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Residential Building Design & Construction Workbook

Second Edition

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SECTION 1

INTRODUCTION

Purpose

This workbook grew out of a nationwide series of seminars sponsored by Energy Design Update. Conducted by EDU Editor J.D. Ned Nisson and Canadian builder Oliver Drerup, the seminar series and workbook were created to provide the practicing field professional with a working manual of construction techniques and background information that would be of immediate practical use.

Beyond Superinsulation

Residential construction technology is advancing at an unprecedented pace. In reaction to the "energy crisis" of the 1970s, much of the development has been in energy-related features such as insulation systems, heating systems, etc. However, just as military research and development often produces useful domestic technologies, so too have energy conservation efforts resulted in many new developments that are not directly related to energy efficiency. Areas such as moisture control, ventilation, and indoor air quality, have been the focus of intensive research and development. New building systems and materials such as stress skin construction, gasketed framing systems, and truss frame construction have been developed and tested. Mechanical systems are evolving at a tremendous pace with the recent introduction and acceptance of integrated heating, cooling, water heating, and ventilation systems.

In addition to major new developments, the energy crisis helped spur an effort toward "fine-tuning" existing design and construction techniques. For example, eliminating "thermal defects" in conventional framing systems led to an examination of the overall efficiency of conventional framing techniques. Beefed-up insulation systems, by allowing for reduction or elimination of perimeter heat distribution, have led to closer scrutiny of the need for air mixing and distribution for comfort.

When the first edition of this workbook was published, the overriding primary emphasis was on energy-efficient construction techniques — "superinsulation." In this edition of the workbook, we have retained reference to the term superinsulation and have included an introductory section on the background of superinsulation and its benefits. Much of the information presented in the body of the workbook, however, is not necessarily specific to superinsulation construction techniques, but rather represents the broader body of knowledge that has grown during and since the development of superinsulation and the publication of the first version of this workbook.

Superinsulation: Background And Benefits

"SUPERINSULATION." The word conjures up images of extraordinary insulating powers and magical levels of energy conservation. True, superinsulated houses can be superbly energy-efficient, with annual heating bills of little more than the cost of one or two nights in a good hotel. However, the technology of superinsulation is common sense — not magic. Encompassing both a new design concept and a collection of construction details, superinsulation is the most recent — and the most widely applicable — development in the evolution of energy-efficient house design.

Until the "energy crisis" of 1974, energy-efficient housing was not much of an issue in the United States. However, high energy bills in the seventies created a demand for houses that people could afford not only to buy, but to live in. Since then, despite fluctuations in the cost of conventional fuel, energy efficiency has consistently remained a prime factor in house selection, as evidenced by surveys both in the private and public sectors. Moreover, government figures and expert opinion indicate that average energy costs for all U.S. households will continue to rise.

Thus the birth and continuing growth of energy-efficient housing technology. The first developments involved solar energy. Early research demonstrated that solar energy falls in sufficient quantity on the roof of the average house to replace all or most of the fossil fuel burned in the furnace or boiler. The question was: how to harness that "free" energy for home heating? At first it was thought that all that we had to do was build solar collectors on the roof and install a thermal storage device in the basement. This is called "active solar" design. A new industry emerged. Many ingenious collectors were developed. But unfortunately, active solar heating proved too expensive and complicated for widespread application.

The next step was the marriage of engineering and architecture called "passive solar," an innovative design concept which asked a few simple questions. Why bother with all that solar hardware? Why not simply let the sun shine into the house through large south-facing windows? Passive solar design certainly makes sense, as evidenced by thousands of new houses that get much of their space-heating energy from the sun.

But there was one question which, throughout the evolution of solar design, remained unasked. It's a question which takes a step back, preceding common suppositions about space heating energy requirements. Is all that energy really necessary? Whether it comes from the sun, from oil, from gas, from electricity — energy is difficult and often expensive to provide. (Although solar energy itself is free, collecting and storing it in active or passive solar-heated houses increases the house cost.) How about designing a house that needs less energy to keep warm in the first place? Before we think about active solar or even passive solar to satisfy the heating demand, is there a practical way to first reduce that demand? The answer is yes.

The answer is superinsulation: a method of design and construction that can reduce energy demand so drastically, a house hardly needs any heating system at all. What's more: the method called superinsulation can be employed without sacrificing comfort, without sacrificing health or aesthetics, and at relatively little extra cost.

What Is A Superinsulated House?

What distinguishes a superinsulated house from any other? One essential feature: superinsulated houses lose so little heat, they need much less energy, solar or otherwise, for space heating and cooling. Typical annual fuel costs for a superinsulated house in North America range from $25 to $250!

If you did not know these houses' annual fuel consumption it would be difficult — at first glance — to tell them from others. Superinsulation is a design tool, not a design type. Builders' favorite designs — from ranch to colonial, Victorian to contemporary split level — can be superinsulated. Single family houses, two-story houses, row houses, attached houses, any kind of residential or light commercial construction can be and have been superinsulated, on sites as far south as Georgia and as far north as the Arctic Circle.

Just looking at a house does not immediately reveal whether or not it's superinsulated. What about cutting a cross section from a wall and studying the thickness of the insulation? This isn't a gauge of superinsulation either. For while amount of insulation is important, it's only one part of a carefully thought-out system designed to minimize heat loss and energy waste.

Every feature of a house — walls, windows, attic, basement, framing, site orientation, heating system, ventilation system — is different in a superinsulated structure. Conventional building methods have not been discarded. Rather, they have been subtly but pervasively rethought to meet one goal: using energy efficiently.

If we all saw with the eyes of a builder of superinsulated houses, conventional houses would seem like sieves leaking preposterous amounts of heat to the outside, wasting energy and the money represented therein. Using large amounts of fuel to heat relatively small areas is commonplace and has become accepted; but it isn't necessary. The investment value of a superinsulated house is its capacity to function at an efficient level which uses every dollar spent for energy to its maximum potential. The aesthetic value is found in heightened comfort, quiet and coziness: the resident of a superinsulated house can stand, for instance, inches from his or her inside wall or even from a window on a cold, snowy, stormy day, and not feel the slightest draft.

The Thermal Envelope

The first step in conceiving a superinsulated house is to think of an artificially created (heated) environment separated from the larger (unheated) environment by a physical boundary, or shell. When discussing space heating and cooling, this boundary is referred to as the thermal envelope. In superinsulated houses, the thermal envelope is never regarded haphazardly: it is carefully defined and, once defined, every possible precaution is taken to make certain that the envelope is insulated and sealed.

Correctly defining the thermal envelope is one of the first steps in building a superinsulated structure. Should the envelope enclose the living room, the bedroom, the kitchen, the bathroom, but leave out the attic, the basement, the crawl space, the garage? This is the conventional approach: to think of the envelope as encompassing only the space actually intended to be heated (or cooled).

The superinsulation approach is somewhat different: the thermal envelope broadens in scope to include not only the primary heated/cooled spaces but, in some cases, secondary spaces as well. For instance, the basement — even though it doesn't have to be kept warm — is often included in the thermal envelope of superinsulated houses; therefore the boundary between the basement and the outside is carefully insulated and sealed. This alternative configuration creates a more effective thermal padding around the primary living area of a house.

Defining the thermal envelope is one of the decisions — based on economics, aesthetics, and efficiency — that must be made when designing a superinsulated structure. Once defined, though, the thermal envelope — in every superinsulated house — is treated the same. It is made as airtight and insulated as effectively as it can possibly be.

Airtightness

If quantities of warm air are allowed to escape from a house, energy will be wasted because the air leaking out is replaced by cold air which must be heated.

In conventional houses exfiltration and infiltration (what we call air leakage) occur unintentionally through so many chinks, gaps, cracks, bridges, and imperfect closures that the air in an average conventional house "turns over" — is replaced by entirely new air — .5 to 3 times per hour! The heating or cooling system must work continuously to replace energy lost via air leakage.

Superinsulated houses are designed and built to guard against air leakage. Airtight construction — meaning careful attention to all potential leaks in the thermal envelope — is essential. Windows, doors, utility entrances, and every other penetration or seam in the building envelope is carefully sealed.

Controlled Ventilation

Uncontrolled air leakage, which is the norm in most houses, is sometimes thought necessary for adequate ventilation. This is a myth. Although air leakage does mean that fresh air can get into a house, the presence of that fresh air is erratic and problematic. Air which enters unintentionally can make a house too dry, can cause moisture problems, can cause too much ventilation in some places and not enough in others, and needs to be continuously heated or cooled.

Superinsulated houses are airtight; residents of airtight houses must rely on controlled ventilation systems. This can be put another way. Residents of airtight houses are fortunate enough to reap the benefits of controlled ventilation, which include uniform temperatures throughout the house, freedom from drafts, freedom from humidity problems, and fresh air at all times. Ventilation is supplied by one of several types of systems generally including an air-to-air heat exchanger, which makes it possible to recover and re-use heat in the outgoing air.

By the way — windows in superinsulated houses can be and are often opened. Superinsulated houses are not sealed boxes: they are at least as well-ventilated as most other houses. However, ventilation in a superinsulated house is intentional, not erratic.

Insulation

Every material has a certain degree of resistance to heat transmission. Those with high thermal resistance are useful as thermal insulation in buildings. A material's thermal resistance is measured by its R-value; the higher the value, the greater the resistance to heat transmission. The most popular insulation materials, such as fiberglass, cellulose, and plastic foam, have R-values ranging from 3.0 to 7.0 per inch.

Superinsulated houses characteristically have a high R-value created through the use of insulation and structural building materials. Walls are typically between R-30 and R-40; ceilings range from R-40 to R-65. Windows are at least R-2 and sometimes higher than R-4. Foundations are insulated below grade to nearly the same levels as above.

Introduction

As we will emphasize again and again, the key to superinsulation is not just to install R-value insulation systems, but to install it in a way that makes it work to maximum efficacy. A truly effective insulation system, for example, reduces or eliminates many or all thermal defects present in ordinary construction — defects like insulation voids, thermal bridges, and convective loops. Techniques and details for designing and constructing a flawless insulation system comprise much of superinsulation building practice.

Passive Solar Features

Many superinsulated houses contain no space heating furnace or boiler at all. Where do they get heat? Some heat may come from small space heaters; more commonly, however, it comes from people, pets, light bulbs, appliances ... and the sun.

On a sunny day, more than 200 Btu/hr (59 watts) shines in through a square foot of window glass during mid-day hours. If a house at 40° N-latitude has 60 square feet of glass facing east and 60 square feet facing south, the solar heat input on a sunny day will be about 20,500 Btu/hr (6,000 watts) from 9 A.M. till noon. The amount of energy gained depends on the area, type, and orientation of windows, and the amount of shading. In superinsulated houses, windows are placed predominantly in the south and east walls to afford maximum solar heat input. Solar energy through windows is the simplest form of passive solar heating. Trombe walls, water walls, sunspaces, wall collectors, and other more sophisticated passive solar features can be integrated into superinsulated house design, but they are seldom necessary.

What, then, is a superinsulated house? It's a house with a thermal envelope that is carefully designed and meticulously insulated and sealed; it's a house characterized by airtightness, high and efficient levels of insulation, controlled ventilation, and passive solar features.

History

The roots of superinsulation predate the energy crisis, extending back to the mid-1960s when two men, Harry Tschumi and Les Blades, were interested in promoting the use of heat pumps. Tschumi sold heat pumps and Blades worked for the Arkansas Power and Light Company. Around 1961, they "discovered" that by increasing insulation levels and improving window thermal performance, houses could be made to use much less energy and would be better suited for heat pump applications. At that time, however, with low energy prices, few homeowners wanted to pay the extra construction cost.

It wasn't until 1974 that a housing analyst named Frank Holtzclaw, working for the U.S. Department of Housing and Urban Development (HUD) brought Tschumi's ideas to fruition. Holtzclaw initiated what was to become known as the "Arkansas Project," a series of radically designed "superinsulated" houses which were not only very energy efficient, but also inexpensive! Between 1974 and 1975, thirty five homes were built and monitored for energy consumption. Annual heating and cooling costs were about $130 — low, even at 1975 energy prices. The Arkansas houses had 6-inch walls with R-19 fiberglass insulation and a special "raised heel" roof truss, now commonly referred to as the "Arkansas Truss."

The man usually credited with coining the term "superinsulation" is Wayne Schick, an architect with the Small Homes Council at the University of Illinois, Urbana-Champaign. Together with several other faculty members, he had been working since the 1940s on methods of increasing the thermal performance of houses. Legend has it that while lecturing about energy savings from increased levels of insulation, Schick made reference to a maximum practical level and called it "super" insulation. In 1976, Schick's team developed a design known as the "Lo-Cal" house. It included double 2 x 4 walls with R-30 insulation, ceilings insulated to R-40, and double-glazed windows with most of the glass on the south side of the house. Computer simulations indicated that a house built by the Lo-Cal design would need only one-third of the heating energy as specified in the newly created HUD standards. Schick's team never built a Lo-Cal house but many of the details of that design are incorporated into present-day superinsulation techniques. If it's a good idea, it's worth patenting. That must have been Richard Bentley's thoughts when he applied for U.S. Patent #3,969,860, issued on July 20, 1976, for a "Thermal Efficiency Structure." Working independently, Bentley developed and patented a design for a double wall house, using an innovative truss system. His patent stresses the need for airtightness and also includes a site-built heat recovery ventilation system (air-to-air heat exchanger). Bentley and his family built a few houses after his design and although he hasn't gained much publicity, he is definitely one of the originators of the concept of superinsulation.

That superinsulation could really perform incredibly was first demonstrated to the American public by two well-publicized houses in distant parts of the continent — The Saskatchewan Conservation Home, built by the Canadian government, and the Leger House, built by Gene Leger. The Saskatchewan Conservation Home was built in 1977 by a Canadian team headed by David Eyre of the Saskatchewan Research Council. It is surely one of the most energy-efficient houses ever constructed — probably the first superinsulated house to demonstrate that airtight construction is practical and can drastically reduce energy consumption. The 12-inch thick walls are filled with R-44 insulation; the ceiling is insulated to over R-60. But the most distinctive feature is its airtightness. A continuous airtight membrane was carefully installed under the supervision of Harold Orr of the Canadian National Research Council. The end result was an air leakage rate far below conventional houses. To ensure adequate fresh air and indoor air quality, a ventilation system with an air-to-air heat exchanger was incorporated into the design.

Of course the most fantastic aspect of this house is its energy performance. When the outdoor temperature is -10°F, the total heat demand is about 3,000 watts (10,640 Btu per hour), or less than the average output of a clothes dryer. Originally, an expensive array of evacuated tube solar collectors were installed on the roof. But the project managers were quick to realize that it would be very hard to justify a $10,000 solar heating system to displace $35 worth of fuel per year. The solar collectors were removed.

With the shutters closed, no people in the house and no heat sources inside, the house cools down at a rate of less than 1 degree per hour. According to Harold Orr, the total annual heating cost would be about $35 (Canadian, at 1978 energy costs) even without the solar heating system.

The Saskatchewan Conservation Home is an example of extreme applications of superinsulated technology. Neither its enormously thick insulation systems nor its general design is likely to be acceptable to the general housing market. But the experience gained in building that house has affected superinsulation more than any other project. It proved an important principle: it's possible to design and build a comfortable house which needs almost no heat.

About the same time the Saskatchewan home was built, a builder named Eugene Leger was inventing a superinsulated house design in eastern Massachusetts. Leger's design also included double walls and extremely airtight construction, although many of his framing details were quite different from those of the Lo-Cal or the Saskatchewan House. His first house, the Leger House, required so little space heat that the requirements could be met by using a regular-sized domestic water heater with no need for a furnace or boiler. The annual heating bill was $40. Unlike the Saskatchewan House, Leger's house looks like millions of conventional American houses and costs only slightly more than standard construction. Leger and his house were widely publicized. Needless to say, the public was impressed by the Leger House, which proved that superinsulation was practical and economical.

With the technical feasibility of superinsulation established, the next natural step was to hand it over to the professional building industry and observe the results. Three projects in Canada and the U.S. did just that with surprising outcomes.

The first was the Saskatchewan Showcase Project. In 1979 and 1980, fourteen superinsulated houses were built by private builders with technical assistance from researchers at the Canadian NRC and Saskatchewan Research Council, some of whom had been involved in building the original Saskatchewan Conservation Home. The results were outstanding. Many of the homes had annual fuel bills under $100 and all were less than $200. Although mistakes were made, those houses still serve as models for much of the superinsulated construction done today.

A similar project was sponsored in the U.S. by the State of Minnesota's Housing Finance Agency. It initiated a demonstration program in which builders put up 140 houses designed to meet a set of minimum performance standards. The builders were given complete flexibility, except for the single requirement that calculated energy use meet the mandatory standards. The houses included a variety of passive solar and superinsulated designs. Completed in 1981, and monitored the following year, most of the houses performed well, although a followup study of homes built under that project showed numerous flaws.

One surprising and paradoxical result was that houses with intentionally expanded areas of south-facing glass for passive solar heating tended to use MORE heating energy than those with average amounts of south glass. Thus it was proven possible to achieve as much or more energy efficiency without resorting to extra-large south-facing glass. The project created a great deal of interest. Several of the builders continued building superinsulated houses. The superinsulated housing industry was born in the United States.

Canada initiated a third program for builders in 1982-83 called the R2000 Program. Designed to encourage superinsulated construction in Canada, the project offered free training and a small subsidy to offset extra costs. Each design had to meet certain energy performance standards and each house had to pass a test for airtightness after construction. The R2000 program has achieved enormous success and is still operating in Canada today.

The rest of the story is difficult to trace. Nobody knows how many superinsulated houses have been built and any attempt to catalog them would surely be frustrated by the lack of generally accepted criteria for defining superinsulation. A conservative estimate puts the number at 50,000 in the United States and Canada; 100,000 is more likely. At the time of this writing, the word "superinsulation" is no longer new to most designers, and more and more builders are making superinsulation an option for their customers. Without the urgent impetus created by an energy crisis, however, superinsulation is likely to be accepted slowly and soberly by the public and the building community.

Leger wrote to William Shurcliff, a Harvard physicist and noted author of books on solar heated houses. Shurcliff was so impressed by Leger's design that within a few days of getting the letter, he put out the following press release.

FROM WILLIAM A. SHURCLIFF — *JUNE 29, 1979*

Arrival Of A Fifth Kind Of Solar Heating System For A House

Everyone knows that a solar heated house may employ an active system, a direct-gain passive system, an indirect-gain passive system, and a hybrid system. But is there not a fifth kind — just now being born?

I think so. Consider the Saskatchewan Energy Conserving Demonstration House. Or consider the Leger House in Pepperell, Massachusetts. They fit none of the four listed categories.

The essence of the new category is:

1. Truly superb insulation. Not just thick, but clever and thorough. Excellent insulation is provided even at the most difficult places: sills, headers, foundation walls, windows, electric outlet boxes, etc.
2. Envelope of house is practically airtight. Even on the windiest days the rate of air change is very low.
3. No provision of extra-large thermal mass. (Down with Trombe walls! Down with water-filled drums and thick concrete floors!)
4. No provision of extra-large south windows. Use normal number and size of south windows — say 100 square feet.
5. No conventional furnace. Merely steal a little heat, when and if needed, from the domestic hot water system. Or use a minuscule amount of electrical heating.
6. No conventional distribution system for such auxiliary heat. Inject the heat at one spot and let it diffuse throughout the house.
7. No weird shape of house, no weird architecture.
8. No big added expense. The costs of the extra insulation and extra care in construction are largely offset by the savings realized from not having huge areas of expensive Thermopane, not having huge well-sealed insulating shutters for huge south windows, not having a furnace or a big heat distribution system.
9. The passive solar heating is very modest — almost incidental.
10. Room humidity remains near 50 percent all winter. No need for humidifiers.
11. In summer the house stays cool automatically. There is no tendency for the south side to become too hot — because the south window area is small and the windows are shaded by eaves.

What name should be given to this new system? Superinsulated passive? Supersave passive? Mini-need passive? Micro-Load passive? I lean toward "micro-load passive."

Whatever it is called, it has (I predict) a big future.

(Shurcliff didn't stop with his press release. He continued investigating on his own and wrote a book, completed that same year, called "Superinsulated and Double-Envelope Houses," published privately by the author and later by Brick House Publishing Co.)

The Superb Functioning Of Superinsulated Structures

When enough superinsulation features are incorporated into a house, the overall heat loss is reduced to the point where the house behaves differently from ordinary houses. It can be kept warm, even during cold, cloudy weather, with tiny space heaters. The homeowner may happily discover his space heating cost is lower than his water heating cost.

At this point, the house can be considered "superinsulated."

Reduced Heat Loss And Lowered Fuel Bills

In a superinsulated house, heat loss — compared to conventional houses — is reduced 60 to 80 percent, but annual fuel costs are reduced by 80 to 90 percent or more. Why does this happen?

There are three main sources of heat in a house: intrinsic, solar, and auxiliary. Intrinsic heat is from people, animals, lights, and appliances. Solar heat comes through windows. Auxiliary heat is from a furnace or other heating system.

A conventional house loses so much heat that to replace it the auxiliary heating system must keep pumping away. In fact, most residents of conventional houses never even consider the heating potential of light bulbs, German shepherds and picture windows, because in conventional houses, intrinsic and solar heat comprise only a small fraction of the overall heat produced.

Let's start adding hypothetical superinsulation features to a conventional house. Fill up the gaps and cracks: now less heat is lost, and the furnace can run less. Add insulation in the right places: even less heat is lost; the furnace runs even less. Triple glaze the windows: even less heat escapes; the furnace's "on" time is further reduced. Shore up those last air leaks and add insulation; now, so little heat escapes that the furnace hardly needs to come on at all. The house, at this point, can be kept warm almost solely by intrinsic and solar heat.

Because of their low heat loss, superinsulated houses can often be heated solely by intrinsic and solar heat, even when outdoor temperatures are extremely low. For example, the Saskatchewan Conservation House often stays warm without auxiliary heat even when the outdoor temperature falls as low as 10°F. If we define heating season as the period during which a house needs auxiliary heat to maintain a comfortable indoor temperature, then one consequence of superinsulation is to effectively shorten the heating season. While conventional houses in cold climates often need auxiliary heat from October to April, superinsulated houses may need it only for one or two months

How Much More Does it Cost to Build a Superinsulated House?

Given the extraordinary attractiveness and benefits of superinsulated houses, one must naturally ask: "OK, great! But how much extra will I have to pay for all those features?" Unfortunately, the answer to that question is very difficult to pin down. Obviously there is extra cost for materials: insulation, plastic vapor barriers, extra framing lumber, more expensive windows, a ventilation system, and possibly an air-to-air heat exchanger. Labor costs also increase: air and vapor barrier installation; possibly some extra framing; more careful construction in general. Balanced against extra costs are savings from downsizing and possible elimination of the central heating system and chimney.

The actual cost for superinsulation is elusive for the following reasons:

1. There is no accepted "base case" with which to compare a superinsulated house. Does superinsulation cost more than what? When compared with a pre-1970 house with minimum insulation and high air leakage, superinsulated houses cost considerably more. But when compared with many of the conventional houses built today with 6-inch walls and foam sheathing, superinsulation increases costs only marginally.
2. Superinsulation covers a broad spectrum of design types. Some require significant "retooling" and modification of construction sequence; others entail mostly extra materials with little change in the construction process. The extra cost for any specific superinsulation design depends in part on the builder. Some custom builders, with one or two framing crews, find it easy to adapt to the changes in framing patterns or construction sequence because their framing crews are used to lots of variation from house to house. To them, switching to superinsulation is less expensive than for the tract builder, with 20 or 30 framing crews, who can frame a conventional house in two days with their eyes closed, but might get slowed down considerably when confronted with some of the modifications involved in superinsulation construction.

Despite the variables mentioned above, we have found a certain range of agreement about extra cost for superinsulation. Surprisingly, it doesn't seem to be proportional to house size. For example, a case study presented as part of the Canadian R2000 program showed the extra cost for superinsulating a 700-square-foot house to be $4,350. But a similar case study, performed by Superinsulation Ltd., a design and consulting firm in Minnesota, examined case studies for six different types of superinsulated houses and found the extra cost to range from $4,500 to $5,500 for a 2,000-square-foot house. With few exceptions, most builders interviewed agreed that superinsulation added between $4,000 and $8,000 to the selling price of their houses.

during the dead of winter. The heating season is shortened from seven months to two or three months.

That's why a superinsulated house costs only 10 to 20 percent as much to keep 100 percent as warm as a conventional house.

Energy-sensitive Inside; Weather-impervious Outside

Because of their remarkably low rate of heat loss, superinsulated houses are highly sensitive to relatively small energy flows within the thermal envelope. A seemingly insignificant addition of heat — say, a clothes dryer running all afternoon — will significantly maintain acceptable indoor temperatures. The homeowner who said, "I heat with cats" was exaggerating but, nonetheless, his words are not without truth.

This indoor "energy sensitivity" makes it possible to get away with very small heating systems — in fact, finding small enough furnaces or boilers is often a problem. Superinsulated houses are typically so sensitive that even moderate amounts of incidental sunshine coming through regular-sized windows can supply 50% to 80% of home heating requirements. Along these lines, while conventional solar structures require specially rigged areas of thermal mass — such as concrete or water tanks — to absorb and store excess solar heat, superinsulated structures are so sensitive, that intrinsic thermal mass of walls, furniture, etc., is sufficient for everyday heat storage.

The combination of intrinsic thermal mass and high insulation levels renders the superinsulated house — so sensitive on the inside — unresponsive, nearly impervious, to shifts in outdoor temperature and wind conditions. Sudden drops in outdoor temperature are not felt indoors for many hours, if at all. Often an entire cold night, with winter storm, will pass without affecting the indoor temperature, and without having to turn on the furnace.

The Benefits of Superinsulation

The Most Obvious Benefit: Savings in Energy and Dollars

Some superinsulated houses have annual heating bills well below $100. While not all superinsulated houses perform quite this well, savings consistently range from 60% to 90% compared to conventional pre-1980 housing.

In other words, a homeowner living in a conventional house pays $1,700 annually for heat. A homeowner in a similarly sized superinsulated house pays $200. Not only is the second homeowner saving money: he or she may also enjoy conserving energy and the security of being protected by a hedge against energy prices which — while not skyrocketing as they were in the mid-seventies — are projected to rise steadily over the next ten years.

Anything could happen. What if some overseas political upheaval doubles energy prices in 1990? Fuel bills may rise 100%. An owner of a conventional home with, say, a $1,000 annual fuel bill will have to pay $2,000 per year. But the owner of a superinsulated house with, say, a $100 fuel bill, will have to pay only $200 — a much more manageable increase. Protection from energy price fluctuations is attractive to many prospective homeowners, particularly those in the low-income bracket and people on fixed incomes.

Almost No Architectural Constraints

One distinctive feature of superinsulated houses is ... their lack of distinctive features! Although walls are usually thicker, this extra thickness is not visible from the outside and usually not noticeable even from the inside. Few energy-related features need to be designed into, or hidden in, the architecture of a superinsulated house and many so-called "energy design dictums" fall by the wayside.

For example, to reduce wall heat loss, designers have sometimes reduced the amount of exposed wall area for a given size house. This is not necessary in a superinsulated house, where wall heat loss is small compared to losses via windows and ventilation. Thus, the designer is free to vary geometry without compromising energy efficiency.

Even more important: the designer does not have to compromise other considerations to make sure there's a lot of glass on the south side of the house. South-facing windows are helpful in any house, superinsulated or not; but in superinsulated houses, broad expanses of south-facing glass can be foregone without dire consequences. They are not the main element of energy efficiency. Window placement can, therefore, be guided by homeowner and/or designer preference.

Microclimate Is Not Significant

Because superinsulated houses are thermally isolated from the outdoors, they are less sensitive to microclimate, to factors of wind and solar availability. In conventional houses, wind increases air leakage, a major component for heat loss. Therefore it's important to protect conventional houses from wind: to build on the leeward side of the hill, plant trees as windbreaks, etc. Superinsulated houses are hardly affected by wind; they leak only minimally even under high wind conditions. The designer is free to site the house as he/she pleases without particular concern for sheltering or construction of windbreaks.

Solar availability is also less critical. At one time, fears arose that sunless north-sloping land would become worthless because solar heating was thought to be the only way to limit heating costs. Superinsulation changed that. While a south-facing site is still desirable, it's much less crucial. The loss of free solar heat becomes relatively minor compared with other home operating costs.

Even the Macroclimate Is Less Important

In the cold but sunny regions of Colorado, large windows may be OK because window heat loss can be easily offset by solar energy input. In the cold but cloudy regions of Oregon, on the other hand, expansive windows are more likely to be an energy liability — sunshine is less available to offset window heat loss. In this respect, window design and placement are significant even in superinsulated houses. But the predominant features of superinsulation — effective insulation, airtightness, quality construction — don't vary drastically with climate. Nearly identical wall construction, for instance, is used in Virginia and Montana. Only in extreme climates are wall and ceilings distinctly tailored to likely weather patterns.

Superinsulation For Hot Climates

In North America, we spend more money on heating than on cooling. For this reason, most of the development work for superinsulation has been in cold climate housing. That is starting to change. The first superinsulated house in the southeastern United States was built in Georgia during the summer of 1983.

Superinsulation is well suited to hot climates. Many superinsulation principles and techniques are the same for hot and cold climates, with some differences. For example: intrinsic heat from people, lights, and appliances is an asset in cold climates but a liability in warm; reflective insulation (radiation barriers) seem to work better in warm climates than in cold; heat recovery ventilation must be designed differently for warm climates.

Unfortunately the technology of warm weather superinsulation is not fully developed. What about superinsulation in really hot climates? What R-value is needed, where does the vapor barrier go? Those questions are only now being fully addressed and while some answers have been produced, much more research is still required.

The Housing Industry Doesn't Have to Retool to Use Superinsulation

Superinsulation is not a new technology; rather, it's a refinement of existing technology. Constructing superinsulated houses does not mean learning a whole new set of skills. Basic materials and tools are used. There are some exceptions, but they are just that — exceptions. Double framed walls, for instance, are often identified with superinsulation because they're so noticeable. But several superinsulation designs use single stud walls. Many superinsulation techniques require only slight departures from conventional construction methods.

There is one new and important demand which superinsulation places on the building industry — strict attention to quality. Not new levels of quality, but new areas of quality: maintaining quality control where it hasn't previously been considered very important. Insulation, for example, must be installed perfectly. Zero gaps. Period. Sound too rigorous? It shouldn't. After all, how many leaks do we allow in the average plumbing system? Zero. Insulation is easier to install than plumbing. Perfection may be new, but certainly not beyond present capabilities.

Superinsulation Doesn't Require Sacrifices

To some people, the concept of superinsulation suggests a dimly lit cave, styrene igloos, foam pillboxes. While there may be a few houses which warrant those descriptions, they are the victims of poor design, not energy efficiency. "Nothing is foolproof because fools are so ingenious," says Harold Orr of the Canadian National Research Council. If improperly designed, superinsulated houses may overheat in spring and fall; indoor air quality may be poor; condensation can be a problem on windows and even on walls; and moisture may cause structural damage. But when approached in an intelligent manner, superinsulation design and construction can result in a house that is airy, well-lit, comfortable, and superbly energy efficient.

Superinsulated Houses Can Have Better Air Quality than Ordinary Houses

Hundreds of substances are released into the indoor air by manufactured products, building materials, even the earth beneath the house and water from the tap. Many of these may be unhealthy or dangerous if not removed.

Ordinarily we rely on air leakage through cracks and openings to refresh home air. But superinsulated houses are airtight; they must have controlled ventilation. For every discernible purpose, controlled ventilation is preferable to haphazard. Fresh air can be supplied to all parts of the house, in any proportion and at any time. Furthermore, since all the exhaust air is discharged through a duct, it is easy to extract the waste heat from the outgoing air. Thus, in an airtight house it is possible to have better ventilation with less energy use.

Superinsulated Houses Can Have Plenty of Natural Light

Many remarkably efficient superinsulated houses have as many windows as conventional houses. Typically, total window area ranges between 12 and 15 percent of the floor area — sufficient to provide adequate light, ventilation, and emergency egress. There are no rigid restrictions; if larger windows are desired, then the design may be adjusted to accommodate them. Neither is there magic: a homebuyer wanting an all glass house must be prepared to provide more heat from a heating system.

Superinsulated Houses Are More Comfortable

What makes people thermally uncomfortable? Temperature change, drafts, cold surfaces, low humidity — all of which are reduced in a superinsulated house.

Temperatures Are Even

Since there are no large expanses of glass and because heavy insulation lengthens the response time to outdoor temperature changes, indoor temperatures in a superinsulated house don't alter abruptly. More important, the temperature is uniform throughout the room, not colder near the floor or walls.

No Drafts

These houses are "wind-tight." Sitting next to a window during a winter storm, one is cozy and comfortable.

No Cold Surfaces

Recent research shows that people feel particularly uncomfortable when one side of the body faces a warm surface and the other a cool surface, like a cold wall or a large cold window. In superinsulated houses, the exterior walls are about as warm as the interior walls and don't contribute to radiant cooling. The windows are only slightly cooler, so the uncomfortable effect is minimized.

Controlled Humidity

Dry winter air adds to body cooling and thermal discomfort and increases the rate of moisture evaporation from the skin. In a superinsulated house, low humidity is rarely a problem because of airtight construction. Humidity is maintained at comfortable levels by the ventilation system.

Superinsulated Houses Are Quiet

Many superinsulation techniques — double walls, thick insulation, multiple pane windows — are like those used in acoustic construction, serving to reduce sound transmission into and out of the house. To some this may be a drawback — cutting off the birdsongs of dawn. For the poor soul living next to the highway, on the other hand, the din of rush hour traffic will probably not be missed.

Superinsulated Houses May Well Be The Ordinary Houses Of Tomorrow

When Tschumi, Schick, and others began experimenting with super-energy-efficient design they were simply trying to improve the technology of housing. The technology they helped develop is now being implemented in thousands of American homes, promoted by the driving force of energy prices. But even without that economic whip, don't superinsulated houses simply make sense? They preserve the best features of traditional design and construction, while adding new dimensions in comfort, air quality, and efficiency. They are well within the reach of most homeowners; and within the scope of most homebuilders. Any other sort of house, in comparison to one that is superinsulated, can only seem disadvantageous.

Communications, transportation, medicine, entertainment — all these fields have benefitted from dramatic technological advances in recent years. But housing has remained comparatively stagnant. Superinsulation is certainly not the only available improvement, but it is the most widely applicable. If better ideas do, in the long run, gain popular acceptance, what is now "super" today may be quite ordinary tomorrow.

Four Characteristics of a Superinsulated House

1. High levels of insulation.

The most identifiable feature of a superinsulated house is the thick insulation in walls floors and ceilings. Throughout this workbook, you will see examples of construction techniques which provide higher R-value and thus greater resistance to heat loss through the building skin or "thermal envelope."

2. Reduced thermal defects.

Conventional houses, even when "fully insulated," are full of thermal defects which can degrade the performance of the insulation. Thick insulation alone does not make a house superinsulated.

Typical thermal defects include:

INSULATION VOIDS
THERMAL BRIDGING
CONVECTIVE LOOPS
AIR LEAKAGE
AIR INTRUSION

As we shall see later, these defects must be designed and built out of the house. Some of them, such as thermal bridging and convective loops (discussed below) are eliminated during the design phase. But many of the most important features depend upon the builder. Quality construction is a prerequisite for superinsulation. When a wall or ceiling is insulated, it must be completely insulated — no spaces or voids. This point cannot be overstated.

3. Airtight construction.

Airtight construction is just as important as high levels of insulation in a superinsulated house. The techniques for achieving airtightness are relatively simple and mostly common sense, but they are new to most builders. Much of this workbook is devoted to illustrating the details for achieving airtightness. We also present some of the methods for testing houses for airtightness.

4. Controlled ventilation.

Houses need ventilation not only to supply oxygen for people to breathe, but also to remove unwanted contaminants in indoor air. Moisture in the air must be controlled. But perhaps more important is limiting indoor concentrations of dangerous pollutants such as radon, formaldehyde, and cigarette smoke.

Because superinsulated houses are airtight, a mechanical ventilation system is necessary to assure adequate ventilation. Superinsulated houses are actually better ventilated than conventional leaky houses. It is a false security to believe that a leaky house is a well-ventilated house. As we shall see below, there are times when even a leaky house has a ventilation rate of zero. Never so in a superinsulated house. The ventilation system is carefully designed to supply adequate fresh air to all parts of the house and to exhaust stale air out.

An added benefit of controlled ventilation is that it allows for recovery of waste heat from stale exhaust air. In a conventional house, stale air leaks out through hundreds of small cracks and openings. In a superinsulated house with controlled ventilation, all the exhaust air leaves through one duct. This allows for installation of an air-to-air heat exchanger or other heat recovery device which captures the waste heat from the exhaust air and uses it to preheat the incoming fresh air.

Examples Of Thermal Defects

Insulation Voids Must Be Avoided in a Superinsulated House

Insulation voids are one of the "defects" found in most conventional houses. Simply an area which was missed during insulation installation, voids can seriously degrade the performance of an insulation system. Some contractors take the attitude that "missing a small area, such as under a window, won't matter," but that just isn't true. Figure 1-1 illustrates what happens to a 6-inch wall, insulated with R-19 fiberglass batts, if just a "tiny area" is missed. If fully insulated, the wall will have an R value of R-23 (ignoring framing). But if only 3 percent of the wall area is missed, the overall R-value is degraded 17 percent to R-19.2! If 5 percent is missed, the overall R-value is reduced 25 percent! Thus insulation voids can seriously degrade the thermal performance of a wall or ceiling. The installation must be perfect — no voids. Period.

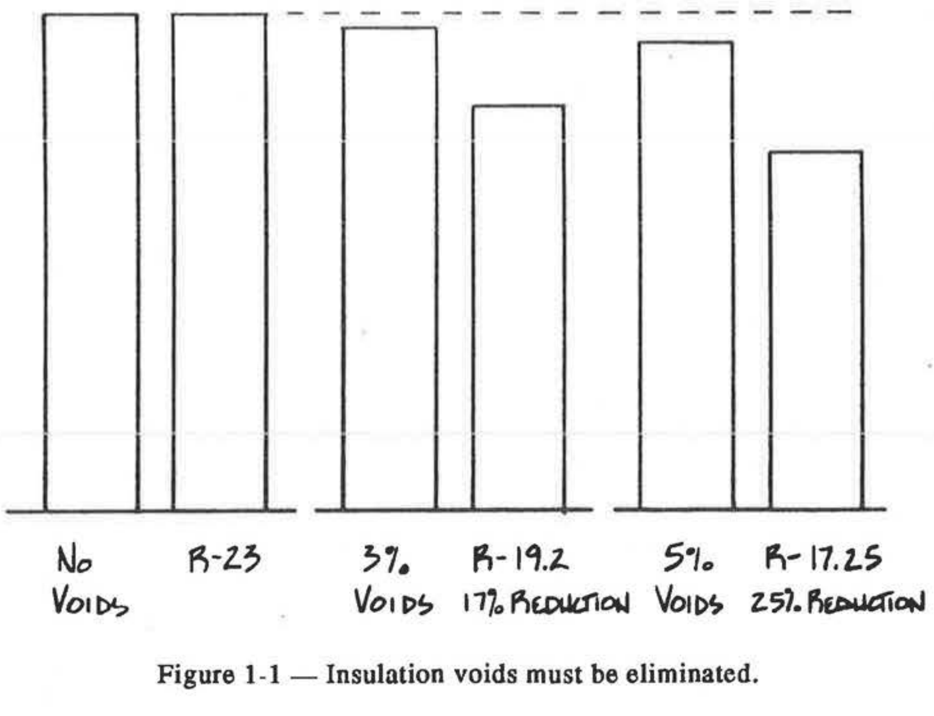

Figure 1-1 — Insulation voids must be eliminated.

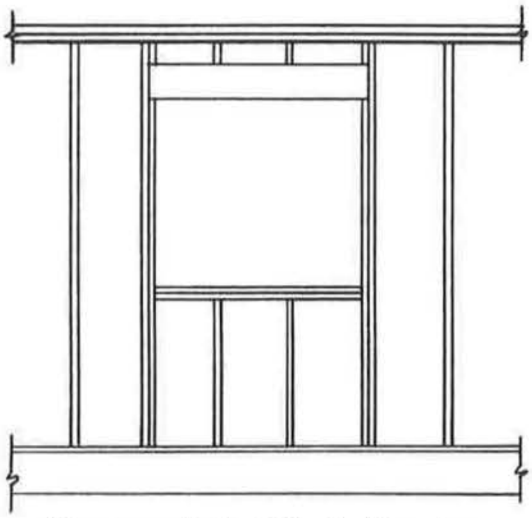

Figure 1-2 — Thermal bridging in 2"x4" frame construction

Thermal Bridging in a 2x4 Frame Construction

Whenever a framing member or other building component passes through or around the insulation, from inside to outside, it forms a thermal bridge. In a conventional 2x4 wall, between 12 and 20 percent of the wall acts as thermal bridging. Studs, window headers, wall plates, sill plates, etc. All are thermal bridges. In a superinsulated house, walls, foundation, and ceiling are designed to reduce thermal bridging as much as possible. The various techniques are shown in later sections of this manual.

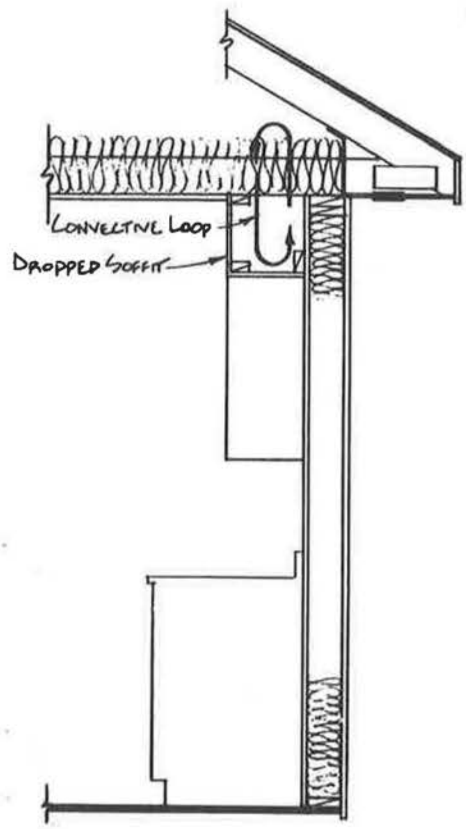

Figure 1-3 — Convective loop in dropped soffit

Convective Loop In A Dropped Soffit

Convective loops are another type of thermal defect found in conventional houses. A convective loop is an air current which carries heat away from the living space. An example is the dropped soffit (Figure 1-3). In conventional houses, a dropped soffit over a kitchen cabinet is usually not sealed from the attic. Thus air can freely circulate from the soffit into the attic, through the attic insulation. In a superinsulated house, this type of convective loop is avoided through proper sealing of all building components.

Air Leakage Through Insulation

Air leaking through insulation degrades the performance of the insulation and carries moisture which can cause condensation problems. In a superinsulated house, air leakage is reduced to a minimum through proper air-tightening techniques.

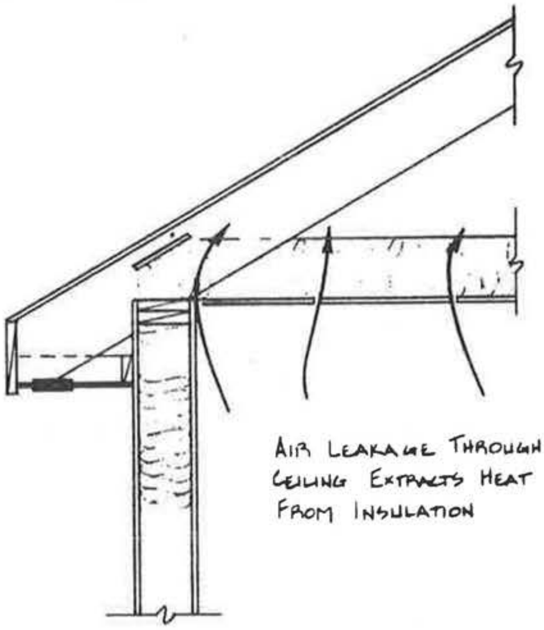

Figure 1-4 — Air leakage through insulation

Air Intrusion

Air intrusion is different from air leakage. It refers to "one-way" intrusion, where air, say in an attic, blows into the insulation from one side, but doesn't go all the way through. Although there is some uncertainty as to how serious a problem it is, superinsulated construction includes measures to avoid air intrusion into wall and ceiling insulation.

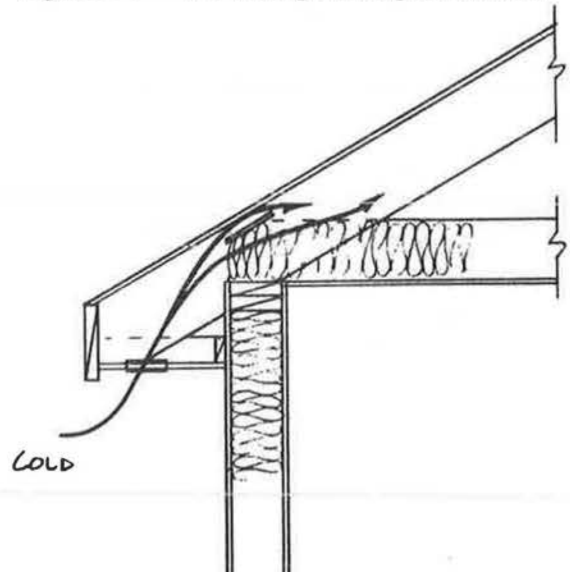

Figure 1-5 — Air intrusion into attic insulation

SECTION 2
ENERGY DYNAMICS

Three Sources of Heat Loss in a House

1. Conduction.

Conduction is the transfer of heat energy by molecular interaction. When you heat one end of a metal rod, the atoms or molecules in that rod begin to vibrate faster, bumping into adjacent molecules, and passing their heat energy down the line. In a house, warm air molecules transfer heat energy by conduction to interior gypsum board which then passes it to whatever is inside the wall, on to the exterior sheathing, and then to the outdoor air. Heat is lost from a house by conduction through all exterior surfaces.

2. Air leakage (infiltration).

Commonly referred to as infiltration, air leakage through the thermal envelope is the second largest source of heat loss in most conventional houses (conduction is the largest).

3. Ventilation.

Ventilation is controlled air leakage. In a superinsulated house, since uncontrolled air leakage (infiltration) is minimal, ventilation is the second largest source of heat loss.

Conduction Heat Loss and R-value.

The rate of heat conducted through any material depends on the thermal resistance of the material. Measured in units of R-value, the greater the thermal resistance, the lower the heat transfer by conduction. Materials with high R-value serve well as insulation. Those with low R-value are poor from an insulation standpoint. R-value is usually expressed in R per inch and increases linearly with thickness. If, for example, a material has an R-value of 5.0 per inch, then 2 inches will have an R of R-10, 3 inches will equal R-15, and so on.

R-values are listed two ways. One is R per inch for materials which come in varying thicknesses; the other is total R-value for a listed thickness, for materials which come in standard thicknesses, such as plywood and gypsum board.

One of the best insulation materials is still air. Air has an R-value of about R-5.5 per inch. The only problem with air as an insulation material is that it is a fluid. A hollow 2 x 4 stud cavity would have an R-value over R-19 (3.5 inches x R-5.5 per inch) if it weren't for the fact that air moves in the wall cavity. Air adjacent to the warm interior wall surface gets heated, becomes buoyant, and rises within the wall cavity. Air adjacent to the cold exterior wall surface gets cooled, becomes more dense, and drops. The combination of the two processes sets up a "conveyor belt" within the wall where circulating air carries heat from the inner surface to the outer surface (see Figure 2-1). This is known as a convective loop and the heat transfer mechanism is known as convection. The result is that the effective R-value of a hollow wall is only about R-1.0.

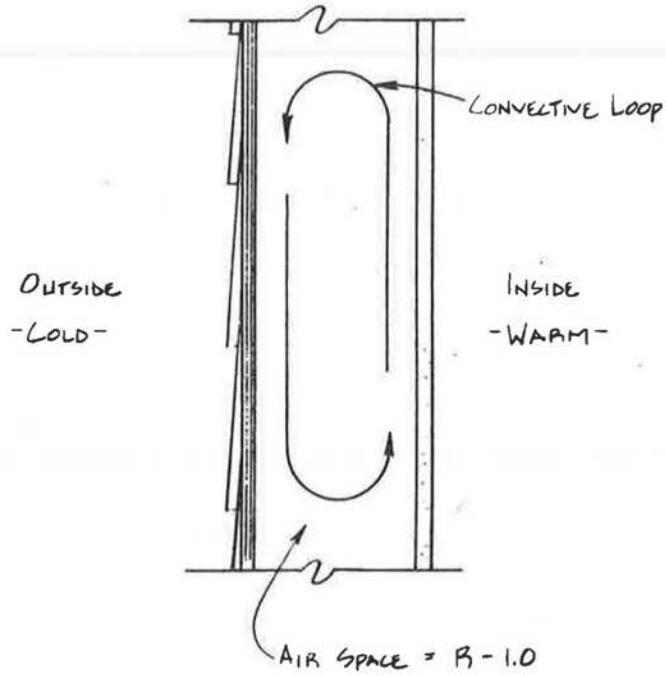

Figure 2-1 — Convective loop in a hollow uninsulated wall

Most insulation materials work by stopping convection. Fiberglass insulation, for example, works by entrapping air in tiny cells, preventing it from circulating within a wall or ceiling cavity. The fiberglass itself is made of glass which has a very low R-value. But by suppressing convection, fiberglass insulation has an R-value around R-3.3 to R-3.4 per inch. Plastic foam insulations — urethane, isocyanurate,

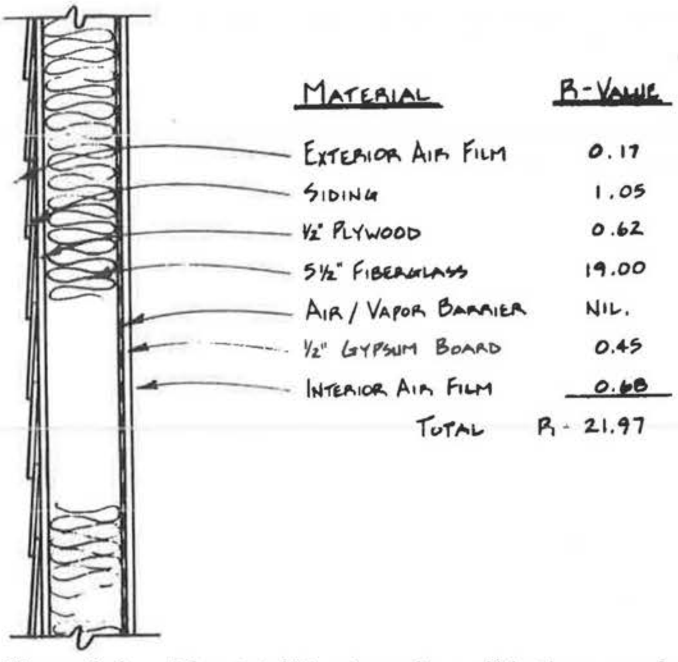

Figure 2-2 — The total R-value of a wall is the sum of the R-values of its components.

and polystyrene — work slightly differently. These materials are filled with another gas which has an even higher R-value than air. Urethane, for example, can have an R-value of R-7.0 per inch and sometimes higher.

