 25 KWH of electricity. At the volume-discounted rate of $0.03/KWH in Cedar Falls, IA, the energy expense attributable to SRRS operation for March 1994 was about $9.75. The solar collector's heat input saved 510 KWH or $15.30.

If each month of operation resulted a similar net expense due to a heavier demand on either heating or air conditioning, the annual SRRS operating bill would be around $117. Complete installation of the SRRS was estimated to be $500 versus a typical $2,500 for sub-slab mitigation, which operating 24 hours per day with the same type of fan would cost 50

KWH/month or $42/year. Negating the time value of money, the energy payback of the SRRS toward the sub-slab system would be about 27 years, most likely beyond the working life of the system and the time most people reside in a home.

CURRENT RESEARCH

Initial SRRS evaluation involved progressively more aggressive system operation and intervention to obtain below action-level radon concentrations. In other dwellings, similar trials and radon recording instrumentation would likely be necessary to determine optimal system operation. In order to simplify subsequent SRRS installations, newly available and affordable continuous radon alarms equipped with start/stop electrical relays (EnvirAlert Model MTL-102 with MTL-106 mitigation controllers), which trigger fans to operate above pre-programmable radon levels, have been incorporated into the SRRS strategy.

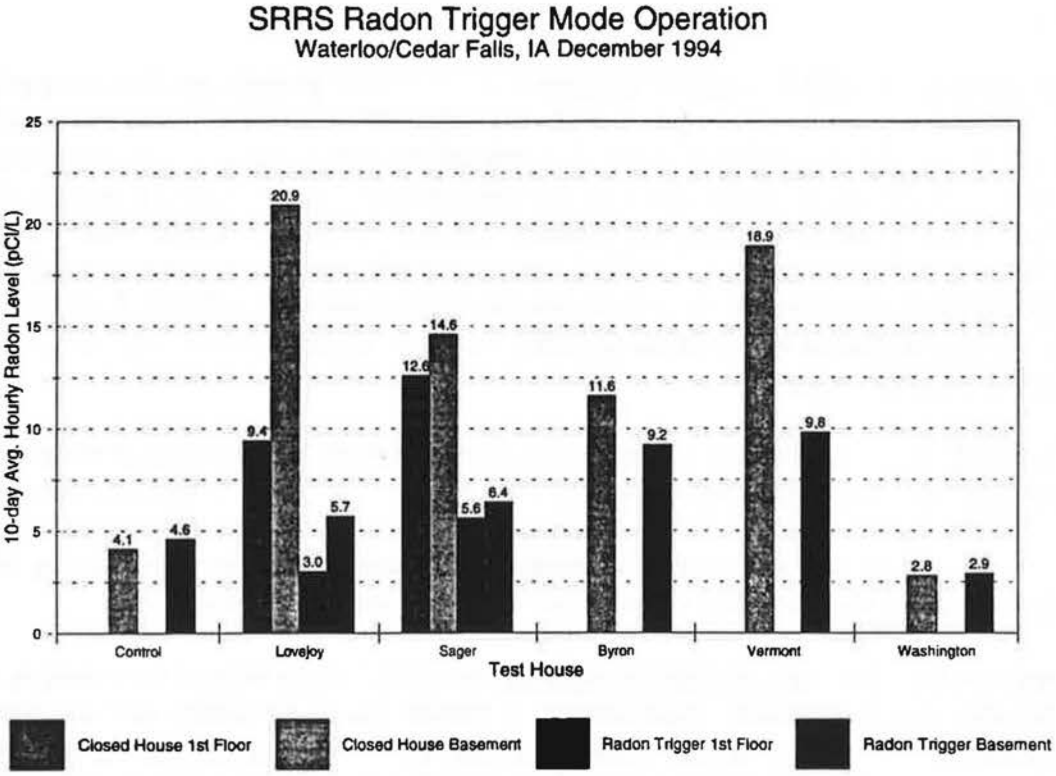
In the summer and fall of 1994, modified SRRS systems were installed at four additional test sites with elevated radon levels. Each house was equipped with EnvirAlert radon-trigger mitigation control devices as well as computer data acquisition systems for continuous datalogging. These "radon-stats" activate the SRRS when radon levels reach 3.0 pCi/L, and to maximize energy benefits, are wired in conjunction with electronic temperature sensors that additionally activate the fan either above (heating mode) or below (cooling mode) a preset intake temperature. The sites were monitored to determine the most suitable operational mode at each to maximize energy savings for desired radon reduction levels. Data collected include radon levels, solar radiation, inlet and outlet temperatures and humidity, air speed, and indoor/outdoor pressure differentials at hourly intervals to assess radon infiltration and energy gains under varying conditions.

Based on initial side-by-side operation for several days, the six EnvirAlert radon monitors were determined to be calibrated at a 90% confidence interval. Preliminary data was collected in December 1994 for closed house conditions and radon-trigger operation (at 3.0 pCi/L mitigation level) at the four new sites Sager, Byron, Vermont, and Washington as well as Lovejoy and a "control" house which had no radon mitigation installed. The two Honeywell monitors were used to record 1st floor radon levels at Lovejoy and Sager, and Air Chek mail-in charcoal radon testers were used to determine 1st floor levels at Byron, Vermont, Washington, and the control.

During the 10-day test periods, SRRS operation significantly reduced the average basement radon concentrations at every house with elevated radon levels for the "radon trigger mode" test period compared to closed house conditions (Fig. 5). The maximum response was seen at Lovejoy, which was the only house which sump pump pit and foundation sealing was included, from a background level of 9.4 pCi/L to 3.0 pCi/L on the first floor (a 68% reduction) and from 20.9 pCi/L to 5.7 in the basement (a 73% reduction). Since the EnvirAlert monitors output a value which is an average of the previous 22 hours, the lag time between the start of an upward radon trend and the electrical activation of the SRRS fan be a limiting factor; additional testing during combined radon-trigger and solar temperature-trigger operation has shown improved reductions.

Based on mail-in testers, below-EPA action level results were also achieved on the first floor at both Byron (3.9 pCi/L) and Washington (3.5 pCi/L) during this operational mode. Foundation sealing and improved weatherization as well as higher capacity fans may achieve even greater reductions at these houses. A further modification of activating the SRRS from RadonAlarms on the first floor radon is also under evaluation to provide a tighter control on living space radon levels, which may be required for houses such as Washington that have higher radon levels upstairs than in the basement.

Fig. 5 Preliminary results of expanded SRRS testing with fans activated when radon levels reach 3.0 pCi/L



CONCLUSIONS

This research has shown that the Solar Radon Reduction System is effective in reducing indoor radon concentrations. Due to the ventilation, air supply, and pressurization principles incorporated in SRRS operation, radon reduction efficiency was found to be related to the duration the system and the volume of fresh air introduced into the dwelling.

In order to meet the EPA action level of 4.0 pCi/L, modified modes of SRRS operation were tested in conjunction other radon mitigation techniques including natural ventilation, sealing foundation cracks and openings, and a variation of sub-slab suction. Compared to SRRS operation before sump sealing at Lovejoy, only a 4% greater radon reduction was achieved, indicating that in this case, the sealing effort had little effect on living space radon concentrations. Installing a forced-draft exhaust fan to the sump pit, a low-cost type of sub-slab suction, showed an additional 11% to 14% radon reduction compared to sump sealing alone, yet later research on the 12-hour SRRS timer-based operation showed the sump fan had little effect. Increased natural basement ventilation with an open basement window had drawbacks in reducing control over ambient basement temperature, and evaluation of SRRS direct basement discharge found that this tactic was not necessary to achieve low radon levels.

Operation of the SRRS system at Lovejoy for two 6-hour periods per day exceeded the prediction based on interpolation of first year data with an average living space radon yield of 2.5 pCi/L; this timer-based mode also maximized energy benefit. The modification to discharge SRRS input air directly into the basement air was a significant optimization in terms of radon reduction, energy efficiency, and indoor comfort levels. This configuration achieved a reduction efficiency of 76%, and this mode renders fan operation during less than ideal temperature conditions less noticeable to homeowners. In addition, basement walls, usually well-insulated by surrounding earth, may provide a heat sink to prolong energy benefits and buffer losses.

The SRRS shows promise as a radon mitigation technique that can reduce radon in almost all cases and can obtain concentrations below the EPA action levels in existing dwellings with elevated background radon levels. While this study was limited in the number of dwellings evaluated, the proven and referenced mitigation techniques incorporated into the SRRS project satisfactory radon reduction results in other "problem" dwellings.

Compared to other radon mitigation options, the SRRS offers control over system operation to balance energy demands, improvement in overall indoor air quality and comfort, low installation costs and the lowest annual operating costs. These advantages suggest more home owners may be likely to install a mitigation system and, once installed, be less likely to discontinue its operation.

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HOUSE DEPRESSURIZATION/BACKDRAFTING/CARBON MONOXIDE POISONING

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ABSTRACT

Four separate families were poisoned by carbon monoxide in North Central Iowa in a seven day period during the winter of 1993-1994, resulting in ten hospitalizations and two deaths. An investigative team consisting of an Iowa State University associate professor and the owner/operator/president of an environmental consulting/mitigation firm investigated three of the cases. The first case involved a relatively new house with two natural gas natural draft furnaces and a water heater. The family had been subjected to elevated carbon monoxide levels several times. The owner/occupant was frustrated with local heating contractors who were unable to correct the carbon monoxide problem, and was frightened when carbon monoxide episodes continued after being told the problem had been fixed. Investigation showed depressurization from furnaces, water heaters, fireplaces, and/or exhaust fans caused reverse flow from the water heater, the two furnaces, and/or the gas fireplace. The owner installed sealed combustion a water heater and furnaces.

In two other two cases numerous design and maintenance problems contributed to the poisonings. These problems were not recognized by local utility employees, the fire department, local authorities, or heating contractors.

THREE CASE STUDIES

<u>Case One</u>

<u>Background, Case 1</u>

The family moved into the house in June 1993, purchasing the house from a retired couple. In October all five family members were hospitalized, with dangerous carboxyhemoglobin levels of 13 to 30 percent. The family was treated with oxygen, and released. A heating contractor determined the problem was an improperly installed thermally-actuated flue damper on the water heater. The 4-inch flue damper was installed over a 3-inch vent pipe, which entered the damper and blocked operation.

After the poisoning, the family purchased 4 carbon monoxide detectors, which sounded intermittently, even after removal of the damper. The detectors required frequent fresh air rejuvenation, and replacement of the sensing cells. A carbon monoxide chemical card also turned black. The heating contractor made repeated calls, but with gas indicator tubes failed to detect any carbon monoxide. Neither did the utility company or the building inspector. A member of the family again experienced poisoning, with carboxyhemoglobin levels in excess of 33 percent.

The heating contractor informed the homeowner the poisonings resulted from three independent problems, all of which he had solved.

1. The water heater damper had been blocked.
2. The gas fireplace left on overnight had backdrafted.
3. Fresh air intakes had frozen shut.

The heating contractor made the following changes and suggestions:

1. Extended the main 7-inch vertical vent an additional 5 feet above the flat roof.
2. Added an elbow above the roof to the existing 9-inch vertical fresh air intake.
3. Added an additional 6-inch combustion air intake, connected it to the return of both furnaces, and advised the homeowner to operate the furnace blower continuously.
4. Advised the homeowner to install glass doors on the gas fireplace, keep the doors closed, and only operate the fireplace during waking hours.
5. Replaced the 1/8 inch screen on the fresh air intakes with a larger screen after frosting occurred (Code requires 1/4 inch mesh.)

With the above steps completed, the alarms continued to intermittently sound. The contractor no longer had solutions and advised the homeowner to monitor the carbon monoxide levels herself, using gas detection tubes furnished by the contractor. The homeowner, by now frustrated and scared, believed her concerns were no longer taken seriously. She asked Iowa State University for assistance, and after a telephone consultation, was given the name of several contractors for further evaluation. She selected Dr. Wiggers, who, after initial evaluation, requested further extension technical assistance.

Physical Characteristics, Case 1

House: 5600 square feet, approximately 10 years old, two story, designer home, well-designed, well constructed, and well maintained.

Heating: Two furnaces, natural gas, natural draft, common vented with water heater, 68,000 Btu/hr and 90,000 Btu/hr, gas log in masonry fireplace (added by current residents), and hanging heater in garage.

Water Heaters: One 40,000 Btu/hr natural gas and one electric water heater.

Venting: A 7-inch diameter vertical double wall gas vent 17 feet in height and a 7-inch horizontal manifold shared by all three gas appliances. Connectors: 3-inch water heater, 4-inch furnace, and 5-inch furnace. The 7-inch vent and manifold met NFPA54-1992 vent tables. The 3-inch water heater vent was undersized, with a 4-inch required. The 4-inch furnace connector was undersized, with a 5-inch required. The 5-inch connector met requirements. These, although contributing to the problem, were not the primary problem.

Venting Pressures:

At less than 4.0 Pascals negative, water heater and furnaces drafted.
Above 4.0 Pascals venting was sporadic.
Above 5.0 Pascals backdrafting occurred continuously.

Exhaust:	Kitchen Exhaust	500. cfm
	South Bathroom #1	44.
	South Bathroom #2	44.
	North East Bathroom #1	82.
	North East Bathroom #2	66.
	Entry Bath	52.
	Basement Bath #1	29.
	Basement Bath #2	50.
	Clothes Dryer	104.
	Subtotal, Mechanical	1035. cfm installed
	Fireplace, gas	535.
	Water Heater	25.
	68,000 Furnace	40.
	90,000 Furnace	50.
	Subtotal, Gas Appliance Vents	650.
	TOTAL EXHAUST	1685. cfm
Outside Air Provided: (maximum flows observed)		
	9-inch fresh air to utility	110. cfm
	6-inch combustion air furnace	138.
	4 -inch combustion air fireplace	86.
	TOTAL OUTSIDE AIR	334. cfm
	SHORTAGE OF COMBUSTION AIR	**1,351. cfm**
Envelope: Blower Door Results		
	Air Changes Per Hour, 50 Pa	3.56 ACH50
	Effective Leakage Area (LBL)	114. square inches
	Equivalent Leakage Area (CANADA)	215. square inches
	Air flow @ 5 Pascals (Pa)	464. cfm

Depressurization:

Under some wind conditions, as high as 6 Pa with no exhaust appliances.

No exhaust flows	2 Pa
Fireplace, doors closed	2
Two bathroom fans	2
Four bathroom fans	3
Six bathroom fans	4
Seven bathroom fans	5
Seven fans and clothes dryer	5
Fireplace alone, doors open	10
Seven fans, dryer, and kitchen vent	11

Carbon Monoxide Levels:

The high CO blood levels in family indicate high CO levels had occurred.
Occurred, as indicated by First Alert detectors.
Occurred, as indicated by Gas Alert chemical sensors
Intermittent, with no readings at times.
Various, 8 to 12 to 18 ppm by Drager 190 recorded by Wiggers.
Present, as indicated during rapid build up during backdrafting tests.

Analysis, Case 1

Multiple problems were identified. First, the water heater vent was blocked. Second, the gas fireplace backdrafted. Third, the gas fireplace caused backdrafting of the water heater and furnaces. Fourth, the venting was undersized. Fifth, the house depressurized when various combinations of exhaust appliances operated. Sixth, originally the vent did not extend sufficiently above the flat roof. Seventh, the vertical combustion air intake was prone to being covered with snow and icing. Eighth, the units were producing carbon monoxide. Two additional possibilities that were not investigated were depressurization of the house caused by winds over the attic ridge ventilator and the possibility that combustion products were being reintroduced back into the house from the combustion air intake located on the flat roof next to the vent termination.

Providing sufficient combustion and make-up air was not adequately considered. The single combustion air opening was not large enough to satisfy Uniform Mechanical Code requirements of one square inch per 5,000 Btu/hr. Addition of the 6 inch combustion air opening did meet these requirements, but the requirement of two openings of 100 square inches each freely communicating with the interior spaces was still not met. This, however, was not the primary problem in the house.

Section 607 of the Uniform Mechanical Code, which states "Operation of exhaust fans, kitchen ventilation systems, clothes dryers or fireplaces shall be considered in determining combustion air requirements to avoid unsatisfactory operation of installed gas appliances" was not applied. As noted in Physical Characteristics, 1,685 cfm of exhaust appliances existed in the house. Only 334 cfm of outside air, plus natural infiltration, was provided. This, as evidenced by operation of the gas appliances, was insufficient, resulting in the primary problem.

To provide sufficient combustion and make-up air would require either large openings to the outdoors, or powered intake fans operating in conjunction with exhaust and heating appliances. Our experience shows that even though combustion air openings are added and meet code they do not always function adequately. Adding powered intake fans, with safety interlocks, alos did not seem the best solution.

It is likely the previous owners, a retired couple, did not experience severe problems because of differing lifestyles. The present occupants used many of the exhaust appliances concurrently and often: the range hood, the bathroom fans, the clothes dryer, and the gas fireplace. The retired couple did not use all four bathrooms concurrently, or the wood-burning fireplace often. Their risk increased when they had guests and used all exhaust appliances.

Heating contractors failed to reduce carbon monoxide production levels from the heating appliances. Carbon monoxide levels rose to over 35 ppm after only 7 minutes of backdrafting combustion products from the furnaces and water heater into the utility room, even with utility room door open. The test was discontinued. The production was most likely caused by either a dirty burner, poorly adjusted burners, inadequate primary air, or overgassing.

Recommendations and Action, Case 1

Homeowner was advised to replace both furnaces with high efficiency sealed combustion units. The water heater should be upgraded by adding draft induction or it should be replaced. She was advised to discontinue use of the gas log, or replace it with a direct vent, sealed combustion gas fireplace insert.

The homeowner was initially unable to secure bids for new, sealed combustion heating units for two reasons: 1) Contractors stated sealed units did not work in the north central Iowa climate, and 2) Contractors were unwilling to risk the liability of working where there was a known carbon monoxide problem. We suspect the female homeowner, a pleasant, well-educated individual who was forced to become knowledgeable about carbon monoxide, intimidated the local contractors and was "blacklisted" in the local community.

Regional representatives of furnace manufacturers were notified. They located dealers willing to install sealed combustion units in the house. The homeowner replaced the water heater and both furnaces with high efficiency sealed combustion units.

The gas log was not replaced and remains as potential carbon monoxide source. Eighteen (18) ppm of carbon monoxide was recorded in the living room when the gas log was operated under backdrafting conditions.

Case Two

Background, Case 2

The family lived in the house for several years. In 1988 they hired a contractor to remodel the basement. The furnace location was changed, and the return air disconnected at ceiling level. The furnace, water heater and water softener were enclosed in a small utility room with solid walls and door. Basement ceilings were finished with drywall. Return air to the furnace was supplied by ducts in the upstairs floor open to the floor joist area which was left open in the utility room.

During the winter of 1992-93 the family noticed a number of flu-like illnesses, which increased in winter of 93-94. In February of 94, after an especially difficult period of flu-like symptoms in the family, the 9-year-old daughter suffered seizures of an undetermined origin. She was evaluated, given medication, and released.

The family continued to be ill, and a week after the daughter's seizures they all become very ill. The father suspected carbon monoxide, and checked the carbon monoxide chemical dot indicator located near the furnace. It indicated no carbon monoxide. Early the next morning the children lost consciousness, the father called for emergency help, and then collapsed over the phone.

They were taken by ambulance to the hospital, where they were treated with oxygen. Carboxyhemoglobin levels were from 25 to 31. All recovered and were released that day.

Physical Characteristics, Case 2

House: 2500 square feet, 10 years old, one story, full finished basement, well-maintained.

Heating:

Natural gas natural draft furnace and water heater, common vent. Wood-burning fireplace in living room not used. Both the furnace and the water heater had a large amount of soot and dirt around the draft diverter, around the burners, and on the floor in front of the units.

Venting:

A 6-inch diameter vertical double wall gas vent approximately 13 feet high. An additional 5 feet was added by a heating contractor after the poisoning. Although there were several elbows, reducing capacity, the vent systems appears to meet NFPA54-1992 requirements.

Exhaust:	Kitchen Exhaust	- Not connected to outdoors
	Basement bath	- Reversed, not connected, and blowing into house
	Upstairs bath	- Yes
	Fireplace, wood	- not used.
	Furnace	- not measured
	Water heater	- not measured.

Outside air provided: One 1 -1/2 plastic pipe to outdoors, negligible flow.

Depressurization:

The utility room operated under a strong negative pressure, caused by the furnace blower. When operated with the utility door and other openings shut (the typical mode of operation for the family), both the water heater and the furnace backdrafted continuously. When operated with an additional two vents installed after the poisoning, both the water heater and furnace vented.

CO Levels:

None indicated on Chemical Dot Carbon Monoxide Sensor. Sensor was several years old, and had expired. No carbon monoxide was present when we inspected the house. Carboxyhemoglobin levels in family indicate high levels had occurred.

Analysis, Case 2

Depressurization, the primary cause of the carbon monoxide poisoning, resulted from non separated combustion and return air which in turn led to dirty burners. The Uniform Mechanical Code, Section 317.2, states that "..there shall be a positive separation between combustion air and outside or return air for blower-type heating systems. The combustion-chamber opening shall be separated from a fan plenum by an airtight separation without openings therein..." Section 703.3 of the code states "Openings and ducts shall not connect appliance enclosures with space in which the operation of a fan may adversely affect the flow of combustion air."

The negative pressure developed by the air circulation fan is more than ten times as great as the natural draft of a furnace or water heater. The furnace blower, when running, backdrafted the furnace and water heater. The original remodeling, which enclosed the furnace in a small utility room without combustion air, caused the dangerous situation when the furnace return air pulled air from the space. No one inspecting the furnace since the remodeling told the owner of the obvious, and dangerous, situation.

The daughter was not checked for carbon monoxide after her seizures. Seizures are one of the many symptoms of carbon monoxide poisoning. Reliance on an expired chemical dot carbon monoxide indicator nearly led to the death of the family. As the father pointed out, the front of the indicator has a line "Date Installed", but the instructions on the front do not point out that the useful life is only one heating season.

Heating contractors who visited the house after the poisoning incident increased the height of the vent above the roof another 5 feet, and installed two combustion air openings communicating with the interior of the house. They did not address the problem caused by the return air from the utility room, and the potential problems that could still arise.

Recommendations and Action, Case 2.

The homeowner was advised to take the following steps:

1. Have the burners and burning chambers thoroughly cleaned.
2. Have the furnace and water heater adjusted and inspected.
3. Provide return air ducting to the furnace and separate the combustion air from the return air.
4. Provide combustion air.
5. Consider new, sealed combustion heating appliances.
6. Purchase backdraft indicators and carbon monoxide detectors.

The failure of persons involved with the case to identify and remedy the basic causes is a major concern.

Case Three

Background, Case 3

In the spring of 1994 the co-owners of a motel were found dead in their living quarters connected to the motel office. Their blood was more than 60 percent saturated with carbon monoxide, a fatal saturation. Investigators were "99 percent sure" the carbon monoxide came from a propane boiler or water heater. Officials were also quoted as suspecting a down draft, caused by high winds and worsened by snow, trapped gas exhaust fumes in the dwelling. Investigators noted the living quarters were "sealed airtight" and the water heater and boiler were venting "almost perfectly."

Physical Characteristics, Case 3

Dwelling: Living quarters at the north end of a one-story wing of a motel with 14-16 units. A small basement area under the living quarters contains a hot-water boiler (for space heating) and water heater.

Space heating:

Natural draft gas-fired boiler, 245,000 BTUH input capacity, relatively new. 8-inch connector to an 8-inch manifold.

Water Heating:

Older 95,200 BTUH 67 gallon water heater. Immediately from the top a 5-inch elbow connects to a draft diverter box, then to the shared 8-inch manifold. Only the rise of the elbow before connector is horizontal.

Exterior Venting:

Exterior double wall 8-inch pipe, approximate length 12 feet. Two 45 degree offsets were used to clear the roof edge. Offset had an area of approximate 1.5 x 5 inch area of outer pipe corroded away. It showed signs of brown and white streaking and was in generally poor condition.

Clothes dryer:

A commercial clothes dryer on the main floor vented through a six inch galvanized pipe out the back wall.

Additional Heating (non-functioning):

64,000 Btu/hr furnace in attic connected to ceiling registers.

Other exhausts:

One kitchen exhaust fan venting through a 6-inch diameter galvanized pipe.

Attic Space: Entire attic open and connected. 12 x 12 inch gable vent on the west end and three 8 x 8 inch roof vents on the south roof face (in the attic above the living quarters). No soffit vents. Cupolas used for high vents.

Envelope: Blower Door Results	
Air Changes Per Hour, 50 Pa	7.16 ACH50
Effective Leakage Area (LBL)	126. Square Inches
Equivalent Leakage Area (CANADA)	221. Square Inches
Est. Exhaust Depressurization	7.2 Pascals
Air Flow @ 5 Pascals	503.7 Cubic feet per minute
Estimated Natural Infiltration	106. Cubic feet per minute
	0.40 Air Changes per hour
Minimum Ventilation Guideline	1350. CFM50

Blower door tests indicate a structure of fairly typical construction and is not "air tight".

Pressure Differences:

Living Area to Outdoors	-5.6 Pascals
Attic to Living Area	-0.6 Pascals

Analysis, Case 3

Measurements were made to determine why flue gases remained in the dwelling. Conclusions:

1. The 5 inch pipe between the water heater draft diverter and the common vent for the water heater is nearly horizontal, with less than 1 foot of rise. A rise is needed to exhaust the gases. With no rise proper venting can not be assured.
2. The 8 inch horizontal manifold is undersized.
3. The 8 inch vertical common vent on the outside of the building is undersized.
4. The vertical common vent is in poor condition, with a rust hole at an elbow.
5. The vertical vent is poorly located on the side of the building, and likely to cool, leading to poor draft, condensation, and rust. The location at the edge of the roof does not take full advantage of wind induced draft and is more likely to experience downdrafts.
6. The boiler and water heater are sized to supply hot water for the entire wing of the motel, yet they are located, and draw their combustion air, from only the residential quarters of the motel.
7. The Uniform Building Code requires one-hour fire rated construction (doors and walls) separating the boiler and water heater from the living quarters and the remainder of the motel. The introduction of combustion air into the utility room is also required.
8. No provision for combustion air was made in the basement utility room, other than removal of the basement door. Windows had been covered with plywood and insulated.
9. The structure was operating under negative pressures. The causes of depressurization include:
    a. Attic depressurizes when the wind pulls air out of roof vent cupolas. There were no soffit vents to allow air into the attic.
    b. Attic depressurization was communicated to the living quarters through a leaky ceiling and attic duct system.
    c. There was no make-up air provided, as required by code, for the commercial clothes dryer.
    d. Inadequate combustion air for the water heater and furnace.
10. The furnace, water heater, and venting appeared poorly maintained. Vents were rusty, and the general appearance was of minimal expenditure maintenance. There were no inspection stickers, and no records could be found showing annual maintenance.

Recommendations and Action, Case 3

Corrections needed include:

1. The utility room be constructed to meet the Uniform Building Code requirements of one-hour fire rating.
2. Both the boiler and water heater be checked for proper combustion, including a check of combustion products to insure compliance with CO emissions.
3. Replacement water heater be considered. If not replaced, it should be completely maintained. The burner must be cleaned, and proper operation assured. The existing draft diverter must be replaced, and the needed rise established in the water heater vent pipe. There is insufficient space in the low basement room to establish sufficient rise, so major remodeling and re-venting will be needed.
4. That all venting be redesigned and all existing vent pipes be replaced. The vertical vent pipe should be routed within the structure and exit near the center ridge.
5. That sufficient combustion air be introduced into the utility room.
6. That sealed combustion units, power vented units, or electrical units be considered as

alternatives.

7. That make-up air be supplied to the clothes dryer and kitchen exhaust vent as required by codes.
8. That additional vents be installed in the attic.
9. That firewalls be installed in the attic between units as recommended by code.
10. The furnace in the attic should inspected before operating.
11. That a professional with experience in meeting Uniform Building Code requirements and in heating system design and installation be consulted to inspect the building and to determine the changes needed to insure safety.

CONCLUSIONS

Several problems contributed to the carbon monoxide problems in the three cases investigated. These problems included a blocked damper, a backdrafting gas fireplace, fresh air intakes frozen shut, insufficient combustion air, insufficient make-up air, lack of glass doors on a gas fireplace, burners producing excessive carbon monoxide, undersized venting, utility room without combustion air, return air not connected to furnace, expired carbon monoxide detector sensors, lack of maintenance, insufficient rise on water heater connector, holes in vent pipes, poor location of common vent, commercial boiler and water heater located in basement without combustion air, and depressurization of structure by attic ventilation.

The long list of problems found in these three dwellings is frightening, made more so since carpenters, homeowners, utility representatives, medical personnel, heating contractors, and building inspectors determined and corrected only a few of the causes of the carbon monoxide.

Interactions between structures and heating systems are numerous and complex. The buoyant forces that carry combustion products up the vent are extremely small and easily overpowered by exhaust fans, fireplaces, and wind forces. For carbon monoxide poisoning to occur there must be a source of carbon monoxide and the venting system must fail, allowing the products of combustion to remain in the structure. These three cases highlight several types of vent failure. There are many others.

More recent studies conducted by the authors, using gas meters, combustion gas analyzers, carbon monoxide detectors, and manometers found over-gassing is often overlooked as a source of carbon monoxide. Over-gassed appliances produce high levels of carbon monoxide (over 4500 ppm) and are prone to sooting and soot blockage.

These three case studies along with others conducted by the authors indicate heating appliances create carbon monoxide problems. To correct these problems requires cooperation of all people involved: including builders, remodelers, heating contractors, firefighters, local authorities, gas utilities, building inspectors, homeowners, appliance manufacturers, medical personnel, and extension educators.

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SUMMER HUMIDITY = YEAR-AROUND POOR INDOOR AIR QUALITY

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The prevailing wisdom is that maintaining indoor air quality is simply a matter of supplying fresh air and using a good furnace filter. Builders and home owners are primarily motivated to use ventilation to prevent condensation on windows. Typically, ventilation is discontinued when the temperature rises. Natural ventilation declines as the temperature rises. Monitoring of carbon dioxide levels show that the highest levels (+ 2,500 parts per million, PPM) occur when air-conditioning without mechanical ventilation. Ideal carbon dioxide levels are 700-800 PPM. Fresh air ventilation should occur anytime the windows are closed and is most critical during the non-heating season.

Fresh air ventilation and filtration are only two elements of indoor air quality. Humidity control is also a critical element. During the warm humid periods, open windows or mechanical ventilation produce high indoor humidity. Two or three months of +60% indoor relative humidity will permanently maintain a year-round dust mite population. Only a couple weeks of high indoor humidity will grow large quantities of mold and mildew. During the summer months, enough allergens can accumulate in the home to cause a serious indoor air quality problem for the entire year. Source control of the allergens inside the home is important. This problem is eliminated by maintaining the proper humidity level and providing controlled fresh air throughout the entire year.

The paper cites a study of ten modern homes with serious allergy problems and indoor air quality problems. A team of allergists, hygienists, engineers, and technicians studied these homes and the occupants for two years. All of the homes were monitored for six months for temperature, relative humidity, carbon dioxide, allergens, and occupant's health to identify the problems. The source of the allergens was the mold in the basements and the dust mites in the furniture, carpets, and beds. Then five of the homes were modified to provide fresh air and humidity control. The other five were used as a control. The mold and live dust mites in the humidity controlled are gone and the allergens are declining. After an additional year of monitoring and testing, the control homes were also modified and the study is ongoing.

Promises of Indoor Air Quality

A national company advertises that air filtering eliminates indoor quality problems. Another company announces that air filters reduce the need for fresh air and save money. Several companies touted by national celebrities claim the solution to indoor air quality is a simple electrostatic air filter. Many companies say fresh air means indoor air quality. Hundreds of companies advertise cleaning air ducts will cure your indoor air quality problems. Truth or fiction? This would be humorous except many people part with their hard-earned money and do not improve their indoor air quality. Indoor air quality products are a several billion dollar market. Most of the concepts are unable to provide indoor quality. What are the facts about Indoor Air Quality?

What Is Good Indoor Air Quality?

An environment free of the contaminants that adversely effect people's health or comfort is the simple answer. Environment is the space we occupy and the air we breathe. If "people" are to include 95% of the population, the presence of the common allergens produced by mold and dust mites must be considered a pollutant.

Fresh Air

Provide an adequate supply of fresh filtered, dry outdoor air to flush out indoor pollutants and an adequate supply of oxygen. The indoor space should be free of recognized pollutants. The quantity of fresh air is debatable. Currently the American Society of Heating, Refrigeration, And Air/Conditioning Engineers (ASHRAE) recommend fifteen cubic feet per minute per person or one third air change per hour of living space, whichever is more. . Because the cost of fresh air is low, most people prefer a little extra.

Air Filtering

Air filtering is a built-in accessory to every human being. It's the nose with those ugly hairs protruding. The air filtering efficiency of a nose is about the same as a low cost furnace filter. That's nothing special. The spectrum of filters available is from the cheap furnace filter up to the air flow restricting High Efficiency Particle Arresting Filter (HEPA) that removes many things including larger air-borne viruses.

The basic spun fiberglass filters are 10% efficient. All filter efficiency is stated using ASHRAE 52 Standard. Electrostatic air filters are 20% efficient (called allergy filter). That's two times more efficient than cheap furnace filters but are not adequate to keep heating/cooling equipment clear of dust. The extended media pleated cloth filters are 30%-40% efficient. They keep equipment and furniture clear of dust and remove all the recognized polluting nongasous airborne particles from the recirculating air. The next level is the premium extended media filter that requires filter paper insertion into a molded frame. It is 65% efficient and will keep equipment and home dust free.

Electronic filters are 65%-95% efficient immediately after washing. The efficiency depends on the amount of turbulence of the air stream. The efficiency of the electronic filters deteriorates rapidly as they collect dust. Manufacturers recommend washing once per month for optimum performance. How good should the filter be? Its important to keep mechanical equipment clean and good to reduce the dust that settles on furniture.

The findings of a review of all the air filter research by Roger M. Fox MD, Tampa, FL are that very little medically sound documentation exist on the benefits of air filtering. Filters do not substitute for fresh air or source control of pollutants. Air filters should not be the primary means of improving indoor air quality. My personal opinion is that unless you are undergoing open surgery or are immunologically impaired, the 30%-40% efficient extended media filter may be acceptable.

Humidity
Regarding "Indoor Air Quality" that's about it, right? Wrong! What's left? Everyone understands the importance of controlling humidity in the winter to stop windows from sweating . In fact those sweaty windows are the motivation that sells 90% of fresh air ventilation systems. When the snow melts, we stop being concerned about ventilation and humidity control. The key is source control of pollutants. Allergens are a pollutant.

What Causes Poor Indoor Air Quality In Wisconsin Study Homes?
An ongoing Wisconsin study headed by Physicians Plus, a local HMO, involves 10 families with serious allergy problems. Most of the patients were ill sporadically throughout the year. The temperature and relative humidity has been monitored constantly for two years. The dust mite, mold/mildew spore count, carbon dioxide, and organic biologicals are being sample every quarter.

Found Mold And Dust Mites
Mold/mildew and/or dust mites were present at some level in all of them. Sixty percent of the homes have the high quality electronic or high grade pleated cloth air filters. All of the homes had residential dehumidifiers. The typical winter humidity of these homes was 35%-40% RH which caused minor moisture condensation on the windows. One home had 50%-55% RH and had mold growth during winter. In the rest of the homes, little or no mold growth occurred during the winter months.

Found Summer Humidity High
Summer humidity repeatedly exceeded 80% for several weeks in seven of the ten homes. The highest relative humidity was recorded when the windows were open during humid cool evenings. Typical summer humidity was 60%-75%, when the air conditioners were operating. Mold presence is best detected by a musty odor associated with basements. A strong musty odor was present in most of these homes. Clearly the majority of mold growth occurred during the humid summer months. Just a couple of weeks of high humidity caused mold/mildew to grow and load the home with allergens. Mold/mildew was usually found in areas where carpeting was on concrete or in basements. Mold/mildew growth is caused by the normal 75°F, 60% RH air infiltrating under the carpet or other material on cool concrete. When the 75°F, 60% RH air is cooled to 50°F-60°F the RH rises to +90% RH. Mold grows rapidly at this condition.

Two of the homes had little or no evidence of mold. The windows of these homes were seldom opened when it was humid outside and the air-conditioner was usually on. The relative humidity in these homes was lower, and seldom exceeded 65%. These homes had no mechanical ventilation except bath fans and kitchen hoods. Cooking, pet, and other odors lingered in these homes. These homes exhibited high carbon dioxide levels, commonly over 2,000 PPM in the summer and approximately 1,500 PPM in the winter. Our meter max outs at 2,000 PPM. High carbon dioxide levels indicates that other indoor pollutants are probably also high, indicating low ventilation rates. Carbon dioxide levels of 1,000 PPM are considered an upper limit. The windows had moisture problems during the heating season. The homes had no carpeting in the basements.

It is critical to stay below 50% RH to prevent mold growth on any concrete surface that is covered by carpeting or storage boxes. After the structure is loaded with mold, extensive ventilation and air filtering are unable to rid the home of these allergens.

Dust Mites
Dust mites require longer periods of plus 50% RH to establish themselves. In addition to several months of the plus 50% RH, dust mites must have a food supply of skin scales, and an upholstered surface to live in. When the relative humidity is below 50%, the adult dust mites desiccate and die in 2-3 weeks, The dormant adolescent dust mites can survive for up to six-eight months below 40% RH. The usual location for dust mites are commonly occupied upholstered chairs, carpets and mattresses. The allergen from the dust mite is its fecal excrement. The allergen is potent for six-eight months after excretion. Tracking the temperature and relative humidity in these homes through a year illustrates that +55%-RH exists during the 3-4 summer months. This environment allows dust mites to thrive and reproduce. The homes had low to high levels of dust mite population. The drier homes had fewer dust mites with two exceptions. The house with highest levels of year-round mold had few mites. One of the homes with minor mold had the highest levels of dust mites. High levels of mold may inhibit dust mite growth.

Identifying Causes Of The Indoor Air Quality Problems
After collecting data for six months, the homes were paired for similar problems and mechanical system. One of each pair was randomly selected for resolution of the indoor air quality problems. Our team of experts agreed all the homes were grossly under-ventilated during the air-conditioning season and marginal during the heating season. We also agreed that the homes had a source of allergens produced by mold and dust mites. To control the source of these allergens, it was necessary to keep the relative humidity below 50% during summer.

Ventilating/Humidity Control Equipment
To control the homes' high summer humidity and the moisture summer ventilation adds, a ventilation system with 100 pint/day of dehumidification was used. A 35% efficient pleated cloth, extended media air filter was used to keep the equipment clean and remove allergens from the fresh air. Five of these homes had the Sahara whole house ventilation/humidity control system installed during Nov.-Dec. 1993. The 100 pint per day dehumidifier blends fresh air with air from the home and draws it through the air filter. The filtered air passes

through the dehumidifier and is routed to cause air circulation in the home. During times of low outside humidity, the fresh ventilation air is adequate to keep the home below 50% RH. If the indoor humidity exceeds 50% RH, the dehumidifier dries the combined air stream. The following table shows the amount of moisture added or removed per day from the home by 100 CFM of ventilation air. Ventilation with 60°F,80% Rh to 80°F, 40% RH outdoor air removes 13 lbs. of water per day if the home is maintained at 78°F, 50% RH. Each person adds 3-5 lbs. water per day. Some water is probably diffusing through the concrete into the home. Forty to fifty pints per day of dehumidification is required when the outdoor moisture is at this level.

Monitoring continued in all the homes during 1994. In the modified homes, the relative humidity during the winter months averaged 30%, compared to 40% in the unventilated homes. The summer humidity was maintained at or below 50% RH in the mitigated homes compared to 60%-80% in the control homes. The occupants of the modified homes reported an immediate improvement in the freshness of the air and the moisture on the windows. The musty odor did not return the following summer. No evidence of Mold/mildew was present in the modified homes.

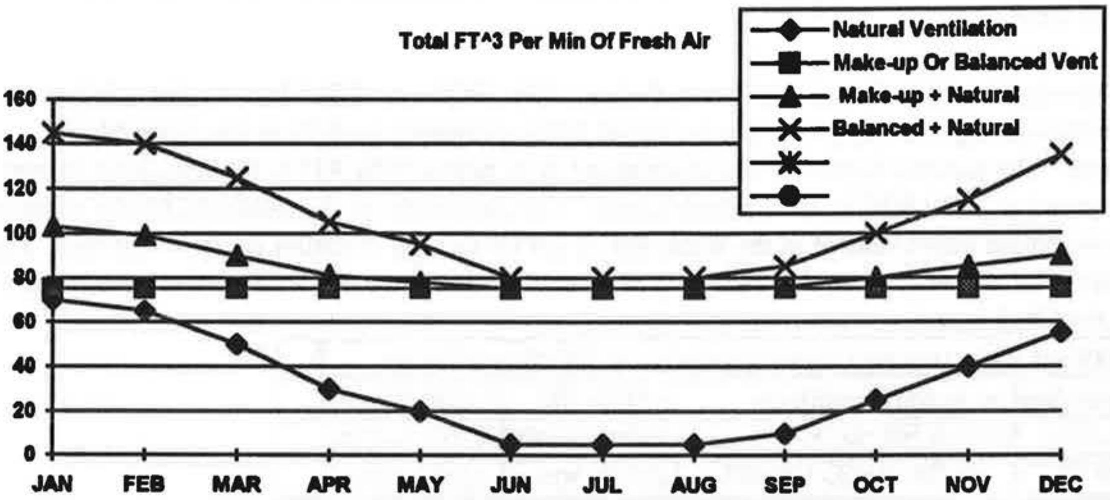
Pounds of water removed or added per day by 100 cfm ventilation			
Depending	on inside conditions	+ -LBS.H2O	+ -LBS.H20
Lbs.H2O	Temp.& Rel.Humidity	24hrs,100cfm	24hrs,100cfm
Per# Air	@ Same H2O Content	@70°F,30%rh	@78°F,50%rh
0.0006	0°f,80rh-15°f,40%rh	-45	
0.003	32°f,80rh–50°f,50%rh	-19	
0.006	50°f,80rh–75°f,35%rh	13	
0.009	60°f,80rh–80°f,42%rh		-13
0.0126	70°f,80rh–85°f,48%rh		26
0.0178	80°f,80rh–100°f,43%rh		81
	Condition Inside The Home	Winter	Summer

No live mites were found in the modified homes. The level of dust mite allergens is dramatically decreasing. The other five homes continued to have indoor quality problems proportional to their level of high humidity.

On a very humid day in Wisconsin, 60-80 pints of water are removed from the combined air streams to keep the home below 50% RH. The moisture comes from the fresh air, the occupants, and moisture entering by diffusion from concrete in contact with earth. The unit, dehumidifying continuously, uses twelve kilowatts per day or about $30/month. The dehumidifier operates continuously only during the most humid days. The amount of electricity to operate the Sahara Dehumidifier is similar to a conventional 35 pint dehumidifier. The Sahara removes 3-4 times more moisture per KWH.

Cost Of Winter Fresh Air

The following graph illustrates the effect of seasonal outdoor temperatures on the natural ventilation rates that were observed in these homes. As the outside temperature dropped during winter, the warmer inside air creates pressure on the homes causing an increase in natural ventilation. On the coldest winter days, this home has adequate natural ventilation (75 CFM). During the summer, natural ventilation rates drop to 5 CFM. Adding 75 CFM of make-up air ventilation increases the total winter ventilation to 105 CFM and the summer ventilation to 80 CFM. Adding 75 CFM of balanced ventilation increase the total winter ventilation to 140 CFM and the summer ventilation to 80 CFM.



Providing a constant amount of fresh air (75 CFM) as make-up air compared to balance air ventilation causes a more consistent ventilation rate during the coldest months. Because of this difference, the make-up air ventilation system pays a smaller heating penalty than thought. The above example shows the additional ventilation on the coldest month being only 40 CFM and 70 CFM during the warmest month. If ventilated for 12 hours a day, heating with a high efficiency natural gas furnace, the increased heating bill is approximately $50/year.

Cost Of Controlling Summer Humidity
Operating the typical 30-40 pint residential dehumidifier is approximately $30-$40 per month. Because of high efficiency, the cost operating the whole house system is comparable. Total operating cost of heating the fresh air during the winter and dehumidifying during the summer is approximately $150 per year.

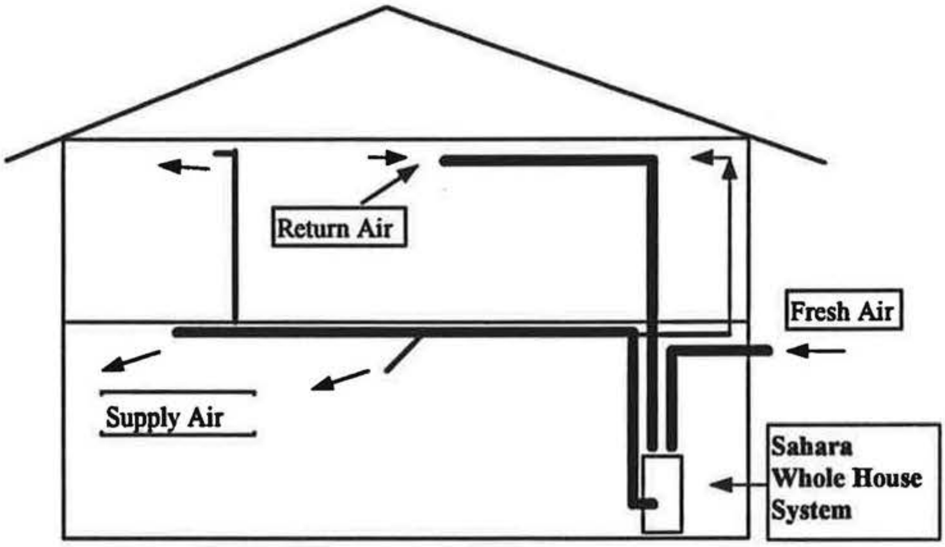
Introduction Of Fresh Air Into The Home
Blending 75 CFM of 0oF fresh outside air with 175 CFM of 70oF inside air from the cold air return combines for a temperature of 50oF. Introducing the fresh cool air into the home requires careful planning. Discharging the fresh air into the supply duct of the furnace or a utility room with a boiler in the basement is acceptable. In a home without a furnace, its necessary to duct the fresh air to the bedrooms and the open part of the home. The fresh air inlets are located high and avoid discharging the cool air on people. In some situations, a heat recovery ventilator and Sahara are recommended to conserve energy and decrease cool drafts. Exhaust ventilation can also be used in conjunction with the Sahara System.

Mitigation Of The Control Homes

During Nov. 1994, the remaining five homes were modified with ventilation/humidity control equipment. The monitoring is continuing. The Physicians Plus Allergists are tabulating the results of a quarterly health questionnaire and examination of the families. The initial appraisal of the medical impact is good. Several other studies are in progress to verify this concept. The American Lung Assoc. "Health Home" and the National Assoc. Of Home Builders are among those testing the concept.

Cost Of Whole House Indoor Air Quality System

A simple ducted system may have a retail installed cost of $1500.



Summary

Most homes are humid enough during the summer months to grow mold and dust mites. Their allergens last through the winter. Family members, pets, plants, and moisture diffusion are the primary sources of moisture in a home. Indoor pollution levels are also high during the summer. Summer ventilation is more important than winter because of the dramatic decrease in natural ventilation. Ventilation flushes the pollutants and controls moisture when it's cold outside, but adds to the summer humidity. To control the summer humidity, a large dehumidifier that is capable of removing 70-80 pints of water per day is necessary. If the home is kept below 50% RH, the home is more comfortable, mold, and dust mites are controlled. In addition, the system is capable of providing air filtering, and circulation of the fresh air throughout the year. This is an ongoing study and a more complete report is being compiled.