The Total R-Value of a Wall, Ceiling, etc. Is the Sum of the R-values of the Individual Components

To calculate the total R-value of any building segment, one simply adds the R-value of the individual components. Figure 2-2 shows the example of a 6-inch wall filled with R-19 fiberglass batt insulation.

Notice the two air films on the interior and exterior wall surfaces. Every surface has a thin film of air which clings to the surface and suppresses, somewhat, convective heat transfer at the surface. Those air films have an effective R-value that depends on air movement near the surface. For interior surfaces, it is assumed that the air is still, giving the film an R-value of R-0.68. For exterior surfaces, it is assumed that there is a 15-mph wind which reduces the film R-value to R-0.17.

Conduction Heat Loss Depends on R-Value, Area, and Temperature Difference Between Indoors and Outdoors

To calculate the amount of heat which flows through any building component by conduction, you need to know the R-value, area of the component, and temperature difference on either side. Temperature difference is the driving force — the larger the difference, the greater the heat flow.

$$Q = (A/R) \times (Ti - To)$$

where Q is heat loss in Btu per hour, A is area of the surface, Ti is indoor temperature, and To is outdoor temperature.

Example — What is the heat loss through a 500-square-foot wall with an R-value of R-25 when the indoor temperature is 70°F and the outdoor temperature is 20°F?

Solution

A = 500 square feet
R = 25
Ti = 70°F
To = 20°F
Q = (500/25) x (70 - 20)
= 1,000 Btu/hr

Unintentional Air Leakage (Infiltration)

Unintentional air leakage is the most important reason why most conventional houses waste so much energy. In order for air leakage to occur, there must be openings in the thermal envelope and a pressure force to drive air into or out of the house. We will discuss the pressure forces later. First let's look at the openings or pathways for air leakage to occur.

Basically, there are two types of openings in all houses: a) "intentional" openings such as windows, doors, fans, and flues; and (b) "unintentional" openings such as building seams between walls and floors, where foundations meet walls, and where windows are set into walls. The first type — intentional openings — are meant to be openable by house occupants, but must be designed so that they form an airtight seal when closed. Windows and doors must, of course, be opened, but should also have good weatherstripping so they form a good seal when closed. Bathroom vents have dampers which open automatically when the fan is turned on. Often these vents don't close effectively and contribute to air leakage.

Unintentional openings — leaks through building seams, etc. — are eliminated to a great extent in a superinsulated house. The process of sealing those openings requires

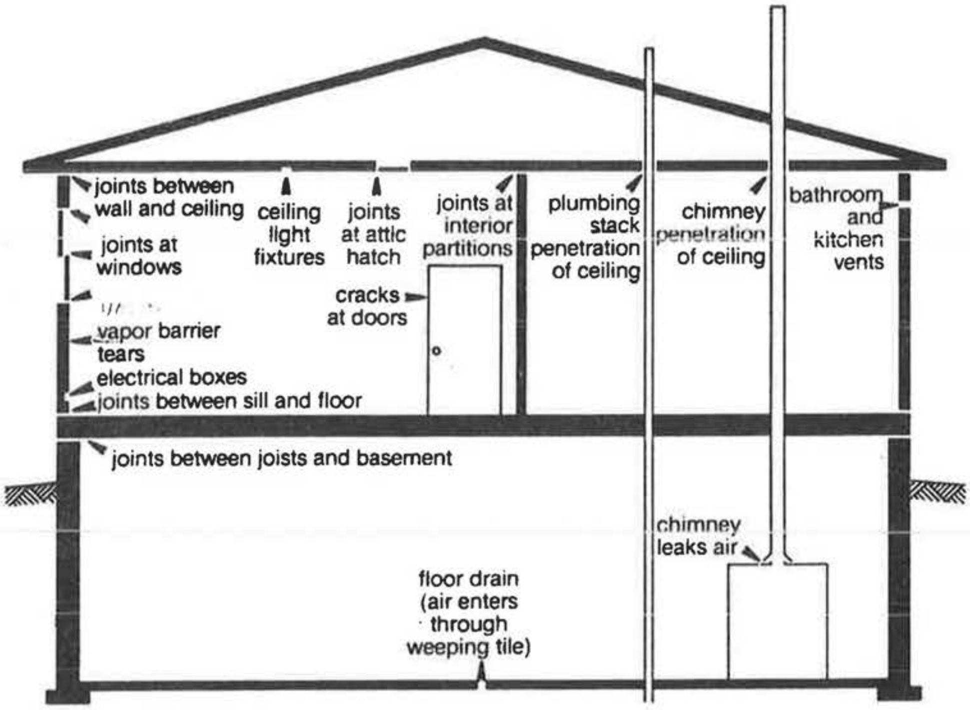

Figure 2-3 — Typical air leakage points.

no special skills but does require care and attention. The magnitude of air leakage through unintentional openings is often underestimated, as we shall see in the next section.

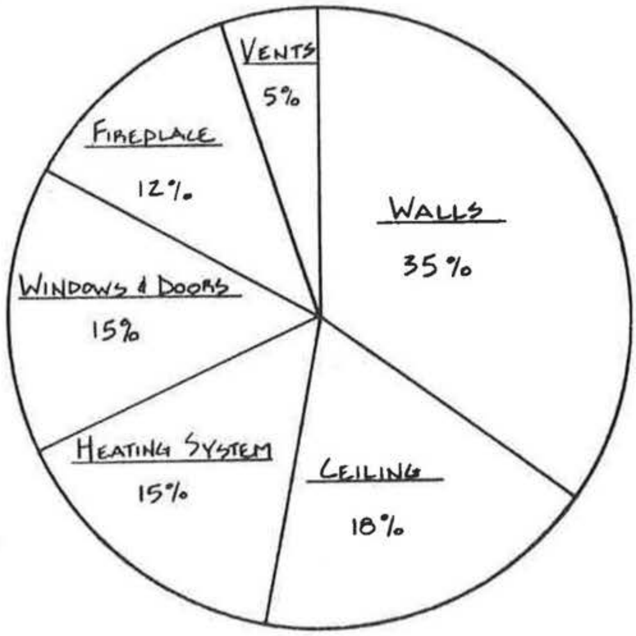

Figure 2-4 — House air leakage distribution.

The pie chart in Figure 2-4 shows a typical distribution of air leakage in a house. The numbers are averages (data is from the ASHRAE Handbook of Fundamentals) but are representative of typical U.S. housing stock. Notice that windows and doors are not the main source of air leakage. Walls and ceilings account for 53 percent of the total, compared to 15 percent for windows and doors. Intuitively, you may not think that much air could leak through the seams between walls and ceiling. But when you consider the total length of all those combined seams, you realize that even a tiny amount of air leakage through each linear foot of seam will add up to a significant amount of air leakage. That fact has been verified through various types of field testing.

Effect of Wind on Air Leakage

The effect of wind pressure on air leakage is well known to anyone who has lived in a drafty house. On windy days, the drafts are worse. The windward side of a house experiences a positive pressure, causing air to leak in. On the leeward side, a complex pressure pattern is set up, causing air to leak in and out in different places.

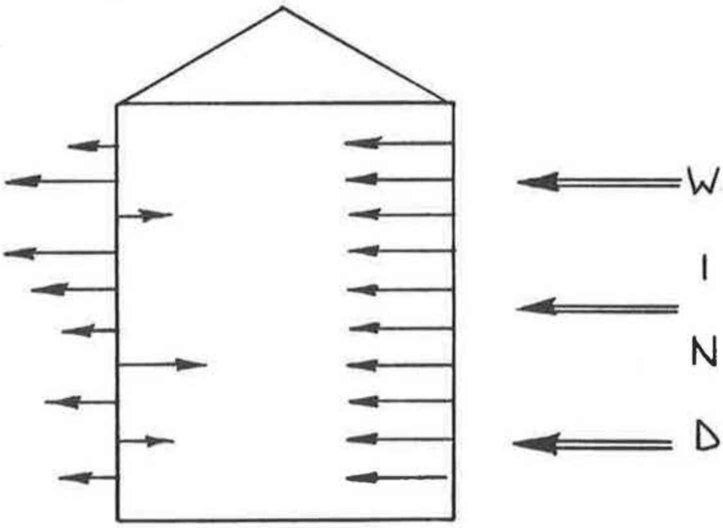

Figure 2-5 — Effect of wind on air leakage.

The Stack Effect

Warm air rises. In a heated house, warm air is constantly pushing up against the top of the house, creating a pressure which results in air leakage out through cracks near the ceiling. Conversely, a negative pressure is created near the bottom of the house, causing air to leak in. In the middle is a "neutral zone" where the pressure is equal inside and out. This pressure pattern is known as the stack effect. The taller the house, the greater the stack effect. Also, the colder it is outside, the greater the stack effect.

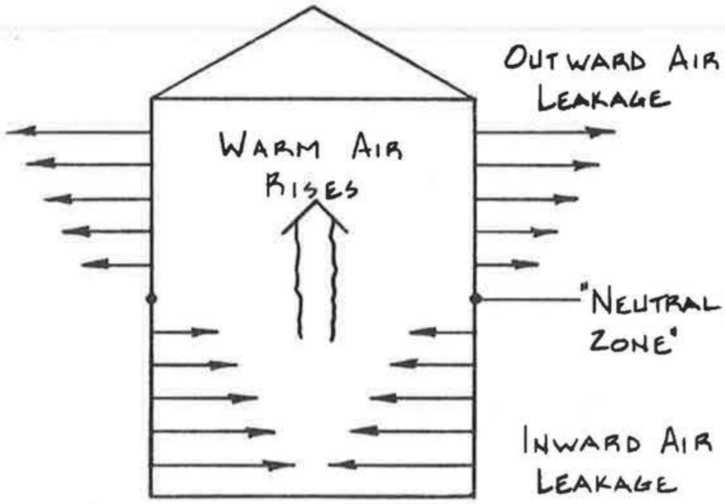

Figure 2-6 — The stack effect.

Effect of Mechanical Equipment on Air Leakage

The third cause of air pressure difference between the inside and outside of the house is mechanical equipment — fans and combustion flues, which force air out of the house, cause a negative pressure inside. For example, a hot chimney over a fireplace draws air up and out of the house. The negative pressure created inside a house by one fireplace can be as great as the pressure created by a 20-mph wind blowing on the house. Kitchen and bathroom exhaust fans have a similar effect.

All three causes of pressure difference — wind, stack effect, and mechanical equipment — act together to create a complex pattern of pressure differences which tend to drive air into and out of a house through all cracks and openings.

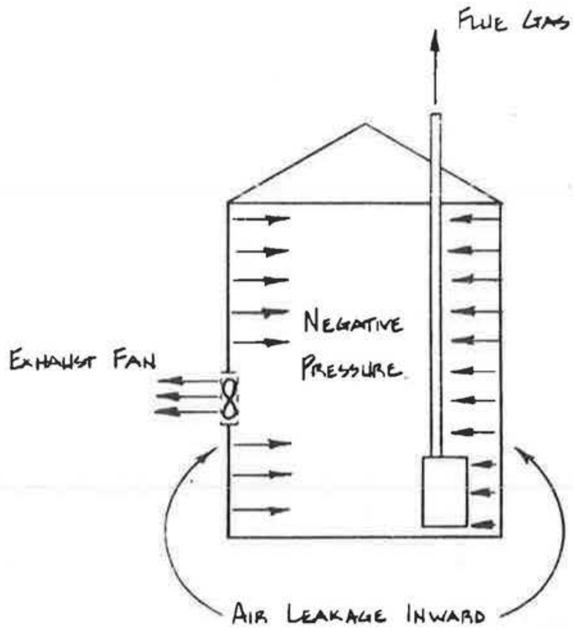

Figure 2-7 — Effect of mechanical equipment on air leakage.

Air Leakage Is Measured in Air Changes Per Hour (ACPH)

To quantify the rate of air leakage into or out of a house, we use the term air changes per hour (acph). An "air change" is one house volume of air. For example, the house in Figure 2-8 is a 2,000-square-foot house with 8-foot ceilings. The volume of the house is 16,000 cubic feet. If this house has a leakage rate of 1.0 acph, it is leaking air at a rate of 16,000 cubic feet per hour or 267 cubic feet per minute (cfm).

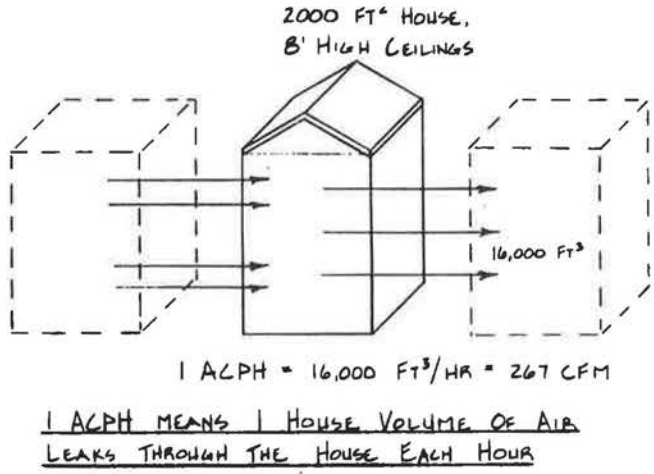

Figure 2-8 — Air leakage is measured in air changes per hour

It is important to understand that when we say a house has an infiltration rate of 1.0 acph, we are stating an average rate. A particular house may have an infiltration rate of 1.5 acph on cold windy days, but may have an infiltration rate near zero on mild, windless days.

Range of Infiltration Rate of Typical U.S. Houses

As discussed above, the infiltration rate of a house varies considerably with weather conditions. Testing of many hundreds of houses in the U.S. has shown that typical houses leak air at rates ranging from 0.3 to 3.0 air changes per hour. Excluding the extremes, the average U.S. house has a leakage rate of about 0.4 to 1.0 acph. Tighter houses built during the 1980s have leakage rates averaging around 0.5 acph.

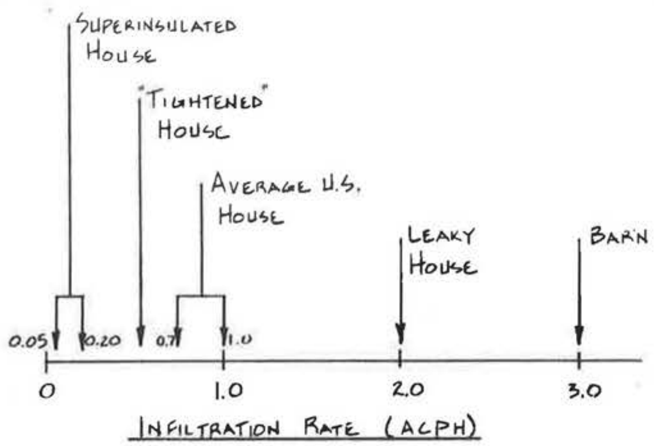

Figure 2-9 — Range of infiltration rates.

Superinsulated houses, built with careful attention to airtightness, should have infiltration rates of less than 0.2 acph and often are less than 0.1 acph.

Heat Loss Due to Infiltration

The amount of heat loss due to infiltration depends on the rate of air leakage and the temperature difference between indoors and outdoors. It takes 0.018 Btu to heat 1 cubic foot of air 1 degree Fahrenheit (see Figure 2-10). To calculate the heat loss due to infiltration, you use the following equation:

$$Q \text{ (Btu/hr)} = 0.018 \times V \times L \times (Ti - To)$$

where Q is the heat loss, V is the volume of the heated space, L is the infiltration rate, expressed in air changes per hour (acph), Ti is indoor temperature, and To is outdoor temperature, both expressed in degrees Fahrenheit.

Example — What is the heat loss rate due to infiltration for a 2,000-square-foot house with 8-foot ceilings with an infiltration rate of 1.0 acph when the indoor temperature is 70°F and the outdoor temperature is 20°F?

Solution

V = 16,000 cubic feet (2,000 x 8)
L = 1.0 acph
Ti = 70°F
To = 20°F
Q = 0.018 x 16,000 x 1.0 x (70 - 20)
= 14,400 Btu/hr

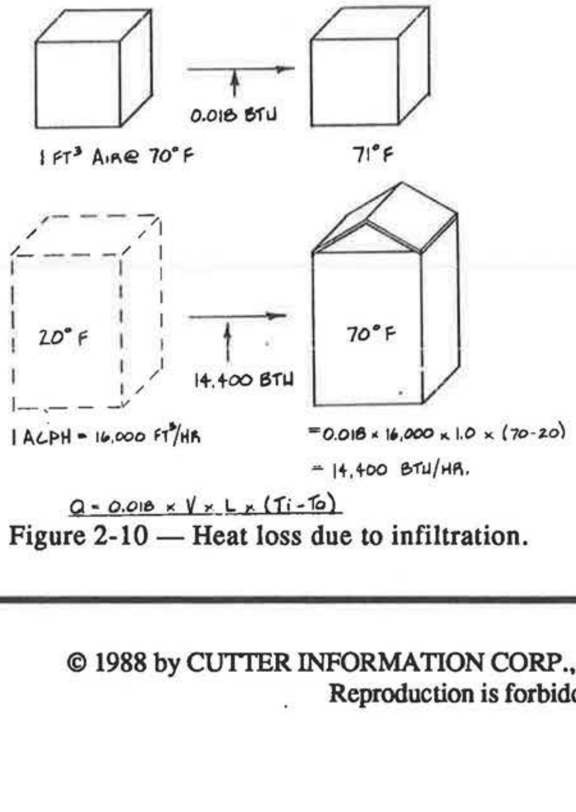

Figure 2-10 — Heat loss due to infiltration.

Heat Loss Due to Ventilation with Ventilation Heat Recovery

When fresh air is intentionally introduced into a house through a mechanical ventilation system, it also must be heated. In a superinsulated house, ventilation heat loss is usually much greater than infiltration heat loss. However, with a mechanical ventilation system, it is possible to recover some of the waste heat from exhaust air and transfer it to the incoming fresh air by using an air-to-air heat exchanger or other heat recovery device. The equation for calculating ventilation heat loss is basically the same as the equation for infiltration, but with the addition of a factor to account for heat recovery:

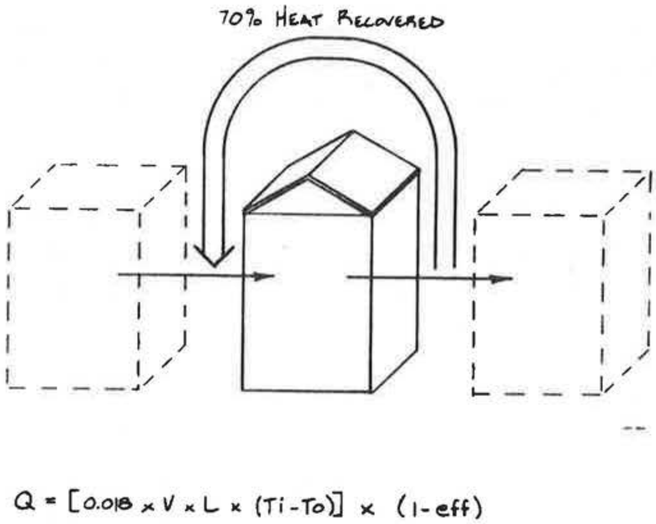

Figure 2-11 — Ventilation heat recovery.

Q (Btu/hr) = [0.018 x V x L x (Ti - To)] x (1 - eff)

where eff is the efficiency of the heat exchanger.

Example — What is the ventilation heat loss from a 16,000-cubic-foot house with a ventilation rate of 0.5 acph when the indoor temperature is 70°F and the outdoor temperature is 10°F? The ventilation system includes an air-to-air heat exchanger with an efficiency of 0.70.

Solution:

V = 16,000 cubic feet
L = 0.5 acph
Ti = 70°F
To = 10°F
eff = 0.70
Q = [0.018 x 16,000 x 0.5 x (70 - 10)] x (1 - 0.7)
= 2,592 Btu/hr

Measuring Airtightness

Two common methods for measuring air leakage are the blower-door pressurization/depressurization technique and the tracer gas method. Additionally, several new experimental methods are now under development.

The blower door test is a useful and practical tool for builders to assess how tight their houses are. Not only is it useful for evaluating airtightness, but it also helps the builder locate leaks and find areas where more attention is necessary for future projects. A complete discussion on blower door usage and available equipment is presented in the following section.

Another way to measure air leakage is called the tracer gas technique. A harmless inert gas (usually sulfur hexafluoride) is injected into a house and allowed to mix well with the indoor air. The household air is sampled periodically and the concentration of tracer gas is measured with a gas chromatograph. As air leaks out of the house, some tracer gas goes with it, and thus the indoor concentration drops. By plotting the rate of decay of tracer gas concentration, you can calculate the amount of air that leaked into and out of the house during the test period.

The value of the tracer gas technique is that it measures actual infiltration, rather than air leakage under exaggerated pressure conditions as the blower door test does. It has been very useful as a research tool, particularly for looking at ways to correlate blower door test data with natural infiltration rate. This technique is not, however, a practical tool for builders or designers. Not only is the equipment very expensive, but the test must be performed many times to truly characterize the airtightness of a house, since natural infiltration varies considerably with weather.

A few other techniques for examining air leakage are the alternating pressure technique, sound detection, and the pressure pulse technique.

The alternating pressure technique is being developed at Lawrence Berkeley Laboratory. With this method, a slow oscillating pressure is created in the house and air leakage is measured using a tracer gas.

The sound detection technique is an interesting test based on the principle that sound waves and air pass through openings in building envelopes in a comparable manner. Therefore, air infiltration can be detected by acoustic means. One builder of manufactured homes uses this technique to find air leaks before each home leaves the plant. A noise generator is placed inside the house and a technician goes around the house with a device consisting of a microphone connected to an amplifier with meter readout. When the microphone is passed over a leakage site, the meter jumps.

The last method, the pressure pulse technique, is purely experimental at this time. It was presented at a recent ASHRAE meeting. It works like this: one single blast of air is suddenly released from a compressed-air cylinder placed inside the living space. A recording instrument measures and records the decay of the induced pressure over time (how long it takes for the pressure to die down to zero). The tighter the house, the longer the decay will take. The idea is attractive because it is quick, easy, and relatively inexpensive. Its most useful application would be for building inspectors (if airtightness becomes a code requirement) or for a builder's final evaluation of his own work. It is not useful for finding leaks. Unfortunately, there are a few serious technical problems with this technique and it may be some time before it is practical for field use.

Testing for Airtightness — A Guide to the Blower Door Depressurization Test

A typical house consists of thousands of components that are nailed, glued, caulked, taped, or otherwise assembled to form a more or less airtight "envelope" around the conditioned living space in a house. Achieving an appropriate level of airtightness is important for several reasons:

1) to reduce energy consumption due to air leakage;

2) to avoid moisture condensation problems;

3) to avoid uncomfortable drafts caused by cold air leaking into the living space; and

4) to assess the need for mechanical ventilation.

But what is an "appropriate level of airtightness" and how does a builder know whether or not that level has been attained? These questions and others are easily answered by performing a simple and inexpensive "blower door depressurization test."

What Is the Blower Door Test?

The blower door depressurization test is an analytical procedure in which a powerful fan, temporarily mounted in an external doorway, is used to draw air out of a house, creating a partial vacuum inside. The lowered indoor air pressure causes outdoor air to flow into the house through all unsealed cracks and openings (see Figure 2-12). By measuring the amount of air flowing through the house and out through the fan, the overall house tightness can be evaluated. Also, by using a leak detection device, such as a smoke pencil, major leakage points can be identified and, if necessary, sealed.

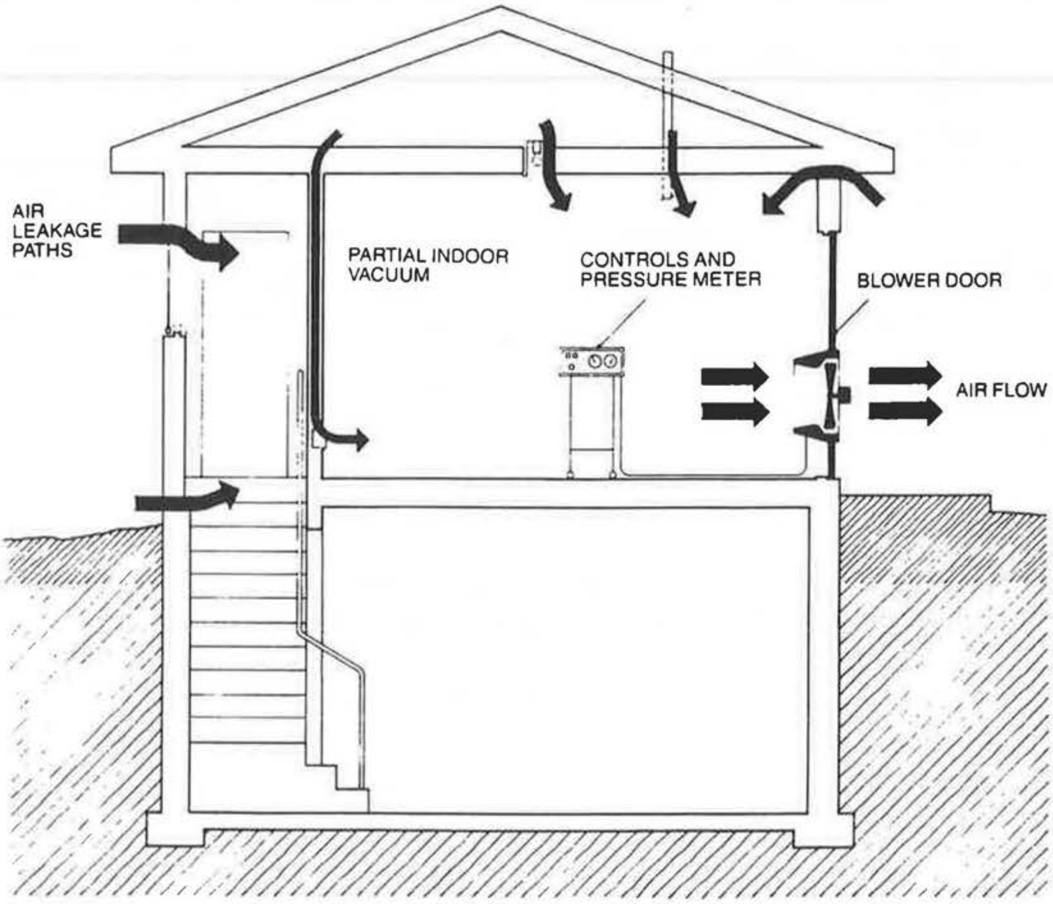

Figure 2-12 — Schematic of blower door depressurization test

What Does a Blower Door Consist of and How Does It Work?

Commercially available blower doors vary somewhat, but all include several necessary components:

1) A door panel which fits snugly into an exterior doorway and accepts a fan element.
2) A fan, usually vane-axial (propeller type), with maximum capacity up to 5,000 cfm.
3) A variable-speed controller for the fan.
4) A pressure gauge to measure "house pressure" — the negative pressure that is induced inside the house by the fan.
5) Some mechanism for measuring air flow through the fan; either
   a. a tachometer that measures fan speed, or
   b. a pressure gauge that measures pressure drop in the moving airstream at the fan.
6) A calculator or computer to calculate induced air changes per hour (ACPH) or leakage ratio (LR). (Optional)

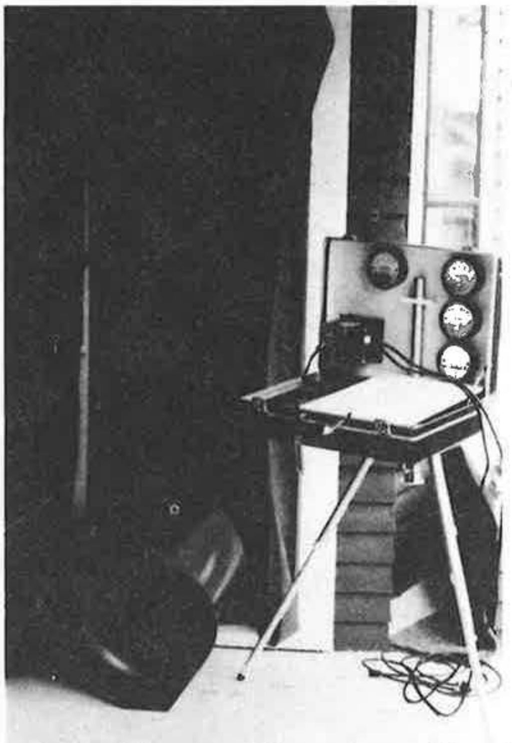

Figure 2-13 - Minnesota Blower Door with calibrated flow nozzle.

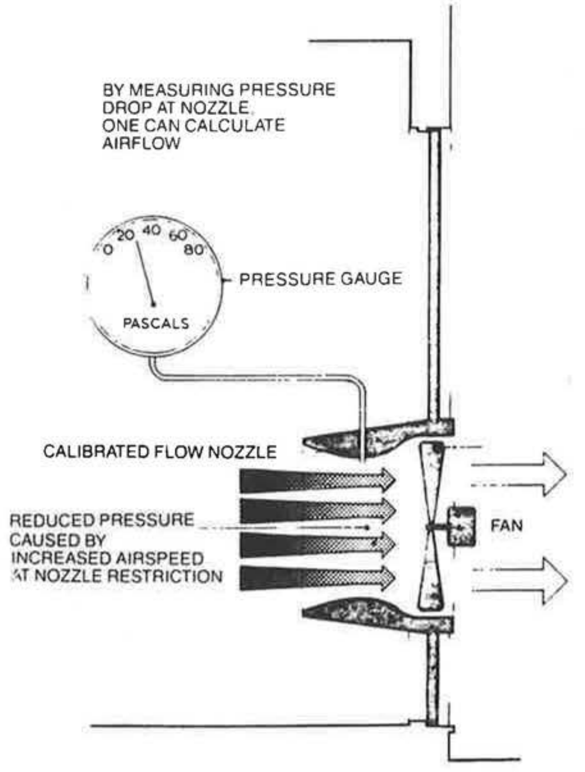

Figure 2-14 — Schematic of calibrated flow nozzle.

Some blower doors have long cylindrical nozzles attached to the fan (Figure 2-13); some have short nozzles; some have no nozzles at all. The difference between those units has to do with the way they measure airflow through the fan.

When air flows through a constricted tube, such as a flow nozzle, the air pressure at the constriction is reduced by an amount proportional to air speed (see Figure 2-14). By measuring air pressure at the constriction (nozzle pressure), we can calculate air speed and volumetric air flow. The calibrated blower door nozzle in Figure 2-13 has four taps around the perimeter. The taps are connected by rubber tubing to a pressure gauge mounted on the instrument stand.

Blower doors without nozzles measure airflow by one of two ways: either they use an "orifice plate" (Figure 2-15) which works by pressure; or they use an "RPM calibration" which allows you to calculate airflow by measuring fan speed with a tachometer.

Although considerable controversy exists within the blower door industry as to what is the best way to measure airflow, it needn't concern the average end-user. Any good calibrated door will be sufficiently accurate and consistent to measure the airtightness of new houses.

How Is the Test Performed?

The blower door test is quite simple. The following is an outline of the procedure.

1. Prepare the house.

Since you want to locate and measure unintentional leaks, all intentional leakage openings, such as vent fans, and fireplace flues should be sealed over. In a new house, all plumbing traps should be filled with water to prevent air from flowing down the vent stack and into the house through the drains. Fuel-burning appliances must be turned off and their exhaust flues should be stoppered. All interior doors and the door to the basement should be left open.

For new construction, pay attention to the air/vapor barrier. If you are using a polyethylene air/vapor barrier, you may want to perform the test before the drywall goes up, in order to find and fix leaks. But be careful. Unless the poly is well sandwiched to the studs by strapping or other structural support, it may get pulled off the wall by the fan suction.

The above procedure may vary somewhat. For example, some researchers don't close off intentional openings such as bathroom vent fans. Others don't include the basement in the test. The procedure outlined here is most appropriate for general evaluation of new house airtightness.

2. Install the blower door.

3. Depressurize the house.

Using the variable speed controller, fan speed is gradually increased until the house pressure gauge reads about 60 pascals. (Pascals are the metric unit of pressure measurement. 50 pascals is

Figure 2-15 — Infiltec blower door

equivalent to about 0.2 inches W.G.) When the pressure stabilizes at that point, airflow through the fan is measured and recorded. Fan speed is then decreased in increments and the corresponding house pressure and airflow are measured and recorded. Usually six to eight readings are taken at pressures ranging from about 20 to 60 pascals.

NOTE: The test can be run either in depressurization mode or pressurization mode. Depressurization is more common.

4. Locate and, if necessary, seal individual leakage points.

5. Plot the results or enter them into the computer.

With the test complete, you now have six to eight data points of measured house pressure and corresponding airflow. If you are analyzing the results manually (no computer), the data is plotted on log-log graph paper and the six points should form roughly a straight line. The graph is then used to calculate the final air leakage rate.

Most blower door manufacturers offer hand-held computers that are programmed to perform all the calculations and plot the results automatically. Later, we will look at a sample output from one of those computers.

How Are The Results Expressed?

Get ready for some alphabet soup. ACPH, ELA, ELA, NLA, and LR — are all acronyms for the various ways to express air leakage. (Yes, there are two ELA's — an American ELA and a Canadian ELA.) For all practical purposes, you only need to understand two of them — induced air changes per hour (ACPH) and Leakage Ratio (LR).

Induced Air Changes Per Hour (ACPH)

Not to be confused with natural infiltration rate, induced air changes per hour (ACPH) refers to the measured air leakage under depressurization (usually 50 pascals house pressure). Typically you would say: "That house has an air leakage of 1.5 air changes at 50 pascals," meaning that, when measured under 50 pascals of pressure, the house leakage rate was 1.5 ACPH.

ACPH is very easy to calculate. Given the airflow in cfm at 50 pascals, you simply multiply by 60 to get cubic feet per hour, then divide by the house volume in cubic feet. For example, if the measured airflow at 50 pascals was 800 cfm for a 2,000-square-foot house with 8-foot ceilings, the leakage, Q, would be:

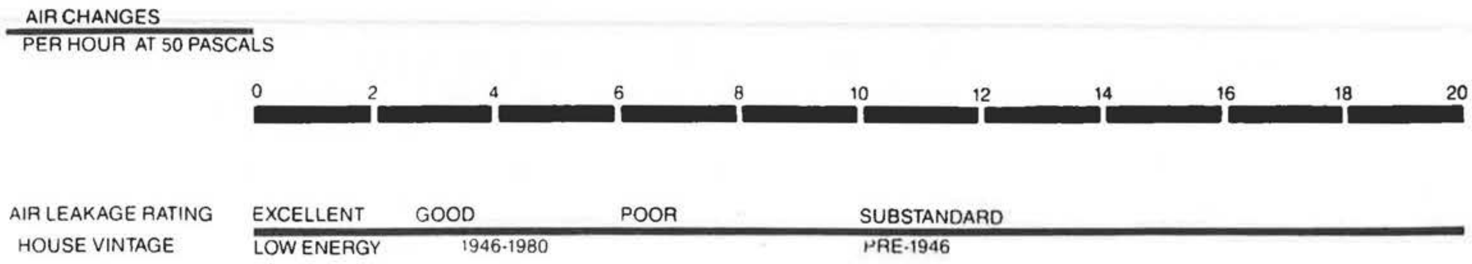

Figure 2-16 — Typical range of air leakage rates, in air changes per hour (ACPH), for various types of houses.

$$Q = (800 \times 60) / (2000 \times 8) = 3 \text{ ACPH}$$

Reporting in air changes per hour (ACPH) is currently the most common practice in the U.S., Canada, and Sweden.

Figure 2-16 shows some typical ACPH values for various types of houses.

One shortcoming of this method of reporting is that it tends to make larger houses look better. If you compare a 1,000-square-foot house with a 2,000-square-foot house of comparable construction tightness, the larger house will have a lower air leakage when measured in ACPH at 50 pascals. Another objection, expressed by some researchers, is that the 50 pascal pressure is too high; that some of the leaks induced at that pressure would rarely leak under natural conditions. This objection is often answered with the fact that 50 pascals is approximately equivalent to the pressure exerted by a 20-mph wind acting perpendicular to the surface of a house.

The Leakage Ratio (LR)

Initially referred to as the Normalized Leakage Area (NLA), the Leakage Ratio (LR) eliminates some of the inaccuracies and limitations of the ACPH method and may very well become the accepted norm in the U.S. and Canada. To understand LR, you must first look at the ELA.

ELA stands for "Equivalent Leakage Area." It describes the area of hole that would exist if all the cracks and leakage openings were gathered into one location. In other words, it is a measure of the combined area of all cracks and openings in the house, expressed in square centimeters or square feet. It is calculated using the same test data as the ACPH reporting method, but ELA uses the measured leakage at 10 pascals rather than 50 pascals. (Even though only the 10 pascal reading is necessary, measurements are still taken at several pressures. If only one reading were taken, the results would

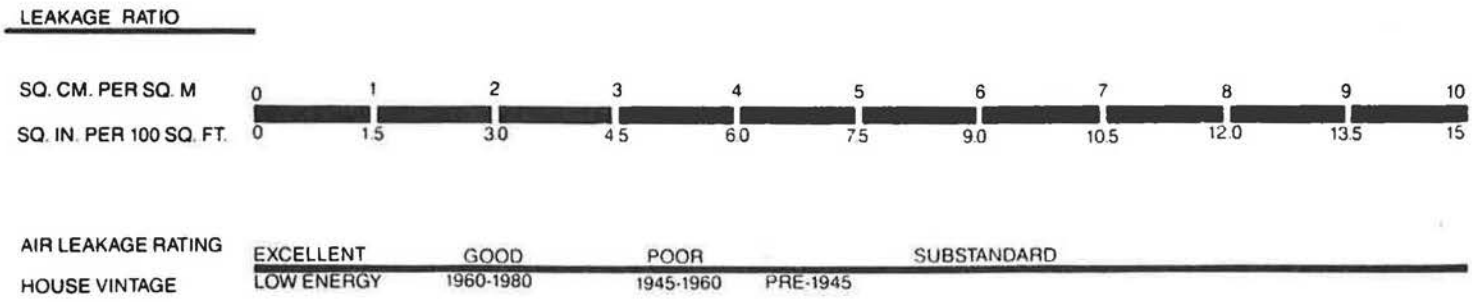

Figure 2-17 — Typical range of air leakage rates, expressed in leakage ration (LR), for various types of houses.
Source: Retrotec Door Fan Operating Manual.

be unreliable.) One of the greatest values of ELA has been as a marketing tool in retrofit work. The homeowner can easily relate to the fact that the leaks in his/her house are the equivalent of a round hole with, say, a diameter of 2 square feet!

Actually, there is quite a bit of uncertainty as to whether the ELA is accurate. Are the leaks in the house really the same as a 2-square-foot hole? The ELA model was developed by the National Research Council of Canada. Another model, the Effective Leakage Area (also called ELA), developed at Lawrence Berkeley Laboratory (LBL), attempts to calculate the same thing — the combined area of all the leakage holes in a house. But the two methods give substantially different results. The Canadian ELA is always significantly higher. But even if neither ELA model gives an accurate measure of the actual area of all leaks in a house, they do give a relative measure of the airtightness of the building skin. As long as everyone uses the same measurement and calculation procedure, so that we are all comparing apples with apples, the test will be sufficiently useful. So far, the Canadian ELA model has gained the most acceptance and is the basis for deriving the Leakage Ratio (LR).

The LR is simply the ELA divided by the total skin area of the house, in 100-square-foot units, including basement walls and floor. For example, if the measured ELA is 160 square inches and the total surface area of the house envelope is 5,560, the LR is (160/55.60), or 2.87 square inches per 100 square feet of surface.

Since LR is expressed in terms of leakage area per unit of wall area, it is independent of house size. If one house has a lower LR than another, it is more airtight, regardless of the relative size of the two houses. Figure 2-17 shows some typical LR values for different types of houses.

Computer Printouts

Most blower door manufacturers supply small hand-held computers and software for performing calculations automatically. (Two manufacturers provide computers that control the entire test. You simply push one button and wait for the results.) Figures 2-18 and 2-19 show one such computer and a sample printout.

The printout includes four sections (boxes):

1) The top box is a summary of the test conditions.
2) The second box shows the actual test results (which you input into the computer) — house pressure (first column), fan pressure (second column), airflow (third column), and percent calculated error. (Percent error indicates how much the data deviates from a straight line correlation.)
3) The third box shows a plot of the five measurements with a "best-fit" line drawn through all the points. If all five points had zero error, the line would pass exactly through the center of each circle. As you can see, this test was pretty close. Sometimes, for various reasons, one measurement point will fall way off the line. Typically a fluke, that data point would be eliminated. The other four or five should be enough to derive the line of best fit. This is the reason why taking only one measurement would be unreliable.
4) The fourth box is the most important. Notice that it lists ELA in square feet and square inches. It also lists SLA (which is the same thing as LR), as well as ACPH at 50 pascals.

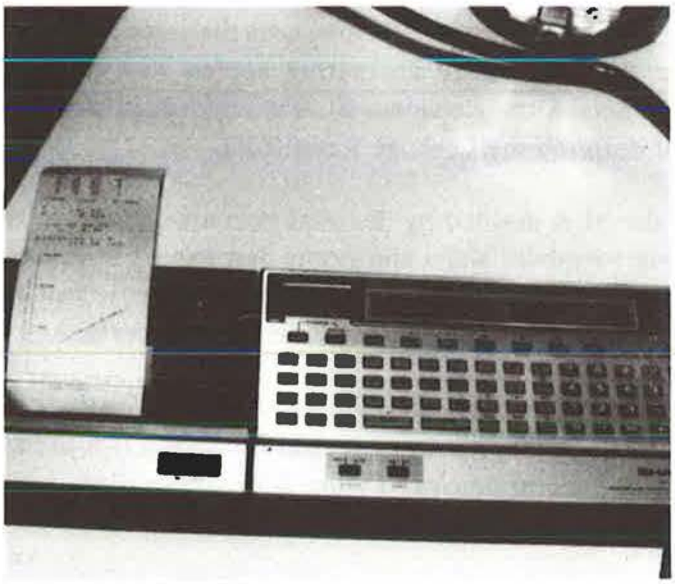

Figure 2-18— Sharp computer supplied as an option with the Minneapolis Blower Door.

Finally, Let's Get Rid of Some Old Baggage

When referring to building air leakage, people commonly refer to an "average natural infiltration rate." As the term implies, this is the average amount of air, expressed in air changes per hour, that leaks into and out of house under natural conditions.

Since the average infiltration rate is useful for projecting annual energy consumption, and since it is difficult and expensive to measure directly, researchers have been trying to develop methods for predicting infiltration rate using blower door test data and local weather conditions. But the calculations are very ambiguous. Common sense alone tells us that no calculation method can accurately predict average annual infiltration rate. First of all, wind is a dominant driving force on infiltration, and windspeed data for specific locations is very unreliable. Secondly, occupant interaction, particularly operation of interior doors, significantly affects infiltration rate. How do you model people's door opening habits into a computer? Research efforts have produced a variety of methods ranging from complex computer programs, like CIRA, developed at Lawrence Berkeley Labs, to the "divide by 20 rule," a simple estimating method developed at Princeton University, in which the ACPH at 50 pascals is simply divided by 20 to get average annual infiltration rate. All in all, any number we assign to an average infiltration rate will probably not be accurate within 100 percent. For characterizing building airtightness, ACPH and LR are much better than average infiltration rate. For example, if someone tells you that a certain house has a leakage rate of 2.0 ACPH at

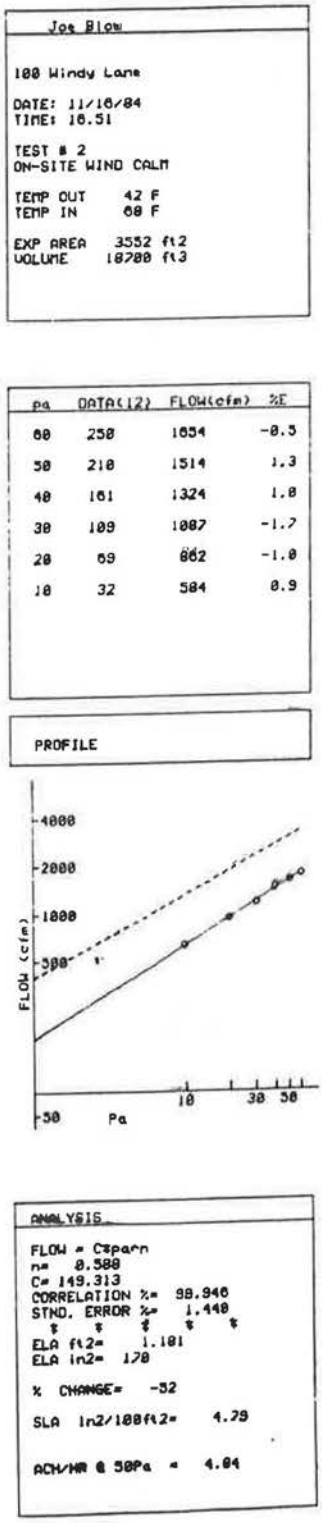

Figure 2-19 — Typical blower door computer printout.
Source: Retrotec.

50 pascals, or a LR of 4.2 square inches per 100 square feet, you know that the building was actually tested and you get a fairly precise picture of the building's tightness. But if, on the other hand, someone says a certain house has a natural infiltration rate of 0.7 air changes per hour, you have to ask a series of questions to determine how that number was obtained and how valid it may be.

What about projecting annual energy consumption? Yes, the natural infiltration rate is necessary for those calculations, but if the house is built very tightly, the infiltration rate will be insignificant compared to the mechanical ventilation rate, and can often be ignored. In less tight houses, it will have to be estimated by some means.

How Accurate and Repeatable Are Blower Door Test Results?

There has not yet been any comprehensive testing of commercially produced blower doors. However, according to limited tests directed by Andrew Persily at the National Bureau of Standards and Sonny Poole at the City of Austin, most blower doors on the market are accurate to within ten percent. Buffalo Homes in Butte, Montana, ran some informal side-by-side tests of the Minneapolis Blower Door and the Infiltec Blower Door. As can be seen from the following test results, they found very good agreement between the two doors:

	Minneapolis	**Infiltec**
ELA (Canadian)	49 square inches	44 square inches
ELA (LBL)	26 square inches	21 square inches
ACPH (50 pascals)	1.6 ACPH	1.7 ACPH

(Notice the difference between the Canadian and the LBL values for ELA.)

What about repeatability? Unless the door or instruments are damaged, a calibrated blower door should provide repeatable results. However, tested airtightness of a single house may vary considerably due to changes in the house. In one study, performed by Persily at NBS, in which a house was tested weekly for one year, the air leakage varied over 25 percent (see Figure 2-20). According to Persily, another study in Canada showed similar results. In both cases, the houses showed greater leakage in the winter than in the summer, evidently due to materials shrinkage in the dry winter air.

Two factors which can affect the accuracy of the blower door test are air density and windspeed. Air density is affected by temperature, barometric pressure, and humidity. Blower doors are calibrated at standard temperature, pressure, and humidity. Unless correction factors are applied, any deviation from standard conditions will result in some loss of accuracy. Most of the software that comes with commercial blower doors includes correction routines for temperature and barometric pressure. Humidity is a minor concern.

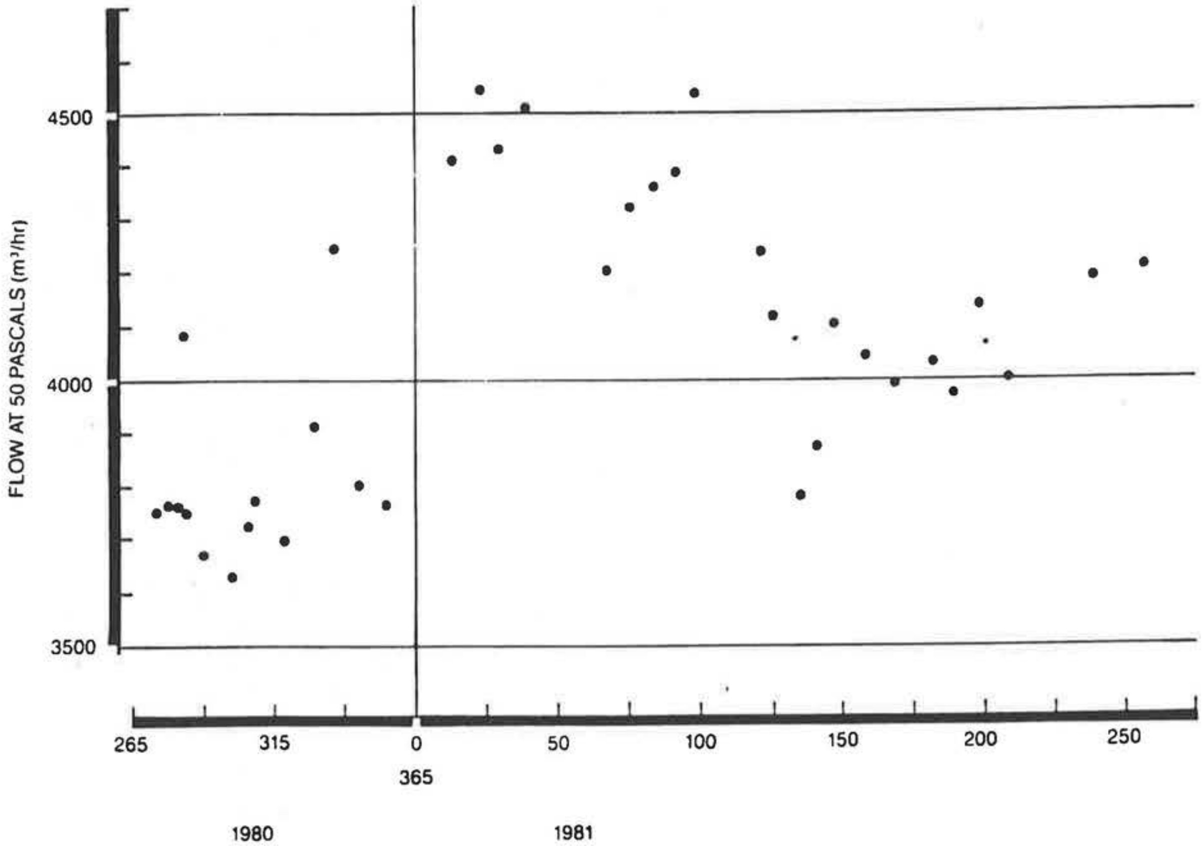

Figure 2-20 — Measured leakage of one house over a year.
Source: Persily, Andrew, "Repeatability and Accuracy of Pressurization Testing," Proceedings of the ASHRAE/DOE Conference on the Thermal Performance of the Exterior Envelopes of Buildings II.

Wind can obviously affect the test significantly. Since the 50-pascal test pressure is roughly equivalent to a 20-mph wind, an outdoor windspeed of 20 mph could double the pressure on the windward side of the house and perhaps nullify the pressure on the leeward side. According to ASTM Standard E779-81, the blower door test should not be performed in winds greater than 5 mph. For most practical field work, that figure is probably somewhat low, but the accuracy of the test will be severely affected in winds greater than 10 mph.