The Environmental Protection Agency recently published "Indoor Air Pollution, An Introduction For Health Professionals" Catalogue NO. US Government Printing Office: 1994-523-217/81322. The recommendations of the publication are well documented and similar to the modifications we made on this group of homes

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Household Contaminants and Household Exhaust and Ventilation Device Usage

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ABSTRACT

This paper identifies a) the pattern of usage of kitchen and bath fans and clothes dryers in a pilot study of twenty-three households with these three appliances and b) the level of contaminants measured in four Minnesota homes when tests were performed as part of a homeowner requested diagnosis of indoor air.

BACKGROUND

The home building industry has undergone changes in construction methods during the last fifteen years. These changes, due in part to consumer demand for comfort and in part to concern for energy efficiency, have led to tighter building envelopes. Unless provided with mechanical ventilation these tighter homes will likely experience a decrease in the number of natural air changes per hour. This condition can, and studies show, has led to problems that include moisture damage in structures and poor indoor air quality. As these problems become more prevalent building scientists are devoting more attention to air flows in homes and to changes in building pressures. Exhaust and ventilation devices directly affect house pressures, making the use of such equipment a timely topic.

During the recent development of the Minnesota Voluntary Residential Mechanical Ventilation Standards many discussions took place regarding how exhaust and ventilation devices affect pressures in homes. If this equipment is included in determining total exhaust capacity in homes, the typical use of that device or the combined use of more than one device being used at one time is an important factor in determining what the standard should be.

Studies done in Canada and the United States have concluded that exhaust and ventilation devices are able to provide the amount of ventilation that manufacturers indicate they will provide if they are installed properly. (Energy Design Update, 1989). When determining total exhaust capacities of residential buildings, it should be assumed that this equipment will perform as rated. The Home Ventilating Institute of America (HVI) tests and rates over thirty brands and models of ventilation and exhaust equipment. In the 1994 Home Ventilating Products Directory, HVI reports that cubic feet per minute (cfm) output ratings for over the range hood type kitchen fans are from140 to 1200 cfm. Bath fan output is from 50 to 410 cfm. If combined with a typical clothes dryer that produces a conservatively estimated150 cfm, these three fans together could be responsible for total exhaustion of from of 340 to 1760 cfm.

As homes become tighter, and they inevitably will, more thought must be given to the interaction between exhaust and ventilation devices and the environment they serve. We need to be concerned with all aspects of negative pressures, from their influence on combustion product venting to soil gas entry. The industry will need to evaluate ventilation and exhaust devices based on several site conditions including, but not limited to, backdrafting, biological and bacterial potential, as well as radon and other soil gas potential.

INTRODUCTION

The paper is presented in two parts. The first part presents findings from a pilot study that recorded the use of fans in twenty-three Minnesota homes. The fans studied are kitchen exhaust fans, bath fans and clothes dryers. Kitchen and bath fans are designed to remove contaminants generated during bathing and grooming and during cooking; clothes dryers are designed to remove the moisture released during the clothes drying process. These appliances are considered in mechanical ventilation standards for family dwellings because their use affects building pressures and can contribute to backdrafting of any natural draft combustion appliance.

The second part of the paper presents case studies of four Minnesota homes. In each case, the investigator was called to the home because of problems perceived by the homeowner. Levels of contaminants found in each home documented.

PART I. THE FAN STUDY

Methodology. Contacts for participants of the study were made from posted notices and through community meetings. Criteria for participation was limited to the presence of the following devices in the participant's home: a clothes dryer, kitchen fan and at least one bath fan in a bath that included a shower and/or tub. It was required that all three appliances be exhausted to the outside.

Participants were asked to complete a survey which included five questions about their household. They were also asked to complete a daily equipment record sheet for each device for a period of seven days. They did so by indicating use of each device during any part of any hour during these seven days. Completed surveys were returned by mail. The five questions were designed to give a profile of the household, clothes drying practices, the facilities provided in the baths, the type of kitchen exhaust in the home and the satisfaction of the sound level of the equipment surveyed.

Twenty three households participated in the study. The households ranged in size from one to five persons with two-person households (35%) being the most frequent size. There were no households with infants or persons over 64 years and four households with children under five years of age.

Results.

Clothes Drying Practices. Sixteen of the 23 households reported line drying of clothes. Six households did line drying indoors, three outdoors and seven reported line drying both indoors and outdoors. Although there were six households who used their dryers during three or less hours for the seven day recording period, all twenty-three households used the clothes dryer during at least one hour. Total use for all households was reported as use during 122 hours. See Chart 4.

Bathroom Facilities. Twelve households reported more than one bath with an exhaust fan. Of the total 30 baths reported, there were no reports of fans in baths where only a tub was present, ten reported fans in baths with showers only and 24 reported fans in baths with both tub and shower. Total use for all households was reported as use during 226 hours. See Chart 3.

Note. One household was equipped with a Van E* heat recovery ventilator which ran continuously during the reporting period. This equipment provides its own make up air and therefore was not recorded as bath fan use.

Kitchen Equipment. Two households reported that their homes were equipped with downdraft fans. The remaining 21 homes reported a hood over the range or cooktop. Total use for all households was reported as use during 43 hours.

Sound Satisfaction. The chart below indicates the results for satisfaction with sound levels of the three fans as reported by the participants.

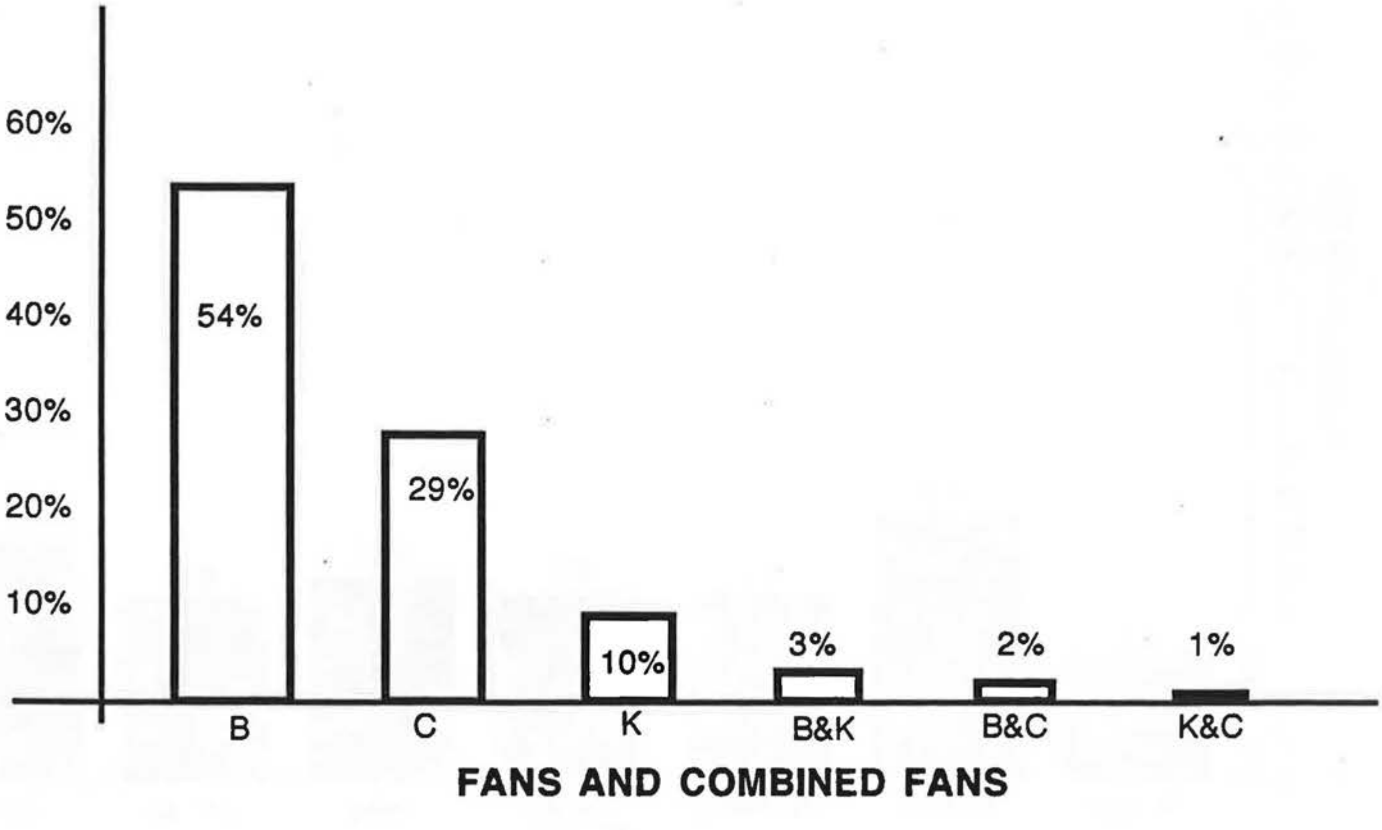
Satisfaction Level	Equipment		
	Clothes Dryer	Bath Fan	Kitchen Fan
High	20	14	5
Moderate	2	4	4
Low	1	5	14

Combined Use. During 54% of all hours during which any fan was being operated, bath fans alone were used. During 29% of all hours of use, clothes dryers alone were being operated. For 10% of the hours of any fan use, kitchen fans alone were used. The combined percentages are as follows: Bath and kitchen fan together, 3%; bath and clothes dryer together, 2%; kitchen and clothes dryer together, 1%. The percent of time that all three were operated at the same time was negligible(less than 1%). See Chart 1.

Discussion. Significant findings are the satisfaction with the sound levels and the frequency and pattern of usage. This information has implications for those building scientists who are charged with the task of determining how fan usage affects pressures in homes. The pattern of usage gives insight into the potential total cfm's that might be exhausted from the house at any one time.

An important component of the Minnesota Residential Ventilation Standards now being developed is the sone rating for exhaust and ventilation appliances. While HVI reports sone level ranges for kitchen fans to be from 3 to 12.5 sones and bath fans from 1 to 7.5 sones (a sone is approximately the sound of a quiet refrigerator in a quiet room or a quiet conversation level), the satisfaction level of the homeowner may give a more accurate indication of how much the fan will be used. The results indicate that while 20 families are satisfied with the sound level of their clothes dryers, only 5 of 23 were satisfied with the sound level of their kitchen fans. The corresponding use of these fans indicate that that kitchen fans are used much less (43 parts of hours) than clothes dryers (226 parts of hours).

CHART 1. **PERCENTAGE OF TOTAL USE- INDIVIDUAL OR COMBINED**



C - CLOTHES CRYER
K - KITCHEN FAN
B - BATH FAN

CHART 2: HOUSEHOLD USE OF KITCHEN FANS (n = 23)

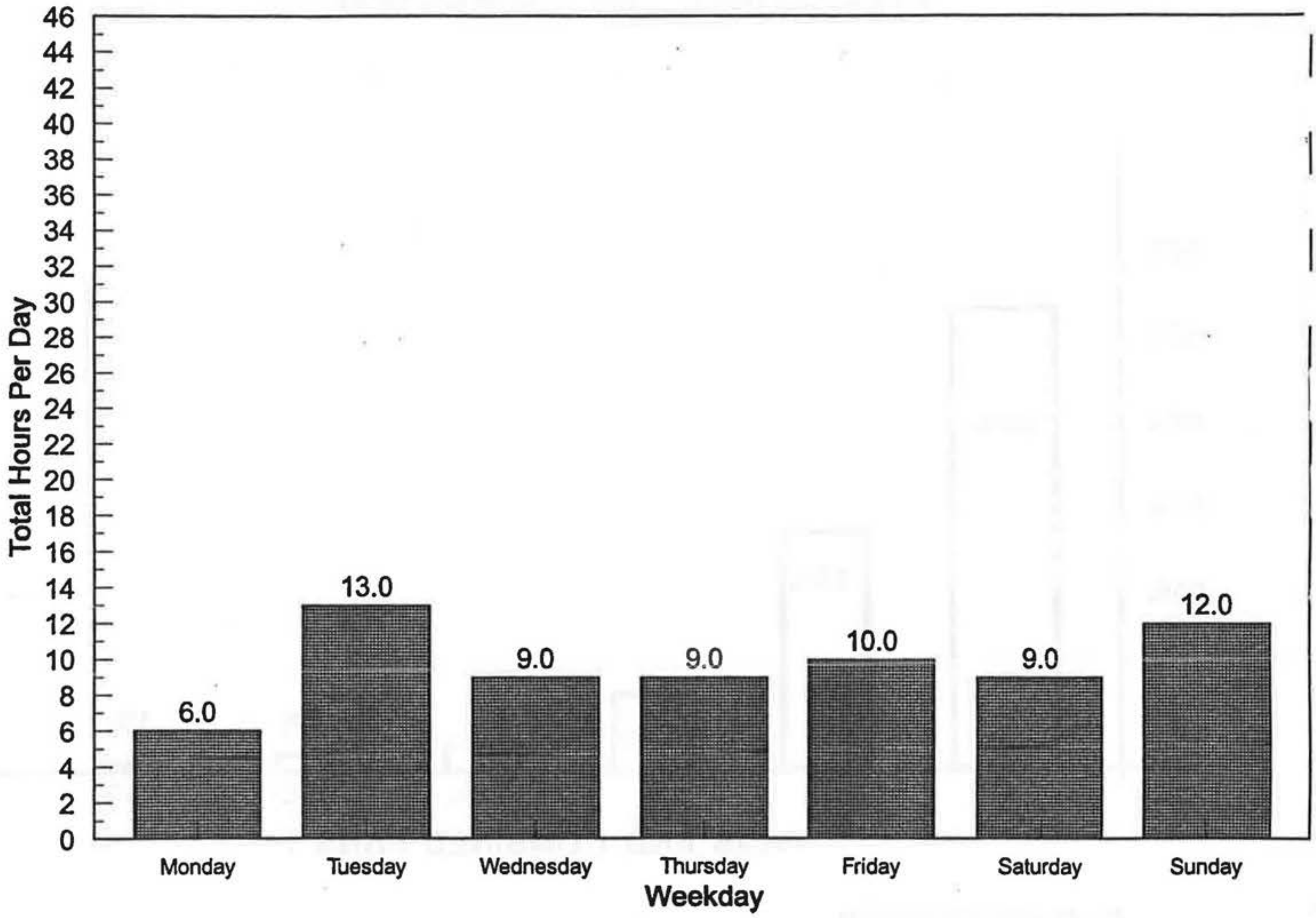


CHART 3: HOUSEHOLD USE OF BATH FANS
(n = 23)

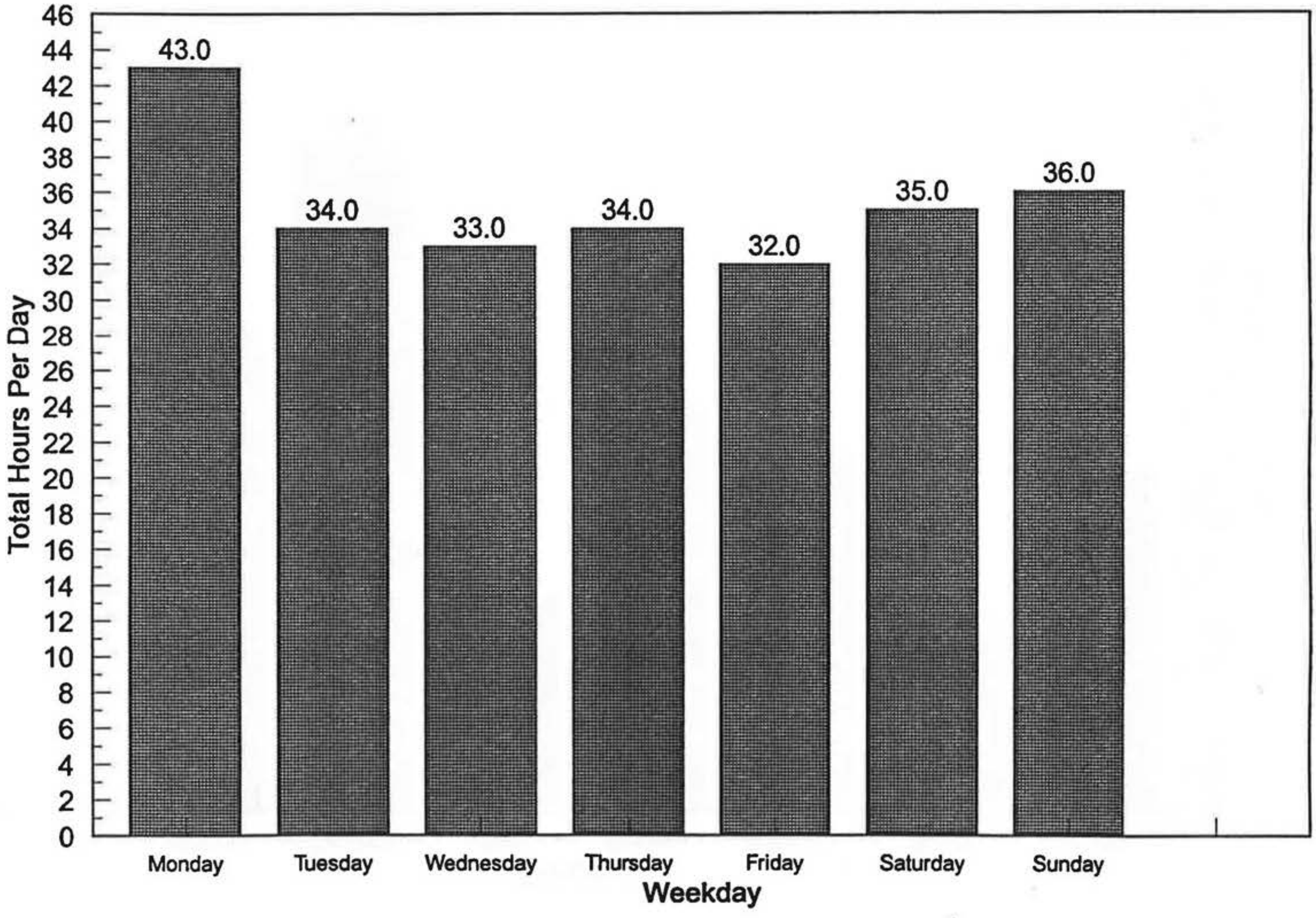
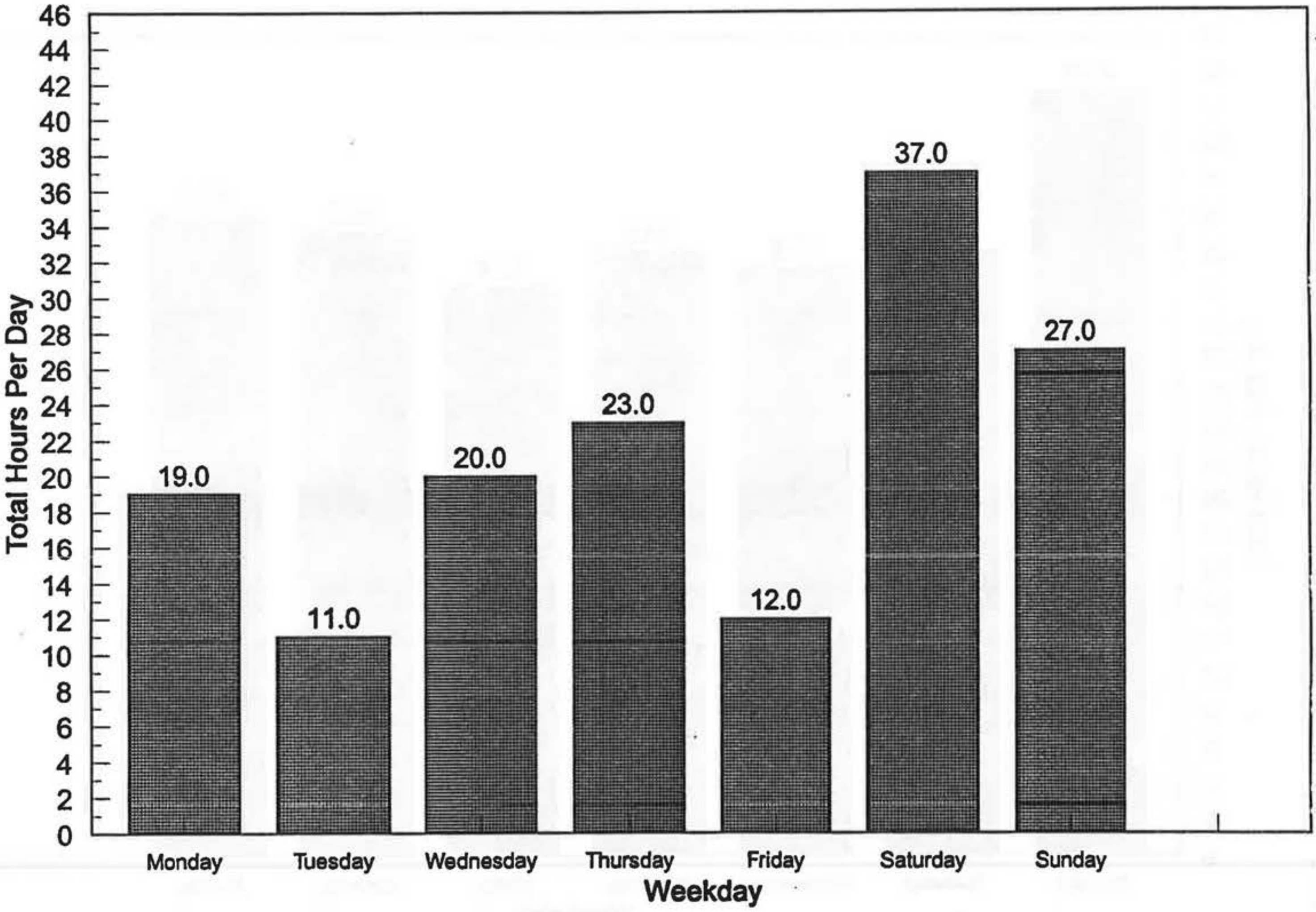


CHART 4: HOUSEHOLD USE OF CLOTHES DRYER (n = 23)



PART II. FOUR CASE STUDIES

Homes today are being equipped with progressively larger exhausting equipment. (Moffat, 1991). What can we expect when we combine bigger exhaust capacity in new and tighter homes? Should we expect a significant increase in negative pressures? Will the addition of additional combustion air lines compensate adequately for this larger exhaust capacity? The following case studies address these questions.

Each study is preceded with a description of certain conditions found in that house: the air tightness of the house as measured with a blower door, the total exhaust capacity of all exhausting equipment in the house and the negative pressure measured in the house when all exhausting equipment is operating at full capacity or worst case conditions. [A tight house would measure less than 1000 cfm; a medium tight house would measure 1000 to1600 cfm; and a leaky house would measure above 1600 cfm. All measurements at a pressure reading of 50 Pascals.]

Case Study One.

Tightness of Home: 1500 cfm
Total Exhaust Capacity: 520 cfm
Worst Case Negative Pressure: 15 Pascals

Homeowner Complaint. The four members of this household were hospitalized with carboxyhemoglobin (COHb) levels in excess of 25%. [While the Environmental Protection Agency recognizes that the length of exposure must be taken into account, a COHb level of 7-17% will statistically diminish visual perception and the ability to learn and perform sensorimotor tasks; a level of 40% will cause collapse; a level of 60% will cause unconsciousness and a level of 80% will cause death.] One of the two adults in this household was a woman in the fifth month of pregnancy.

The homeowners had complained of flu-like symptoms for over three months and at least one member had lost consciousness on more than one ocassion. Their complaints to their physicians were diagnosed as probably the flu brought home by school aged children. The homeowners requested that the utility company supplying gas to their home test the home for the presence of carbon monoxide. This test was done, but only after the furnace had been turned off and the windows left open for two hours. No carbon monoxide was measured by the gas company under these conditions. The installing mechanical contractor visited the home on more than one occasion and assured the homeowners that the furnace was functioning properly. It is not known what tests, if any, were performed by the contractor.

Investigative Findings. The house was equipped with a G20 non-induced draft furnace. It was found to backdraft at 3-4 Pascals of negative pressure, significantly lower than is typical (levels of above 5 would be acceptable). The furnace was also found to produce carbon monoxide (CO) of over 3000 parts per million (ppm) during backdraft conditions. Even when drafting properly, CO levels in the flue were measured at levels up to10 ppm. Long term monitoring showed furnace flue backdrafting for over a twelve hour period of time even though no exhaust equipment was operating. When this period was interrupted, ambient CO levels of over 1200 ppm were measured in second floor bedrooms. (See appendix for acceptable CO levels.)

Suggested Remedial Action. The homeowners were advised to vacate the house for several weeks while testing was being completed. The furnace has since been removed and replaced with a closed combustion furnace. Legal action has been initiated.

Post Test Report. None yet available.

Case Study Two.

Tightness of home: 1100 cfm
Total Exhaust Capacity: 500 cfm
Worst Case Negative Pressure: 12 Pascals

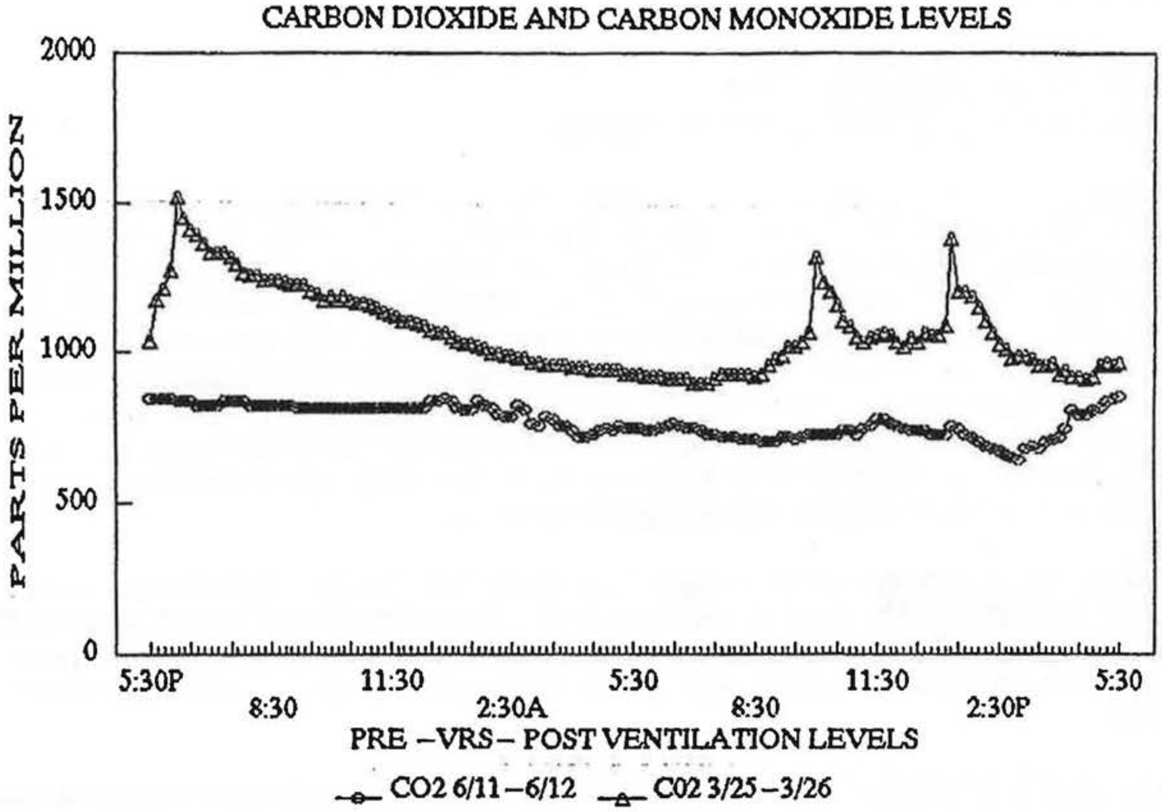
Homeowner Complaint. The homeowners, a retired couple, engaged the investigator to find the cause of excess moisture in the home. In particular, they were concerned about condensation on windows.

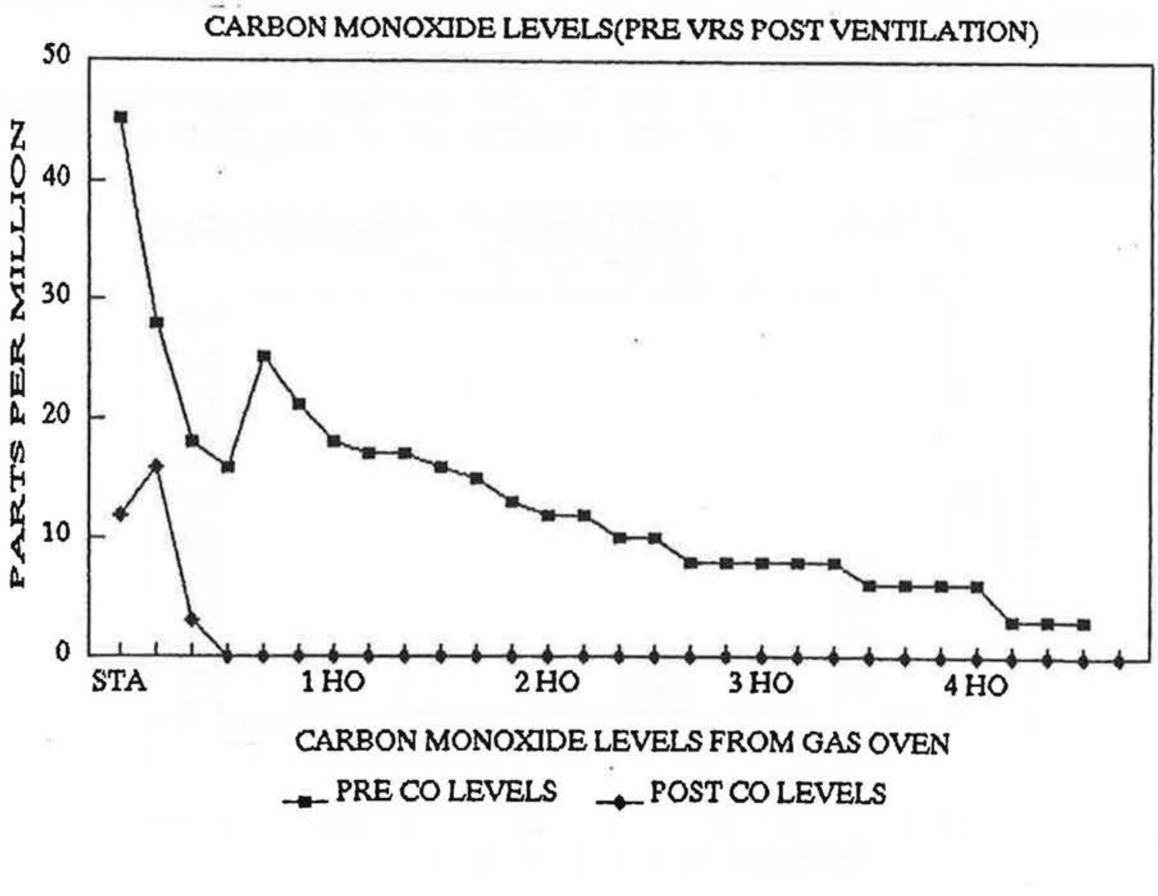
Investigative Findings. A significant problem with backdrafting was found. Operation of the gas oven produced CO levels of over 40 ppm in the kitchen. Decay was slow, with CO levels remaining at 4 ppm four hours after the oven was turned off. In an effort to reduce the CO levels in the kitchen, the kitchen fan was operated. However, the furnace and water heater were found to backdraft while the kitchen fan was operating. The water heater produced significant levels of CO only during backdrafting. Carbon Dioxide (CO^2) was logged for a three day period and was measured above 1000 ppm during this time. [EPA recommended ambient levels for CO_2 are less than 1000ppm.]

Suggested Remedial Action. A balanced heat recovery ventilation system was installed at the investigator's recommendation. Instructions of operation were presented to the homeowners and explained to them. Legal action has been initiated.

Post Test Results. See charts below.

ADVANCED CERTIFIED THERMOGRAPHY





Case Study Three

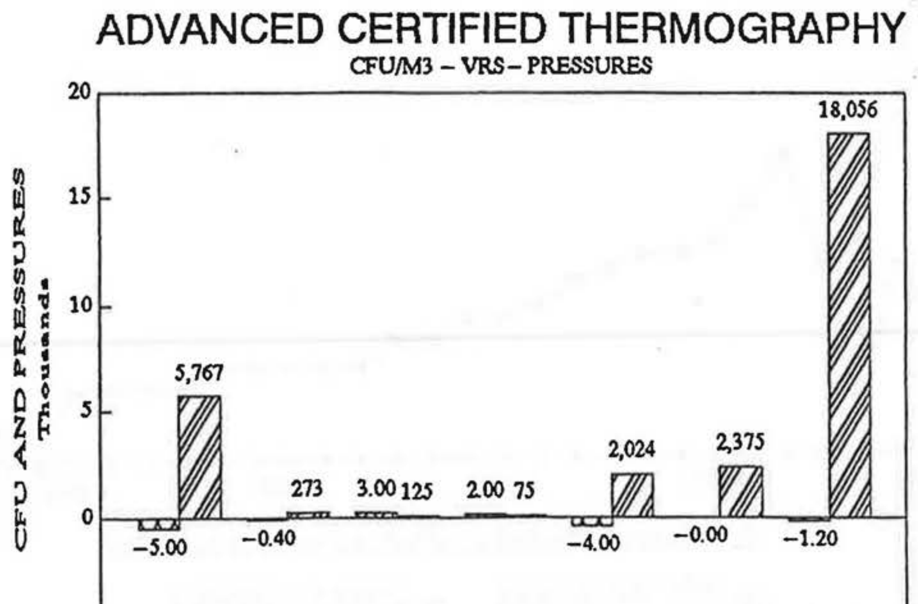
House Tightness: 2200 cfm
Total Exhaust Capacity: 300
Worst Case Negative Pressure: 5 Pascals

Homeowner Complaint. The household consists of a husband, wife and one child. The home also provides day care services. The entire family reported experiencing allergic reactions in the home. They requested testing with the belief that their symptoms were being caused by a propane leak into the house. Previous to the onset of these investigations, two separate fires had broken out in the home. The source was traced to a propane leak in gas lines to the home. The gases had leaked into the sump basket and erupted into fires. In an attempt to keep propane from entering the house, a fan blowing air into the sump basket was installed for three days. It was after this procedure that the family began experiencing the allergic reactions.

Investigator Findings. A very high level of biologicals (See definitions) were found throughout the house. Rooms in the lower level were found to have the highest levels. When exhaust equipment was operating, testing at an open block core showed extremely high levels were entering the house. See chart below.

Suggested Remedial Action. The blocks and basement were thoroughly cleaned. A radon mitigation system was installed in the sump basket and the soil and blocks were depressurized to draw the biologicals out of the building. Legal action is being considered.

Post Test Results. Follow-up testing revealed significant levels of biologicals in only one room. This was attributed to incomplete cleaning of the original contamination.



Case Study Four

House Tightness: 2500 cfm
Total Exhaust Capacity: 225 cfm
Worst Case Negative Pressure: 3 Pascal

Homeowner Complaint. The homeowner, a single woman, became alarmed when, over a five year period of time, she realized that three foster children had all developed "asthma like" symptoms.

Investigator Findings. Biological contamination levels exceeding 40,000 CFU/m^3 were found in several areas of the basement. Further investigation found that the ground under the entire basement slab had settled approximately twenty inches. Approximately twelve inches of standing water was documented in the space.

Suggested Remedial Action. On the advice of her physician, the homeowner abandoned the property. No remedial action was taken due to the cost of repairs. Legal action is being considered.

DEFINITIONS

Pascal: A unit measurement of pressure. House air tightness tests are typically conducted with a pressure difference of 50 Pascals between the inside and the outside. Fifty Pascals is equal to 0.2" of water at 55 degrees F.

Biologicals contaminants: Tiny particles that are alive, were once alive, or are part of something that is or once was alive (e.g. molds, insect parts, pollen, animal dander). These contaminants can cause health effects such as allergic reactions, Legionnaire's Disease and pneumonitis. Symptoms range from eye, nose and throat irritation to life-threatening fevers. (Source: EPA.)

Exhausting device: any device that removes air from the home as a secondary function. These devices, which use house air and direct it outdoors, include but are not limited to gas, oil or solid fuel burning equipment, clothes dryers, and central vacuum systems.

Ventilation device: any mechanical device, usually a fan, that is specifically intended to remove house air in order to reduce indoor air pollutants or moisture including, but not limited to, bath, kitchen and laundry area fans.

Parts per million: a term generally used to designate the number of particles of a substance compared to the total of all other particles present. Common unit used to measure concentrations of compounds in air.

notes

notes

F. remodeling, rehab & miscellaneous

AUTOMATED BIOMASS-FIRED HEATING PLANTS - A RENEWABLE OPTION FOR MULTIFAMILY HOUSING

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ABSTRACT

The purpose of this paper is to bring to the attention of the energy-efficient building community a renewable energy option for larger facilities: automated biomass heating plants. Drawing from many examples (including the retrofit of a nine-building 50-apartment housing project converted from electric heat to a central biomass boiler plant), it will be demonstrated how wood-chip fuel can give dramatic reductions in costs for space heating and domestic hot water. The paper will focus not only on the economic and environmental benefits of biomass heating, but also on the system components and their costs. Policy issues around substitution of biomass fuels for fossil fuels will also be addressed.

INTRODUCTION

Biomass is any organic material that can be burned for energy. For the purposes of this discussion, we will look at the most commonly available forms of woody biomass: wood chips, sawdust, bark and chipped sawmill wastes. These forest products are readily available in much of North America, and are generally the lowest cost combustion fuels on the market. In some areas some forms of biomass are available as waste products, priced at the cost of trucking. But more commonly biomass is either harvested for energy or sold as a byproduct of the forest products industry. Its cost is typically 40-50% less than that of bulk-purchased no. 2 fuel oil or natural gas.

Most biomass residues are burned at sawmills to run steam kilns, sold to electric generating plants, or marketed as a feedstock to paper mills. But there are a growing number of institutional, commercial and industrial facilities that are purchasing biomass to burn for heat. These include schools and colleges, hospitals, greenhouses, municipal and state buildings, correctional facilities, hotels and district heating systems. A recent survey of installations in the northeastern U.S. and maritime Canada found over 150 such facilities.

Biomass can be an excellent fuel for large multifamily housing developments, particularly in harsh winter climates and in areas where the competing conventional fuels are very expensive. Because biomass fuel is so inexpensive, burning biomass in a central boiler plant can provide high levels of comfort at very low cost. There is an additional maintenance benefit in having a single heating plant to take care of, compared to separate heat and hot water systems for individual apartments.

This paper will examine one such installation in some detail. Green Acres is a 50-unit low-income family housing project owned by the public housing authority in Barre, Vermont. In 1992 the project was converted from individual electric heat and hot water systems to a central wood-chip system. Over the last three years, the fuel cost for supplying all heat and hot water at Green Acres has averaged $25 per apartment per month in the 8600 degree day climate of central Vermont. This represents a 76% reduction in energy costs for heat and hot water, compared to the previous electric heat. The Green Acres project will be discussed in detail later in this paper.

AUTOMATED BIOMASS HEATING

In most institutional applications biomass fuel handling systems are automated. The operator never handles the fuel, and there is no manual labor involved in running the system. The overall system consists of a storage bin, automated mechanical equipment to move the fuel from the bin to the point of combustion, a combustion chamber and a boiler to act as heat exchanger (see Figure 1).

In cold climates the bin is usually a below-grade concrete bunker which can hold more than one truck load of fuel (in warmer climates, above-ground metal silos or bins are sometimes used). Fuel deliveries are made by either tractor trailer trucks, fitted with self-unloading hydraulic floor systems, or large dump trucks. The truck approaches at the top of the bin and discharges down into the bin, filling it by gravity. Tractor trailers generally deliver 25-30 tons of fuel per load, and dump trucks 15-20 tons.

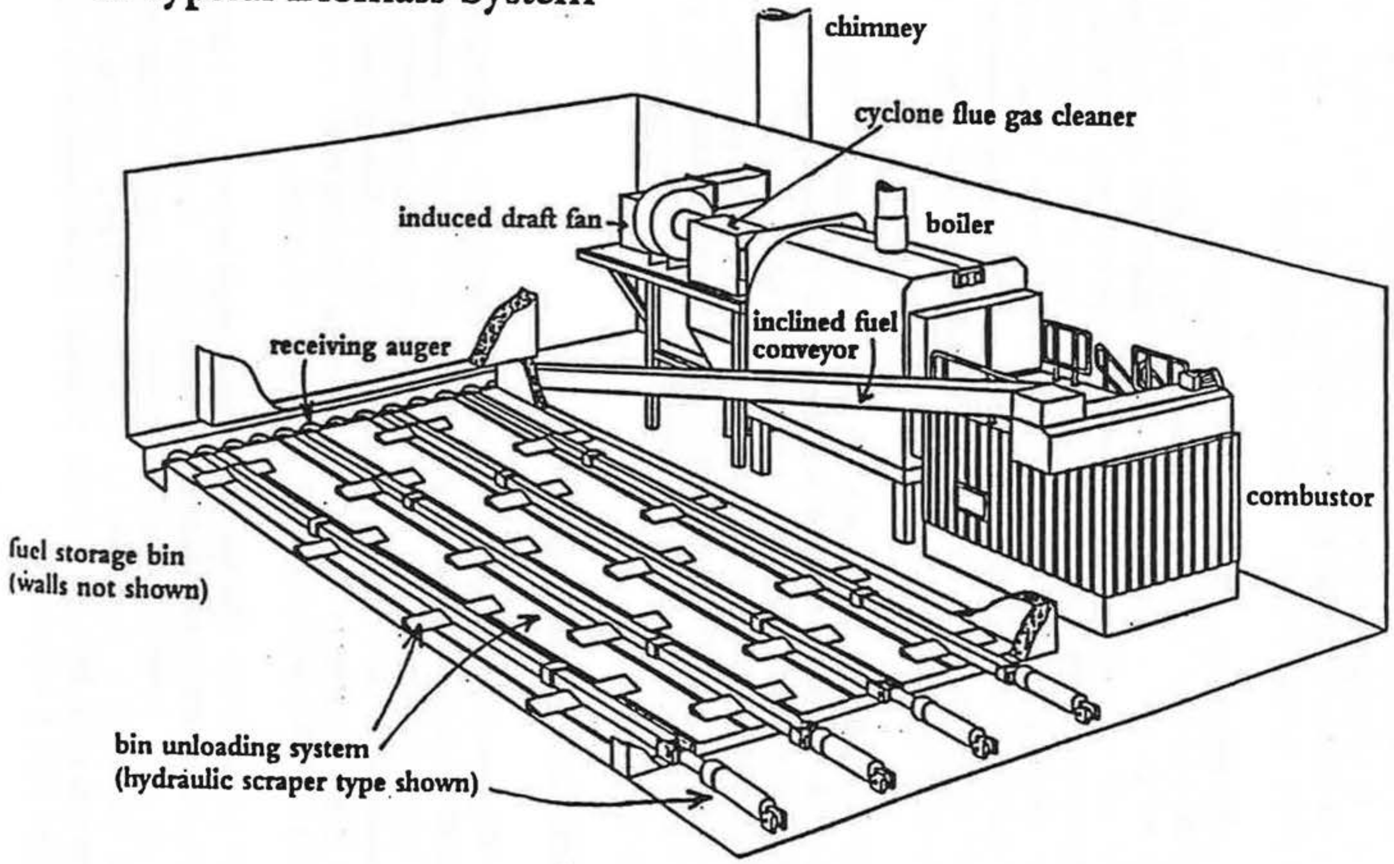
Fuel is withdrawn from the base of the bin automatically, using either a hydraulic scraper system (shown in Figure 1) or a travelling auger that sweeps the base of the bin, discharging to a fixed auger outside the bin. The fuel conveying system, generally consisting of two to five motor-driven augers, moves the fuel from the bin to the combustion chamber.

Some biomass-burning facilities, such as greenhouses and industrial plants, may use small tractors or front-end loaders to handle the biomass fuel. This approach, combined with a simple roofed storage shed for the fuel, is much less costly than a fully automated system and may be used in cases where operators are willing to spend some time each day to load a small day-bin which in turn feeds the boiler.

The primary combustion chamber can either be located in the base of a large conventional solid-fuel boiler (Figure 2), or in a separate combustor which sits adjacent to the boiler (Figure 3). The biomass fuel generally burns on grates in the combustion chamber, with under-fire air blown up through holes in the grates from below and over-fire air injected above the grates.

Figure 1

A Typical Biomass System



Courtesy KMW Energy Systems

Hot combustion gases pass from the primary combustion into the heat exchanger of the boiler. Here the heat is transferred to the heat exchange medium, either hot water or steam. Cooled exhaust gases then exit via a steel stack or masonry chimney. Most systems use an induced draft fan just upstream of the chimney and a "cyclone" or particulate removal device to remove solid pollutants from the exhaust gases.

The central boiler plant supplies hot water or steam to the distribution piping, whether the plant serves a single building or multiple buildings. If there is more than one building, they will be connected back to the central plant with buried pre-insulated piping. Boiler water is used directly for heating, while domestic hot water (DHW) can be supplied using one or more heat exchangers. If there are dedicated supply and return DHW pipes originating in the boiler room, a single DHW heat exchanger and storage tank in the boiler plant can be used. Alternately, the distributed space heating medium (hot water or steam) can be run through DHW heat exchangers in each building or in other multiple locations closer to the end use.

In institutional biomass plants, it is common to have 100% backup capability using conventional fuels. If the biomass system goes down for any reason, the backup system takes over automatically and can handle the full heating load. Biomass heating plants are often shut down in the summer, when the heating load is low, with the backup system taking over to supply DHW and any heating loads. However, a biomass system which also serves the DHW load might be set up to run twelve months of the year to satisfy that load.

THE ECONOMICS OF BIOMASS HEATING

Biomass heating plants carry high capital costs for construction of the storage bin and a boiler room large enough to house the equipment, for the handling system, for the combustion system and boiler, and for the chimney system and controls. Below-grade bins might cost $50-60,000 to build and the need to build additional boiler room space will vary from project to project. Automated biomass systems in the 1-5 million Btu range generally cost $80-$250,000 for the installed equipment.

For systems to be economic, the fuel cost savings must be great. The economics works best when the conventional fuel being replaced is very expensive or when the heat load is very high. In retrofit situations, biomass can compete favorably with electric heat when the prices are $.10 per kWh or more, and with oil or natural gas when the annual heating fuel bill is $25,000 or more. Biomass systems are more economic in new construction than in retrofits.

In some situations, economics can be greatly enhanced when there is biomass available nearby at very low prices. For example, a Trappist monastery in Massachusetts purchases nearly the entire wood-chip output of a nearby hardwood sawmill at a very reasonable price. A hospital in northern Wisconsin purchases bark from a large mill a few miles away for $1 per ton plus trucking, and burns the bark for heat in the winter and to run steam absorption chillers for air conditioning in the summer.

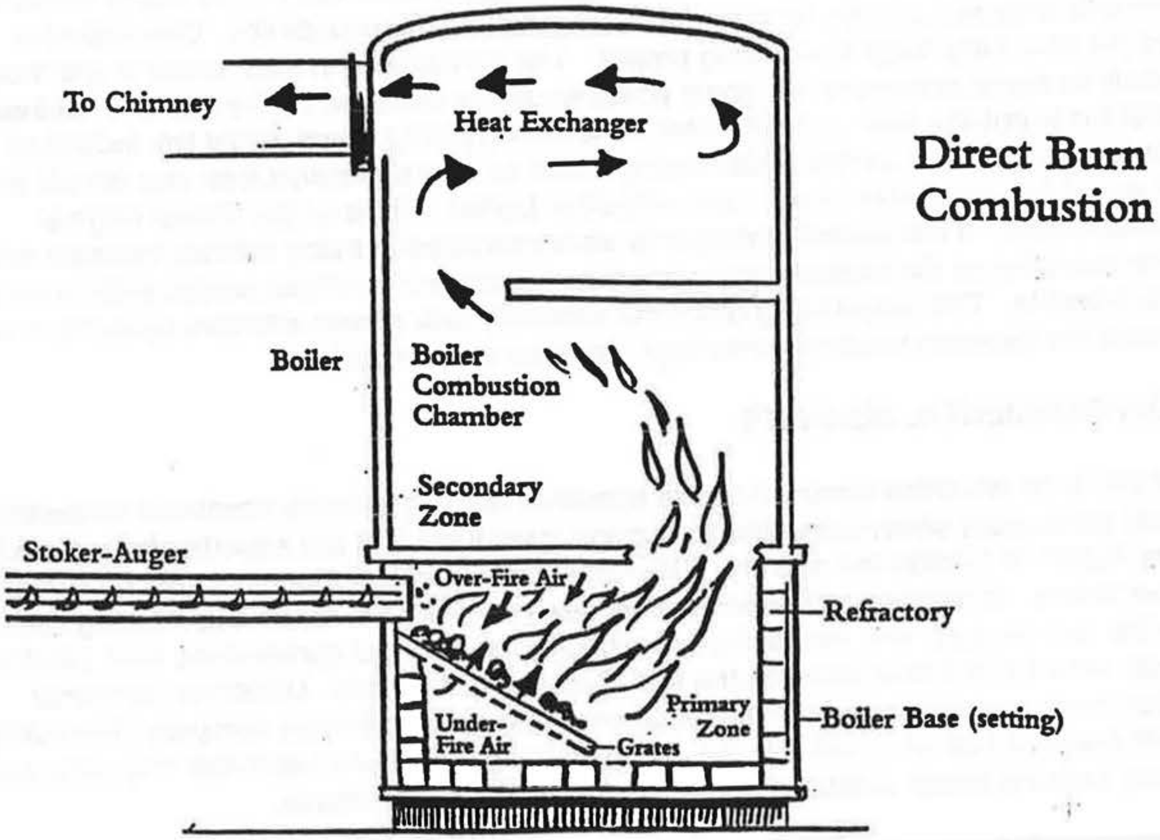
For multifamily housing, biomass has the best chance to compete in large projects with large heating bills. One example might be electrically heated low-income housing where the tenants pay their own electric bills (such as Green Acres). High winter electric bills lead to high vacancy rates in this type of housing, so a biomass conversion can dramatically increase the project's financial stability as well as benefitting tenants directly. Another example might be high-rise urban housing with a large oil or gas bill and an aging central boiler plant. If the project were located on a site with room to add a fuel storage bin and there were a rural forested area within 50 miles, the biomass conversion might be feasible. Having a hot water or steam distribution system already in place makes the biomass conversion more likely to be economic.

For new multifamily construction, biomass heating is most likely to be viable when the project does not operate on conventional market-based economics. One example might be a fairly large co-housing project. The participants in such projects are more likely to share environmental goals which would be furthered by the use of a renewable fuel for supplying heat and hot water. The buried piping which would link individual buildings back to a central boiler facility would be less expensive than in a retrofit since it would be installed in conjunction with other buried utilities at the time of original construction. If the project participants were interested in being actively involved with the operation of the biomass system, a less automated (and less costly) system might be possible. This would bring down the threshold size of cost-effective systems and make the biomass heating technology viable for smaller projects.

ENVIRONMENTAL BENEFITS

There is an attractive common-sense appeal to burning a locally-produced renewable fuel, particularly when compared to burning fossil fuels that are imported from outside the region or outside the country. This appeal can speak eloquently to decision-makers and voters. In Vermont, 15 schools have been converted to wood-chip heating systems in the last decade. For new school construction and school conversions from electric heat, wood chips have become the fuel of choice in the state. Under conventional short-term economic analysis, these conversions would not have competed favorably with low-cost fuel oil or natural gas. However taxpayers have taken the long view and have voted to invest additional money to install biomass systems.

Automated biomass systems, because of the sophistication of their controls, are a clean-burning technology. In proper operation they produce no visible smoke - only a steam plume in cold weather. There is no associated odor or noise. The emissions test favorably compared to fossil fuels. Particulates have typically tested below air quality emission limits in all state jurisdictions. Wood fuel has no sulfur and so does not emit sulfur oxides when burned. There is some concern about the oxides of nitrogen from very large plants (utility scale), but not from the smaller plants discussed here.



To Chimney
Heat Exchanger
Direct Burn Combustion
Boiler
Boiler Combustion Chamber
Secondary Zone
Stoker-Auger
Over-Fire Air
Refractory
Under-Fire Air
Grates
Primary Zone
Boiler Base (setting)

FIGURE 2

Two-Chamber Combustion

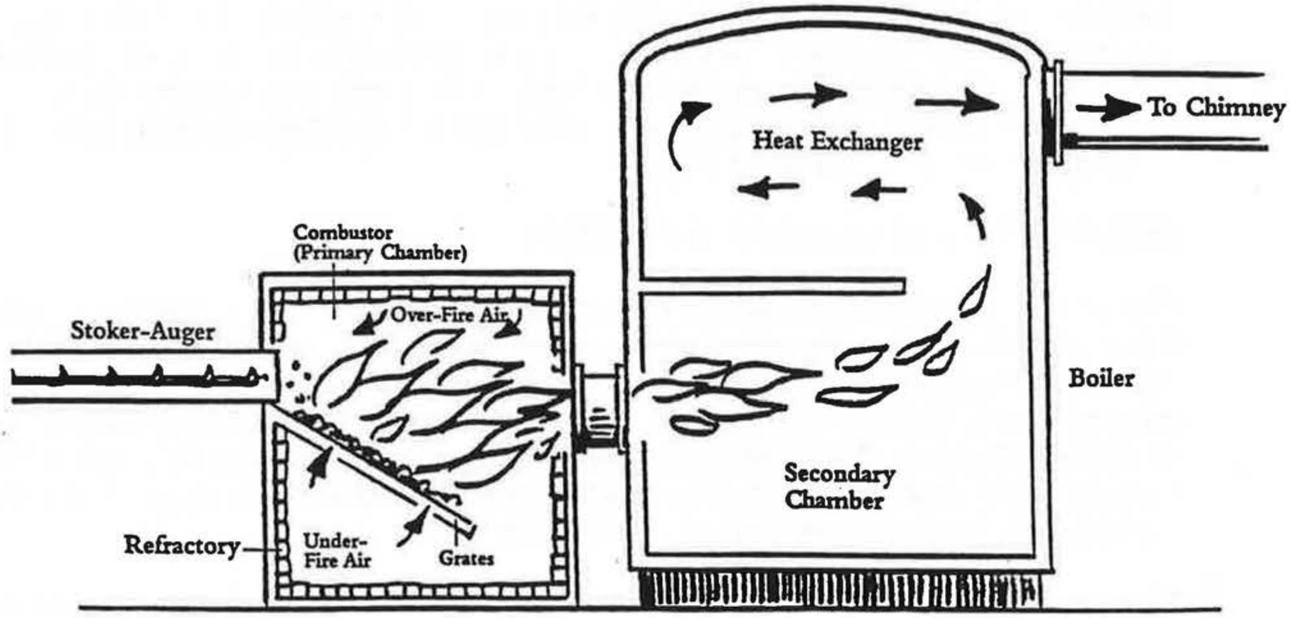


FIGURE 3

In terms of possible contributions to greenhouse gases, it is generally accepted that burning wood is carbon dioxide neutral when the fuel is harvested using sustainable forestry practices. In other words, while wood combustion does produce carbon dioxide, there is no net addition to atmospheric carbon dioxide when harvested trees are replaced with new growth.

The ash content of clean biomass fuel is generally less than 1.5%, so that for each ton of fuel burned there is no more than 30 pounds of ash produced. The ash is not toxic or harmful and in fact is a good soil additive for agricultural applications. Most plants either send the cooled ash to the landfill or give it away to local farmers or gardeners.

While the environmental benefit of burning sustainably harvested biomass or biomass from the waste stream is clear, compared to burning fossil fuels, it is difficult to monetize this benefit for combustion plants smaller than industrial or utility-scale facilities. This makes it difficult to justify the investment in conversions to biomass systems when fuel oil prices are very low, as they continue to be. However, initiatives such as the President's Climate Change Action Plan, which aims to make sharp reductions in greenhouse gas emissions, are beginning to make a positive contribution to justifying biomass-for-energy projects.

BIOMASS FUEL AVAILABILITY & DELIVERY

Biomass is readily available across the rural forested areas of the northern tier states, in the southeast, and in other areas where logging is common. A 1993 survey of the eleven northeastern states found an excess capacity of marketable biomass in every state with no indications that the resource would have trouble keeping up with an increase in demand. Most institutional heating users of biomass buy from within 50 miles of the source, whether that is a sawmill or a whole-tree chipping operation. In some cases, biomass is trucked up to 100 miles.

Biomass is a good match for energy users in rural areas, but it is also possible for it to be used in urban settings where there is a forest resource within relatively close distance. The capitol complexes of state buildings in both Concord, New Hampshire and Montpelier, Vermont are served by biomass district heating systems. The Montpelier system uses about one truckload of fuel per day; deliveries are so inconspicuous that most residents of the city are not aware of the existence of the plant.

In some markets, such as the northeast, hardwood chips are the dominant biomass fuel while in others, such as the Pacific northwest, softwood is far more common. Although systems are generally designed and tuned for one or the other, either fuel works well in automated biomass combustion systems. Green sawdust can be a good fuel, except that it can freeze in the bin in a cold climate. In some rural markets bark is very inexpensive, but is a difficult fuel to handle and burn. The costs of sawdust and bark as combustion fuels are highly dependent on competing uses. Close to urban areas, for example, bark is expensive because of high demand for landscaping mulch.

While biomass fuel is widely available, potential suppliers may not be accustomed to dealing with purchasers outside the forest products industry. A facility that wants to burn biomass may have to work hard to find and set up a relationship with a supplier, and even then delivery scheduling will not be as easy as for fuel oil.

POLICY CONSIDERATIONS

Most states have energy policies which support and promote the use of renewable energy. Yet when it comes to heating larger buildings, it is the general belief that there is no renewable option. Almost all larger buildings use the conventional fossil fuels, gas and oil, or electricity for space heating and domestic hot water. For those who are committed to promoting the use of sustainable energy, biomass provides a unique opportunity to substitute a renewable combustion fuel for non-renewable conventional fuels. Large multifamily buildings or complexes are among the many possible settings in which biomass combustion technology can be used today.

Another attractive feature of using biomass fuel is that it keeps energy dollars in the local economy, rather than exporting capital out-of-state, out of the region or out of the country. The use of biomass supports local forest products industry jobs and can help to vitalize rural economies.

Unlike most conventional forms of energy, the pricing of biomass is largely de-coupled from the national and global energy markets and so tends to be stable, promoting economic and energy security. In Vermont, which has a decade of experience with burning biomass in institutional settings, prices have risen only 5% during the ten year period, with no up-and-down fluctuations.

Only in the last two to three years have the federal government and the states begun to take aggressive steps to curtail greenhouse gas emissions. For large buildings, these initiatives generally translate into increasing the efficiency of the buildings so that they will consume less fossil energy and less electricity. Reducing fossil fuel consumption by 25% is seen as an ambitious target for energy efficiency projects. The use of biomass for heating, on the other hand, goes a quantum step beyond, providing the same level of heating while cutting fossil fuel consumption by 85-90%. As society learns to put a dollar value on greenhouse gas emissions, biomass will be likely to be incorporated into more new construction and retrofit projects.

CASE STUDY: GREEN ACRES

Green Acres is a 50-unit low-income family housing project located in central Vermont. It was built in the early 1970's when electric baseboard heat was still being vigorously promoted by utilities in the state. By the mid 1980's it was clear to the owners, the Barre Housing Authority, that the electric bills associated with electric heat at Green Acres represented a severe economic hardship to their tenants. Residents saw electric bills averaging $250 each month for the four-month winter peak period, with some bills over $300. Even with utility allowances, the cash flow impacts of having to spend in excess of $1,000 in electric bills over four months led to tenants getting behind on their bills. It also created a vacancy problem for the Housing Authority when tenants moved away to get out from under electric bills they could not afford.

In 1988 the Housing Authority undertook an ambitious $1.2 million program to modernize Green Acres, using funds provided by HUD. The project included converting the individually metered electric heat and water heaters to a central hot water boiler system with wood chips as the primary fuel and oil as the backup fuel. A central boiler plant was built onto the existing maintenance building, which connected to the eight residential buildings using pre-insulated buried pipe. The constant-circulation hot water loop supplies space heat directly through hydronic baseboard radiation, and serves one domestic hot water heat exchanger tank in each building. The plumbing infrastructure (electric heat removal, installation of buried pipe, installation of hydronics, oil boilers and ancillary boiler room equipment) cost $540,000 of HUD grant money.

The biomass portion of the project consisted of building a below-grade fuel storage bin, capable of holding one-and-a-half truck loads of wood chips, and a new boiler room with wood boiler, fuel handling equipment and controls. The wood-chip portion of the project went on line in March of 1992.

The wood-chip system was financed under a unique partnership. The building construction (for the bin and boiler room) was done out of $100,000 in grant money supplied by the state's low-income weatherization trust fund and Vermont's multifamily housing energy conservation program. The wood-chip system cost $95,000 and was financed by a local non-profit energy service company, Vermont Energy Investment Corporation (VEIC), using a payment-out-of savings approach. VEIC borrowed the funds from the Vermont Housing Finance Agency and is paying off the loan out of payments made to them by the Housing Authority. In effect, the Housing Authority is buying hot water from VEIC, which owns and maintains the system on the Green Acres premises, and purchases the fuel. At the heart of this arrangement is a HUD rule which allows a local housing authority to retain energy savings for a period of time, instead of having the savings revert to the federal government.

Over the first two years of operation, the system has met or exceeded all the savings and financial goals on which it was premised. Energy costs for heat and hot water have been reduced by 76%, with a monthly cost for heat and hot water of $25 per apartment, averaged over a 12-month period. Tenant electric bills have been reduced to an average of $34 per month.

It costs about $1,100 per year to maintain the Green Acres wood system and about $650 for the backup oil system. In the last year, wood has supplied 89% of heat with 11% being made up by oil. The oil system runs when the wood system is shut down for any reason, such as a late wood-chip delivery or an unplanned loss of wood fire because of an over-sized chip jamming the auger system. Although the wood system runs twelve months of the year (to supply summer DHW loads as well as heat), it is often shut down for periods of weeks in the summer due to very low loads. The Housing Authority maintenance staff spends about 20 minutes a day on the wood system, primarily in manual ash removal. The system runs untended at night and over weekends, so the Housing Authority incurs no additional labor costs or overtime in its operation.

notes

Transforming the Market through High Performance Home Building: The U. S. EPA Energy Star Residential Buildings Program

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Abstract

This conference program presents a 15 to 20 minute overview of the recently announced EPA Energy Star Residential Buildings Program. EPA professional staff making the presentation will then use the remainder of the time to seek input, comments and ideas from home builders, sub-contractors, mortgage lenders, weatherization specialists, energy engineers, code officials, utility program managers, and other shelter industry stakeholders. EPA is interested in this input to help fine tune its vision of a true builder-oriented market driven program which results in higher market penetration of super efficient homes aimed at significant reductions in air-pollution.

Background and Significance

The EPA-Residential Energy Efficiency and Pollution Program -- which will result in pilot testing of several hundred "Energy Star Homes" nationwide has been envisioned to be entirely voluntary and market driven. Its goal is to transform the way American consumers, builders, lenders, and public officials view housing construction, remodeling, finance, marketing, material supply and its critical relationship to the environment.

Our Nation's housing is a large reservoir of untapped potential for reducing damaging air-pollution now resulting from energy waste. Significant pollution reductions through leveraging energy efficiency in profitable and cost-beneficial ways will boost the economy across a very broad spectrum, from the individual consumer's pocketbook to the health and well being of society and its institutions.

By 2010 there will be approximately 110 to 115 million built dwellings in the U.S. Authorized by Federal statutes, EPA seeks to work directly with the shelter industry to significantly reduce housing energy-related air-pollution, particularly of the gases implicated in global climate change such as CO_2, Methane, NOx, and CFC's -- through an aggressive national participatory campaign.

The EPA "Energy Star Homes" program has targeted a 50 percent reduction in new home energy use compared to the 1992 CABO Model Energy Code, to be implemented in at least 10 percent of new housing by the year 2010. This would represent an approximate 75% improvement in overall energy efficiency of housing compared to the consumption levels prevalent prior to the 1973 oil-embargo.

In addition, the program aims to foster energy efficient rehabilitation through transforming housing finance methods, in a significant portion of the approximately 60 million existing energy-inefficient homes that do not qualify for low income weatherization programs. To reach these tough goals the program will conduct analysis of existing finance, engineering, design, technical, applications, demographic, and marketing information and attempt to "learn by doing."

The EPA strongly believes that by tapping into the innovation that characterizes today's energy efficient builder and remodeler, and propagating this knowledge and dedication throughout the building industry, broader applicability of designs, techniques, products and quality assurance will transfer effectively to production housing. Such results will more fully capture the air-pollution potential and improved sustainability of development through high-performance buildings, compared to the less efficient although improved housing being built today.

Intended Audience: Home builders, sub-contractors, lenders, weatherization specialists, energy engineers, code officials, remodelers, utility program managers, consumer groups, home energy raters and inspectors, and other shelter industry stakeholders are expected to attend this session.

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Program Description (January 1995)
EPA Energy Star Residential Buildings Program

Goal: Transform the residential market to higher energy efficiency and reduced air-pollution emissions associated with its energy use.

Overall Objectives: Create an enhanced market pull for environmentally high performance residential development and refurbishment of existing buildings.

Strategic Approach:

- Form market pull consortiums to promote use of super efficient design, material specification, and operating strategies in new and existing homes.
- Partner directly with home builders and remodeler across the Nation to voluntarily explore together, accelerated application of the most profitable and cost effective measures.
- Conduct the necessary financial, cost, applications, marketing, and performance analysis to verify the packages selected by builders and remodelers are profitable and buildable.
- Improve financing for housing consumers, persons remodeling homes, builders, and developers with an emphasis on uniformity, simplicity, availability and security.
- Provide marketing assistance to amplify partner's position in the local marketplace with the improved product.
- Treat the building as a system, using existing popular models and features as the base line for enhancement and pilot testing.
- Engage in modest redesign during the pilot phase, emphasizing increased functionality, thermal performance, and indoor environmental quality in partner's current model new homes.
- Pilot test the most profitable packages of new construction and retrofit related energy efficiency strategies to furnish real results for the marketplace.
- Evaluate the overall performance and cost effectiveness of pilot projects together with the program partners, and communicate the successes and lessons learned to the public.
- Create and sustain industry-wide collaboration and professional alliances with the broadest spectrum of building trades, energy service providers, consumer groups, financial interests, federal agencies, product manufacturers, the dynamic utility sector, and environmental groups.

FOX VALLEY WHOLE HOUSE RESEARCH PROJECT

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ABSTRACT

The intent of this paper is to review the results from a collaborative research project that assessed the effectiveness of a whole house approach to energy conservation. The objectives of the project were 1) determine how effective the whole-house system was in reducing natural gas consumption by residential customers; 2) determine what health and safety procedures must be used by contractors if the whole-house system is utilized; 3) evaluate contractor interest in adopting new techniques; 4) evaluate a pilot training effort for interested contractors; and, 5) evaluate the economic potential of the system from the customer's perspective.

INTRODUCTION

During the 93-94 heating season two Wisconsin utilities collaborated on a joint research project to determine the effectiveness of using a whole house system approach to residential energy conservation. The system involved the identification of hidden air passages and treatment work to seal them off when determined to be cost effective. A pre and post safety assessment was performed on all combustion appliances as part of the process. Differential pressure testing also was key in assessment of savings potential.

THE PROJECT

The experiment consisted of 48 treatment potential homes and 45 control homes. All structures involved in the project had previously participated in an energy conservation program. Only 16 treatment homes were found suitable based on the project assessment protocol. Savings on space heating in 11 of the 16 receiving treatment exceeded 20% on an annual basis. Treatment costs ranged from \$250 to \$2850. The cost associated with the assessment protocol was estimated at between \$100 to \$200 per house. Significant safety problems involving combustion appliances were discovered in 17 of the 93 homes participating in the project. Local contractor interest in the project was encouraging. Customer response to the treatment was extremely favorable with increased comfort often cited as one of the noticeable benefits.

BIOGRAPHICAL SKETCH FOR RANDY CHASE

Randy Chase, Residential Programs Coordinator for Wisconsin Natural Gas Company, has been involved with energy conservation programs since 1982. During his eight years with Wisconsin Natural, he has been responsible for low income weatherization, residential conservation, sales, training coordination, and technical support for customer service field personnel. Several programs he has worked on have received national awards.

notes

Retrofitting Interior Gas Piping and Energy Systems in Existing Buildings

Robert Torbin, Foster-Miller, Inc.

1. Introduction

There are many obstacles preventing the conversion of existing multifamily buildings from centralized space and water heating to individual apartment services. The conversion from electric and/or fuel oil to natural gas for individual apartments can be cost prohibitive. Although there are significant potential energy and cost savings in undertaking these types of conversions, institutional, financial and technical obstacles have prevented wide scale implementation. Two critical issues must be addressed in the conversion of centralized heating services to individualized apartment sized natural gas systems:

- Gas Distribution: Large diameter steel pipe to a central boiler must be replaced with smaller runs of pipe to each apartment unit.
- Appliances: Small capacity apartment sized units must be introduced which require floor space, distribution ducts/baseboards, and venting.

The dual integrated appliance (DIA) combines space and water heating in a single unit which saves floor space, operates at a high efficiency, and requires only a single vent. Flexible gas piping consisting of corrugated stainless steel tubing and mechanical joints operating at 2 psi can be retrofitted for significantly lower cost than rigid steel pipe. These technologies have one thing in common: they have been developed to reduce the cost of installation and improve the utilization of natural gas.

Multifamily units have been studied in various ways to identify factors that affect fuel savings and consumption. Certain studies have concentrated on centralized versus decentralized heating in an attempt to pass the responsibility and reward for energy savings directly to the tenant. These studies range from individual unit billing allocation schemes for central heating systems to the complete changeout of centralized heating systems to individual heating units and controls.

The individual unit billing allocation study charged each building unit relative to floor area and realized 6 percent savings. It is important to note that this billing structure may not effectively maintain an overall savings. This is because one tenant's efforts/savings will be divided among all the units. Tenants may notice that their efforts do not appreciably affect their energy bill, and therefore, reduce or abandon their conservation efforts causing usage to increase.

In metering studies, where master meters are replaced by individual meters, submeters, or individual consumption monitors, savings vary from 5 to 77 percent. The savings variations are partially a result of differences in the building structures, climates, heating system types, and type and use/non-use of weatherizing. Table 1 gives a summary of the energy savings achieved through decentralization of heating. The Palermini and Hewitt 1991 study contained two buildings where the central gas-fired boiler systems were converted to individual gas space heating units. In these instances, savings of 69 percent and 77 percent were obtained. These

Table 1. ***Summary of energy savings achieved by changing from centralized heating to decentralized heating with a shift in responsibility for energy use to the tenant***

Study	Building Type	Year	Type	Savings (%)
Palermini, D. and Hewitt, D.	Multifamily building	1991	Conversion from central oil to individual electric	28
			Conversion from central gas to individual gas	69 to 77
			Central gas with allocation added	6 to 29
Scott, W.L.	Multifamily buildings, 90 units or more each. Low-rise 4 stories or less and high-rise 10 stories or more	1991	Metering	19
Bohac, et al.	Multifamily building, single and two-story	1990	Decentralized heating, DHW	13 to 19
Byrene and Fay	Multifamily building, 3-story	1989	Computer modeling	20
McClelland, L.	Multifamily buildings	1983	Metering	14

savings were directly influenced by increased tenant control of interior unit temperatures, the use of weatherizing, and the replacement of old heating systems with more efficient systems.

Use of a DIA system, where space heating and domestic hot water systems are combined, is another way savings may be realized. A study by Bohac et al. 1990 on the effects of installing DIA systems in place of conventional systems showed savings on fuel use between 13 and 19 percent. In this study, the DIA systems (with minimum AFUE values of 76 percent) replaced furnaces with AFUE values of 60.2 percent. Further analysis of these systems is needed to compare the savings of DIA systems with conventional systems of the same AFUE. Based on the information available, significant savings can be achieved by shifting from centralized to decentralized systems. In all the cited studies, energy/cost savings were realized.

2. Gas Piping Technologies

2.1 Piping Systems

Currently, steel pipe (both threaded and welded) is the most commonly used material for gas piping systems in multifamily buildings. This is a time proven system that is considered by the gas industry as being both safe and reliable. In the last few years, some plumbing contractors have taken a closer look at the benefits of installing copper tubing gas piping systems as a replacement for steel pipe in residential and commercial buildings. Primarily, the benefits are economic and ease of installation.

In large multifamily buildings, the gas piping system usually consists of two distinct portions, vertical and horizontal piping. The portion of the gas piping system in a large building that distributes gas to each floor is referred to as the "vertical riser" or "vertical main." All gas codes require that the vertical riser be constructed from Schedule 40 steel pipe. If the building is to have decentralized gas metering, a few gas utilities have assumed responsibility for the design, installation and maintenance of the vertical riser. The National Fuel Gas Code (NFPA 54) 1992 allows threaded fittings to be used on steel pipe sizes up to and including 4 in. Larger pipe sizes must be joined as welded joints. Some of the other model codes and/or utility practices are more restrictive and require welded joints for pipe sizes larger than 2-1/2 in. Most vertical risers use pipe lager than 4 in. because the systems are typically designed for low pressure service (7 in. of water) and carry large capacities of gas to service the entire building.

2.2 Semirigid Tubing Systems

The use of semirigid tubing for natural gas distribution within residential and commercial buildings has been going on for many years. Until recently, the tubing used was exclusively copper. In 1988, corrugated stainless steel tubing (CSST) was introduced to the United States plumbing industry. Corrugated stainless steel tubing is an acceptable code listed material for natural gas piping systems in the National Fuel Gas Code, Standard Gas Code, Basic/National Mechanical Code and One- and Two-Family Dwelling Code.

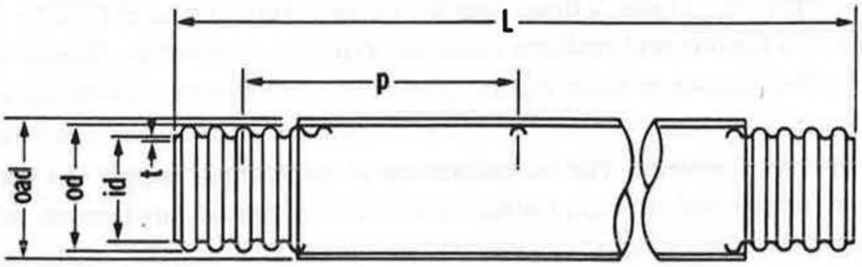
The design of corrugated stainless steel tubing used for gas piping is similar to flexible appliance connectors used by the gas industry for over 30 years. The CSST is manufactured from stainless steel and is fabricated with annular corrugations. The number of convolutions per inch and the amplitude of each convolution are both much smaller than that found on the typical appliance connector. (Table 2 describes the various dimensions of CSST.) Therefore, the CSST is much less flexible and resilient than an appliance connector. However, CSST is only intended to be flexed once or twice during installation. Unlike the appliance connector, CSST is used neither as a vibration damper, nor is it expected to be moved once installed.

CSST is sold only as a system. The manufacturer must not only supply the tubing, but also the associated mechanical fittings, multiport manifolds, special mechanical protection shields, and detailed installation instructions. In the United States, CSST systems must be certified by an independent testing organization and each component must be marked with specific information. The system is certified in accordance with the requirements of an ANSI Standard: ANSI/AGA LC-1 entitled "American National Standard for Fuel Gas Piping Systems Using Corrugated Stainless Steel Tubing." CSST is lightweight and is extremely easy to install. It has excellent corrosion resistance characteristics and is protected by an outer covering of plastic. It can be easily bundled for multiple tubing runs and can be manufactured in almost any length required. CSST uses simple mechanical fittings for joining, requiring only hand tools for assembly. CSST is currently available in four sizes: 3/8, 1/2, 3/4 and 1 in. (ID).

The use of corrugated tubing has several installation advantages over rigid steel pipe. In most installations there will be no intermediate joints between the manifold and appliance because the tubing is capable of being installed in one continuous run. This minimizes the number of potential leak sites and eliminates concealed joints. Because the tubing is bendable by hand, it can be installed more quickly and in areas that would be inaccessible to rigid pipe. This feature is especially critical in the retrofitting/remodeling of existing structures. The tubing installation requires only hand tools and, therefore, needs no heavy, electrically powered cutting/threading equipment and/or truck to carry and store piping and fitting inventories.

Table 2. Typical CSST dimensions

Effective Hydraulic Diameter	EHD	14	19	26	31
Nominal diameter	in. mm	3/8 (10)	1/2 (15)	3/4 (20)	1 (25)
Inside diameter (id)	in. mm	0.45 (11.5)	0.59 (15.0)	0.79 (20.0)	0.98 (25.0)
Outside diameter (od)	in. mm	0.56 (14.2)	0.72 (18.4)	0.98 (24.9)	1.21 (30.8)
Pitch/10 corrugations (p)	in. mm	1.34 (34)	1.50 (38)	1.97 (50)	2.36 (60)
Tube wall thickness (t)	in. mm	0.008 (0.20)	0.008 (0.20)	0.01 (0.25)	0.01 (0.25)
Coating thickness	in. mm	0.024 (0.6)	0.024 (0.6)	0.024 (0.6)	0.024 (0.6)
O.D. of coating (oad)	in. mm	0.61 (15.4)	0.77 (19.6)	1.03 (26.1)	1.26 (32.0)
Length (L)	ft m	250 (76.2)	250 (76.2)	180 (54.9)	180 (54.9)



cutting/threading equipment and/or truck to carry and store piping and fitting inventories.

Because the tubing comes in coils and is lightweight, a tubing reel can be used to expedite the running of the service and appliance lines. This technique makes it possible, in some cases, for one plumber to install the entire system. The installation is insensitive to the construction materials and structural elements. The tubing can be installed through holes drilled in the wooden floor joists, through open spaces in trusses, strapped to the sides of a floor joist, or beneath the joists. It can be run through steel studs as easily as through wooden wall studs. Since most gas piping is field run, the added flexibility of the corrugated tubing allows the installer to seek the path of least resistance around existing obstacles, either in new construction or in remodeled structures. This eliminates the repetitive measuring, cutting, threading and joint assembly common with steel pipe systems.

Mechanical fittings are used to connect the tubing with the system. Compared to steel cost. The fittings are lightweight and small enough to be easily carried around in the plumber's belt pouch. Fewer joints combined with easy, fool-proof assembly assures few, if any, problems during pressure testing of the system.

Extensive field assessments of current tubing/piping hardware and installation practices have been completed. The field tests included time and material studies in several different single family, multifamily and commercial buildings, including both new construction, retrofitting and rehabilitation. In all test buildings, both low pressure steel pipe and elevated pressure corrugated tubing systems were designed and installed. The data were analyzed for both installation labor (man-hours) and total cost (labor plus materials). The results, summarized in Table 3, have been calculated using a labor rate and material prices which have been found to reflect average costs in the United States (Torbin, Belkus, Campbell, Valentine 1989). Results from the research clearly indicate that semirigid tubing systems operated at elevated pressure are both safe and reliable, and can be installed for less cost than conventional low pressure steel piping systems.

2.3 Distribution Networks

Traditionally, when gas piping systems are installed in multifamily buildings, they are designed for low pressure service applications. This requires much larger pipe sizes than would be required if higher pressures were used to distribute natural gas within the building. As an example, if gas operating pressure was increased from 1/4 psi (~7 in. of water) to 2 psi, an increase of eightfold, the gas carrying capacity of the pipe would be increased 2.8 times. As a result of operating with increased pressure, there are large potential savings to be realized with reduced pipe sizes (both material and installation costs). Couple this with other potential savings using semirigid tubing, and the total cost savings could be substantial compared to installing low pressure all rigid steel pipe systems.

A typical advanced gas distribution network for a multifamily structure can be described as follows: Gas is supplied via a street main at a pressure up to 60 psi and reduced to a lower pressure of 5 psi by a service regulator at the building entrance (see Figure 1). Total gas supplied to the building would be monitored by a conventional gas meter, possibly equipped

Table 3. Results from piping field tests installation labor and cost comparison (CSST versus steel pipe)

Building Type	Percent Average Labor Savings Over Steel Pipe	Percent Average Total Installed Cost Savings Over Steel Pipe
Single family (all types): detached/attached wood frame/new construction	30 to 50	15 to 40
Multifamily low-rise: wood frame/new construction	10 to 70	10 to 40
Multifamily high-rise: concrete and steel frame/new construction	40 to 65	30 to 40
Multifamily rehabilitation:	70 to 80	50 to 60
Light commercial buildings: (all types)	40 to 80	30 to 60

with an automatic meter reading device. This portion of the piping system is called the gas entrance header. From that point, the gas would be distributed via a steel pipe vertical riser(s) to various upper level floors (including the roof) and/or a horizontal header to common or retail use areas on the first floor level within the building. The size of these pipes would be in the range of 2 to 4 in. The vertical piping would require chaseways and engineered floor penetrations and support devices. The horizontal piping would also require engineered supports and wall penetrations.

On each floor, gas would be distributed via a subnetwork, including another service regulator to reduce the pressure from 5 to 2 psi, compact gas meters, and semirigid distribution piping to each apartment unit. This portion of the piping system is called the gas service header. The compact gas meters, required valves, and hardware to connect the components could be installed in pre-assembled modular cubicles. Finally, the gas would be

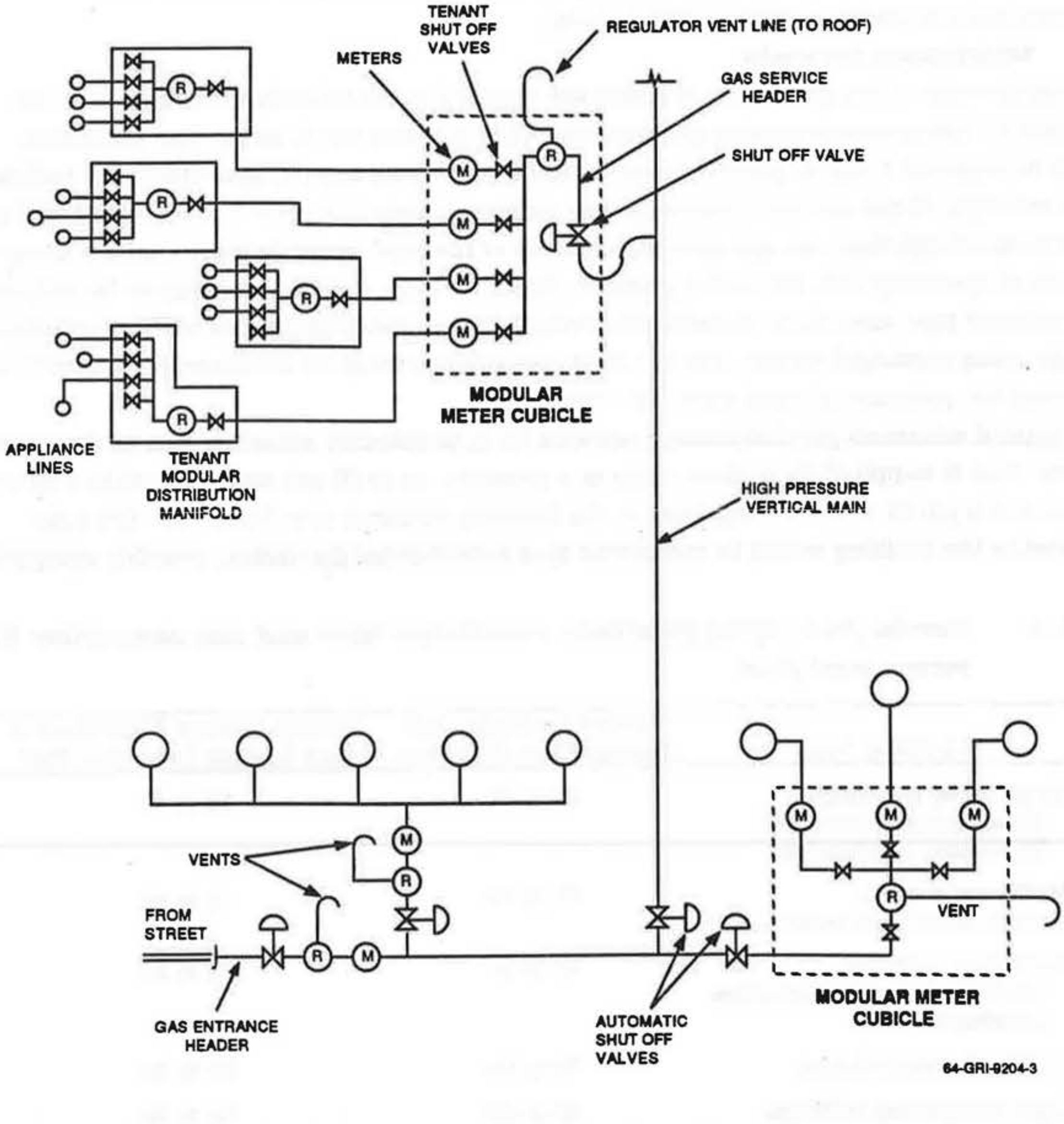
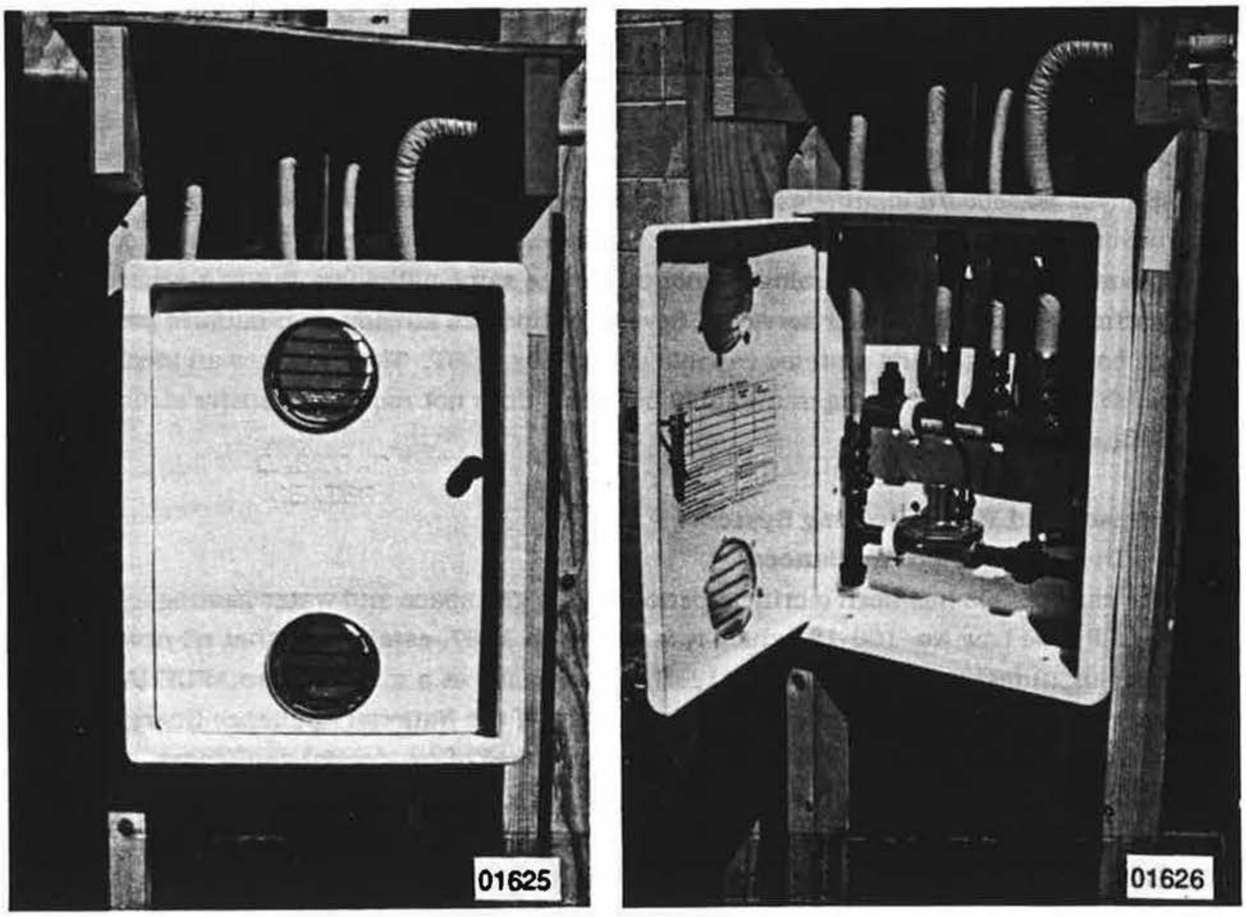


Figure 1. Gas distribution network - typical residential-commercial building

components could be installed in pre-assembled modular cubicles. Finally, the gas would be distributed within each tenant unit via the modular distribution manifold or Gas Load Center (GLC). This is essentially a second subnetwork which includes a line regulator to reduce the pressure from 2 to 1/4 psi, and a multiport manifold for delivery of the gas to each appliance or gas outlet. This approach will streamline the design and installation of the piping system by making it highly compact and efficient from a fluid dynamic standpoint, and a repetitive, common installation for each apartment.

The GLC is a fabricated plastic or steel box, designed to be installed either between two standard wall studs or on a wall surface (see Figure 2). When fully installed, the box includes a service shut-off valve, drip leg, a Maxitrol regulator (for 2 psi systems), a piping union (to facilitate regulator replacement), inspector test port, and a multi-port steel manifold with mounting bracket. The entire manifold assembly can be removed from the enclosure to



a) Door closed b) Door open showing 4 port manifold

Figure 2. Typical gas load center

permits greater access during the tubing installation. The panel includes a hinged door which can be specified for either left or right-hand opening. The enclosure is also provided with knock-outs for five tubing runs, and can be oriented for tubing runs from above or below.

Although the manifold is designed with a standard four port configuration, it can also be customized in terms of the number and size of the ports. An optional two tier horizontal configuration is also available. All manifold components can be pre-assembled at the plumbing contractor's shop prior to field installation. Once assembled, the entire Gas Load Center can be pre-inspected and pre-tested for leakage. After the enclosure is installed between the studs, the field operation is reduced to installing the meter and appliance tubing runs, and completing the joint assembly. As an option, appliance shut-off valves can be installed at each manifold port to facilitate the servicing of the piping system, and to provide the consumer with some enhanced safety features. Each port can be numbered and recorded on a log sheet attached to the door, so that each appliance connection can be easily identified. Safety information and important telephone numbers can also be listed on a notice located on the door panel.

Chaseways are an integral part of the design of some multifamily buildings for running services between floors and along horizontal sections on each floor. These pathways are designed into some multifamily buildings for electric and water supply/drainage/fire suppression, but not necessarily for gas. It is important to minimize the size of gas piping to more easily accommodate already tight space requirements allowed for services requiring chaseways. Baseboard channels located within rooms and offices are becoming more popular for running services such as electric power, communications, and data transmission. There is no reason why semirigid gas tubing cannot utilize the same pathways, but in a separate compartment from these other services. Several companies already manufacture prefabricated plastic baseboard molding systems capable of carrying CSST. This becomes an ideal solution when rehabilitation of existing multifamily buildings does not require extensive structural or cosmetic changes.

3. Space and Water Heating Systems

3.1 Dual Integrated Appliances

The early 1990s has been a critical period for the gas space and water heating appliance market. Public Law No. 100-12, which was passed in 1987, established that all new gas furnaces manufactured after January 1, 1992 must have as a minimum an AFUE (Actual Fuel Utilization Efficiency) of 78 percent. The law is part of the National Appliance Energy Conservation Act of 1987 (NAECA) and affects 14 classes of residential appliances, of which seven classes include gas appliances. The act requires that the Department of Energy set, review and raise minimum efficiency standards over the next 15 or 20 years. Any changes in minimum efficiency standards must be "technologically feasible" and "economically justified." The law applies to appliance installations in all states, with few exceptions.

One class of gas furnaces has been devastated by the new standard. Conventional atmospherically vented furnaces cannot meet the new standard. The problem is the NAECA defines the AFUE for these appliances based on the assumption that the furnaces are installed indoors and all combustion air is supplied from the outside via ducts or grills. Any efficiency increases as a result of vent dampers are not included in the AFUE calculation. In 1991, these units accounted for approximately 65 percent of the market. The two remaining types of furnaces on the market are fan-assisted combustion systems with AFUEs of 78 to 83 percent and full condensing units with AFUEs of 90 to 95 percent. Both of these alternatives are significantly more expensive to purchase and install than the conventionally atmospherically vented furnaces. Only one manufacturer has been able to market a furnace with a 78 percent AFUE that can be conventionally vented.

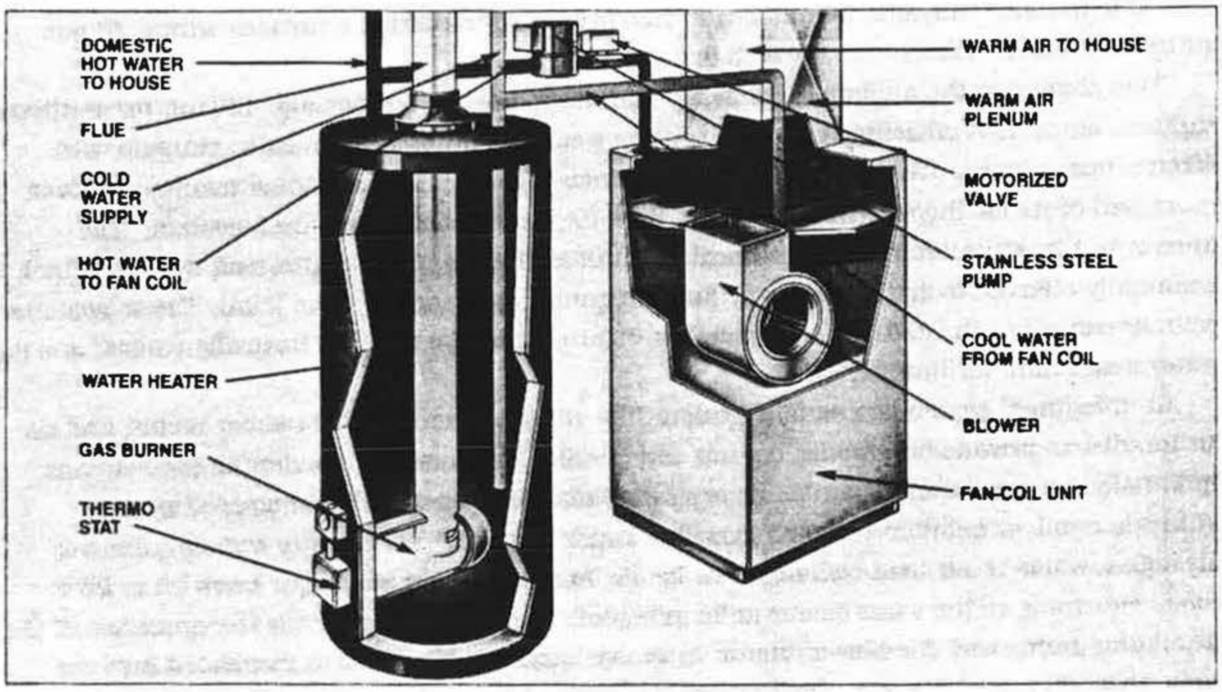
This change in the appliance efficiency standards has been especially difficult for southern utilities, since high-efficiency gas-fired heating systems cannot economically compete with electric heat pumps. The changes in the appliance efficiency standard has resulted in lower increased costs for the electric heat pump than for the equivalent gas-fired system. The answer to this situation for the southern gas utilities has been the hydro-heat system, which is commonly referred to as the combo or dual integrated appliance system (DIA). These systems were developed in the 1970s. As depicted in Figure 3, combo systems basically consist of a gas water heater and air handler.