How to Get a Blower Door Test

There are probably several hundred businesses around the country that offer blower door testing services. Most of them are retrofit contractors, but they can easily perform a test on a new house. The cost for a test usually runs around $100 to $150.

The problem is that blower door contractors are hard to find. They aren't listed under "B" in the yellow pages. The first place to look is under "insulation contractors." The next best bet is to write to us at EDU; we may have someone listed from your area in our Professional Referral Service.

How to Buy a Blower Door

An alternative to getting a test done by an outside service is, of course, to buy your own door.

If you are a builder looking to test your houses, the most important selection criteria, other than price, is ease of use. Look for a door that is lightweight and easy to install and operate. How long does it take to set up and take down? How much space will it take up in the truck? How about appearance? Some doors are very slick looking, others have a homemade look. If you are out to impress your clients, the slick door may be worthwhile; it's quite impressive to have a technician set up a scientific looking device to test your house. It could be used as a marketing tool.

As for accuracy, all of the good quality calibrated doors are accurate. Typically, when you pay more for a blower door, you are paying for features other than accuracy.

What's Available

On the following page is a partial list of commercially available blower doors. No claims are made for its completeness and EDU would welcome submission of new product information. Listings are alphabetical.

How about Building Your Own?

Let's face it. If you build five or six houses a year, you may not want to spend $3,000 or $4,000 on a blower door. The good news is that if you are willing to put some time into it, you can save quite a bit of money by assembling one yourself. The most expensive component on most doors is the calibrated fan element. Since most blower doors are made for retrofit work, they need a fan with enough capacity to depressurize a leaky old house to 50 pascals. But if you are only going to use your door for testing small to moderately sized, tightly-built houses, you can get away with a much smaller and less expensive fan and flow nozzle.

For example, a well-built house should have a leakage rate no more than 3 to 4 ACPH at 50 pascals. If the house has a volume of 16,000 cubic feet, then the maximum required air flow is (4 x 16,000) or 64,000 cubic feet per hour, which is 1067 cfm. So any fan which can produce 1,000-cfm airflow against 50 pascals (0.2 in. W.G.) should

Commercially Available Blower Doors

The Care II Fan Door
Air Quality Labs, Inc.
P.O. Box 141296
Spokane, WA 99214
(509)534-6932

The CMS Blower Door
Conservation Management Svcs, Inc.
1012 NW Wall
Suite 203
Bend, OR 97701
(503)382-2727

325 NW 21st Suite 201
Portland, OR 97209
(503)227-0400

The Detecdoor
Eder Energy
7535 Halstead Drive
Mound, MN 55364
(612)446-1559

The Draft Arrester
Hy-Temp Energy Plus Systems
3035 Saratoga Street
Omaha, NE 68111
(800)228-7256

Enercorp Infiltrometer
Enercorp
2 Donald Street
Winnipeg, Manitoba R3L 0K5
Canada
(204)477-1283

Enerpressure Blower Door
Enerpressure
1701 Greenville Ave., Suite 1105
Richardson, TX 75081
(214)680-9510

Infiltec Blower Door
Infiltec, Div. of Saum Enterprises
Box 1533
Fall Church VA 22041
(703)820-7696
Box 1125
Waynesboro, VA 22980
(703)949-7933

Minneapolis Blower Door
The Energy Conservatory
920 West 53rd Street
Minneapolis, MN 55419
(612)827-1117

The Retrotec Fan Doors
Retrotec Energy Innovations Ltd.
225 St. Anne Ave.
Ottawa, Ontario K1L 7C3 Canada
(613)745-1515
P.O. Box 939
Ogdensburg, NY 13669

The Y.E.S. Blower Door
Your Energy Service, Inc.
P.O. Box 90034
Nashville, TN 37209
(615)383-9546

be fine. If you are building "superinsulated" houses, the leakage should be less than 2 ACPH at 50 pascals and a 500-cfm fan should suffice.

In the August 1984 issue of EDU, we ran an article by Rob Dumont on how to build a low-cost blower door. Just after publishing that article, we heard that the company that sells the calibrated low-flow nozzles had gone out of business. However, a new

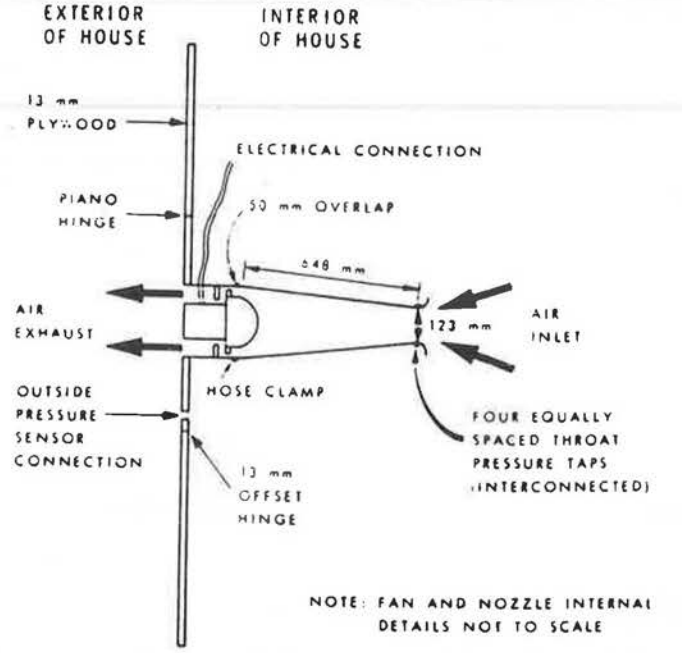

Figure 2-21 — Schematic of homemade blower door. The calibrated flow nozzle is the same design as the Carlson nozzle.
Source: Harold Orr and D.A. Figley, "An Exhaust Fan Apparatus for Assessing the Air Leakage Characteristics of Houses," National Research Council of Canada, BRN #156.

calibrated flow nozzle, specifically designed for tight houses, is now available. The new nozzle is 124 mm diameter and is suitable for pressure testing average-sized houses in the range of airtightness levels from about 0.5 to 5.0 ACPH at 50 pascals. There is also an insert which allows for testing of even tighter houses — down to 0.05 ACPH at 50 pascals. (They build 'em tight in Canada.) The cost is $175.00 for the 124-mm calibrated nozzle plus $160.00 for the extra-low flow insert. It is available from:

Carlson's Structural Glass
2925 Miners Avenue
Saskatoon, Saskatchewan
(306)931-0001
(ask for Dave Harder)

Standard Procedures for Performing the Blower Door Test:

- Housing and Urban Development Association of Canada "Standard Procedure for Determination of Airtightness of Houses by Fan Depressurization Method." Available from HUDAC, Ottawa, Ontario, Canada

- ASTM E779-81 "Standard Test Method for Determining Air Leakage Rate by Fan Pressurization." Available from ASTM, 1916 Race Street, Philadelphia, PA 19103.

- Canadian General Standards Board draft standard for "Determination of Tightness of Buildings by the Fan Depressurization Method." Available from CGSB, Ottawa, Canada K1A 1G6.

- Norway Standard NS8200.

- Sweden Standard SS021551.

Section 3
Moisture Control

Stopping Moisture Penetration into the Building Skin

If moisture from indoor air is allowed to penetrate through the building skin, condensation may occur inside walls, ceilings, and floors. Liquid water not only causes damage to the building structure, it can also degrade the thermal performance of the insulation. Thus, it is extremely important to control the passage of interior moisture through the building skin.

Water vapor from interior air gets into walls by two mechanisms: diffusion and convection.

Moisture Transport by Diffusion

Diffusion is the transport of water molecules through a surface (sheetrock, plywood, etc.). The water vapor moves independently of air. Since water molecules are smaller than other air molecules, they can pass through certain materials which are impervious to air. The driving force which "pushes" water vapor through a surface is the difference in vapor pressure caused by a higher relative humidity on one side than on the other side. Diffusion is controlled by installing a low-permeability vapor barrier or "vapor diffusion retarder" on or near the surface of the wall which is exposed to the higher vapor pressure (usually the warm side).

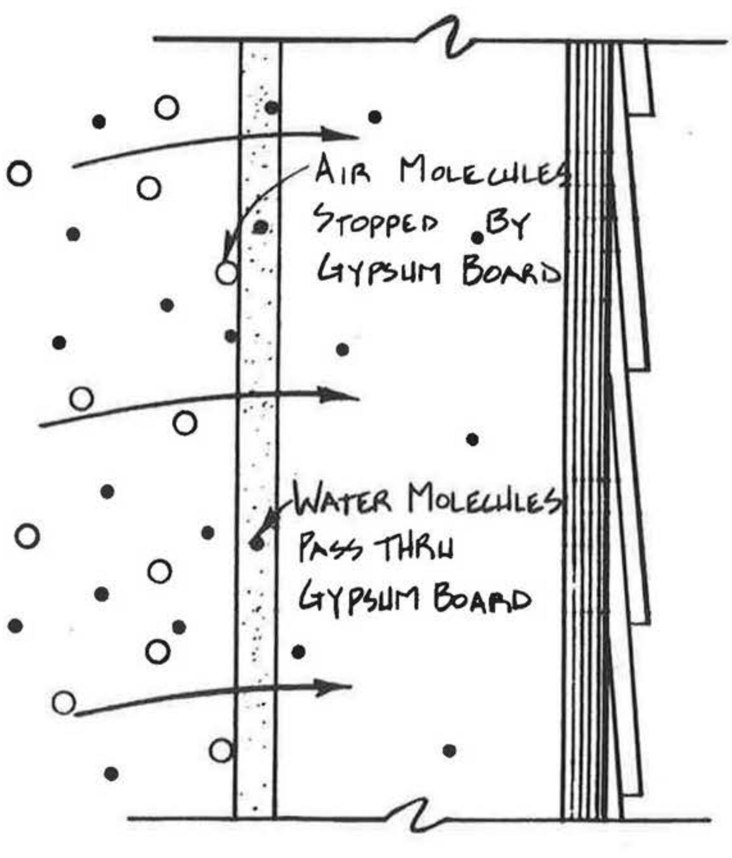

Figure 3-1 — Moisture transport by diffusion

Moisture Transport by Convection

Convection is the movement of air. Air (and the water vapor in it) passes into and out of a wall through cracks, holes, and building seams whenever there is a difference in air pressure on one side over the other.

Traditionally, diffusion has been thought of as the dominant mechanism of moisture migration into walls, ceilings etc. Thus traditional methods of moisture control focused on installing a low-permeability barrier on the inside surface of the building skin. No special attention was given to making the vapor barrier airtight. For example, one very common vapor barrier was the foil facing on fiberglass batts. Obviously, that barrier is not airtight since it has a seam at every stud and joist which is simply not sealed. Air can easily move around the foil.

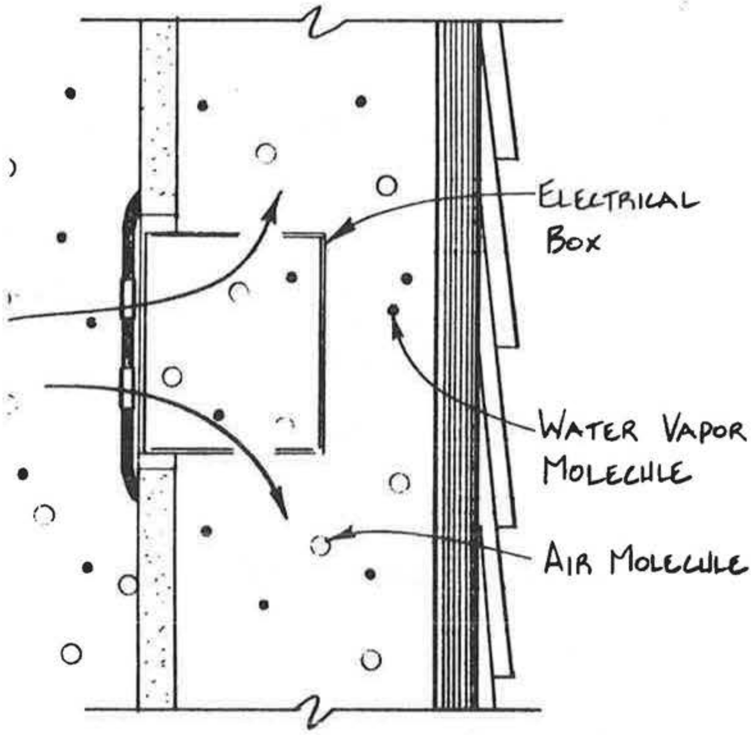

Figure 3-2 — Moisture transport by convection

But recently it has become evident that convection, not diffusion is the main source of moisture in wall cavities. To effectively protect a building from moisture damage, an "air barrier" is necessary to prevent moisture-laden interior air from penetrating into wall cavities.

Air Barriers, Vapor Barriers, and Air/Vapor Barriers

During the initial development of superinsulated house design and construction techniques, the approach taken to provide effective air and vapor barriers was to begin with a polyethylene vapor barrier and seal it at all seams and penetrations to make it completely airtight and, thus, an effective air barrier as well as vapor barrier. When installed in that manner, the polyethylene membrane is appropriately called an "air/vapor barrier."

Another approach that has also been tried and proven is to create a structural air barrier composed of, for the most part, existing building components that have been effectively sealed at all seams, joints, and penetrations. Developed in Canada and refined by Canadian engineer Joseph Lstiburek, this method of construction, generally referred to as the Airtight Drywall Approach (ADA), due to the fact that gypsum wallboard serves as a large part of the total air barrier area, has gained widespread acceptance and popularity.

In this section we present both approaches. Techniques for installing a polyethylene air/vapor barrier was originally presented in a booklet entitled "Air-Vapor Barriers," written by David Eyre and David Jennings of the Saskatchewan Research Council (reproduced by permission). ADA techniques are presented in a section written and illustrated by Joseph Lstiburek, P.E. (Building Engineering Corporation, 157 Richard Clark Drive, Downsview, ON M3M 1V6 Canada, (416)738-9319).

Air/Vapor Barriers

The air/vapor barrier is a continuous membrane which surrounds the entire thermal envelope of a house, broken only for doors, windows, and other necessary penetrations. Its purpose is to retard or stop air and water vapor from passing through the building skin. In a superinsulated house, the air/vapor barrier is given particularly careful attention both during the design phase and during installation.

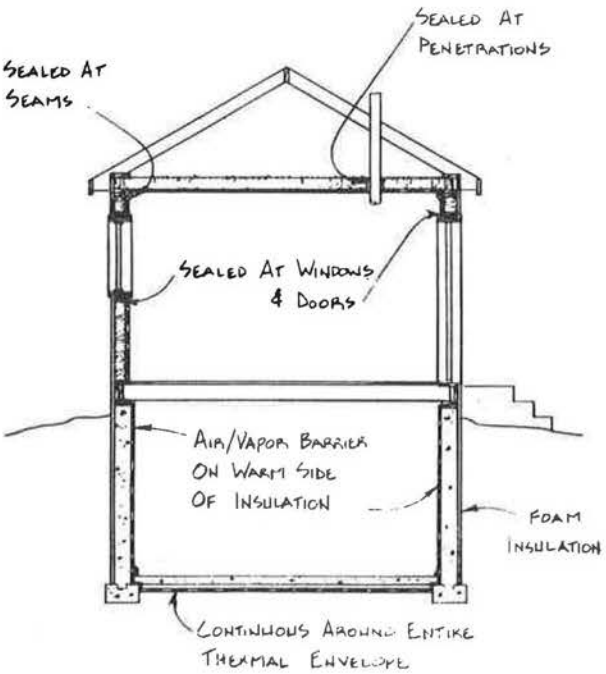

Figure 3-3 — The air/vapor barrier

MATERIALS

Sheeting

Polyethylene sheeting is the most common material for air/vapor barriers. Although thickness makes little difference from a performance standpoint, 6-mil or thicker is recommended to avoid damage during construction.

A special type of sheeting called cross-laminated polyethylene is stronger than common polyethylene and is fast becoming the standard for superinsulated house construction. The following article describes how the material is made. Three companies now sell cross-laminated poly. All three brands are actually made from the same material — Valeron — manufactured by Van Leer plastics, Houston, Texas.

What Is Tu-Tuf?

Among members of the energy-efficient building community, the term "Tu-Tuf" is to vapor barriers as "Kleenex" is to tissues. Sketches of superinsulated houses often label the vapor barrier simply as "Tu-Tuf." We have listed this product twice in ENERGY DESIGN UPDATE, but still receive inquiries from readers about what it is and where to get it. Tu-Tuf is plastic sheeting for use as a vapor barrier. Its main attraction is its strength. Nearly impossible to tear with your hands and even difficult to puncture with a screwdriver, Tu-Tuf is likely to withstand even the more vicious plumbers or sheetrock contractors.

Distributed by Sto-Cote Products, Richmond, Illinois, Tu-Tuf is listed as a "cross-laminated poly sheeting." A unique process of extrusion and lamination is used to produce the super strength of this product. High-density polyethylene is extruded in long "tubes." Those tubes are stretched, producing molecular alignment in the direction of the stretch (see Figure 3-4).

If you take a piece of regular polyethylene and stretch it until it begins to turn white, you are essentially creating the same effect. The molecular alignment can be thought of as a "grain" in the sheet. After the tubes are stretched, they are cut lengthwise in a spiral pattern similar to the seam on the cardboard tube in the center of a roll of paper towels. When the tube is opened up, the "grain" of the flat sheet is at a 45-degree angle to the edge.

Two of those sheets are then laminated together with their "grain" at right angles. The cross grain imparts strength to the laminate just as the cross grain of wood imparts strength to plywood.

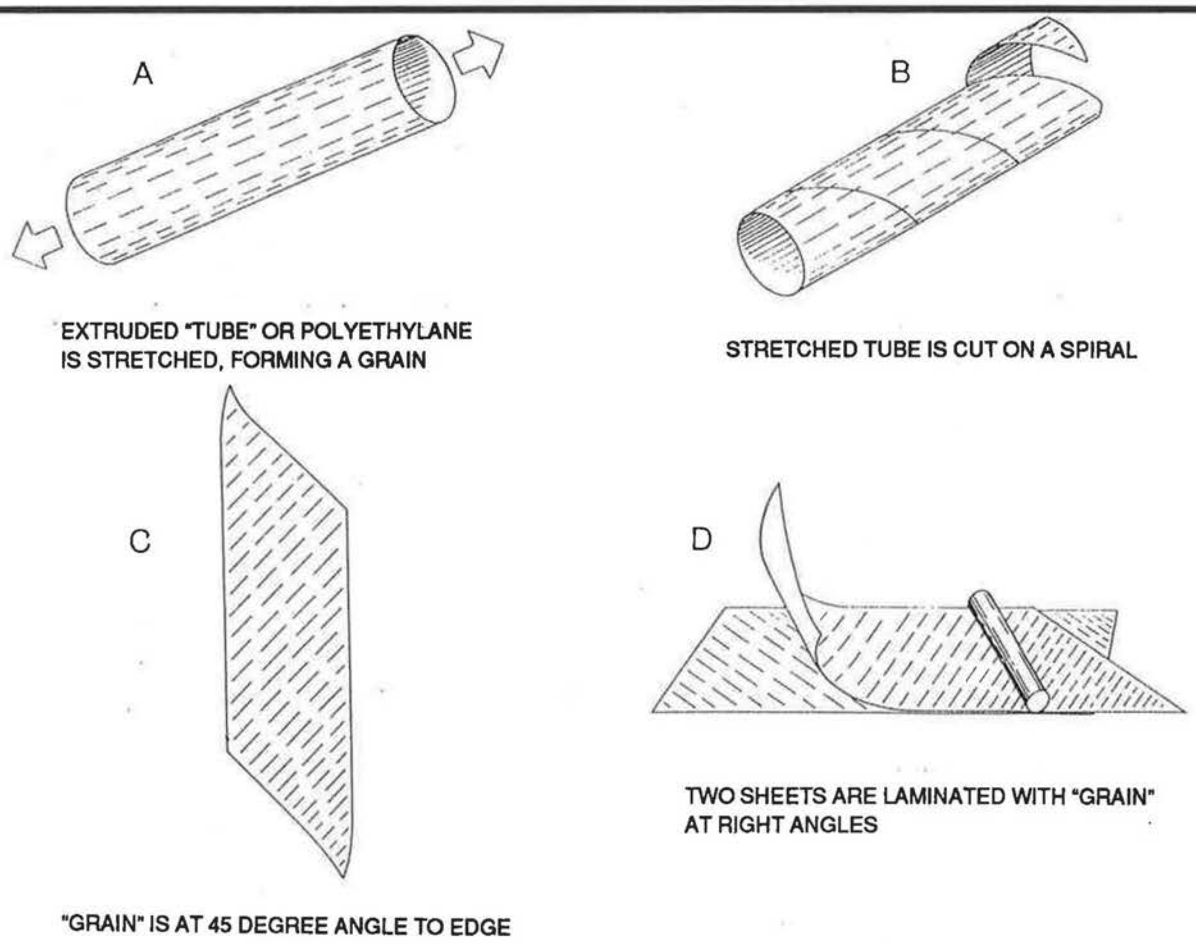

Figure 3-4 — Manufacturing Tu-Tuf cross-laminated polyethylene

Tu-Tuf is manufactured by Van Leer Plastics, Houston, Texas. Its name for the product is "Valeron." According to Peter Van Onselder at Van Leer, only high-density polyethylene is used to manufacture the product; low-density polyethylene is too soft and elongates too much during the "stretching" process. A UV stabilizer is added to reduce degradation from sunlight exposure. Van Leer produces Valeron in 60-inch rolls. Sto-Cote puts the narrow rolls together to produce rolls of any width up to 40 feet. It is available in two thicknesses — 3-mil and 4-mil.

Advantages

1. Strength.

The 4-mil Tu-Tuf has a puncture resistance of 275.8 Beach Units, 6.4 times that of regular 4-mil polyethylene. The tensile strength is 8,507 pounds per square inch, about 3.6 times that of polyethylene. (Test results from U.S. Testing Labs, Hoboken, New Jersey, and Gaines Lab, Chicago, Illinois, are available from Sto-Cote.) The 3-mil product is strong enough for use as a vapor barrier and is a good substitute for 6-mil polyethylene, but Sto-Cote recommends that the 4-mil product be used for below-grade applications.

2. Ease of use.

Tu-Tuf is thin and flexible, particularly in the 3-mil thickness, making corner wrapping easy with minimal bunching. Because it is so strong, less care needs to be taken to avoid damage. Also, of course, there is usually less damage to repair.

3. Low permeability.

Tu-Tuf is about one-sixth as permeable as regular 4-mil polyethylene. Although this sounds impressive, it is of relatively minor importance in construction practice since even 4-mil polyethylene provides an adequate vapor transmission resistance for most applications — if it doesn't tear.

4. UV resistance.

Sto-Cote calls the product "weather stabilized." According to Mark Yonker, head of sales at Sto-Cote, Tu-Tuf contains a UV inhibitor to protect it against degradation when exposed to sunlight.

Disadvantages

1. Slipperiness.

You really have to scrape to find fault with this product, but it is more slippery than regular polyethylene, making it a little more difficult to handle (and walk on), particularly in very cold weather.

Recommendation

All in all, this product is so superior to common low-density 6-mil polyethylene that it is definitely recommended for use in any permanent installation such as vapor barriers and moisture barriers, above and below grade.

For More Information

Tu-Tuf is sold through a nationwide network of distributors. For the name of your closest outlet or for more information, contact: Sto-Cote Products, Drawer 310, Richmond, IL 60071; (800)435-2621.

Sealant:

The air/vapor barrier should be sealed at all seams and terminations. To ensure a long-lasting, effective seal, a non-hardening caulk should be used. Regular latex, oil-based, or silicone caulk may lose their seal over time.

Tape:

In some applications, tape may be used to seal air/vapor barrier seams. There are only two brands of tapes which claim to maintain their holding power to polyethylene for extended periods of time.

Positioning the Air/Vapor Barrier

The air/vapor barrier must always be placed on the warm side of the insulation.

The air/vapor barrier must be positioned such that it never gets cold. Traditionally, it is simply placed on the interior surface of the insulation, just behind the wall or ceiling drywall (Figure 3-5a).

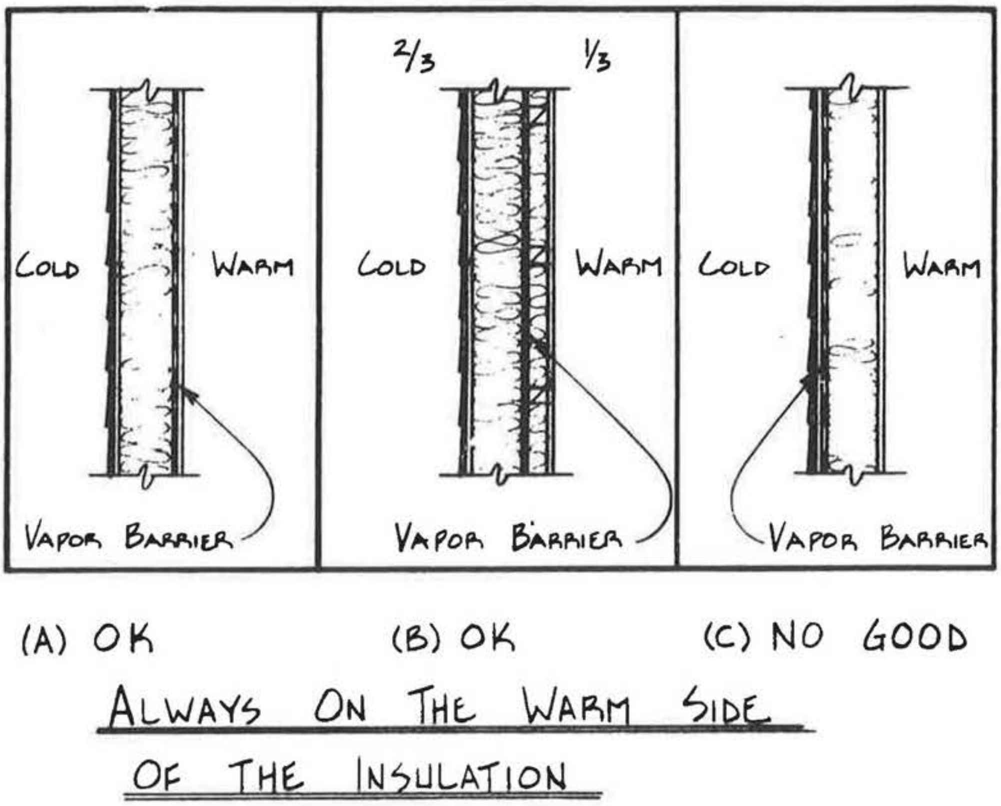

Figure 3-5 — Positioning the air/vapor barrier

The 1/3-2/3 Rule

Some of the wall systems developed and tested in Canada use two layers of insulation (strapped wall and double wall) with the air/vapor barrier positioned between the two layers (Figure 3-5b). This is OK as long as at least two-thirds of the insulation (R-value) is outside the air/vapor barrier. With twice as much R-value outside the air/vapor barrier as inside, the barrier should never get cold enough to cause moisture condensation. This technique has been used in climates with 12,000 degree days without problems.

One exception to the 1/3-2/3 rule would be in spaces with very high indoor relative humidity, such as swimming pool enclosures or hot-tub rooms. In those applications, you should position the air/vapor barrier on the inner surface of the wall.

Except in warm, humid climates, the air/vapor barrier should never be installed on the outside of the insulation as in Figure 3-5c.

The Joist Header Problem

The most troublesome spot when designing and installing the air/vapor barrier is at the floor joists. How do you make an effective airtight seal between floors? One approach is to terminate the air/vapor barriers at the joists, then install panels made of rigid foam insulation between all joists, sealing the panels to the joists and floor above. When properly done, this is a satisfactory method, but it is very time consuming. Each panel must be precut, set in place, and sealed.

Another approach is to wrap the air/vapor barrier around the joist system, sealing it top and bottom to

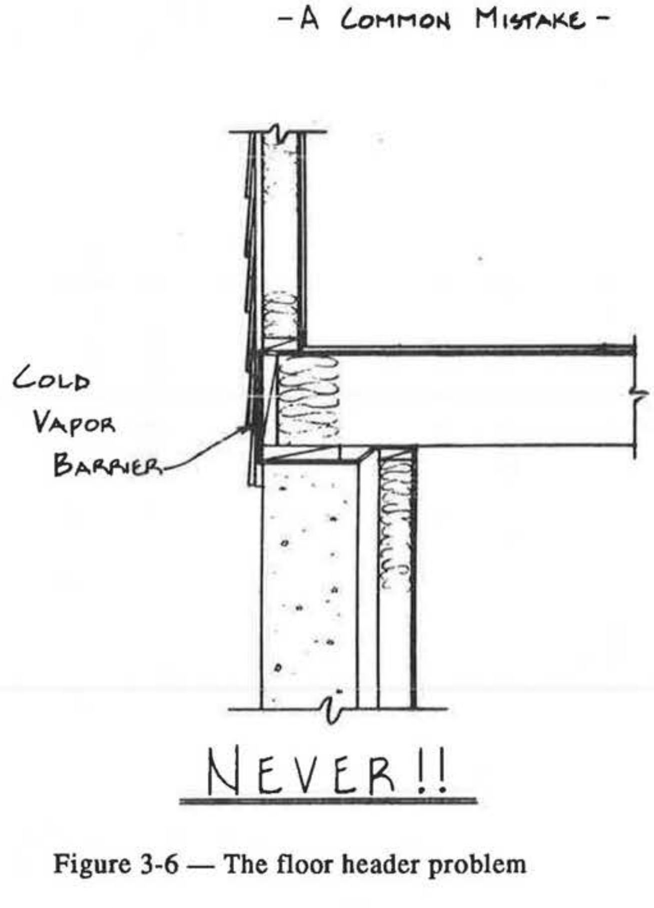

Figure 3-6 — The floor header problem

the vapor barriers above and below. However, if polyethylene is used for this application, it is very important to avoid running the air/vapor barrier outside the insulation. Figure 3-6 shows one of the worst mistakes that can be made in a superinsulated house. Unfortunately, this error, or some variation of it, is quite common and has even been shown in superinsulation construction guides. Never do it. If the air/vapor barrier is to run around the joists, then it must be insulated on the outside.

An exception to the above warning is if Tyvek or some other permeable membrane is used, in which case it would be OK to run the membrane outside the joist header.

A Proper Air/Vapor Barrier Installation at Joist Area

Figure 3-7 shows good air/vapor barrier placement. This house has 2x6 walls on the first floor and 2x4 standoff walls in the basement. The joist header is recessed 2 inches back from the outer wall surface to allow a 2-inch thick foam inset. In this example, the house walls are also sheathed with 2 inches of foam. Thus there is a total of 4-inches of foam insulation outside the air/vapor barrier. The temptation to stuff more insulation between the floor joists should be avoided. You must not put insulation between the joists unless there is twice as much R-value outside the air/vapor barrier.

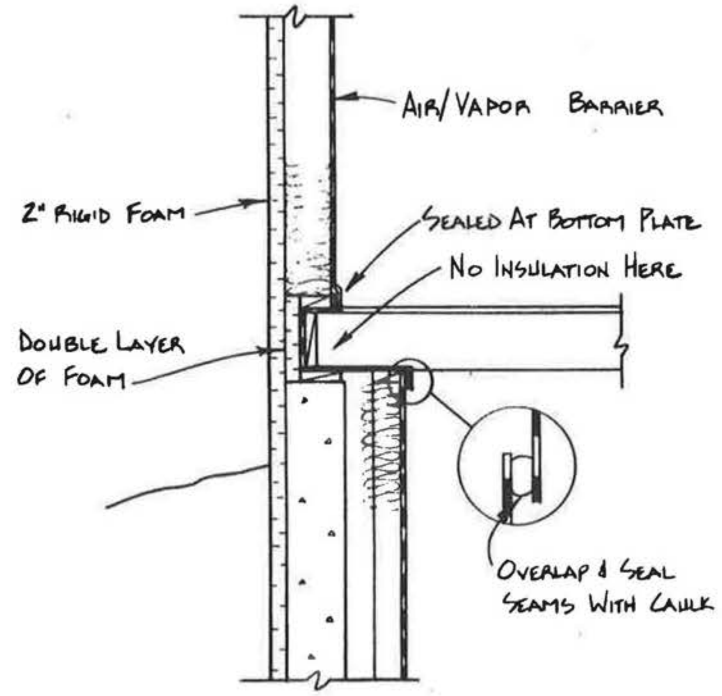

Figure 3-7 — Air/vapor barrier installed at floor joists

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

Air-Vapour Barriers

A General Perspective and Guidelines for Installation

Prepared by
D. Eyre and D. Jennings
Saskatchewan Research Council

Under funding from
The Saskatchewan Provincial Council of HUDAC
The New Home Certification Program of Saskatchewan
The Government of Saskatchewan

Fourth Edition
1983 January

Acknowledgements

Many of the techniques included in this guide were pioneered in the Saskatchewan Conservation House, built in Regina in 1977-78, and were taken to a higher level of development by the builders on the Energy Showcase project – a group of 14 energy-efficient houses built in Saskatoon in 1980 by individual builders. The authors take pleasure in acknowledging the contribution of these builders, who found a number of ingenious solutions to the various vapour barrier problems:

Amber Homes Ltd.
Cairns Homes Ltd.
Concept Construction Ltd.
Hilton Homes Ltd.
Medallion Homes Ltd.
Milbrandt Homes Ltd.
Nu-Central Homes Ltd.
Plainsman Developments Ltd.
Rathgeber Homes
Schurman's Construction Co. Ltd.
Shir-Lee Homes Ltd.
Stellar Developments Ltd.
Victory Homes

The author wishes to thank Mr. John Haysom, of Scanada Consultants Limited for his constructive comments on the draft text.

Preface to the fourth edition

This fourth edition of Air-Vapour Barriers has been reprinted by popular demand because of the usefulness of the material and the general acceptance of the technique within the building and construction industry in Canada. The edition has been updated to include a number of suggestions for improvement made by the author, David Eyre of the Saskatchewan Research Council, together with several changes recommended by the Energy Conservation and Oil Substitution Branch of Energy, Mines and Resources Canada. In addition, this fourth edition has been converted to metric standards which are used extensively today in Canada. Please note, in particular, that insulation R values are given only in metric. 1R(SI) = 5.6783 R(Imperial).

Requests for additional English or French copies of this report should be addressed to:

Energy, Mines and Resources Canada
Energy Conservation & Oil Substitution Branch
580 Booth Street
Ottawa Ontario Canada
K1A 0E4

Preface to the second edition

This second edition incorporates a number of small changes to the text. The page numbering system has been changed, and an index has been provided.

Most of the textual changes have arisen from the valued comments of Mr. Harold Orr, of the Prairie Regional Station of the National Research Council. In particular, a discussion of the sill plate problem has been included on page 38, the ice flexing section on page 66 has been modified, and the discussion of the double frame design on page 76 has also been modified — though in this last instance the authors have felt the need to retain some comments about the practical problems in this design.

A cautionary note has been added to the basic air-management system design, shown in figure 116 on page 74. This note was prompted by an informative discussion with Mr. J. White, of the National Office of the Canada Mortgage and Housing Corporation.

Preface to the third edition

The Energy Conservation and Oil Substitution Branch of Energy, Mines and Resources Canada, through its Buildings Technology Support Program, is pleased to reprint this Air-Vapour Barriers guide by D. Eyre and D. Jennings of the Saskatchewan Research Council. Our aim is to make such information readily available to builders, developers, owners, operators and designers of buildings and homes all across Canada.

Although this report has been reviewed by the Conservation and Renewable Energy Branch of EMR Canada and approved for publication, this does not signify that the contents necessarily reflect the views and policies of the Department, nor does mention of trade names, commercial products, or companies constitute an endorsement or recommendation.

This report has been prepared with the cooperation of the Housing and Urban Development Association of Canada for the information of the public. HUDAC and their employees and agents, however, make no warranty, expressed or implied, with respect to the matter described herein.

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A general perspective on the air-vapour barrier

Section II
How to install an air-vapour barrier

Section I

A general perspective on the air-vapour barrier

1.0 Introduction

The developing global energy situation is now beginning to make its presence felt in Canada's housing industry. New standards of energy-efficient construction are being evolved and, in several pilot projects across the country, builders and engineers are exploring various ways of improving the thermal performance of houses. By 1990 it is not unlikely that most new housing starts, if not all of them, will have to conform to fairly stringent energy efficiency requirements. In the meantime, the building industry will have to adapt to changes in constructional technology and practice, and these changes will be greater and more wide-ranging than any the industry has encountered in the past.

There is not, as yet, any clear picture of what these changes will be. The whole field of energy-efficient design is still in an early stage of development, with little agreement on the basic design and economic factors. However, there does appear to be an increasing acceptance of the design concepts that have been developed primarily in Saskatchewan, and it is probable that these concepts will play a large part in shaping future standards. The energy-efficient home of the future will probably differ from current designs in four main respects:

a) It will have an air-vapour barrier instead of a vapour barrier;
b) It will have far higher levels of insulation;
c) There will be a greater utilization of passive solar gain;
d) It will have an energy-efficient air management system.

Each of these elements is developmental at the present time. It will take several years of trial and error, hardware development and constructional refinement before they acquire the status of standard building practices. This is particularly true of the air-vapour barrier, which is important not only for its energy conservation aspect, but also for its beneficial effects on other aspects of house construction and performance.

Saskatchewan has taken a leading role in developing the techniques of air-vapour barrier installation. The Saskatchewan Conservation House was probably the first in the world to achieve the high levels of air tightness that are now being adopted in many energy-efficient designs. The concept has been applied and improved by a number of home owners and builders in the province. The Energy Showcase of 14 homes, completed in 1980 in Saskatoon, provides an impressive example of air-vapour construction by each of the participating builders.

Two lessons can be drawn from builders' experiences in these projects. The first is that the air-vapour barrier has to be regarded as something quite different from the traditional vapour barrier, calling for different techniques, greater emphasis on quality, and more consideration during the design stage. These new skills are not easily acquired, and individual builders may find that they have to try out the techniques on several houses before their skills become streamlined and efficient. Secondly, there is a need for some kind of publication that gives a comprehensive treatment of the fundamentals and the practical problems of air-vapour installations. This guide is designed to fulfill that need. However, the guide should not be interpreted as a building standard; the techniques and materials of air-vapour barrier installations can be expected to evolve considerably over the next decade, and this guide is merely a starting point that builders can use in developing and refining their techniques. Eventually, when air-vapour barriers start to become a standard feature of house construction, an appropriate building standard will doubtless be formulated.

Apart from the practical aspects of air-vapour installation, there are a number of related issues that builders will have to confront over the next few years and it has been thought advisable to include a consideration of these issues in this guide. Specifically, the following topics have been considered:

a) The effect of air-vapour barriers on air management.
b) The effect of air-vapour barriers on combustion heaters.
c) Limitations imposed by existing building codes.
d) The importance of comprehensive design details on drawings.
e) Representing the air-vapour barrier on design drawings.
f) What is the optimum target for air tightness?
g) Procedures and standards for air tightness testing.

This guide was written primarily with Saskatchewan conditions in mind and, therefore, a note of caution is necessary for those who apply the techniques elsewhere. Over the next few years, as houses evolve towards higher levels of energy efficiency, their designs will become more finely attuned to the local climate. Regional climatic effects will become important, and the techniques that apply in one region may not be particularly applicable in another. The techniques in this guide have been evolved for the kind of climate and the type of construction that prevail in the Canadian prairie. The details, and even the underlying economic factors, may not be applicable elsewhere.

2.0 The fundamentals of water vapour movement and control

In a typical household, somewhere between 10 to 15 kg (9 to 14 L) of moisture may be generated every day by the combined effects of perspiration, cooking, laundering and bathing. This moisture, in the form of water vapour, becomes mixed with the house air. Several factors determine the amount of water vapour in the air at any one time, but two factors are generally more influential than the others, namely, the rate at which water vapour is generated in the house, and the rate at which it is carried out of the house by ventilation and exfiltration. In the typical household there is usually around 2.5 to 5 kg (2 to 5 L) of water vapour in the air at any one time.

Water vapour behaves like a gas and exerts its own pressure, called the vapour pressure. The greater the amount of water vapour in the air, the greater is the resulting vapour pressure.

2.1 Relative humidity

The term 'relative humidity' is often used to express the amount of water vapour in the air. If this amount of water vapour is increased, the relative humidity of the air also increases – but only to a point. If water vapour is continuously added to air, there comes a point when the air can no longer hold any more. This is called the saturation point, and under these conditions the air is said to have 100% relative humidity, or 100% RH. If more water vapour is added after the saturation point has been reached, then the excess will condense on local surfaces.

Air's ability to hold water vapour depends on the air temperature. As the air temperature increases, it becomes capable of holding more water vapour. If we have two equal volumes of air, each with 100% RH, but one much warmer than the other, then the warmer one will contain a greater amount of water vapour. It follows that if we take a volume of cold air, with 100% RH, and raise its temperature, its relative humidity will decrease even though it contains the same amount of water vapour. This is because, at the higher temperature, the air can take on more water vapour before reaching saturation.

To give a practical example of this: suppose we were to open all the doors and windows of a house in winter, and flood the house with cold outside air that may have a relative humidity of 80% (that is: it is carrying 80% of the water vapour that it is capable of holding at that temperature). Next, we close all doors and windows and allow the air to heat up to normal house temperature. We would soon notice that the air had become very dry, or, putting it another way, that its relative humidity was very low. The explanation is as follows: in normal winter temperatures the air can support only a very small amount of water vapour, therefore, even though its relative humidity is high, its water vapour content is low. When the air is brought into the house and heated up, it becomes capable of holding far more water vapour than it actually contains, therefore its relative humidity may fall to as little as one or two percent. When a house has a low humidity in winter, or if it needs a humidifier to maintain reasonable levels of humidity, this is usually a sign that too much outside air is finding its way into the house.

To look at an example of the opposite kind of effect: suppose we take a volume of warm air with a relative humidity of 80% and cool it to somewhere near the freezing point. It will gradually lose its ability to support water vapour and its relative humidity will gradually increase until, at some point during the cooling process, it will become saturated, or 100% RH. If the air is cooled even slightly beyond this point it will have to shed some of its excess water vapour in the form of condensation. This is what happens when warm, humid air comes into contact with cold windows or a cooled beer can. When air is cooled to the point where condensation starts to occur, it is said to have reached the dewpoint temperature. This dewpoint temperature obviously depends on the amount of water vapour that was in the air to begin with. If it was close to saturation at its original temperature, then its dewpoint temperature would be only a few degrees lower. But if it had a very low relative humidity to begin with, then its dewpoint temperature would be very low. In some cases the dewpoint temperature may be below the freezing point, in which case the excess water vapour would be deposited as frost instead of condensation.

2.2 Permeance of materials

Most construction materials have a porous structure that allows water vapour to pass through. This applies, to a greater or lesser degree, to paper, plaster, wood, insulation and even concrete. In some materials, such as loose fill insulation, water vapour can pass through the material with relative ease. Such materials are said to have a high 'permeance'. In other materials, such as wood or concrete, there is more resistance to the flow of water vapour. These materials have a lower permeance. Vapour barrier materials, such as polyethylene sheet, are required to have a very low permeance because their main purpose is to resist the movement of water vapour.

2.3 How a vapour barrier works

To understand how a vapour barrier works, first consider what happens in a house in winter if there is no vapour barrier. The house interior is warm and the relative humidity is usually somewhere between 20% and 30%. The exterior is cold and the relative humidity is usually high, somewhere around 80%. The air inside the house has a much greater water vapour content than that outside, and it follows that the vapour pressure inside the house is higher than that outside. This pressure difference causes the water vapour to move outwards through the house envelope, and particularly through the exterior walls and ceiling. Since there is no vapour barrier, the walls and ceiling offer little resistance to the movement of water vapour, therefore the rate of water vapour movement can be very high. When the water vapour moves outwards through the wall and ceiling it will get progressively colder because of the temperature drop through these structures. At some point, a dewpoint condition will be reached and the water vapour will condense or form frost, depending on whether the dewpoint temperature happens to be above or below freezing. If this were the only mechanism involved, then water vapour would continue to move from the house interior to the dewpoint location, giving a continuous build-up of condensed water or frost at that point. However, both frost and condensed water give off water vapour, which continues to move outwards through the wall and ceiling, producing frost or condensation beyond the dewpoint location. Therefore, at every point beyond the dewpoint location, two mechanisms are at work: the first is the build-up of condensed water or frost due to the movement of water vapour from the house interior; the second mechanism involves the removal of the build-up by evaporation or sublimation (a process in which ice gives off water vapour), creating a fresh supply of water vapour that can move even further outwards. In a typical house structure in winter conditions, these two mechanisms occur mainly in the insulation, which has little resistance to the movement of water vapour.

As a result, the second mechanism tends to predominate, and any condensation or frost is removed as quickly as it is formed. Therefore the water vapour will usually pass beyond the dewpoint location without causing condensation or frosting, and it will continue to move outwards through the wall or ceiling until it encounters the right conditions for build-up. In walls, this usually occurs at the surface of the exterior sheathing or sheathing paper. Compared with the insulation, these materials have a relatively high resistance to water vapour movement, therefore the rate at which water vapour moves outwards to the sheathing is much higher than the rate at which it can penetrate the sheathing. Since the sheathing temperature is usually well below the freezing point, the conditions are usually right for frost build-up.

A similar process is at work in the ceiling. There is a tendency for the water vapour to move outwards until it encounters the roof sheathing. If the roof space is poorly ventilated some frost build-up may occur on the sheathing. If the roof is well ventilated the airflow may carry away the water vapour before it has a chance to produce frost build-up. On the other hand, it may promote frost build-up by cooling the humid air below its dewpoint temperature.

2.4 Possibility of structural damage

In this type of house, with no vapour barrier, the process of frost build-up will usually continue through winter, giving a progressive accumulation of frost on roof sheathing and wall sheathing. In spring, or whenever the exterior sheathing temperature rises above the freezing point, the frost will begin to melt. The meltwater will drop or flow where gravity takes it. In the roof, it may fall onto the ceiling, causing wetting or discolouration. In severe cases there may be enough meltwater to flood the ceiling, causing water to flow through ceiling fixtures and, perhaps, causing ceiling collapse. In the walls, the meltwater will tend to accumulate on blocking or on the sill-plate, where it may discolour the drywall or cause rot, fungus and odour problems within the wall structure. In some cases, the accumulation of water on the sill-plate could be several inches deep. This could cause total deterioration of the lower drywall, with seepage under the baseboard or through electrical fixtures.

Many older houses (especially those built before the advent of plywood) have stayed immune to these problems, even though they have no vapour barrier. This is usually because the structure is able to dissipate water vapour quickly. The rapid dissipation may be due to the high permeance of the exterior sheathing, or to a leaky construction that allows air to flow through the wall structure. Although such houses have avoided the problems of frost build-up, this is not to say that they are good designs; it is merely a lucky circumstance in which one bad feature helps to eliminate the problems caused by another one.

Now consider what happens when a house is fitted with a vapour barrier. Since the vapour barrier has a very low permeance it reduces the rate of water vapour movement into the exterior walls and ceiling. In the walls, this means that the water vapour can pass more easily through the exterior sheathing than it can through the vapour barrier. Therefore, water vapour escapes from the walls as quickly as it penetrates from the house interior, and no condensation or frost build-up will occur. In the roof, even a moderate amount of ventilation can carry away the water vapour as quickly as it penetrates the ceiling. Therefore, once again, build-up will not occur.

The vapour barrier works, not by eliminating the movement of moisture into the walls and ceiling, but by reducing the movement to a rate that the house structure can handle.

2.5 Positioning the vapour barrier

In anticipation of some of the points that will be raised later in this guide, it is important to consider the positioning of the vapour barrier. The position of the vapour barrier in the walls and ceiling is dictated by only one technical criterion: it must lie inside the dewpoint location in a typical worst case situation, such as the mean low January temperature. If the vapour barrier lies outside the dewpoint location, water vapour will penetrate the wall until it reaches this location. It will then condense or form frost. There will be a natural tendency, as discussed earlier, for the condensed water or frost to give off water vapour that will move further outwards through the wall. However, this further outward movement is restricted by the vapour barrier, and, as a result, there will be a continuous build-up of water or frost on the interior surface of the vapour barrier. This could result in effects as severe as those mentioned on page 14.

2.6 Guarding against the creation of a second vapour barrier

Another problem arises when a wall has two major restrictions to water vapour movement. This could occur as a result of retrofit, when a wall may accidentally be fitted with two vapour barriers. It may also occur when the exterior sheathing has a low permeance and is tightly sealed, so that it acts effectively like a second vapour barrier. Under these conditions, the risk of build-up is determined by two factors: the rate at which water vapour penetrates the inner vapour barrier, and the rate at which it penetrates the outer one. If the inner rate exceeds the outer one, and if the dewpoint location falls between the two effective vapour barriers, build-up will occur. In this respect, a number of builders have expressed concerns about the use of low permeance insulating foams as sheathing material. In some cases there does appear to be a risk that a second vapour barrier might be set up.

This guide recommends that, where low-permeance sheathing might constitute a second vapour barrier, a deliberate attempt should be made to introduce breathing gaps between the sheathing panels or where the sheathing terminates at the top of the wall. Ideally, the breathing openings should be just large enough to allow the water vapour to leave the wall space as fast as it enters it, but not large enough to allow air circulation through the wall space (excessive air circulation through the insulation can impair the insulating effect). If the breathing openings are too small there might be enough frost build-up to cause dampness in the wall space later. With a virtually impermeable vapour barrier and sheathing, it could take several weeks of warm weather to dry out the wall space.

3.0 Infiltration and exfiltration

So far, we have concentrated on the way in which water vapour can pass through solid building materials by a process of permeation, and we have seen how the vapour barrier is used to control this. But there is another way in which water vapour can get into the exterior walls and roof, namely by air movement. The vapour barrier was never intended to control this second process and it is not specifically designed to do so.

A complicated pressure pattern generally exists around a house, both on the outside and inside. The pattern is determined by wind, thermal convection currents in the house, furnace draft, combustion processes, fan usage etc. At any instant the house will be simultaneously subjected to infiltration through one set of openings, and a balancing exfiltration through another set. The term 'infiltration' is used to denote air flow from the exterior to the interior; the term 'exfiltration' denotes flow in the opposite direction. The openings through which these flows occur can be found all over the house, but usually where there is a structural discontinuity: around windows and doors, in drywall corners that have cracked due to settling, at the joint between the wood frame and the concrete foundation, around the attic hatch, around chimneys, vents, pipes and cables where they penetrate the exterior envelope, through electrical outlets, milk chutes, mail slots, floor drains, foundation cracks, and so on. At many of these points there is some kind of break in the house structure, and usually a matching break in the vapour barrier. In addition to these structural openings there is also a range of 'intentional' openings that serve some kind of air-handling function: furnace chimneys, fireplace chimneys, bathroom and range fans, openable window sections, dryer vents, fireplace fresh air vents and so on. It has been estimated* that, if all the openings in a house could be collected together, they would make up a hole about the size of half a door. Because of this large combined area of openings a house can experience large infiltration and exfiltration flows, even when exposed to fairly moderate pressure patterns.