An integrated system is a simple system that utilizes a domestic hot water heater and an air handler to provide both space heating and potable hot water for residential applications. Optionally, air conditioning can be incorporated into the system. The integrated system utilizes a small circulation pump to draw hot water from the water heater and circulates it through a water-to-air heat exchanger in the air handler. There the water loses 10 to 20°F before returning to the water heater to be reheated. A thermostat controls the operation of the circulating pump and the blower/motor in the air handler. Warm air is circulated into the home through a duct system. Cooling can be provided through the use of a split system with an evaporator coil in the air handler and a remote condensing unit (optional items).

A typical integrated system includes:

- Water Heater - A high efficiency water heater is used to satisfy both heating and space heating requirements.
- Air Handler - The air handler may be one of several configurations including a vertical unit for closet installation; a horizontal unit for ceiling installation; a wall unit for "between-the-studs" installation; or a duct coil for retrofit applications.
- Pump System - A small pump circulates hot water from the water heater to the hot water coil in the air handler. The pump may be integrally mounted in the air handler or may be mounted in the piping.
- Controls - The control system is relatively simple and includes typical controls such as a cooling/heating thermostat, pump and fan relays, 115/24V transformer.
- Water Piping - Water piping between the water heater and the air handler is field supplied. Water lines are typically 3/4 in. nominal copper or approved plastic pipe. The lines should be insulated. In addition, check valves and service valves may be required, though application varies by manufacturer.
- Condensing Units - Split system condensing units are matched to the evaporator coil in the air handler. The outdoor condensing units may be manufactured by someone other than the OEM.

Dual integrated systems are efficient, competitively priced, space saving, easy to install and maintain, and extend the life of the water heater by increasing water circulation, which reduces



How do Gas Combo-Heaters work?

The water heater operates like any conventional water heater. When space heat is needed, the sequence of operation is as follows:

1. The wall thermostat energizes a small pump which circulates hot water from the water heater through a coil in the air handler.
2. The fan in the handler comes on and blows air over the coil where it absorbs the heat.
3. This warm air is then circulated through the ducts and into the home.

Reference Source: American Gas Association

Figure 3. Combination space and water heating system

sediment buildup and corrosion. Within the United States, approximately 375,000 units have been installed in starter homes and multifamily buildings. If water heaters are properly sized, DIAs can work perfectly well in northern multifamily buildings. However three states, including New York, restrict or do not allow installation of combo units. The problem appears to be in the classification of the unit. Some state code officials have classified the water heater used in the combo unit as a boiler, thus requiring the water heater to comply with all applicable boiler codes and standards. Since boilers are pressurized, they are designed to more rigorous standards than water heaters. None of the water heaters sold currently meet the boiler standards.

Since combination space and water heating appliances are an integrated system comprised of components from several different manufacturers, a means to determine overall system efficiency was needed. To address this need, an ASHRAE Standard, ANSI/ASHRAE 124P entitled: "Method of Testing for Rating Combination Space Heating/Water Heating Appliances" was developed. The standard covers electric, gas-fired and oil-fired combination space and water heating appliances up to a rated input of 300,000 Btu/hr.

3.2 Appliance Venting

Venting systems have not changed significantly since the 1950s. What has changed, which has had a dramatic affect on venting methods, is appliance design. The products of combustion for the new classes of appliances, mid-efficiency with AFUE of 78 to 83 percent and high-efficiency with AFUE greater than 90 percent, have required that a new set of standards be developed for safe venting. To complicate matters further, many of these new appliances have fan-assisted combustion systems.

Conventional venting systems include a draft hood or diverter and an atmospheric burner. The buoyant force of the hot gas is enough to drive it from the combustion chamber, up the vent pipe and out to the atmosphere. The draft hood, among other things, allows additional indoor air to mix with the combustion products. This is called dilution. Diluted air lowers the dew point of the mixture by reducing the humidity, which also helps reduce condensation. There is a price to pay for adding indoor heated air to the combustion products. The overall efficiency of the appliance is lowered because some of the indoor air heated by the appliance goes out the vent.

To reduce off-cycle appliance losses, fan-assisted combustion systems were developed. Fan-assisted systems reduce dilution air in the vent. Unfortunately, this causes the humidity and gas dew point to rise. Also, there is less flow in the vent. With a higher dew point temperature and less gas to warm the sidewalls of the vent, the potential for condensation increases. This is true for mid-efficiency and high-efficiency appliances, which are also referred to as near-condensing and full-condensing units, respectively. Therefore, the development of a variety of more efficient appliances increased the need for different venting requirements.

On a combination pace and water heating system, there is only one vent pipe to size and install, which is an economic advantage over the separate appliance system. Multistory vents are necessary for multifamily buildings where appliances on each floor are connected via a common vertical pipe system. For rehabilitated multifamily buildings, the question is whether fan-assisted appliances can be retrofitted to replace draft-hood equipped appliances originally installed with larger vent systems. For example, the original vent system may have been sized for a 60,000 Btu/hr furnace. The replacement unit is apt to be a 40,000 to 45,000 Btu/hr mid-efficiency furnace. The smaller unit has less products of combustion. Thus, the vent system will experience a lower flow rate than with the original larger furnace. However, current research results indicate that retrofitting fan-assisted appliances into a multistory vent does not add to the risk for vent system failure.

Combination space and water heating systems require a Category 1 vent because the water heater portion of the system produces combustion products. The water heaters have efficiencies ranging from 76 to 83 percent, operate in the non-condensing range and vent under negative pressure. Therefore, no special materials or installation practices are required for the vent systems of combination space and water heating systems.

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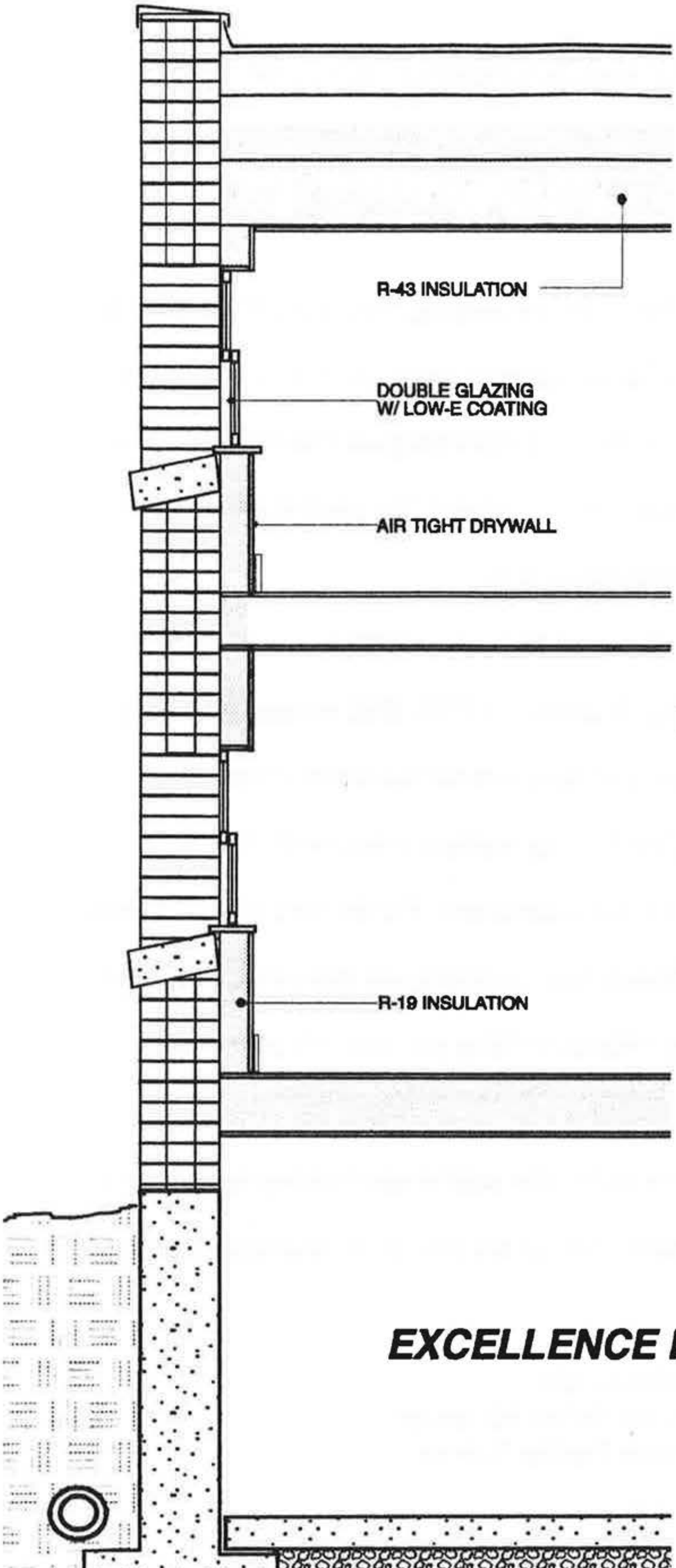
notes



SUPERINSULATION REHAB OF MULTI-FAMILY BUILDINGS

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EXCELLENCE IN HOUSING CONFERENCE

MINNEAPOLIS, MN
March 8-11, 1995

ENERGY EFFICIENT AFFORDABLE HOUSING PROGRAM

MULTI-FAMILY BUILDING SUPER INSULATION REHABILITATION

I. BACKGROUND

The US Department of Housing and Urban Development defines affordable housing as a place to live that costs no more than 30% of an occupant's income, *including energy costs.* Typically, affordable rents or mortgages are achieved by minimizing construction costs. Yet, in an effort to meet this goal, energy efficiency is often excluded. The result is housing with affordable rents or mortgages, but unaffordable energy costs.

The Illinois Department of Energy and Natural Resources (ENR) has taken the lead in promoting energy efficient affordable housing. Beginning in 1988, ENR initiated the Energy Efficient Affordable Housing Program. ENR is working with Illinois non-profit affordable housing developers to integrate energy efficient building practices in both multi-family building rehabilitation and new single family home construction. The objective of the Program is to demonstrate the impact that energy efficiency has on creating and maintaining affordable housing. This paper will focus on the energy efficient building practices utilized for multi-family building rehabilitation.

The energy efficient building practices included in multi-family building rehabilitation are collectively referred to as "Super Insulation" (SI). SI is a package of measures consisting of three components;

1. High Insulation Levels
2. An Emphasis on Indoor Air Sealing
3. High Efficiency Heating Systems

ENR provides grants of up to $2,000/unit to cover the incremental costs of SI upgrades in multi-family building rehabilitation. By comparison, rehab costs in these buildings range from $50,000/unit to $80,000/unit. Energy savings range from 24% to 88% with an average savings of 70% when compared to rehab without SI measures. Monthly energy costs range from $10/unit to $42/unit in the SI rehabbed buildings.

Information about energy efficient building practices utilized in multi-family building rehabilitation are presented. Energy consumption analyzes are also given.

II. MULTI-FAMILY BUILDING REHABILITATION

The SI Multi-Family Program was initiated in 1988. Efforts were made to identify other groups from around the country who were doing similar energy efficient multi-family rehab work. No groups could be found thus SI practices originally developed for new single family home construction were modified for masonry buildings undergoing rehab.

A total of 20 buildings (192 units) have been rehabbed to date with SI building techniques. The energy efficient building practices described next are those that are typically used in SI rehab. However, methods to improve upon these practices are constantly being sought. For example, wet-spray cellulose insulation is being considered instead of batt insulation for open cavity insulation. A continuous ventilation system was used rather than individual bathroom and kitchen exhaust fans that are used as needed. Dense-pack cellulose was used where the interior finish was not removed as part of the rehab work. These variations and future plans are also explained. The practices are described in terms of **Insulation, Air Sealing** and **Mechanical/Ventilation.**

A. Insulation

Wall Insulation - Typical

Most buildings requiring substantial rehabilitation ("gut" rehab) have been abandoned for a number of years. The roof is in poor condition and all the windows are missing or beyond repair and require replacement. Electrical, plumbing and heating systems require replacement. The walls are beyond simple patching and painting.

Consequently, all plaster and lath has sustained major damage. New interior wall finishes are necessary. Original rehab plans call for removal of all plaster and lath with new furring and drywall installed over the exposed masonry. In some cases, the framing and drywall is installed over the plaster and lath given high demolition costs to remove the existing plaster and lath. Wall insulation is generally not planned.

Wall Insulation - SI

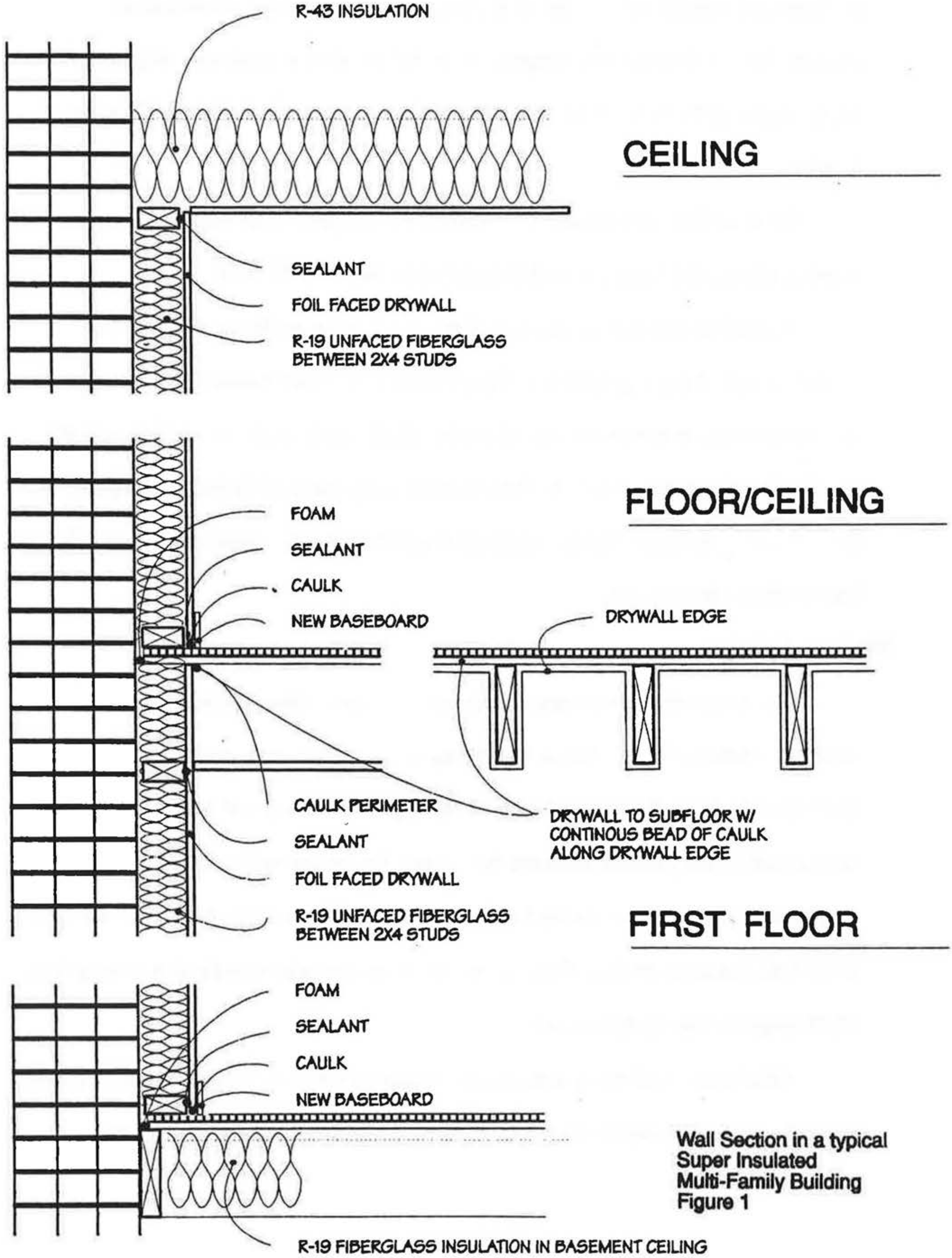
The framing system generally planned for rehab may be 3/4" metal channels or 2" x 4" framing (wood or metal studs) spaced 18" or 24" oc. SI work requires a 2"x 4" framing system.

Framing is installed on average about 1" away from the masonry wall (existing plaster/lath). This is done to move the new wall away from all irregularities that are on the surface of the masonry wall. The bottom and top plates are attached to the subfloor and ceiling joists, respectively. This is a typical framing practice where 2"x 4" framing is used in a masonry rehab project (Figure 1).

R-19 (6") insulation is used rather than 3-1/2" insulation (either R-11, 13 or 15) to completely fill the cavity. A standard 3-1/2" batt leaves a 1" air space between the

CEILING/FLOOR DETAILS

(JOIST PERPENDICULAR TO WALL) **SECTION A-A**



Wall Section in a typical Super Insulated Multi-Family Building Figure 1

insulation and exterior wall which would allow the establishment of convective air currents. Though there is some compression of the batt, therefore not achieving the full R-19, it is believed the trade-off of completely sealing the cavity outweighs the slight loss of R-value.

Unfaced fiberglass insulation is installed. Polyethylene is not used as the vapor retarder. Rather, foil backed drywall is included as part of the SI rehab.

A problem with batt insulation in SI rehab is that the insulation is not always continuous behind framing members. Thus, there is an air space between the framing and the masonry wall. A convective current can be established in this space which lowers the effective R-value of the insulation. There is some compression of the batt as it is pushed in the wall and it was hoped that the insulation would find its way behind the framing. This has not always been the case.

Wet-Spray Cellulose

Wet-spray cellulose is being considered in lieu of unfaced batts in a number of buildings scheduled for SI rehab in the coming months. There are a number of advantages to this system. First, the space between the framing and masonry wall is filled. All spaces around conduit and junction boxes are also sealed. The insulation is installed at a higher density which acts as an air barrier but with a slightly lower R-value (R-value of cellulose drops with increased density). Cellulose is also environmentally friendly as it is made from 100% recycled material (newsprint).

Disadvantages of the system include the slight decrease in R-value of the insulation. Secondly, if installed during hot humid weather, 3 to 5 days will be needed for the insulation to dry. It is also more expensive than fiberglass batts at approximately $.65/ft^2. Air sealing measures currently required under the SI Program will be examined to determine if they are still necessary given the air sealing properties of wet-spray cellulose. Wet-spray cellulose is being considered for most buildings to receive SI rehab in the future with an open framing system.

Dense Pack Cellulose

One rehab (533 Fisher) was completed this past year where the plaster and lath was not removed because it was in good condition. This two-story, eight unit building is balloon frame construction with brick veneer. It was decided that dense pack cellulose would be used to insulate the exterior walls.

Dense pack cellulose is blown in dry at a density between 3.5 lbs/ft^3 and 4.0 lbs/ft^3 (at this density, it is very difficult to push one's finger into the insulation). Typical cellulose installation is between 2.5 lbs/ft^3 and 3.0 lbs/ft^3. Like wet-spray, increased density provides for increased air sealing but with a slightly lower R-value. 2" holes were drilled through the interior finish in each stud cavity (holes could not be drilled from the exterior because of the brick veneer). The drilled cores were retained and used to patch the walls. Pulley wells were also packed with cellulose as part of the application as the existing windows were replaced and the pulley wells were no longer needed.

Rim Insulation - Typical

The "rim" is defined as the exterior wall surface in the ceiling/floor cavity. If exterior wall insulation is planned, insulation is usually installed in the rim, although not necessarily. If built without rim insulation, heat simply bypasses the wall insulation.

Air leakage can also occur through the rim. The ceiling/floor cavity serves as a convenient path for air movement into the building via the ceiling, floor and interior walls. An effective air barrier in the rim can be created if sealed to the framing system properly. This is discussed in greater detail under "Air Sealing."

Rim Insulation - SI

R-19 unfaced fiberglass insulation is installed in the rim as part of the SI package. The insulation is cut to fit snugly between the ceiling joists and is installed concurrent with the wall insulation. Wet-spray cellulose will be installed in the rim where this insulation technique is used.

Cellulose was used to insulate the rim where dense pack was used (533 Fisher St.). This cavity was easily accessible as the wall construction was balloon frame and the rim was insulated while the walls were being insulated. Holes would have to have been drilled in the ceiling cavity between joists next to exterior wall had the building been platform construction.

Interior Masonry Bearing Wall ("fin" wall) - Typical

The objective of sidewall insulation is to provide a continuous thermal break between the interior and exterior. The key word is "continuous." Insulation can be placed behind corner studs of interior partition walls, thereby maintaining the continuity of the insulation and providing a thermal break between the interior and exterior. However, it is impossible to make this same break between an interior masonry wall and the exterior wall. These interior structural masonry walls, which are common in masonry multi-family buildings, act as "fins" by wicking heat to the outside. Addressing this problem is excluded multi-family building rehab projects.

Interior Masonry Bearing Wall ("fin" wall) - SI

Typically, the plaster/lath on fin walls is removed in a substantial rehab. The furring strips often remain on the wall and serve as a nailer for new drywall. The first 4' to 6' on the heated sides of the fin wall are insulated with 3/4" polyisocyanurate insulation following removal of the plaster and lath. The 3/4" insulation was selected for two reasons. First, it fits neatly between the existing furring strips - the fin wall does not have to be framed as the exterior walls. Secondly, it has the highest R-value per inch than other rigid insulation systems at 7.2 (Figure 2).

PLAN

TYPICAL EXTERIOR WALL WITH EXISTING BEARING WALL (FIN WALL)

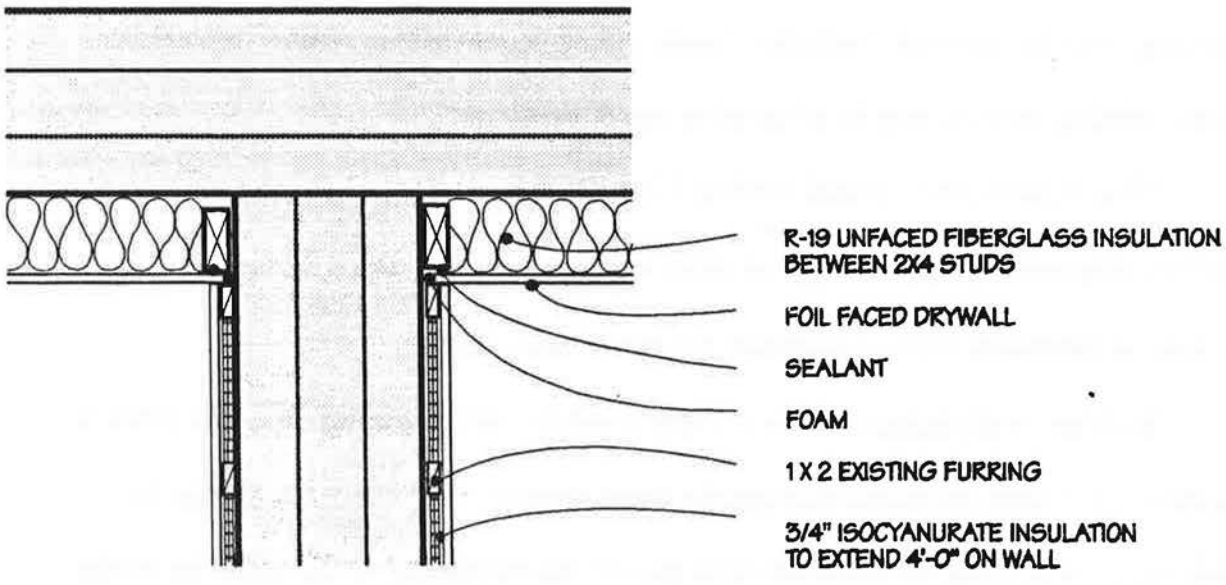


Figure 2

Attic Insulation - Typical

Older masonry multi-family buildings are often said to have a flat roof which is not entirely accurate. The roofs usually pitch front to back creating a roof crawl space of about 4' at the high end. The roof rafters are often located next to and slightly higher than the ceiling joists at the low end leaving no crawl space at all. Typical multi-family building rehab includes either R-19 or R-30 ceiling insulation where there is adequate roof crawl space. Either blown cellulose or fiberglass insulation or fiberglass batt insulation is used.

Attic Insulation - SI

Attic insulation is upgraded to R-43 under the SI Program. Where R-43 cannot be obtained given the roof /ceiling framing, the highest R-value possible with the insulation is achieved.

Windows - Typical

Windows are in such disrepair in buildings undergoing a substantial rehab that in all cases they must be replaced. Typically, double glazing is provided in window replacement. Double glazing, though, may be achieved in one of two ways.

First, a prime single glazed window is installed along with a single glazed storm window. Alternatively, a double glazed prime window (without a storm) is installed. Both are used in substantial rehab even though the second has a distinct advantage.

Both layers of glazing must be in place to achieve double glazing. If a prime/storm combination is used, the tenant must put the storm window down during the winter. In other words, it is being left to the tenant to provide double glazing. If the tenant leaves the storm up during the winter, single glazing is achieved even though the developer had "planned" for double glazing. Double glazing is achieved whenever the sash of a double glazed prime window is down - achieving double glazing is not left to the discretion of the tenant.

Little attempt is made to seal the space between the window and rough opening. In addition, pulley wells are not insulated nor are wood mullions between windows.

Windows - SI

Double glazed windows with a low-E coating are required in the SI Program. The addition of the low-E coating provides the same R-value that a triple glazed window provides at less the cost and weight of a triple glazed window.

Air sealing the windows within the wall is also emphasized. Pulley wells are packed with insulation. Spaces between the window and rough opening are stuffed with insulation and/or foamed. Wood mullions between windows are also insulated.

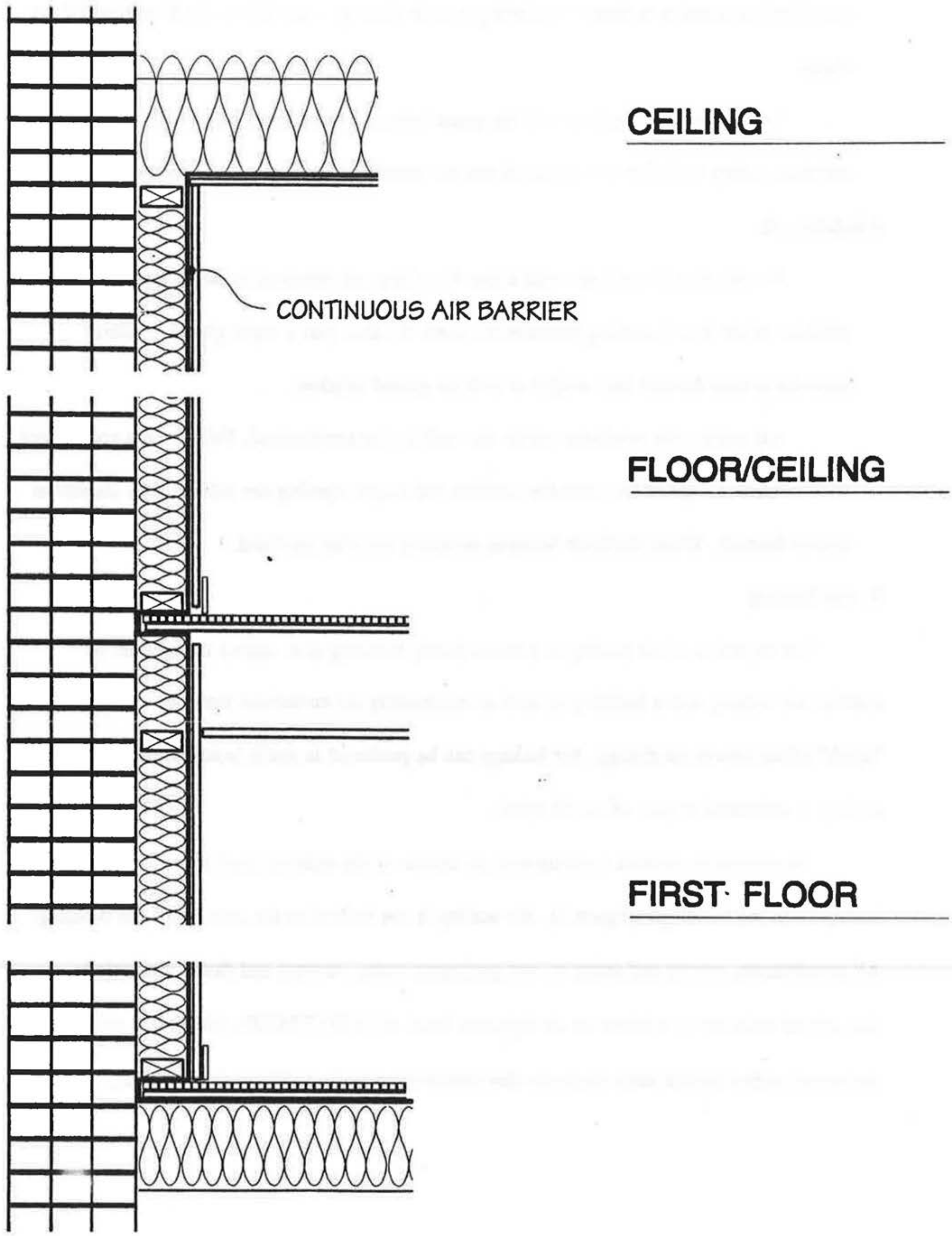
B. Air Sealing

The objective of air sealing in a multi-family building is to reduce the amount of exterior air leaking into a building as well as minimizing air movement between units by the "stack" effect (warm air rising). Air leakage can be profound in multi-level buildings and air sealing is addressed as part of the SI rehab.

An attempt to provide a continuous air barrier at the exterior shell is made to reduce air leakage into the buildings (Figure 3). Air sealing is not limited to the exterior of the building. All penetrations, cracks and joints in unit perimeter walls, ceilings and floors are sealed. Completed units are to achieve an air tightness level of 1100 CFM50Pa (about 0.5 ACHNa) as measured with a blower door to assure that indoor air quality problems do not occur.

CEILING/FLOOR DETAILS-AIR BARRIER

SECTION B-B



A conscious effort to include air sealing in a typical substantial rehab in Chicago is rarely, if ever, made. Air sealing is limited to caulking the exterior frames of windows and doors. No attempt to provide a continuous air barrier in the building shell or reduce air movement by the stack effect is made. However, including air sealing can be done at a relatively low cost utilizing inexpensive materials. Some of these same materials are often used in a typical rehab. Simply changing the manner in which they are installed, coupled with an understanding of air movement principles, can reduce air leakage.

Air Sealing the Building Shell

The Airtight Drywall Approach (ADA) is used. Drywall, coupled with sealing key joints in the wall, is used as the air barrier. The first step to air sealing the building shell is, ironically, sealing penetrations in the wall that contribute to stack effect.

Air movement by the stack effect occurs at the exterior wall and is a result of the manner in which these buildings were constructed. After the floor joists were attached to the exterior wall, furring strips were attached to masonry. The furring strips extend down past the floor joists. A subfloor was then laid across the top of the joists. However, the subfloor could not be installed up to the masonry because of the presence of the furring strips. A 3/4" gap (the width of the furring strips) exists between edge of the subfloor and the masonry wall. "Sleepers" were installed across the subfloor followed by the finished floor, usually tongue-in-groove hardwood. The 3/4" gap is maintained across this assembly due to the furring strips.

This construction is typical at each floor level and the third floor ceiling. Consequently, a continuous channel from basement to the roof crawl space is present along the masonry walls, both exterior and interior masonry walls. This cavity serves as a convenient escape path for heat moving through the wall as warm air rises.

This gap is visible when the baseboard is removed. It is especially pronounced when the plaster and lath are removed. This gap referred to as the "masonry/subfloor joint" can be sealed with expanding foam. Wide joints may be first stuffed with scraps of fiberglass or drywall and then foamed.

Sealing the joint at the first, second and third floor is necessary to cut-off the stack effect. The joint is to be sealed prior to the installation of the exterior wall framing.

Sealing this joint serves three functions. First, it eliminates the stack effect along the masonry wall. Second, it helps reduce air movement into the "sleeper" area of the subfloor where it can exit into building units from penetrations in the ceilings, floors and interior walls. Finally, it makes the airtight drywall continuous along the exterior wall from floor to floor.

Drywall is used as the major component of the exterior air barrier. An acoustical sealant is used to seal the drywall to the framing members. A continuous bead of sealant is applied to the framing members at the wall perimeter along the top and bottom plates, corner studs, and rough opening framing members. The sealant prevents air from moving into the living space from behind the drywall, for example, air moving into an interior partition wall.

In a typical rehab, drywall is installed from the subfloor to the bottom of the ceiling joists. No drywall is placed in the rim area. If the drywall is used as the air barrier, it must be continuous in the rim area. In buildings receiving SI rehab, the drywall is installed from subfloor to subfloor.

The drywall is notched to fit around ceiling joists where the joists are perpendicular to the masonry wall. The drywall is simply installed up to the subfloor where the ceiling joists are parallel to the wall.

The joint between the drywall and ceiling joists/subfloor is sealed with caulk or foam. This joint will not be seen when the ceiling drywall is installed. The bottom joint between drywall and subfloor is also sealed with caulk. This joint will be covered when baseboard is installed. The drywall is now continuous from floor to floor as can be seen in Figure 1.

There is one final advantage to this drywall system. Recall that foil back drywall is being used with the foil serving as the vapor retarder. The vapor retarder is also continuous in the rim area. A poly vapor retarder is rarely, if ever, installed in the rim area and kraft faced batts to not provide vapor seal at the framing members.

Reducing Stack Effect

A common air movement mechanism in multi-story buildings is caused by the "stack" effect; that is, warm air rises. It is quite common to have air infiltrating at the lower levels and air exfiltrating at the upper levels. Air moves up through the building through penetrations in the floor/ceiling cavities. Another objective of air sealing in SI rehab is to seal, or cut-off, these penetrations.

In essence, any penetration through the floors, ceilings and perimeter walls of a unit are sealed. Existing penetrations are exposed as part of the substantial rehab. Penetrations created as part of the rehab can also be easily sealed.

The most pronounced existing penetration found in these buildings are the plumbing stacks. These chases are open from basement to the roof cavity. The cavities are sealed at each floor level in a number of ways. If the opening around a pipe is fairly small, foam or caulk is used. Larger openings require backing with scraps of insulation or drywall followed by sealing with foam.

New penetrations that result from rehab include conduit penetrations through wall plates, panel boxes, fans and junction boxes. In all cases, caulk is usually sufficient to seal these penetrations. Caulk is also sufficient to seal the joint between drywall and panel boxes, exhaust fans and junctions boxes for lights, switches and outlets.

Air Sealing Standard

A common reaction to a discussion of the air sealing work in buildings receiving SI rehab is that they will be "too tight." This has not been the case. First, it is improbable that all holes, joints and other "nooks and crannies" found in these buildings will be sealed.

The goal of the SI Program was never to make the units as air tight as possible. Doing so would require the use of a continuous mechanical ventilation system. The cost of installing such a system has been beyond the $2,000/unit incremental cost allowed under Program guidelines needed to upgrade to SI. However, a continuous ventilation system was used in the 533 Fisher St. building. Exhaust fans are used in bathrooms and kitchens in all other buildings that received SI rehab.

An air leakage standard was set that would not require a more advanced mechanical ventilation system. That standard is 1100 CFM@50Pa, or approximately 0.5 Air Changes per Hour (ACH) natural. At this level, it is felt that sufficient ventilation air is available to prevent indoor air quality problems.

C. Mechanical/Ventilation

Buildings undergoing substantial rehab require a new heating system. Either a new central heating system is installed or forced air furnaces are installed in each living unit. The tenants usually pay the heating bills in the latter case. However, in the two Woodlawn buildings, a master meter was used with individual furnaces and the owner pays the bills.

The SI Program does not require one heating system over another. Energy consumption can be significantly reduced with either system type in the SI rehab. However, measured consumption in SI buildings has shown individual heating to generally use less energy than a central system.

The Fisher and Ellis buildings utilize a modular hot water central heating system. The Weil-McLean GV boilers (AFUE 87%) were used in both buildings. Two boilers with a rated input of 140,000 Btus (total 280,000 Btus) were installed in the Fisher building. Four boilers with a rated input of 175,000 Btus (total 700,000) were installed in the Ellis building. An outdoor reset with cutoff control was installed on each system. Weil-McLean 78% boilers were used in the Ingleside, Central Park and Van Buren buildings.

Forced air furnaces were installed in the Sunnyside, Kenmore and both Woodlawn buildings. The furnaces are direct vent sealed combustion with an AFUE of 90%. These furnaces have rated inputs of 40,000 Btus. A central domestic hot water system is used in each of these buildings.

A combination heating system was installed in each unit in the Fairfield, Washtenaw, and JP buildings. A combination heating system is simply a water heater with a fan coil that meets both space heating and domestic hot water needs. When space heating is required, water is pumped from the water heater to the fan coil. A blower then passes air over the coil where heat is exchanged. The warmed air is distributed through a standard duct system.

The Mor-Flo (now called SABH) Polaris 100,000 Btu units was used for the combination system. Though the Polaris is rated at 100,000 Btus, 40,000 Btu fan coils were installed with the units. The Polaris has an AFUE rating 90%. The appliances is direct vent sealed combustion.

Chicago building code does not require exhaust fans in bathrooms and kitchens with windows. However, exhaust fans are required in all bathrooms and kitchens receiving SI rehab to assure adequate indoor air quality. The purpose of the exhaust fans, which must be vented directly to the outdoors, is to remove moisture and pollutants from the units. The bathroom exhaust fans are rated at 75 CFM while the kitchen exhaust fans have a minimum rating of 150.

All buildings but one completed this past year have bathroom and kitchen exhaust fans that are used when needed by the occupant. The Fisher building has a continous exhaust only system manufactured by Aldes American, Two fans are used to exhaust air from the eight units. Grilles are provided in each bathroom and kitchen that exhaust 25 cfm continuously. Make-up air is provided through trickle ventilators installed on the window sash in windows in the bedrooms and living rooms.

III. ENERGY CONSUMPTION

Energy consumption was analyzed in twelve SI buildings. For comparison, energy consumption was also analyzed in eight multi-family buildings that received a "typical" rehab. In a "typical" rehab, energy efficiency improvements are generally limited to attic insulation, replacement windows and boiler replacement or repair. Energy consumption results are shown in Table 1 for the SI buildings. Energy consumption in the eight "typical" buildings is shown in Table 2..

Normalized space heating energy consumption in the SI buildings ranged from 4.22 Btus/ft^2-°FDay to 12.04 Btus/ft^2-°FDay with an average consumption of 7.58 Btus/ft^2-°FDay. Normalized space heating energy consumption in the "typical" buildings ranged from 15.91 Btus/ft^2-°FDay to in excess of 36 Btus/ft^2-°FDay with an average consumption of 25.11 Btus/ft^2-°FDay. Space heating consumption was 24% to 88% lower in the SI buildings with an average savings of 70%. Monthly heating costs/unit ranged from \$10 to \$42 in the SI buildings and \$40 to \$92 in the typical buildings.

Table 1

ENERGY CONSUMPTION - SI BUILDINGS

BUILDING	NUMBER OF UNITS	SQUARE FOOTAGE	BTU's/ SQ-FT/ DEG(F)DAY	CONSUMPTION PER UNIT (ANNUAL THERMS) MONTHLY	COST PER UNIT (ANNUAL COST) MONTHLY
JP BUILDING	20	19,500	4.31	(271) 23	(\$127) \$11
829 W. SUNNYSIDE	12	11,400	4.22	(259) 22	(\$122) \$10
4130 N. KENMORE	14	14,444	4.38	(292) 24	(\$137) \$12
6138 S. WOODLAWN	10	12,531	6.11	(494) 41	(\$232) \$19
6141 S. WOODLAWN	6	8,556	4.99	(459) 38	(\$215) \$18
1323 S. FAIRFIELD	3	3,994	5.22	(449) 37	(\$211) \$18
1332 S. WASHTENAW	3	3,135	9.17	(618) 52	(\$290) \$24
533 FISHER (Rockford)	8	5,632	5.82	(284) 24	(\$133) \$11
4119-29 S. ELLIS	23	30,234	7.40	(628) 52	(\$295) \$25
4746 S. INGLESIDE	15	14,784	11.30	(719) 60	(\$338) \$28
305 S. CENTRAL PARK	23	25,952	12.04	(877) 73	(\$412) \$34
3502 W. VAN BUREN	13	19,725	10.87	(1064) 88	(\$500) \$42

Table 2

ENERGY CONSUMPTION - TYPICAL REHABBED BUILDINGS

BUILDING	NUMBER OF UNITS	SQUARE FOOTAGE	BTU's/ SQ-FT DEG(F)/DAY	CONSUMPTION PER UNIT (ANNUAL THERMS) MONTHLY	COST PER UNIT (ANNUAL COST) MONTHLY
4740 S. INGLESIDE	6	11,700	18.58	(2339) 195	($1099) $92
4737 S. INGLESIDE	12	14,784	21.20	(1686) 140	($792) $66
400 S. LARAMIE	21	28,800	18.31	(1621) 135	($762) $63
418 S. LARAMIE	30	30,000	15.91	(1027) 86	($482) $40
500 S. LARAMIE	44	44,000	25.96	(1675) 140	($787) $66
743 N. CENTRAL	59	43,890	36.69	(1762) 147	($828) $69
541 N. PINE	50	45,182	25.07	(1462) 122	($687) $57
5700 W. RACE	43	48,978	20.14	(1480) 123	($696) $58

notes

DEVELOPING APPROPRIATE RETROFIT TRAINING PROGRAMS

BY

MIMI BURBAGE

ALASKA HOUSING FINANCE CORPORATION

THE RETROFIT PROCESS

The word "retrofit" is defined by Webster's as " ...a change in design, construction or equipment..... in order to incorporate later improvements..." Retrofit, rehabilitation, and reconstruction are all descriptions of various processes by which a building is modified, hopefully for the better. Retrofit has been the key word used to indicate an investment of time, energy and money into an existing building which might improve the building in a number of ways but which specifically targets the energy characteristics. It is the process that starts with an insightful analysis with some combination of diagnostic tools that results in a series of recommendations that are selectively prioritized based on cost benefit analysis, health and safety, personal choice and budgetary resources.

The basic challenge to the retrofit process itself, as well as to the development of a retrofit curriculum, is that it is so very site specific. Like a fingerprint, there are no identical existing situations even when two structures are identical in construction detailing, layout and dimension when first constructed. Through the aging process, and through the specific occupancy, each home develops its own unique personality, dynamic and appearance. Identifying this is key to an appropriate retrofit process. The first goal then is distinguishing that fingerprint and all of its unique characteristic. And, the first goal of any training would be to provide students with the tools to successfully identify those characteristics and to determine the dynamics of the structure and how best to rectify weaknesses in the system.

KEY ELEMENTS AND TRAINING AIDS

What are the key elements to a successful retrofit training? The first consideration of any training should be to define the purpose, goals and need for that specific training. These should be clearly defined at the outset of the training so that all participants are in agreement as to the measurable outcome of the training. There should be a trainers guide and a student manual. These do not have to be elaborate productions, but should outline all of the material to be taught, give definitions of all "concepts" discussed, describe all diagnostic equipment, provide checklists that can be used by the student in the field, and list all appropriate reference material. Also, it is important to provide a basic guide for construction management. The success of even the smallest retrofit project will hinge greatly on sane construction management principals.

In retrofit training, a great deal of emphasis is placed on audio-visual aids. Extensive slides depicting in detail all of the key construction techniques to be discussed, are vital to an effective presentation. Video tape of specific projects is also effective although harder to procure. Overheads, blackboards and/or flip charts are also required and will be used frequently throughout the presentation. Scale models, such as a plexiglass house demonstrating pressure diagnostics or air leakage, for use in the classroom are excellent tools for explaining complex concepts. Another example would be cross sections of walls, ceilings, etc. It is much easier to demonstrate the appropriate installation sequence with three dimensional models. Retrofit training automatically generates a great deal of spontaneity as individual students will draw from their experiences and specific problem resolution can become a critical part of any training.

DIAGNOSTICS

Inclusion of the full range of diagnostic equipment when possible is important to all retrofit training. This includes: the blower door; infra-red camera; combustion test kit; CO/CO2 monitors; thermometer and humidistat; pressure manometer; pressure pan; weather data charts; a bag of basic carpentry tools; safety equipment for the assessor; and, a flashlight.

The most successful retrofit classes will set up all of this in a demonstration house and spend at least a half a day conducting, discussing and interpreting the full blown assessment with all of the tools. Homes to be used for training purposes can usually be procured from volunteers, local banks, real estate agencies, housing authorities, and home lending institutions among other sources. Sometimes a trade for some basic improvements can be made for use of the house. Empty buildings are always the best when you have a number of people. Cleanup of the borrowed building is critical to ensure your reputation in the business and to encourage future cooperation from those with buildings that are perfect for training.

Many times information gleaned from this type of hands on demonstration will help the student to understand the basic dynamic of a building that will enhance assessment skills whether or not he or she can continue to bring the full array of equipment to the field in every case.

When doing diagnostics on a demonstration house during retrofit training, time is very limited. Since the training is not in the use of the diagnostic tools themselves and is simply an overview of the function of the tools and what is often found when used, there are some ways to involve the class beyond just observation. First of all, if some of the class is experienced, have them help with the tests. For those that are not, set up the blower door and give everyone a simple sketch of the floorplan of the house. Turn on the blower door and have each person (or small group) walk around the building looking for leaks which they will mark on the plan. Then bring everyone together and go over their findings in a group and take recommendations for rectifying each leakage area. There are many variations to this but it is quite effective in involving everyone in the assessment process.

Another technique is to divide the group into teams (two to four people) and assign them to different parts of the house. As diagnostics are performed, each team focuses on their particular area to bring an indepth assessment, report of unusual findings, and recommendations back to the group. If more than one demonstration house is used, the teams then switch assignments. The group then must make overall recommendations with the underlying theme that the house must be viewed as a system and that all recommendations must be looked upon in terms of their impact on the whole structure. The key is to prevent everyone standing and watching someone else demonstrate. The greater the active participation, the greater the success of the training.

RESOURCES

The more samples of commonly used products that one can bring to a training session, the better. Depending on the level of training of the participants this could include samples of all of the following: insulation, caulks and sealants, vapor barrier materials, duct sealing mastic and material, poly pans, outlet gaskets and covers, fasteners, particular types of wood products (especially trims materials used in air sealing), gaskets, siding materials, etc. Many times explaining the details of a given repair is facilitated greatly with actual material samples that might be used. Scrap lumber should be available for testing caulks and foams. Various types of caulking guns and foam applicators should be on hand so that students will have an opportunity to actually test a variety of tools. A discussion on allocated space for proper storage of materials and tools should be included. This is part of good construction management and could also be presented in a separate section.

Resource and reference materials that should be available for the class to browse includes code manuals, energy specific building manuals, general building science, basic carpentry books, and the host of excellent periodicals that are on the market today that deal with the many facets of remodel and retrofit. Brochures that describe related public programs are also appropriate, such as Energy Rated Homes, Weatherization, etc. A suggested reading list or resource directory should be compiled and given to each participant before the end of the class. Allow time for a review and discussion of the materials included. A glossary of terms is also an invaluable tool that participants can add to their own library.

PARTICIPANT CONSIDERATIONS

Controlling the size of the class is crucial to an effective training. Although there is no one correct size, a number of factors should be taken into consideration. Since retrofit does require a great deal of interaction between the trainer and the participants size of the group should be a major factor in the planning process, especially for on-site portions of training. Large groups will become easily bored and drift off if they cannot actively participate in the training. Very little is retained when people are crowded into an area where numbers of them cannot see what is happening and are not a part of the process. Keep class size to a reasonable level to maximize training. It is often difficult to limit classes to a particular level of expertise, but in teaching retrofit it is preferable to have small classes of participants with similar levels of experience and knowledge. If this is not possible, the trainer should try to discern the level of experience at the outset and mix all working groups. The more experienced students can be incorporated as training assistants.

Although it would be ideal to group class participants by experience and knowledge, this is rarely the case. Most retrofit training classes are composed of a range that begins with the inexperienced homeowner wanting to work on his own home, to the experienced builder and subcontractors, to public housing maintenance personnel, etc. All of the participants have one goal which is to learn techniques that can be applied in building to reduce energy costs, enhance comfort levels, and extend the life of their buildings. For the most part, the same curriculum can be used while varying certain aspects according to the needs of the audience.

When working with multi-cultural groups training has to be tailored to take into account some of the characteristics of the trainee group. Many of the techniques applied here are also relevant when working with groups that have a mixed experienced level as well.

One of the first rules that is basic to a good cross-cultural or mixed experience training is to realize that no one has all the answers (not even the trainer), and that often, local people will have a much better solution to a given problem than anyone else might. The oldest traditional housing was efficient, environmentally sound, maximized the use of indigenous materials, and incorporated many of the major elements of the shelter industry, i.e. sources of heat, ventilation, light, providing protection from the cold while maximizing the unique features of the site itself. It was only after the introduction of the lowest quality "modern housing" throughout the State that the quality of life degenerated to a low point creating a major crisis in these areas.

TRAINING CURRICULUM AND OUTLINE

Attached to this narrative is a section of a sample outline that is commonly used for Basic Retrofit Training. The percentage that is listed following each category is the percentage of classroom time that is spent approximately on that category. Depending on the level of training that the class has previously had, these percentages may vary some, but, a minimum of forty percent of time is spent on actual case studies. The key to producing an effective retrofit training is in gathering detailed documentation of a variety of retrofit projects from the local area. They do not all have to be successful. Those that failed in some way or another are often the greatest training tools one can use. It is critical, though, that they be well documented with slides and a narrative outline that can easily be used by a trainer who may not have been on site during the project.

A separate and specific curriculum is usually required for on-site use in the field with untrained crews. This curriculum should heavily emphasize a hands on approach throughout the training with only a minimal time is spent in the classroom. A tailored version of "Building Science" can be used as an introduction to the class. Early approaches to training on-site crews involved slight adaptations of the standard curriculum with additions of "hands-on" time. This approach was adequate but not highly effective. Much better is an approach that is centered around on-site activities with short instructional periods for the basic building sciences.

FUNDAMENTALS OF RETROFIT TRAINING

Often those that teach retrofit workshops have long histories in the construction arena but are not professional teachers. They are very good at the subject matter, but can often improve upon delivery and training technique. To ensure the long term success of any training, the following should be recognized and implemented by the trainer:

1. Before beginning the class state the rules, lay down the goals, and define the purpose and scope of the training. Be specific in what you are going to attempt to accomplish. Through

a round of introductions of class participants, try to get a feeling for the levels of experience and expectations of the group.

2. Do not talk too fast. Experienced trainers that have been giving the same curriculum over and over again, can easily breeze through the material without ever really stopping to see that the students are still actively following the class. Slow down. Ask questions that provoke a response, and wait for the response. Don't be afraid of a few moments of silence while class participants gather their thoughts. Don't just say "Does everybody understand? Okay..." and then move on. Most people will not say they do not understand. When you lose them once, you often lose them for the rest of the class. Be very specific in questions that might prompt feedback that will indicate whether or not you are being understood? You can always ask if anyone has a story that might illustrate the point you just made. If you do get back that kind of response you know that you have been understood and you can go on. Too often trainers have a "hard agenda" that they set before even meeting the class. For them success has more to do with accomplishing that agenda than making sure the curriculum is digested by the class. And, in many instances the only successful outcome of this type of approach is that the agenda was completed.

3. Do not interrupt. If someone is talking or developing a thought, let them finish. If you finish for them, you may discourage them from talking again. Allow for sufficient time for people to respond and plan your schedule accordingly. Also, be sensitive to your students and do not embarrass them in any way. Trainers who are not aware of their students feelings may lose their participation at the outset. Be positive in encouraging participation.

4. Try to limit "if this...then that" situations. This is extremely difficult in retrofit, for it is often necessary to present in terms of supposition. "If the insulation is wet and deteriorated, then we might assume that there is high moisture, no air/vapor barrier on the interior, no air barrier on the exterior, etc..." Focus on concrete examples. The best way to present all of this is through case studies where specific situations are documented and examples of retrofit strategies discussed. Do stress the immediate and long term benefits of any given measure both in potential energy savings, health and safety and increased life of the building. Focus on the practical.

5. Use a positive not a negative approach in all of your descriptions of the existing situation. Care must be given not to insult the people that you are training by criticizing their existing situation. Objectively pointing out cause and effect is essential to an effective training, but, it is wise to refrain from making judgements or acting as if there have been deficiencies on the part of local people, agencies, etc. in creating these situations. Training should strive to be non-political and positive in its approach to avoid alienation of the students. Especially in small communities, it is inevitable that someone in the class may have been involved in or responsible for the initial construction of buildings that would be good candidate for retrofit. A "let's go from here, avoid making the same mistake again, and fix what's wrong" is a great deal more productive than any kind of finger pointing.

6. If you have trouble engaging the class in actively participating, ask for their help. One of the exercises that can be done in each class is to describe the "existing situation" of a case study before reviewing what actual retrofit procedures were implemented. This exercise is a great icebreaker and will get the class actively involved and relating to each other. Break the class into small groups, give each a basic sketch of the house, describe what was found by diagnostic testing, and have each group make recommendations for retrofit. Depending on how thorough you want their recommendations to be, you can allow from fifteen to forty five minutes for this exercise. Once completed, list all of the class recommendations on a flip chart and then present the actual case study. Discussion that follows should encourage class commentary on what actually was done and why. What were the cost considerations? What code deficiencies had to be rectified? How were the results of the diagnostics given at time of the assessment incorporated into the final retrofit strategy? Were energy savings realized? If not, why? Did the class come up with recommendations that might have been better or more effective at saving energy? Were there health and safety issues to consider?

   Having the class brainstorm in small groups on case studies should be done at least twice during the class and more if possible. At some point, a case that is basically not a good candidate for retrofit should be included. For example one where the foundation is very poor and not repairable, the cost benefit just isn't there, or the framing is rotten and the structure should be condemned, and etc. Present it as a problem and let the class determine what to do. It is good to present one case that is not a good candidate to drive home the idea that there are parameters to retrofit, that cost is a big issue, that there are some things that are beyond repair, and, that sometimes it is appropriate to say "no" to a project. Since one of the biggest issues in retrofit is when to stop, and/or how far to go, this can be the most important assignment that you give your class.

7. Avoid statistics and use illustrations. Studies and compiled statistics are meaningless to many people outside of the "bureaucracy". Most points can be made much more effectively through story telling. Compiling an array of true stories to illustrate the basic principals of building science will make a mediocre training curriculum exceptional. Years after the training, these stories will be remembered and applied. This is another reason why the "case study" should be such a large part of this kind of training.

8. Be open to a different set of values that may be displayed by the class or individual students. Every culture and every economy exhibit vast differences in the style of their housing and the end use of that housing. The things that each of them consider important may not at all be what the trainer considers important. Western culture puts a high premium on space and cosmetics. Most other cultures do not. Furnishing and appliances are placed for convenience, possessions are shared, bedrooms are for sleeping, kitchens and living rooms become one, common space is often used for workshop space (especially in cold climates), and, upkeep often becomes a function of when it can be afforded. In these cases, a retrofit strategy might involve a very different set of parameters than one in an suburban neighborhood. Always keep in mind that the ultimate goal is to save energy and increase health, comfort and safety and there are many ways to get there.

9. Emphasis must be placed on the client education that is necessary to ensure continued long term energy savings after rehabilitation. It is of critical importance that anyone involved in retrofit understand that the investment in the building itself will be of minimal consequence if a long term operating and maintenance plan is not implemented and if the homeowner does not implement available low and no cost measures. Successful weatherization and retrofit programs will incorporate a client education training strategy into all aspects of their program delivery. Throughout the course of retrofit training reference should be made to client education where appropriate.

10. Develop an atmosphere of partnership with your students. You are all in this process together and their input and experience will be important in the process of discovering what the problems are in a given house and how to solve them. Stay away from the traditional teacher-student role. In every successful training the trainer as well as the students should walk away having learned something new.

FUNDAMENTALS

There is one issue that stands out as the key to a successful retrofit training. It also lies at the crux of the "retrofit dilemma" today. This is how to instill the concept of "DO NO HARM". From the world of weatherization, to HUD's moderate rehabilitation to private sector major retrofit projects, bringing a balance of energy saving measures to the house without incurring possible health and safety dangers into the dynamic of the home truly is the challenge. It is a paramount concern, especially to a retrofit trainer who may be giving a student just enough information to create dangerous situations. In most training programs, this concept should be reinforced throughout the training and specific time should be set aside separately for this issue. The role of diagnostic tools in determining the potential for health and safety problems needs to be underscored.

Emphasis must be placed on building science and viewing the house as a system. This concept must be reiterated frequently throughout training. All strategies must tie together and become accountable to their impact on the "system". Training must emphasize not only what to do, but when to walk away (even if its before beginning). Training must also stress the time, place and circumstance for calling in a professional diagnostician, such as a heating contractor, or a blower door technician, etc. This is perhaps the greatest responsibility that can be assumed by the trainer, and, the most difficult task to be accomplished through the training process.

By incorporating many of the above mentioned training techniques and by recognizing that retrofit is a most fluid science, the successful trainer will be able to help in opening up what is the most complex and challenging aspect of the construction industry today.

BUILDING ENERGY RETROFIT

A SAMPLE AGENDA

I. BUILDING SCIENCE (10%)

II. DIAGNOSTICS (15%)
- A. AIR LEAKAGE
- B. HEATING SYSTEM
- C. HEALTH AND SAFETY
- D. STRUCTURAL
- E. VENTILATION
- F. ENERGY PRIORITIES
- G. SITE CONSIDERATIONS
- H. BUILDING TRIAGE

III. METHODOLOGY (10%)
- A. COST/PAYBACK
- B. LIFE CYCLE COSTING
- C. INTERIOR
- D. EXTERIOR
- E. PROPERTY VALUES
- F. STRUCTURAL CONSIDERATIONS
- G. REQUIREMENTS ATTACHED TO $
- H. OTHER

IV. ASESSMENT STRATEGIES (20%)
- I. ON-SITE ASSESSMENT FORMS
- J. WEATHERIZATION PRIORITIES
- K. INTERPRETING THE DIAGNOSTICS
- L. COSMETIC
- M. STRUCTURAL
- N. ENERGY PRIORITIES
- O. HUD HOUSING QUALITY STANDARDS
- 8. OTHER

V. QUESTIONS OF "OPERATING AND MAINTENANCE" (5%)
- P. COST
- Q. COMPLEXITY
- R. TRAINING

VI. CASE STUDIES (40%)
- S. WEATHERIZATION
- T. LOW COST/MODERATE RETROFIT
- U. SUBSTANTIAL REHABILITATION
- V. BACK TO THE FOOTPRINT
- W. "JUST SAY NO"

HOT2000 VERSION 7 AND AUDIT2000

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ABSTRACT

HOT2000 is a comprehensive, easy-to-use energy analysis and design software, for low-rise residential buildings, that is used in the industry by builders, engineers, architects, researchers, utilities and government agencies. Utilizing current heat loss/gain and system performance models, the program aids in the simulation and design of buildings for thermal effectiveness, passive solar heating, and the operation and performance of heating and cooling systems. AUDIT2000 is a simulation software based on HOT2000 with extra features for modelling existing houses, energy conservation measures and reconciliation with utility bills.

The programs include facilities for viewing and editing weather data and fuel cost rate structures. An economics model may be used to estimate the pay-back of energy conservation measures. All reports may be viewed on screen, printed directly, or saved in ASCII files for later printing by either a built in or a separate print spooling utility. Either a mouse or keyboard may be used for navigation through the program menus and editing screens. Both HOT2000 and AUDIT2000 are available in MsDos format. A Macintosh version of HOT2000 is also available.

INTRODUCTION

HOT2000 has been used in the industry for the last ten years. Initially developed as a compliance tool for the Canadian efficient housing program, R-2000, it is now widely used as a design tool across Canada and the United States by individuals as well as for programs. However, as housing is getting older and efficiency standards are increasing the need for an auditing/retrofit tool has become apparent. Thus AUDIT2000, based on the HOT2000 program was created. AUDIT2000 was initially released in 1993 as a beta version, and has since been revised to respond to the needs of the retrofit industry.

The following report explains the technical aspects and features of both programs.

HOT2000 TECHNICAL MODELLING FEATURES

HOT2000 conducts a monthly energy balance on a house design to determine potential energy (space heating, water heating, appliances, and lighting) requirements. The monthly energy balance includes monthly and hourly bin analyses of specific building components and mechanical systems. HOT2000 contains the following technical modelling features.

Above-Grade Envelope Components

The above-grade envelope components support the following technical modelling features:

1. Areas and insulation thermal resistance values can be entered for individual building components (such as walls, floors, and ceilings). The effective thermal resistance of the assembly is calculated by the program from the construction details the user enters through pop-up lists. It takes into account thermal bridging and compression of insulation in the attic along the eaves.

2. Up to 10 entries per building component are permitted.

3. The building main wall and roof components include the solar surface heating effect of sunshine.

4. The monthly heat loss for each component is based on the area, effective insulation, and a temperature bin analysis that uses the setpoint temperature, the average monthly temperature, and the standard deviation of temperature.

Window Components

The window components support the following technical modelling features:

1. East, west, north, south, southeast, southwest, northeast, and northwest window orientations can be entered for passive solar gain calculations.

2. Based on the entry of a 6 digit code which defines the glazing type, coatings, gas fill, window type, spacer, and frame material, overall thermal resistance values and solar heat gain coefficients are calculated for each window (Enermodel Engineering, 1990).

3. Overhang geometry information is used to determine the window shading effect on passive solar gains for individual windows.

4. Shutters on individual windows on each orientation are modelled using empirically derived shutter closure periods based on latitude and solar position.

5. The window rotation feature reorients all windows by entering a new orientation for the south-facing windows. All other windows are automatically rotated to reflect the reorientation.

6. The window exchange feature exchanges all of the windows on two or more orientations without affecting the windows on the remaining orientations.

7. Monthly passive solar contribution and utilization are calculated on the basis of available solar gains, internal building mass, interior temperatures and temperature swings, house heating loads, and building mass heat storage parameters (Barakat and Sander, 1982).

Foundation and Below-Grade Building Components

The foundation and below-grade building components support the following technical modelling features:

1. Modelling of below-grade building components includes different soil and moisture characteristics to calculate heat loss rates to the surface and to the deep ground (Mitalas, 1982).

2. Open, closed (sealed), and ventilated crawl spaces are modelled, including transient heat flows to the earth.

3. Unheated crawl spaces are modelled using a derived monthly crawl space balance-point temperature.

4. Slab on grade foundations are modelled, taking into account interior, exterior or slab perimeter edge insulation.

5. Shallow-depth basements and full-depth basements are modelled, taking into account interior or exterior insulation.

6. Combination basements, including common corners, are modelled.

Infiltration and Ventilation Heat Losses

The infiltration and ventilation heat losses support the following technical modelling features:

1. Natural air infiltration rate can be determined in one of two ways; either based on fan depressurization test results (CGSB, 1985) or by choosing from a list of four air tightness types (Loose, Average, Present, Energy Tight).

2. A monthly wind-induced infiltration rate and temperature-induced infiltration rate is calculated, based on the exposure of the house to winds, wind speed, airtightness and leakage areas, and temperatures. The natural air infiltration model is based on the Alberta Air Infiltration Model (AIM-2) developed at the University of Alberta. (Wilson & Walker, 1990; Bradley, 1993).

3. Minimum continuous ventilation rates are either derived using the R-2000

ventilation guidelines, which are based on the Canadian Standards Association Preliminary Standard F326.1, *Residential Mechanical Ventilation Requirements*, or entered directly.

4. Heat recovery ventilator efficiencies are modelled using sensible heat recovery test data at 0°C and -25°C (32°F and -13°F) (CSA, 1985).

5. The heat recovery ventilator model derives an efficiency-to-temperature curve based on the test data, and derives a monthly weighted efficiency using an hourly bin analysis of temperatures against the efficiency profile curve. The effect of direct heat transfer on HRV effectiveness is accounted for (Wray, 1986; Bradley, 1993).

6. Fan and pre-heater energy consumptions are derived using a normalized temperature distribution to determine fan energy above and below the indoor setpoint temperature, so that the contribution to heating and cooling loads can be determined (Wray, 1986; Bradley, 1993).

7. The supply and exhaust ducts between the exterior of the house and the HRV are modelled to take into account the effect of heat transfer and air leakage from the duct to the space (Bradley, 1993).

Space Heating Systems

The space heating systems support the following technical modelling features:

1. HOT2000 contains default steady-state efficiencies for various types of space heating systems and calculates both monthly and seasonal efficiencies for the selected space heating system. Furnace type, fuel type, capacity, steady state efficiency, and pilot light energy consumption may be specified by the user.

2. HOT2000 calculates a design heat loss for the January 2 1/2 % temperature condition to size a heating system with or without the impact of a heat recovery ventilator (based on the National Building Code of Canada).

3. Space heating heat pumps (air, water, or ground source) are modelled using an hourly temperature and heat loss bin distribution. HOT2000 determines the heat pump capacity, coefficient of performance, and energy consumption for each hourly bin, as well as the load and part-load capacities, cycling times, and energy consumption for backup space heating systems for each hourly bin.

4. The space heating heat pump model considers various heat pump control strategies (temperature-restricted operation, unrestricted operation, or full heating load balanced operation).

Space Cooling Systems

The space cooling systems support the following technical modelling features:

1. Space cooling (air conditioning) systems are modelled using an hourly temperature and heat loss bin distribution.

2. HOT2000 models the following central air conditioning systems: conventional, ventilation, and economizer air conditioners.

3. For the purpose of determining the air conditioning size required for a house, HOT2000 can estimate the required rated capacity, indoor fan flow rate, and fan power.

4. Sensible cooling load modelling includes the effects of thermal storage and of changes due to the opening and closing of windows.

5. Latent load modelling includes the effects of outside humidity on the inside latent load (Barringer, 1991).

6. Variations in the air conditioner capacity and coefficient of performance (COP) with outdoor temperature is modelled.

7. Dehumidification by the air conditioning system is modelled.

8. Loss of efficiency due to part-load operation is modelled.

Domestic Hot Water Heating Systems

The domestic hot water (DHW) heating systems support the following technical modelling features:

1. HOT2000 calculates the contribution of a solar domestic water heating system from test data using the Canadian Solar Industries Association annual rating.

2. Primary and secondary water heating system combinations are modelled.

3. Standby losses, flue loss, hot water temperature, intake temperature, room temperature, location, and occupancy are accounted for in estimating DHW energy consumption.

Internal Heat Gains

The internal heat gains support the following technical modelling features:

1. Internal heat gain modelling includes standby losses for domestic water heating systems, interior electrical usage, pre-heater energy, and occupant heat energy.

2. A monthly internal gain utilization is derived, based on available gains, heating loads, temperatures, and utilization parameters (HOT2000 Technical Manual, 1989).

OTHER HOT2000 FEATURES

Comparing House Data Files

HOT2000 enables you to compare house data files. Entire files, as well as specific aspects such as air conditioning or above-grade components, can be compared. The comparison report may be displayed on the screen or sent to a printer.

Creating Custom Weather Data Files

HOT2000 provides Canadian and U.S. weather data files. Canadian monthly weather data, based on Atmospheric Environment Service 30-year averages, is available for 76 sites. U.S. monthly weather data, based on Typical Meteorological Year (TMY) data, is available for 200 sites. Data is also available for 10 international locations, and has been compiled from various sources and represents typical weather.

These weather data files may be edited and saved under a different name, or they can be used as the basis for creating a custom weather data file. Custom weather data files can be used in house data analyses and calculations to test designs for heat loss or gain under varied weather conditions.

From the average monthly temperatures and the standard deviation of temperatures, each month is divided into 32 bins using the EKB model (Erbs, Klein, Beckman, 1983). Calculations of heat loss and equipment operation (space heating, ventilation, infiltration) are carried out in each bin (if applicable) in order to more precisely account for temperature dependant effects.

Performing Economic and Financial Calculations

HOT2000 can do an economic analysis on the performance of energy conservation investments, or, alternatively, it can determine the energy conservation investment required to meet specific economic conditions. The program takes into account rates for data on price escalation, inflation, mortgage, savings, and taxes, and will generate an economics report.

Calculating Fuel Costs

HOT2000 enables you to select a fuel type from a number of options, and to specify a rate structure to determine the fuel cost of a particular fuel at a specified rate. These fuel cost calculations can then be included in the analysis of the proposed design.

Reporting

HOT2000 performs detailed energy efficiency calculations and provides thorough and accurate reports. The following is a list of the major features of HOT2000 reports for performing heat loss or gain analyses and comparing house data files.

1. Reports can be viewed on the screen, printed, or sent to a spool file.

2. Printed reports are available in lengths from 32 to 88 lines per page. Paper feed may be set to continuous form or single sheet.

3. All entered data can be included in a report to provide a permanent record.

4. Approximate heat loss (in megajoules or millions of British thermal units (Btu)) is reported for each building component.

5. Design heat loss results provide information for sizing space heating equipment.

6. Month-by-month summaries of gross space heating energy loads, usable passive solar and internal heat gains, net space heating energy loads, and heat recovery efficiency (if applicable) are presented in tabular form. A month-by-month summary of the below-grade heat loss, temperature, and air change rate is also provided.

7. Monthly and annual performances of heat pump and space heating systems are presented, including energy inputs, energy outputs, and coefficient of performance (COP).

8. Ventilation requirements are presented for sizing ventilation systems.

9. Annual fan use in Kilowatt (kW) hours is presented for heat recovery ventilator fans, exhaust fans, and space heating and cooling system fans.

10. Monthly and annual performances of air conditioning systems are presented, including: sensible and latent loads; air conditioner, fan, ventilator, and total fan energy; COP; and average relative humidity (RH).

11. Estimated annual fuel consumption and costs for space heating systems, domestic hot water heating, appliances, and lighting are reported.

12. The R-2000 Home Program energy consumption is reported for each house.

AUDIT2000

AUDIT2000 is an energy analysis software based on HOT2000, but targeted towards retrofit. All of the models which were mentioned previously in this report are found in AUDIT2000.

However, in order to make it more applicable towards retrofit analysis, some new features were added, including, detailed appliance and lighting entry screens, an archetype model, reconciliation against metered energy consumption, energy conservation measures (ECM), supplemental heating, a detailed indoor temperature screen, a homeowner report generator and some additional screens for making comments on the renovation history and potential of the house (structure and equipment), moisture assessment and leakage sites. Following is a description of these models.

Appliance and Lighting Screens

The appliance and lighting screens allow for either detailed entry or quick entry of the appliances and lighting in the house. The fuel type for each appliance can be specified (electricity, natural gas, propane or wood), as well as its location in the house (to account for internal gains).

For lighting, either the total load for each of the main floor, basement and exterior can be entered or a detailed summary, including the type of lightbulb used, its consumption rate and a lighting usage schedule can be entered.

Archetype Model

The archetype model allows for a quick, approximate means to generate a house file. The user inputs a minimum of details describing the house, such as its age, geographic location, length and width, number of storeys, foundation type, heating and ventilation system type and general construction of the walls and roof. The program uses these inputs to algorithmically derive wall and window areas, and to generate physical house characteristics from stored look-up-tables. The algorithms and look-up-tables were developed using an extensive database of housing characteristics. The values are then passed to the HOT2000 "core" to perform a full heat loss analysis of the house. The user can review the generated report on the house and make changes to the file through the main house editor.

Reconciliation

Actual meter readings from the utilities can be entered into AUDIT2000 (for electricity, natural gas, propane, oil or wood) for the house being analyzed. The reconciliation model will run the AUDIT2000 energy analysis and compare it to the metered readings for the specified year. A means is provided for the user to quickly assess the impact on the reconciliation of changes to three of the most error-sensitive parameters: air infiltration, amount of supplemental heating and indoor temperature.

Energy Conservation Measures

Once the house has been entered and analyzed as is, upgrades to the house can be modelled. The ECM model allows the user to specify upgrades to the envelope or to equipment (including cost) and rerun the analysis taking into account financial analysis parameters such as the inflation rate and energy escalation rate. Once the upgrade has been analyzed it can be compared against the base house or other upgrade packages to determine payback or rate of return.

Indoor Temperature Model

This is an approximate method which allows the user to account for temperature variations in different parts of the house (such as those caused by zoning) and the effect of setback thermostats. The method calculates average heating and cooling temperatures weighted by floor area and time.

Supplemental Heating

This model estimates the effect of supplemental heating systems by treating them as internal gains to the house. The types of systems that can be selected as supplemental heating systems include all primary heating systems as well as several other common secondary systems, such as gas space heaters, electric fan heaters and wood fireplaces.

Homeowner Report

AUDIT2000 passes the results and other specified information from a simulation run to a separate "WINDOWS" application which then allows the user to manipulate, preview and print a report for the homeowner. The report includes text and graphics and presents summaries of energy consumption and costs, savings potential, recommended ECMs and relevant notes of the auditor.

CONCLUSION

In order to ensure that HOT2000 and AUDIT2000 continue to be accurate and useful simulation tools, user requests, results of monitored data and the emergence of new technologies are continually being incorporated into the program.

The ongoing development of both HOT2000 and AUDIT2000 is supported by the Buildings Group of CANMET, the research and development arm of Natural Resources Canada. HOT2000 is distributed through the Canadian Home Builders Association. The basic calculation methods used for HOT2000 are derived from the National Research Council of Canada, ASHRAE and CANMET research. Validation of the program against BLAST and DOE as well as field monitoring of actual R-2000 houses built under the R-2000 Program in Canada has demonstrated the accuracy of HOT2000 as a design tool. The results from simulations of existing houses run on AUDIT2000 also correlated well with data collected in a 200 home study.

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Developing a Grassroots Political Campaign for Conservation

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ABSTRACT

The intent of this paper is to present a concept for developing a marketing campaign for conservation. The goal is to encourage support from the National Association of Homebuilders (NAHB) for a more appropriate standard of conservation in construction practices. The paper begins by discussing some of the problems builders are currently facing in the rapidly changing energy market. It then proposes some solutions that builders should consider. Finally, the paper highlights the fact that the NAHB has a gold key to unlock our environmental problems and be the new "American hero." Through education, promotion, and implementation of appropriate building techniques, the NAHB can dramatically reduce energy usage and provide a healthier and more comfortable indoor environment.

Ralph Cavanagh, Natural Resources Defense Council, states, "Marketing barriers in the residential sector are largely due to lack of information about energy use and related cost and about technologies available to reduce energy use. Energy efficiency is quite simply the most powerful engine of environmental protection ever devised..." He goes on to state," Progress remains paralyzed by inexplicable inabilities to distinguish efficiency from pain and economic stagnation..."

INTRODUCTION

In the last EEBA Newsletter, the Opinion Page addressed the fact that the NAHB has once again opposed standards that are essential to EEBA's building techniques. The greatest marketing barrier for conservation is the NAHB building industry's lack of understanding of the advantages of adopting construction techniques based on building science. The most unfortunate aspect is lack of support for mechanical ventilation. NAHB is in opposition to ASHRAE's added requirement for controlled mechanical ventilation in the proposed revision of it's Residential Ventilation Standard 62-1989. The article ended urging members to make their voices heard. Before EEBA members start writing letters and calling our local politicians to complain, let's come up with a uniform plan.

Since NAHB is the national backbone to the building industry in America and the voice for builders in Congress, it seems logical that its endorsement in appropriate energy conservation should be our highest goal. In order to achieve this goal, we must demonstrate to the NAHB that energy efficiency is indeed economic development for its industry. EEBA needs to develop a concise strategic plan that clearly demonstrates the economic development and the improvement to the final product, the house. The message that we want to deliver is that EEBA can assist NAHB on education in energy conservation so that the NAHB can ride high on a public education campaign, waving the NAHB flag.

The logical steps in developing a national grassroots campaign should be taken toward educating NAHB on why they should consider supporting conservation to its fullest. We need to set goals, define our message, and build advocacy. Most important, we need to do our research. Why don't builders support energy conservation? Why don't builders support mechanical ventilation? In order to resolve these concerns, we need to put ourselves in their shoes. We need to understand why the NAHB has not strongly adopted the new energy conservation standards, which are in line with the Canadian, Swedish and some European standards such as those set in France.

The builder sees the additional energy measures as the major threat to housing because he sees these measures as adding a higher cost to the home, often without analyzing the whole picture. We often hear from builders that energy efficiency is bad for business. If a survey was taken, the findings would show that it cannot, does not, and will not sell. It is so tough to make it in this business - all we don't need are more rules and regulations which will send us under.

I hear these myths voiced daily. They exist due to the spread of incomplete and often inaccurate information. We need to inform builders correctly by demonstrating the economic and long-term benefits of energy conservation and by giving them the tools to succeed. Education and marketing are certainly key tools in the plan. Another reason for the builders' reluctance is that all the responsibility of meeting the higher energy standards falls on their shoulders. There is so little room for financial error. If, for example, they fail to pass the blower door testing, they could lose their shirts. Builders feel that they cannot afford to take that risk. Another major hindrance is the fact that it's expensive for a builder to change his building techniques and retool his operation. If energy efficient construction is to become mainstream, incentives are needed to begin the changeover.

We must also realize that this is an industry in which the techniques have been passed on for generations. Change is typically slow and methodical. However, now we are suggesting that builders rapidly change their building techniques. Many builders are sensitive to change and feel that they are being told that they don't know how to build or are somehow at fault. This is simply not the case. Those individuals need to understand that they were following the accepted methods of the time, but now there are too many people in the world and too much fuel being used for a sustainable future. In the last 20 years dramatic changes in our understanding of how houses work have taken place. The oil shortages of the '70s and the awareness of the environmental impacts from energy usage and resource depletion has mandated the acceleration of change within the building industry. The world's appetite for energy and resources is growing exponentially. The Canadian Homebuilders Association (CHBA) has been the backbone of its energy programs. The NAHB, with EEBA's involvement, should develop an Educational Program modeled after the Canadians' successful R2000 Program. This duplication was the approach in Alaska, and with tremendous cooperation from CHBA, has been a successful national leader.

The R2000 Program refers the new building science as THE HOUSE AS A SYSTEM. Comfort and energy efficiency in these buildings are achieved by designing and constructing the structure with the understanding that the building is a combination of the various components, such as walls, floors, ceilings, windows, heating appliances, ventilation systems, and the people who use the building. A change in one component of this building "system" will affect the performance of the other parts and, therefore, the overall comfort, health, energy use and long-term durability of the building. The design and construction must account for these interactions, and most important, the effect the outdoor environment has on the building.

THE MESSAGE

The message is that EEBA would gladly assist the NAHB with a strategy to help them become successful and develop a strong marketing image at the same time. We want to help the NAHB set up a national training program. The curriculum could be developed and delivered through EEBA in conjunction with the NAHB Energy Office. We want to help them lobby for the government funding for proper training, assistance for training the crews, and on-site technical education. We want to assist in obtaining funding for professional energy education programs for the general public, as well as the industry at large, such as the architects, engineers, bankers, realtors, appraisers and inspectors.

Fortunately, energy efficient mortgages (EEMs) which recognize the added value of energy efficiency and offer financial incentives for these added measures are being set up across the country. We need to continue to make sure these programs are established for a national uniform rating system. EEMs also need to address the true cost and life of a house, as well as the energy use of the house. Through spreading the initial cost of energy efficiency across the life of the mortgage (as opposed to a 5-year payback), the added construction measures become very affordable and logical.

In Alaska a few years ago, the state funded an early adopter program through the U.S. Department of Energy (DOE) for the first Five Star Plus homes in Alaska. The financial incentives made the projects possible and successful. The builders were excited about the programs, but without the incentives (and considering tight budgets), there was not a market for these homes until recently with the new programs. All builders should have access to this fund. It is essential because it is not yet cost-effective for builders to implement a new technology in a sensitive building economy, which is especially important for small builders. They do not have extra capital, and if they do not receive assistance to retool their industry, their businesses will suffer. Financing for the NAHB/EEBA educational and incentive programs should be of highest priority for government funding.

The building industry is slowly beginning to undertake revolutionary changes, and EEBA needs to act as a catalyst by guiding the way for the industry. The NAHB has been the predominant player in the national building and energy policies; therefore, we need to set our direction to ride along with them to make the pathway for appropriate building regulations. EEBA needs to first develop a uniform building science curriculum for the building industry similar to the Canadian R-2000 Program. Then we will have the opportunity to teach the building industry the proper building techniques for a more sustainable global future. EEBA will then have a greater opportunity to be directly involved in making technical decisions on energy efficient building policy.

Energy efficiency means economic development for the building industry. It is also a key to resolving the world's environmental problems. The building industry is a logical place for launching the new public education campaign on the "Big Picture," as well as the basics of building science. The marketing message that NAHB should deliver to the public is that through housing, we can affect the environmental future by revamping the existing market and retooling the industry. The NAHB should ask for funding support from DOE and HUD for industry-wide training and public education. If the builders do not take advantage of these monies, the utilities will. Builders need to be informed about the advancing technology, have hands-on training, and receive incentive funding to assist each builder as the industry is retooled to address indoor air quality and energy conservation issues.

The NAHB should also play a major part in the energy efficient programs rather than the utilities and the government agencies. Policy on energy conservation should not be only in the hands of the local utilities who are looking at what is exclusively cost effective for their utility. The builders are the industry that has to live with the regulations, so the rules need to be understandable to them. NAHB and EEBA should be active at the local, state, and national levels. This involvement offers the NAHB the opportunity to be the recipient of the benefits from economic development and growth that the industry will experience from adoption of higher energy standards: There will be more jobs for the building industry.

Research and implementation of energy efficient building techniques have matured greatly over the last 20 years, refining super insulation technology into a building science. What is lacking is sufficient education showing the public (the demand side) and the builder (the supply side) how much energy can be saved by changing building techniques and how these techniques can improve the quality of life by making buildings more healthy, comfortable and durable - in short, better investments.

The plan will show that by investing in conservation measures, the builder can now offer a superior product. The EEBA home provides a more durable structure by eliminating moisture damage in the walls, floors, and ceilings. The indoor environment created by the EEBA house will provide improved levels of comfort and health. The energy use is typically reduced by 50-60 percent compared to conventional construction practices.

When reviewing current information on housing developments in the energy conservation field, the cost-effectiveness of the energy improvements is always carefully analyzed. Decisions are based on various formulas for payback and return on investment criteria. Included with these formulas are a variety of items, which should certainly be part of the decision process. However, in determining the appropriate expenditure for energy conserving measures, perhaps non-traditional factors should be considered.

One factor which is now receiving needed attention is the effect energy conservation has on the homeowners' quality of life. How do they feel in the house? What are the health implications of an under-ventilated house? What are the associated health care costs? Food for thought: According to The American Lung Association, asthma in the US has increased 60 percent since 1970. Weatherization efforts began to create more energy efficient buildings in a response to the energy crisis of the early '70s. Perhaps a relationship exists. Conferences and research around the world are targeting the IAQ/health issues. It seems prudent that to realistically evaluate the return on energy conserving measures, health and comfort, along with energy savings, should be factored into the equation. Future generations will benefit from this approach and the corresponding changes in building design and construction.

THE CAMPAIGN

If builders receive funding to enable them to retool their industry and funding for a public education campaign, it seems logical that the NAHB will endorse these ideas. EEBA needs to work to help builders get through this major transformation in their industry. Let's show the builders what an opportunity this change can be for their industry. We need to stress that building techniques are changing, so why not be aggressive and strong - be a leader, not a follower. By taking the bull by the horns, they can become winners in the battle to create quality homes for all Americans, have a viable economical industry and a sustainable future for generations.

Working together as a team with a uniform voice, EEBA, with cooperation from the R2000 Program and the CHBA, can develop a successful grassroots political campaign. Together we have to make a lot of noise from coast to coast - one message, loud and clear. The campaign that we want to deliver is a winner for everybody: the builders, the homeowners, and future generations. Because it's the classic WIN-WIN for all, there is no reason why we can't succeed. By following the logical steps listed on the following attachment for developing a grassroots campaign, EEBA will be successful in achieving its goals.

STEPS FOR DEVELOPING A GRASSROOTS POLITICAL CAMPAIGN

1. Join the NAHB Team:
   The goal is to have every EEBA member become actively involved with the NAHB by volunteering to sit on the regulation, energy or marketing committees. If your chapter doesn't have one, set one up.

2. Create Legislation:
   Define what you want to accomplish. Draft legislation rather than just opposing an issue.
   - A. Seek legislative funding for builders for a national training program, individual assistance, hands-on training and continuing education
   - B. Support a National Uniform Rating System with incentives for mechanical ventilation, sustainability, and conservation measures
   - C. Seek funding for a public education campaign, as well as an education curriculum tailored to all the players in the building industry, such as Realtors, Appraisers, Architects, Engineers, Designers, and Government Agencies
   - D. Shop for a sponsor and seek positive press coverage

3. Research Statistics:
   Independent research on the economic benefits and environmental implications substantiates the credibility of energy efficient building.
   - A. Publicize the fact that the Canadian government has put over $50 million into research on building science, therefore, the NAHB does not have to take years to reinvent a new program.

4. Look for Advocates and Define the Audience:
   - A. Identify and list potential advocates/opinion leaders. Educate and mobilize them to spread the message to target audiences.

5. Carrying the Message:
   - A. Shape dialog, generate PR, host hearings, develop speakers bureaus, write letters to public officials, newspaper editors, etc.
   - B. Enhance mailing lists and launch a letter writing campaign. Provide a toll free 800 number to call for more information. Follow up with phone calls to establish contacts

6. Organize & Mobilize:
   - A. Create events, hold district meetings, and field hearings

7. Media Relations:
   - A. Publicize success stories, create press kits, educate reporters on issues and provide independent research findings.

THE SPEAKER

Louise Palmer Nicklas

Louise Palmer Nicklas is originally from South Carolina where she studied advertising and public relations. She went on to do 2 years of graduate work in mass communications until she changed over to the fine arts for her master's degree. As a wildlife artist interested in environmental conservation, she witnessed the destruction of the shorelines on the South Carolina coast from the Savannah River nuclear power grounds and other industries. Louise was a volunteer with the Palmetto Alliance, an environmental group in the South, until she moved to Alaska in 1980. Since then she has been promoting conservation by helping establish the organization, Regroup, designed to promote recycling, reducing and reusing on the Kenai Peninsula. Watching her husband's interest in building, seeing the relationship between his work and the environment, she gave up her career as a professional potter in 1987 to devote her time to helping him start the company, HEAT Alaska, Inc., which markets energy conserving building products and services in Alaska. Her mission is to help create an awareness of how much energy can be saved by improving our buildings so that nuclear power will no longer have to be a part of the energy equation.

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REUSE OF MATERIALS READILY MARKETABLE WITH LITTLE OR NO PROCESSING

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Introduction

This paper presents a summary of a four-month study by SOLTERRE Design to assess the feasibility of opening a retail venture for reused building materials gained from renovation and demolition activity in the Metropolitan Halifax area.

Metropolitan Halifax, in the province of Nova Scotia, has a population of 330,000 people and an approximate construction value of $265 million in 1993 (This value includes residential, institutional, commercial and industrial activity).

Jennifer Corson, principal of SOLTERRE Design, is president the of recently established 'The Renovator's ReSource', a private retail venture marketing reused building materials from renovation and demolition activity in the Metropolitan region.

This paper will outline a proposed classification system for construction and demolition waste by the Construction Association of Nova Scotia (CANS). CANS represents those contractors who could use certain components of this waste stream, such as concrete,asphalt, bricks, other masonry, and materials associated with the demolition, roadbuilding, new construction and renovation industries.

Presented, as well from SOLTERRE's extensive survey of renovation projects, are factors which were developed for assessing reusable materials per square foot of renovation and demolition activity are presented.

Background

In September 1993, in recommendations addressed to the Nova Scotia Minister of the Environment, CANS summarized findings after conducting a four-month study regarding construction and demolition waste practices in the province.

In the letter, CANS proposes a new classification of material for easier handling, segregation, recycling and reuse of this material. To summarize, CANS recommended the following classification of materials:

- Class A materials would be those materials that do not release levels of contaminants above standard allowable limits. These materials would be classified as inert.

- Class B materials would be those materials which can be reused or recycled.

- Class C materials would be those materials that do release levels of contaminants above standard allowable limits. Such materials would be classified as non-inert.

Class A and Class C material are determined by physical characteristics alone. Class B materials would be those materials that can be recycled. These materials may be composed of both Class A and Class C materials, but are defined by economics rather than physical properties. It is important to note that a material may be both a Class A and a Class B, or a Class C and a Class B material. Identification of materials, that are sufficiently inert to be buried in a simple pit, will greatly aid municipalities in permitting and designating locations to be used for this purpose. Present lack of understanding regarding the pollution potential of these materials has contributed to a lack of municipal confidence as to the effects of such sites on the environment.

Construction and demolition debris may be classified into the three waste categories; Class A - clean, inert fill; Class B - recyclable or reusable; and Class C - waste. Much of the debris is inert material that will not decompose or release contaminants into the environment. Examples of such materials are concrete, structural brick, clean excavated material and gravel. These components of construction and demolition waste make up approximately 30-40% of the construction and demolition waste stream. Other components have the potential for reuse and recycling and make up approximately 60-70%. Such materials include asphalt pavement, roofing, wood, certain metals, plastics, paper, cardboard, etc.

There will be some overlap of Class B with Class A and Class C materials. Some Class B materials are inert and may be suitable for fill, while others may require disposal in the manner of municipal solid waste. Due to the lack of recycling efforts in Metropolitan Halifax, some of the recyclable materials have had to be disposed of as fill.

Table I. CANS Proposed Classification of Construction and Demolition Material

Material Type	Destination
<u>Class A - Clean Fill</u> Inert, uncontaminated material, approved by Dept. of the Environment for burial (i.e., concrete, brick, excavated material)	Private fill sites and fill on job sites. Fill sites act as a stockpile and/or permanent disposal. Such sites would be permitted by a Topsoil Permit
<u>Class B - Reusable/Recyclable</u> Materials that have potential for reuse on other jobs or can be recycled into new products (i.e., glass, plastic, doors, windows, fixtures, cardboard, roofing, wood, metals)	Until recycling becomes economically feasible, Class B materials will be disposed of as Class A with approval or as Class C. It is feasible to recycle Class B materials, and they should be **banned** from all landfills and private fill sites.
<u>Class C - Waste</u> Materials left over which must be disposed of at a special facility (i.e., contaminated fill, fibreglass, hazardous materials)	These materials are composed of municipal solid wastes and hazardous wastes that must be disposed of accordingly.

The classification of building materials, specifically the Class B materials as proposed by CANS, will lead to the flowing back of construction and demolition debris to reuse and recycling rather than to landfills. This proposed classification system is being considered as part of an extensive revision of the Nova Scotia Environment Act. It is anticipated that the new system will be tabled in the Legislature during the fall of 1994.

The Company

The Renovator's ReSource, established in August 1994, is the product of the SOLTERRE study to determine the amount of reusable building material from the construction, renovation and demolition waste streams in Metropolitan Halifax. 'The Renovator's ReSource' is a retail venture marketing retrieved, reusable construction and demolition material for the Metropolitan area. Required materials for this venture are windows, doors, lumber, fixtures (plumbing and electrical) and other valuable materials currently being landfilled. It is noted that the implementation of 'The Renovator's ReSource' will also signal to home-owners, manufacturers, and suppliers, that their unwanted items have value, and can be diverted from land fill with handling facilitated by 'The Renovator's ReSource'.

The business has three inter-related parts: the first consists of a retail location for sorting, storing and selling of inventory. An electronic inventory facilitates both the buying and selling of materials. The second part consists of the operation of a collection service for retrieving goods from smaller renovation job sites and individual home-owners. The third part will consist of a contract demolition team that will bid on and manage demolition contracts. This latter part of the operation is important for a continuing supply of goods to the retail location.

Renovation Project Site Surveys

Estimating volumes of renovation and demolition inventory for 'The Renovator's ReSource' was a difficult task. Many projects are not registered with the municipal building permit authorities, particularly residential renovation (the largest potential supplier of reusable building materials to a retail facility). This challenge was rivalled by the task of changing the mind-set of owners, contractors, renovators and demolition companies, from the waste stream approach, to the retrieval and reuse approach.

To assure the material flow and, therefore, potential sales for 'The Renovator's ReSource', an on-site survey was conducted on twenty-six renovation project sites. Sites were found with assistance of the City of Halifax Building Department. Residential projects of various sizes were also located, including additions, renovations and replacements. As well, eleven demolition contractors were interviewed by telephone as to their interests in a dismantling approach.

Contractor Attitudes Towards Recycling, Reuse and Landfill

Interest level tended to be high for smaller renovators and builders. The cost of buying new materials and disposing of wastes encourages reuse, but the lack of storage space does not allow these firms to keep useful materials. These are superb potential clients for 'The Renovator's ReSource'. Interest level is increased by the free pick-up of materials. The removal costs and ease of removal, are prime considerations for this user group.

Types of Debris Generated in Metropolitan Halifax

Types and quantities of waste materials were determined by interview or observation. Plaster and lath were a large portion of the waste generated from interior renovation projects. Wood waste was by far the largest debris component. Most of this was deemed not reusable because of size or condition (rot or nails), but possibly recyclable. Asphalt shingles and vinyl siding were universally scrapped. Fixtures, doors and windows were seldom saved unless requested.

As noted previously, many residential contractors lack the space to store materials. Some materials were reused in the same project where applicable (windows, doors and plumbing fixtures being the most common). Many items were given away when requested by clients or passers-by. Recyclable items such as copper or aluminum, if in sufficient quantity, were most commonly sold.

Volume of Debris Generated

The estimated waste generated per square foot of residential renovations and additions was 0.1 yd^3. This volume is about the size of a toilet tank. Volumes of waste for replacement repairs tended to be smaller as many items were reused.

Expenditures on residential construction were obtained from Canada Mortgage and Housing Corporation (CMHC), and from the City of Halifax. A basis of structural square footage, to determine material volumes, has been developed, against which survey factors/square foot are applied. Industrial, commercial and institutional (ICI) expenditures were obtained from the City of Halifax, and from Statistics Canada for the entire Metropolitan area.