3.1 Exfiltration flow and chimney effect

Infiltration and exfiltration flows occur simultaneously and approximately in balance, with infiltration through one set of openings and a matching exfiltration through another set. The pattern of infiltration and exfiltration varies from instant to instant according to the changing pressure patterns imposed on the house. Under winter conditions, infiltration flows bring cold and relatively dry air into the house. This creates no moisture problems in passing through the house envelope. The moisture problems arise from exfiltration flows, in which the warm, humid house air flows through the various openings in the house envelope. When this humid air passes into the wall space or attic space, the water vapour becomes subject to the processes of condensation and frost formation described earlier. Therefore, the process of exfiltration is potentially capable of causing the sort of water damage that has been described. The phrase 'potentially capable' has to be stressed, because it is a fact that water damage is uncommon, even in those houses that are known to have high levels of infiltration and exfiltration. This may be partly due to the changing patterns of infiltration and exfiltration, in which condensation may be created by exfiltration at one stage, and then removed by infiltration at a later stage. In most cases, however, the absence of water damage is due to the chimney effect of the furnace. When the furnace is operating, this effect creates a strong draft of humid house air up the

* This graphic statement is attributed to Mr. Harold Orr, of the National Research Council, Division of Building Research.

furnace flue, thereby ensuring that most of the exfiltration flow goes up the flue. While this is happening, the rest of the house structure is subjected mainly to infiltration flow.

Exfiltration water damage is occasionally observed in houses that have combustion furnaces. In such cases the cause may sometimes be traced to excessive water vapour generation in the house, or to some major construction defect.

3.2 The special case of electrically heated homes

In electrically heated houses, where there is no chimney and no chimney effect, incidences of water damage are more prevalent.

3.3 Relating air changes to energy loss

Because of the processes of infiltration and exfiltration there is a continuous exchange of air between the house and its surroundings. The rate at which this exchange takes place is an indication of how tightly the house is built, and is expressed in terms of 'air changes per hour'. If a house is said to have an infiltration rate of one air change per hour, or 1 ach, this means that all the air in the house is replenished every hour. In a house that has an air volume of 425 cubic metres for example, an infiltration rate of 1 ach corresponds to a through-flow of about 0.12 m^3/s.

Tests conducted by the Prairie Regional Station of the National Research Council, in collaboration with the University of Saskatchewan, have shown that houses in the Saskatoon area have infiltration rates ranging from 0.2 ach to about 1.5 ach, with an average level around 0.3 ach. This average level is equivalent to 7075 cubic metres of air passing through the house each day. This volume of air is equivalent to the combined volume of 16 houses. This provides far more ventilation than is absolutely necessary, and it has the effect of reducing the house humidity level to the point of discomfort. When a house needs a humidifier for the maintenance of a comfortable humidity level, this may be an indication that the infiltration is excessive.

In the past there has not been much attempt to improve the infiltration performance of houses. Infiltration (or, to be more precise, exfiltration) has been recognized as a potential source of condensation damage, but the severity and frequency of this effect were never sufficiently high to warrant changes in standard building practice. It is only in the last few years, with the emerging importance of energy conservation, that the infiltration performance of a house has come under scrutiny as a major source of heat loss. Some idea of the wastefulness of infiltration can be gained by imagining 7075 cubic metres of cold air being brought into a house each day, then heated to the normal interior temperature of the house, then expelled from the house. The heat that is wasted in this way accounts for typically 25% to 30% of the annual space heating consumption.

4.0 The air-vapour barrier

The air-vapour barrier is primarily an energy conservation measure. Its primary purpose is to reduce air-change heat losses to a practicable minimum by sealing the house as tightly as possible against uncontrolled air-change. To achieve this the house has to be provided with an almost perfectly sealed envelope, and it is logical to adapt the vapour barrier to this task. The air-vapour barrier is therefore a much improved version of the conventional vapour barrier, serving a double duty as a barrier against water vapour penetration and a barrier against uncontrolled air-change. Hence the name 'air-vapour barrier'.

To achieve the high standards of air tightness that are required in an **ideal** air-vapour barrier, the materials must be selected with care and the barrier must be installed with more care and more attention to detail than is customary in normal vapour barrier installation. One of the main differences between vapour barrier construction and air-vapour construction is that the former can usually be installed in one operation, whereas the latter often requires preparatory work at various stages of construction. In some cases, a lot of this preparatory work can be avoided by careful design or by modification of building practices.

The air-vapour barrier, on its own, does not constitute a completely sealed envelope, since it has to be terminated around doors, windows, chimneys, vent stacks and so on. Therefore, whenever an air-vapour is installed, some attention should be given to the special infiltration problems of these various features, and this should be regarded as an essential part of air-vapour barrier installation. Doors and windows present obvious problems. If their infiltration performance is to be consistent with that of the air-vapour barrier, they must be provided with efficient seals. Often this necessitates the selection of a higher quality door or window, with a corresponding cost increment. Similar comments apply to the dampers on vents and fireplace chimneys.

4.1 The real objective of the air-vapour barrier

This has never been properly stated, and tends to be misunderstood by many of its critics. It is generally assumed that the objective is to provide a hermetic seal between the house and its surroundings. This is only partly true.

The air-vapour barrier is a necessary first step in achieving total environmental control inside a house, with minimum energy usage. The air-vapour barrier should therefore be viewed as a means to an end, and not as an end in itself.

4.2 Air management

The air management system of a house involves two components: ventilation and distribution. Ventilation is achieved by removing stale air from the house and replacing it with fresh air. Its purpose is to maintain a satisfactory air quality in the house. The distribution system ensures that fresh air is circulated to all parts of the house.

Once a house has been provided with an air-vapour barrier, it can no longer rely on the processes of infiltration and exfiltration for its ventilation needs, and a ventilation system becomes essential. The typical ventilation system consists of two vents through the house envelope. The stale house air is exhausted by a fan through one vent, and fresh air is drawn through the other vent by a second fan. It should be noted that, if this system were installed in a house without an air-vapour barrier, it might react unfavourably with the infiltration and exfiltration flows, and aggravate some of the problems described earlier. The air-vapour barrier not only makes controlled ventilation necessary, it also makes it possible.

With all the stale house air being exhausted through one vent, and all the fresh air being drawn through another, the right conditions exist for using a heat exchanger in the ventilation system. The heat exchanger is a device that extracts heat from the exhaust air and passes it to the incoming fresh air, thereby achieving a considerable reduction in ventilation heat loss. In the few heat exchanger designs that are now commercially available, typically 60% to 70% of the waste heat is recovered.

In a typical ventilation system, stale air is drawn from the humid and odorous parts of the house – the kitchen, washrooms and laundry – and is exhausted via the heat exchanger. The incoming fresh air is drawn through the heat exchanger, where it picks up heat from the exhaust air, and is then passed to the return-air duct of the house air distribution system.

There does not need to be anything special about the distribution system; a conventional furnace and ducted air system is generally sufficient. But some thought should be given to the special air circulation needs of energy-efficient houses. Since these houses are tightly sealed, there is no infiltration to induce air circulation. Also, since the walls are well insulated and the windows are of higher quality, there are not so many temperature differentials as in the conventional house, and there is not so much air circulation by thermal convection. These houses usually employ a high level of passive solar gain through south-facing windows. When the house has an open-plan design, this solar heating effect can generate useful circulation through thermal convection. But when the house is divided into a number of small, closed rooms, there is an even greater need for air circulation as a means of distributing the solar heat gain through the house.

At the moment, the ventilation rate is the major issue in air management design. The recent emergence of airtight houses and commercial buildings has focussed attention on the ventilation needs, and a number of concerns have started to arise. **In an ideal situation, the ventilation rate should be low enough to minimize heat losses, but high enough to provide an acceptable and harmless atmosphere in the house.** A good ventilation system must provide control of oxygen level, humidity level, odour and pollutants. The mechanics of the first three components are generally well understood, and it is not difficult to define appropriate ventilation levels for their control. However, there are still a great number of unknown factors concerning the admissible levels of pollutants in house air. Some of these pollutants come from the new materials now being used in the manufacture of furniture, carpets and fabrics, and some come from the cleaning materials, aerosols and other chemicals used routinely in most households – not to mention the many (and possibly more harmful) chemicals generated by tobacco smoking.

Recently, there has been a growing concern about the build-up of radon in tightly sealed structures. Radon is a gas generated by trace radioactive materials. In particular, it is generated in the soil around the house and can enter the house through the weeping tile and floor drain system, through cracks in the concrete foundation, and even by diffusing through solid concrete. It is also generated by naturally occurring trace elements in concrete, drywall and other materials. Although radon is carcinogenic, its concentration in a **poorly sealed house** is probably not high enough to constitute any significant health hazard. Those who are worried about radon build-up in **tightly sealed houses** have tended to overlook the positive features of this type of construction: the air-vapour barrier inhibits the flow of radon into the house, in just the same way as it inhibits the flow of air or water vapour.

Two main factors determine the radon concentration in a house: the first is the rate at which radon enters the house, and the second is the rate at which it is removed from the house by air change. In a tightly sealed house, with a good ventilation system, the air change rate is probably around a half to a quarter of that in a poorly sealed house. At the same time, the rate of radon infiltration is far lower in the tightly sealed house than in the poorly sealed house. As an educated guess, it should be at least ten times lower. Therefore, on the basis of these figures, a tightly sealed house with good ventilation should experience lower radon concentrations than a poorly sealed house – all other conditions being equal. Radon tests were conducted on the Energy Showcase houses in December 1980. From the report on these tests* it is clear that, with the ventilation systems operating normally, the radon level in each house would fall well inside the safety limits established by United States health guidelines.

It will take some years of investigation before the appropriate levels of ventilation control can be defined. In the meantime, it makes sense to allow for the uncertain risks arising from increasing use of new chemicals, and to design for over-ventilation rather than under-ventilation. An air-change rate of 0.5 ach (about 0.06 m^3/s in a typically sized house) seems to be acceptable to a number of authorities on pollutant build-up. This is somewhat larger than the 0.02 to 0.03 m^3/s rates that have been advocated in the past, but it is not an excessive premium to pay as a way of avoiding the possible effects of build-up. The extra ventilation heat loss incurred by increasing the ventilation rate from 0.03 m^3/s to 0.06 m^3/s is not large, particularly if most of the heat loss is recovered by a heat exchanger.

4.3 Air supply to combustion devices

The fourteen houses in the 1980 Energy Showcase have raised a number of problems concerning air supply to combustion devices in an airtight house. The furnace, the water heater, and maybe a stove or fireplace are all competing for combustion air and draft air, and there may not be enough infiltration flow to meet the combined need. Under these circumstances the various combustion units will interact and may create a hazardous backdraft situation.

To quantify the effect, consider a typical Energy Showcase house with a natural gas furnace and water heater, rated at 15 kW and 10 kW respectively. When both are operating simultaneously, their combined air supply requirement is about 0.006 m^3/s. But, in this typical energy-efficient house, the natural air infiltration rate is only 0.025 ach, which corresponds to an airflow of 0.003 m^3/s. The natural infiltration rate is therefore incapable of meeting the combustion needs of the house.

Of course, it is immediately obvious that the ventilation system can provide all the air that is needed, but there are two objections to this. The first objection is not particularly serious: if the ventilation system is relied upon for combustion air supply, there will be a certain amount of interaction between the system and combustion units. If the ventilation rate is set at about 0.06 m^3/s, as discussed earlier, the 0.006 m^3/s demand of the combustion systems will not have much effect. However, if the ventilation rate is set at a lower level, say 0.02 to 0.03 m^3/s, there could be quite a strong interaction, with an unpredictable outcome. The second objection is a major one, and it is based on the undesirability of

* Besant, R.W. Radon Gas Testing Report for Low Energy Houses, Dept. Mechanical Engineering, University of Saskatchewan, January 1981.

obtaining combustion air through anything but a simple duct system. It is quite likely that, even when heat exchanger designs have been thoroughly debugged, there will still remain a risk of plugging by frost build-up or accidental blockage by owners who do not understand the system. Accordingly, the ventilation system should not be relied upon for combustion air and draft air supply.

During the construction stage of the Energy Showcase, the local gas authority considered this problem and came to the decision that the ventilation air supply did not constitute an adequate combustion air supply.

4.4 The code governing air supply

The code governing air supply to combustion units in airtight houses is therefore as laid down in the C.G.A. Installation Code for Natural Gas Burning Appliances and Equipment, CGA B149.1-1976. The relevant section is 6.2.1 on page 53, and reads as follows:

"When an appliance is located in an unconfined space within a building having insufficient infiltration, the air supply shall be obtained from outdoors and a permanent opening, or openings, having a total free area of not less than [10 square centimetres] per [2.25 kW] of total input rating of all appliances, shall be provided".

In the example considered earlier, the combined rating of 25 kW requires an opening of at least 110 square centimetres to conform with the above code.

In the Energy Showcase, the majority of houses have furnaces and water heaters installed inside a sealed furnace room that is provided with its own combustion air and draft air supply. The codes governing air supply in this situation are too lengthy to quote here, and appear in Section 6.3 on page 53 of the above document.

The primary purpose of the furnace rooms in these houses was to improve the seasonal efficiency of the combustion units by having them use cold exterior air instead of warm house air. In an airtight house it makes more sense to do this than to have the combustion units in an unconfined space with a large hole through the vapour barrier. Apart from this, the furnace room has been found to have other benefits:

a) By isolating the furnace and water heater from the rest of the house, complicated interactions with the ventilation system, stoves and fireplaces are avoided.
b) Infiltration rates tend to be reduced even further.
c) By installing the floor drain inside the furnace room, one of the main avenues of radon movement is isolated from the house living space. When the floor drain is located inside the furnace room it is advisable to install the furnace room door without a sill to facilitate draining.
d) The house has more protection against operational defects of the combustion units.

It is obvious, from what has been said previously, that stoves and fireplaces should be provided with their own localized air supplies, and should not be dependent on the ventilation system.

4.5 The optimum air tightness

The Prairie Regional Station of the National Research Council has conducted pressure tests on the Energy Showcase houses to determine their infiltration performance. The results indicate that twelve of the houses have natural infiltration rates lower than 0.05 ach*. It will be recalled that, in a conventional house, the infiltration rate ranges from 0.2 to 1.5 ach.

This information shows that very low levels of infiltration can be achieved if the air-vapour barrier is installed with great care. At the same time, it raises a number of doubts about the feasibility of air-vapour barrier construction. Does it make sense to try to achieve these levels of air tightness, particularly when one considers the incremental costs and problems that it creates for air management and combustion appliances? In principle, there is no doubt that the air-vapour barrier makes a great deal of sense — as an energy conservation measure, as a means of achieving proper ventilation control, as a protection against moisture damage by exfiltration, and because of its beneficial effect on the comfort level in the house. But isn't it possible that these same benefits would be experienced if the infiltration rate were as high as 0.10 ach or even 0.15 ach? How far can the quality of the barrier be relaxed, and how far can the infiltration rate be increased, before some of the benefits start to disappear? At the moment, there is no clear answer to these questions.

Air-vapour barrier techniques are still in their infancy, and a great deal of development and testing is needed before the optimum approach can be defined. The aim so far, under the direction of the scientific community, has been to explore the limits of what can be achieved in practice. The Energy Showcase has been invaluable in this respect. Looking at some of the things that were done on the Energy Showcase houses, it is clear that, in a great many instances, extreme measures were adopted in attempting to provide a perfect seal around awkward constructional features. Less extreme measures, at far less cost, would not have achieved a perfect seal though they might have achieved something not far short. The emphasis on high quality was justified in the Energy Showcase because of the exploratory and educational nature of the project, and it would be a good learning experience for all builders if they were to attempt a perfect air-vapour barrier installation at the outset. However, the time is now ripe to consider some relaxation in the quality of air-vapour barrier installation – mainly with the intention of streamlining the installation and reducing its cost.** The best techniques, and the optimum air tightness, will not be found without a few years of trial and error.

4.6 The position of the air-vapour barrier

The existing building standards and codes stipulate that the vapour barrier must always be positioned on the warm side of the insulation:

Residential Standards 1980, Section 26, Sub-Section E.1
". . . vapour barriers shall be installed on the warm side of insulation.."
National Building Code of Canada 1980, Part 5, Sub-Section 5.2.1.1
". . . the assembly shall be designed to prevent condensation by providing a continuous vapour and air barrier in the assembly on the high vapour pressure side of the material that has the major thermal resistance.."

* There is no reliable way of deriving the natural infiltration rate from pressure test data. The above figure has been obtained by applying a rough correction factor.

** Houses now being built under Saskatchewan's Home Energy Loan Program (HELP.) are achieving high levels of air tightness for modest installation costs.

The intention is to ensure that the vapour barrier is always positioned on the warm side of the dewpoint location, but the Codes are written in such a way that they do not allow for the alternative vapour barrier positions that have now been made possible by new wall designs and new methods of construction.

A number of complex thick-wall designs have evolved as a way of increasing the insulation levels in exterior walls. The most common designs are the double-frame wall and the strapped wall. In both designs there are certain advantages to be gained by positioning the air-vapour barrier some distance into the wall, with insulation on both the warm and the cold side. It is a primary requirement of such designs that the air-vapour barrier should always be positioned on the warm side of the dewpoint location. The appropriate position can be determined by a simple rule-of-thumb: in Saskatchewan, for example, the insulation on the outside of the air-vapour barrier must have twice as much thermal resistance as that on the inside. The dewpoint will then fall on the cold side of the air-vapour barrier except for short spells of extreme winter temperature in Saskatchewan. The same rule-of-thumb can be applied to houses built in a more moderate climate, but a different rule would have to be applied to houses built in a more severe climate.

In positioning the air-vapour barrier some distance into the wall, the main aim is to preserve the integrity of the barrier. There is less risk of accidental damage during construction and there is enough room to install pipe and cable runs on the warm side of the barrier, thereby eliminating the need to puncture the barrier for electrical outlets and other features. In the double-frame wall the best position for the air-vapour barrier is on the outside face of the inner frame. In the strapped wall the best position is on the inside face of the vertical studs, before the horizontal strapping is installed. Such designs make it possible to achieve very high levels of air tightness.

This new approach to air-vapour barrier positioning obeys the principles built into the existing building codes, but it does not conform to the strict wording of the codes. Because of the advantages of this new approach it can be expected that the codes will eventually be changed to allow greater flexibility in air-vapour barrier positioning. In the meantime, and as demonstrated on the Energy Showcase, the agencies responsible for implementing Standards will probably interpret the codes leniently.

4.7 Floor headers

Floor headers constitute a special problem in the positioning of the air-vapour barrier. To achieve air tightness, it is necessary to run a preparatory strip of barrier material over the outside of the headers in such a way that it can be joined later to the main wall barriers above and below.* To avoid a dewpoint 'situation' at this point it is necessary to set the headers back from the normal position, so that insulation can be installed on the outside of the header and the air-vapour barrier. There is another aspect to this problem when the headers are set at the top of a basement wall. When working inside the basement it is usually very easy to install insulation against the headers (between the floor joists), and it is very tempting to pack large amounts of insulation into these spaces. This temptation must be resisted since it might provide more insulation on the inside of the air-vapour barrier than the outside — and, in so doing, it will bring the dewpoint location inside the barrier. The rule-of-thumb, described above, also applies to insulation levels around the headers.

* This practice may contravene some local by-laws.

4.8 Testing procedures and standards

There are currently no Canadian standards on air tightness of houses, but it is probable that, within a few years, Canada will follow the example of countries such as Sweden and establish both testing procedures and standards for air tight construction.

It is likely that the testing procedures will be based on the pressure testing technique. This technique has already been used extensively by the Prairie Regional Station of the National Research Council. A few manufacturers in Canada and the United States are now offering commercial models of the test equipment. Essentially, the technique consists of mounting a variable speed fan on one of the exterior doors. The fan is set up to draw air from the house. After a short period of operation, a steady condition is reached in which the air extracted by the fan is balanced by air infiltrating into the house. By measuring the air flow rate through the fan, and the pressure difference that has been established between the house interior and exterior, a comparative assessment of the air tightness of the house can be made. It is necessary to emphasize the comparative nature of this test; it does not provide a good approximation to the conditions that exist in normal house operation, and there is no generally accepted way of deriving the natural infiltration rate from the test results, but it is a reliable and repeatable test procedure that can measure how tight the house is compared with some 'standard'.

The Swedish standard for air tightness requires the house to have an air change rate less than 3 ach when subjected to a pressure differential of 50 Pascals* – as measured by a testing procedure similar to the above. It is probable that a Canadian standard would be stated in much the same way, though perhaps with a different air change requirement. The Swedish standard would not be too effective in many parts of Canada, since the average house performance already falls fairly close to this standard.

4.9 Some general comments on design problems

House designers can play a major part in simplifying the air-vapour barrier installation and reducing its cost. The air-vapour barrier installer has a much easier task if he can work in a house that has a simple rectangular shape. As soon as stylistic features are introduced into the house design the air-vapour barrier starts to become more complicated and there is a consequent increase in cost.

Different building styles create different problems for the installer. After two or three years' experience the installer will have a fairly good idea of how to tackle the various problems. During those first two or three years, while the installer is learning the new skills, he will find that a good set of detailed drawings are of great help. The air-vapour barrier requires a lot of preparatory work at various stages of framing, and the amount of preparatory work increases with the complexity of the building design. This preparatory work is a critical part of the air-vapour barrier installation, and if it is not done right it could defeat the whole object of the barrier. During the framing work it is sometimes difficult to visualize where the air-vapour barrier should go, and where the preparatory work is needed. This is where a good set of drawings becomes useful.

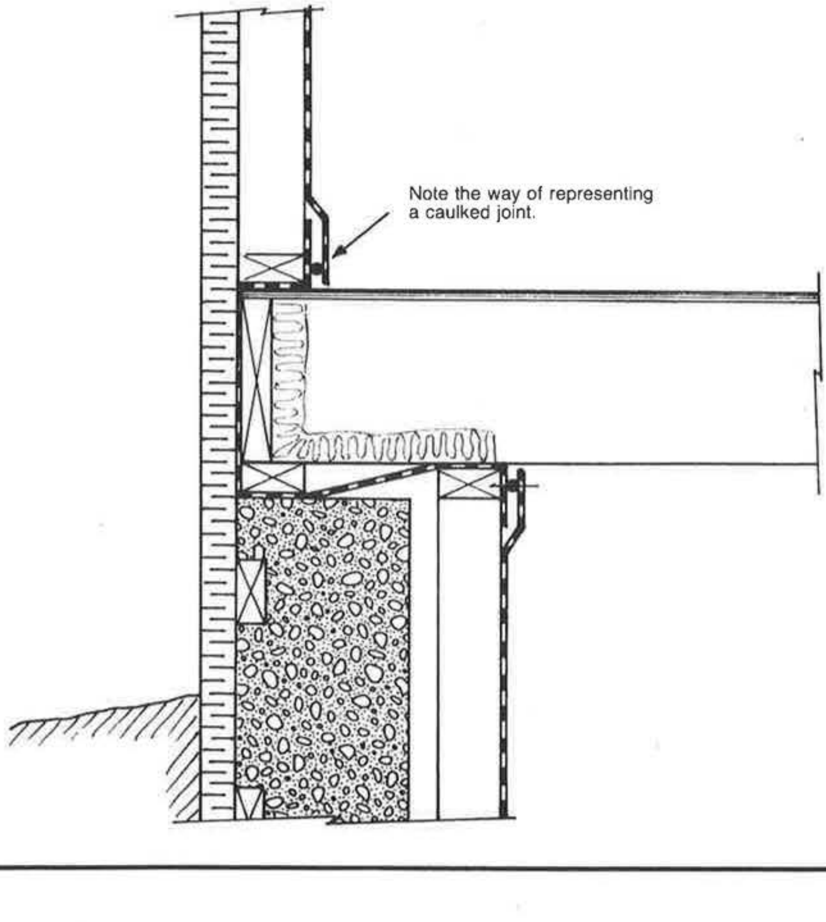
* 1 Pascal is equivalent to a pressure of 0.0025 kg/m (0.000145 psi) or the pressure exerted by 5 mL (a fifth of an inch) of water.

As a general rule (until the installers have learned instinctively what to do) design drawings should be required to include all relevant barrier detail. This will not only help the installer directly, but it will also help to simplify the barrier design – since the designer will have to identify the main problems on the drawing board and find effective ways around them.

4.10 Preparation of house drawings

The air-vapour barrier calls for an entirely new approach in the preparation of house drawings. It is not good enough to show a vertical wall section and indicate the position of the barrier, because the real installation problems do not occur on walls or ceilings – they occur at corners and other structural breaks. Air-vapour barrier designs should therefore concentrate on details at corners, around floor headers, at the point where split-levels intersect, around stylistic features and so on. Also, it may often happen that a particular barrier detail is affected by the direction of the wall, the joists or the trusses. In fitting the barrier around a joist header, for example, the design detail may depend on whether the header runs across the end of the joists or parallel to the joists. In cases like this, both design details should be given.

When showing air-vapour barrier detail on a drawing, the aim should be not only to show where the barrier is located, but also in what sequence it is installed, where it should be joined and how it should be joined. The builders on the Energy Showcase have developed a variety of ways of doing this. The best way – because it is the most easily understood – is a large-scale schematic detail. The following drawing is an example of this technique, and shows the air-vapour barrier detail around a floor header with a developed basement. It is recommended that this technique, or something similar, be adopted as standard drawing practice.



Section II

How to install an air-vapour barrier

5.0 Choice of materials

5.1 The air-vapour barrier sheet

Polyethylene sheet is recommended. There is no great technical advantage in using one thickness rather than another, and the selection of thickness should be based on constructional factors. 0.05 mm sheet is too easily damaged during installation and subsequent construction work. 0.10 mm is slightly less resistant to damage. 0.15 mm is the best choice.

5.2 Caulking material

The use of caulking material for joining two sheets of polyethylene has never been thoroughly tested. To remedy this defect, Saskatchewan Research Council has conducted simple tests on a wide range of caulks and sealants. The tests closely simulated the actual conditions of a caulked joint. A bead of material was run between two sheets of polyethylene, and the two were then pressed lightly together. The joint was then inspected at intervals over a period of one year to determine its adhesion and flexibility. During this period the samples were maintained at normal room temperature. It should be noted that this is not an authoritative testing procedure – it merely gives a good idea of the most suitable type of caulk or sealant.

The tests were conducted on 45 different commercial products – this being the number of different types available through retail and wholesale outlets in 1979. New products have become available since 1979, but these have not been tested.

Many of the samples lost adhesion or became too rigid after only a few months. Eleven samples maintained their flexibility and adhesion for six months. Only three samples maintained their adhesion and flexibility after one year.

The following materials lasted up to six months:
DAP Butyl Flex
MACCO Guard House
MACCO Gutter Tite
GRACE Hornseal
GIBSON-HOMANS Butyloid
PRC Acoustical Sealant
CHEMTRON Metaseal Acoustical
MIRACLE Adhesive SCS #21.

The following materials were still satisfactory after one year:
TEMCO Butyl Sealant
TREMCO Acoustical Sealant
PRC Rubber Caulk #7000.

The authors of this guide feel that it would be wrong to endorse one group of materials and condemn another group on the basis of the tests described above. There is an obvious need for authoritative testing of caulks and sealants for air-vapour barrier use. Until such tests are instituted, builders may wish to base their selection of sealant on the above information.

Throughout this guide the terms sealant and caulk will be used in the following sense: sealant implies the joining and sealing of two materials; caulk implies the filling of cracks or openings. The same materials can be used for caulking and sealing.

6.0 A general guide on installation procedures

6.1 The air-vapour barrier should be installed in such a way that it provides a completely sealed envelope, except at doors, windows, vents and other obstacles.

6.2 The air-vapour barrier should be terminated at doors, windows and other obstacles using the detailed procedures given in this guide.

6.3 All joints between two sheets of polyethylene should be made against a solid wood backing. A continuous bead of caulking material should be run along the joint between the two sheets. The two sheets should then be pressed lightly together along the line of the caulk, and the joint should then be strengthened by driving staples into the wood backing and along the line of the caulk. It must be emphasized that caulk should not be treated as an adhesive; it cannot be relied upon to hold two sheets of polyethylene together without the support of staples.

6.4 At the joint between two large sheets of polyethylene, the two sheets should be overlapped by at least one stud space or one truss space.

6.5 Joints should be stapled at intervals of about 150 mm. If the polyethylene sheet is very wrinkled at the joint, an extra amount of caulking material and a closer spacing of staples will be necessary.

6.6 When installing a sheet of polyethylene at an inside corner at least 150 mm of spare material should be allowed at the corner, to prevent it from pulling tight at the corner and being damaged during subsequent drywall installation.

6.7 Generally speaking, it is better to use too much caulking material and polyethylene sheet, rather than too little.

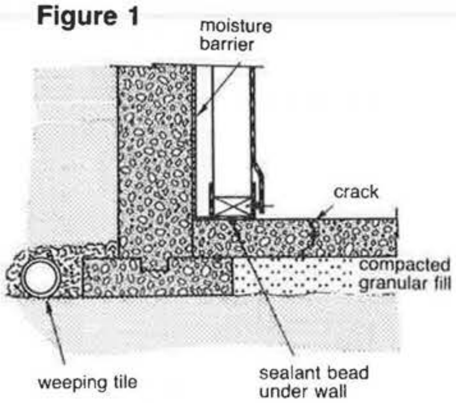
6.8 If wind forces are likely to be a problem during construction, all stapled joints and all stapled attachments of the sheet to the wood frame should be strengthened by driving the staples through pieces of strong tape placed on the sheet at the stapling point. One way of relieving the wind loading on the vapour barrier is to leave out a large section of the ceiling barrier – about 10 square metres – which is then sealed and stapled in place just before the drywall is installed.

6.9 Where the polyethylene sheet is likely to be damaged during construction it should be protected with thin sheets of plywood or panel material. Typical examples occur on the outside of floor headers, where the sheet can be protected with a permanent covering of plywood. Also, in some preparatory work, a loose strip of polyethylene is left at the foot of the walls, ready to be joined later to the wall vapour barrier. A temporary protective strip of material should be laid on top of this exposed vapour barrier, particularly at exterior doors.

6.10 When the air-vapour barrier installation is complete, and before it is covered by other work, it should be given a careful inspection for damage or poor joints. Small holes in the barrier can be repaired with vapour barrier tape; large holes or rips can be repaired with a generously sized patch of polyethylene, caulked to give a thoroughly sealed joint. Where possible, patches should be made large enough to cover the damage and overlap any wood frame nearby – so that the seal can be strengthened with staples.

7.0 Foundations

Figure 1



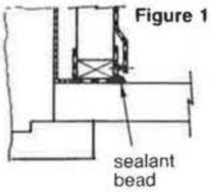


Figure 1a

Figure 2

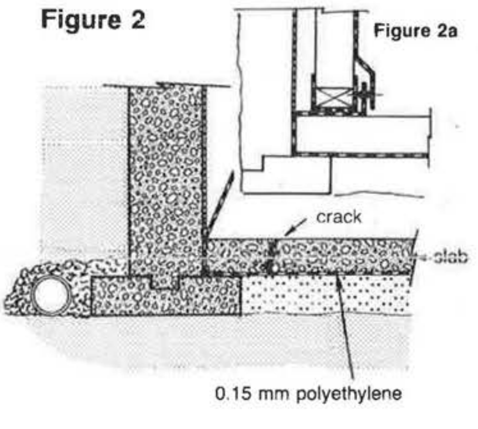


Figure 2a

Figure 3

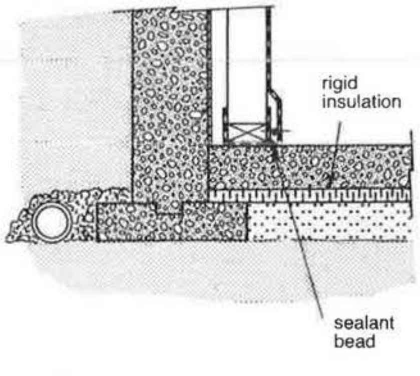


Figure 1 shows the arrangement around the footing of a concrete basement. When the basement is finished with an insulated stud frame, the bottom plate should be protected against moisture damage by a strip of vapour barrier around the bottom plate as shown. This moisture may come through the floor slab, or it may occur as a shallow pool of water that has run down the inside of the concrete foundation wall.

Air leakage under the bottom plate can be prevented by a sealant bead under the plate, as shown in figure 1, or by a bead along the edge of the plate, as shown in figure 1a. The second method is easier and has the advantage of being visible for inspection.

The wall vapour barrier is joined to the vapour barrier around the bottom plate as shown, with a sealant bead and staples.

Note that the vapour barrier, and its method of attachment, will be indicated in this way throughout the guide. Also note that, to simplify the drawings, such things as sheathing board, plaster-board and insulation will not be shown unless they have a bearing on the vapour barrier design.

The moisture barrier *is not* a vapour barrier. Its purpose is to control the flow of moisture through the concrete and into the house. The moisture barrier material has to allow the movement of water vapour but not the flow of free water. Vapour barrier materials are not suitable, but there is a wide range of moisture barrier materials in sheet, spray or paint form. The moisture barrier should cover the inside face of the concrete from the footing to a point level with the grade surface outside. It is good practice to carry the moisture barrier about 150 mm across the floor slab. The exterior of the foundation wall should be damp-proofed in accordance with Section 13 of Residential Standards 1980.

Air can flow quite easily through soil and, as a result, any cracks in the concrete foundation or slab can become channels for air leakage. They can also act as channels for the infiltration of radon – generated from naturally-occurring radioactive materials in the soil. It is not customary to install a vapour barrier beneath the slab in a concrete basement (though this is required if the basement is to be developed), but this may become standard practice — mainly as a way of reducing radon build-up in houses. Figure 2 shows how the slab vapour barrier should be routed, and figure 2a shows how it should be joined to the frame vapour barrier at a later stage.

The same effect, though not so effective, can be achieved by installing a sheet of low-permeance rigid insulation under the slab, as shown in figure 3. This also has the advantage of reducing heat losses through the slab.

There is some concern that the kinds of construction shown in figures 2 and 3 may have a weakening effect on the slab by depriving the concrete of moisture from the soil. The effect has not been fully studied. The National Research Council Building Practice Note ISSN 0701-5216 No. 8 by R.G. Turenne should be consulted. This recommends that the water/cement ratio be kept as low as possible, consistent with workability, and that recommended curing methods be followed.

7.1 Unheated crawl space

Figure 4 shows a typical arrangement for an unheated crawl space with concrete foundation. The moisture barrier inhibits the build-up of moisture in the crawl space, since this can lead to structural deterioration. The crawl space should be vented in accordance with Residential Standards 1980, Section 18C.

Figure 4

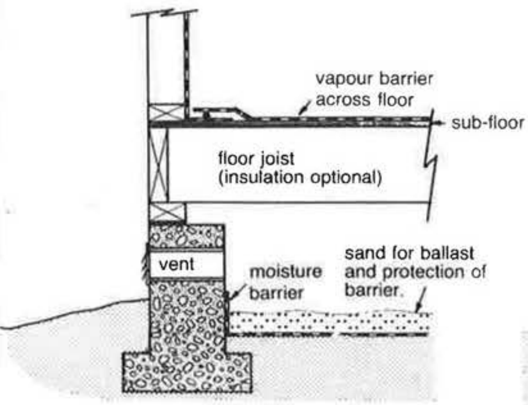


Figure 5

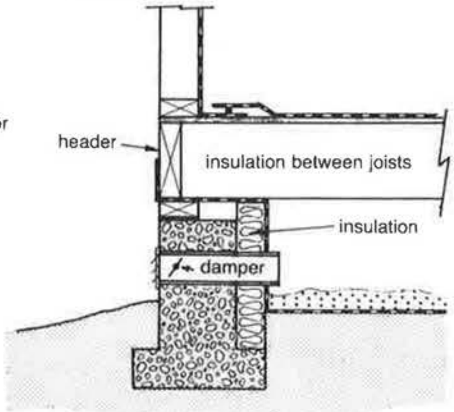


Figure 6

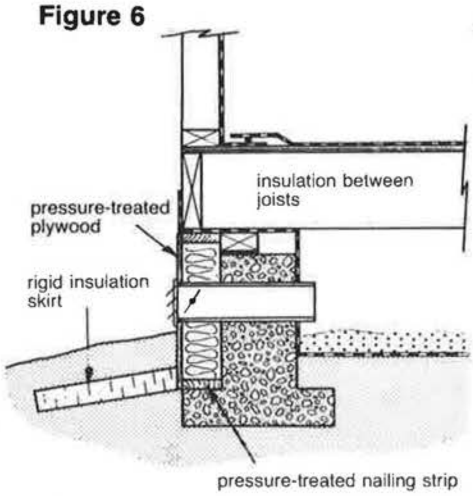


Figure 7

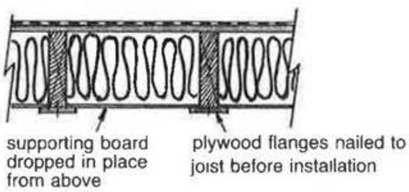


Figure 5 shows an improved design for an energy efficient house. Insulation is provided against the foundation wall to reduce heat losses, and the moisture barrier is extended around the header to reduce infiltration of cold air into the crawl space. The venting system should be provided with a damper, or some other system, to allow the vents to be closed in winter and opened in summer.

The insulation technique shown in figure 5 is not too good, since it isolates the foundation wall from the warming effect of the house, and exposes the concrete to severe temperature effects. Figure 6 shows an improved design, in which the insulation is placed on the outside of the foundation. The peripheral insulation skirt provides further protection for the concrete, and helps to reduce heat losses from the house.

Figure 7 shows a convenient way of supporting the floor insulation over the crawl space. This technique allows all the insulation work to be done from above.

7.2 Independent slab and foundation

Figure 8 shows an accepted way of installing a concrete foundation with an independent slab-on-grade. A continuous sealant bead is applied at the exterior joint of the wood frame and concrete. The rigid insulation reduces heat losses through the slab perimeter. In this design there is no good way of joining the slab vapour barrier and the wall vapour barrier, and some infiltration (of air or radon) will occur at the gap between the two.

An improved design is shown in figure 9. Note that a good joint of the two vapour barriers is made against the bottom plate of the wood frame. The sealant bead can still be applied on the exterior of the frame, but is not strictly necessary.

Figure 8

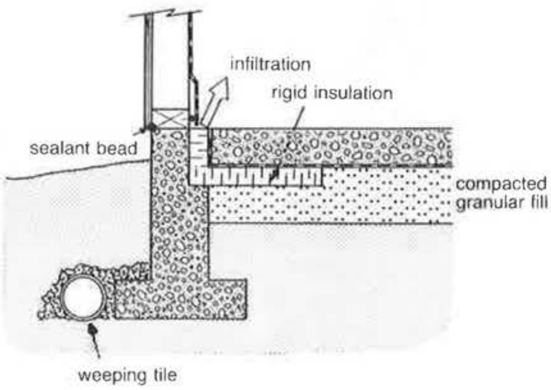
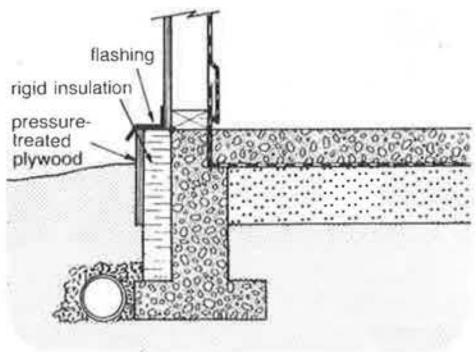


Figure 9



7.3 Combined slab and foundation

Figure 10 shows a typical way of installing a combined foundation and slab-on-grade. Air leakage at the joint of the wood frame and concrete is controlled only by a sealant bead, whose effectiveness can be destroyed by local cracks in the concrete.

An improvement in air tightness can be achieved with a simple extension of the slab vapour barrier, allowing it to be joined to the wall vapour barrier as shown in figure 11.

Figure 10

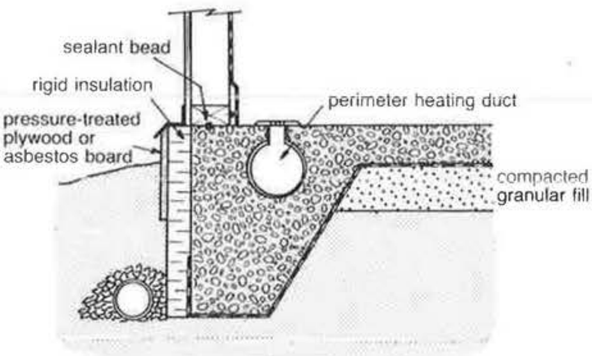
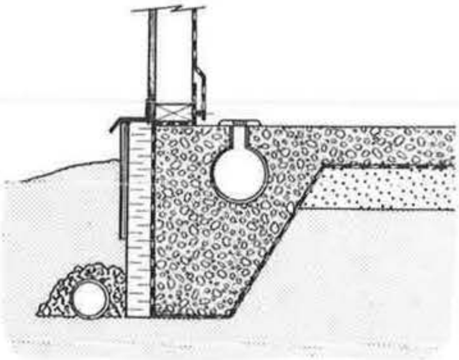


Figure 11



7.4 Pressure-treated wood foundation

Figure 12 shows a pressure-treated wood foundation with a concrete slab. Figure 13 shows the detail where the two vapour barriers come together. Note that the screed board is used to bridge the gap between the two vapour barriers. This is because there is no continuous wood backing – in an accessible position – along the foot of the wall. Also, the exposed edge of the slab vapour barrier is subjected to considerable damage when the slab is being poured and screeded.

Before the slab is poured, the vapour barrier should be stapled loosely in place against the wood foundation, allowing plenty of slack at the corners. A continuous sealant bead is then run along the vertical edge of the vapour barrier, and the screed board nailed in place through this bead. Later, the wall vapour barrier can be sealed and stapled to the screed board as shown.

A note of caution

Before proceeding with this type of installation, builders should familiarize themselves thoroughly with the recommended procedures for pressure-treated wood foundations, and with any special local problems and requirements. The information published by the Canadian Wood Council should be consulted.

Figure 12

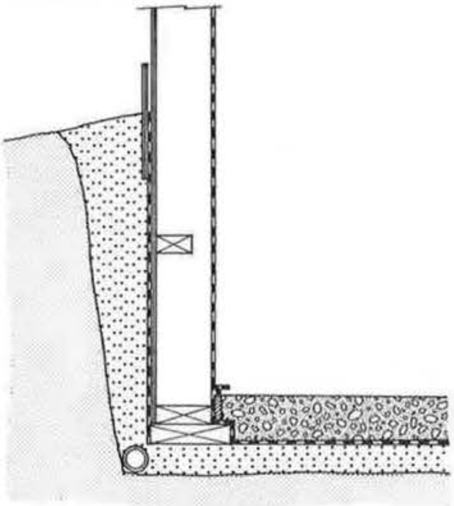
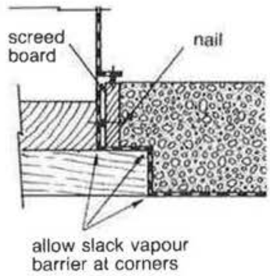


Figure 13



8.0 Working around floor headers

Figure 14 shows a typical construction detail where a platform-built wood frame is joined to a developed concrete basement. This type of construction, with the floor joists and headers set into the concrete, is fairly widespread. The air leakage paths, as indicated by the large arrows, arise partly because of the structural gaps and partly because of the break in the vapour barrier at this location. In some houses insulation is packed tightly at the top of the foundation wall. The main intention is to reduce air leakage, though the effectiveness of this measure is doubtful. Generally, this part of the structure accounts for somewhere around 10% to 20% of the total air leakage in the house, depending on individual construction details. A stuccoed exterior, for example, can reduce header leakage to a low level.

Figure 14

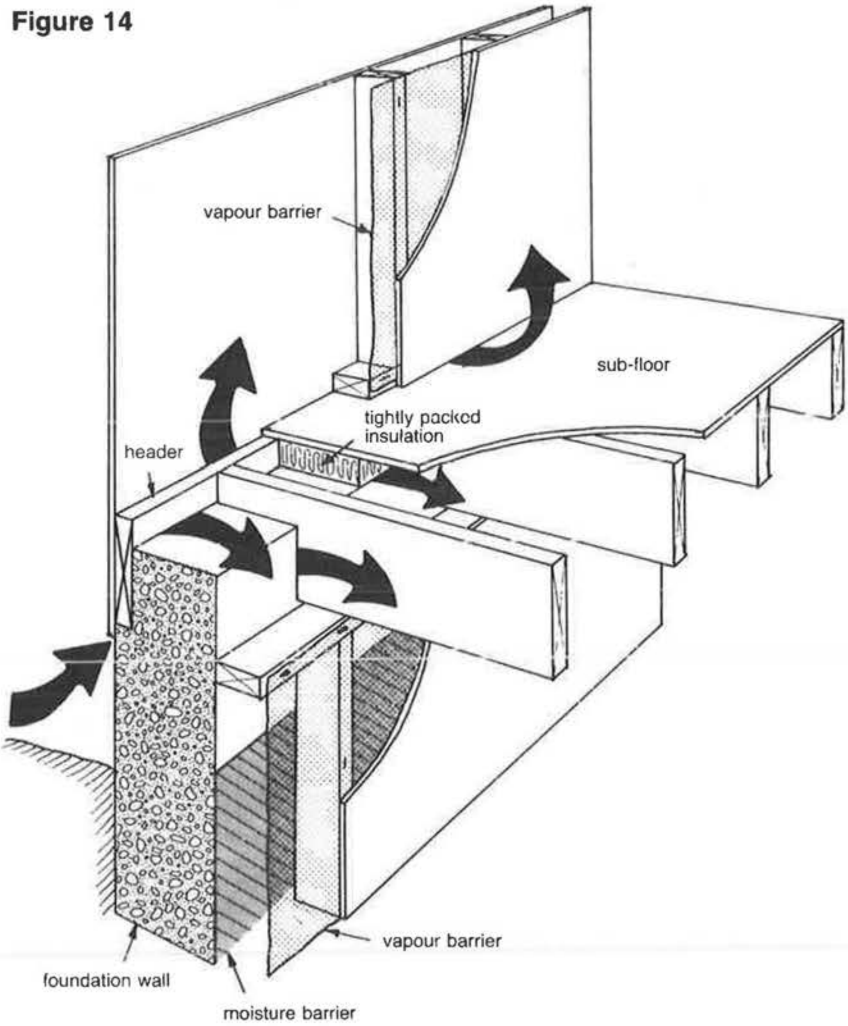
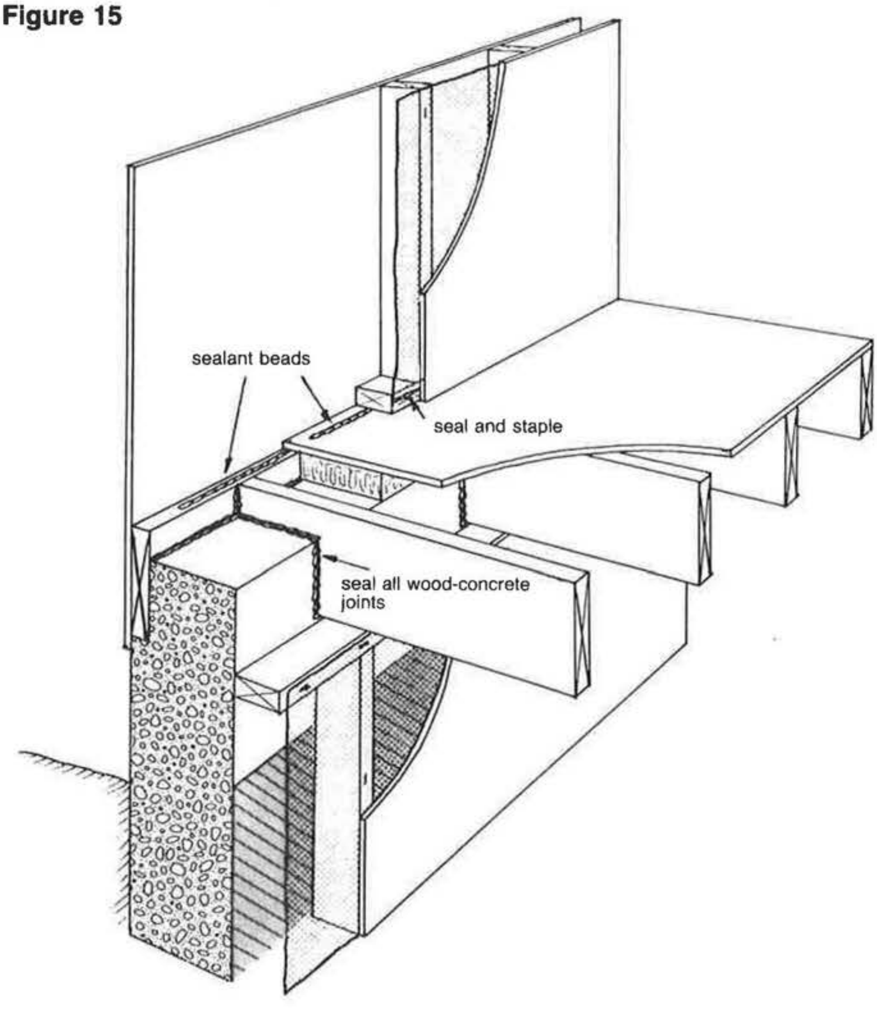


Figure 15 shows what can be done to seal the structure against air leakage. If this work is properly done, it can reduce air leakage to a negligible level at this point. However, it does not provide what is needed for good vapour barrier action. There will probably be some build-up of frost at the header and on top of the concrete foundation, since there is now no air circulation to carry away the water vapour. This technique will improve the thermal efficiency of the house, but it creates some risk of structural deterioration.

Figure 15



8.0 Working around floor headers

Figures 16 and 17 show two ways of improving this situation. In the first, kraft-backed batt insulation provides a continuity of vapour barrier. If this is to be effective, the vapour barrier component of the batt must be sealed to the sub-floor, the basement stud frame and the sides of the floor joists as shown. In the second method, the continuity of vapour barrier is achieved by using a rigid insulation panel that has low permeability (such as Styrofoam SM). This must be caulked and sealed as shown. Figure 17 also shows the best way of terminating the vapour barrier at the floor above.

Both methods require a great deal of time and care to achieve satisfactory results. For this reason they are probably not cost-effective in a professional building operation. Also, by blocking off the supply of warm air that would normally circulate against the headers above an undeveloped basement, this type of construction tends to produce cold spots at the points shown. This approach may be the best that one can adopt in a retrofit situation, but it is not recommended for new constuction.