Table II. Square Footage - Construction and Demolition, Metropolitan Halifax, 1993

		Expenditure (million) $	Average Value/ Square Foot $	Square Feet
New Construction				
-Residential	2,419 units	189.4	70	2,706,000
-ICI		75.6	100	756,000
Renovations, Repairs, Additions	1,850 permits	335.1	70	4,787,000
Demolitions	98 permits	n/a	-	147,000

New Construction Debris

While new construction accounts for substantial activity, waste generated is a fraction (perhaps 10%) of renovation activity. No new construction sites were surveyed for this project. In Table III, no values for debris retrieval were recorded, although opportunities do exist.

Renovation - Factor per Dollar Spent

Survey data was summarised and factors developed which are applied against structural square footage in Table III.

Table III. Estimated Retrieved Construction and Demolition Materials - Annual Supply for Metropolitan Halifax.

	Area ft^2/yr	Lumber (bd. ft.)	Doors (units)	Windows (units)	Cabinets (lin. ft.)	Plumbing Fixtures (units)(1)
Factor/ Sq. Ft.		1.439	.00207	.00196	.01174	.00204
New Construction(2)						
-Residential	2,706,000	0	0	0	0	0
-ICI(3)	756,000	0	0	0	0	0
Res. Renovations (4)	1,596,000	2,297,000	3,304	3,128	18,737	3,256
Demolition						
Residential	48,000	69,072	99	94	564	98
Other	99,000	142,461	205	194	-	-
Total		2,508,533	3,608	3,416	19,301	3,354

(1) Plumbing fixtures are assumed to be 50% sinks and 50% toilets.

(2) New Construction was not surveyed for waste retrieval. While some materials would be retrieved, to be conservative no values are recorded.

(3) Industrial, Commercial and Institutional.

(4) A large value for square feet (4.787 million s.f., Table III) is based upon retail sales and owner surveys. It is deemed more realistic to reduce this value by two-thirds so that repairs, which produce little valuable waste, are excluded. The remainder, as shown, represents additions and renovations, a likely generator of material supply.

Demolition

In 1993, 98 demolition permits were issued in Metropolitan Halifax. No information on structural square footage was available, however, about one-third were residential and an estimate of 1,500 sq. ft. per structure demolished, is used.

Demolition contractors tend to use machinery which precludes the careful separation of materials necessary for salvage. Tender specifications indicate the method used and time period allowed. Contacts are found prior to demolition, when materials are saved, since most contractors do not have storage space available.

Business Potential

Once 'The Renovator's ReSource' is operating at full capacity, it is estimated, with means of the survey material volumes that the outlet will have annual estimated sales as listed in Table IV. The prices for the reused materials will be generally from 10-30% of their market value.

Table IV. Estimated Annual Supply

($ Dollar Value of Sales)

Product	Potential Supply	Price	Sales
Lumber	2,508,533 bd. ft.	$ 0.10/bd.ft	$250,853
Doors	3,608 units	$ 5.00 / unit	18,040
Windows	3,416 units	$ 5.00 / unit	17,080
Cabinets	18,737 lin. ft.	$ 5.00/lin.ft	93,685
Plumbing Fixtures	1,677 toilets	$15.00/toilet	25,155
	1,677 sinks	$25.00/ sink	41,925
	POTENTIAL SALES		$446,738
	TOTAL SALES (1)		$893,476
	ESTIMATED NET ANNUAL TOTAL(2)		**$223,369**

(1)On the basis of the Winnipeg ReStore experience it is estimated that the above items will be approximately 50% of total annual sales of 'The Renovator's ReSource', therefore, the potential annual sales from all renovation, construction and demolition activity is expected to be $893,476.

(2)It is anticipated that 'The Renovator's ReSource' will have involvement with 1 in 4 projects, or 25%, which generate saleable materials, therefore, the expected sales from the first year of operations is expected to be $223,369.

Conclusion

Progress has been slow in achieving tangible gains in the reuse or recycling of valuable waste. Long standing beliefs and attitudes by owners, engineers and contractors are giving way to recycling initiatives and to public demand for improved environmental protection. A recent hike in tipping fees, from $43 to $74/metric tonne, will continue to put pressure on the owner and contractor to separate their building materials prior to general disposal.

There is great opportunity to expand the entire retrieval system of materials from construction, renovation and demolition waste stream in Metropolitan Halifax. SOLTERRE is expanding its' business opportunities by initiating a pre-demolition audit consulting service and an electronic materials exchange. Other companies are currently looking at the feasibility of opening construction and demolition disposal sites for the Metropolitan region. It is recognized that the lack of legislation pertaining to construction and demolition disposal is retarding progress for these sites.

A review of this legislation at all levels of government pertaining to the management of construction and demolition debris within Nova Scotia is needed. Recommendations with respect to controlling all aspects of construction and demolition debris, specifically, the defining (classification system) and handling processes must be clarified.

The above mentioned projects, specifically the establishment of 'The Renovator's ReSource' will result in reduced amounts of construction and demolition debris going to landfill sites and increased amounts being reused and recycled. This will extend the life of all municipal landfills which now receive construction and demolition debris, and will reduce the amount of virgin material being used in construction. This certainly supports a sustainable construction future for Nova Scotia.

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ENVIRONMENTAL AND ECONOMIC IMPACTS OF VARIOUS RESIDENTIAL BUILDING PRODUCTS, CONSTRUCTION METHODS, AND DESIGN CHOICES

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ABSTRACT

This study demonstrates the use of an environmental audit for three model houses. The impacts of house size, material selection, and level of energy efficiency on raw material consumption, energy use, and building and maintenance expenses are examined. A baseline house serves as the model for comparison. Choices of building products for this house are based on a survey of home builders in a three-county area of New York State. The two alternative models are designed using advanced technology for decreasing raw material inputs.

INTRODUCTION

Humans have manipulated and consequently have had an impact on the natural environment for thousands of years (Wagner, 1974). The first Earth Day which occurred on April 22, 1970 was perhaps the beginning of the heightening of public awareness of the negative impacts that human activities often have on the planet (Kneese, 1990).

With the evidence of environmental problems such as erosion of farmland, deforestation, the continuing problem of ozone depletion, and signs of global warming mounting (Worldwatch Institute, 1992), the concern for environmental problems has grown, and the realization of the need to take action is becoming apparent throughout the global community. In the decade of the 90's even American industry is concerned about environmental issues and is cooperating to begin to address environmental problems (Kneese, 1990).

With the global population continuing to increase and as the economies of the world become globally linked, the demand for energy and raw material inputs is expanding at a brisk rate. In the span of 40 years, global per capita consumption of copper, energy, steel, and wood has doubled (Durning, 1991).

Statistics collected by the U.S. Government illustrate that increasing demands upon natural resources also continue within the United States. In 1975, 32.6 billion board feet of lumber were consumed in the U.S. In 1985, this figure had increased to 36.4 billion board feet and by 1989 had further increased to 43.6 billion board feet, (Agricultural and Forestry Statistics reported by Statistical Record of the Environment, 1991). Modern industrial economies require a vast amount of natural resources to provide the varied raw materials from which to manufacture products, devices, machines, and structures (Material and Mans Needs, 1974).

The U.S. economy is a giant consumer of natural resources to convert to raw materials and to supply the energy that the economy requires. The rate of domestic output in the U.S. has been especially dramatic since late in the decade of the 1940's, with total goods and services doubling every fifteen years since that time (Stephenson, 1981).

The US construction industry, comprising 8.4% of national GNP in 1988, is one of the largest industries within the US economy (R&D in the Construction Industry, 1989). As a major industry, construction places high demands upon existing natural resources to supply raw materials for the manufacture of building components. In addition, many waste products are generated from the manufacture and installation of these products, to the extent that the building industry is currently responsible for approximately 35% of emitted chlorofluorocarbons into the atmosphere, 30% of carbon dioxide emissions, 35% of solid waste, 35% of annual energy consumption and vast quantities of natural resource consumption (Wilson, 1992).

The United States housing industry, as a significant proportion of the nation's total construction industry, consumes a vast amount of natural resources, by both type and volume. In 1987, the National Association of Home Builders (NAHB) estimated that a typical 1,700 square foot single family home required 9,726 board feet of lumber, 55 cubic yards of concrete, 2,500 square feet of insulation, 3,016 square feet of aluminum, brick, or wood siding; 1,992 square feet of asphalt roofing shingles; 3016 square feet of roof, wall, and floor sheathing, 750 linear feet of copper wiring; 280 linear feet of copper tubing; 302 pounds of nails, and 55 gallons of paint (NAHB, 1987). In addition, the average size single family home produced in the US has been steadily increasing for the past 40 years. In 1963 the average size home constructed was 1,365 square feet; 1,660 square feet in 1973, 1,740 square feet in 1983 (Prowler, 1985) and 1,966 square feet in 1991 (F.W. Dodge Statistical Services, 1993). The raw material and energy inputs required to manufacture the products for and to construct housing have a significant impact upon the natural environment.

GREEN BUILDING

The impact that buildings place upon the environment has been gaining attention within the construction industry. Articles have started to appear in professional and trade publications on the subject of "green buildings." These articles illustrate designers', builders', and engineers' concern about the environmental impact of the erection and operation of buildings . "Building Green," an article in Civil Engineering (1991), reviews the work of several groups attempting to answer questions such as "is it possible to choose construction materials made from renewable, safe resources?...(and)...must they require an excessive amount of energy to produce or transport?" (Austin, 1991; p. 52). The American Institute of Architects (AIA) has been working to encourage designers to design environmentally responsible buildings by publishing the Environmental Resource Guide, a quarterly journal that attempts to provide design professionals in the construction industry with information."about how design choices affect the environment" (Crosbie, 1992, p.99).

In addition to the increasing number of articles appearing in professional and trade journals in the construction industry, conferences on the subject of "green buildings" are being held around the world. The Royal Institute of British Architects (RIBA) held a conference for its members in 1989 entitled, "Towards Green Buildings." This conference presented "an overview of what the current environmental issues are from a number of perspectives...(and)...raised the question of how environmental issues are likely to affect the commissioning, design, operation, and maintenance of buildings within the next 10 years" (Lorch, 1990; p.58). The United States National Institute of Standards and Technology (NIST) recently held a conference entitled, "US Green Building Conference." Papers were presented at this conference which examined methodologies for determining criteria for "green buildings" as well as on new technologies currently being explored in the areas of building materials, lighting, and indoor air quality (NIST Publication 863, 1994).

Typical criteria for determining which material, method or design to choose when building or renovating are "aesthetics, budget, performance, codes, and availability" (ERG; 1992, p.I.1). Currently emerging in the design and construction industry is the idea of including criteria that take into account the environmental impact associated with different material, method and design choices. Green Building is the term that has emerged to describe buildings that do include environmental criteria when making these decisions. However, the term "Green" is cause for confusion within the building industry (Crosbie, 1991). As Wardell (1993) states: "There's no definitive meaning of the term 'green' and no widely accepted way to measure or quantify it" (p.54).

Market Failures and Environmental Impacts of Buildings

One of the factors that make it necessary to define and attempt to determine what the environmental impacts of various building choices are (or what is a 'green' building) originate with the way national economic accounting systems are structured. External costs cause resources to be poorly allocated in an economy. That is, the optimal combination of goods are not being produced with the lowest cost combination of inputs (Wonnacott & Wonnacott, 1990).

Inadequate Pricing of Natural Resources

Currently the environmental costs to society associated with building construction and operation are external from the economic accounting system (Reppetto,1992). Price acts as a signal to a society that its members are consuming resource 'A' at levels that are severely increasing its scarcity. Thus increasing price works as an economic incentive to conserve resource 'A' and to search for substitutes. However, current methods of counting national income fail to count natural resources as assets. Reppetto (1992) illustrates this point well when he observes that...

"Buildings, equipment and other manufactured assets are valued as income producing capital, and their depreciation is written off as a charge against the value of production. This practice recognizes that consumption cannot be maintained indefinitely simply by drawing down the stock of capital without replenishing it. Natural resource assets, however, are not so valued. Their loss, even though it may lead to a significant decrease in future production, entails no charge against future income." (p.96) For example, the dollar cost of building a house under the present system of economic accounting methods does not reflect the true cost incurred by society to construct that house. If the economic accounting system were structured in a way that accounted for depletion of natural resources, then the environmental impacts of constructing buildings upon the natural environment would become more clear (Cole & Rousseau, 1992).

Market Barriers to Energy Efficiency

Rosenfeld and Hafemeister (1989) list two market barriers that work against the adoption of energy efficient practices and technologies in US buildings. The first barrier is identified as "different time horizons (that) the various principles consider when making decisions" (Rosenfeld and Hafemeister,1989; p. 84). To illustrate this principle, the example of a utility company's investment in a new electrical generating facility is given. The company expects to pay for this investment over a ten to twenty year period. However, homeowners typically do not invest in energy efficiency if the payback period is longer than two years (Rosenfeld and Hafemeister,1989).

Public and private institutions typically do not invest in efficiency if the pay-back period is longer than three years (Rosenfeld and Hafemeister, 1989). The second barrier arises from the fact that utility companies are usually required to set their rates to cover their average costs plus a small return on investment. This causes another distortion. If consumers were paying the replacement cost of additional energy, that is if they were paying the amount of money per unit of electricity which would be required to produce more energy generating plants, then consumers would have a stronger economic incentive to invest in energy efficiency improvements (Rosenfeld & Hafemeister, 1989).

Discounting

Discounting devalues money that is expected to be received in the future (Pezzey, 1992, p.336). Norgaard and Howarth (1991) illustrate this point when they note that For example one million dollars invested at a 5% rate of interest for 100 years has a present value of only $7,604. Some studies have shown that lowering effective discount rates will decrease consumptive pressures bearing upon natural resources (Pezzey, 1992). However in an economic model developed by Farzin (1984), he determined that lowering the discount rate will increase "investment demands on environmental resources and thus speed rather than slow their decline" (Pezzey, 1992, p.366). Daly and Cobb (1989), maintain that when the discount rate is higher than the reproductive rate of any renewable resources asset, then that asset will be threatened with consumption levels higher than it can sustain.

Ackerman (1994) applies this principle to forests when he notes that private owners of timber look to maximize the net present value of their asset. If the discount rate is increasing at a higher rate than the forests' rate of growth, then it becomes more profitable to harvest than to allow the forest to continue to grow (Ackerman, 1994). However, forests must be held at some minimum level to be able to sustain yields over indefinite periods of time (Ackerman, 1994). Pezzey (1992) points out that further research into the problem of discount rates and natural resource consumption is needed.

Hidden Costs of Energy

The 1992 issue of the Environmental Resource Guide identifies The ill-effects of acid rain, produced as a by-product from the burning of coal to produce electrical energy, as another market failure which causes the price paid for energy to not reflect its true cost. These costs include air and water pollution which are often difficult to assign a value to. However, these costs are real. The by-products of generating energy from fossil fuels subtract real value from the economy. Mount Mitchell, N.C. provides an excellent example. Researches determined that in that area, over a two year period, 43% of the fir trees died as a result of high levels of acid rain produced by coal fired electrical generating plants (Nicklas, 1992, p.IV. A1). Pimentel *et al.* (1994) cite a 1989 Worldwatch report which estimated a per gallon cost for oil of over $4.00 if price also reflected environmental and social costs associated with oil consumption.

Additional factors responsible for market failure with respect to environmentally responsible design include resistance to innovation in the construction industry, industry fragmentation, institutional roadblocks such as resistance to unfamiliar practices and products from local code officials and building inspectors and from builders themselves. All of these issues are compounded by the paradox of price. Price may deter many builders and contractors from using innovative products and methods. However, the price of these products cannot drop until they are used widely enough in the industry so that manufacturers can realize production efficiencies (Jones, 1992).

Environmental Auditing for Building Construction

Crosbie (1992) notes that no agreement has yet been reached on what qualifies as a "truly green building" Cole and Rousseau (1992) suggest that in response to this problem the building industry needs to develop methods that allow analysis of the impact upon the natural environment that different material, construction method, and design choices have and that the way to achieve this is by developing a method for conducting environmental audits for buildings, which are defined as:

> "... an accounting of the quantifiable environmental factors that will be incurred in building production and use, reducing them to equivalent terms and presenting them in meaningful categories. The purpose of the audit is to add an environmental dimension to design decisions."
>
> (Cole & Rousseau, 1992; p. 23)

This definition goes beyond traditional economic measures such as cost-benefit analysis and life cycle cost analysis, which have demonstrated significant limitations as methods for assigning monetary values to environmental costs.

Embodied Energy

Embodied energy is the amount of energy consumed to actually build a structure (Malin, 1993). It is a "hypothetical construct used to audit the energy expenditures required for a product's manufacture" ERG, year, p.). according to Malin (1993) embodied energy research is typically divided into three areas:

- "First order energy: fuel use for mining, transporting raw material, energy use at manufacturing facility (p. 8)"
- "Second order: energy used to produce the equipment and machinery that does the work, and to transport workers to and from the site" (p.8).
- " Third order: general support services and social services for workers. second order energy for machinery, equipment and infrastructure" (p.8).

A study conducted for The Committee on the Renewable Resources for Industrial Materials (CORRIM) by Boyd, Koch, McKean, Morschauser, Preston and Wanagaard (1970) contains significant information on the embodied energy of solid wood dimension lumber. Included in this report were comparison embodied energy figures for frequently substituted materials for wood in construction projects; aluminum, steel, concrete, and plastic. The CORRIM report investigated the process of cutting trees and then converting them to dimension lumber. The amount of energy required to complete this process was recorded at each step. Information was also gathered and analyzed for the energy requirements "...from source to end commodity for steel, aluminum, concrete, bricks, and petro chemical derivatives" (Boyd et al p.3).

The advantage of embodied energy analysis is that it provides a common measure from which to rate the environmental impact of different building materials (ERG, IV.D2). Consumption of energy to do work, in this instance to produce building products, requires the burning of limited reserves of fossil fuels and emissions of the by-products of this consumption process.

However, there are currently some major problems with studies that have been conducted. Malin points out that the durability differences that exist between similar products can "offset or reinforce conclusions based on embodied energy" (p.9). In addition, no generally agreed upon set of methods is used or available to researchers, so that comparisons between studies are of limited usefulness. Access to detailed and reliable data is also often a problem in conducting an energy analysis of building materials production. Current commonly accepted "system boundaries are "extraction, transportation and processing, which account for about 90% of energy used" (Cole & Rousseau,1992, p.24).

BREAM is a system developed by Bartlett & Baldwin (1993) to provide environmental labeling of buildings if they meet the set of criteria .The system awards points based on the degree to which a building minimizes environmental impacts in three broad areas; "global issues and resources, local issues, and indoor issues" (Bartlett & Baldwin, 1993, p.6). Global issues consider such criteria as amounts of carbon dioxide emitted in the process of maintaining the building; local issues are categories such as water conservation, and indoor issues are such factors as lighting and indoor air quality. The more points awarded to a building, the better it is judged to be at minimizing environmental impacts. However, this rating system does not actually quantify pollutant levels that each building may be emitting. For example actual levels of carbon dioxide emissions are not measured or calculated, but instead, points are awarded to a building based on factors that would tend to decrease it's output of carbon dioxide. For example if the building has higher than average levels of thermal insulation, or makes use of highly efficient appliances, then the more points the building would be awarded for decreasing its level of carbon dioxide emissions.

Building Environmental Performance Assessment Criteria (BEPAC) is a building rating system developed in Canada. This assessment system was modeled after BREAM (Cole, 1994). BEPAC evaluates the environmental impact of buildings in five areas: ozone layer protection, environmental impacts of energy use, indoor environmental quality, resource conservation, and site and transportation (Cole, 1994).

Environmental Value Engineering

Environmental value engineering (EVE) is a method developed by Roudebush (1992) that combines methods from standard value engineering techniques with a method called "EMERGY," a term used by Odum (1991) to describe the method he developed for assigning a single unit of measure to all inputs of a project in a economy. This single unit of measure is solar emjoules. Basically, the methodology of EVE is to determine all inputs for a given project; raw materials required, fuel energy and money used to pay for human labor, and then using Odum's EMERGY analysis. These various inputs are all converted to solar energy, a form of energy common to inputs of production. Roudebush (1992) maintains that by using EVE analysis, alternative materials and construction methods for a project can be evaluated. A determination of which inputs to a project will minimize environmental impacts while maximizing economic value can then be made.

Challenges facing the construction industry in implementing an understandable and manageable environmental auditing system on a widespread basis are substantial. But studies reviewed here demonstrate that there may be movement to a consensus. The development of a manageable method for conducting environmental audits for buildings would be useful for designers, builders, other housing professionals, and consumers and would be invaluable in the growing market of environmentally conscious design.

ANALYTICAL METHODS

The central concern of this study is with the tensions and balances between environmental and economic costs in new home construction. As a specific case exploring these tensions and balances, this investigation focuses on new home construction in the northern United States, in the counties of Cortland, Schuyler and Tompkins in what is generally termed "Upstate" New York. The peculiarities of climate in this area set certain parameters for building construction. In this setting, the investigation poses and seeks answers to three questions.

> What are the environmental impacts of different building product, construction method, and house size choices?
>
> What effect does each of the following--building product choice, construction method and house size have upon the economic cost of operating a house?
>
> What is the relationship between the initial house construction dollar cost and the long term dollar costs of maintaining and operating the structure?

These three questions are explored and answered by developing four simulation models of four types of new home construction that might be done in these areas. These simulation models consist of three independent variables: namely building product choice, construction method and house size. The independent variable of building product choice is examined for five component areas, those being the foundation, structural framing, roofing, siding, insulation. The structural framing component is further divided into four sub-components, those being the floor framing, exterior wall framing, interior wall framing and roof framing.

Two major component areas, mechanical/electrical and interior finishes are not included in this study, as the large number of sub-component areas that exist within these two components put them beyond the scope of this study.

Construction method, within the context of this study, is defined as the way in which the house is built. Choices such as structure type, one story versus two story; and construction system choice: full basement versus slab on grade, are examples of different construction methods.

House size in this study is determined from standards set by professional appraisal systems. The Marshall system, being the most widely followed in the United States, was used to measure the size of each simulation model. The Marshall system calculates square footage from measurements taken at the outside of exterior walls and includes only enclosed finished living space: not porches or garages (Carlson, 1991). Only above grade stories are included in this calculation of square footage of primary living space. In addition, nothing is deducted for thickness of exterior walls, interior partitions or stairwells.

Overview of Each Simulation Model

Four simulation models were created as a technique for answering the questions posed in this study. Each model was chosen to represent various combinations of each of the three independent variables: house size, building product choice, and construction method.

Simulation model H-1 is representative of the size, building products and construction methods typically selected by home builders in Cortland, Schuyler and Tompkins Counties, New York. To determine what choices are typically made in this three-county area, a builder survey was conducted. Builders' names and addresses were obtained from local yellow page, cross street, and trade association directories. Each builder so located in Cortland, Schuyler and Tompkins County of New York State was then mailed an eight-page questionnaire about the number and size of houses built in 1993, as well as the building products and construction methods most often used in five major component areas of a house. Those five component areas were the foundation, structural frame, thermal insulation, roofing and siding. These five components were selected because they are the components which require the greatest amount of materials when a house is built. The results of this survey informed the size, building product selection and construction methods of H-1. The study area was limited to a three-county geographical area to keep the data collection and analysis at manageable levels.

The products selected for H-2, the second simulation model, were chosen as being representative of technologically advanced and green products. Identification of these products was determined by examining each issue of four residential building trade journals published between 1990 and 1993: Fine Homebuilding, Builder, The Journal of Light Construction and Professional Building and Remodeling Magazine. The number of advertisements and/or articles mentioning or promoting an alternative product were counted. The product with the highest number of advertisements/articles within each of the eight component areas, foundation, floor framing, exterior wall framing, interior wall framing, roof framing, roofing material, siding and thermal insulation was the one chosen for the H-2 model.

Simulation model H-2 is matched with H-1 on the variable of size. H-1 and H-2 are also matched on the variable of construction method in seven of the eight component areas. Models H-1 and H-2 are not matched and differ on the variables of construction method and materials used for the exterior wall framing component. The exterior wall framing component of H-1 uses the stick built method, while the exterior framing component of H-2 uses a series of pre-manufactured foam-core panels that are assembled on site. Thus, for the exterior wall framing component, H-1 and H-2 vary on both materials and construction method.

Simulation model H-3 also has 2,000 square feet of finished floor area and uses typical construction products for each component area except for insulation. H-3 uses cellulose insulation in the exterior walls and ceilings rather than the fiberglass insulation used in the H-1 walls and ceilings. The construction method used for the H-3 foundation and the exterior wall framing component also differ from those used in model H-1. The H-3 foundation uses the Scandinavian technique of a slab on grade shallow foundation system. That is, an eight wide by 20" deep continuous foundation wall that rests on a piece of two inch thick extruded polystyrene foam. The perimeter of the foundation wall is further protected from frost by the addition of more extruded polystyrene insulation. The exterior wall framing component of H-3 consists of a double studded wall that is 12" thick. The outer portion of this wall is framed by using 2x4 studs placed at 16" centers with built up headers over window and door openings using double 2x10s: a typical framing method. The inner portion of this double studded wall uses 2x3 studs placed at 24" centers. The exterior wall cavity is insulated with 12" thick cellulose insulation and the attic is insulated with 16" of cellulose insulation. H-3 is identical to H-1 except for the factors just mentioned. In summary, those factors are: a shallow foundation system rather than a full basement, 12" thick double studded walls rather than 5-1/2" thick single studded walls, cellulose wall and attic insulation rather than fiberglass insulation, and R-44 thermal resistance in the exterior walls and R-60 thermal resistance in the attic rather than R-19 and R-38 in simulation model H-1.

The fourth simulation model (H-4) uses the same products and construction methods as those used for simulation model H-3 However, it is 25% smaller than models H-1, H-2, or H-3. Simulation model H-4 is based on a simple thesis: the best way to minimize environmental and economic costs of house construction is to consume less. That is, build smaller houses and use construction methods to minimize consumption of raw materials and energy. Thus H-4 is 25% smaller than H-1, H-2, or H-3. It has 50% higher levels of built in thermal efficiency than H-1 and uses construction methods that further reduce this structures demand for raw material inputs compared to those used for H-1. For example the Scandinavian shallow foundation system reduces the amount of raw materials and energy required to construct a typical full basement.

Measures

Three environmental and three economic measures were used in this study in an effort to quantify the effects of building product choice, construction method and house size upon the environmental impacts and economic costs of house construction.

Given current understanding of the impact of human development upon the natural environment, a clear, concise operationalized definition of a "green" or "sustainable" house is not possible. For example it cannot be said that a green or sustainable house consumes less than 30 million BTUs of embodied energy and no more than 100,000 BTUs of annual operational energy, or that it consumes no more than 10 trees per 1,000 sq. ft of living space. However, we can say that a house that uses less embodied and operational energy and consumes fewer resources to build is greener than a similar structure that uses more. Thus green becomes a comparative or relative term.

The environmental measurement techniques listed here are very basic indicators. They illustrate only the amounts of raw material, embodied and operational energy requirements of various house design and building decisions. A description of each measure and reasons it was selected as an indicator of the environmental cost of house construction is included here.

Environmental Measures

The volume of raw material inputs consumed to manufacture each building product quantified the volume of raw materials that would need to be mined, pumped, or harvested from the earth to manufacture each building product. Using concrete as example, how much sand and stone would have to be dug from the ground for to produce the aggregate for each cubic yard of concrete? To produce the Portland cement required to make concrete, how much limestone, sand, bauxite, gypsum and iron ore had to be dug out of the ground to produce the cement required for each cubic yard of concrete?

As noted in the above definition given for a green house, a structure that consumes fewer resources to build has a lower environmental impact than a similar structure that consumes more. Thus this measure gives a relatively accurate indication of how green a house is based on the consumption of natural resources required to build it.

Energy consumed to operate the structure over a twenty year period was computed as follows: the amount of heating fuel: oil, natural gas, electric k.w. hours, required to supply heat for each of the three sample house's for a typical heating season was calculated. In addition the annual energy required to supply domestic hot water was also calculated. Using this annual figure as a basis, the costs of supplying energy to the structure were calculated for a time period of twenty years into the future. Dollars were held constant to 1994 values, that is no adjustment for future inflation was made.

This measure was selected as an indication of the environmental impact of a home construction for two reasons. First, the consumption of fossil fuels depletes finite reserves of this vital resource. Secondly, combustion by-products from fossil fuel use contributes to the build up of carbon dioxide in the atmosphere, a factor which may contribute to global warming. Thus it is maintained that a house that requires less energy will have a lesser impact upon the environment than a house that needs more.

In this study embodied energy figures were included for products when that information was available. For example the Portland Cement Association has conducted an analysis on amounts of energy consumed to produce cement and concrete (Wilson, 1993). This study served as the information source on the energy consumed in the production of concrete for each of the three simulation models.

PROCEDURE

Once the building products and construction methods of the eight component areas of each model were determined, a set of construction drawings for each simulation model was drawn. A meticulous estimate of building materials was then executed to determine the amount of product required for each of the five component areas within each of the three models. Information required to quantify each of the environmental and economic measures was collected from various sources, with much of the material coming from forestry, engineering and architectural texts, journal articles, reports from federal government agencies, published conference proceedings, direct conversations with individuals from various building product manufactures, researchers within industry and academia, and local building product suppliers.

<u>Procedure to quantify raw material inputs</u>

Two basic items determined in this section of the analysis were:

> What are the raw material inputs required to produce each building product?
>
> How much of each raw material input is required to produce each unit of building product?

For the first step, collected information sources (listed previously) were searched to determine what the basic raw material inputs to each building product are. For example, concrete is produced from sand, stone, Portland cement and water, and Portland cement is produced from calcium (usually limestone), silicon (clay or sand), bauxite and iron ore. Thus the raw material inputs required to produce concrete are sand, stone, water, limestone, clay, bauxite, gypsum and iron ore.

The second step, determining how much of each raw material input is required to produce each unit of building product, was much more involved and requires a more detailed explanation. Using solid sawn dimension lumber as an illustrative example, the method used to quantify the volume of raw material inputs (trees) that would be required by each model is described here. A similar method was followed for each building product.

Lumber producers, sawmills, must obtain sawlogs as the raw material inputs required to produce wood building products. Sawmills typically purchase the sawlogs they need to produce lumber from timber growers. This being so, the forest products industry has developed techniques for determining the amount of finished product that can be obtained from each unit of raw material input, that is the amount of lumber that can be produced from each sawlog. The unit of measure used to determine wood volumes in the forest products industry is the board foot, one board foot being equal to a piece of wood one inch thick by twelve inches square. Within the forest products industry, log rules, also called log scales, exist which closely estimate the amount of lumber, in board feet that can be obtained from logs of various diameter, length, and form class. Form class is the amount of taper that exists over the length of the log (Holland *et al.*., 1982). Log rules also factor in a deduction for the amount of waste that occurs from making square and rectangular shapes from cylindrical objects, and also make adjustments for waste due to saw kerf. Saw kerf is the amount of material lost due to the thickness of the saw blade as it cuts through the log.

The next step in this analysis was to estimate the number of trees required to produce the sawlogs needed to manufacture the lumber for each simulation model. Following visits to several retail lumber yards in the study area a determination was made that much of the lumber sold in this area originates from forests in the southern portion of the US. Continuing to trace the lumber manufacturing process backwards, Interviews were conducted with a forester and a statistician from the Southern Forest Products Association. To increase the accuracy of the estimate concerning the amount of sawlogs produced from a single tree, it was necessary to narrow the point of origin of these trees to a specific forest in South Alabama. Frank Stewart, a forester with the Southern Forest Products Association noted that an intensively managed private industrial forest in South Alabama has a typical tree rotation time of 40 years. During that time period, trees have commonly grown to be 14 to 16 inches in "diameter at breast height" (DBH). DBH is a term used in the forest industry to denote the diameter of a tree, measured at four and one-half feet above the ground. Using International Log Rule volume tables, allowing for a saw kerf of 1/4" and a log taper allowance of 1/2" per four lineal feet of log length, a 14" tree (DBH) will produce approximately 335 board feet of lumber.

Returning back to the four simulation models, the number and size of each piece of lumber required to construct each model was noted. (i.e.. the number of 16' long 2x10s, 16' long 2x6, etc.). These figures were then converted to board footage figures using the following formula:

$$N = P\ \frac{T(W)}{12}\ L$$

where

N= number of board feet,
P= number of pieces,
T= thickness of the piece in inches,
W= width of the piece in inches,
L= length of the piece in feet.

Thus, the total pieces of lumber for each model were converted to a total board footage figure. Then by dividing the volume of lumber required to produce each model by the amount of board feet of lumber produced by a 14" DBH tree, a determination could be made of the number of trees that would be consumed to produce each model.

To summarize: there was a basic method followed to quantify the raw material inputs for each of the building products included in H-1, H-2, H-3 and H-4. That is, first a meticulous materials takeoff of the product was executed. Next, these amounts converted into standard units used within each building product manufacturing industry. Then through information obtained from forestry, engineering and architectural texts, journal articles, reports from federal government agencies, published conference proceedings, direct conversations with individuals from various building product manufactures, researchers within industry and academia and local building product suppliers, the amount and type of each raw material input per unit of building product was determined. Through calculations it was then possible to quantify the amounts of raw material inputs required to produce each building product.

<u>Procedure followed to quantify embodied energy</u>

Several studies have been conducted within the building products industry to determine the amounts of energy required to produce various building products. (See, for example, the report done by the Committee on Renewable Resources for Industrial Materials sponsored by the National Academy of Sciences and the National Resource Council, reported in Wood and Fiber, 1976). These studies served as the information source to quantify the energy required, in BTUs, to produce each building product. Again, using wood as an example, approximately 30,000 BTUs are required to produce one 8' 2x4 (ERG, 1993, p.I.V). With this basic piece of information, calculations were used to convert this one 8' 2x4 into a board footage measure. At this point it was possible to calculate the number of BTUs per board foot of solid sawn lumber. This figure was then multiplied by the number of board feet of solid dimension lumber required by each simulation model. The results of these calculations give the total amount of BTUs of energy embodied within the solid lumber of each of the three simulation models. Similar techniques were followed to calculate the embodied energy of each building product for each of the three simulation models.

Procedure followed to calculate operational energy

Operational in this study is defined as the amount of energy required to supply the annual space heating needs of each simulation model. The calculations of annual energy consumption and dollar cost was performed using the degree-day method as outlined by Nisson and Dutt (1985). Calculations are included in Appendix G.

Procedure followed to calculate price

To quantify this measure, material take-off lists from each simulation model were taken to sample retail building supply outlets in Tompkins, Cortland and Schuyler Counties. Prices obtained from each establishment were then averaged to obtain a representative price for each product that was typical for this three county area.

ORGANIZATION OF THE DATA AND SELECTED RESULTS

When calculations were completed the data were arranged into tables. One table for each of the five component areas analyzed: the foundation, structural framing, roofing, siding, and thermal insulation components. The environmental and economic measures of each building component within the three simulation models are listed in these tables. In addition, a summary table was constructed to present overall findings for each environmental and economic measure for each simulation model.

SIMULATION MODELS

Table 1 shows amounts of product, natural resource inputs, and energy required to produce the foundation for each of the four simulation models. The use of polystyrene blocks filled with concrete to produce the H-2 foundation wall decreases the amount of concrete required to produce the same foundation as that produced with the more typical method used for the H-1 foundation. In addition the use of foam block forms decreases the amount of energy embodied within the foundation of H-2 compared to the foundation of H-1. H-3 consumes the least amount of concrete, 20 cubic yards compared to 36 cubic yards for H-2, 51 cubic yards for H-1, and 21 cubic yards for H-4. Thus H-3 consumes a smaller amount of natural resources and embodied energy than H-1, H-2, or H-4. In addition, the dollar cost of the products required for the H-3 foundation are less than that required for the H-1, H-2, or H-4 foundation.

Table 1. Foundation Component

FOUNDATION COMPONENT					
	H-1	H-2		H-3	H-4
Product	Concrete	Concrete	Polystyrene blocks	Concrete	Concrete
Amount of product	51 cubic yards	36 cubic yards	298 blocks, 898lbs. polystyrene	20 cubic yards	21 cubic yards
Raw materials consumed for concrete manufacture					
Stone	26.8 cu. yds.	18 cu. yds.		10 cu. yds.	6.5 cu. yds.
Sand	16.5 cu. yds.	12 cu. yds.		6.65 cu. yds.	4.3 cu. yds.
Portland Cement	7.7 cu. yds.	6 cu. yds.		3.35 cu. yds.	3.2 cu. yds.
Energy embodied within product	571 million BTU	446 million BTU		224 million BTU	235 million BTU
Gallons of oil equivalent	4,134 gallons	3,231 gallons		1,622 gallons	1,702 gallons
Dollar cost of product	$2,907	$5,109		$1,140	$1,197

Table 2. Floor Framing Sub-Component 1

Floor Framing Component				
	H - 1	H - 2	H - 3	H - 4
Material	wood	wood	wood	wood
Product	solid sawn lumber and plywood	Engineered wood products	solid sawn lumber and plywood	solid sawn lumber and plywood
Amount of product	5,445 board feet	4,289 board feet	1,677 board feet	1,328 board feet
Trees consumed	16 trees	11 trees	5 trees	4 trees
Energy embodied within product	47.2 million BTU	72 million BTU	17 million BTU	11.8 million BTU
Dollar cost of product	$4,744	$8,100	$2,123	$1,089.00

The floor framing component of simulation model H-1, with 2,200 square feet of floor framing constructed with 2x10 floor joists at 16 inch centers and covered with 3/4" thick plywood would consume 5,445 board feet of lumber, or 16 trees (assuming a yield of 335 board feet of lumber per tree). H-2 contains the same amount of floor framing area as H-1, however the use of engineered wood products instead of solid wood lumber decreases the amount of trees required to construct the same floor area from 16 trees to 11 trees. The manufacture of the floor framing products for H-2 would consume larger amounts of energy than the floor framing products required by H-1 or H-3. In addition the dollar cost of the framing products required by model H-2 is the highest. H-3, with 531 square feet of floor framing, requires the smallest number of trees, embodied energy and money to produce the floor framing products it would require.

Table 3. Exterior Wall Framing Sub-Component 2

Exterior Wall Framing Component					
	H - 1	H - 2		H - 3	H - 4
Products	WOOD: solid sawn lumber and plywood R-19 fiberglass insulation	ENGINEERED WOOD: 7/16" osb wall sheathing,	Polystrene: Foam core panels; expanded foam (R-22 insulation) btw. 2 sheets osb	WOOD: solid sawn lumber and plywood, R-44 cellulose insulation	WOOD: solid sawn lumber and plywood, R-44 cellulose insulation
Amount of lumber	5,128 board feet	2,592 board feet	73 panels: 1,022 lbs. polystyrene	5,448 board feet	4,380 board feet
Trees consumed	15 Trees	7 Trees			13 Trees
Energy embodied within structural component	43 million BTU	49 million BTU	51.1 million BTU	47 million BTU	39 million BTU
Insulation EE	7.2 million BTU			2.7 million BTU	2.4 million BTU
Total EE	50.2 million BTU	TOTAL FOR H-2: 100.1 million BTU		49.7 million BTU	41.4 million BTU
Dollar cost of structural component	$3,738	$5,723		$3,753	$3,037.00
Dollar cost of wall insulation	$460			$616	$552.00
Total dollar cost	$4,198	$5,723		$4,369	$3,589.00

The exterior wall framing for H-1 requires 15 trees compared to seven trees for H-2. H-1 uses the typical exterior wall framing method of stick built walls using individual pieces of 2x6 solid wood members placed at 16" centers. H-2 uses foam-core panels, 5-1/2" thick expanded polystyrene, sandwiched between two pieces of 7/16" thick OSB. The OSB skins account for the 2,592 board feet of lumber used by the H-2 exterior wall framing sub-component. The H-3 exterior wall framing sub-component consists of double studded wall constructed from solid wood 2x4 members placed at 16" centers for the outer portion and 2x3 solid wood members placed at 24" inch centers for the inner portion.

The H-4 exterior wall framing consumes two fewer trees than the H-1 exterior wall framing, and six more trees than the H-2 exterior wall framing. The H-2 exterior wall framing requires 100 million BTUs of embodied energy, while H-1 requires 43 million and H-3 39 million. The dollar cost required to purchase the products for the H-2 exterior framing is greatest: $5,723 compared with $3,738 for H-1 and $3,037.

Table 4. Interior Wall Framing Sub-Component 3

INTERIOR PARTITION FRAMING COMPONENT					
	H - 1	H - 2		H - 3	H - 4
Product	WOOD: 2x4 wood studs @ 16" o.c.	STEEL:8'x1-1/2" x3-1/2" 25 ga. steel studs		WOOD: 2x4 wood studs @ 16" o.c.	WOOD: 2x4 wood studs @ 16" o.c.
Amount of product	1,903 board feet	1,006 pounds of steel	If recycled steel is used	1,903 board feet	1,214 board feet
Natural resources consumed					
Trees	15 Trees			15 Trees	4 trees
Iron ore		1,600 lbs.	0		
Limestone		150 lbs.	0		
Coke		450 lbs.	0		
Energy embodied within product	10.8 million BTU	19.3 million BTU	7.5 million BTU	10.8 million BTU	6.9 million BTU
Gallons of oil equivalent	78 gallons	140 gallons	54 gallons	78 gallons	50 gallons
Dollar cost of product	$1,067	$1,659		$1,067	$684

H-2, using steel studs rather than wood, consumes no trees. It does consume 8.5 million more BTUs than H-1 to produce the same linear feet of interior partitions with the same number of openings. If 100% recycled steel were used to produce the steel studs the embodied energy would be reduced from 19.3 million BTUs to ?? BTUs. The H-3 interior partitions consume 1,214 board feet of lumber compared to 1,903 board feet for H-1. H-3 consumes 1,214 board feet of lumber to produce the interior partitions compared to 1,903 board feet for H-1. Thus producing the lumber required for the H-3 interior partitions would consume two fewer trees than those required for the H-1 interior partitions.

Table 5. Roof Framing Sub-Component 4

Roof framing component					
	H - 1	H - 2	H - 3	H - 4	
Product	WOOD: 2x4 wood trusses @ 24" o.c.	WOOD: 2x4 wood trusses @ 24" o.c.	WOOD: 2x4 wood trusses @ 24" o.c.	WOOD: 2x4 wood trusses @ 24" o.c.	WOOD: 2x10 rafters with 2x4 firring over eating and entrance areas
Amount of product	2,344 board feet	2,344 board feet	2,344 board feet	2,648 board feet	
Natural resources consumed					
Trees	7 trees	7 trees	7 trees	8 trees	
Energy embodied within product	21.7 million BTU	22.6 million BTU	21.7 million BTU	23.4 million BTU	
Gallons of oil equivalent	157 gallons	164 gallons	157 gallons	170 gallons	
Dollar cost of product	$2,857	$2,690.87	$2,857	$2,525.5 8	

The products and construction methods used for the roof-framing sub component vary little between models H-1, H-2 and H-3. All three use 2x4 wood trusses placed at an incremental spacing of two feet. However, H-1 uses 1/2" cdx plywood as roof sheathing while H-2 uses 7/16" oriented strand board (OSB). This difference accounts for the additional .9 million BTUs of embodied energy required to produce the building materials for the H-2 roof-framing component. H-3, although having 25% less floor area than H-1 or H-2, requires the greatest amount of product to construct, 2,648 board feet of lumber compared to 2,344 board feet for H-1 and H-2. H-3, although having 25% less floor area than H-1 or H-2 (1,122 square feet compared to 1,142 square feet) has only a 20 square feet smaller foot print (the square feet of land area covered by the house structure) than H-1 or H-2. In addition, H-3 joins a large one-story area with a smaller two-story area, while H-1 and H-2 join a large two-story area with a smaller one-story area. The H-3 roof framing also contains several roof breaks (different roof heights joined together) and also has a section of cathedral ceiling over the entrance and eating areas. The H-1 and H-2 roof framing components have no roof breaks or areas of cathedral ceiling.

Table 6. Structural Framing Component

	Summary framing component			
	H - 1	H - 2	H - 3	H - 4
Products	WOOD: solid sawn lumber and plywood	ENGINEERED WOOD STEEL EXPANDED POLYSTYRENE	WOOD: solid sawn lumber and plywood	WOOD:solid sawn lumber and plywood
Amount of product	14, 820 board feet lumber	10,231 board feet lumber 1,022 lbs. polystyrene	11,372 board feet of lumber	9570 board feet lumber
Natural resources consumed				
Trees	53 trees	25 trees	43 trees	29 trees
Iron ore Limestone Coke		1,600 lbs. iron ore 150 lbs. limestone 450 lbs. coke		
Energy embodied within products	123 million BTU	214 million BTU	96 million BTU	81 million BTU
Dollar cost of products	$12,421.00	$18172.00	$7900.00	$7,335.00

Table 6 lists the amounts of product, natural resources and dollars required to construct the structural framing for models H-1, H-2 and H-3. This table combines the information contained in preceding tables. Simulation model H-3 consumes the most trees: 53, while H-2 consumes the least: 25. The structural framing component H-2 consumes the most embodied energy: 214 million BTUs, while H-3 consumes the least: 81 million BTUs. The dollar cost to purchase the building products necessary to construct the structural frame of H-2 is highest: $18,172 and lowest for H-3: $7,336.

Table 7. Roofing Component

Roof Shingle Comparison			
Shingle durability	20 year organic asphalt shingle	25 year organic asphalt shingle	30 year organic asphalt shingle
Amount of material			
Squares	17 square	17 square	17 square
Weight	3,980 lbs.	4,028 lbs.	5,100 lbs.
Embodied energy	17.7 million BTU	14.3 million BTU	15.12 million BTU
Initial dollar cost of shingles	$374.00	$493.00	$935.00
Annual costs	$31.47	$24.83	$31.16
Total cost of maintaining the roof for a period of 30 years*	$944	$745	$935

This table illustrates the durability and cost comparisons of 20, 25 and 30 year organic asphalt roofing shingles. It uses simulation model H-1 as the method for comparing each shingle type, so that these three comparisons assume the same size and type of roof.

Table 8. Annual Space Heating Cost Comparisons

HEAT LOSS AND ANNUAL FUEL COST COMPARISONS				
Conduction	H - 1	H - 2	H - 3	H - 4
WALLS	R-19 fiberglass 17.4 million BTU	R-22 polystyrene 12.5 million BTU	R-44 cellulose 7.6 million BTU	R-44 cellulose 8 million BTU
CEILING	R-38 fiberglass 4.5 million BTU	R-49 fiberglass 3.5 million BTU	R-60 cellulose 2.9 million BTU	R-60 cellulose 3.5 million BTU
GLASS R-3.3	17.8 million BTU	17.8 million BTU	17.8 million BTU	10.7 million BTU
DOORS R-15	.7 mllion BTU	.7 mllion BTU	.7 million BTU	.46 million BTU
HEAT LOSS DUE TO INFILTRATION	16.2 million BTU	3 million BTU	3 million BTU	2.2 million BTU
HEAT LOSS DUE TO VENTILATION	ventilation supplied by infiltration	7 million BTU	7 million BTU	5.5 million BTU
TOTAL	56.6 million BTU	44.5 million BTU	39 million BTU	30.4 million BTU
AMOUNT OF HEATING OIL REQUIRED PER HEATING SEASON	410 gallons	322 gallons	285 gallons	220 gallons
Dollar cost of fuel at curent price ($.80/gal.)	$328	$258	$228	$176
Asumes a typical upstate New Yok heating season: base 65- 6,983 heating degree days. Also assumes a furnace AFUE of 85%				

DISCUSSION

The primary aims of this study were to determine the effects that various building product, construction method and house size choices have upon the natural environment. In addition the monetary cost of maintaining a house for a twenty year period and the initial dollar cost of the building materials as affected by building product, construction method and house size choice was examined.