Figure 16

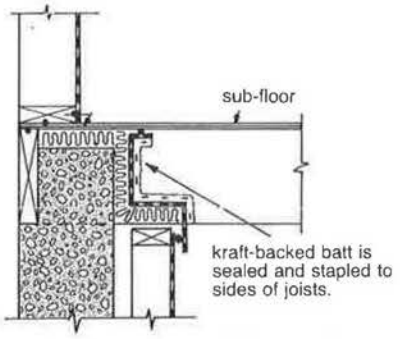
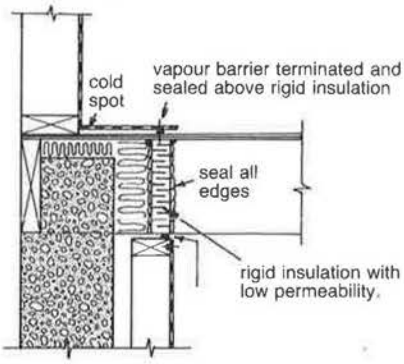


Figure 17



A reasonably good technique, for this type of construction, is shown in figure 18. There are three main features: first, the joists are raised above the concrete to allow a strip of vapour barrier to be passed around the header; secondly, the header is set back from the outside line of the foundation wall to allow the installation of insulation outside this vapour barrier; thirdly, the vapour barrier is passed beneath the sill plate to protect it from damage when the floor joists are being installed. The vapour barrier may still suffer some damage by being pressed against the upper surface of the concrete foundation; this can be alleviated by putting a felt or foam strip beneath the vapour barrier.

The rigid insulation outside the header should, ideally, be 25 to 50 mm thick. If it is less than 25 mm thick it will not provide much insulation effect. If it is more than 50 mm thick it will constitute a weak point when sheathing and siding are attached. A greater thickness can be used, but, to provide the necessary support for sheathing and siding, the insulation should be interrupted with vertical blocking nailed to the header as shown in figure 18a. This blocking should be installed on the same centres as the wall studs above.

Figure 18

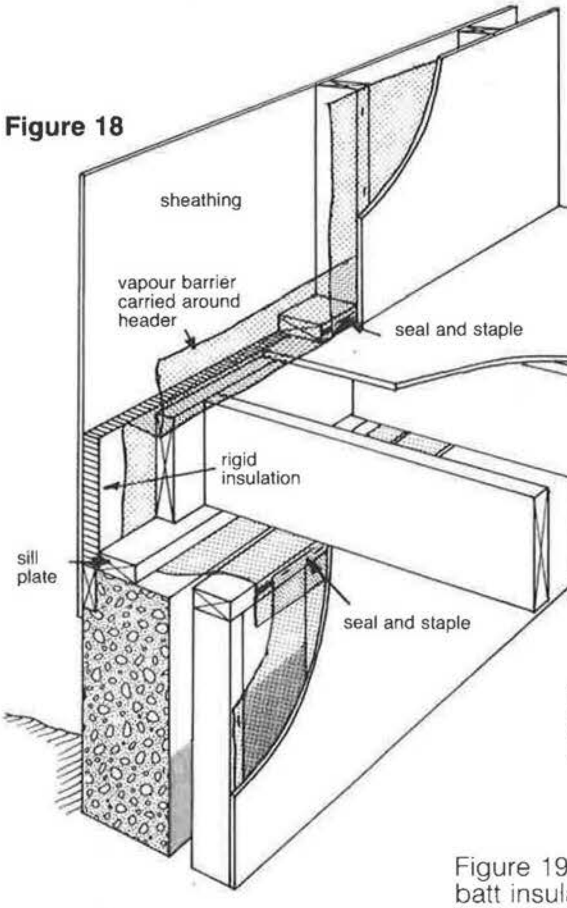


Figure 18a

view of header from above, showing blocking.

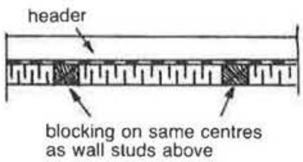


Figure 19

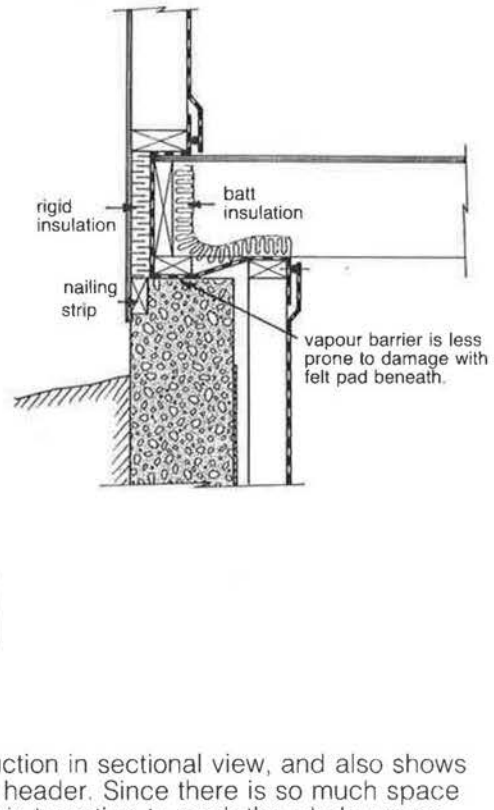
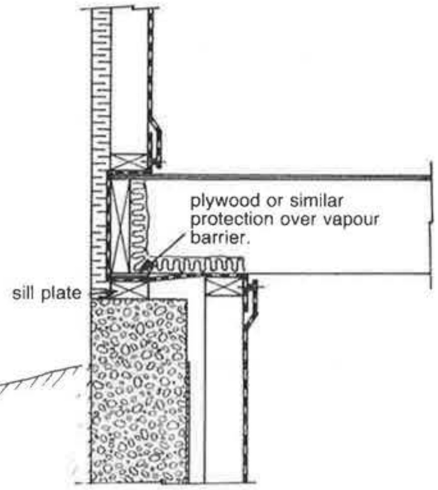


Figure 19 shows the same construction in sectional view, and also shows batt insulation on the inside of the header. Since there is so much space between floor joists at this point, it is tempting to pack the whole space with insulation. **This must not be done.** The amount of batt insulation that can be used at this point is determined by the amount on the outside of the header. The thermal resistance of the interior insulation should not be more than half that of the exterior insulation (see the earlier section dealing with positioning of the vapour barrier, Section 1, page 22).

8.0 Working around floor headers

Figure 20



8.1 The sill plate problem

Figure 20 shows an alternative and slightly improved routing of the vapour barrier. It should be noted that, since the rigid insulation terminates at the top of the foundation wall, the sill plate can experience low temperatures because of heat loss through the concrete. This can cause condensation problems at the sill plate. The solution is to place the sill plate outside the vapour barrier, as shown.

In a two-storey wood-frame house the vapour barrier is routed around the intermediate floor as shown in figure 26. Note that, in this situation, the vapour barrier is protected by a plywood strip instead of a 38 × 89 mm sill plate.

In figure 21, where the insulation is continuous down the wall exterior, there is no need to place the sill plate outside the vapour barrier, and there is a marginal cost saving in running the vapour barrier under the sill plate.

The same general comments and technique apply to pressure-treated wood foundations. Figure 22 shows the air leakage paths in a standard type of construction.

Figure 21

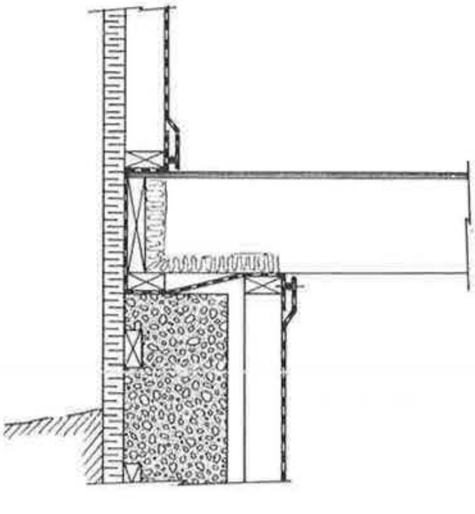


Figure 22

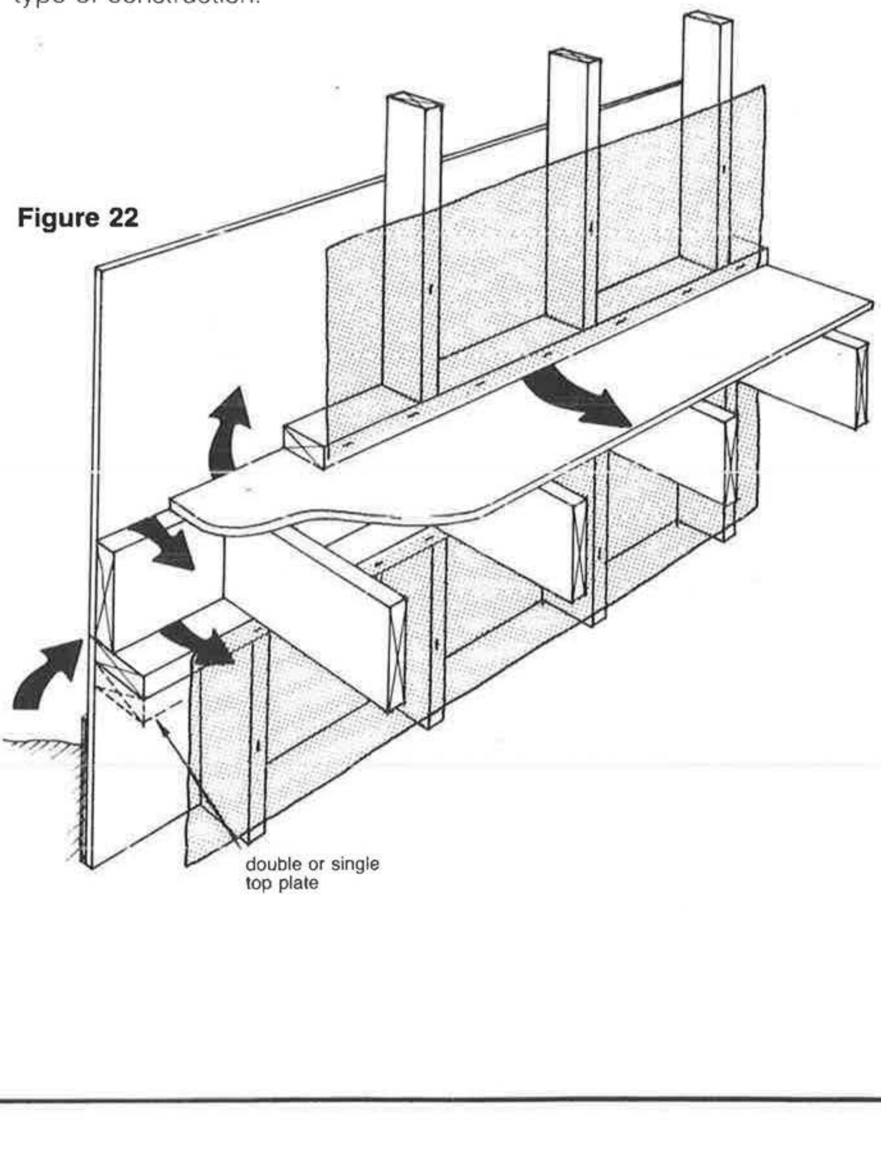


Figure 26

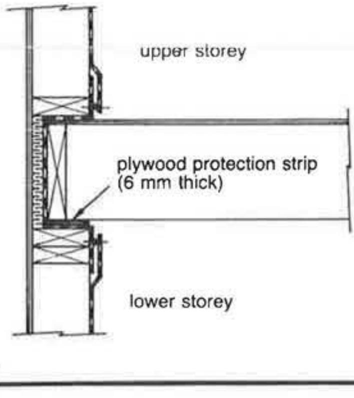


Figure 24

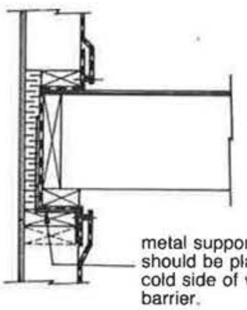


Figure 23 shows a set-back header with the vapour barrier passing around it. Basically the same design, with a different type of sheathing, is shown in figure 24. Note that the use of a 38 × 89 mm bottom plate on the upper wall allows a better level of insulation at this point.

Another design variation is shown in figure 25. In this design, because of the extra thickness of insulation at the header, it is advisable to provide extra support for the siding nails. The blocking detail shown in figure 18a is good, and so is a strip of plywood between the two layers of insulation.

Figure 25

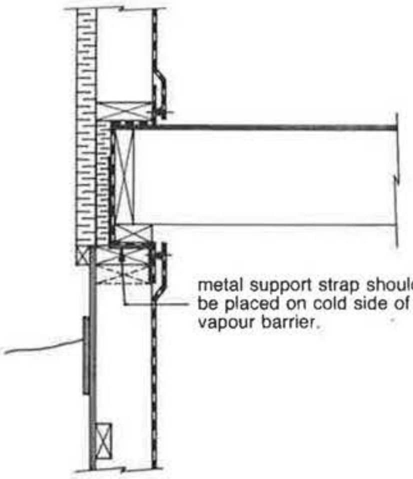
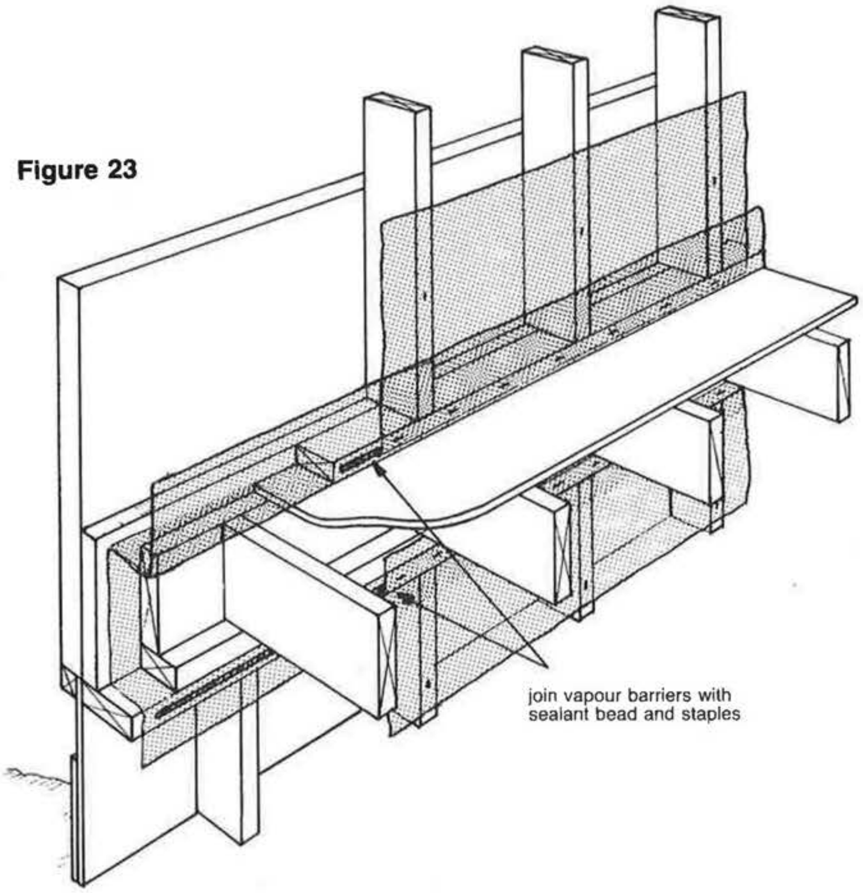


Figure 23



9.0 Support beam problems

Figure 27

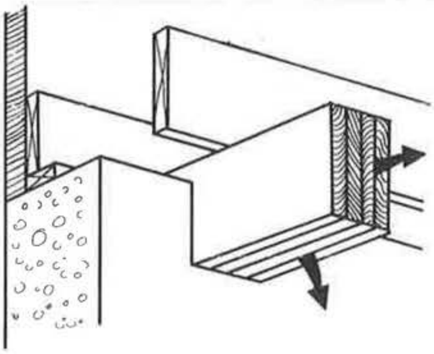
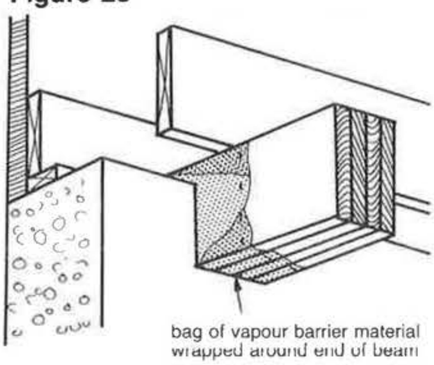


Figure 28



The support beam is a source of air leakage. Air can penetrate between the plies at the ends of the beam and pass along the beam – bypassing any vapour barrier work. Figure 27 shows this process.

One solution is shown in figure 28. The ends of the beam are wrapped in vapour barrier material before the beam is set into the concrete. This is not a good technique, since it exposes the vapour barrier to damage during the concrete work.

A better solution is to seal the ply joints at the ends of the beam, as shown in figure 29. The sealing work should extend at least 600 mm along the beam.

If this procedure is overlooked during construction, figure 30 shows one way of remedying the problem. A 6 mm hole is drilled vertically through the beam at each joint, then sealant is applied under pressure to fill these holes. Finally, the sealant is carried along the ply joints back to the concrete.

Figure 31 shows how the header vapour barrier should be attached to the support beam. Note how the beam butts against the sill plate; this eliminates the need for special folding or cutting of the vapour barrier at this point.

The next step is to cut the vapour barrier along the edge of the beam and fold it down over the basement stud frame, as shown in figure 32. Note that, once the stud frame is in position, it may restrict access to the header space in this area. Therefore, it is advisable to install the interior header insulation before installing the stud frame.

Finally, after the basement walls have been insulated, the wall vapour barrier is sealed and stapled around the support beam as shown in figure 33.

Figure 29

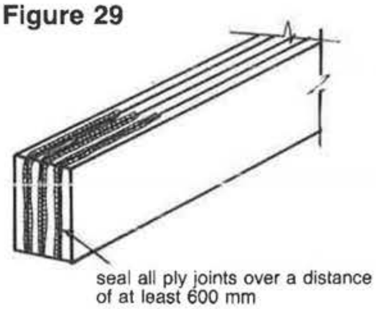


Figure 30

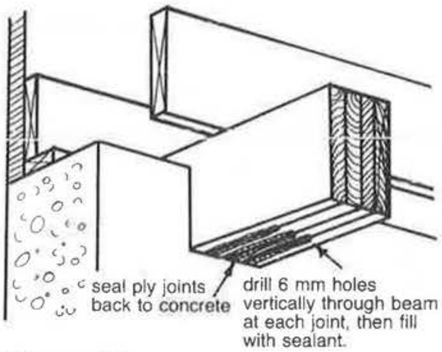


Figure 31

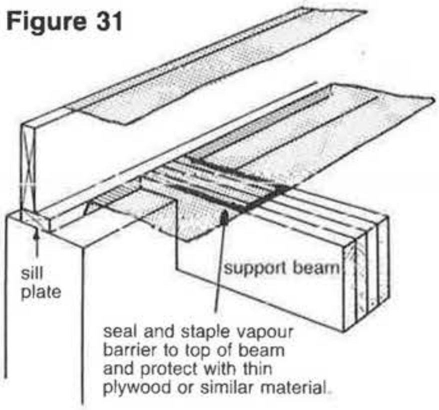


Figure 32

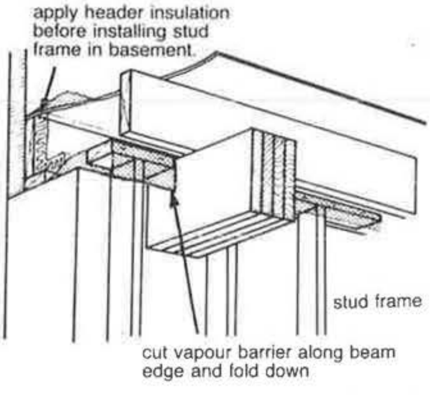
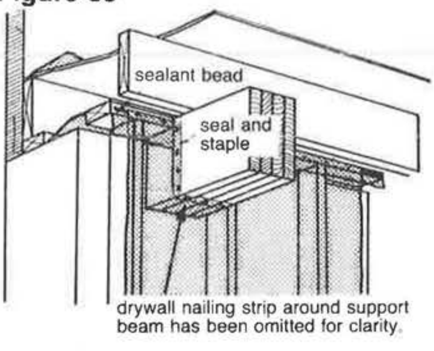


Figure 33



10.0 Partition walls

10.1 The problem

There are obvious advantages in scheduling house construction so that all the framing is done in one operation. This means that the partition walls are installed at an early stage of construction. Later, when the vapour barrier is installed, it has to be fitted around the various partition walls. This may create a number of air leakage paths as shown in figure 34.

This figure shows a type of construction that has been adopted recently by some sectors of the building industry. A strip of vapour barrier is sandwiched between the two top plates of the partition wall, as a way of maintaining vapour barrier continuity across the top of the wall. But, because the ceiling vapour barrier is not sealed to this strip, an air leakage path exists at the vapour barrier joint. This is not much better than an earlier technique, in which there was no vapour barrier strip between the wall top plates.

10.2 A moderately good solution

Figure 35 shows a partition wall with a single top plate, as favoured by some builders. This technique, however, can also be applied to a double top plate. It consists of sealing and stapling the ceiling vapour barrier to the sides of the top plate, and caulking all cable holes. A certain amount of air leakage can still occur through cracks and knot holes, therefore this is not an ideal technique.

Figure 34

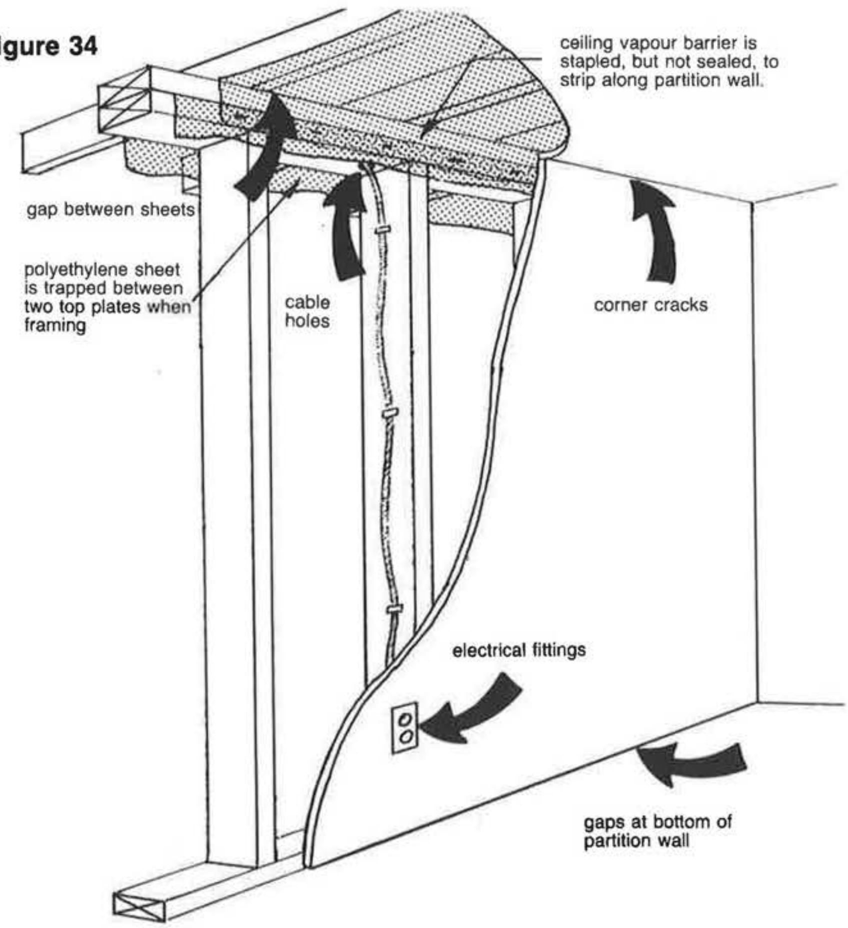
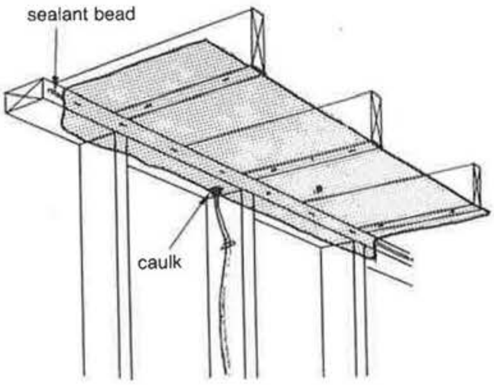


Figure 35



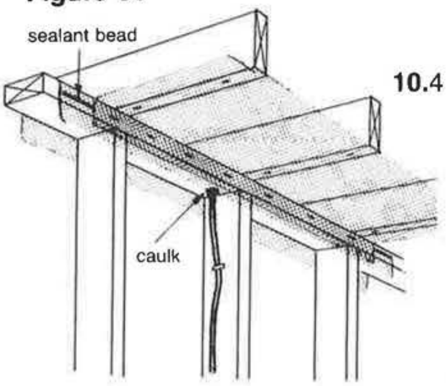
Note that Residential Standards 1980, Section 26E(5) requires continuity of vapour barrier at the top of partition walls.

10.0 Partition walls

10.3 Making matters worse

The defects of the top plate can be overcome by installing a strip of vapour barrier material over the top of the plate, and sealing it to the ceiling vapour barrier as shown in figure 36. This is not good practice; the vapour barrier at the top of the wall is exposed to damage when the roof trusses are being installed, and the vapour barrier provides a very slippery footing when the trusses are being installed.

Figure 36



10.4 A better solution

Figure 37 shows a better way, in which the vapour barrier is sandwiched between two top plates. This maintains vapour barrier continuity, provides a good footing for truss work, and places the vapour barrier out of harm's way. It is similar to the construction shown in figure 34, except that the two vapour barriers are sealed in this case.

When the partition wall runs parallel to the ceiling trusses it is usual to provide a nailing strip as a support for the ceiling plasterboard. This can provide the needed protection for the vapour barrier, making it unnecessary to use a double top plate, as shown in figure 38. The only problem with this construction is that it calls for a different type of construction on partition walls running parallel to the trusses and transverse to the trusses. A parallel construction needs only a single top plate, whereas a transverse construction needs a double top plate. This means that two different stud lengths are needed for the two types of partition wall. It simplifies matters if both walls employ a double top plate.

Figure 39 shows a partition wall parallel to the roof trusses, but with a double top plate.

If the preparatory strip of vapour barrier is accidentally omitted during construction, it is tempting to remedy the situation by running a strip of vapour barrier over the top of the finished wall. This creates no special problems on a transverse partition wall, but on a parallel wall it can give rise to air pockets beneath the insulation, as shown in figure 40. These pockets may run to the outside edge of the roof, creating channels through which cold air can circulate. This may cause frost build-up or condensation at the top of the partition wall.

Figure 37

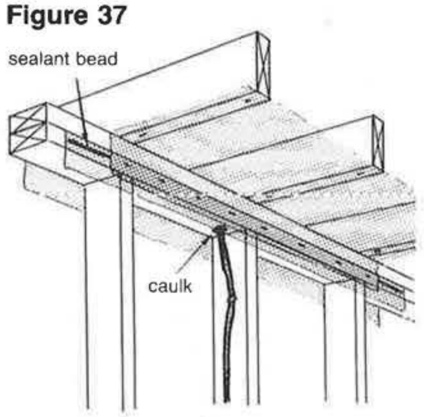


Figure 38

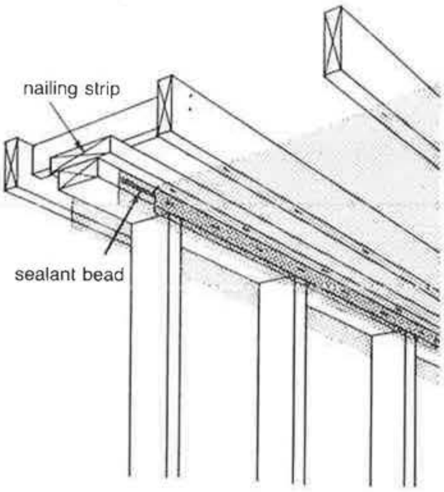


Figure 39

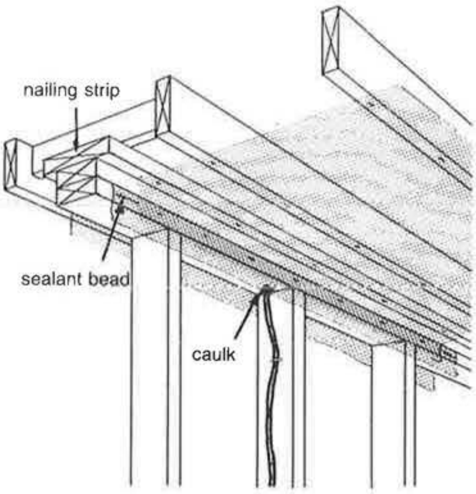


Figure 40

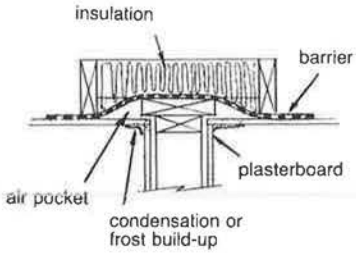
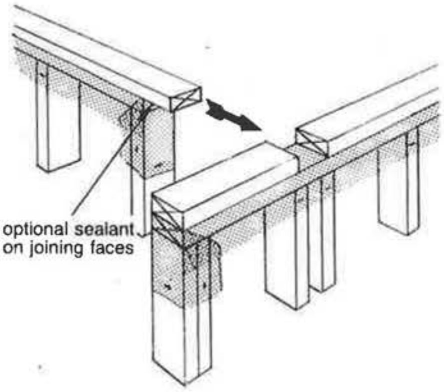


Figure 41



At the free end of the partition wall there is no need to indulge in elaborate dress-making procedures with the vapour barrier. It is simplest, and best, to fold the vapour barrier down the end stud and staple it neatly, as shown in figure 41. This allows a good joint between two partition walls, as shown.

It is difficult to fit the ceiling vapour barrier around the end of a partition wall without creating small gaps at the corners. Some patching is usually necessary, and this can be made easier by providing a suitable backing for the work. Figures 42 and 43 show preparatory work at the free ends of partition walls running in different directions with respect to the trusses.

Figure 42

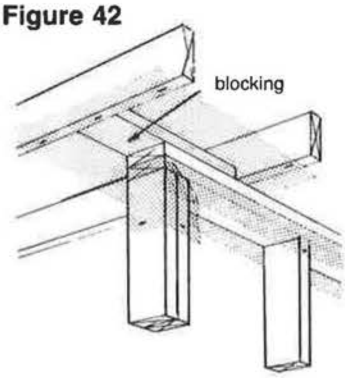
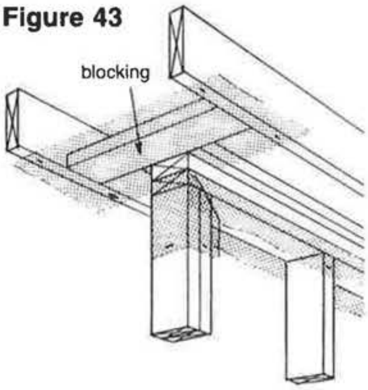


Figure 43



10.5 The partition wall as a whole

The preparatory work on a partition wall depends on where the wall is to be installed. Figure 44 shows a number of different partition wall configurations. Wall 1, for example, needs a preparatory strip of vapour barrier across the top and down the outside stud. Wall 4 needs preparatory work down the outside stud and along the bottom plate.

Figure 45 shows the preparatory work on a wall corresponding to Wall 1 in the above figure. Note that it is good practice to allow a generous amount of spare material at each end, rather than having to patch a piece that has been cut too short.

Figure 44

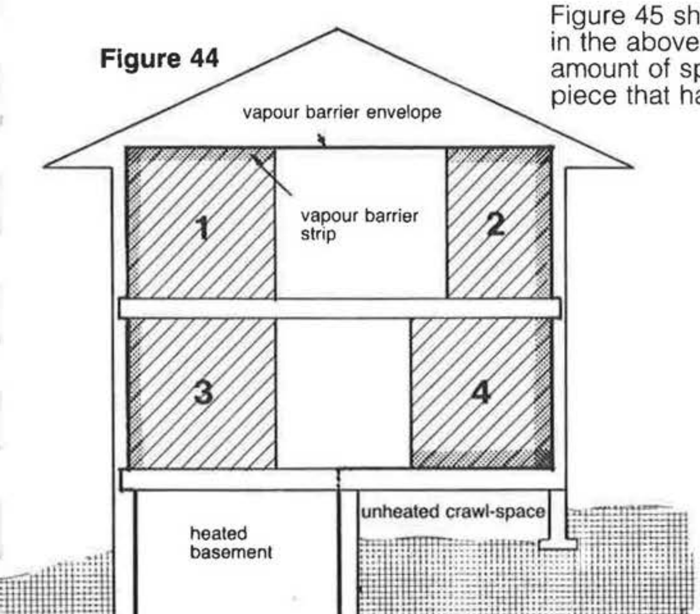
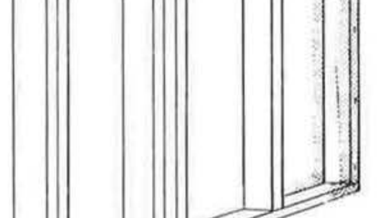


Figure 45



10.0 Partition walls

Figure 47

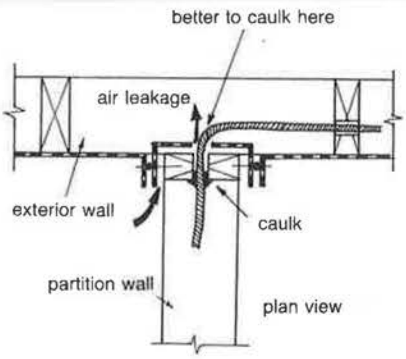


Figure 46 shows how this wall type is installed against the exterior wall. Note the way that it is joined to the vapour barrier that has been passed around the floor header. The best way is to coat the mating surfaces of the two vapour barriers with sealant before the wall is fixed in place.

Also note the horizontal blocking on the exterior frame. This provides backing for the plasterboard along this wall, and is an improvement on vertical nailing strips, since it allows a higher level of insulation at the end of the partition wall.

Figure 46 shows the most convenient way of caulking around an electrical cable where it passes through the end of the partition wall. This is not the best way of dealing with the problem, since it still leaves some slight risk of air leakage, as shown in figure 47. The best way is to caulk where the cable passes through the vapour barrier, as shown. However, this may not always be possible, and the advantages of this method are not great enough to justify any extraordinary changes in construction scheduling.

Figure 48 shows how to prepare a partition wall for a single storey wood frame over an unheated crawl space. The following sequence of figures is fairly self-explanatory, and demonstrates most of the features of fitting the house vapour barrier around a partition wall.

Figure 46

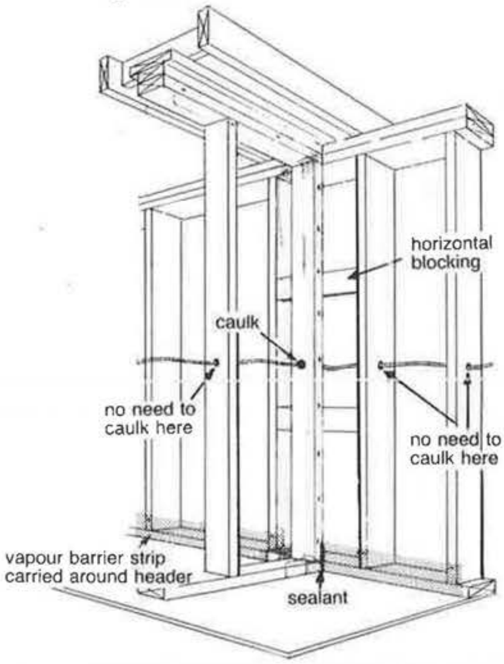


Figure 48

Figure 49: installing the ceiling vapour barrier.

Figure 50: installing the wall vapour barrier.

Figure 51 shows how the construction should appear on completion of the drywall work. The sub-floor is cleaned at this stage, and a continuous bead of sealant is run along the exposed floor strips just before the floor vapour barrier is installed.

Once this vapour barrier is in position there is some risk of damaging it. Special care should be taken during installation, and the underlay should be installed on top of the vapour barrier as soon as possible.

Figure 49

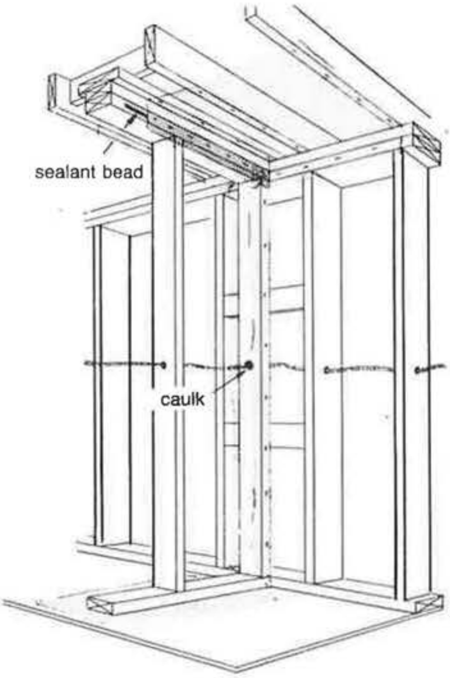


Figure 50

Figure 51

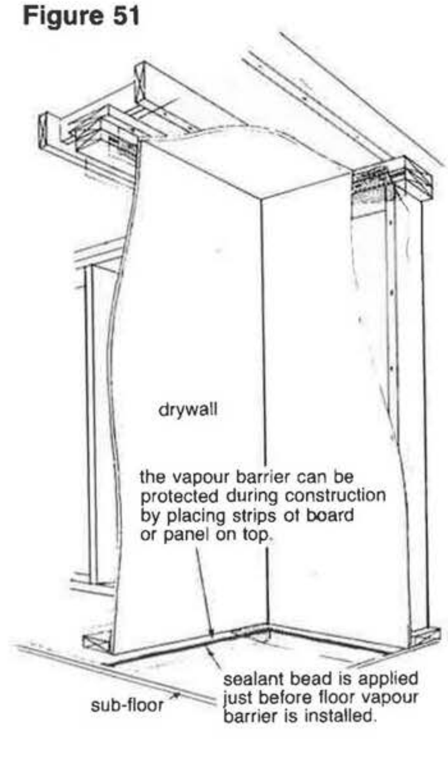


Figure 52

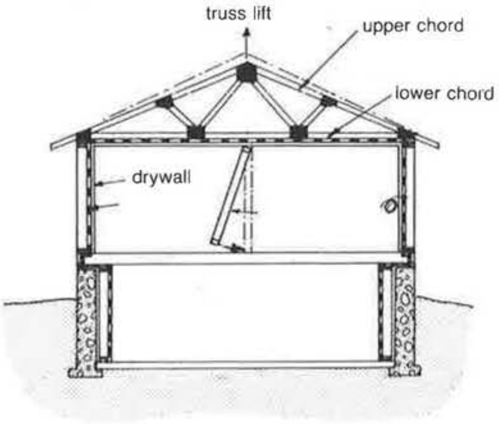
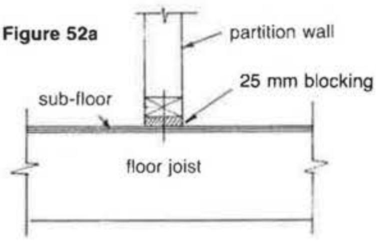


Figure 52a



10.6 The best way of dealing with partition walls

By now it should be clear that partition walls add considerably to the complexity of air-vapour barrier construction. This leads to an important point:

In a conventional house there are advantages to be gained by scheduling all the framing work in one operation, but in an air tight house these advantages can be more than offset by the problems of fitting the vapour barrier round the partition walls.

Builders of energy-efficient houses have shown some interest in a new type of construction, in which the vapour barrier is installed before the partition walls are put in place. This allows the vapour barrier to be installed around the building shell with a minimum number of joins and interruptions. The saving in vapour barrier installation costs probably outweighs the cost penalties of an interrupted framing schedule and electrical installation schedule.

The main features of this type of construction are shown schematically in figures 52 and 52a. The partition wall is built 25 mm short of its finished height, to allow it to be swung easily into place as shown. It is then fitted with 25 mm blocking under the bottom plate. When the wall is being maneuvered into position there is no problem in feeding existing cables into the partition wall.

The main issue raised by this type of construction is: should the partition walls be installed before or after drywalling the building shell. There is only a slight advantage in installing the partition walls first: it makes it easier to see where nails should be driven to hit the framing, but, at the same time, it leaves the vapour barrier exposed to wind effects over a long period.

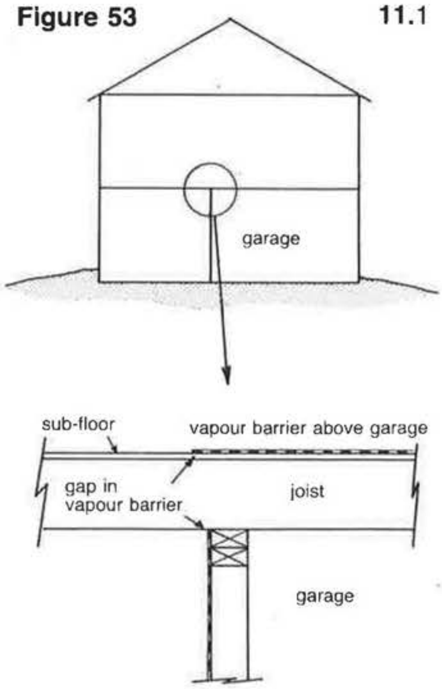
The other technique – installing the partition walls after drywalling the shell – gives better all-round protection of the vapour barrier. It protects it against wind loading and against possible damage when the partition walls are installed. It also gives better long-term protection against the effect of truss lift. Note that the ceiling trusses are able to support the ceiling drywall without the assistance of partition walls – the concerns of some builders on this point are groundless.

Truss lift can occur when there is a different moisture content in the upper and lower chords of a roof truss. In winter, the lower chord is warmer than the upper one, and has a lower moisture content. The upper chord therefore tends to expand, relative to the lower chord. This creates a lifting effect at the centre of the truss, and can lead to the formation of cracks in the drywall, where partition walls meet the ceiling. In an energy-efficient house, the extra insulation over the lower chord produces a greater temperature differential between the upper and lower chord. It is anticipated that this will produce an even greater lifting effect, though there has not yet been enough systematic study to confirm the effect. If the effect becomes a problem in energy-efficient houses, then truss designs may have to be changed to counteract it.

The type of construction shown in figure 52 – with the partition walls installed below the drywall – gives good protection against truss lift. It will not prevent the formation of cracks at the top of partition walls, but it will prevent a major impairment of the vapour barrier above the partition wall. For this reason, and the possible saving in construction costs, the authors therefore recommend this type of construction.

11.0 Dealing with problem corners

Figure 53



11.1 Attached garage

Figure 53 shows the problem of maintaining vapour barrier continuity around an attached garage. The joists create a break in the vapour barrier, and there is no easy or efficient way of overcoming the problem.

The recommended solution is shown in sectional view in figure 54, and in perspective in figure 54a. The gap in the vapour barrier is bridged with either wood blocking or rigid insulation with low permeability (such as Styrofoam SM). If wood blocking is used, the construction can be improved slightly by painting the warm side of the blocking with a vapour-barrier-type paint or by wrapping the blocking in polyethylene before installation. The sealing work is particularly important: the aim is to achieve an airtight seal between the free edges of the two vapour barriers.

Figure 54

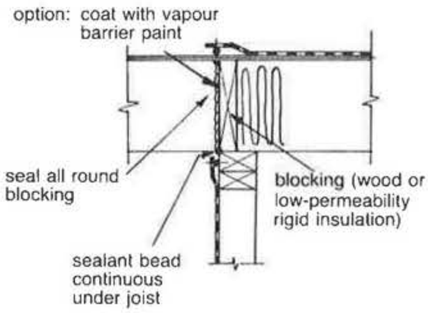


Figure 54a

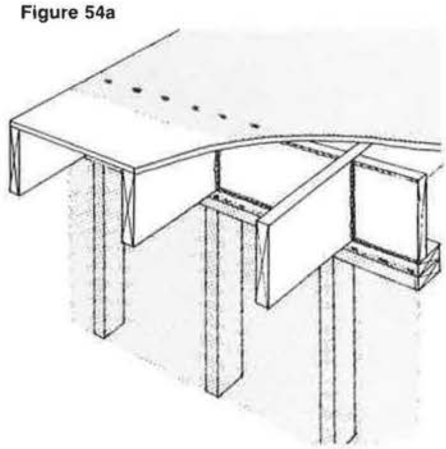
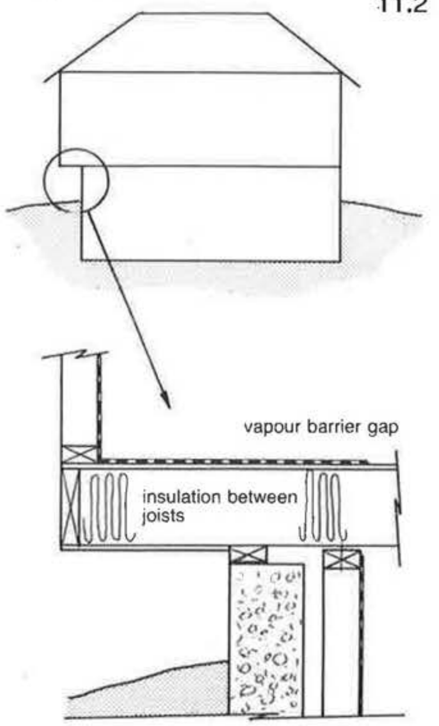


Figure 55



11.2 Overhangs

The problem area is shown in figure 55. The situation is similar to that of the attached garage (figure 53): the vapour barrier gap has to be bridged through the joists.

The procedure shown in figure 56 is **not an acceptable solution.** It places the vapour barrier outside the overhang insulation, and is certain to cause moisture problems inside the floor structure at this point.

The recommended solution is as shown in figure 57. The technical details are exactly the same as for the attached garage (figures 54 and 54a). Note that if rigid insulation is used for the blocking between joists, the building code requires it to have a protective covering.

Figure 56

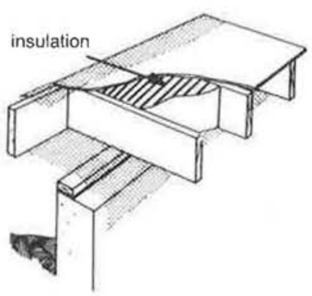
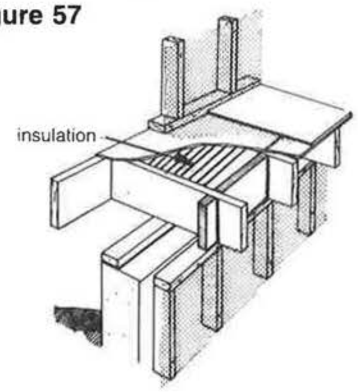
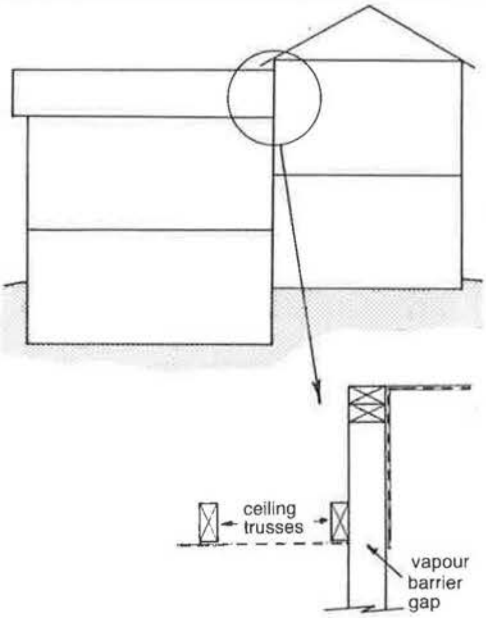


Figure 57



11.0 Dealing with problem corners

Figure 58



11.3 Split level ceilings

The problem is to bridge the vapour barrier gap through the stud wall, as shown in figure 58.

Figure 59 shows four acceptable solutions, though each has some advantages and disadvantages:

In figure 59a the gap is bridged with sealed wood blocking. The technique is laborious if it is to be effective.

Figure 59b shows a good solution that requires no extra framing work. However, this is not a good solution if this wall serves as a plumbing wall, since it adds to the complexity of sealing round pipes and stacks.

In figure 59c the vapour barrier routing has been simplified by breaking the stud wall into two pony walls. It is good from the point of view of vapour barrier continuity, but it is not good from a structural point of view (problems of shrinkage and alignment of the two wall sections).

Figure 59d is technically sound, and achieves good air tightness at low cost. There is no objection to routing the vapour barrier outside the stud, provided that there is twice as much insulation on the cold side as on the warm side. There are problems in stacking an adequate amount of insulation against this vertical wall. These can be overcome by using 100 mm of rigid insulation, which also helps to protect the vapour barrier.

The technique shown in figure 59d can also be applied when the roof trusses run at right angles to the stud wall, as shown in figure 60. The only difference is the inclusion of a nailing strip. The main purpose of this nailing strip is to provide a solid backing for joining the two pieces of vapour barrier, but it can also be used for attaching the bottom corner of the trusses.

Figure 59

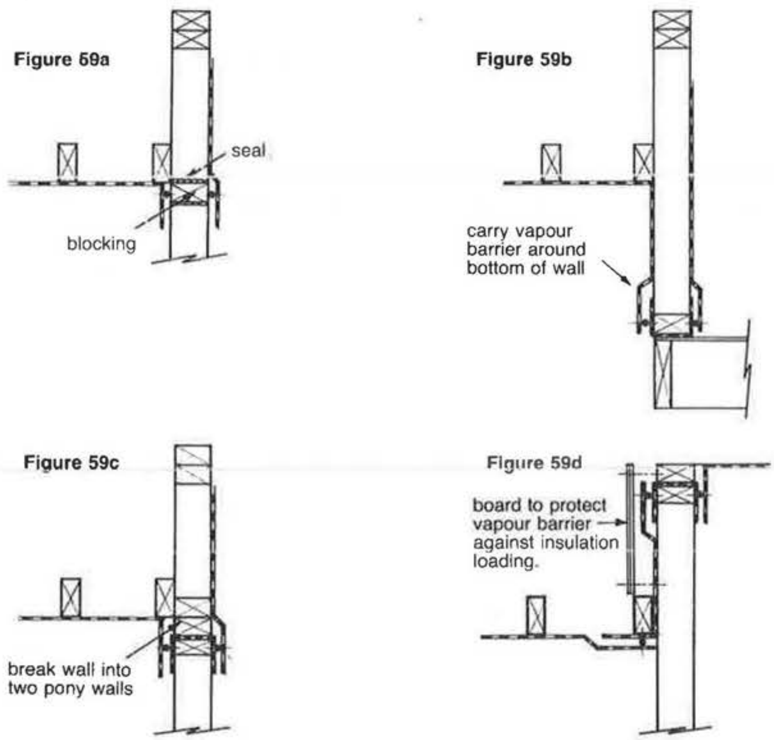
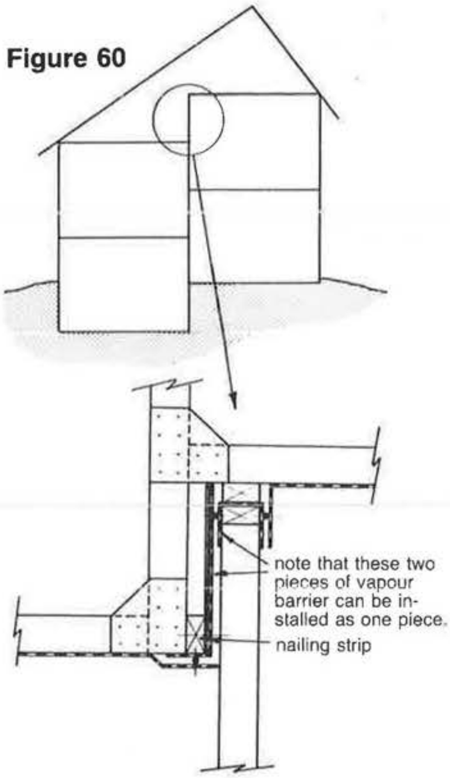


Figure 60



11.4 Split-level floor over an unheated crawl space

Figure 61 shows the problem area, and the recommended solution for a pressure-treated wood foundation. The problems of vapour barrier installation at this point are aggravated if the house is designed with a continuous vertical stud wall. In figure 61 the vapour barrier routing is simplified by allowing the floor structure to break into the stud wall.

A similar technique can be applied with a concrete foundation, as shown in figure 62. Note that the floor joists are cantilevered over the foundation wall to simplify the constructional details. The sill plate is moved to the inner edge of the foundation wall to give better support for the load-bearing wall above.

Figure 61

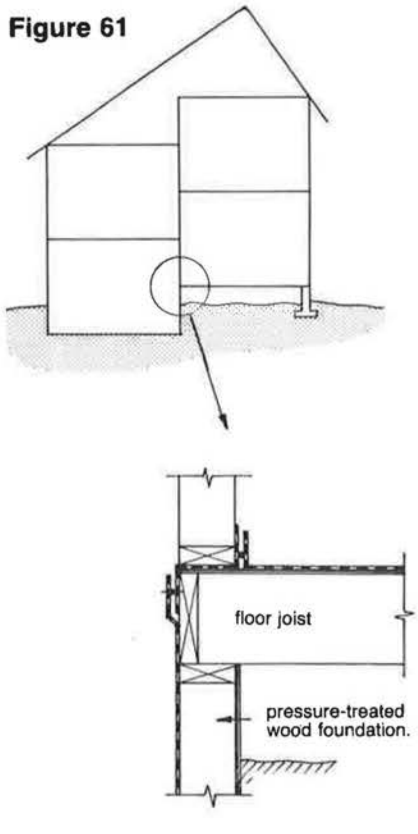
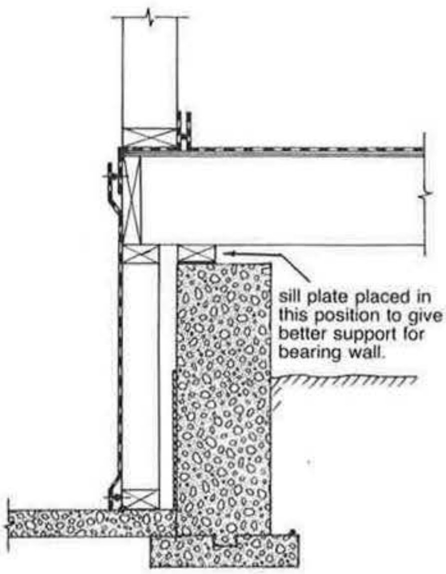


Figure 62



12.0 Doors and windows

12.1 The problem

Conventionally, the vapour barrier is terminated around doors and windows as shown in figure 63. A rough opening is cut in the vapour barrier, and the edges may be stapled to the surrounding wall frame, but there is usually no significant attempt to seal around the window. A large gap, often as wide as 12 mm, exists around most doors and windows installed in this way. This provides a major channel for air leakage, and the only barrier against this leakage is exterior and interior trim, neither of which is effective.

12.2 An easy solution

The obvious solution is to carry the vapour barrier to the edge of the window frame and seal it to the frame as shown in figure 64. This is a good technique, if properly done, but there is not much exposed frame to work on.

Figure 64

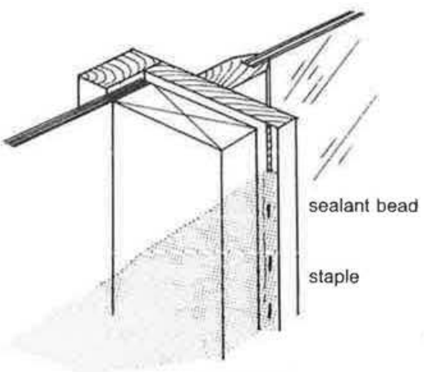
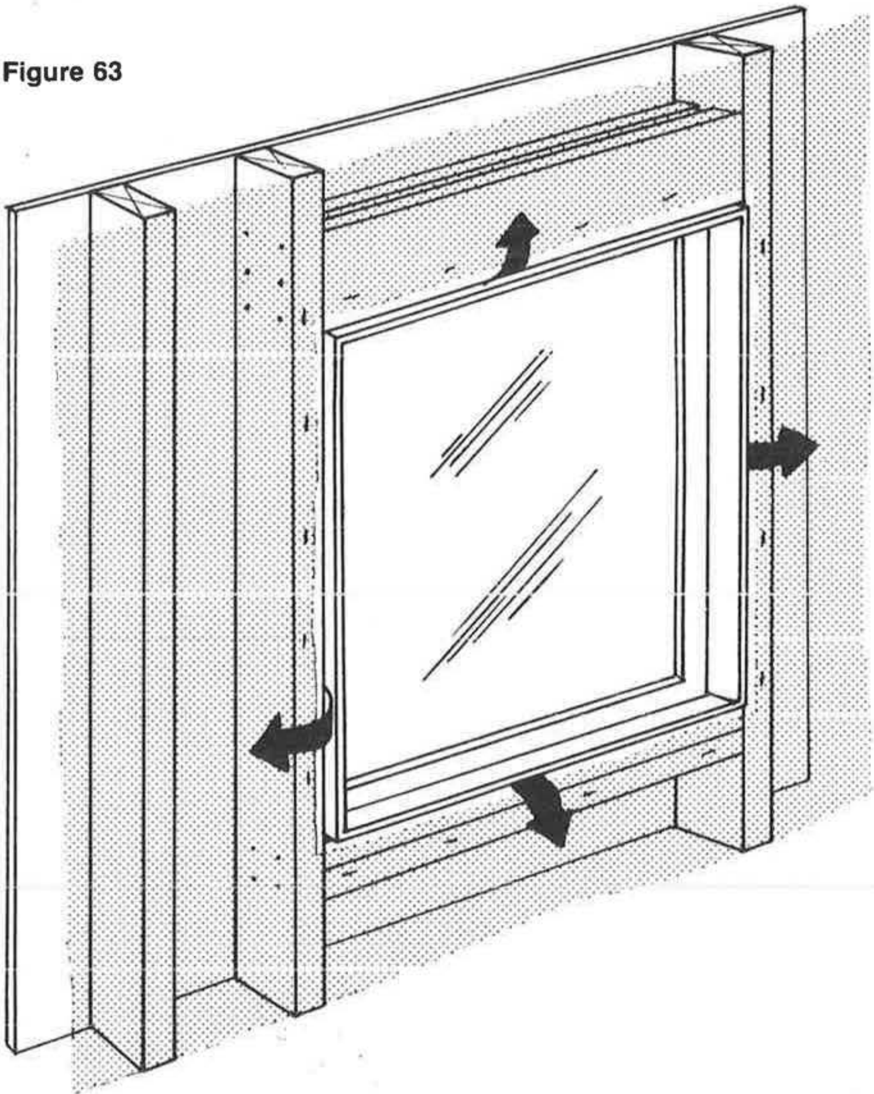
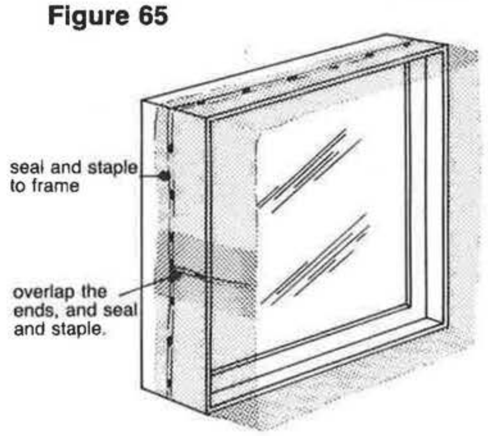


Figure 63



12.3 The best way

Figure 65



The procedure shown in figures 65 and 66 is generally more reliable. A strip of vapour barrier material is sealed and stapled around the window frame before insertion, as shown in figure 65. When the window has been positioned in the wall, the strip of vapour barrier is folded back against the face of the wall, and the main wall vapour barrier is joined to it as shown in figure 66.

The only problem with this method is that the window vapour barrier has to be cut at the corners before it can be folded back against the wall. The corner cuts then have to be repaired with vapour barrier patches, which can be time-consuming. An alternative is to fold a small amount of spare material into the vapour barrier at the window corners, as shown in figure 67. To avoid air leakage through the folds, they should be sealed as indicated in the figure. Generally, an extra 25 to 50 mm of material will be adequate at each corner.

Figure 66

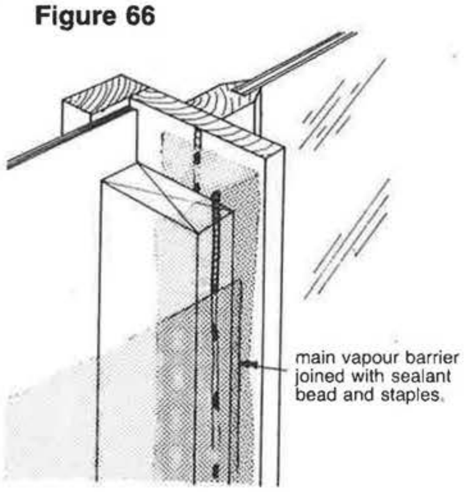


Figure 67

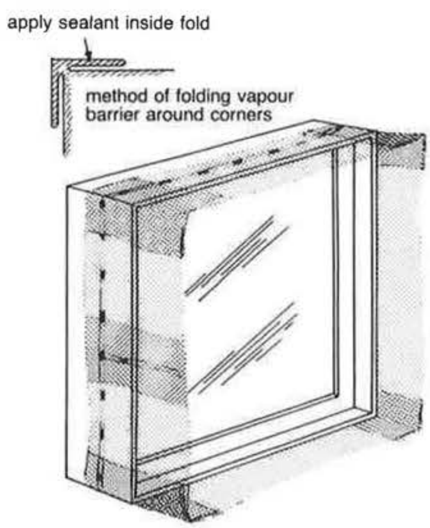


Figure 68

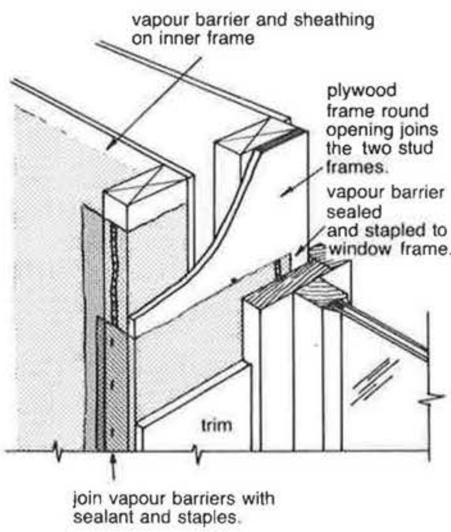


Figure 70

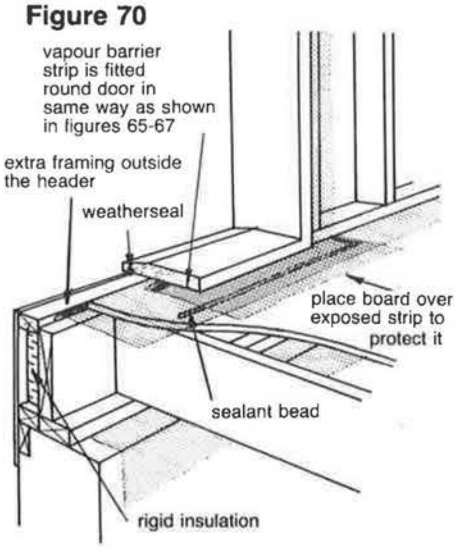


Figure 68 shows a window installation in a double frame wall. This wall design will be discussed in more detail at a later stage of the guide. Note that the wall vapour barrier and sheathing are attached to the outside of the inner frame, and that the vapour barrier is folded around the edge of the frame.

The treatment of doors is the same as that of windows, except that the door sill rests on the floor, and the vapour barrier at this point must be joined to the vapour barrier that passes around the joist header, as shown in figure 70. Note that the insulation outside the header is interrupted by extra framing under the door sill.

Figure 69 shows a bay window installation, and demonstrates a number of interesting features that have already been discussed. The detail at the top of the foundation wall is of particular interest. It is the same situation as shown in the overhang of figures 55 to 57, but this opportunity has been taken to show a slightly different approach. In this instance, the air tightness is achieved by sealing blocking between the joists, and by sealing this blocking to an extra sill plate. This is a useful technique when the basement is to be left undeveloped (for reasons that will be discussed later), and it can be adapted to a finished basement design by joining the vapour barrier as shown.

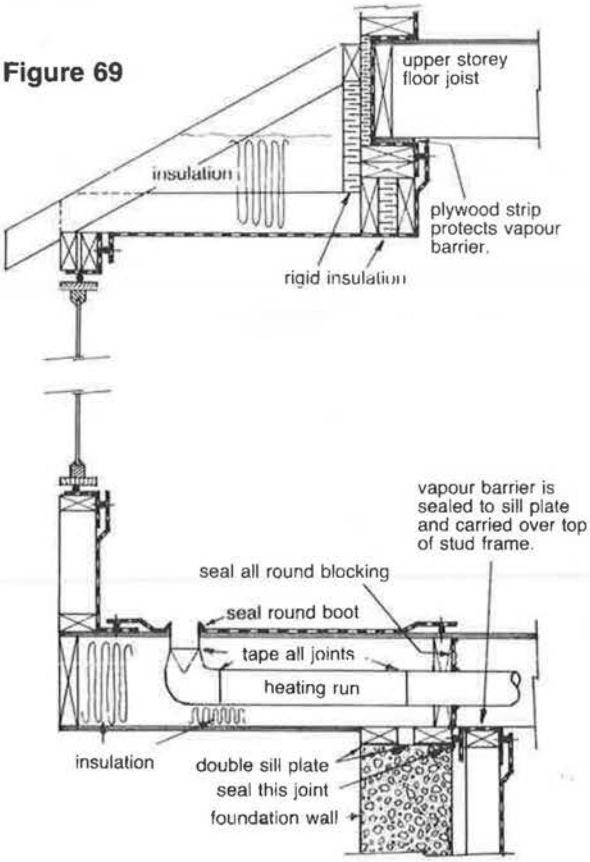
12.4 A note on air leakage through doors and windows

When care has been taken to seal door frames and window frames to the vapour barrier, it is inconsistent to use doors and windows that have a leaky construction. Doors and windows should have the same high standards of air tightness as the air-vapour barrier. When selecting doors and windows, as much thought should be given to their air tightness as to their general thermal performance.

When an exterior door is equipped with a storm door, or when a window is equipped with a storm window, the inner unit should always be made more air tight than the outer unit. Otherwise, moisture will be able to enter the space between the two units, but will find it more difficult to pass through the outer unit. The resulting build-up of frost or condensation could cause structural deterioration.

Some air leakage should be built into storm doors anyway, to disperse the pressure build-up when the main door is closed.

Figure 69



13.0 Electrical receptacles

Figure 71

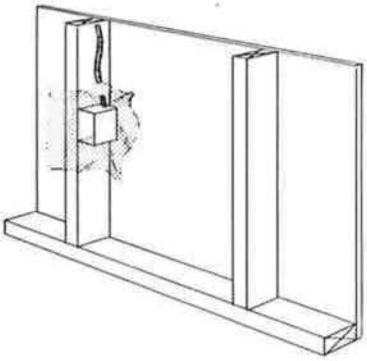


Figure 72

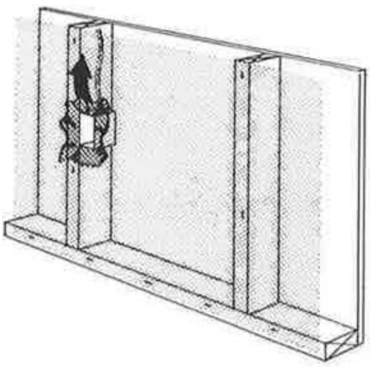
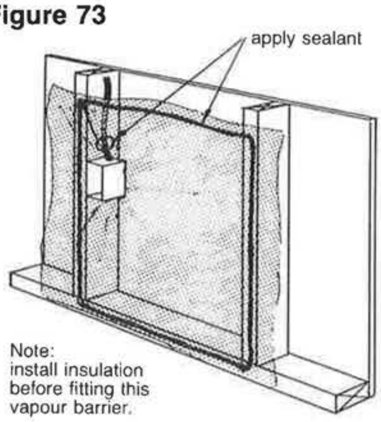


Figure 73



Figures 71 and 72 show the conventional way of fitting the vapour barrier around an electrical receptacle. A small piece of 0.05 mm polyethylene is wrapped around the receptacle at the time of installation, and is punctured to accept the cables. Later, the edges of this piece of vapour barrier are pulled through a hole in the main vapour barrier, as shown in figure 72. There is rarely any attempt to seal the two pieces of vapour barrier together, or to seal around the cable entries. As a result, there can be a large air leakage through the receptacle, and the extra vapour barrier work has not done much to improve the situation.

Note that these details apply only in exterior walls, where the receptacle interrupts the vapour barrier.

13.1 A good method

The air tightness at this point can be improved by using a larger piece of vapour barrier (0.15 mm) – large enough to allow attachment to the neighbouring studs and the bottom plate, as shown in figure 73. Sealant is applied around the cable entry and around the edge of the vapour barrier. This approach has two faults: first, there is no solid backing for the seal around the cable; secondly, since there is also no solid backing across the top of this piece of vapour barrier, a good seal to the wall vapour barrier cannot be guaranteed — particularly with the numerous folds that occur at this edge. The seal around the cable where it enters the vapour barrier can be made firmer by stapling the polyethylene to the blocking and caulking.

The method can be improved by adding blocking as shown in figure 74. Then, when the wall vapour barrier is installed, it is pressed lightly against the sealant bead and stapled along the line of the bead. This method gives a good air tight seal, and would be acceptable in an air-vapour barrier construction. There is a slight risk of air leakage around the unsecured sealing at the cable entries, but not enough to detract from the advantages of this low-cost, simple method.

If this method is adopted, it is important to provide plenty of spare material in the piece of vapour barrier, so that it can be folded loosely around the back of the receptacle. If it is pulled too tightly against the receptacle it may be damaged by the sharp screws protruding through the back.

Figure 74

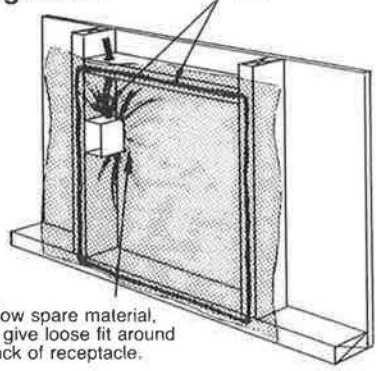
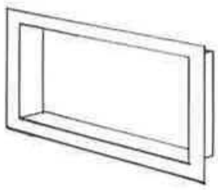


Figure 75



13.2 Variations on the method

A number of commercial products, designed to simplify vapour barrier work around receptacles, are now being marketed. One such is the 'Polypan' shown in figure 75. This is a shallow, rectangular pan molded in polyethylene.

13.0 Electrical receptacles

Figure 76

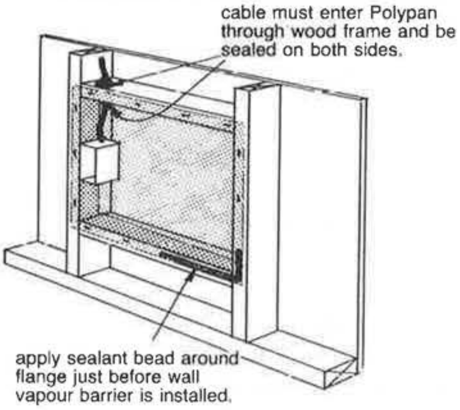
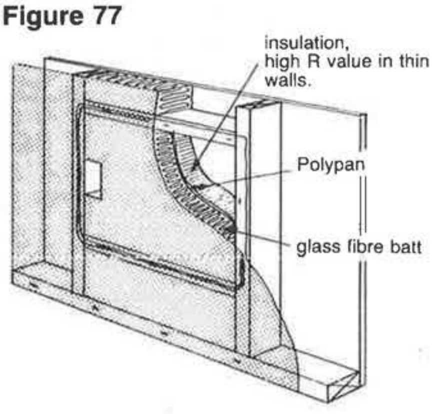


Figure 77



It is installed against the studs and blocking as shown in figure 76, and is insulated as shown in figure 77. Note that, to avoid the dewpoint problem discussed earlier, the insulation behind the Polypan should have at least twice as much thermal resistance as that in front. In a 38 × 89 mm stud wall this can create a minor problem: because of the depth of the Polypan there is not much room for a high thermal resistance per inch. Foam board insulation offers the best solution. In thicker walls there is generally enough space behind the Polypan to warrant the use of batt insulation.

Figures 78 and 79 show the construction of a home-made Polypan as developed by one of the builders on the Energy Showcase project. This builder has noted that the full house quota of these units can be made at the workbench in about two hours. The polyethylene should be carefully folded or tailored to avoid too many leakage folds at corners. A plywood backing on the rear of this assembly will give some protection against damage from careless drywall saw work.

13.3 Avoiding damage during drywalling

The vapour barrier around the receptacle is exposed to possible damage during drywalling. Often, when the plasterboard is being fitted around the receptacle, the opening is cut with the plasterboard held loosely against the stud frame. If the knife or saw blade penetrates too far, the vapour barrier work can be damaged locally. The practical solution is to move the receptacle away from critical vapour barrier points. The technique is shown in figure 80, where a Polypan installation is used for an example. Note that blocking is used to move the receptacle away from the critical vapour barrier point around the flange of the Polypan.

A better solution is to make sure that drywallers are aware of this problem, and that they modify their practices accordingly.

Figure 78

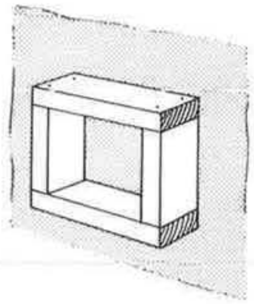


Figure 79

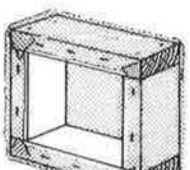
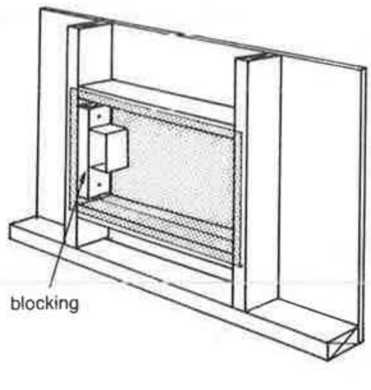


Figure 80



13.4 Ceiling receptacles

The techniques shown in figures 74 to 79 can also be applied to ceiling receptacles, as shown in figure 81. The detail is self-explanatory.

With the latest designs of flush-fitting receptacles the installation is relatively simple. The main problem is to provide a recess for the cable clamp, and to provide a good seal at this point. The solution shown in figure 82 is not ideal but it is tolerable. A more thorough design would destroy the cost advantages of this type of receptacle installation.

13.5 A note of caution

Energy-efficient houses have not been around for too long, and the long-term effects of some of the construction techniques can only be guessed at. In ceiling receptacles, the conventional method of installation, with a low level of ceiling insulation, has helped to disperse local heating from lighting. With higher levels of insulation the ceiling receptacle will run hotter, and may cause some deterioration or embrittlement of the vapour barrier and sealant over a period of twenty years or more. Therefore, this guide recommends that only suspended lighting systems, or low wattage systems such as fluorescent lighting, be used in ceilings. This recommendation applies particularly to the flush-fitting design shown in figure 82.

Figure 81

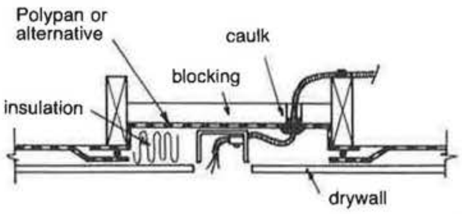
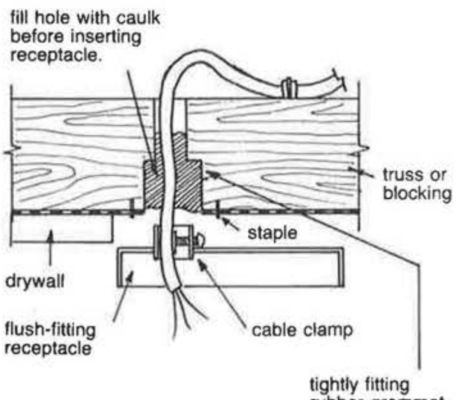


Figure 82



14.0 Vents, pipes and flues

Figure 83

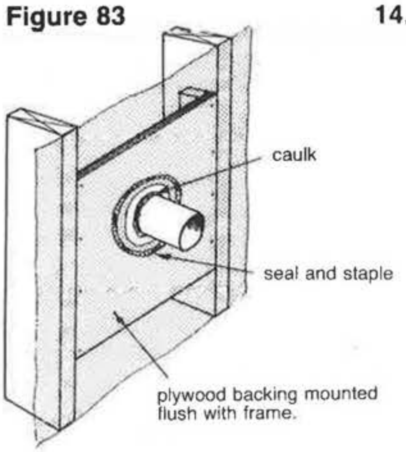
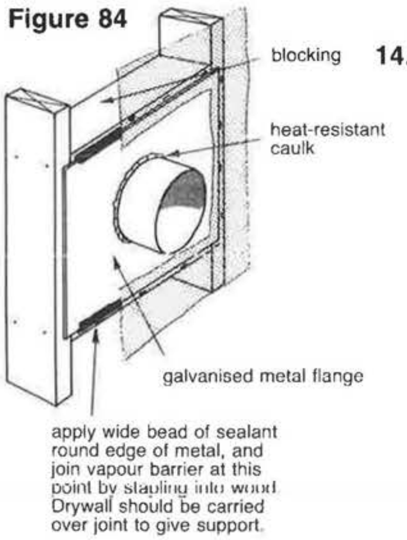


Figure 84



14.1 The general technique

Figures 83 and 84 show the general techniques for sealing the vapour barrier around pipes, vents and chimneys.

The method in figure 83 is applied wherever there is no risk of overheating. This includes gas pipes, electrical service inlets, fan vents, ventilation pipes, water pipes (hot and cold), combustion air supplies, vent stacks, dryer vents and waste pipes. Figure 83 shows how to install a solid backing around the pipe (when one is not otherwise available) and how to join the vapour barrier to the pipe.

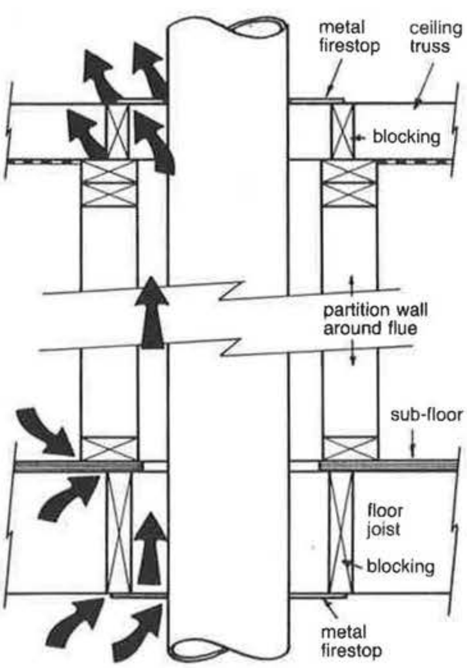
The method in figure 84 is applied whenever there **is** a risk of overheating. This includes fireplace chimneys, stove chimneys and furnace flues. In such cases, **a certain amount of clearance should be maintained between the hot pipe and any surrounding combustible materials.** The required clearance varies according to the chimney design and application, and is usually covered by the appropriate construction code. **Note that standard plasterboard and polyethylene sheet are to be regarded as combustible materials.** The heat resistant caulk between the chimney and the flange is one of the few instances where a special caulking material is required.

14.2 A note on heat-resistant caulking

Most chimneys exhibit a severe cycle of expansion and contraction because of the wide temperature variations to which they are exposed. As a result, any caulked joints around the chimney will be subjected to the enormous forces of expansion and contraction. An air tight sliding joint around the chimney would be ideal, but this cannot be achieved without resorting to elaborate and costly methods. When making a caulked joint around a chimney the aim, therefore, is not to make an air tight seal, but to minimize the size of the air leakage gap around the chimney.

The caulking material should be selected primarily for its anti-combustion properties. Most latex-based caulks are suitable. Some builders have used muffler cement, which is acceptable and probably more resistant to long-term deterioration than the latex caulks.

Figure 85



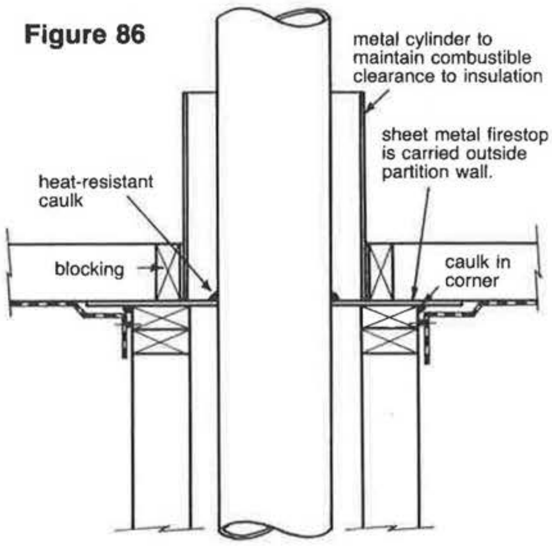
14.3 Furnace flue

Figure 85 shows a typical way of installing a furnace flue, and shows the various air leakage paths that arise from this construction. The worst part of this construction is usually to be found at the upper metal firestop, which is often so small that it does not cover the rectangular opening around the flue. In a severe case, the air gap at this point may be as much as 50 mm wide.

Figure 86 shows the recommended way of achieving an air tight construction around the flue at the upper ceiling level. The main advantage of this technique is that, by extending the firestop beyond the partition wall, the vapour barrier joint can be made in an easily accessible location. It is difficult, and very time-consuming, to try to make air tight joints inside the flue enclosure.

The metal cylinder serves as an insulation stop, to maintain the required combustion clearance between the flue and the insulation. It is recommended that this be adopted as standard practice. The cylinder does not need to be fixed; the best technique is to centre it around the flue with the help of the blocking.

Figure 86



14.0 Vents, pipes and flues

14.4 Vent stack

Figure 87 shows a technique that has been widely used on energy-efficient houses. Usually, when the vent stack is installed in the plumbing wall, there is a large air leakage gap where the stack passes through the top plate of the wall. This figure shows one way of sealing this gap. The expansion joint is a necessary feature of this type of construction; its purpose being to prevent damage to the caulking from stack expansion. More elaborate systems have been tried, in which the upper stack is prevented from moving by a metal bracket, attached to the top plate. Generally, this type of construction gives an effective air tight seal, but it is unnecessarily complicated and costly.

Sometimes the old ways are best. In figure 88 the gap around the stack is sealed with compressed oakum. This achieves a tolerable level of air tightness and provides a sliding seal. To ensure the effectiveness of this method, the hole through the top plates should be circular, with a diameter about 12 to 25 mm greater than that of the stack. This guide recommends this technique.

Figures 89 and 90 show two variations of the technique, to be used when the partition walls are installed after the building shell has been vapour barriered. Figure 89 applies when the partition wall is installed *before* the ceiling is drywalled. Figure 90 applies when the partition wall is installed **after** the ceiling is drywalled.

Note that, in figure 90, a continuous circle of sealant can be applied between the top plate and the plasterboard. In order to do this, the vent stack location has to be selected and the hole drilled through the top plate before the partition wall is installed. Sometimes, this may not be possible. Under such circumstances, and because of the marginal effect of this sealing, the procedure can be omitted.

Figure 87

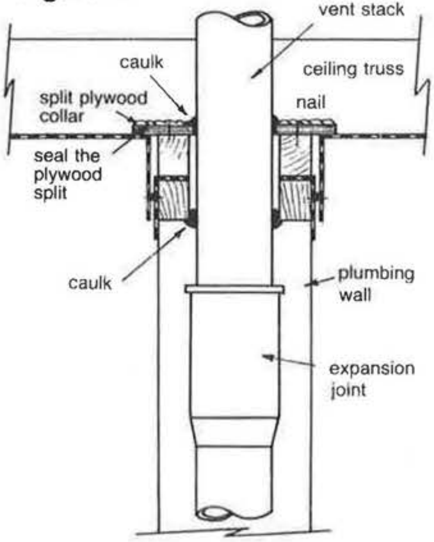


Figure 88

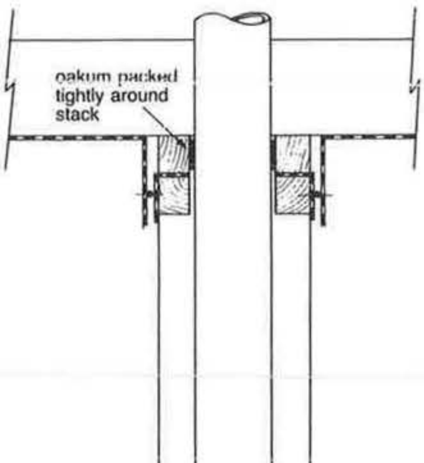


Figure 89

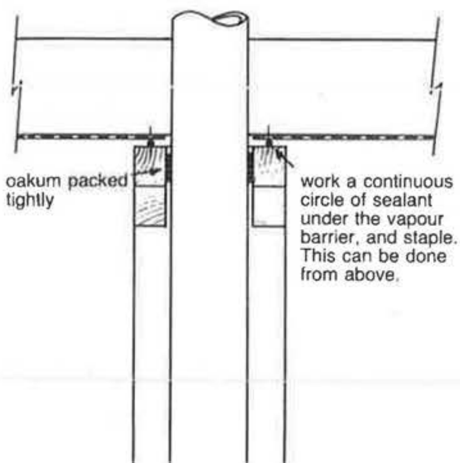
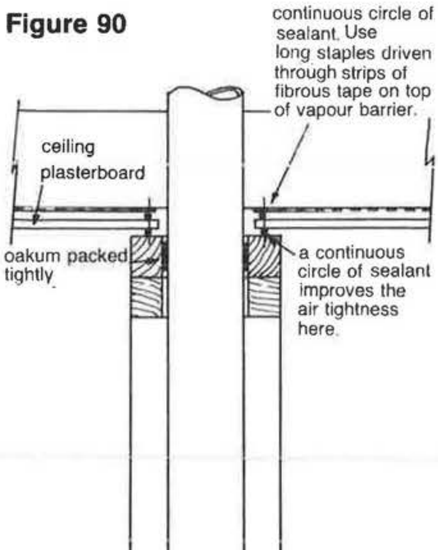


Figure 90



14.5 Plumbing into an unheated crawl space

Figure 91 shows a way of sealing around a vent stack where it passes into an unheated crawl space. The expansion joint protects the caulking against stack movement, and the neoprene flashing maintains a flexible air tight joint. The method gives a good reliable seal, but is relatively complicated and costly.

Once again, the oakum technique is a recommended low-cost option with a tolerable level of air tightness. Figures 92 and 93 show the technique applied to a vent stack and a water pipe.

Figure 91

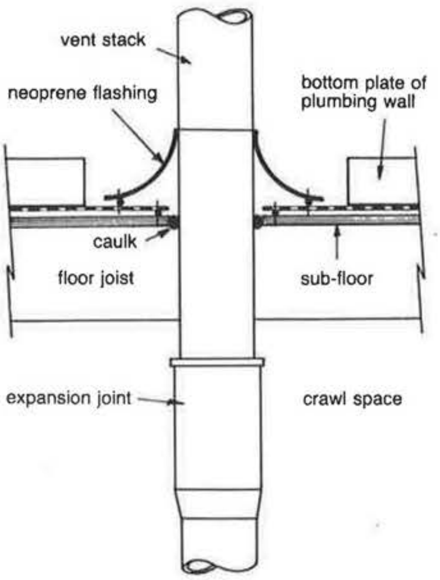


Figure 92

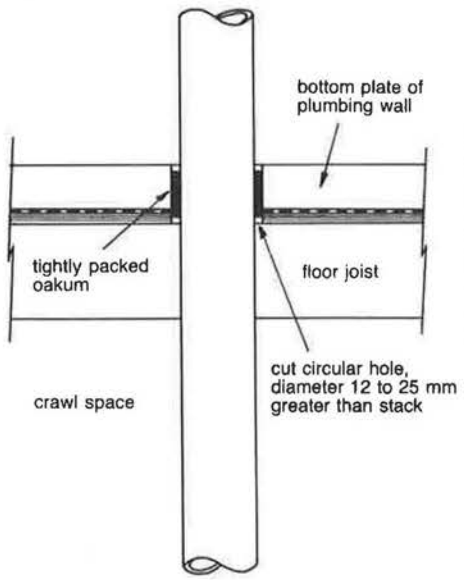
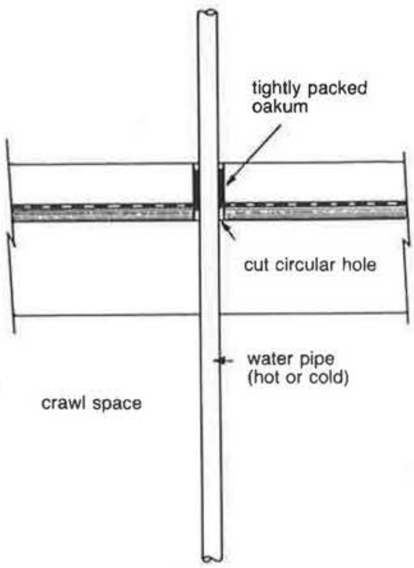


Figure 93

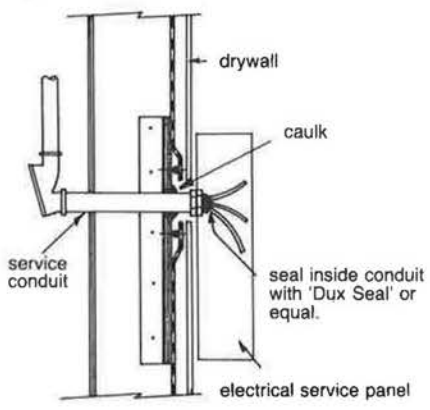


14.6 Electrical service panels

A typical service inlet is shown in figure 94. Air leakage can occur both around the conduit and through the conduit. The exterior of the conduit is sealed to the vapour barrier using the plywood backing technique shown earlier in figure 83. The interior of the conduit should be sealed with 'Dux Seal' or an equal product, approved for this type of application.

Note that if the electrical service panel is installed in an unfinished basement, some provision must be made to allow the vapour barrier to be sealed around this panel when the basement is developed at a later stage. It is recommended that a section of stud frame be installed, and the panel mounted as shown in figure 94.

Figure 94



14.0 Vents, pipes and flues

The service inlet shown in figure 95 used to be fairly common some years ago, but is now going out of practice. It has been included here to make a point about the selection of the sealing position. The seals, both inside and outside the conduit, should be made as close to the vapour barrier as possible. On the outside of the conduit it is not always possible to caulk at the vapour barrier, in which case the caulk must be applied at the nearest accessible point as shown. When there is a long conduit run inside the house, it is better to seal inside the conduit at the exterior wall, using the entrance ell for access.

Figure 95

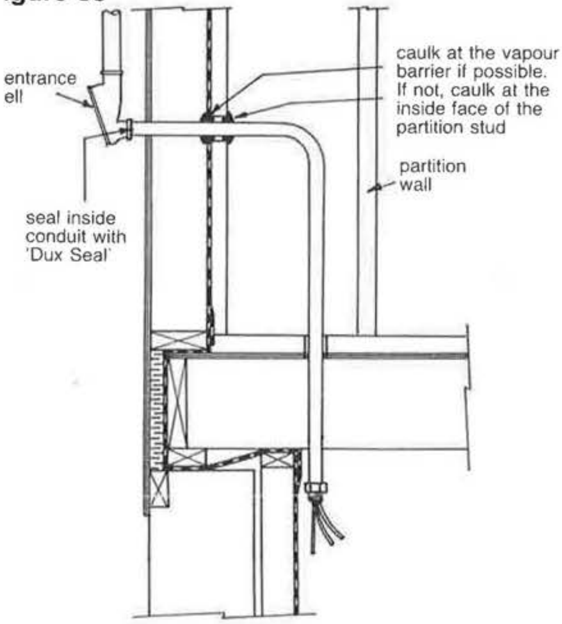


Figure 96

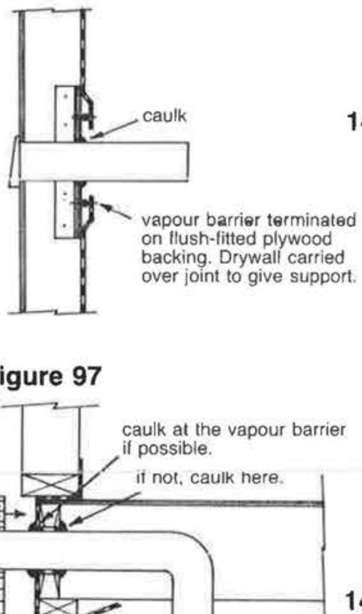


Figure 97

14.7 Air vents

Figure 96 shows an air vent through an insulated stud frame wall. It follows the general procedure detailed in figure 83. This type of construction can be applied to dryer vents, heat exchanger vents, combustion air supplies and other air vents.

Sometimes, it may be necessary to take the air vent through a floor joist header as shown in figure 97. In this situation it is better to apply caulk where the pipe passes through the vapour barrier — before installing the exterior header insulation. If this cannot be done, the caulk can be applied on the inside face of the header. The air tightness of the seal is not quite as good here, but it is still tolerably good.

In houses that have no central air management system (such as is required with a heat exchanger) it is preferable to vent bathroom fans and kitchen fans down through the sub-floor and out through the joist header. This inhibits the inflow of cold air, and makes it easier, at a later date, to fit a heat exchanger to the system — if desired.

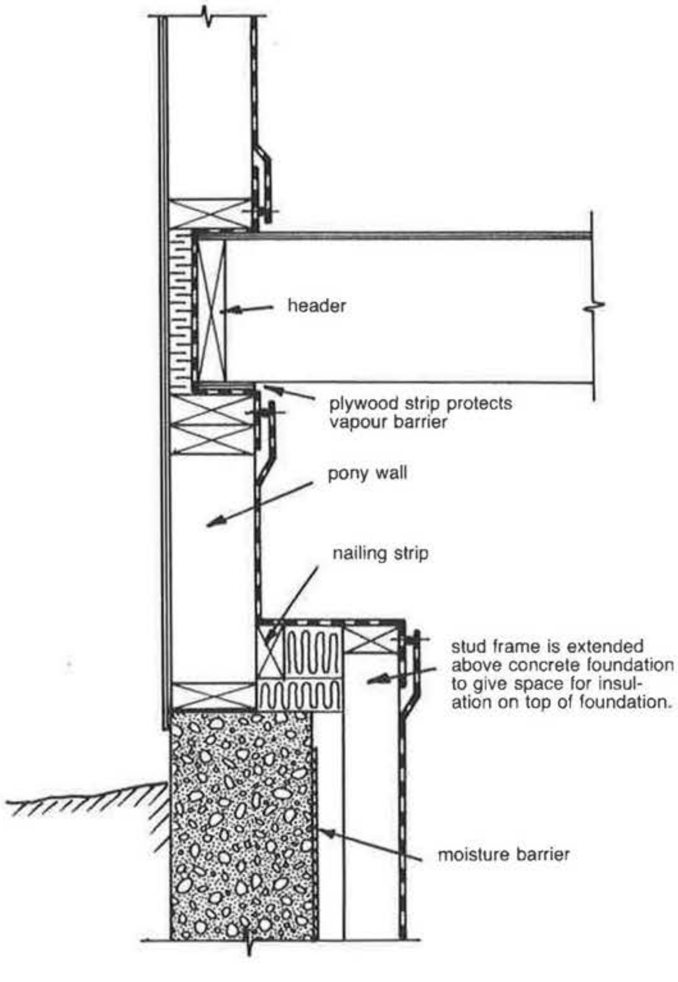
14.8 An important note

If a house is provided with a natural gas service, the gas codes require a specified clearance between any gas connection and any vent opening – no matter whether the vent is for exhaust or inlet flow. This should be taken into account when selecting the position of vent openings.

15.0 Pony walls

Figure 98 shows a pony wall construction on top of a concrete foundation wall. The header detail is the same as that shown in figure 26 for a second storey floor. Note how the basement stud frame is extended to give space for insulation at the top of the foundation.

Figure 98



16.0 Stairwells

Figure 99

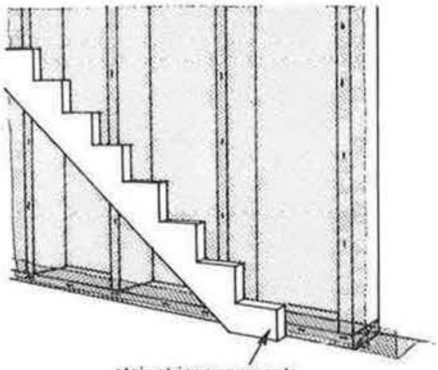


Figure 99 shows a stair stringer against an exterior stud-frame wall. In this position, the stringer can prevent the proper sealing and joining of vapour barriers, either at the foot or the head of the stair. In this situation the stair should not be firmly fixed in place until the vapour barrier work and the drywalling are complete.

Where a stair landing breaks into an exterior wall, as shown in figure 100, the vapour barrier detail and the construction detail are similar to those around a main floor header.

Figure 101 shows a stairwell against a concrete foundation wall. This is a common housing feature. In an energy-efficient house, the foundation should be lined with a stud-frame and insulated. The stud frame is extended above the foundation wall (as in a poly wall) to give space for insulation on top of the foundation.

It is important to design the stairwell with enough width to accommodate both the stair and the extra stud wall structure. If the partition wall in the stairwell is not correctly positioned, it may prevent the construction of a well-sealed insulated wall at a later stage. **It is recommended that, in this situation, a clearance of at least 150 mm should be provided between the foundation wall and the stringer – as a matter of general practice.**

Figure 100

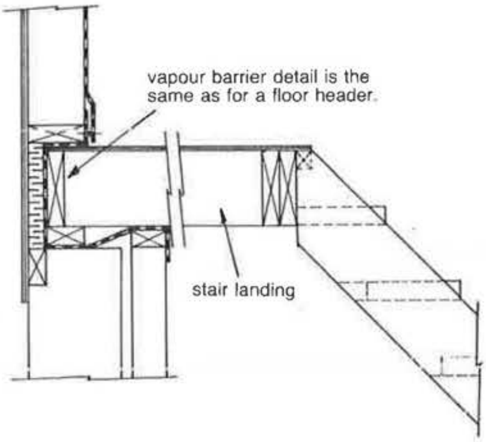
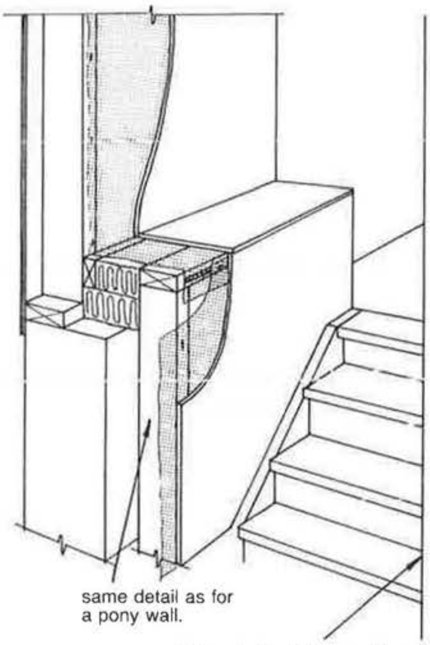


Figure 101



17.0 Bath tubs and fittings

Figure 102

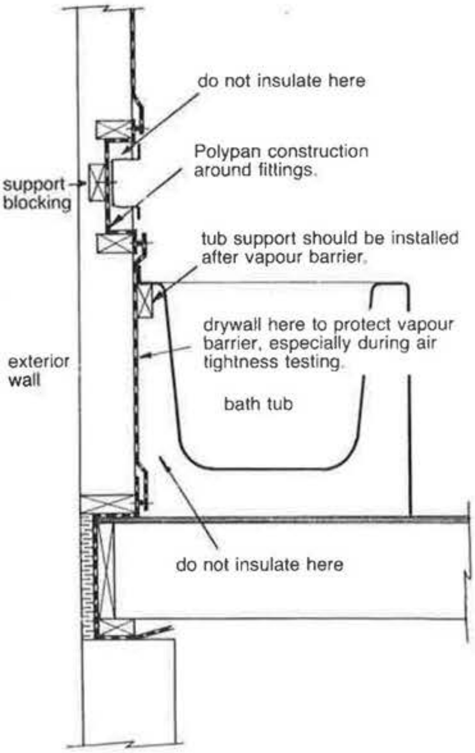


Figure 102 shows the main features of a bath tub installation against an exterior wall. Note that the tub support should be installed after the vapour barrier is in position. Fittings such as soap dishes should be installed on partition walls if convenient. If not, they should be installed inside a Polypan construction as shown.

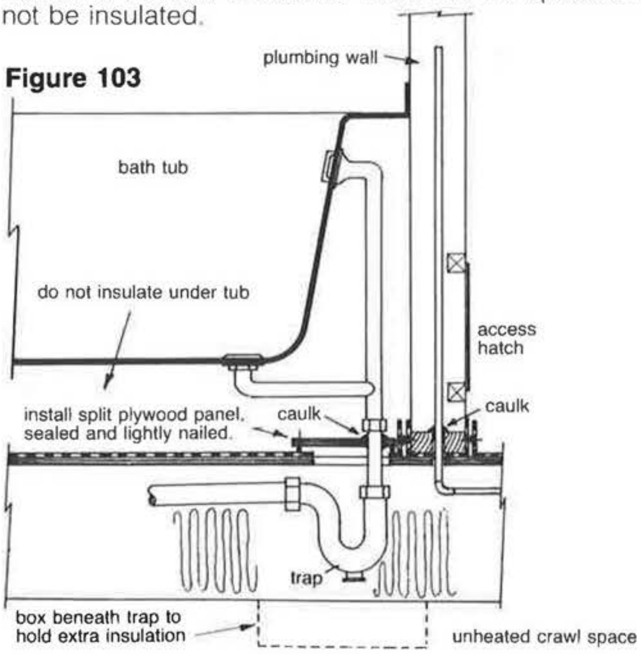
The support blocking for the fitting has the effect of reducing the insulation level outside the Polypan. Because of this, and because of the high humidity levels that occur in bathrooms, there is a risk of moisture build-up inside the Polypan. To minimize this risk, insulation should not be installed inside the Polypan. This will have the effect of moving the dewpoint position outside the Polypan. The reduced level of insulation will produce a cold spot around the fitting, but this is preferable to the long term drywall damage that might otherwise occur.