Table 9. Space Heating Costs

Space heating fuel costs and net present value comparisons				
	Baseline H-1	H-2	H-3	H-4
Annual dollar cost of fuel oil for space heating	$328	$258	$228	$176
Total dollar cost for heat at end of seven year period	$2461	$1,935	$1710	$1,320
Total dollar cost for heat at end of 20 year period	$8,212	$6,459	$5,708	$4,406
Dollar cost of thermal insulation investment over baseline	$4,835 (Baseline)	+$1618	-$37	-$313
Net present value 7 years into the future		-$1125	+$745	+$1388
Net present value 20 years into the future		+$34	+$2399	+$3913

* Assumes an annual fuel escalation rate of 2.3%
** NPV calculations assumed an alternative return on investment of 6% annually.

The results of this study indicate that the independent variables of building product choice, construction method and house size each have an impact, although in varying amounts, on the environmental impact of new home construction. The three independent variables also effect the monetary expense of constructing a house, and then of maintaining it over a twenty year period.

The results show that building product choice does have an impact upon the environment, at least when measured in terms of the amount of raw-materials consumed. The two different products used for the H-1 and H-2 exterior wall framing component demonstrate this. Although the linear feet of exterior wall framing and the size and number of openings are identical , the exterior wall of model H-2 would consume seven trees, compared to 15 for H-1. A reduction of eight trees to construct the exterior walls of the same size and style house. The only lumber required for the exterior walls of H-2 s is contained in the interior and exterior OSB skins that sandwich the foam-core. In addition, the total weight of the expanded polystyrene foam contained in 73-4'x8' foam-core panels is 1,022 pounds: which certainly represents a much smaller amount of raw material consumption than that of eight trees, each with a diameter of 14" at 4'-6" from the ground, and each producing four-16' sawlogs.

Although polystyrene foam is manufactured from petroleum, the material it uses as its major raw material input is ethylene or ethane: a by-product from the refining process used to produce gasoline and fuel oil. Thus the petroleum by-product used to manufacture polystyrene does not increase demand for crude-oil, but actually works to allow fuller utilization of crude-oil reserves.

Building product choice does have a significant environmental impact when that impact is measured in terms of the amount of energy embodied within the products. The results of this study indicate that typical building products, as represented by those selected for model H-1, would produce a house with lower amounts of embodied energy than those selected for H-2. However, at the house-to-house comparison level, H-1 used only 17 million fewer BTUs of embodied energy than H-2, an amount equivalent to just 123 gallons of oil. Comparing the embodied energy requirements of H-1 and H-2 at the component level does show significantly greater differences. Using the exterior wall framing component as an illustration, the foam core panels used for H-2 compared with the typical method of stick built walls represented in model H-1, used considerably larger amounts of embodied energy. The H-1 exterior wall framing component consumes 43 million BTUs of embodied energy while H-2 consumes 100 million BTUs of embodied energy to produce the same amount of exterior wall. However, the foam-core panels combine two components into one. Those being the structural element of the exterior wall framing and the thermal insulation component for the exterior walls. If the embodied energy of the 5-1/2" fiberglass insulation required by the H-1 exterior walls is included with the embodied energy of the structural component, the total energy embodied within the exterior walls of H-1 becomes 57.7 million BTUs. The difference between the embodied energy of the H-1 exterior wall component compared to the H-2 exterior wall component then becomes 42. 3 million BTUs, or an equivalent of 306 gallons of oil.

The much smaller amount of concrete that would be required for the H-3 basement illustrates that a shallow foundation system can conserve natural resources. Although the footprint of the H-3 foundation is just 22 square feet smaller than the foundation footprint of H-1 and H-2 (1,120 square feet for H-3 compared to 1,142 square feet for H-1 and H-2) H-3 consumes 42% less concrete than H-2 and 59% less concrete than H-1. This reduced consumption of concrete is reflected by the reduced amount of aggregate (sand and stone) required to produce H-3 compared to H-1 and H-2.

Other impacts examined in this study show how choices in the design and construction of homes and the materials used to implement those choices can have significant environmental and economic impacts. Further research in this area may focus on methods to convert such quantitative information into easily understandable indices that would be useful to designers, builders, other housing professionals, and consumers.

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notes

SUSTAINABILITY AND THE ROCKY MOUNTAIN REGION OF THE NATIONAL PARK SERVICE

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INTRODUCTION

The National Park Service has made a commitment to environmental sustainability. The Rocky Mountain Region of the National Park Service (NPS) has addressed this commitment through the design and construction of employee housing and visitor centers which incorporate sustainable practices. A significant opportunity to integrate sustainability and affordability is now being realized through a program to design and construct over 500 units of prototypical housing to replace trailer housing in national parks throughout the country. The program intends to create housing that conserves resources and improves livability with cost conscious design and construction processes.

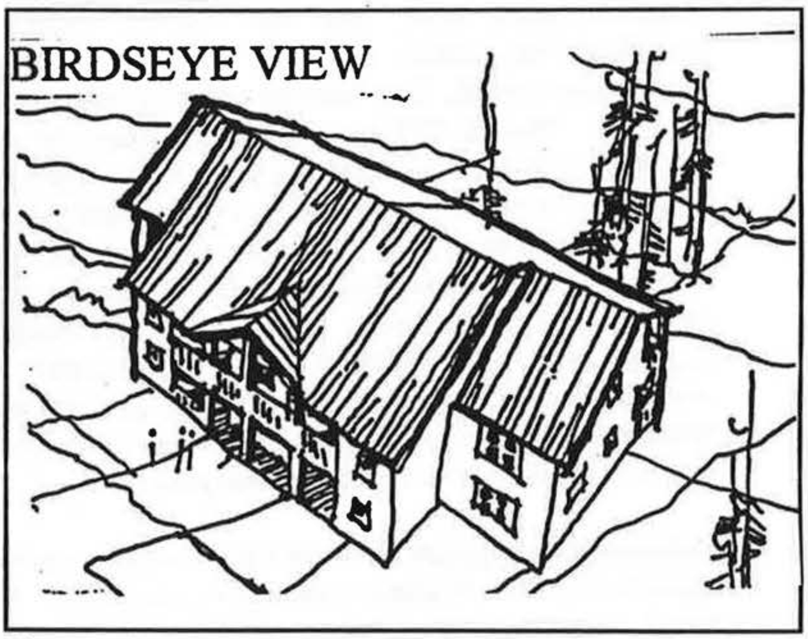

Figure 1 Housing for Trailer Replacement: 6-Plex, seasonal occupancy, 2-story, (4) 1- bedroom, (2) efficiency apartments.

One of the design team's primary goals with the replacement housing for existing trailers is to design high quality, durable, living units which minimize their impact on the local and global environment. While we have the advantage of being able to learn from and build upon the experience with recently constructed housing, the time available for design and construction of the trailer replacement housing is very tight. The design and documentation process resulting in prototypical drawings and specifications for over 20 unit types and a variety of multi-unit building designs will be completed in less than a year. Additional resource information to allow the designs to be adapted to historical, climatic and other site-specific constraints will also be created by the design team.

The design of the first housing units under this program is detailed here. We also present plans for subsequent housing which will benefit from the research performed on systems and products for the first units.

BACKGROUND

The National Park Service has approached sustainability by emphasizing energy conservation through the use of passive solar design, well-insulated and tight structures, high-performance windows, and high efficiency mechanical and electrical systems. Recently constructed modular units at Capitol Reef National Park in south-central Utah took the next step by addressing material and equipment selection relative to sustainable principals.

The modular, 2- and 3-bedroom housing units at Capitol Reef were completed in 1994. The homes are single-family, ranch-style residences with basements. Outside of the fact that they provide shelter, warmth, light, and water there is very little else that can be said about them that is conventional. They have an east/west aspect ratio which allows for greater southern exposure. There is 18% of windows per square foot in the homes with an average of 55%of the window area facing south. Along with the high-performance, low-E windows, full-height waterwalls have been incorporated into the south facade behind high-transmitting, low-iron, insulating glazing. Active living spaces are positioned to the south while the kitchen, bathrooms, and closets provide a buffer to the north. Clerestories provide sunlight as well as daylight to the north spaces. In addition, large, southerly window wells allow sunlight and daylight into the basements. The walls are structural insulated panels (SIP) and the houses were dimensioned to accommodate the SIP production sizes. This energy-conserving design resulted in 50% lower energy use last winter on a square foot basis as compared to a conventionally constructed unit in this park .

Material and equipment selection for these units was based on affordability as well as life-cycle costs, resource impact, and indoor air quality. For example, the wood skins on the SIP panels are oriented strand board which is made from small diameter, fast growing trees. The adhesives in the board are an exterior-grade, phenol formaldehyde which off-gas less than interior glues which are typically urea formaldehyde. The rigid insulation in the SIP is expanded polystyrene (EPS). EPS is blown with pentane which has an ozone depletion potential and global warming potential of zero. Carpeting is made from recycled pop bottles and the specified finishes have low VOC ratings. Water conservation is addressed in these units through fixtures which meet current federal standards, and the piping runs are all minimized. A detailed description of the units is given in Lobato 1994.

TRAILER REPLACEMENT HOUSING

Design Team Roles

The Rocky Mountain Region of the National Park Service is managing the trailer replacement housing project. They hired the Denver-based architectural firm of Barker Rinker Seacat & Partners, Architects to provide architectural and engineering services. The firm's principle responsibilities are to provide leadership to research and define housing needs and priorities; develop housing design concepts; prepare prototypical documents (drawings and specifications) for housing designs; and develop processes and resources to enable other design teams within or serving the Park Service to complete site-specific final bid documents. Enermodal Engineering is serving as the sustainable design consultant on the project. They are responsible for ensuring compliance with the 1992 Model Energy Code and NPS 76 Housing Design and Rehabilitation Guidelines, and identifying sustainable alternatives that meet structural, thermal, acoustic, regional, affordability and aesthetic criteria for the design.

Project Design Requirements

The design program requirements are established by various sources: NPS 76, national and local codes and laws regarding construction, life safety and accessibility, and specific criteria developed by the Design Team. In addition, the designs must address the following issues:

● The designs must be able to be constructed by either pre-manufactured (modular) or site-built methods.

● The designs must be adaptable to a wide variety of constraints including cultural and historical context, climatic, physical site and occupant characteristics. The sites for housing in many instances will be in-fill sites, where the building's orientation and other design parameters are pre-established.

● The designs will reflect recent NPS sustainable design criteria for energy and natural resource conservation and material choices for life cycle and environmental impact.

● The designs will be affordable.

● All housing will be constructed within the next two years.

The First Prototypes

The first housing units to be designed under the Trailer Housing Replacement Program are a 6-plex (see Figures 1 and 2) and a 4-plex in Yellowstone National Park. The 6-plex is comprised of one-

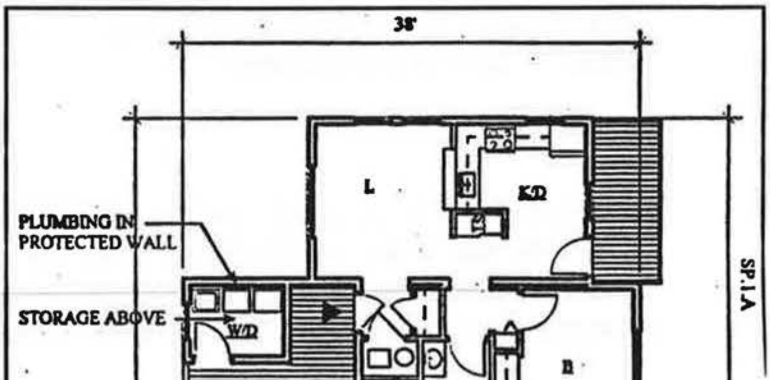

Figure 2 Floor plan of 6-plex.

bedroom units with a total of 4200 square feet. The 4-plex is comprised of 2-bedroom units with a total of 4630 square feet. The Yellowstone housing has an east-west orientation; however, the 4-plex has a 100-ft high stand of trees to the south which obstructs the sun. The 6-plex has a road to the south and takes advantage of the solar exposure. The units have 11% window area as a percentage of the conditioned floor area and 40% of the glazing faces south.

Federal housing is required to meet the energy efficient standards set forth in the 1992 Model Energy Code (MEC). Cooling is not an issue with the Yellowstone housing, so the MEC should be adequate for setting minimum insulation levels. In southern locations where cooling loads are an issue the MEC is not sufficient for addressing cooling loads. In these locations more attention will be given to glazing selection and minimizing cooling loads. NPS 76 will be met in instances where its requirements exceed the MEC.

Yellowstone sees 9125 °F-days annually and the MEC specifies a total wall U-value of 0.148 Btu/hr-ft2-°F (R-7), a ceiling U-value of 0.026 Btu/hr-ft^2-°F(R-38), and a floor U-value of 0.05 Btu/hr-ft^2-°F (R-20) over the unheated basement, or basement wall insulation with a U-value of 0.06 Btu/hr-ft^2-°F (R-17). (The basement will be heated to protect piping and items in storage from freezing. See discussion below.) The wall U-values include the windows. NPS 76 requires a ceiling R-value of 48 which will be met. Incidently, each additional R-value is worth about $0.6 per square foot annually, so we can easily show that increasing wall and ceiling R-values is cost effective.

Foundation

All concrete will be specified with 20% of the portland cement replaced with flyash. This reduces the cost of the concrete by $1-$2 per square yard although it is questionable whether or not the savings are always passed on. The flyash does retard the setting time which gives the concrete greater strength, but care must be taken when pouring in cold weather conditions.

The Yellowstone housing will have basements for storage, and will be heated to keep piping and items from freezing. Based on the MEC requirements, the floor over the basement and the basement walls will be insulated to a U-value of 0.09 Btu/hr-ft^2-°F (R-11). Because these are remote sites, the cost to deliver concrete is exorbitant so we are considering stay-in-place insulating formwork. Such systems reduce concrete requirements by 10-50%, but typically require more reinforcement than conventional concrete foundations. The cost of the forms varies between $2 and $3 per square foot and the finished wall system costs on the order of $6 per square foot (not including the interior finish). There are some outstanding issues which need to be resolved including moisture protection given that there is solid insulation between the concrete beams and a cost comparison given the low-heating requirements in the basement. With conventional construction, the floor joists and the basement walls would be insulated with fiberglass batts which is less expensive than rigid board insulation and has a substantially lower embodied energy.

Much of the housing that will be built will have a crawl space. For units which will be occupied year around we will propose a frost-protected shallow foundation. Frost-protected shallow foundations reduce excavation and concrete requirements, are simpler, and can save money. The National Association of Home Builders has developed design guidelines (NAHB 1994) for heated buildings which have recently been adopted into the 1995 CABO One-and Two Family Dwelling Code. These guidelines also cover unheated buildings. (As an aside, the Denver Building Department has recently approved frost-protected shallow foundations. The technology is being used for a residential addition and is proposed for a large public housing project. Initial estimates show savings of $300,000 from use of the shallow foundations on the housing project.)

Envelope

The walls will be 2x6 construction, 24 inches on center with 5/8 inches of oriented strand board (OSB) sheathing. We considered using sheathing made from 100% recycled paper products. The sheathing has an R-value of 1 greater than OSB and the additional cost is paid for in one year of reduced propane use. However, the sheathing does not meet lateral loading requirements so OSB will be used. A 6 mm polyethylene vapor barrier will be installed on the interior. If cellulose insulation is used, no air barrier is required around the exterior; if batt insulation is installed, an air barrier will be required. The siding is a fiber-cement product which is fire resistant and carries a 50-year, limited, transferrable product warranty. The installed cost of the product is on the order of $1/square foot.

The windows are aluminum clad wood with low-E coated glass and have a U-value of 0.4 Btu/hr-ft2-F, rated in accordance with the National Fenestration Rating Council's 100-91 U-value procedure. The ceiling is an R-48 which also proved to be very cost effective given a less than $0.1/square foot installed cost for an additional R-10 of blown-in cellulose insulation. A standing-seam metal (hot-dipped galvanized steel) roof will be used. The roof deck will be oriented strand board. The floors will be constructed with I-joists and have OSB floor decking. For the porches, wood-plastic composite lumber will be used for the decking and con-heart redwood will be used for the columns. The composite lumber costs 50% more than construction-grade redwood but it requires no maintenance and carries a 10-year warranty. With the extreme weather conditions in Yellowstone, the composite lumber should pay for itself well within 10 years.

While this is all simply stated, multiple discussions took place as to whether to build 24 inches or 16 inches on center, which sheathing and wallboard to use, the higher first cost of blown-in cellulose in the walls, how tight to build the structures, and differences in site-built and modular construction. Seismic considerations in the Yellowstone area drove structural decisions, and the requirement to design for either modular or site-built construction lead us to specify alternative products and construction methods.

For example, with the specification of cellulose insulation, the fact that modular manufacturers are not set up to install cellulose in the walls forced us to reconsider the use of cellulose. Cellulose was our first choice because it provides tighter construction and it has the highest recycled content of the available insulation materials. Modular manufacturers use a spray-on cellulose in the ceilings, but they use batt insulation in the walls. The assembly line is not set up to use spray-on insulation in the walls, so the question arose as to whether a dry-pack, blown-in system would work. Concerns over the insulation settling, especially during transportation, and over the flexibility of a modular manufacturer to switch to the dry-pack system lead us to the decision to specify either spray-on cellulose or fiberglass batt insulation.

Heating and Ventilation

As to the tightness of construction, this was one of the more difficult areas to discern. Using the MEC requirement of 0.65 ACH, we determined that we could reduce energy costs by $230 annually at the 6-plex and $250 annually at the 4-plex by reducing infiltration to 0.3 ACH. ANSI/ASHRAE 62-1989, the standard for Ventilation for Acceptable Indoor Air Quality, specifies 0.35 ACH for residences. With 0.3 ACH we would need mechanical ventilation. Baseboard heating is planned for the units with a gas-fired boiler with an AFUE of 87%, so the mechanical ventilation would require that ductwork also be installed. We estimated the cost to install 6 separate, heat recovery ventilation units in the 6-plex to be $6000. Taking into account energy savings and energy use to run the fans, the payback on the heat recovery ventilation units is more than 20 years.

What is lost from this calculation are the comfort advantages and the real cost of energy and pollution emissions. Offsetting these considerations somewhat is the fact that the units may not be occupied year around so a lower level of energy savings would be realized. Also, the installed cost for the heat recovery ventilators in the 6-plex is greater than that for the 4-plex even though the overall square footage of the 6-plex is less than the 4-plex. The calculations were done assuming $0.13 per kWh cost for electricity, $0.55 per gallon of propane, and a 9% discount rate. If we were to consider a 1800 square foot, 3-bedroom house in the same location the payback would be less than 10 years. In homes with forced-air systems the payback is even faster because there are no additional costs for ducting. In locations within the Park Service where forced-air systems will be used we will be proposing combination units which integrate a heat recovery unit with the domestic hot water heater to heat the home. No furnaces will be required and the payback will be less than 5 years.

We did not abandon tight construction completely for the Yellowstone housing. There are potential energy savings by achieving an 0.4 to 0.5 ACH level. The reduction in peak heating energy use from 0.65 to 0.45 ACH is 10,000 Btu/hr. This reduction along with the savings from the higher insulation levels reduces the peak heating load from 89,400 Btu/hr to 60,000 Btu/hr. This reduction in peak load allows us to downsize the boiler from one that has an 106,000 Btu/hr rated output to one which has an 80,000 Btu/hr rated output. The cost difference is $200. In addition, annual savings of $150 could be achieved with the tighter construction.

Interior Finishes

For wallboard we simply specified sheet rock so the contractor will purchase what is locally available. The material cost for sheet rock is a strong function of transportation costs. The closest gypboard manufacturer essentially sets the price and manufacturers only sell into an area where they can compete. There are products on the market with higher than average recycled content; however, they are either not locally available or are cost prohibitive in Yellowstone. In other locations they may be competitive.

Low VOC, water-based paints, sealers, and stains will be used on interior surfaces. Our challenge with paints was to identify the most durable, low VOC paint. Consumer Reports (1994) published an article on interior paints that ranked products relative to cost, application, and durability. Based on this information and product Material Safety Data Sheets, we chose products which meet California VOC requirements of less than 250 grams per liter.

There are alternatives for cabinetry that are formaldehyde-free, although we found that they are currently cost prohibitive for these projects. We have instead specified that all particle board be sealed, including all edges, with a water-based polyurethane.

Linoleum will be installed in the kitchens, bathrooms, and utility rooms. All living areas and bedrooms will be carpeted. Carpet with fibers made from 100% recycled PET (plastic pop bottles) has been used on park service projects and is being considered for this project. Of the more sustainable options for carpeting, there is still no clear winner. Cost-wise it is clear that either a nylon carpet will be used or the carpet made from recycled pop bottles. Installation will be a tackless system which is common for residential applications.

Water Conservation

All plumbing fixtures will meet current federal standards of 1.6 gallons per flush for the toilets, 2.5 gallons per minute for the showers and faucets. We looked at options for lower flow devices and concluded that for the toilets we would stay with the more common 1.6 gallon/flush models because of complaints with the lower flow devices. Consumer Reports (1995) covers the performance of various products on the market today to help in selecting fixtures. All landscaping will be developed to support NPS criteria of minimum impact, no irrigation, and native material only.

CONCLUSIONS

In the design of the trailer replacement housing, any new design element must meet the approval of the Rocky Mountain Region and the region in which the housing is being constructed. Early on it became apparent to the design team that our efforts had to be focused in terms of sustainable alternatives that were being presented. We chose to focus on building elements which have the most intense resource requirements, such as siding, sheathing, insulation, roofing, wallboard, paints, and heating and ventilation. Federal standards for water and NPS 76 requirements for landscaping addressed water conservation for us. We are not involved in the specification of appliances although we will make recommendations along the way.

TABLE 1 - Standard Practice and Affordable Sustainable Alternatives for the Trailer Replacement Housing

Element	Standard	Yellowstone	Next Housing Projects
Energy Design	1992 MEC; NPS 76; 0.65 ACH	1992 MEC; NPS 76; 0.45 ACH	1992 MEC; NPS 76; 0.3-0.45 ACH; Passive Solar
Foundation	Crawl Space -conventional	Basement - flyash in concrete mix; insulate with batt insulation	Crawl Space - flyash in concrete mix; frost-protected shallow foundation, stay-in-place insulated formwork
Walls	2x6 - 16" O.C.	2x6 - 24" O.C.	2x6 - 24" O.C.
Insulation	Batts	Blown-in Cellulose & Batts	Blown-in Cellulose & Batts
Sheathing	Oriented Strand Board	Oriented Strand Board	OSB; 100% recycled paper product
Siding	Varies with region	Fiber-cement	Fiber-cement
Windows	Al Clad Wood with Low-E	Al Clad Wood with Low-E	Low-E selected for climate; Frame alternatives (wood and fiberglass; vinyl)
Wallboard	Locally available product	Locally available product	Locally available product - cost effective alternatives with high recycled content
Paint / Sealers	Water and oil based	Water-based	Water-based
Floor Covering	Vinyl flooring and carpet	Linoleum and carpet	Linoleum and recycled-content or recyclable carpet
Flooring	2x10 - 16" O.C.; oriented strand board	I-joist; oriented strand board	I-joists; oriented strand board
Roofing	Regional with oriented strand board deck	Regional: Metal with oriented strand board deck	Regional with oriented strand board deck
Outside Decking	Con-heart Redwood	Wood-plastic composite for non-structural	Wood-plastic composite for non-structural; ACQ treated lumber for structural
Heating and Ventilation	Forced-air or baseboard heating	Baseboard heating; Downsized due to energy-efficiency measures	Baseboard, or Forced-Air with heat recovery ventilator - combo unit: water heater used for heating
Lighting	Incandescent	Compact Fluorescent and Incandescent	Compact Fluorescent and Incandescent
Water Conservation	1993 Federal Stds; NPS 76	1993 Federal Stds; NPS 76	1993 Federal Stds; NPS 76

Table 1 documents building practices that were standard in the national parks, what sustainable features are being incorporated at Yellowstone, and what we plan to follow-up with on the subsequent housing projects.

Relative to some of the "sustainable indicators," we achieved the following:

- Heating energy is reduced by over 30% (primarily through tighter construction) as compared to the MEC which translates into resource conservation, reduction in pollution emissions, and operational cost savings;

- Embodied energy is reduced by going to 24 inches on-center stud spacing, specifying soft insulation (cellulose or fiberglass batts) rather than rigid board insulation, and specifying flyash in the concrete mix;

- Detrimental indoor air quality effects are minimized by sealing all wood products with the potential for outgassing VOC's with water-based polyurethane, specifying water-based paints and stains; locating boilers outside the living space;

- Housing is made durable through specification of materials such as fiber-cement siding, metal roof, high-performance windows, and linoleum; and

- Affordable housing is ensured through first-cost and life-cycle analyses.

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notes

EXPLORING ALTERNATIVES TO THE DISPOSAL OF RESIDENTIAL CONSTRUCTION WASTE[1]

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ABSTRACT

The National Association of Home Builders (NAHB) Research Center has just completed the first year of a two and a half year construction waste management project funded by the EPA Office of Solid Waste. The project was designed to investigate and evaluate cost-effective, voluntary alternatives to the disposal of residential construction waste. The first year tasks included waste assessments and workshops. The waste assessments were conducted on two homes to establish baseline generation rates. The workshops, conducted in three different areas, were designed to explore obstacles and opportunities in source reduction, re-use of materials, and recycling. In subsequent work, results of the waste assessments and workshops will be used to develop and evaluate alternative waste management programs in two pilot communities. A builder's field guide and video tape will be produced to disseminate the most successful approaches to the reduction and recovery of construction waste. This paper describes the results of the project to date and the alternative management strategies proposed for the two pilot communities.

INTRODUCTION

Waste generated in the building or demolition of a home, office, road, dock, or bridge is commonly referred to as construction and demolition (C&D) waste. Estimates of total C&D waste for the United States vary considerably but center around 40 million tons per year, which constitutes approximately 20 percent of the 225 million tons of waste generated annually in the United States.[2] In the past, open burning and job-site burial of C&D waste were common and acceptable methods of disposal. When clean air and waste regulations largely reduced these means of disposal, C&D waste was taken to either municipal solid waste (MSW) or C&D landfills, depending on the tipping fees and availability of each. Rapidly diminishing MSW capacity, however, has led to reductions or elimination of this disposal option in many areas.

[1]This paper includes information from a report being prepared for the U.S. Environmental Protection Agency. All data and conclusions are preliminary.

[2]This is a rough approximation of construction and waste totals and is used for illustrative purposes only. Reliable national estimates of C&D waste are not available. Source: Peter A. Yost, "A Feasibility Study and Cost Analysis of Recycling Construction Site Gypsum Wallboard Waste", thesis submitted to University of New Hampshire (September 1993).

Additionally, many states have adopted or are considering stricter design and operation requirements for C&D landfills. These changes may result in sharply increased waste disposal costs for builders.

The construction of an average single-family home typically yields four tons of debris, and many of these materials have the potential for recovery or recycling. Although much effort is being devoted by federal, state and local governments to developing markets for recyclable MSW, little comparable time and money is focused on recovering, recycling, and improving markets for C&D waste materials. While some localities have attempted to create reclamation incentives, little or no guidance has been provided to builders and remodelers on alternatives to traditional landfilling.

In cooperation with the United States Environmental Protection Agency, the NAHB Research Center has initiated a project to demonstrate and evaluate environmentally sound and cost-effective waste reduction and recycling methods for residential and light commercial construction. This paper summarizes the key tasks of the project performed thus far, including: 1) the results of detailed waste audits of typical residential construction in three regions of the United States; and 2) the key points from workshops in the same three regions, which included discussions of waste reduction, on-site reuse, and recycling measures with representatives of local and state governments, the building and building materials industries, and private sector waste haulers.[3]

CHARACTERIZATION OF CONSTRUCTION WASTE

The first step in managing a waste stream is identifying its components and quantifying their contribution to the total stream. Only with an accurate assessment of construction waste can new waste recovery industries and channels of distribution be developed. Relatively little work has been done to assess light-frame construction waste and comparison among studies is complicated by variation in measuring units (volume or mass) and categorization. While waste volumes are important because the capacity of landfills is based on available space, weight is also important as it determines the costs of handling and transporting construction waste. The lack of standard units of measure makes extrapolation for regional or national estimates difficult.

Baseline construction waste assessments were conducted in Grand Rapids, Michigan; Bowie, Maryland; and Portland, Oregon.[4] The sites were selected based on their high level of residential construction activity, interest from a local home builders association (HBA), and an atmosphere of

[3]An additional task still in progress focuses on strategies to increase the development and ultimately the use of recycled content and/or recyclable building materials.

[4]The waste assessment in Portland was conducted for Metro Regional Services by Eco+Tech Construction Co. in 1992. The NAHB Research Center acknowledges Metro Solid Waste Department in Portland for access to all of their waste assessment data and participation in the first year of this project.

cooperation among local solid waste officials, builders, waste management firms, and building product manufacturers.

During the assessments, all construction waste was collected, separated, and weighed. One home from each site was chosen to be representative of the region based on design, size, and construction materials and practices. The results of the Bowie, Maryland assessment are presented in figures 1 and 2 below. (Detailed results from all three assessments are included in Appendix A).

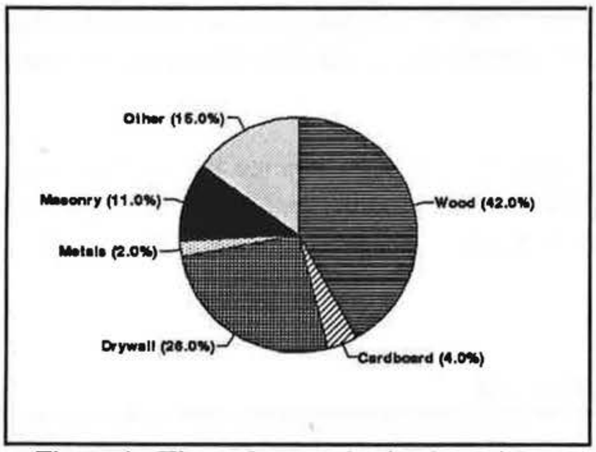

Figure 1. Waste characterization by weight - Bowie, Maryland.

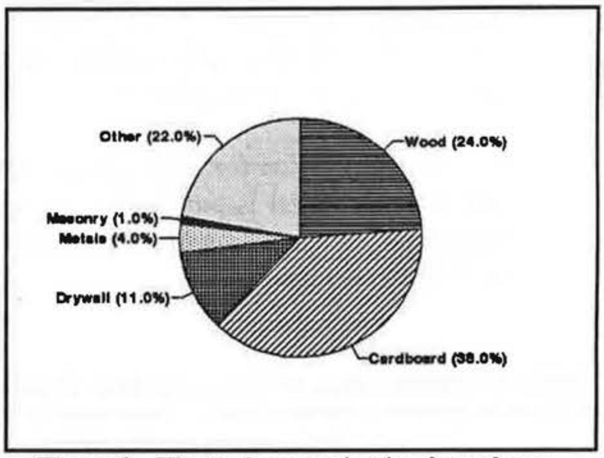

Figure 2. Waste characterization by volume - Bowie, Maryland

The results from all three sites were similar enough to extract some general conclusions:

- At all three sites, regardless of the units of measure, wood, drywall, and corrugated cardboard comprised 70-80 percent of the total waste generated.

- Despite significant differences in methods of construction and the builders' production volume, results from all three sites were somewhat similar. For example, variations in waste composition due to differences in regional building practices (a brick front facade in Maryland, wood siding in Portland, and vinyl siding in Grand Rapids) were notable, but as a percentage of the total were relatively minor. Similarly, the fact that the Maryland builder was a large production builder, and the Grand Rapids and Portland builders were small custom builders had relatively little impact on the results.

- Drywall waste at all three sites was similar to the industry rule of thumb of one pound of waste per square foot of living space.

- Engineered wood products (containing adhesives) can make up as much as 50 percent of total wood waste, an important consideration as recycling opportunities for wood are explored.

- Generation rates of corrugated cardboard waste can vary, depending on the selection of certain materials, and the proximity of suppliers. For example, local millworks (doors, windows, and cabinets) reduce the need and hence the volume of packaging; and the choice of exterior finish material (wood or brick versus vinyl or aluminum) also affects the volume of cardboard generated.

- Builders often are unaware of their *total* waste disposal cost and its breakdown. The most significant portion of total disposal costs are not tipping fees but rather the costs associated with the handling, containment, and transport of waste materials. Table 1 illustrates that the total cost of construction waste disposal at the Maryland site was essentially the same as Portland ($136.00/ton), despite a tipping/pickup fee more than twice as high in Portland. Builders need to understand their total waste management costs as they consider alternatives to disposal.

- Builders pay twice for usable construction materials that end up in the waste pile - once when the material is purchased and again when it is hauled away. Decisions regarding source reduction of construction waste must include the cost savings of avoided purchase and disposal costs.

Table 1. Translation of Construction Waste Assessment

	Bowie, Maryland	**Portland, Oregon**
Total Waste	5.1 tons	6.8 tons
Container/Hauling fee	$570.00 (2 pulls @ $285.00/pull)	$255.00 (3 pulls @ $85.00/pull) +
Tipping fee	Does not apply**	$510.00 (6.8 tons @ $75.00/ton)
Labor	$122.40 (5.1 tons @ 2.4 hours/ton* @ $10.00/hr)	$163.20 (6.8 tons @ 2.4 hours/ton* @ $10.00/hr)
Total Waste Disposal Costs	$692.40	$928.20
Total Cost Waste Disposal (per ton)	$136.00	$136.50

* national average per waste analyses from Metro, Solid Waste Department, Portland, Oregon

** $35.00/ton charged at landfill but not directly charged to builder by hauler

WASTE REDUCTION, RE-USE, & RECYCLING WORKSHOPS

In addition to the waste assessments, workshops were conducted at each of the selected sites. The workshops consisted of discussions of waste reduction measures with members from the building industry, and discussions of on-site reuse and recycling measures with representatives of local and state governments, building and building materials industries, and private sector waste haulers. The workshops were a guided discussion of: opportunities for waste reduction and the recovery of individual construction waste materials; methods of containing, collecting, transporting, and processing the materials; and development by manufacturers and use by builders of recycled content building materials.

Some key points from the workshop sessions focusing on waste reduction included:

- Although numerous waste reduction methods were discussed with building industry members, those present did not see any of the methods resulting in significant waste reduction. Design-oriented opportunities, such as overall dimensions, house configuration and the layout of doors, windows and stairs, raised concerns among some builders regarding the marketability of "value-engineered" houses which can be labeled by competitors as inferior. The consensus was that effective reduction of waste could only be achieved through a comprehensive re-education process involving architects, engineers, builders, and inspectors.

- Although the builders were skeptical that waste could be reduced via hands-on, technically-based construction techniques, many added that structuring subcontracts to include a supply-install concept (i.e., create a direct link between material purchaser and installer) resulted in the generation of less waste.

- Many builders are interested in alternatives to disposal, as long as the alternatives do not result in increases in their costs, i.e., disposal options are usually pursued for economic gain before environmental gain. In many cases, recycling is driven not by the value of the materials (a market pull), but rather by the avoided cost of disposal (a market push). In fact, perhaps the most significant impediment to the development of recovery opportunities is the low value of many construction site recoverables.

The workshop sessions focusing on the on-site re-use and recovery of waste materials included both a material-specific discussion and a general discussion on methods of recovery. Some key points included:

- ***Wood*** - Recycled wood, without market structures in place and with significant processing costs, can not compete with sources of virgin wood fiber in the production of building materials. Nonetheless, some counties currently accept source-separated wood waste at a reduced tipping fee (A facility in Prince George's County, Maryland for example accepts pallets, brush, and "untreated" wood for eventual sale to mulching operations). However, because there is some controversy as to the acceptability of engineered wood products for mulch because of adhesive content, and a significant portion of the wood waste generated in residential construction is engineered wood (see Appendix A), the possibility of topsoil-applied new-construction wood waste is uncertain. Research needs and opportunities regarding the suitability of glue-containing wood products for various agricultural uses from an environmental, health and safety standpoint were discussed at the Prince George's County workshop.

- ***Drywall*** - Recycling of drywall into new wallboard is only feasible in areas of the country close to certain wallboard manufacturing plants that have or can easily add the technology required to handle waste wallboard processing. One manufacturer, for example, has 140 building product distribution centers nationwide that could become involved in the recovery of waste gypsum wallboard if cost-effective methods of handling the materials can be established. Additionally, some research on agricultural and/or topsoil application of ground gypsum has been done, but no studies to date have addressed any potential hazards from trace organic compounds such as heavy metals or dioxin from the paper content in waste gypsum wallboard. The Gypsum Association is just embarking on a research effort to address this issue with the USDA Agricultural Research Service. Depending on the results of this investigation, certain agricultural and topsoil uses of waste gypsum wallboard may become formally acceptable as an alternative to disposal of this material.

- ***Corrugated cardboard*** - The market value of cardboard is changing this material from a waste to a good. With a current market value (baled) of approximately $100/ton, and strong interest among waste hauling firms, this material is a likely candidate for cost-effective recovery.

- ***PVC Building Materials*** - Although plastic wastes have relatively high value and well-established market structures, the amount typically generated during the construction of one home (see Appendix A) would not by itself justify the processing and transporting costs for this material's recovery. If, however, this material can be accumulated into large enough amounts, arrangements could be made to recover the material, via either intermittent pickup, or collection containers at building supply centers.

Specific methods of recovery presented and discussed at the workshop included:

- ***Commingled Processing*** - Commingled recovery processes involve separation and recovery of the materials off the construction job site. The waste is generally contained and collected in the same roll-off containers used for construction waste disposal. Materials are recovered by mechanical or manual separation. If markets exist for cardboard, drywall, and all uncontaminated wood waste, then conceivably 70 - 80% recovery rates are obtainable. The advantage to this approach is that no change in operation is required for the builder - construction waste is handled in the same manner as for disposal. The disadvantage to this approach is that separation costs reduce the net value of the recovered materials, and contamination resulting from commingling (dirt, dust, spilled paint, etc.) can render some materials unrecoverable or not worth separation. Additionally, significant capital investment is required to initiate and operate such a facility.

- ***Source Separation*** - Source separation involves individual containers on the construction job site with materials identified for recovery going into designated containers. This approach involves the greatest change in waste management practices for builders and all of their subcontractors. Prior experience has shown that the general contractor must aggressively educate all job site workers, with requirements to separate the materials written into subcontracts. A commitment is required not only of upper management, but of the supervisors as well to make the separation effort work. Prior experience has also shown that the educational and retraining efforts must be ongoing for up to a year before the system begins to be self-managing. The advantage to this approach is that easily separated materials are kept so and contamination from commingling is eliminated.

- ***Passive Time Separation*** - Passive time separation of materials takes advantage of the fact that certain construction materials - wood, drywall, cardboard (to some extent), and siding materials - are generated during specific and discrete stages of construction. If job site service by the waste hauler can be coordinated with the construction cycle, waste materials can be passively separated over time. This method is used by an increasing number of builders in both Portland, Oregon and surrounding areas of Chicago. Because this method is significantly less expensive than other waste management approaches, charges for the service can be determined up front on a square foot basis, and an employee (laborer to clean up job sites and place construction waste in the roll-off) can be eliminated from the general contractor payroll. The disadvantages of this approach may be that: 1) this approach is not likely to interest large, well-established waste hauling firms and, hence, require new entrants to the business of waste management; and 2) building and OSHA inspectors may adversely react to a container-less approach to on-site waste management.

- ***Re-use of Construction Waste Materials*** - Non-profit building materials recycling operations recover used building products and rejected building materials for discounted sale to low-income homeowners. For example, The Loading Dock in Baltimore, Maryland is the oldest retail business of its kind in the nation and has served as a model for the establishment of numerous similar operations around the country. Any material given to the Loading Dock, whether picked up by The Loading Dock or delivered by the builder to the Baltimore warehouse, represents a tax-deductible donation. Similar operations were identified in Portland and Grand Rapids.

  On-site re-use of wood, drywall, and possibly cardboard may be possible after the materials have been processed in a mobile grinder. At least one manufacturer markets a low-speed, low-noise, mobile grinder well-suited for this method. The acceptability of on-site application with state and local sold waste officials can vary and may depend on research into the suitability of individual waste components for on-site application as noted above.

FUTURE WORK

A primary objective of this phase of this EPA-funded project has been to identify barriers and opportunities related to voluntary and cost-effective residential construction waste management. This has led to: 1) a detailed characterization of the waste materials generated on typical residential construction sites, 2) an understanding of the importance of involving *all* of the potential players in construction waste management, and 3) an understanding of strategies that could be used to reduce construction waste from these sites.

With this information, pilot programs designed to test and evaluate selected techniques will be conducted during 1995. Elements of the programs will include:

- A focus on wood, cardboard, and drywall recovery opportunities
- Supply-and-install contractual relationships with subcontractors, creating a direct link between material purchaser and installer
- Continued investigation of on-site re-use of both clean wood waste and drywall as a soil amendment
- Assistance to waste haulers/processors and builders in determining the costs and feasibility of commingled processing, source separation, and passive time separation methods of waste management
- Fenced or other container-less designated areas for construction waste on job sites and issues related to this waste management technique

More definitively, discussions with waste processors and product manufacturers at the workshops in Michigan and Maryland have led to several region-specific developments:

- Through funding from the Gypsum Association, research by the USDA Agricultural Research Service should formally determine the acceptability of waste gypsum wallboard for certain agricultural and topsoil uses.
- The Research Center is working with the American Plywood Association (APA) to determine the nature and need for research on the suitability of engineered wood products for topical application either on-site or in mulching/landscaping operations.
- United States Gypsum has a plant in Baltimore, Maryland which will accept drywall cut-off waste from new construction sites as part of the Prince George's County, MD pilot program.
- Certainteed will be working with the Research Center in the Grand Rapids, Michigan pilot program on the potential for recovery of vinyl siding cut-off waste.
- Alcoa Building Products will be working with the Research Center on the potential for metal and vinyl siding cut-off waste recovery in the Prince George's County pilot program.
- Local builders, waste haulers, and waste processors in both communities will participate in the pilots and be an integral part of the evaluation process.

The results of the pilot programs will be used in the development of both a builder's field guide and a video tape on construction waste management.

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`THE IDEAL HOUSE: INTEGRATING AFFORDABILITY, ENERGY AND ENVIRONMENTAL EFFICIENCY, AIR QUALITY AND DISASTER RESISTANCE

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ABSTRACT

Much has been researched and written about the individual qualities of good home design and construction in terms of energy efficiency, affordability, indoor air quality, sustainability and wind, fire, and flood resistance. The real challenge is to integrate all these characteristics into the ideal house. The purpose of this paper is to review the characteristics of each of the above features and explore the integration of them into the ideal residential structure. The house would take the shape of a compact two-story structure. The first floor would be constructed using an insulated, strong, high thermal mass masonry system resistant to flood, wind, fire, and termite damage. The second story would be constructed using a lighter reinforced wood frame system with between stud insulation coupled with exterior insulated sheathing to minimize thermal bridging across studs. A geometrically compact structure uses less construction materials per floor area, presents less area for improved thermal efficiency, and less profile for wind and flood resistance. Optimizing floor plan living and sleeping areas present opportunities for efficient split HVAC zoning, natural ventilation, and solar passive adaptation. The design would emphasize the 4, 8, and 12 foot dimensioning for waste reduction, selection of environmentally friendly building materials, such cellulose insulation, and efficient lighting and appliances. Features providing improved indoor air quality such as duct selection, design and location; radon barriers, omission of carpeting, ventilation, and control of moisture would be addressed. The design philosophy, concepts, and rationale for the integration of these and many other features of the ideal residence will be addressed in this paper.

INTRODUCTION

Once upon a time in the near future, there was a house that was everything a house could be. It was energy efficient, comfortable, affordable, easily maintained, contributed favorably to the environmental quality of the area, strong, and durable; capable of withstanding violent winds and floods. Although it may sound like the beginning of a fairy tale, the design and construction of such a house is feasible. Integrating affordability, energy and environmental efficiency, air quality and disaster resistance in a building is no small task. Often one factor impacts other factors in a building design.

DISCUSSION

When designing the ideal house the major concept boils down to simple geometry. The emphasis should be to maximize the living area and minimize the external surface areas. The concept of geometry impacts on all factors under consideration. By using a compact design we present a smaller profile to fires, insect damage and most natural disasters such as hurricanes, tornadoes, and floods. We also use less building materials, energy and natural resources for construction which improves the affordability and environmental impact. Let's examine the concept of geometry a little closer.

Geometry: When looking at energy efficiency in a building, geometry has an impact on a lot of the current formulas used for conduction, convection and radiation. Heat is transferred from hot to cold by conduction, convection and radiation which may be expressed by the following formulas:

Conductive heat transfer can be expressed as: $Qcd = A \times 1/Rt \times (T_2 - T_1)$; Where QCd = Quantity of Conductive Heat Transferred (Btu/hr); A = Area of Surface (ft^2); Rt = Resistance to Heat Flow, Total (ft^2 OF hr/Btu); and $(T_2 - T_1)$ = Temperature Difference Across Surface (°F).

Convective heat transfer (sensible) can be expressed as: $QS = V \times Sh \times DA \times (T_2 - T_1)$; Where Qs = Quantity of Convective Heat Transferred (Btu/hr); V = L x W x H = Volume of Air Movement (ft^3/hr); Sh = Specific Heat for Air (0.24 Btu/lb); $(T_2 - T_1)$ = Temperature Difference of Air Masses (°F); so $Qs = 1.06 \times CFM \times (T_2 - T_1)$ sensible heat transfer (Btu/hr).

Radiant heat transfer can be expressed as: $Qr = A_1/A_2 \times a_1 \times e_2 \times (T_2 - T_1)^4$; Where QR = Quantity of Radiant Heat Transferred (Btu/hr); A_1/A_2 = Ratio of Apparent Areas; a_1 = Absorption Factor of Receiving Surface; e_2 = Emissivity Factor of Transmitting Surface; and $(T_2 - T_1)^4$ = Temperature Difference Between Surfaces (°F).

Homes of compound shapes, that is with courtyards, different angles, and a long length-to-width ratio will inherently use more energy and generally cost more to purchase than homes with simple shapes. A two-story home that is relatively square may have 28 percent less surface area for heat transfer and less exterior construction materials than a long, narrow ranch home of the same square footage. A two-story offers more opportunities for cross-ventilation and zone air conditioning. We also make better land use and have less environmental impact. There are many relatively compact two-story shapes that have nice architectural lines provided by positioning of unconditioned porches, garage, workshops, etc. So by reducing the area component of the building, particularly the surface area (walls, and roof), we impact favorably on the energy use in the building.

Affordability: A definition of affordability is now in order. Too often we think of the affordability or cost of home ownership as equal to the principle interest and taxes. Other factors need to be entered into the affordability equation which could be expressed:

$A = (P+I+In+t) + O + M+SI (E) + T$; where

A = affordability; P = principle; I = interest; I = insurance; t = taxes; O = operational costs, such as utilities; M = maintenance costs; SI = societal impacts (environment); T = transportation to and from work, entertainment, shopping, etc.

Owners are obligated to pay off the interest, taxes and principle on a residential buildings and it is prudent or required by the mortgage company to have insurance. Then there are maintenance costs. Many of us fail to consider the operational or energy costs and the other utilities to operate the house. Even fewer of us consider the societal impacts or the externalities, which is the latest buzz word for environmental consequences. We must not overlook the cost of transportation to and from homes, schools, entertainment centers and so forth. During the middle ages in Europe, transportation costs was not a factor. Most people could walk to their business, entertainment and shopping within ten minutes. Proprietors often lived above the stores that they operated. Modern Americans, on the other hand, often travel tens of miles to their places of employment, places where they shop or entertainment centers. Many people now live in what is called the urban fringe. Too often people spend more for transportation to and from business, shopping, schools and entertainment than they pay for energy to operate their homes. Therefore, constructing the ideal home would include selecting a site that is convenient and presents a good passive solar orientation.