Some energy conservation enthusiasts have suggested that the space beneath the tub should be insulated. **This must not be done** when the tub is against an outside wall, since it may bring the dewpoint location inside the vapour barrier. However, it is a useful practice if the tub is located away from any vapour barrier.

It is customary to cut a large opening beneath bath tubs to allow installation and repair of the drain system. When the tub is installed over an unheated crawl space this creates a major source of air leakage under the tub. The best solution is to install the tub on a raised floor. The main sub-floor, under this raised floor, can then be fitted with vapour barrier and insulation in the usual way. The only leakage point will be around the drain pipe where it passes through the vapour barrier. This should be sealed in the usual way.

Figure 103 shows what is needed when the tub is mounted directly over the crawl space. A split plywood panel is installed around the trap system as shown, and is sealed and lightly nailed in place. The best sealant to use in this case is one with low adhesion, so that the panel can be removed easily for repair. A latex-based sealant is best. If possible, the floor beneath the tub should be covered with overlay before the tub is installed. This protects the vapour barrier from the sharp edges at the bottom of the tub. Note once more that the space beneath the tub should not be insulated.

Figure 103



18.0 Attic hatch

The attic hatch is a source of air leakage, and, if possible, should be installed outside the house rather than in the ceiling. If a ceiling installation cannot be avoided, the hatch should be provided with a good level of insulation and an air tight seal.
Details of the construction are shown in figures 104 and 104a, and are fairly self-explanatory. Note particularly how the ceiling vapour barrier is terminated at the hatch.

Figure 104

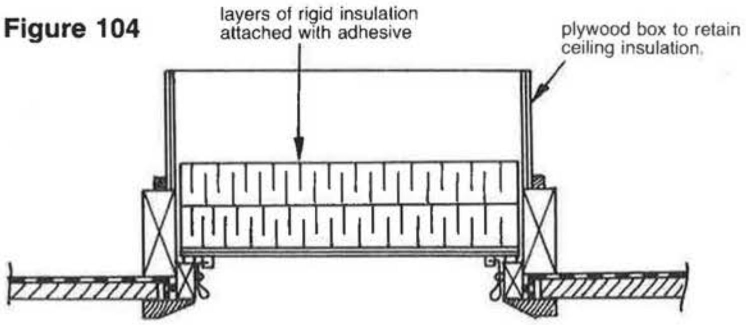
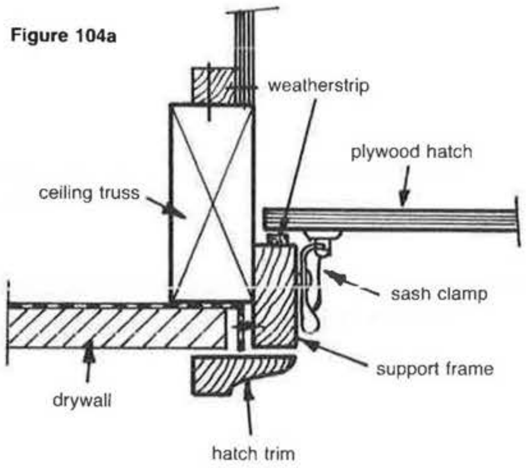
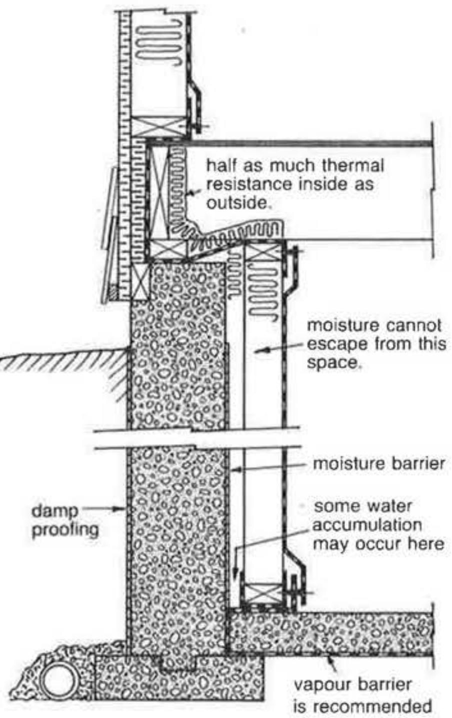


Figure 104a



19.0 Problems with concrete basements

Figure 105



19.1 The concrete curing problem

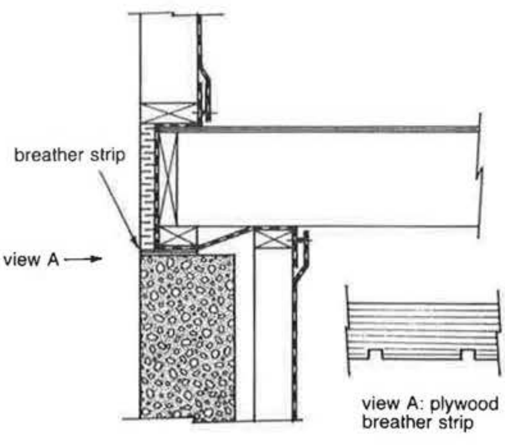
Figure 105 shows all the features of a properly finished concrete basement, with an insulated interior. The vapour barrier makes a virtually air tight enclosure over the interior face of the concrete. Therefore, any moisture generated by the concrete will find it difficult to escape. The only escape route (if the vapour barrier is properly installed) is under the vapour barrier where it passes under the joist sill plate, where the irregularities in the concrete surface may create some openings. Under ideal conditions, with the concrete in a dry state, the moisture may be able to escape through these openings as quickly as it is generated by the concrete, and there will probably be no moisture build-up behind the basement vapour barrier.

However, if the concrete is still uncured (or green) it will have a high water content and may give off moisture faster than can be handled by the small openings under the sill plate. Under these circumstances three undesirable conditions could be set up: firstly, the air space between the concrete and the vapour barrier will probably become saturated. Secondly, any moisture given off by the concrete will tend to accumulate as water at the floor level, as shown. Thirdly, the high water vapour content in the air space will impede the curing of the concrete, though this will probably not affect the concrete strength.

If an uncured basement is finished as shown in figure 105, a highly moist condition will persist for a long time (perhaps several months) in the space between the concrete foundation and the vapour barrier. Under these conditions some deterioration of the stud frame could take place. There are three solutions: First, and technically the best, is to insulate the foundation wall on the exterior, as discussed on the following page. Secondly, the basement can be left unfinished until the curing process is complete. Thirdly, a moisture-breathing strip can be installed on top of the foundation wall as shown in figure 105a. The suggested design is a plywood strip that is saw-grooved at intervals of about 25 mm, as shown – though there are obviously other ways of doing this job.

Given a choice between insulating the basement from the outside or inside, many professional builders will prefer the inside approach, since the finished basement adds more to the value of the house. In such cases the construction shown in figure 105a (or a similar type of construction) should be adopted. However, builders should give serious consideration to the many technical advantages of an exterior insulation approach.

Figure 105a



19.0 Problems with concrete basements

Figure 106

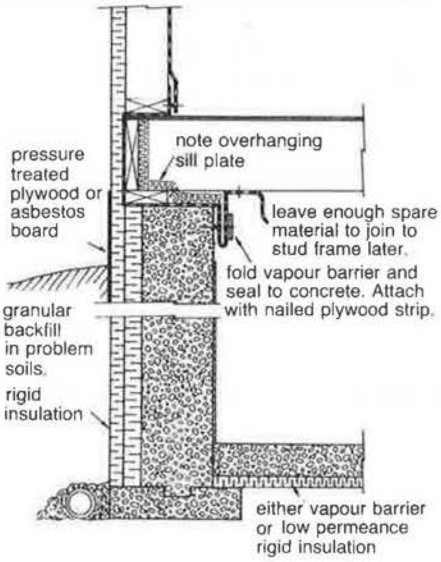
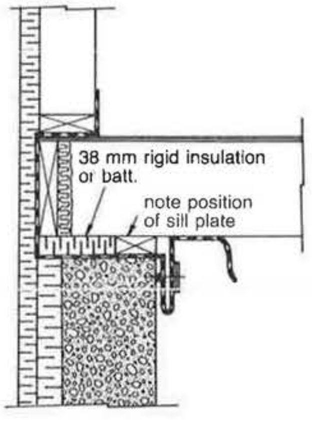


Figure 106a



There are three major advantages in insulating the foundation wall on the outside:

a) It avoids the moisture problems discussed on the previous page.
b) The concrete, by being inside the insulation, is no longer exposed to severe temperature swings, and is therefore less likely to sustain damage.
c) By bringing the concrete inside the warm envelope of the house, the large mass of the concrete acts as a thermal storage. This tends to smooth out the temperature swings that occur from day to night, and makes it possible to employ a slightly higher level of passive solar gain (through south-facing windows).

Figure 106 shows a basement that is insulated on the outside with two layers of rigid insulation. Note that, in this situation, the vapour barrier has to be terminated in such a way that the air tightness of the house is maintained. The procedure shown in figure 106 has two features: it creates a permanent air tight seal around the top of the foundation wall, and it allows the continuity of vapour barrier to be maintained when the basement is developed at a later stage. This procedure should be used whenever the basement is left undeveloped.

There are many ways of dealing with the constructional design around the joist header. Figure 106a shows another option that allows a smaller sill plate to be used.

19.2 Ice flexing

Most soils react in some degree to the annual freeze-thaw climatic cycle. In soils that have a high water retention, the winter transition from water to ice *may* cause expansion of the soil-water mixture which, in turn, can give rise to high lateral pressures on foundation walls. These pressures can be high enough to crack the foundation wall.

When the foundation wall is insulated, either on the outside or the inside, the soil around the house is deprived of the normal heating effect of the house. As a result, it will be exposed to greater temperature swings. This will aggravate the problems described above. The problem of soil behaviour around a house is a complex one, with many variable factors and few general rules. Until such time as there is a definitive building guide on this topic, the authors recommend the following practice: **where the local soil has a known tendency to damage basements, the foundation should be backfilled with gravel or granular fill in the same way as is now required on pressure treated wood foundations.**

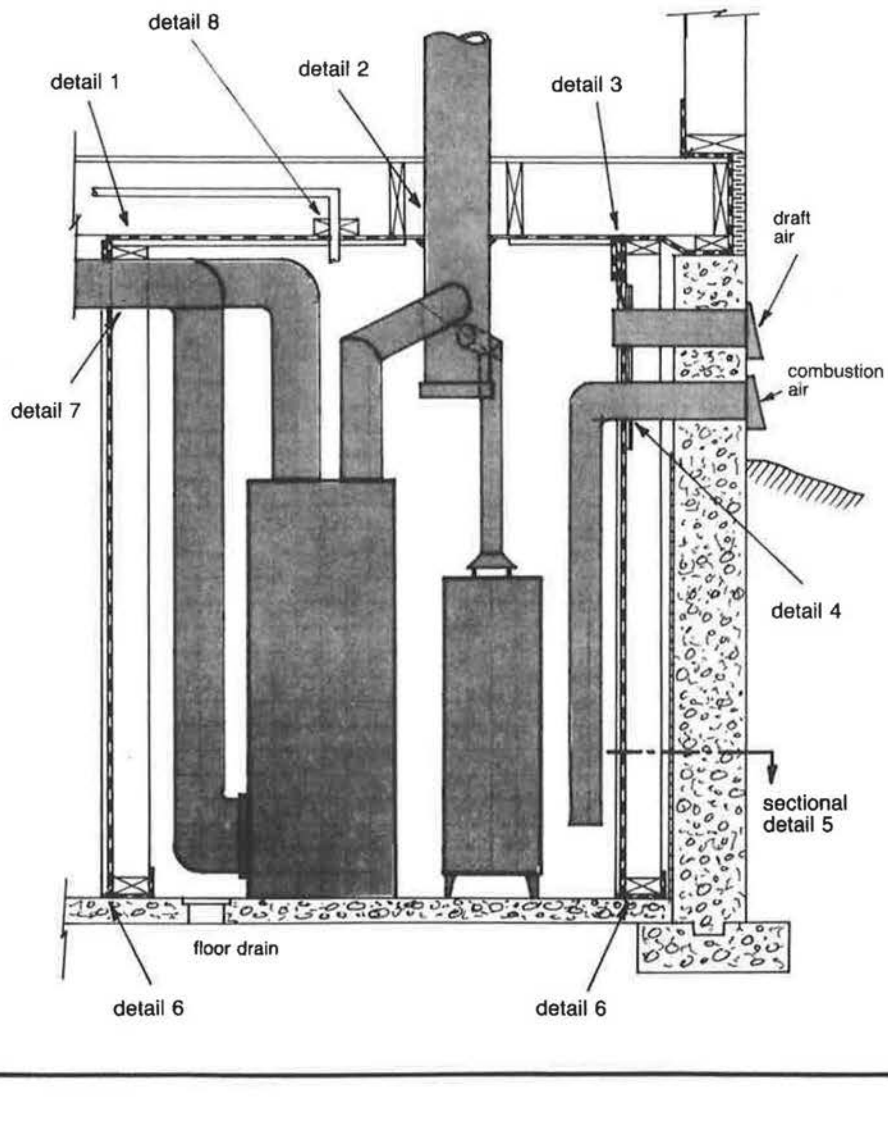
20.0 The furnace room

Publishers' Note

The furnace room concept was developed as a method to isolate the furnace and its demand for combustion air from the rest of the house. As furnace rooms are still experimental and may not be the most appropriate or cost-effective solution to providing combustion air, consult your utility and furnace research organizations before construction. It is important to avoid a situation where moisture or ice might accumulate in the flue pipe due to too low temperatures in the flue pipe and furnace room. Factors affecting these temperatures are proper sizing of the furnace and air inlets, insulation levels in the furnace room and its size.

The main purpose of the furnace room is to make the furnace and water heater independent of the house air. This calls for an air tight construction around the furnace room, which produces several other benefits, as discussed earlier. Figure 107 shows the main constructional features of an air tight furnace room. The details are shown in larger scale on the following pages.

Figure 107

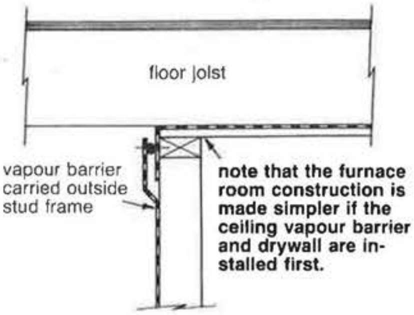


20.0 The furnace room

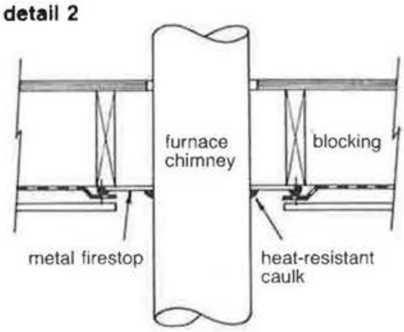
Figure 107 shows all the equipment that should be put in the furnace room. There is no advantage in putting the electrical service panel or the heater exchanger in this room, since they create a number of unnecessary cable runs and pipe openings that have to be sealed. However, it is recommended that the floor drain be installed in the furnace room if possible. The drain is a major source of infiltration, of both air and radon gas, and there are obvious advantages in isolating the drain from the rest of the house. Note that if this is done, the furnace room door should have no sill plate. This creates a small problem in achieving the air tight seal that is needed around the door, but it facilitates the draining process if there is a minor flood in the basement. The alternative is to provide a second drain, with trap, outside the furnace room.

Figure 107

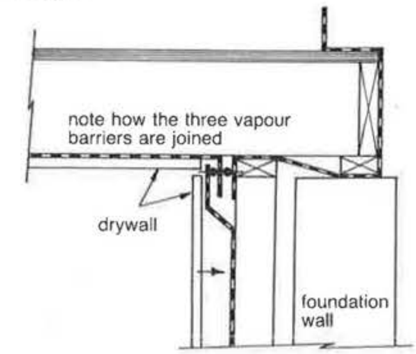
detail 1



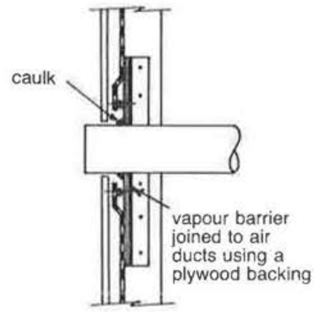
detail 2



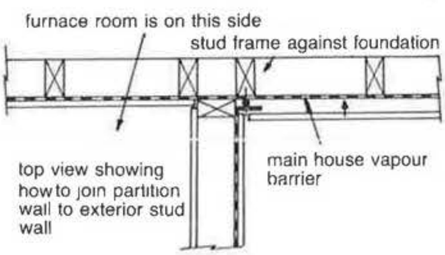
detail 3



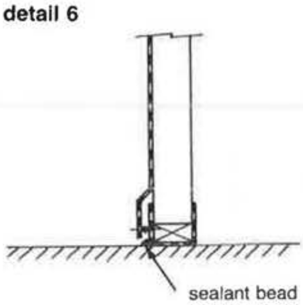
detail 4



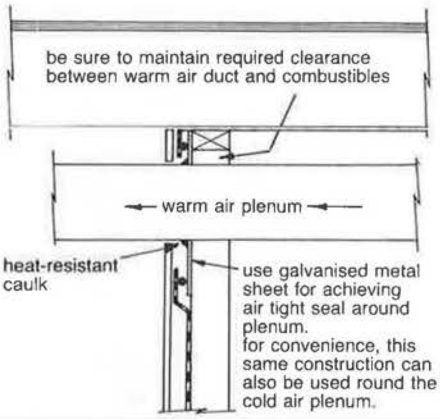
detail 5



detail 6



detail 7



detail 8

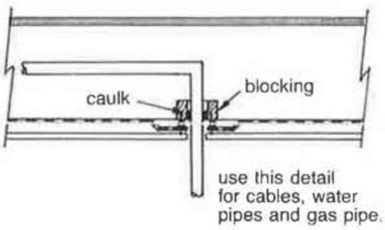
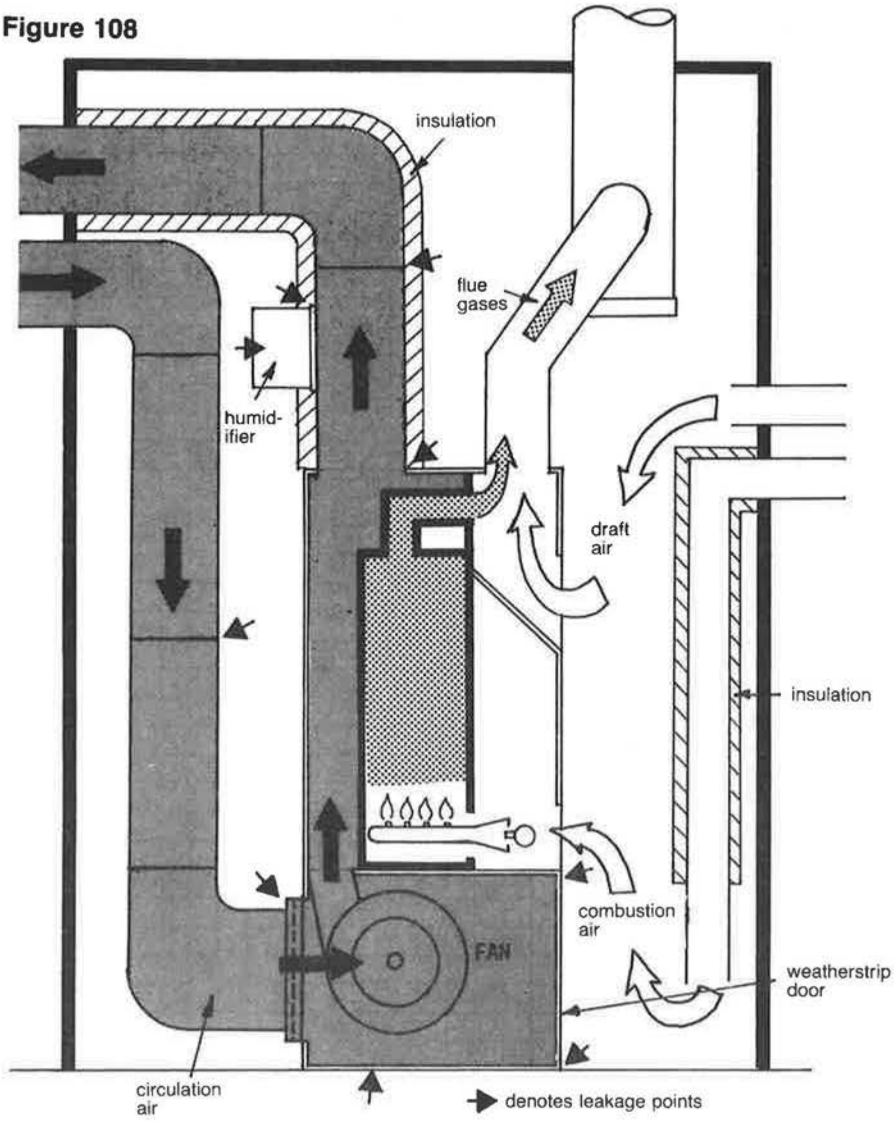


Figure 108 shows the various flow processes that occur in and around the furnace. Note that the two air inlets, for draft air and combustion air, are as prescribed by the code on gas appliances.

The path of the circulation air through the furnace has been emphasized in figure 108, and the relation of this to the rest of the house is shown in figure 109. It is important to note that the circulation air path, inside the furnace room, is really a part of the main house air envelope. This means that the circulation air path has to be sealed from the draft and combustion processes in the furnace room – in exactly the same way as the rest of the house is sealed from these processes by the furnace room itself.

The various leakage points in the circulation air path are shown in figure 108. Each of these should be sealed efficiently. Plenum joints, and gaps around the humidifier and filter, should be sealed with good quality duct tape. On the warm air plenum use cloth-backed duct tape rated for hot duct applications.

Figure 108



20.0 The furnace room

In a number of furnace designs the cavity around the fan is provided with a poorly sealed door. The door should be sealed with weatherstripping where practicable.

When the house has an unheated crawl space, any duct which runs through this crawl space should be treated as part of the warm envelope of the house. The duct runs should be sealed and insulated as shown in figure 109a. This applies to both warm air and return air runs.

Figure 109

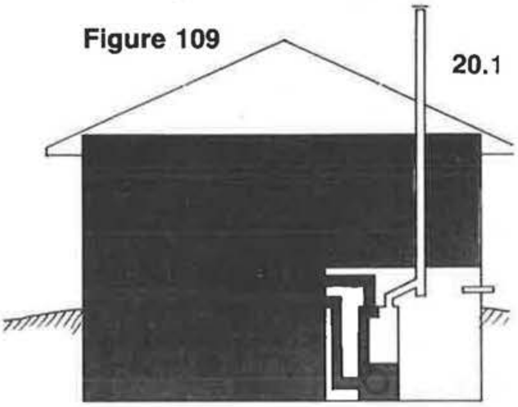
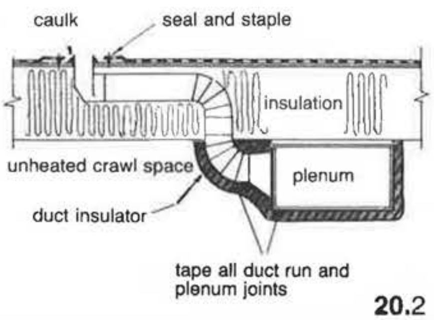


Figure 109a



20.1 Insulation

Furnace rooms, with the construction shown in figure 107, have not been in use for too long. Much needs to be known about the air demand in these rooms, and the temperature at which they operate. It is now known that air tight furnace rooms will operate with room temperatures somewhere between 5 and 25 degrees Celsius. The cooling effect of the incoming cold air is partly counterbalanced by the heat given off from the furnace body and warm air plenum. Therefore, it may not be strictly necessary to insulate the furnace room, though there are some marginal advantages in doing this.

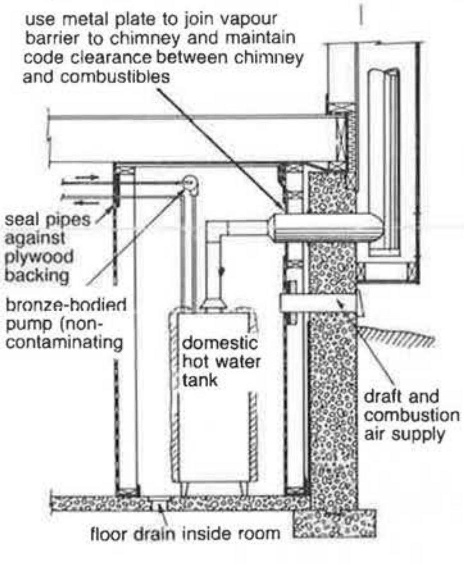
The heat that is dissipated from the furnace and the warm air plenum is lost heat, since it eventually finds its way up the chimney. This heat loss can be reduced by insulating the warm air plenum. **The furnace body should not be insulated.**

Figure 110 shows the construction of an air tight room around an innovative heating system. This system is incorporated in one of the Energy Showcase homes in Saskatoon. The house is heated by water from the domestic hot water tank – the justification being that the house does not have enough heating demand to warrant the use of a furnace. When the house requires space heating, the thermostat activates the pump, which circulates hot water through a coil mounted in the air circulation system of the house (not shown). Note that, since the pump is part of the potable hot water circuit, it has to be of non-contaminating design. Note also the construction where the chimney passes through the wall.

20.2 Air tightness testing

The procedures to be used during air testing depend on what the test is designed to achieve. If the air test is designed to measure the air tightness of the vapour barrier envelope, then the air circulation channel in the furnace room should be isolated, so that it does not contribute its leakage effects during the test. In this situation it is best to conduct the air test before the plenums are installed. A temporary seal can then be placed over the plenum openings (at the point shown in detail 7 of figure 107). Also, in this situation, make sure that the furnace room door is properly sealed prior to the test. On the other hand, if the air test is designed to measure the air tightness of the whole house structure, the air plenums and furnace should be installed before the test, and the air circulation channel should be sealed around the furnace as described earlier. Here again, make sure the furnace room door is properly sealed before the test.

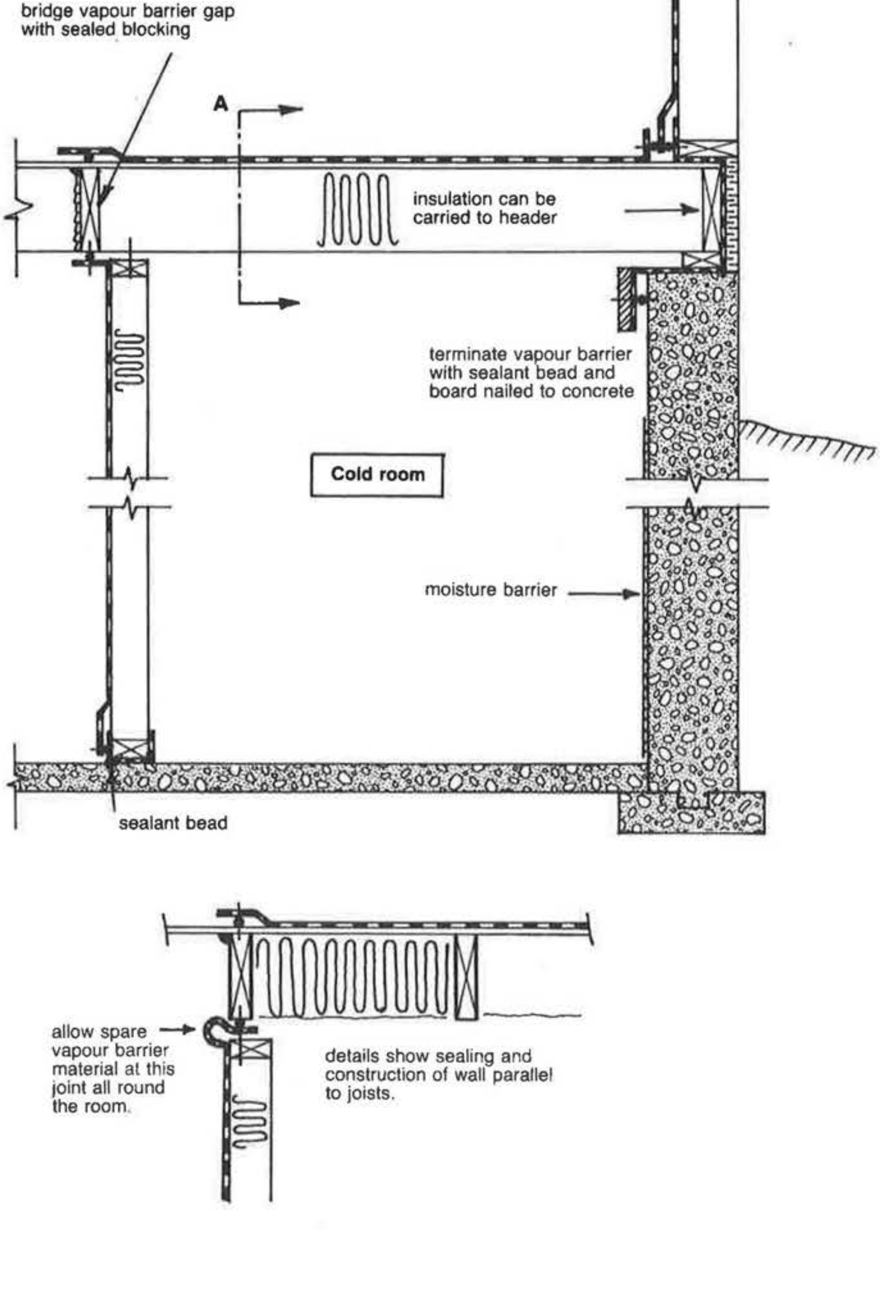
Figure 110



21.0 Cold room

Figure 111 shows a cold room construction, with self-explanatory details.

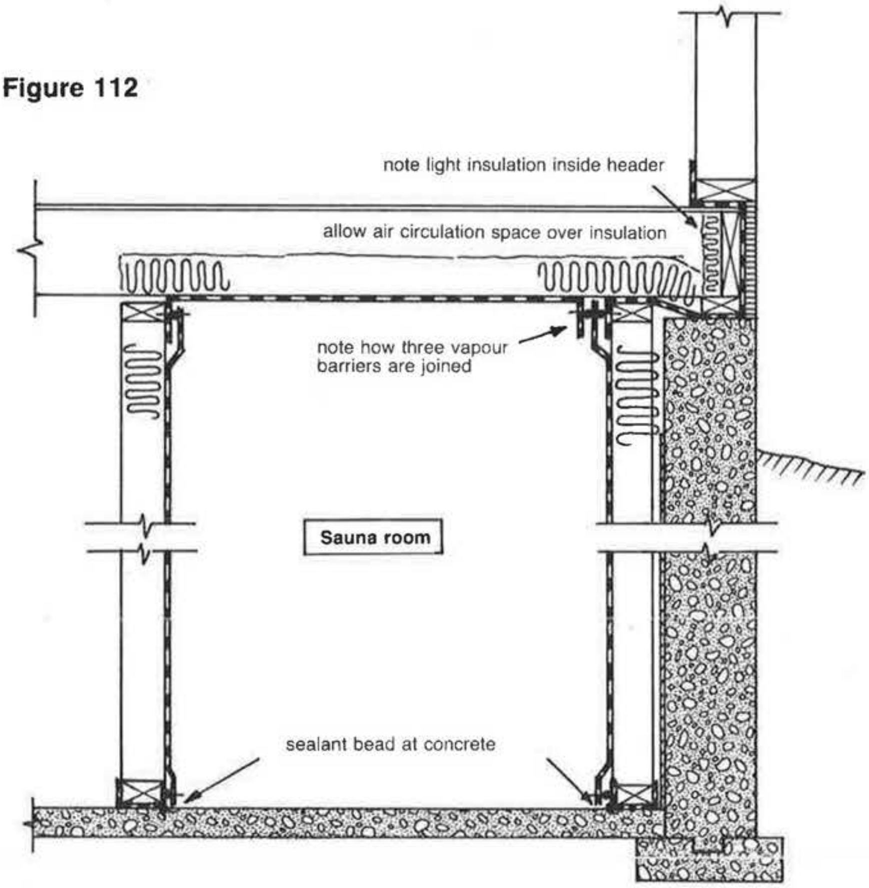
Figure 111



22.0 Sauna room

Figure 112 shows a sauna room construction. The vapour barrier around the sauna room should be of the approved metal foil type. It is joined to the polyethylene vapour barrier in the usual way. Care should be taken at the header to avoid a dewpoint situation (see previous comments on this constructional feature).

Figure 112



23.0 Fireplaces

Figure 113 shows the variety of techniques that need to be employed when installing a fireplace. The selected example is a zero-clearance fireplace with combustion air supply and convection heating system. It is mounted outside the main exterior wall of the house, on canti-levered joists. This type of installation is now becoming fairly common, and is an excellent example of most of the problems encountered in fireplace installation.

The details are fairly self-explanatory, since most of them have already been covered at various points in this guide. The feature of greatest interest is the sub-frame construction over the fireplace. Note that the exterior house wall has been terminated well above the fireplace. The purpose of this is to avoid penetration of the vapour barrier by the convection outlets. Before the sub-frame is installed, the house vapour barrier should be continued round the fireplace recess, using the recommended joining techniques around the chimney and at the floor joists. The recess should be finished with drywall and underlay before the fireplace is installed. Note that the chimney space above the firestop can be insulated – but only if the correct clearance is maintained around the flue.

The combustion air inlet is shown schematically. Most fireplaces of this type have a fairly complicated air ducting system with a built-in damper. Because of problems of accessibility, it may not always be possible to make a perfect seal around the inlet pipe, as shown earlier in figure 96. At the very least, an attempt should be made to caulk around the inlet at the drywall.

Figure 113

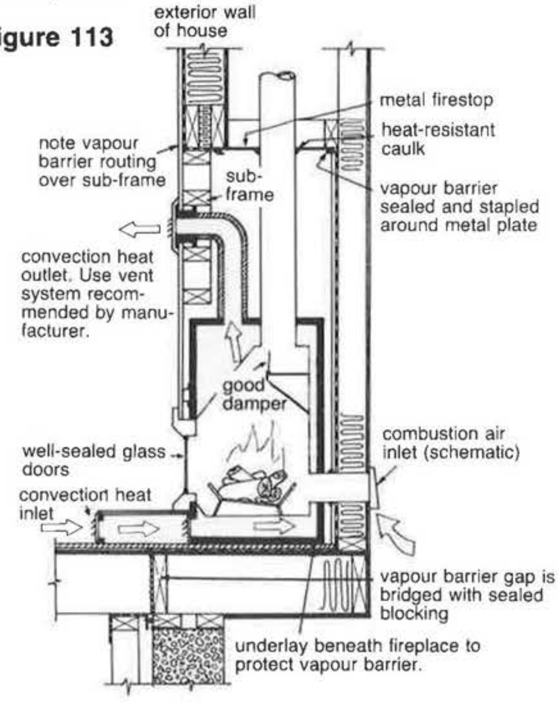


Figure 114

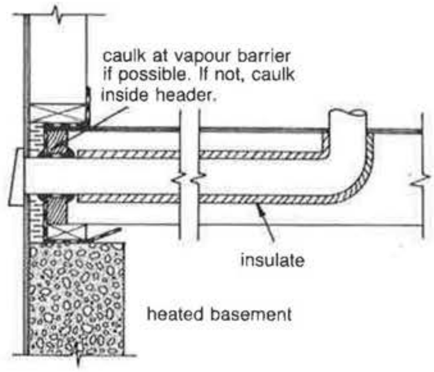


Figure 114 shows a combustion supply to a fireplace located well inside the house, over a heated basement. Note that the pipe is brought through the header and is insulated.

Figure 115

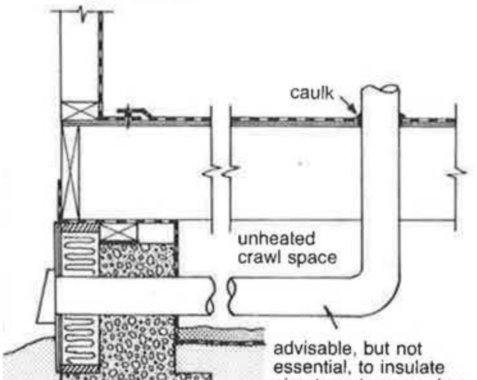


Figure 115 shows a combustion air supply to a fireplace located over an unheated crawl space. Note the caulking location.

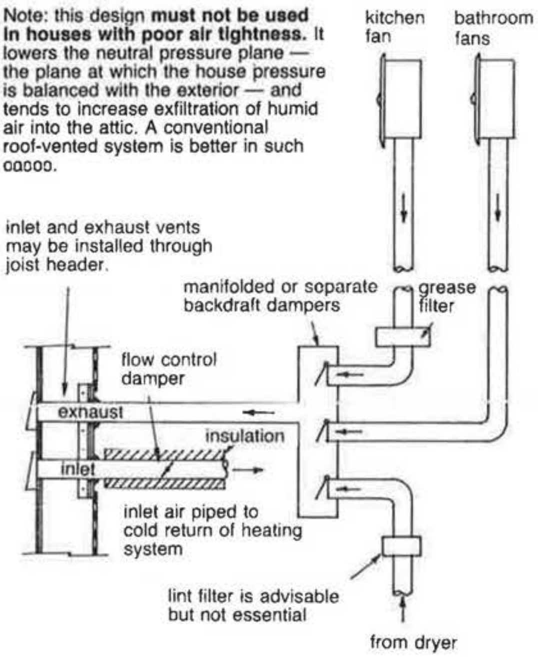
24.0 Air management systems

Figure 116 shows the main features of a basic air-management system. Note that the dryer, kitchen fan and bathroom fans are manifolded so that only one exhaust vent is required. The fans are prevented from interacting with each other by backdraft dampers. It is better to exhaust kitchen and bathroom fans downward and out through the floor header, rather than to exhaust through roof vents. This reduces convection heat losses and makes it easier to install a heat exchanger at some later stage, if desired. The inlet pipe should be connected to the cold air plenum of the furnace, where the suction of the furnace fan will draw fresh air into the house. The inlet flow should be controlled by a manual damper, and the whole pipe should be insulated.

The inlet and exhaust vents should be positioned far enough apart to **avoid cross flow,** but close enough to ensure that both vents experience the **same wind loading.** It is recommended that the vents have a separation of 900 to 1200 mm, and that they be installed on the same wall, well away from corners.

The national code on natural gas burning appliances, CGA B149.1, 1976, requires a clearance of at least 914 mm between these vents and any gas connection.

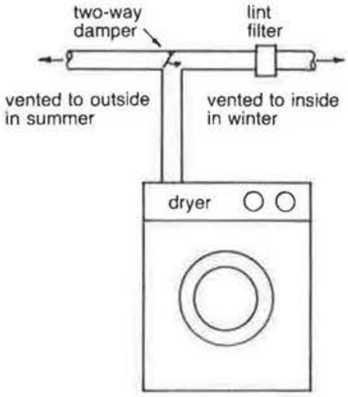
Figure 116



24.1 Dryer venting

In Residential Standards 1980, Section 33D, part 6, it is stated that "Exhaust ducts shall discharge directly to the outdoors." This code is interpreted as applying to dryer vents. The feeling amongst CMHC and provincial building inspectors is that, because of the energy conservation implications, this part of the code should be interpreted leniently in the

Figure 117



case of dryer vents. Builders who wish to vent the dryer to the house interior, or wish to insert some device in the dryer exhaust pipe (such as a heat exchanger or a backdraft damper) should first consult with the local building inspection authority.

With a lenient interpretation of the dryer venting code, it may be possible to install the type of system shown in figure 117. This is a schematic drawing of a new commercial product. The dryer vent is provided with a two-way damper that can divert the dryer exhaust into the house in winter (via a lint filter) and out of the house in summer. If the lint filter becomes plugged, the two-way damper switches automatically to outside venting. This system avoids some of the problems of venting the dryer through a heat exchanger. To avoid the installation of an extra vent, the outside vent pipe in this system can be coupled to the dryer pipe shown in figure 116.

Note that when the dryer is vented inside the house it delivers large amounts of moisture into the house, and this can cause excessive condensation on windows, etc. One solution is to provide an exhaust duct in the laundry area.

Figure 118

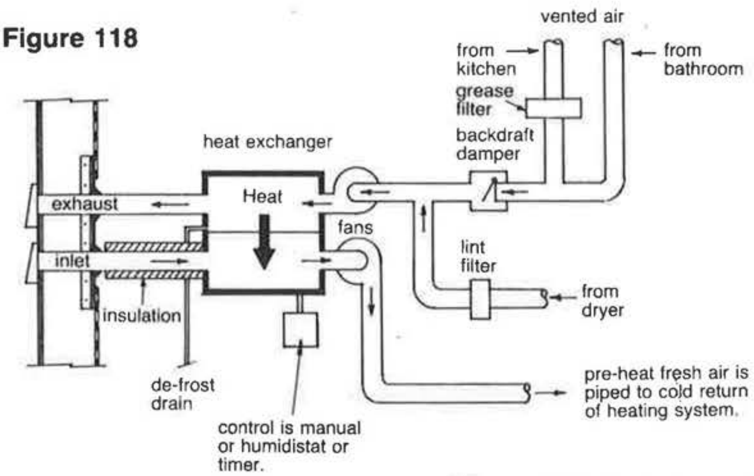


Figure 118a

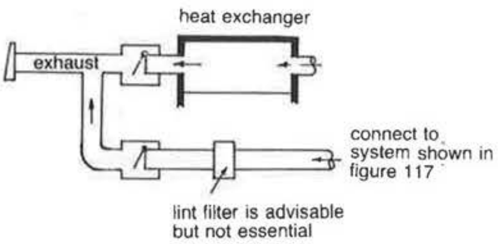
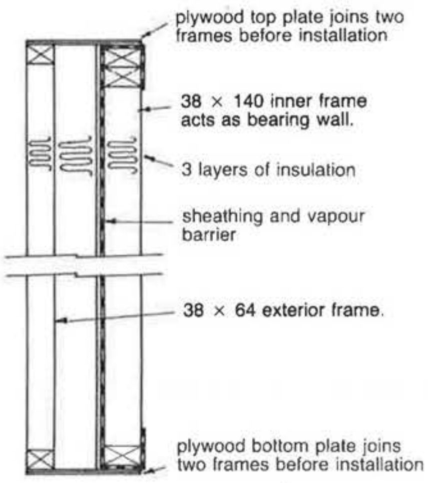


Figure 118 shows the main features of an air-management system with a heat exchanger. The heat exchanger is shown schematically, and indicates how heat is passed from the exhaust air to the incoming fresh air. If the dryer is to be connected to this system as shown, **it is important to ensure that the heat exchanger is big enough to handle the dryer exhaust flow, and that the heat exchanger can withstand the hot humid air from the dryer.** Note that the other vented air systems are provided with a backdraft damper to prevent the dryer air from entering the kitchen and bathrooms.

An alternative is shown in figure 118a. In this design, the heat exchanger system is combined with the dryer venting system shown in figure 117. This system is connected to the exhaust vent through a lint filter (optional) and a backdraft damper as shown. Also, to prevent backflow through the heat exchanger, a second backdraft damper is provided in the heat exchanger line. With this system, the dryer coupling and the backdraft damper in figure 118 can be eliminated. Because of the problems associated with venting dryers through heat exchangers, the authors of this guide prefer the system shown in figure 118a. **This preference, however, is subject to approval of the inspection authorities.**

25.0 Super-insulated walls

Figure 119



Super-insulated wall designs are discussed in some detail in the publication "Energy Efficient Housing — A Prairie Approach," issued jointly by Saskatchewan's Office of Energy Conservation and Alberta's Energy Conservation Branch. Builders are advised to consult this publication if they require a more comprehensive treatment of these wall designs.

Figures 119 and 120 are taken from the "Prairie Approach." They show one possible way of building a double-frame wall. They are included in this guide to show the unusual routing of the vapour barrier (a point that was examined on pages 22 and 23 of Section I of this guide). Figure 119 shows how the wall is put together and figure 120 shows how the vapour barriers are joined at an inside and an outside corner.

These designs have been included in this guide for the sake of completeness, but the authors wish to emphasize that they do not necessarily agree with the design detail.

Figure 120

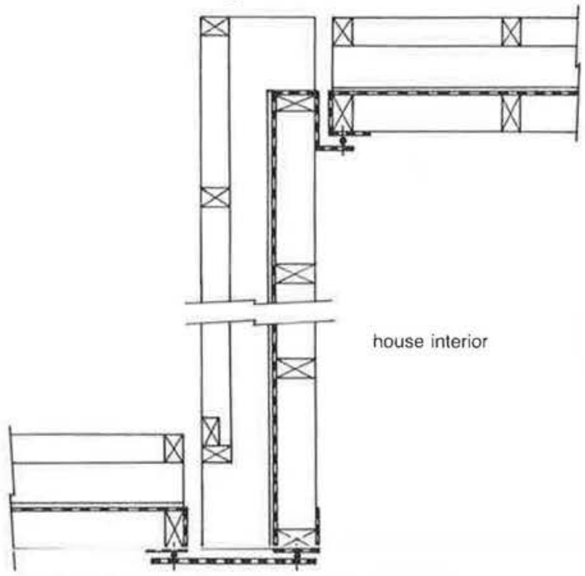


Figure 121 is taken from the "Prairie Approach" and shows the essential structural features of a double-frame wall in a single-storey wood frame with concrete basement. In this design there is a notable lack of vertical support for the exterior frame (the authors understand that this is due to some loss of drawing detail during the preparation of the publication). Nevertheless, it appears that a few of the earlier examples of double-frame construction are beginning to show settling effects on the outer frame. It is difficult to authenticate such cases, but it is worth noting that some of the proponents of the double-frame wall are now incorporating bracing between the two frames. From the authors' own experiences in retrofit (by adding another frame outside an existing one) it appears that the large temperature difference between the two frames may set up the same kind of differential expansion effects as in the truss lift phenomenon.

On balance, the authors prefer the design approach shown in figure 122. Note that the exterior frame uses 38 × 89 mm studs and is firmly attached at the top and bottom. At the top the frame is attached to the roof trusses, which extend further outwards than in figure 121. At the bottom, the frame has a slight toe-hold on the concrete foundation that is useful during construction, and its studs are nailed to the header. Note that this design does not require any great sacrifice of insulation levels around the header. Good insulation levels can be achieved by using rigid insulation outside the header, and the positioning of the joist sill plate allows the interruption of conduction paths through the wood members. The disadvantages of this design are that the walls encroach on the living space by about 127 mm, and the double-frame cannot be constructed as a single unit — although the advantages of single-unit construction have sometimes been questioned. Also, the design lacks the protection of the vapour barrier that is given by the plywood braces in figure 121.

It is important that readers of this guide recognize that double-frame construction is still in the stage of development. There is a great range of design alternatives and it will be some time before the best design emerges. The two figures on this page show two design options, neither of which is perfect, but which at least give some indication of the problems.

Figure 121

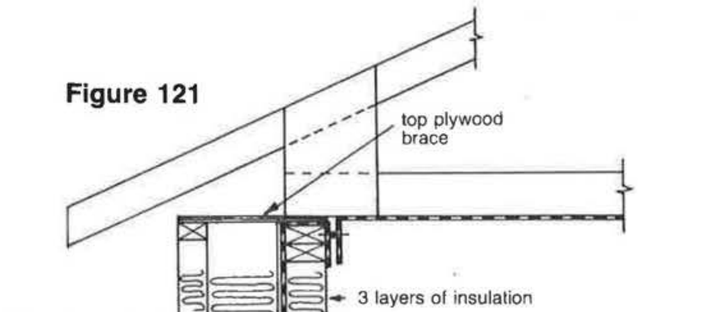
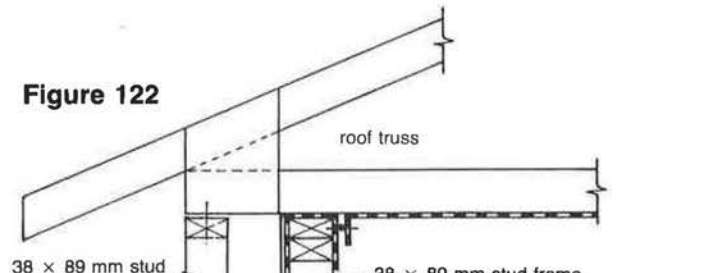


Figure 122



Note: R values used throughout the text are metric R values (m² °C/W), often written as R SI. 1R(SI) = 5.6783 R(Imperial)

25.0 Super-insulated walls

25.1 The strapped wall

Figure 123 shows a strapped wall construction in a single-storey house with concrete basement. Its construction is identical to that of a standard 38 × 140 mm wall, up to the point where the vapour barrier is installed (compare with figure 106). The 38 × 64 mm straps are installed over the finished vapour barrier as shown, then the electrical runs are installed in the new wall extension, with minimum risk to the vapour barrier integrity. The strapped wall extension is insulated with R1.4 batt before drywalling.

The advantage of this design is that it allows the builder to achieve high levels of insulation (typically R7.0) with very little departure from standard building practices. On this account it may prove to be more popular than double-frame walls in energy-efficient housing. The disadvantages are that it encroaches on the living space by 65 mm, compared to the standard 38 × 140 mm wall, and it has a moderately high heat loss through the continuous wood at the top and bottom of the wall. Figure 124 shows design variations that overcome this problem.

The performance of the wall depends partly on the use of insulated sheathing (such as Styrofoam SM). Some builders have expressed concerns about the strength of attachment of siding over this relatively soft sheathing. If the sheathing is too thick, say 50 mm or more, the siding has to be supported on nails that receive very little support from the sheathing. Some movement of the siding may therefore take place. This appears to be no problem if the siding thickness is limited to 38 mm or less, as indicated in figure 123. Since rigid insulation sheathing generally has little structural rigidity, the wall will require cross-bracing. Also it is advisable to space the studs on 406 mm rather than 610 mm centres when this sheathing is used. There are a number of new siding materials now appearing on the market, with integral sheathing and insulation. These new materials are fairly rigid, have good strength and large thermal resistances.