Energy Efficiency: Referring to our affordability equation: Considering the (O) portion of the affordability equation, A = (P+I+In+t) + O + M+SI (E) + T, it is possible to spend more for utility bills over a typical 30 year mortgage life than for the principle and interest on the loan. Lower utility costs place the buyer in a better position to make mortgage payments, a factor some banks will consider when qualifying a buyer.

The purchase of an energy-guzzling home can lead to startling expenditures, especially when considered over a 30 year mortgage period. For example, such a home might cost $85,000. If a conventional 30 year mortgage is secured with 20 percent down, $68,000 would need to be financed. At 10 percent interest, monthly payments would amount to approximately $1,025 for 360 months, totally about $369,000. Adding this to the $17,000 down payment, results in a grand total of $386,000 for principle and interest over the 30 year mortgage period. Owners of less energy efficient homes in this price range may pay an average of $195 per month or more for utilities. Assuming $0.08 per kilowatt hour and $0.65 per therm for natural gas, if the cost of utilities escalates at seven percent a year, as some experts estimate, the owner could pay about $221,000 for utilities during the 30 year mortgage period. Therefore, the owner could pay almost 60 percent of the principle and interest on the mortgage loan for utilities. If the designer or the contractor has wisely chosen energy-conserving measures, a significant reduction in energy costs could be achieved with little or no extra investment. Even if a builder makes a $2,500 investment in energy-conserving features, this will only add about $38 a month to the mortgage payment, but may actually reduce the utility bill by as much as $60 per month. Considering the escalation of utility costs over a 30 year mortgage life, this could lead to a savings of $54,320. Another factor to consider is that money saved through energy conservation is after tax dollars; that is, a savings of $1,000 a year in energy costs equates to $1,200 a year before taxes if one is in the 20 percent tax bracket.

Disaster Resistance: Building strength into a building can save resources and reduce environmental impact. It could be said that Hurricanes Hugo and Andrew devastated thousands of acres of forests in the northwest and southeast. This was the indirect destruction caused by the cutting of replacement timber necessary to rebuild coastal South Carolina and south Florida homes. Many construction professionals conclude that good design and construction could have reduced much of the damage caused by Hurricanes Hugo and Andrew. In some cases, the extra costs would have been limited to a few dollars if extra nails had been used or more attention paid to details. The cost of these omissions has been placed over 30 billion dollars and includes loss of valuable natural resources.

In addition to using valuable forest resources, the rebuilding effort takes a tremendous amount of energy to transport and process raw timber into finished products such as concrete block, steel, aluminum, glass and other materials used in construction.

The approximate energy needed to produce various building materials ranges from 17.4 million Btu/ton (MBtu/T) glass for windows to 219 MBtu/T for the aluminum used to manufacture their frames. So when we build strong, durable buildings, we save energy and reduce the impact on the environment.

The energy needed to produce the construction materials in a 1960 square foot residential building (exclusive of furnishings and appliances) is approximately 271.7 M BTU (Table 1). This is equivalent in energy to almost 47 barrels of oil, or about two years of energy used to generate the electricity needed to operate appliances and lighting in the average house.

There is an expression in the construction trade: "measure twice, cut once." It is important that the job be done correctly the first time. It takes energy to manufacture, transport and install almost every building material such as aluminum frame windows, asphalt shingles, 2x4s and plywood.

Table 1
Approximate Energy Used in Construction Materials for a 1960 Square Foot Residential Building*

System	Materials	MJ	BTUs
Exterior Walls	4" face brick 2"x4" stud, 4" insulating sheathing	126,200	119,620,000
Glass Windows	17.5% wall area, 1/4" single pane	3,400	3,223,000
Interior Walls	3/8" gypsum, 2"x4" studs, 1/4" plywood panels	12,300	11,659,000
Floor (off grade)	1-3/16" hardwood, 3/4" subfloor, joists, w.f. beam	60,000	56,872,000
Foundation, 30" stemwall	30" concrete block with 12"x12" concrete footer	14,860	14,085,000
Roof	asphalt shingles on 1/2" plywood, rafters, joists	69,900	66,256,000
Total Energy in the	building materials =	286,660	271,715,000

*Adapted from Wong and Sauer, 1983.

Energy resources are finite and costly. It is important to conserve and use them wisely, saving our money in the process.

As the saying goes, it doesn't take a rocket scientist to understand structural integrity. The concepts of a strong home or building are simple:

- a strong foundation firmly bonded to the ground
- strong walls bonded to the foundation
- a strong roof bonded to the walls.

A weak link in any of these three areas could cause the home to be severely damaged or destroyed. Most of the damage caused by Hurricanes Hugo and Andrew was not caused by weaknesses in the building code, but by omissions of the builders and inspectors.

Wind Force Phenomena: Hurricane winds start at 75 mph. At this speed, winds can produce a direct force of almost 15 pounds per square foot on a perpendicular surface. So theoretically, a 2,514 pound force could be exerted on an 8-foot x 20-foot (160 square foot) wall by a 75 mph wind blowing directly on it. But the pressure exerted by wind increases exponentially so that a 150 mph wind could exert a pressure of 60 lbs/sq. ft. or 9,600 pounds of force on the same wall. Consequently, it would be extremely difficult to protect a home or any building from major damage against winds in excess of 150 mph. The direct force of wind on a vertical component of a building (p), in pounds per square foot (lbs/sq. ft.), can be expressed by the formula:

$p = (\partial V^2)/2g_c$; where p = pressure in lb/ft^2; ∂ = density of air = 0.077 lb/ft^3; g_c = gravity constant or 32.17 ft./sec^2; V = velocity of air in ft/sec

So at 60 mph, $p = \dfrac{(0.077)(88)^2}{2 \times 32.174} = 9.2$ lb/ft^2

at 75 mph, $p = 14.4$; at 120 mph, $p = 36.8$ lbs/ft^2; and at 180 mph, $p = 82.8$ lbs/ft^2.

As the wind passes around a building, a vacuum is produced on the leeward side which pulls the building. So on the windward side the wind produces a force trying to push the building over, and on the opposite side a vacuum tries to pull the building over. Another interesting phenomenon is that wind can be deflected by trees and other buildings so that wind forces are rarely direct Wind directions constantly change, which produces constant tugging, twisting and bending forces on a building. These are called **dynamic forces**, or forces associated with motion. All these forces and directions should be addressed in a building that has good structural integrity.

If, during high winds, a window breaks or a wall is penetrated by debris, pressurization of the home can occur. An opening as little as 2% of the wall area on the windward side of an enclosed building can result in full pressurization of the home. This could be analogous to blowing up a balloon. Theoretically, the force tending to blow the house apart due to pressurization could reach as high as 34 lbs/sq ft with hurricane force winds of 120 mph blowing directing through a broken window. The converse is true with an opening on the leeward side of the building. This will tend to create a vacuum on the interior. By the way, experts recommend windows be kept tightly closed at all times during high winds. This contradicts a well-established myth suggesting windows on the lee side be opened during a tornado.

Minimizing the profile will reduce the pressure on the building from wind and flood and risk of being hit by flying debris.

Thermal Mass: Massive buildings, such as those built with concrete block, have the capacity to store great quantities of heat, thereby delaying heat transfer in or out. Heavy buildings with thermal mass or thermal inertia have good thermal stability and resist temperature change. Thermal mass can be defined as the characteristic of a material to resist temperature change due to its own capacity to store heat. Concrete, concrete block, building brick, steel and water have this characteristic in varying amounts. Thermal mass can effectively dampen or average outside temperature extremes.

In construction, thermal mass is generally measured by its heat capacity, that is, its ability to store heat per unit volume. For example, one pound of dry air has about the same net heat storage capacity as one pound of concrete, but one pound of solid concrete occupies less than 1/100th of a cubic foot while a pound of air occupies about 14 cubic feet.

Concrete is extensively used in both commercial and residential construction. Theoretically, warm air at 90°F inside a 1,500 square foot super-insulated home could be cooled to 75°F with just 27 concrete blocks at 60°F. There could be as many as 2,160 blocks in such a home representing tremendous thermal storage capacity.

Properly enhanced with shading and outside insulation of R-6 or more in cold climates, thermal mass can make a building more energy efficient than its lightweight frame counterpart because:

1. Air conditioning and heating loads can be deferred to off-peak rates. (Thermal lags as long as 12 hours can be obtained.)
2. Heating and cooling systems can be sized smaller (temperatures of massive materials never reach outside design extremes.)
3. By preheating or cooling, the heat storage capacity of the thermal mass can provide extra conditioning to carry over peak conditions.
4. The seasonal efficiency if air-cooled air condition systems can be improved through a reduction of operating hours during high daytime temperatures.
5. The non-heating and cooling seasons can be extended from three to eight months due to the temperature damping effect of thermal mass.
6. In some cases the phenomenon known as "thermal wicking" of stable ground temperatures can be effective.

Many Florida homes were built in the 1950's and 60's using concrete block systems (CBS) without insulation. From an energy performance standpoint, they often did better than frame homes without insulation. Midway through the 1970's we found it imperative to use insulation in Florida buildings because of soaring energy costs. The questions is not to use insulation but where to apply it and in what quantity?

1. For buildings with long occupancy profiles (homes, apartments, hotels and most commercial buildings), placing at least R-6 rigid closed cell insulation on the outside of the thermal mass is the best option. A 1,500 square foot CBS home could have 2,160 blocks weighing more than 70,000 pounds. Add another 60,000 for a 4" slab.

This concrete mass equates to about 31,000 BTUs per degree Fahrenheit of thermal capacity. Precooling the walls to 73°F, for example, and then letting the temperature rise to 78°F could provide the equivalent of over 10-ton hours of cooling. This capacity paves the way to be used as a load management tool to get over peak periods. By extending the outside insulation 3' or more below grade, thermal storage can be maximized even further. In many Florida locations ground temperatures below 3' tend to stabilize between 69°F - 76°F. Extending insulation several feet below grade traps this heat sink and, in some cases, a favorable heat transfer can be wicked up in the winter and down in the summer through the slab and walls.

2. For buildings with short occupancy profiles (auditoriums, churches), placing R-8 to R-11 rigid or batt insulation on the inside is the better option. Temperatures of massive structures tend toward Florida's mild average temperatures allowing better discrimination of heat and cooling. For example, the average temperature in Miami and Tampa during the hottest month (August) is only 83°F. With the temperature in the structure approaching this average, most of the cooling capacity can be dedicated to cooling the internal load (occupants) instead of heat gained through the building envelope.

3. To further enhance the benefits of thermal mass in Florida, for example, it is necessary to minimize direct solar heat gain by shading the proper building orientation. Overhangs, landscaping, sun screens, and Bahama shutters are effective ways to employ shade. If possible, orient the long sides of the building to face south and north instead of east and west. Not all locations in the country are as well suited for thermal mass as Florida. Florida's mild ground and average temperatures contributes to its success.

IAQ Checklist for Building Professionals: There are many causes of poor indoor air quality in buildings and there are many techniques that can mitigate the problems. The list presented is by no means complete, but does address the more common problems associated with sick buildings. If these suggestions are followed, it may save a considerable amount of natural resources, energy, litigation, and could improve the reputation of any building professional.

Building Envelope Design and Construction Considerations:

1. Emphasis should be placed on elimination of pollution sources rather than relying on ventilation air dilution intended by ASHRAE 62-89 proposed standard.
2. Design the building to provide maximum usable area with minimum surface areas (squares and cubes) translates to better IAQ, less building materials, and less heat transfer surface.
3. Tight building construction practices should be employed. Roofing and wall system should prevent water intrusion and provide for water exit from building. Weather strip and caulk around windows, doors, plumbing and wiring accesses through the building envelope. The exterior structure should be tight enough to prevent the outside air entry.
4. Vapor retarders, including vinyl wall coverings, important for preventing moisture problems in stud spaces in cold climates, should never be used on the inside of exterior walls in hot humid climates such as Florida otherwise mildew growth and wetting of the insulation result.

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5. The plastic vapor seal under concrete floor slabs should be installed with holes or tears sealed before the concrete is poured. Use a 6 mil black plastic sheet for ground cover below off-grade structures (seal seams and to stem wall as appropriate) to prevent moisture and toxic soil gas entry.
6. For high radon areas to prevent entry: use crushed rock or course sand to provide gas communication under building and foundation, then use high density plastic gas retarder between this fill and building.
7. Allow drying of construction materials and the structure prior to sealing and painting.
8. Use guttering and down spouts to carry rainwater away from building to reduce the opportunity for rain to seep under and enter building.
9. Consider installing a central vacuum system with an outside exhaust .
10. To minimize hydrocarbon and other VOC transfer prevent air from garage and workshop areas from entering occupied areas of house and building.

Heating, Ventilation and Air Conditioning (HVAC) Design, Operation and Care:

11. In general, a positive air pressure should be maintained within a building, particularly commercial buildings. Portions of a building identified to have potential indoor air pollution problems (i.e., copy rooms, garage, etc.) should be kept under negative pressure, exhausting well away from other portions of the building.
12. Carefully control ventilation which should be conditioned and filtrated such that the indoor air is maintained at a temperature between 70 to 78°F and 30 to 60%. Ventilation should be kept to the absolute minimum necessary to provide proper indoor air quality and a uniform carbon dioxide level below 1,000 parts per million.
13. The HVAC system should be sized for the expected sensible and latent load.
14. For residential and other applications having a fan selection on the cooling thermostat, the fan should be kept in the automatic position.
15. Bathroom exhaust fans should have humidity sensors or 20 minute timers to best remove moisture from the tub and shower area.
16. When moisture problems in a building are recurrent, consider the use of innovative heat pipes, hot gas bypass, or desiccant moisture exchange technologies. First, make sure major moisture sources have been addressed. Dehumidifiers are costly and not energy efficient.
17. Be skeptical of ozone generators as a method of reducing indoor air pollution.
18. Smokers should only be allowed to smoke outside or in designated areas with dedicated HVAC systems and under negative pressure with respect to adjacent spaces.
19. Air conditioning filters should be changed regularly. Treating filters with germicides, fungicides or deodorizers should be done with caution and only with EPA approved substances. In general, HVAC filters are designed to protect equipment, not people. High efficiency particulate air filters (HEPA) may restrict air flow if used as a retrofit on existing equipment. Using medium efficiency filters or room air cleaners with HEPA filters and activated charcoal may be a better option.
20. Periodically examine the air conditioner drip pan to make sure that the drain is not clogged. Also, drip pans should be treated with the proper air conditioning germicides to prevent bacterial growth.

Duct Design and Installation Considerations:

21. Return air and ventilation air intakes should be placed well away from moisture and potential pollution sources such as garbage dumpsters, cooling towers and loading docks. Roof intakes should be placed well above the roof mildew prone surface.
22. Unlined or uncoated fiberglass ducts are a potential source of mold and air quality problems and should be avoided. Galvanized steel ducts insulated and wrapped with a vapor retarder on the outside are preferred.
23. Avoid fiberglass insulation where the fiberglass particles may come in contact with humans either from ventilation carrying the particles or by direct contact.
24. Use air doors and smoke sticks to identify leaks, and then seal leaks in AC duct work with approved acoustical sealing or mastic.

25. For residential applications, consider return air ducts or doors with proper undercutting or lovers for bedroom areas.
26. For residential applications, provide air circulation into and throughout closets with such things as louvered doors, open shelving and AC registers.

Interior Design Considerations:

27. Avoid indoor water fountains and pools and water-guzzling indoor plants (cactus okay). Fountain water evaporates to increase humidity.
28. Avoid deep pile carpets particularly those imported which may contain formaldehyde as fix for dyes. Deep pile carpeting tends to be a haven for dust mites, fleas, human dander and other irritants which can never be totally removed. Fabrics suspected of containing formaldehyde should be washed and dried for an extended period of time before installation.
29. Avoid furniture and paneling containing particle board and plywood constructed with interior glue or urea resins which contain formaldehyde.
30. Select furnishings that have low moisture absorption capability, such as wicker, cane, glass, steel and ceramic tile.
32. Schedule painting (Low or no VOC's) and heavy cleaning during periods of low occupancy.
33. Use insect baits instead of chemically treating with insect poisons.

Landscape Considerations:

34. Do not locate hedges or shrubbery too near the building which can create a micro climate much more severe in terms of humidity than reported by the weather bureau.
35. Consider low maintenance landscaping and drip irrigation systems

Integrating the Concepts:

Floor Plan: As mentioned the floor plan should take advantage of maximizing the floor (living) area while minimizing the surface (wall, roof) area. In addition precut studs and standard 4', 8', and 12' dimensioning should be used to minimize waste and environmental impact.

In hot climate regions the kitchen should be located on the northeast or east side of the home, if practical. The reason for this is that most of the heat-producing type of cooking is done for the evening meal, and this internal heat build-up tends to become quite localized in the kitchen. If the kitchen is placed on the west side of the home, the afternoon heat contribution from the sun can worsen the problem, making the kitchen and adjacent dining room very hot. This tends to force the occupant to turn the thermostat to a lower setting to compensate for the heat build-up. In the process, the whole house will be excessively cooled just to satisfy the required comfort level in the kitchen and dining room areas. If the kitchen and dining room are located on the east or northeast side of the home, the sun's impact will be minimized as those areas tend to be the coolest portion of the house in the late afternoon. If the house is two-story and the bedrooms are located upstairs, this offers an opportunity for nighttime cooling, cross-ventilation and zone air conditioning where the upstairs bedrooms could be cooled or heated only in the evening and the downstairs unit turned off. In the daytime the upstairs air conditioning unit could be turned off, while the downstairs unit is turned on. This strategy is effective during periods of low humidity if mildew is not a problem.

Foundations: The recommendation to "build your home on solid rock" is thousands of years old. Million dollar homes have slid down California hills because of foundation undermining. In Florida, the author's residence, there is little rock on which to build, but a solid foundation can be built with steel reinforced concrete or heavy treated piers to form a good bond to the earth. A good foundation is especially important to prevent damage during hurricane tidal surges and flooding. Moving water can undermine a foundation, causing the building to collapse and break up. A well constructed foundation can minimize this damage.

Concrete block walls. Concrete block wall structures generally have been shown to be stronger and more resistant to hurricane winds than wood frame walls. Although there was damage to block walls from Hurricanes Hugo and Andrew, the frequency of damage appeared to be much less than homes with wood framing. This was shown to be true even if the blocks were poorly laid. However, the strength of wood framing was severely compromised by poor design and craftsmanship.

Wood frame walls. Although wood frame walls are not generally as strong as block walls, they can be made hurricane resistant with proper design and construction. Stud walls are normally attached to the foundation through the sole plate which is bolted to the foundation with J-bolts imbedded in the foundation/slab. Studs are secured to the sole and top plates with hurricane clips, metal straps and toe nailing, and proper corner bracing should be used.

The capability of high mass masonry construction to possess thermal inertia, be strong, wind, flood, fire and insect resistant; and the capability of frame home to hold more insulation and be resistant to earthquakes leads the writer to consider both wood and masonry for construction of the ideal house. The first floor was selected to masonry for strength and the other characteristics above. It will be built three feet below grade, water table permitting, for the dual benefit of presenting a lower profile to wind and flood, and capability for geothermal wicking (stable temperate ground temperatures) . The first floor would contain the living areas: the kitchen, dining room and living room. The second floor would be frame using good strong construction bonding to the first floor's masonry walls, The frame walls would contain R-13 insulation between the studs and R-6 insulation board on the outside which would serve to insulate any thermal short circuits from studs and gaps in the wall insulation. In the summer evenings, with the windows open to receive the cool night breezes, this light mass component would cool rapidly often providing comfort with out mechanical cooling. It would also shade the high mass first floor and serve as a second zone for a split zone HVAC system. In the evening the HVAC equipment could be turned on to and dedicated only to the upstairs sleeping areas (if needed at all); in the daytime the HVAC system would be dedicated to the downstairs living areas. Thus only half of house would need to be heated and cooled at one time.

Windows: Poorly installed windows can blow out in high winds. Unprotected windows can also be broken by flying debris. Large bay windows, fixed glass picture windows and sliding glass doors are particularly vulnerable to flying debris and are hard to protect. Windows should be made as small as practical consistent with providing appropriate viewing and natural lighting. It is suggested that a properly designed window should start no lower than 3 feet from the floor and end no higher than 6 1/2 feet from the floor. This allows a view of the outside while sitting down or standing up. Large vertically oriented windows should be avoided unless called for by Code for possible egress during fires. Reduced window area is also consistent with energy efficient home design. In disaster prone regions, glass used for architectural or aesthetic purposes should be avoided because of risk of damage during high winds; also excessive energy use will be avoided. Installed skylights generally weaken the roof system and should be avoided or made as small as possible using extra reinforcement.

Use of Bahama shutters will provide both shading and good viewing through windows, but can also protect the windows from flying debris during high winds. Solid wood or metal awnings will also provide shade on the windows and serve to protect the windows during high winds, if properly closed. Solid wood or metal shutters will also protect windows but will not provide shading.

Windows that face south under a one or two foot overhang will have much better energy performance than windows facing east or west, and moderately better performance than windows facing north, especially in hot climate regions. Consequently, two homes with identical floor plans may have considerably different energy usages if one home faces west and the other home faces south. The reason for this difference is the natural migration of the sun from a high altitude in the summer to a low altitude in the winter. Also, the unshaded east and west windows allow entry of morning and afternoon sunlight. In the summer the sunlight is restricted from coming in the windows by the overhang. However, in the winter when heat is needed, the sun is low enough to provide direct solar heating. For example, in south Florida the noontime sun in late June will be almost directly overhead or about 87 degrees from the south horizon. However, in late December the noon sun will only be about 40 degrees above the horizon.

Windows should allow cross-ventilation and functional viewing without using excessive glass. On a hot summer day with the sun shining directly on a glass window, an extremely small one-square foot pane of clear glass will allow more heat to enter a room than would enter from conduction through the rest of the wall. For the best functional viewing, the window height should start at about the three foot level and end at about six to six and one-half feet from the floor. That way comfortable viewing can take place whether a person is sitting or standing. In addition, horizontally-oriented glass will provide much better panoramic viewing than vertically-oriented glass of the same square footage. Horizontal windows provide more ventilation than vertical windows of the same type and area. Relatively long spring and fall seasons in Florida provide excellent opportunities for cross-ventilation. Casement windows provide the largest open aperture, almost 100 percent of the window area. Awning windows generally provide about 70 percent, and single- or double-hung windows approximately 40 percent of the area. The window system should be properly sealed with caulk or weather-stripping.

While double-paned or insulated glass is a necessity in the northern states, in many cases they will not prove cost effective in regions with mild weather such as Florida, southern California and Texas. Since double-paned windows address conductive heat loss or gain, they only become cost effective when the average temperature difference between inside and outside is over 20°F. However, insulated glass should be considered anywhere if street or airport noise is a problem.

Roofs: While a foundation is important to prevent water and flood damage, a strong roof is the key to preventing wind damage caused by hurricanes and tornadoes. A poorly designed or constructed roof that has not been properly attached to the walls with steel hurricane clips or straps will be most susceptible to damage during high winds. Many homes damaged during hurricane Andrew had nails missing in the metal clips or straps (usually eight are required) or the straps were too short for the application (18- inch straps are stronger than 12-inch straps for tying down roof trusses or rafters).

From observations in the aftermath of Hurricanes Hugo and Andrew, it appears that most structural failure occurred first at the roof. Failure was also common when the sheathing was improperly nailed to the roof trusses or rafters. All too often when the roof system fails, wall system failure follows, especially in frame construction. The strongest roof systems are flat and the hip roofs. Flat roofs present a very small profile. Hip roofs are structurally stronger and deflect winds better than gable designs.

Our ideal home will have a low slope or flat roof that will use triple dip galvanized steel for durability, low maintenance and a low profile for possible wind damage. In addition, galvanized (zinc-coated) metals acts as a fungicide which will not permit molds to grow, presenting a healthier microclimate around the building. It also provides an opportunity to use of cisterns or water collection from the roof to flush toilets or other greywater applications.

Landscaping: In some cases during Hurricanes Andrew and Hugo, and even during the more current March 13, 1993 winter storm of the century, homes escaped damage from the high winds only to be damaged by falling trees or limbs blown from trees. No tree is wind proof and given enough velocity, any tree will fall or break. Investigation made after these hurricanes and storms revealed that some trees resist wind damage better than others.

One of the most durable trees was the Florida state tree--the Sabal palm. Palm trees in general are very resistant to high winds. Other wind resistant trees were shown to be hickory, pecan, live oak, bluff oak, bald cypress and American ash. Trees that do not do well in high winds and could cause damage to homes and buildings were identified to be laurel oak, water oak, sweet gum, sugarberry, cherry laurel and pine trees.

In addition to providing aesthetic and environmental stability, trees can also make homes more energy efficient. If you are able to choose your site or choose your landscaping that will be near the home, it is suggested that wind resistant trees be selected. The less wind resistant trees should be placed at a considerable distance from the home, if practical. Prior to hurricane season, all trees and shrubs should be pruned and trimmed to minimize potential damage.

Placing the home between shade trees, particularly those that may be on the east or west side of the home, can be to an owner's advantage. These trees are particularly effective if they are deciduous trees; that is, trees that lose their leaves in the wintertime. They provide shade in the summer and allow the sun to pass through in the winter. Pine trees and evergreen trees located on the north and northwest sides of the home will provide a barrier against cold winter winds. Landscaping can also be used to effectively channel prevailing summer breezes into the home.

Landscaping should make use of native plants and ground cover. Plants and ground cover native to the area tend to be low maintenance, self-perpetuating and drought tolerant. There are a number of attractive bushes, flowering plants and ivies that make excellent landscaping, requiring little effort on the part of the homeowner to maintain and thereby saving energy and contributing to a more favorable environment. Use of mulches from bark and wood chips for driveways is much more energy-saving than use of concrete and asphalt which absorb the sun's energy and re-radiate this heat to the house. Use of natural cover also provides better drainage.

Insulation and Infiltration Control: Installation is just as important as the level of insulation (R-value). Avoid gaps and compressing; use the proper density. A frame house generally offers opportunity for a greater degree of insulation, and performs exceptionally well if an insulated sheathing placed on the outside of the home coupled with batt insulation in the stud wall cavity. Attics should be insulated according to geography/weather considerations; R-28 for Florida, R-38 to R-50 for Minnesota.

Joe Lstiburek emphasizes that buildings should be built using a map. Climate conditions vary significantly between regions of the United States. There are hot dry regions, cold, damp regions, cold dry regions and there are hot humid regions. A house built in one area is not necessarily a good house for another area. Constructing our ideal home, the weather map should be taken into consideration. Placement of the vapor barrier, vapor retarder on the inside or next to the conditioned space in a hot, humid climate can lead to disaster. Conversely, placing a vapor retarder on the exterior of a cold climate could lead to disaster. So the rules change from locality to locality. In cold climates vapor retarders should be on the interior heated side of a building, while in hot humid climates they should either be omitted or an infiltration barrier placed on the exterior of the building.

Vapor barriers, such as polyethylene sheeting, are not recommended for installation in Florida residences. However, infiltration barriers or house wraps are recommended. Vapor barriers do not breathe or allow moisture to pass, and could cause problems with moisture condensing in the insulation and forming mildew. House wraps or infiltration barriers do breathe and do allow moisture to pass while keeping air infiltration out of the house. It is prudent to make sure the house has been properly caulked and sealed, particularly under the sole plates and wiring and piping through the top plate.

Installation of a radiant heat barrier in the attic is also an attractive option in terms of providing a greater degree of comfort to the occupants and lowering energy bills. A radiant heat barrier is basically aluminum foil on paper backing. Radiant barriers are effective in keeping the sun's radiant heat out, especially if there is no external shading on the home. Keep in mind that insulation such as fiberglass batts and cellulose reduces conductive heat transfer, whereas a radiant barrier reduces radiant heat transfer. In the summertime radiant energy might account for as much as 40 percent of the heat energy coming into the home.

HVAC: Generally, the heating and air conditioning ventilation systems are employed into one system. The most efficient form of heating is generally natural gas, with the heat pump following a close second. The most inefficient form of heating is electric strip heating. This can be very expensive to use for heating in northern Florida. If a heat pump is used, the efficiency is normally referred to the "coefficient of performance" or COP. The higher the number the better. Heating equipment may also be rated with a heating system performance factor or HSPF. For natural gas, the system efficiency usually is 70 percent or greater. There are some impulse-type of furnaces that are over 90 percent efficient. These may be very expensive.

For cooling systems, a measurement of efficiency is termed the SEER or seasonal energy efficiency ratio. The higher the SEER, the greater the efficiency. There are some with efficiencies as high as 14 or 15, particularly those referred to as ground or water coupled (geothermal) heat pump systems. These usually employ a closed-loop water recirculating system that exchanges heat directly with the ground or a body of water such as a swimming pool. There are other open-loop systems called water source heat pumps that require a pump, pumping water from the ground and then returning it to the ground. Some of the these may be counterproductive in terms of water conservation and some efficiency is lost due to scaling and water impurities. Some air-to-air systems may lose some of their moisture removing capabilities at very high efficiencies. There are exceptions and these should be verified with the contractor.

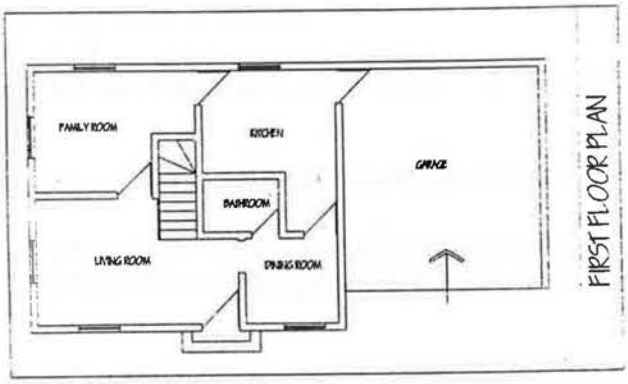
The moisture-removing capability of an air conditioner is very important in Florida because of potential for mildew problems. It is therefore especially important to have the air conditioning system sized properly using Manual "J" or other load calculating procedures. If the air conditioning unit is oversized, which is a real problem in Florida, then the air conditioning system will not run long enough to remove the moisture and the humidity in the home will be high, creating an excellent environment for mildew growth.

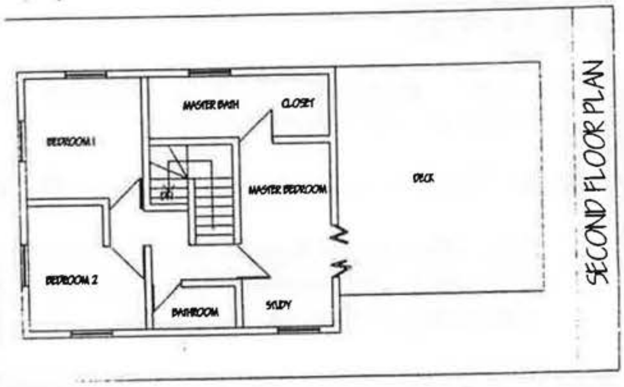
Water Heating: Next to heating and air conditioning, water heating is usually the next largest consumer of energy in a home. Here again, natural gas is the most efficient for water heating, and electric strip heating is the least efficient. Generally speaking, an electric water heater will cost about three times as much to operate as a natural gas water heater. There are also accessories, such as heat recovery units (HRU), that reclaim heat normally wasted in an air conditioning system to heat water. These HRU's can be cost effective especially if used with a heat pump. A solar preheating system may also be effective.

Efficient Lighting: Fluorescent lighting is about three times more efficient than normally used incandescent lighting. In many cases, compact fluorescent lighting can be used in place of incandescent bulbs used in lamps, and strip-tube fluorescent lighting can be effectively used for general overhead lighting. High pressure sodium lighting should be considered for outside and security lighting purposes. Although it has a slight orange cast, it is about three times more efficient than mercury vapor lighting or incandescent lighting.

SUMMARY

Ideal house description: Our ideal home would be located in a hot, humid climate such as Florida or southern Texas, will be a two-story split zoned structure, with sleeping (bedroom) areas upstairs, living areas downstairs, would emphasis 4, 8 and 12 foot standard dimensioning to accommodate sheetrock and minimizing construction waste. Construction of the masonry first floor will have exterior R-6 rigid insulation, be three foot below grade, steel reinforced; and with exception of structural corners etc., all other cores will be filled with inexpensive fly ash low-grade concrete for higher thermal mass. If located on radon-bearing soil, a high density plastic ground gas barrier will be installed under the slab with high communications soils beneath this gas barrier. The second floor will be wood frame with R-13 in the exterior walls and R-6 exterior rigid insulation. The structure will have low sloped galvanized metal roof with installed radiant heat barrier and R-19 cellulose insulation. The HVAC system would be a high efficiency geothermal heat pump with heat recovery water heating unit, or combination high efficiency air conditioner with natural gas heating and water heating. All ducts will be galvanized sheet metal and located in the conditioned space.





Home buying can represent an exceptionally high investment. Most builders and buyers tend to be preoccupied with the principle, interest and taxes on the home with much less consideration given to the operational costs, which over a 30 year mortgage life could, in some cases, amount to more than the principle and interest paid on the mortgage. If the questions addressed earlier are asked and satisfactorily answered, it could mean a considerable dollar savings for the buyer, not to mention the favorable environmental consequences associated with energy conservation.

By using a good foundation and securely attaching the walls to the foundation and the roof to the walls, most homes can be made wind resistant to wind forces of 110 mph or more. It is important that good construction techniques and materials be used. It is important that metal straps be used to anchor the roof trusses and the top plate to the wall studs. Inspections should be made that all the nails through the roof sheathing are anchored to the truss and that extra nails be used on the gable end of the roof. Metal cross-bracing or plywood sheathing should be used on the corners of the walls and lateral bracing should be used to give extra support to the roof trusses. In general, masonry homes are inherently stronger than wood-frame homes. Even so, proper techniques should be used to reinforce block and concrete with the proper steel reinforcement rods or rebar. Prudent design, construction and inspection of your home will give you extra security during hurricanes and other high wind conditions and save energy and natural resources at the same time.

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BUILDING SUSTAINABLE COMMUNITIES:
Habitat for Humanity's Environment Initiative

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ABSTRACT

Habitat for Humanity builds houses in partnership with low-income families through 1100 affiliates in the United States. The Department of Environment of HFH seeks to make Habitat houses examples of decent, sustainable living conditions by focusing on: (1) resource efficiency in house designs, (2) recycling of construction and other waste, and (3) permaculture applications for homeowners.

INTRODUCTION

Habitat for Humanity International (HFH) builds houses in partnership with low-income families. Its Department of Environment, begun in the Spring of 1993, serves as a resource center offering technical advice to 1300 affiliates in 36 countries, 1100 of which are in the United States. It endeavors to conserve the earth's resources through learning, teaching and example. The Department seeks to insure that HFH provides decent, sustainable housing, which will have a minimal environmental impact, while fostering wholesome communities which can be sustained in perpetuity.

In order to effectively focus its environmental program, the HFH Environment Initiative has been established. It has three interconnected components:
1. Resource Efficiency: This is the major emphasis which applies to both the building materials used and to the performance of the houses. Designs are being developed and implemented to make Habitat houses highly appropriate to local climates and traditions.
2. Recycling: This includes three main features: (a) the use of viable local building materials with a high content of recycled products, (b) a program for construction waste, and (c) raising funds through HFH stores that sell used and surplus building materials.
3. Permaculture: HFH is beginning to serve as a facilitator for other organizations which have the knowledge and experience to benefit Habitat homeowners in this area. Permaculture incorporates arborculture, organic agriculture, and xeriscaping in a holistic stewardship of natural resources.

Through adoption and implementation of this program, HFH affiliates are becoming true stewards of the gifts of Creation, examples worthy of emulation in hundreds of communities.

PROGRESS TOWARD IMPLEMENTATION

The Problem.

If one is a responsible adult he or she must be concerned for future generations. To put it in the most basic human terms, if we care for our children, the children of this generation, we must leave them a good earth. We must all become stewards of this gift of creation.

Never before in history have the two most prestigious scientific organizations on the planet given a joint declaration on any subject. In 1992, The Royal Society of London and The National Academy of Sciences issued just such a joint statement. In summary, it said if mankind does not change his ways dramatically, he may well become extinct in the near future. In modern society with all the great successes of advanced science, most of us have come to believe that science could solve just about any physical problem that came up. And now the best minds on the planet are telling us that this time they can't bail us out. We have no choice but to do it the hard way...to roll up our sleeves and help ourselves. The planet's brightest minds agree. Science cannot bail us out.

As rapidly as the fabric of life is unraveling about us, it apparently has not been quick enough to make the environment the number one priority of world leaders. Despite this apparent lapse of attention, it is heartening that the alarm is beginning to be heard. The threat of a rapid loss of our ozone shield was the first crisis to raise global environmental awareness. Nations are meeting and making decisions and taking action: Montreal (ozone), Rio (general) and in September '94, Cairo (population and sustainable development). We have a long and challenging way to go toward getting our collective house in order. You must have asked yourselves as individuals and as members of this organization: "What can we do now?" We at Habitat for Humanity have been asking that very question and we have the audacity to think that, with the help of people like you, we can indeed... make a difference. In fact, we have a fantastic opportunity if we can marshal the fortitude and resources to seize the initiative. Let's get specific.

Construction Waste and Saving Trees.

In upscale housing, golf course developments are becoming increasingly popular, even though as many as 75 percent of the people who live in such developments do not play golf. Golf course grasses use an inordinate amount of water and harmful chemicals. Since many of the people are really buying the view, not the golf, let's give them the beautiful natural expanse without the golf. In the past, civil engineers have laid out building lots cookie cutter style on paper in their offices. Finally they site the houses on the lots, and send workers out to cut down trees.

That is traditional but it is absolutely backwards environmentally. In the past you would build 200 houses on 100 acres on 200 half acre lots. You could still build 200 houses, but designate half the land as common area with 50 acres of wetland, woods and trails, perhaps even a stream. Let all the houses have a view of the wild area. In addition, planners should steer away from wide boulevards and adopt rustic roads just wide enough for two cars to pass. Keep wild areas intact. Professional arborists or urban foresters must be employed so that as the houses are sited on the lots and then built as many good trees as possible are saved. Establishing the actual property lines should be the last step.

WHAT CAN BE DONE ON SMALL PROJECTS?

PROTECT TREES
- Site houses to save trees on individual lots.
- Learn techniques for protecting trees during construction.
- Network with organizations that plant trees, then assure that a tree is planted to replace each tree cut or used in construction.

RECYCLE CONSTRUCTION WASTE.
- Recycle cardboard. Grocery and department stores make good money selling their baled cardboard. Habitat affiliates are encouraged to work out a partnership with them.
- Chipped lumber and trees can be used in the fabrication of oriented strand board, parallel strand lumber, and Faswall building blocks. And, if these aren't viable options in a given community, the wood chips can be composted.
- Scrap lumber can be finger-jointed and reused or given away to handymen or high school wood-working classes.
- Gypsum scraps can be shredded and used to make new wallboard or used as a soil amendment where clay content is high.
- Scraps of foam sheathing and fiberglass insulation batts can be shredded and used for loose fill insulation.
- Concrete overpours can be used on the next worksite or carried back to the plant and poured into forms for stopping blocks. As manufacturers of builders and building materials become more environmentally aware, virtually all building "waste" should be reused or recycled.

Education.

Habitat for Humanity is completing over 30 houses a day in 1600 communities throughout much of the world. A number of HFH affiliates are already taking leadership in resource efficiency. We believe in leadership by example, and we depend upon them to give us good field-tested examples. As outstanding examples of resource efficiency are brought to our attention we are committed to having them published in the popular press and our own newsletters. Habitat World, our flagship publication, has a circulation of 800,000.

Each year Habitat holds numerous training conferences and staff meetings across North America and throughout the world. Serious efforts are being made to have various aspects of our Habitat Environment Initiative as a prominent part of each of these meetings. Environmental stewardship and concerns are rapidly becoming an integral part of the fabric of our organization. Some examples are in order. You will see us moving to two-by-sixes on 24" centers instead of two-by-fours on 16" centers. That will improve R (i.e. insulation) values by close to 60%. In some of our states that produce the most lumber, the size of trees cut for lumber is falling dramatically. In a recent 10 year period the cross section of saw timber fell by an astonishing 50 percent. We find that traditional dimensional lumber wastes half the tree, while manufactured lumber, such as laminated veneer lumber, parallel strand lumber, and oriented strand board, consume over 80 percent of a tree. We encourage our affiliates to try such products taking care that they contain a minimum of volatile organic compounds such as formaldehyde. There are numerous applications for using waste and recycled materials in building. As our resources permit we are monitoring an increasing variety of innovative building materials. We interact with the manufactor's researchers and developers and find that many of them share our interest in sustainable building practices.

Steel studs and beams from recycled automobiles present a unique challenge. In many places they are cheaper than dimensional lumber. However, depending upon their fabrication, they can conduct heat as much as hundreds of times better than wood and that negates energy efficiency measures. Methods are now being developed to thwart this problem. But the procedures involved must be kept simple in order for volunteers to use them. Steel framing is an effective approach for rafters and interior walls just about anywhere. For now, we do not recommend this material for exterior walls in areas that require significant heating in the winter. The total cost of termite damage in Florida is one half of that for the whole country. If for no other reason than damage control, some of our most successful Florida affiliates are embracing steel framing.

Permaculture.

In the yard we want to get away from ornamentals which are fertilizer and water intensive. We want to move toward bio-diverse indigenous species of grasses, shrubs, and wild flowers, which flourish under existing natural conditions. We want to facilitate the work of gardening organizations. Some have offered to help us with indigenous ornamentals while others intend to help Habitat homeowners establish bio-intensive organic vegetable gardens. Such gardening practices recycle household waste by using compost and gray water.

Bio-intensive organic gardens can produce abundant vegetables from small, extremely fertile beds. This technique recycles kitchen and yard waste through composting. Facilities for recycling kitchen and other household waste should be integrated into the house design. If local code allows, the plumbing can be designed so that household gray water can be recycled as well.

Traditional organic gardening is a daunting challenge, especially in developing the soil to full productivity. There was some thought that it may be too much of a challenge until we discovered the work of Dan Barker of Portland, OR. He has placed more than 1000 gardens with low-income families with 85 per cent retention after the second year. Dan has been advising us on his methods. They seem to be tailor-made for Habitat, and we have already experienced dramatic success in trying them out.

Some of our first individual, raised-bed organic gardens were provided to Habitat homeowners this past June in Americus, Georgia. This summer in Cleveland, Ohio, existing residents and new HFH homeowners cooperated to establish 20 raised bed organic gardens. Rather than detract from what Habitat does best, which is building houses, these projects have been accomplished with the enthusiastic support of avid professional gardeners. The results have exceeded all expectations, and have enhanced the quality of life of Habitat homeowners. They will serve as effective examples to all HFH affiliates.

Greg Sandor, a great Habitat leader, has dozens of the homeless people of Washington, DC, gardening, and they love it. They are connected, they are productive and fulfilled, and it is spreading to other cities. Eventually we hope that some of these gardeners will become Habitat homeowners.

Recycling and Waste.

Dozens of Habitat stores are recycling everything from clothes to paint, from furniture to light fixtures and windows. Several of these operations are called Habitat ReStores. They trade in surplus and recycled building materials. Through them, needy people can afford to buy the materials to keep their houses in good repair, thus reducing the demand for new housing. Besides serving as an outstanding resource for low income people, some of our stores are providing over 40 percent of the funds that affiliates raise for building houses. They are recycling and they are reducing the demand on our precious resources. Such stores are environmentally correct and they help people to help themselves, the Habitat way. They are an exciting and growing part of our work.

Some affiliates are already taking the lead with special projects. Last year the Lynchburg, VA. Habitat built our first earthwise house, and our second such environmental concept house was completed in Austin, Texas, this past spring. Recycled materials were used throughout and after occupancy they have proven to be very high in their resource efficiencies.

Turning traditional waste into superior building material is a real bonanza. When grains are harvested the waste straw is usually burned, creating darkening skies and contributing to greenhouse gasses.

Our affiliate in Silver City, New Mexico broke ground for our first plastered straw bale house on Sunday, September 18, 1994. The walls of most of our houses carry an R-value of 11 or 12. The walls of this house will be four times that value... cool in the summer, warm in the winter. Super insulated and certified passive solar at a cost comparable to traditional construction.

One option that we are finding increasingly attractive is plastered straw bale with steel post and beam framing. The steel penetrates only a fraction of the straw bale walls. The thermal conduction problem is completely negated.

We are working with two U.S. government agencies toward providing electrification for Habitat built houses in India, Uganda, and Kenya. Using the Solar Electric Light Fund, initially hundreds and later possibly thousands of photovoltaic units will be installed and homeowners will be trained in the utilization of these systems and service personnel will be trained in their upkeep. This project promises to be our most productive excursion into the renewable energy arena and should serve as a prototype for future applications.

Resource Efficiency and Climate Specific Design.

Canadian affiliates are building super resource efficient houses. Most of them are coming quite close to the very high R-2000 Canadian standard, which provides guidance in building houses that use a minimum of energy and water. The Homestead, Florida affiliate is providing an example for the sunny south. They are well on their way to raising the funds to build a model ecological community of 200 houses. The guidelines which are being used are Cool Community, which have been specifically formulated for hot climates. In addition to guidelines for resource efficient housing for Canada at one extreme and South Florida at the other, we also have available for our affiliates, guidelines for some intermediate climates. A research professor of architecture at UCLA and a Habitat volunteer, has developed computer software that assists in the custom design of very resource efficient houses. The designs are specifically matched to climates and traditions, as they occur across the continent. We intend to vigorously pursue this approach and develop such a resource for low-income housing. Within a few short years we should have a multi-media program assisting in the design of houses appropriate to local conditions wherever Habitat builds houses.

The design program will be experience based. For example the Texas low-cost housing project will build thirty houses stretching across three climate zones. The performance of each house will be monitored for a year after its completion. Based upon the data gathered, user friendly homeowner's manuals will be published. Eventually we want to develop such manuals for every climate. It is our ambition to help everyone we can reach, to get the most benefit from their houses with the least damage to this precious planet.

During a week in July of 1994, Jimmy and Rosalynn Carter, Habitat co-founders Millard and Linda Fuller, and 1200 volunteers joined together to build 30 houses with a Sioux Indian tribe. The location was Eagle Butte, South Dakota. Eventually there will be 105 houses in the community. Due to the severe winters of the area the houses are super insulated. Special and thoughtful efforts were made to have the dwellings and the community at large conform to characteristics in keeping tribal customs. An outstanding environmental feature is the wetlands area which was created to provide sewage treatment by natural processes. This particular system has already proven its effectiveness in Minnesota and Canada. In 1995 the Tijuana-San Diego affiliate will install a similar system suitable for hot climates as part of their comprehensive environmental project. The seeds of environmental stewardship are being planted. Habitat is beginning to make a difference, but there is much to be done.

CONCLUSION

Our generation is unique in history. No generation in the past has faced this problem. Common sense applies to common occurrences. It corresponds to how it happened before. The unraveling of the fabric of life has no precedent and it makes no common sense. That is why so few really accept what is happening. No generation in the future will have the luxury of this responsibility. We alone must solve it. It is our fervent hope that we have the wisdom and the time . As we build houses in each community we can make them that bright and shining light. A beacon for all to see. Habitat staff and volunteers, as well as energy efficient builders like you, can make an example of environmental sustainability for the world to follow. No other group has such a great opportunity and responsibility. Habitat for Humanity is accepting the challenge, and with the commitment of builders like you, we can do it!