Figure 123

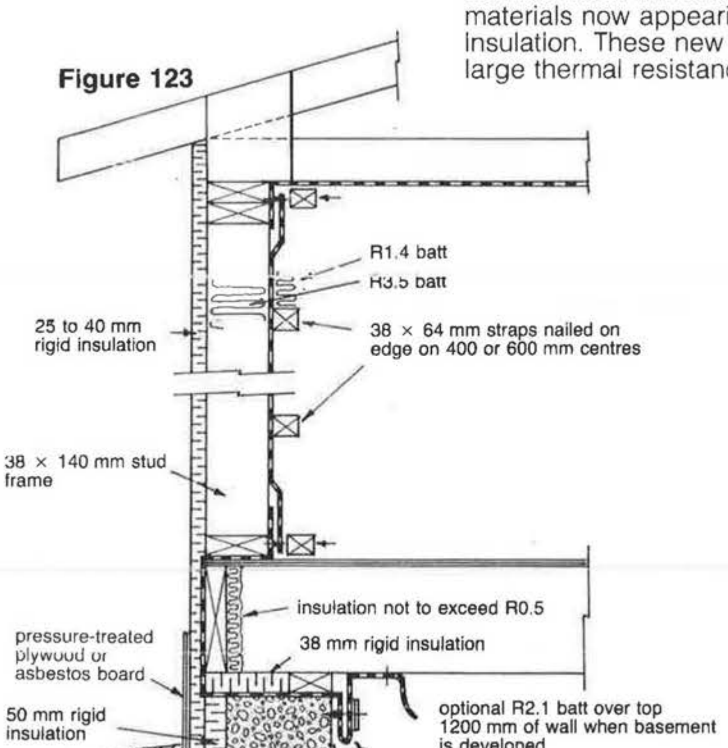
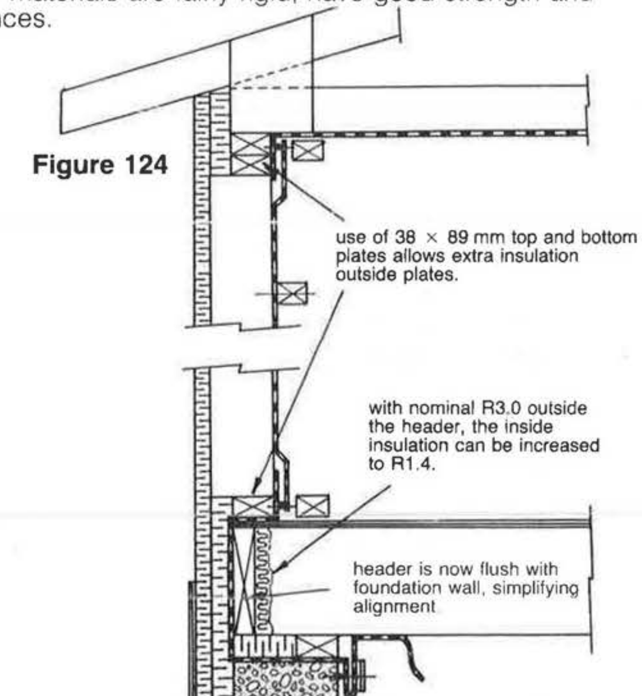


Figure 124



26.0 Educating the home owner

The energy efficient house contains many features that are new to the average home owner and, unless these features are explained to the owner, there is a chance that he may unknowingly harm some of them. This applies particularly to the air-vapour barrier. The owner must be made aware of the work that has gone into the air tight house construction, and the ease with which this air-tightness can be destroyed by modifications (such as adding more electrical receptacles) to the exterior walls. Unless the owner knows the purpose of the loose edge of vapour barrier at the joists of an unfinished basement (see figure 106 for example) he may decide to trim it off. Apart from this, the home owner has to be told about the purpose of furnace rooms and the various features of air management systems.

This guide recommends that builders prepare an explanatory brochure for owners of energy efficient houses; identifying the main features and pointing out their purpose. This brochure should also include a list of **do's and don't's.**

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Drastic Failure of Air/Vapor Barrier

Editor's note — Questions have been raised about the durability of polyethylene and the expected life span of polyethylene air/vapor barriers installed in houses. Most notable was a report about a documented case of an air/vapor barrier somewhere in Canada which "self-destructed" (see the June 1984 issue of EDU, page 9). Needless to say, that kind of story caused some panic among builders who rely on polyethylene air/vapor barriers for energy efficiency and moisture protection. After countless phone calls, we finally found the source and documentation of the story. The following paper, written by David Eyre, explains what was observed as well as some speculation on the causes of the failure. Although Eyre's general conclusion is that it was an unusual occurrence resulting from a rare combination of circumstances, he raises an important point or two concerning the practice of vapor barrier installation.

An Incident of Drastic Failure of a Polyethylene Vapor Barrier

by David Eyre, Saskatchewan Research Council

The house in question is an owner-built unit in Loreburn, about 130 km south of Saskatoon. It is an energy-efficient design with air/vapor barrier construction and 18-inch double-framed walls.

The house was framed and sheathed over a three-week period in July 1983. The weather during that period was exceptionally warm and sunny. The generally-accepted method of double-framing was followed; the interior frame was assembled flat, the 6-mil polyethylene was installed over the outside surface of the frame, and was then covered with plywood sheathing. The exterior frame was joined to the interior one before lifting into position. Construction started on the east wall and proceeded in a clockwise direction. The house is a split-level unit, and to reduce the number of vapor barrier joints, the owner/builder used polyethylene in both 10-foot and 20-foot widths. Both rolls had CMHC numbers. At the end of the three-week framing period, the house was fully sheathed, with openings for windows and doors. The owner cannot recall the exact history of the polyethylene in this period. It was purchased just before use, but may have been stored for a few days in direct sunlight. It is also fairly certain that the installed polyethylene was exposed to direct sunlight for up to two weeks before the roof sheathing was installed.

The first polyethylene failure occurred in October. At that stage, all doors and windows had been installed, except D.3 and W.1 (see Figure 3-8). The owner feels that this was due to strong winds from the Southeast. The location of the failure is consistent with this.

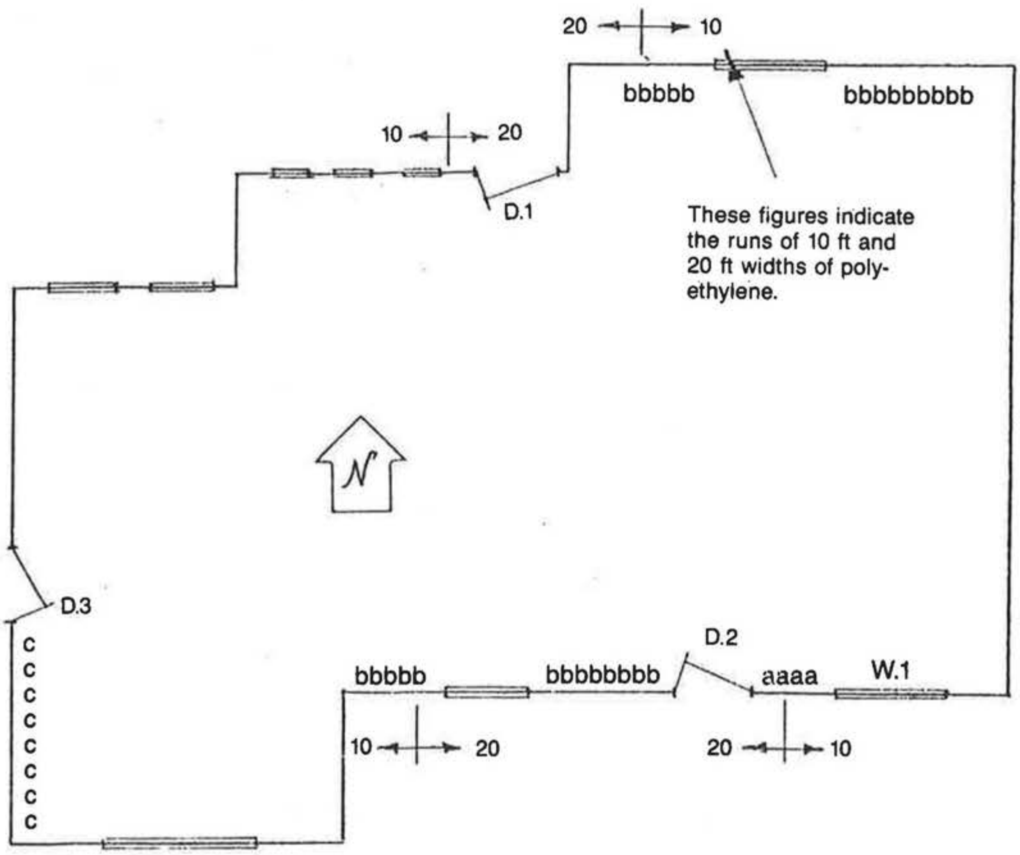


Figure 3-8 — Plan of house showing vapor barrier layout and affected areas (not to scale).

The main failures occurred around December 17, 1983 (the exact date is uncertain). At that time the house had been insulated on the outside of the sheathing, and building paper had been installed. Siding was in progress. No insulation had been installed inside the vapor barrier, which was still exposed. Window W.1 was in place, but door D.3 had still not been fitted. The house was unheated.

On arriving at the house in the morning, the owner noticed a drastic failure of the vapor barrier in the areas indicated by b's (see Figure 3-8). Later in the day, just after noon, there was a series of sharp popping sounds, accompanied by failure of the vapor barrier along the southwest corner of the house — indicated by c's in Figure 3-8.

In all cases, the damage suggests brittle fracture. In most cases, the pattern of fracture suggests that the polyethylene was subjected to strong horizontal stress. On questioning, the owner stated that the polyethylene may have been stretched a bit tightly during installation (during an excessively hot period in July). He further commented that, on the day when the main failures occurred, the vapor barrier along the east wall was "as tight as a fiddle string."

The climatic records for Saskatoon for that period show the onset of a severe spell of cold weather, starting on December 15. Daily maximum temperatures were around -15°F, while minimum temperatures fell to around -27°F. Winds were light to very light and the sky was overcast for several days.

Possible Causes of Failure

Defective batch of material

Two rolls of polyethylene were used: one of 10-foot width and the other of 20-foot width. The probability that both came from a defective batch is remote.

Chemical attack

Polyethylene is resistant to most forms of chemical attack. The most likely chemical in this instance was formaldehyde from the plywood sheathing, which had been in contact with the polyethylene for about 5 months when the failure occurred. However, polyethylene is resistant to formaldehyde.

Ultra-violet (UV) radiation effects

The polyethylene may have been exposed to direct and indirect sunlight for two weeks or more, before being protected by the roof sheathing. During that stage of the construction, the sun was just past the summer solstice, and the strongest radiation effects would have fallen on the polyethylene on the south wall of the house. This is consistent with the observed failure patterns and, therefore, UV radiation is believed to have played a part in the failure.

Wind effects

This could explain the earlier failure in October, but the winds were too light to have caused the failures in December. Wind effects may have constituted a slight secondary cause.

Temperature

The main failures occurred when the polyethylene was exposed to severe low temperatures, in the range -15°F to -27°F. Low temperature alone is not enough to cause damage to polyethylene, which is often used as weather protection at construction sites in winter, and does not generally display the kind of drastic failure that was observed here.

Combination of stretching and temperature

This appears to be the most likely cause. The polyethylene was installed during very hot weather, and the owner/builder admits to having stretched it a bit during installation. In hot weather, polyethylene is plastic and will stretch fairly easily. The polyethylene therefore had a built-in strain.

In December, the temperature dropped to around -22°F. This caused a change in the physical properties of the polyethylene. It is believed that the yield point of the material shifted with temperature until it fell just below the existing strain level. At that point, the polyethylene suffered stress failure. Photographs of the failure show damage that is consistent with this type of stress failure.

Conclusions

It is concluded that the failure of the polyethylene had three contributory causes:

1. The polyethylene was stretched too tightly during installation. This was facilitated by the unusually high ambient temperatures.
2. The failure was triggered by excessively low temperatures, which changed the physical properties of the polyethylene to the point where it could no longer sustain the strains placed on it during installation.
3. Exposure to UV radiation from the sun is believed to have contributed to the eventual failure.

In conventional building practice, the building schedule is relatively short and the vapor barrier receives minimum exposure to direct sunlight. By the same token, the houses are completed and the heating is installed much quicker than in this particular case. Therefore two contributory causes of failure are removed, and the probability of this kind of failure is small in commercial operations.

However, this incident of failure does emphasize the importance of installing the polyethylene without stretching it. Any stretching builds strains into the material, and may ultimately lead to stress failure. As a point of good building practice, it should therefore be stressed that a baggy vapor barrier is better than one that is fitted tightly. This recommendation applies particularly to exterior-wrap polyethylene vapor barriers when used in retrofit. These may get a high exposure to low temperatures and UV radiation during installation.

This article was originally issued by the Saskatchewan Research Council, March, 1984; SRC Publication No. R-825-10-E-84.

Current Airtight Drywall Approach (ADA) Techniques

The following section is reprinted with permission from "Applied Engineering Science," by Joseph W. Lstiburek, P.E., Building Engineering Corporation.

Current Airtight Drywall Approach (ADA) Techniques

A major component of a good building envelope may be the air barrier system. The Airtight Drywall Approach (ADA) uses gypsum board or drywall and various components of the building envelope as the air barrier system.

The major function of the air barrier is not the prevention of vapor diffusion but, rather, the prevention of through-the-envelope air leakage. In addition to reducing energy consumption, the elimination of air leakage by the use of an air barrier system located towards the interior of the building envelope also eliminates exfiltration and the effect of interior/envelope cavity convective air movement, the major causes of condensation problems in heating climates.

The concept that four different methods — bulk water movement, capillarity, air movement, and vapor diffusion — are responsible for moving moisture into and out of the building envelope has been greatly misunderstood. This misunderstanding has been partly due to the emphasis on vapor diffusion along with the unfortunate use of the term air/vapor barrier, which couple two of the four independent moisture transport mechanisms, air movement and vapor diffusion. Recently, builders have tried to use one material in the building envelope to serve both as an air barrier and a vapor barrier. However, it may be more practical to use one material as the air barrier and a different material as the vapor barrier.

Any material or system of materials may be used as an air barrier if the following requirements are met:

1. The material or system must be continuous.
2. The material or system must be impermeable to air, allowing not more than 0.1 liters of air to pass through the system per second per square meter at 75 Pascals.
3. The material or system must be able to withstand the air pressure loads which act on it. That is, both the local minimum wind design loads and the influence of mechanical systems and stack action must be taken into account.
4. The material or system must be adequately stiff or rigid to maintain pressure equalization behind exterior cladding, in order to control rain penetration under fluctuating wind pressures.

5. The material or system must be durable and easy to maintain over the service life of the building.

These five requirements are necessary and sufficient, and any material or system which meets these requirements can be used as an air barrier.

Vapor barriers, to be effective, do not have to stop diffusion completely. The vapor barrier need only slow down or retard vapor diffusion, and thus it is more correct to call it a vapor diffusion retarder. The vapor diffusion retarder does not need to be made of the same material as the air barrier and, unlike the air barrier, does not need to be continuous. Its only function is to retard vapor diffusion, which acts independently from the movement of moisture-laden air through the cracks and joints within or around building materials.

It has been calculated that the movement of water vapor through a 2-centimeter-square hole as a result of a 10-Pascal air pressure differential is 100 times greater than the movement of water vapor as a result of diffusion through that same 2-centimeter-square hole. The amount of vapor which diffuses through a vapor retarder is a function of area. That is, if 90 percent of the building envelope is covered with a vapor retarder, then the vapor diffusion retarder is 90 percent effective. In other words, continuity of the vapor diffusion retarder is not as significant as continuity of the air barrier and control of the other major moisture transport mechanisms, namely bulk water movement and capillarity. For instance, a paint film applied only on the interior exposed surface of the building envelope will act as an effective vapor retarder as well as polyethylene film, which may have tears and numerous punctures present.

Continuity of the air barrier can be a major factor in controlling the movement of water vapor into wall and building assemblies. If the movement of moisture-laden air into a wall or building assembly is eliminated, movement of moisture by vapor diffusion is likely not significant.

Control of moisture movement using a continuous air barrier and an effective vapor diffusion retarder is more efficient than the use of an effective vapor diffusion retarder by itself. Confusion arises because most building codes clearly define the function of a vapor barrier but neglect to adequately define the function of an air barrier.

Building envelope design incorporating the previously defined concepts of air barriers and vapor diffusion retarders is illustrated by the Airtight Drywall Approach (ADA). It consists of interior cladding and structural elements assembled to act as a continuous air barrier and able to withstand wind and other mechanical loads. Because the air barrier is on the warm side and is visible, it is exposed to a stable environment. Its airtight characteristics can be maintained inexpensively (after years of occupancy) by retouching seals after removing baseboards and moldings and reapplying sealing compounds and/or gasket materials. ADA focuses on how to make gypsum board or drywall air barrier continuous in a conventional wood-frame house.

In constructing a building using the ADA technique, it is still necessary to install an effective vapor diffusion barrier. This requirement, however, is independent of the ADA system, as ADA only deals with the air barrier system. As such, it is possible to use numerous approaches and install numerous materials to act as vapor diffusion retarders. It is not uncommon to use low-perm paint, foil-backed gypsum board, aluminum foil-backed insulation batts, and sheet polyethylene. The most common approach is to install sheet polyethylene to act as the vapor diffusion retarder. In this approach, it is not necessary to install the sheet polyethylene in a continuous, "airtight" manner, as it is not acting as the air barrier.

ADA uses caulking, sealants, adhesives, and gaskets in various combinations to provide air barrier continuity between the standard interior gypsum board finish and typical framing components such as rim joists, top plates, bottom plates, etc.

Framing carpenters may install gaskets, sealants, adhesives, etc., between the framing members. A separate trade, usually laborers, often install the remaining gaskets and sealants between the drywall and the framing before the drywall is secured with a staple gun.

It is possible to install all the gaskets, sealants, etc., in one trip without interacting with other trades. This would be done immediately prior to the installation of the gypsum board interior finish. Thus, scheduling can proceed normally. The frame carpentry is done at one time, as is the electrical rough-in, etc.

Where interior partition walls intersect exterior walls, air barrier continuity is maintained by installing a gasket on both sides of the first stud of the intersecting partition wall and by sealing this stud to the top and bottom plates with caulking (Figure 3-9). Where an interior partition wall intersects an insulated ceiling, a similar approach is used. A gasket is installed on both sides of the top plate of the interior partition wall (Figure 3-10).

Between floors, the air barrier is kept continuous by gasketing and/or sealing between plates, rim joist, and subfloor (Figures 3-12, 3-15). Vertical joints in the rim joist are sealed as well. The rim joist may be set toward the inside of the wall plates to allow room for insulation on the cold side of the air barrier (so condensation will not form there). This is recommended for cold climate construction (most of Canada), and not necessary for other climates where standard framing approaches are satisfactory.

If the basement area is finished, then the air barrier in the basement area consists of the gypsum board or drywall on the exterior walls and the concrete floor slab (Figure

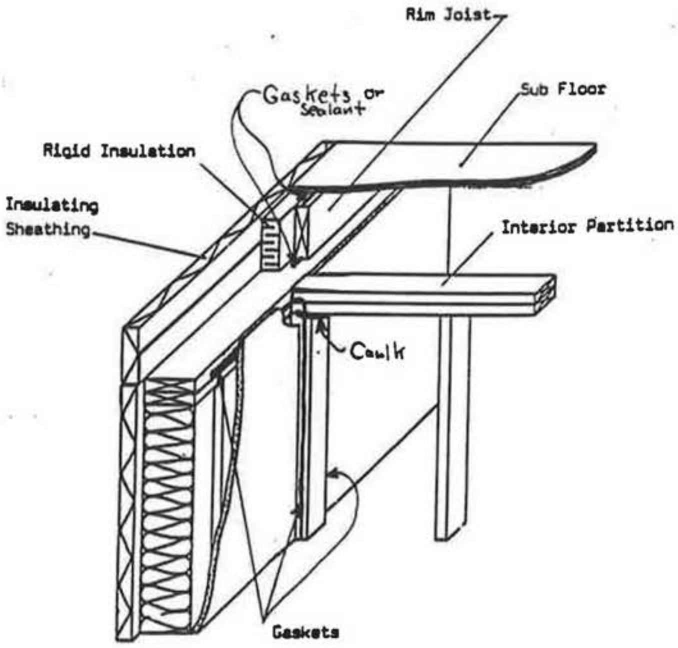


Figure 3-9 — Intersecting interior wall

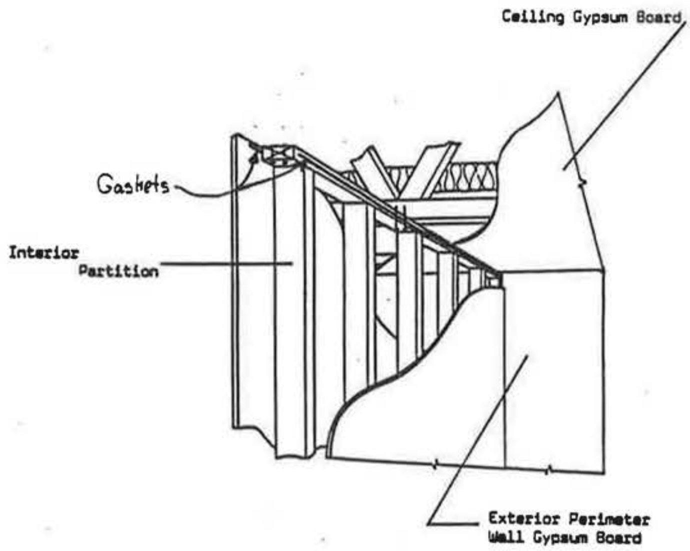


Figure 3-10 — Interior wall intersecting insulated ceiling

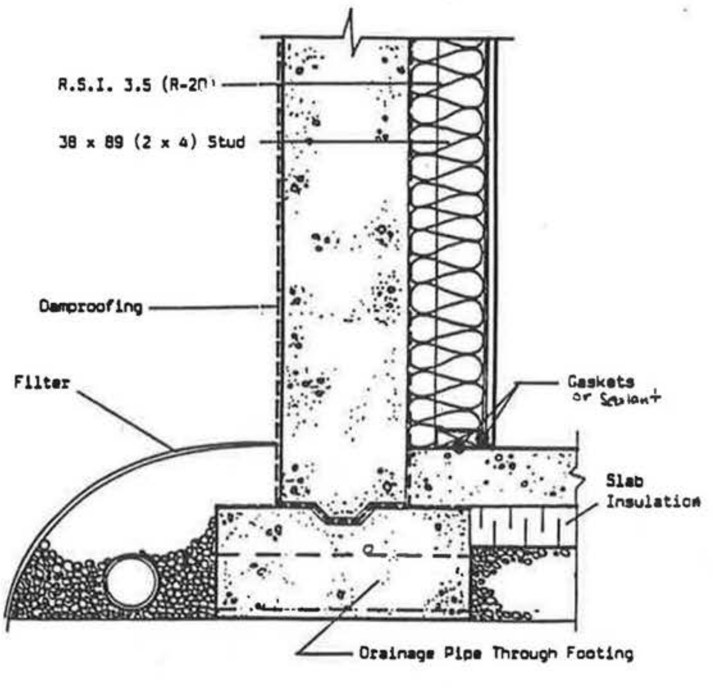


Figure 3-11 — Footing detail

3-11). The joint between the floor slab and the gypsum board or drywall is sealed by installing gasket material or a sealant between the bottom edge of the perimeter drywall and the bottom plate, and between the bottom plate and the concrete floor slab. The joint between the foundation wall and floor slab is sealed.

Damp-proofing is installed on the outside surface of the concrete foundation wall, as well as between the case concrete footing and the foundation wall to inhibit capillary action from drawing moisture into the foundation wall. It may be desirable or necessary to install damp-proofing on the interior surface of the concrete foundation to grade level in order to meet local building code requirements.

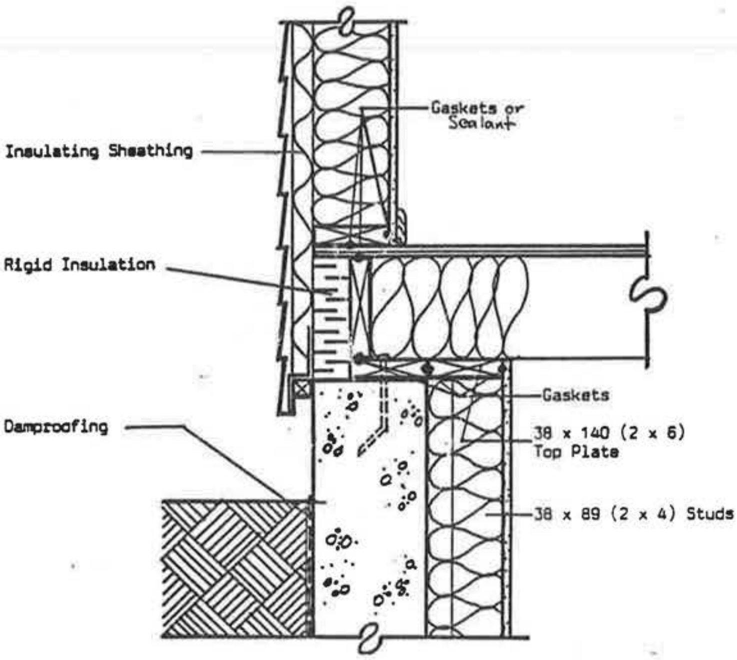


Figure 3-12 — Subfloor at grade

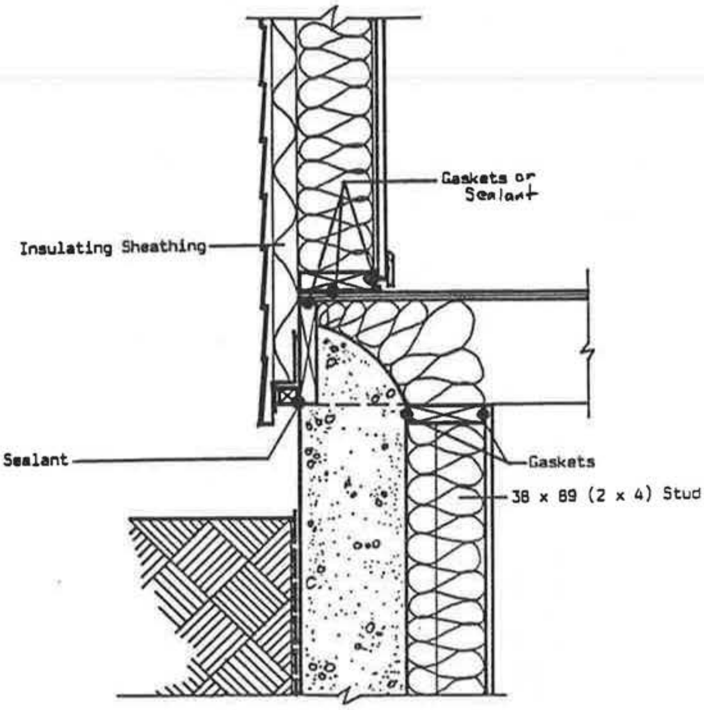


Figure 3-13 — Subfloor at grade — western detail

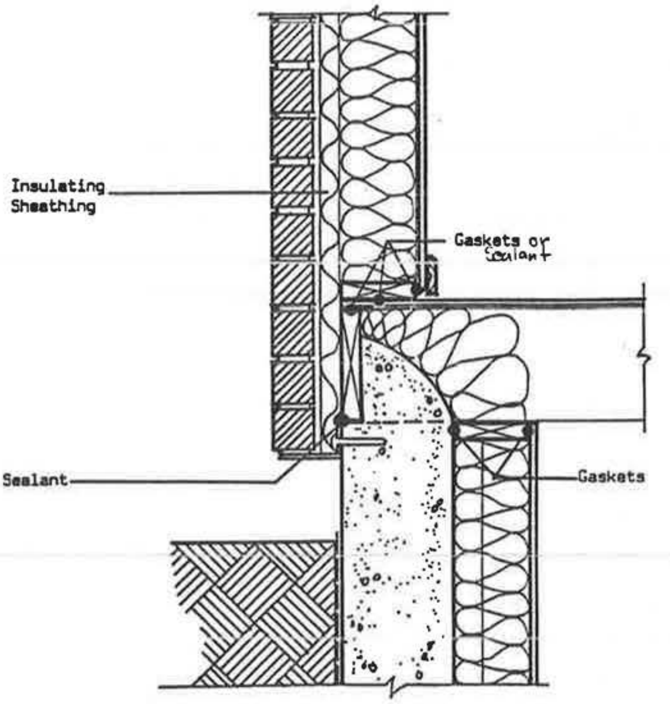


Figure 3-14 — Subfloor at grade — brick veneer

In climatic regions where long drying periods occur, such as western Canada, it is common practice to cast the foundation concrete walls so that the floor joists are embedded in the concrete. This approach provides support to the case concrete foundation wall during the backfilling process. This practice is not recommended in climates that do not have sufficient drying potential. The air barrier is made continuous by installing gasket material or a sealant between the top edge of the embedded rim joist and the underside of the subfloor sheathing, and by sealing the bottom edge of the embedded rim joist to the cast concrete wall with an appropriate sealant or caulking material (Figures 3-13, 3-14).

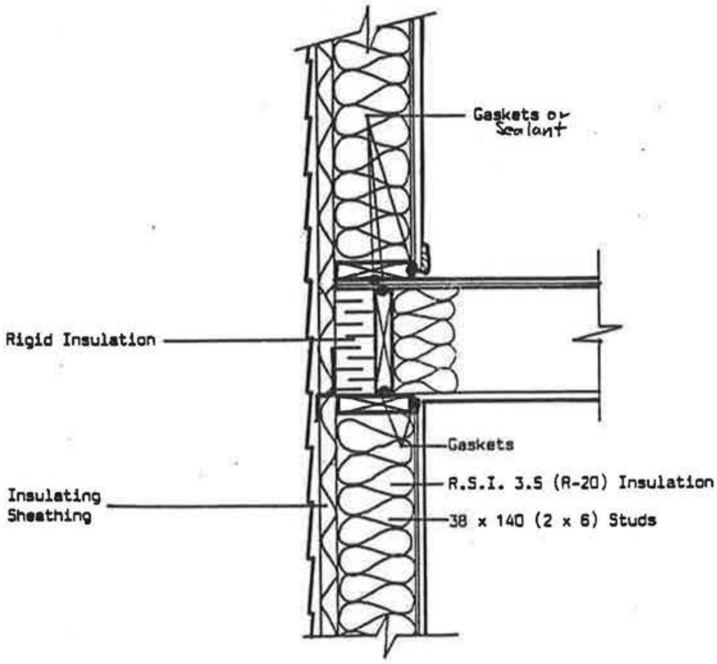


Figure 3-15 — Second floor subfloor

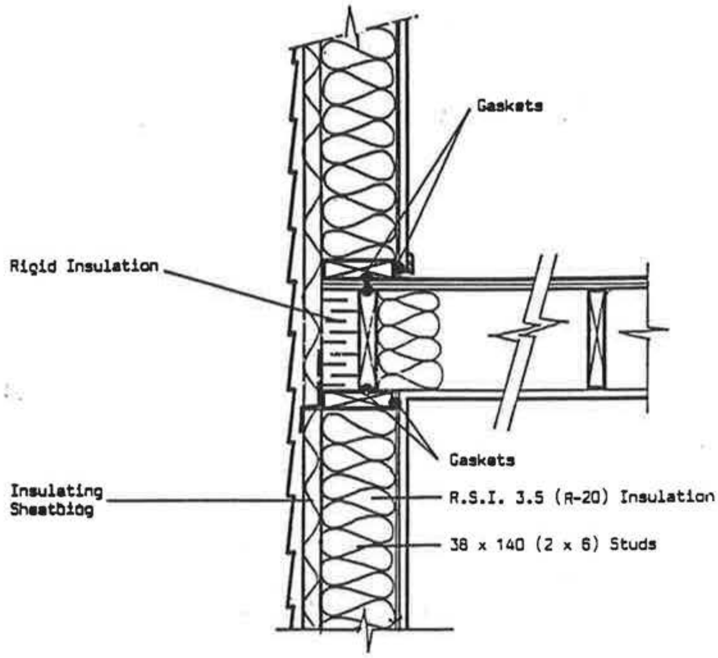


Figure 3-16 — Second floor subfloor parallel joists

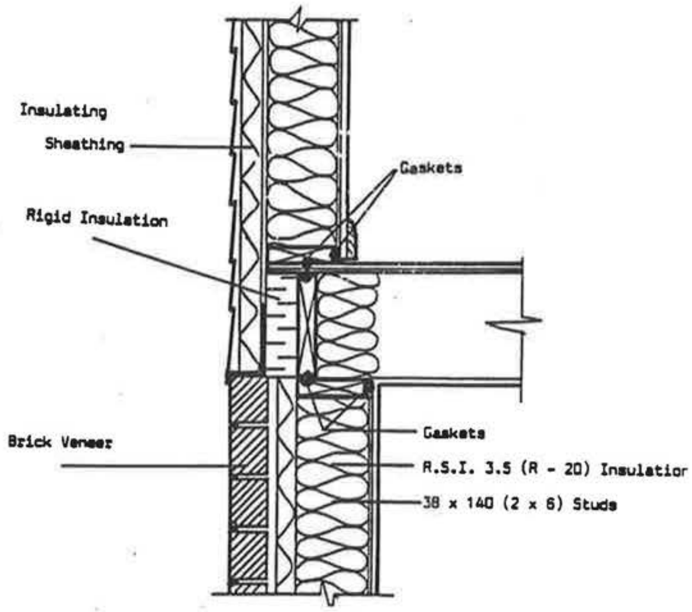


Figure 3-17 — Second subfloor brick veneer/siding transition

Where floor trusses are used, air barrier continuity between stories at subfloors is accomplished as in Figure 3-18. The major point to note in Figure 3-18 is the use of plywood as a rim joist, header, or band joist in place of a standard wood joist. This is necessary to compensate for differential shrinkage rates between waferboards, plywoods, and floor trusses, as compared to typical floor joist material. Floor trusses, which for all intents and purposes do not shrink, are combined with standard rim joist or header materials which also shrink. A construction adhesive is used to provide a seal between the top of the plywood rim joist and the plywood subfloor in Figure 3-18, as opposed to a gasket. A gasket was judged to be too difficult to install in this location. A wide gasket, of rectangular profile, may be used at the bottom of the plywood rim joist, as it is difficult to ac-

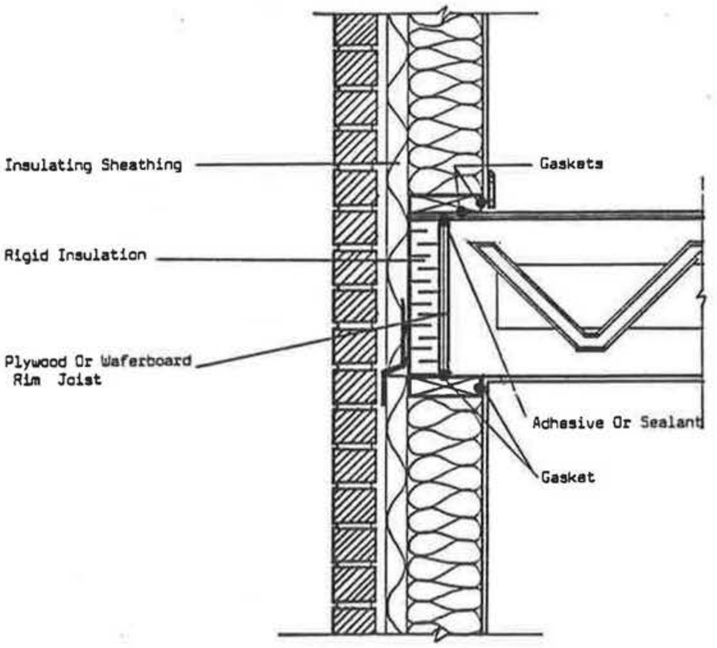


Figure 3-18 — Second subfloor — floor trusses

curately position a narrow gasket directly under a narrow rim joist. If a sealant is used in this location it must allow for building frame movement.

Where floor joists run parallel to exterior perimeter walls and where cladding of different thicknesses, such as brick veneer meeting siding, intersect at subfloor level, details contained in Figures 3-16 and 3-17 are used respectively.

Air barrier continuity, where exterior perimeter walls meet insulated ceilings, is provided for as described in Figure 3-19. The air barrier is made continuous at this location by virtue of the taped gypsum board joint between the wall gypsum board and the ceiling board. It should be noted that baffles of treated paper or other materials are installed between the roof trusses, directly in line with and above the exterior perimeter wall tip plates, in order to limit the deleterious effects of wind washing or blow-through, in which wind

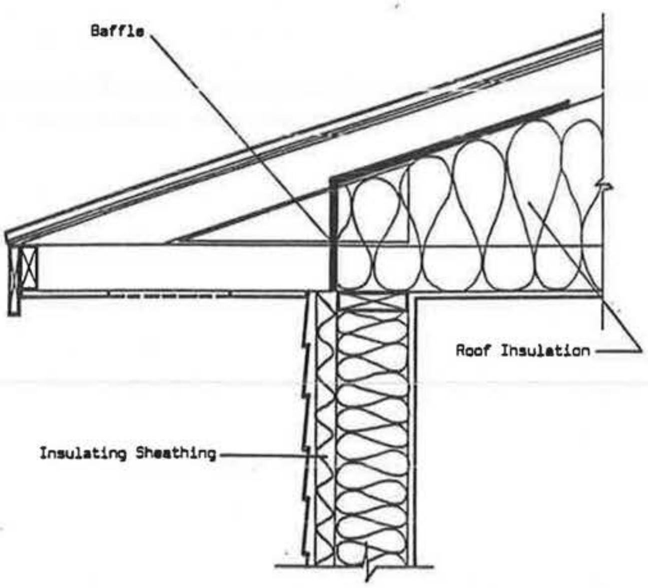


Figure 3-19 — Roof/ceiling interface

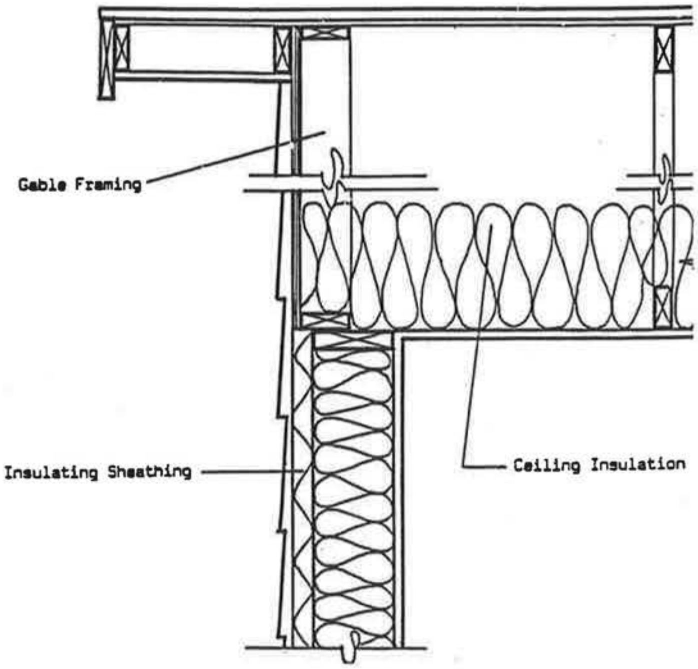


Figure 3-20 — Gable construction

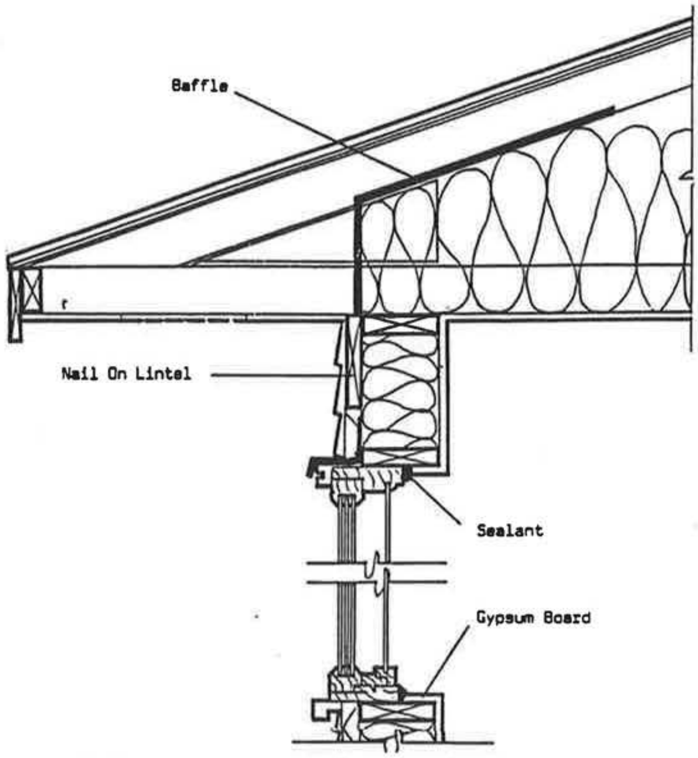


Figure 3-21 — Window detail, drywall return

can short-circuit thermal insulation and lead to local chilling of the interior cladding, which often results in high interior surface relative humidities and, hence, mold and mildew growth. It is important to note that a perfect air barrier located on the interior of an exterior wall will not eliminate mold and mildew formation, as it does not prevent wind washing. Gable walls are constructed as in Figure 3-20.

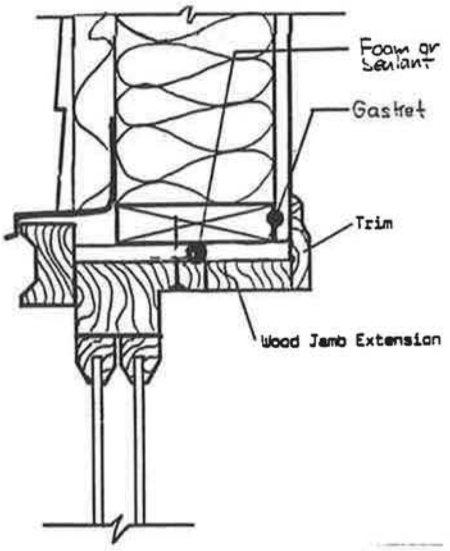


Figure 3-22 — Window detail — wood jamb extension

At window and door openings, the drywall may be returned directly to the window or door frames and the resultant joint caulked. The caulking is either painted or capped with a wood molding (Figure 3-21). A more typical approach is to install a gasket between the drywall and framing material of the rough stud opening and then seal the window frame to the rough stud opening with caulking, spray foam, or some other sealant (Figure 3-22). These seals are easy to maintain over the service life of the building.

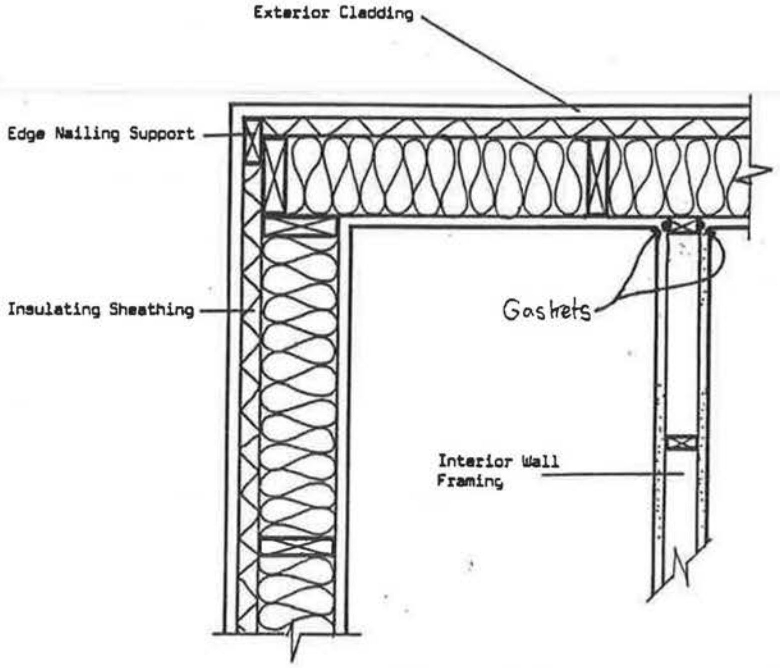


Figure 3-23 — Exterior corner

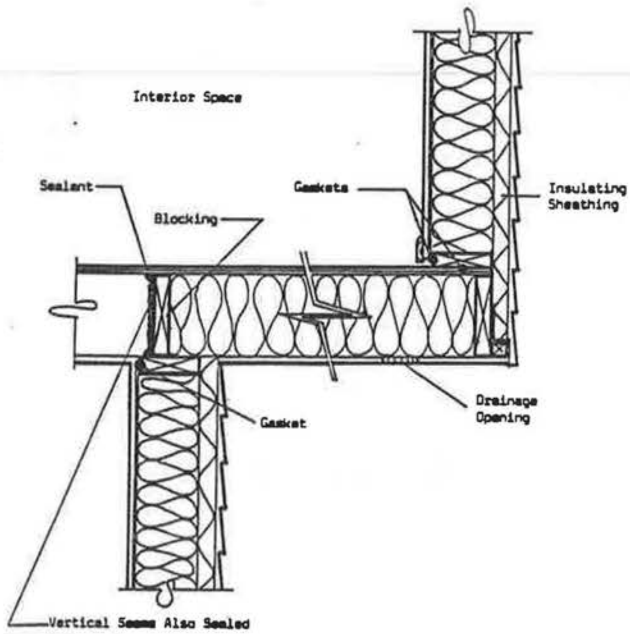


Figure 3-24 — Cantilever floor, intersecting joists

The air barrier is made continuous at exterior corners by taping together the gypsum board or drywall sheets (Figure 3-23). The use of drywall clips at corners, instead of backup studs for nailing support, results in several benefits. An extra degree of freedom of movement is provided for the gypsum board or drywall. Furthermore, since less wood is used in corner construction, the space that would normally be taken up by the wood is replaced by insulation. Since the corner is warmer, there is less chance of mold and mildew growth, provided of course that wind is not allowed to short-circuit the insulation by blowing through the exterior insulating sheathing or through the fiberglass batts.

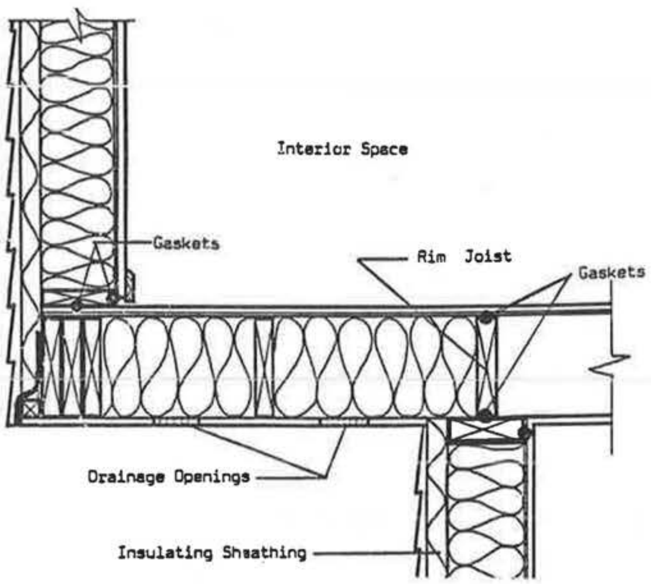


Figure 3-25 — Cantilever floor, parallel joists

Cantilevered floor construction, typically encountered at second-floor subfloors, is facilitated by the use of the construction details presented in Figures 3-24 and 3-25. In Figure 3-24, where intersecting floor joists cross over a perimeter exterior wall, wood blocking, or blocks of rigid, non-air-permeable, insulating sheathing are inserted into the joist spaces and sealed around their edges with caulking to provide

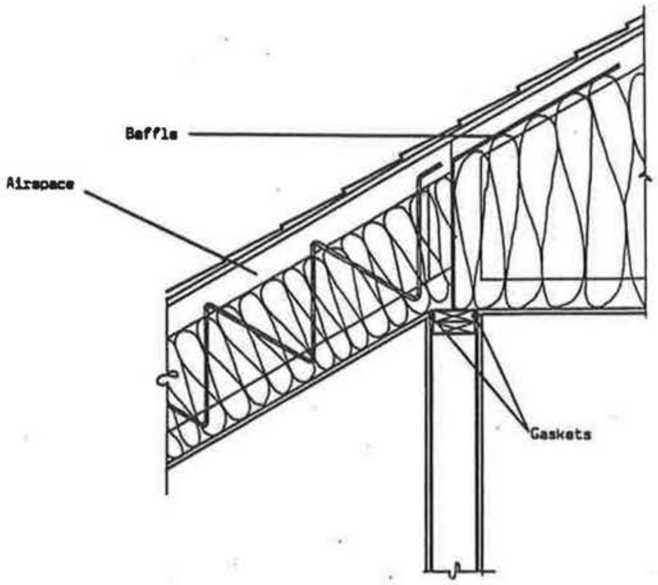


Figure 3-26 — Load bearing wall-sloped ceiling

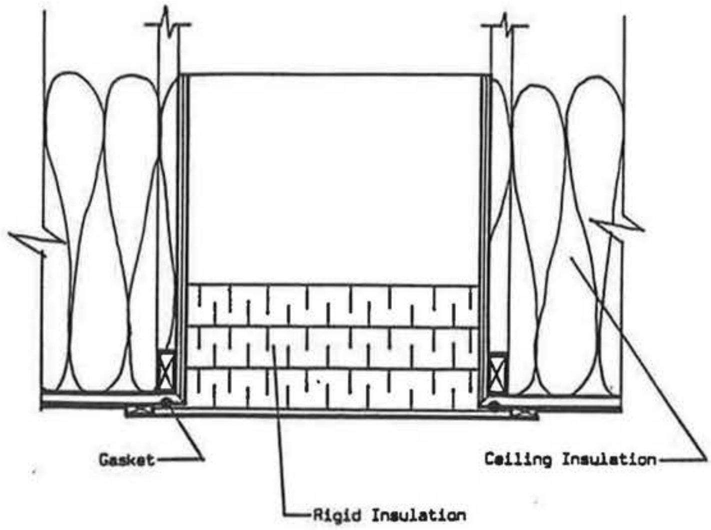


Figure 3-27 — Attic hatch

air barrier continuity. The air barrier over the cantilever portion of the subfloor therefore becomes the subfloor sheathing. Seams in the subfloor sheathing are sealed with subfloor adhesive. In Figure 3-25, where floor joists are aligned parallel to a lower perimeter wall, a floor joist is positioned directly over the lower perimeter exterior wall and gasketed similar to a typical rim joist or header. Since the subfloor sheathing is the air barrier over the cantilever portion of the subfloor, seams in the subfloor sheathing are sealed with a subfloor adhesive as in Figure 3-24.

Attic hatches constructed penetrating the air barrier and post supports are described in Figures 3-27 and 3-28 respectively.

Where a split-level dwelling is constructed, horizontally installed blocking between vertical stud members is used to make the air barrier continuous between the gypsum board or drywall ceiling on the lower level and the gypsum board or drywall on the upper level exterior wall (Figure 3-29).

Where plumbing penetrates the air barrier, such as in the ceiling, the pipe is clamped to wood

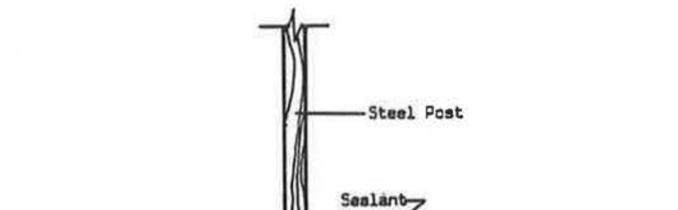


Figure 3-28 — Post detail in basement

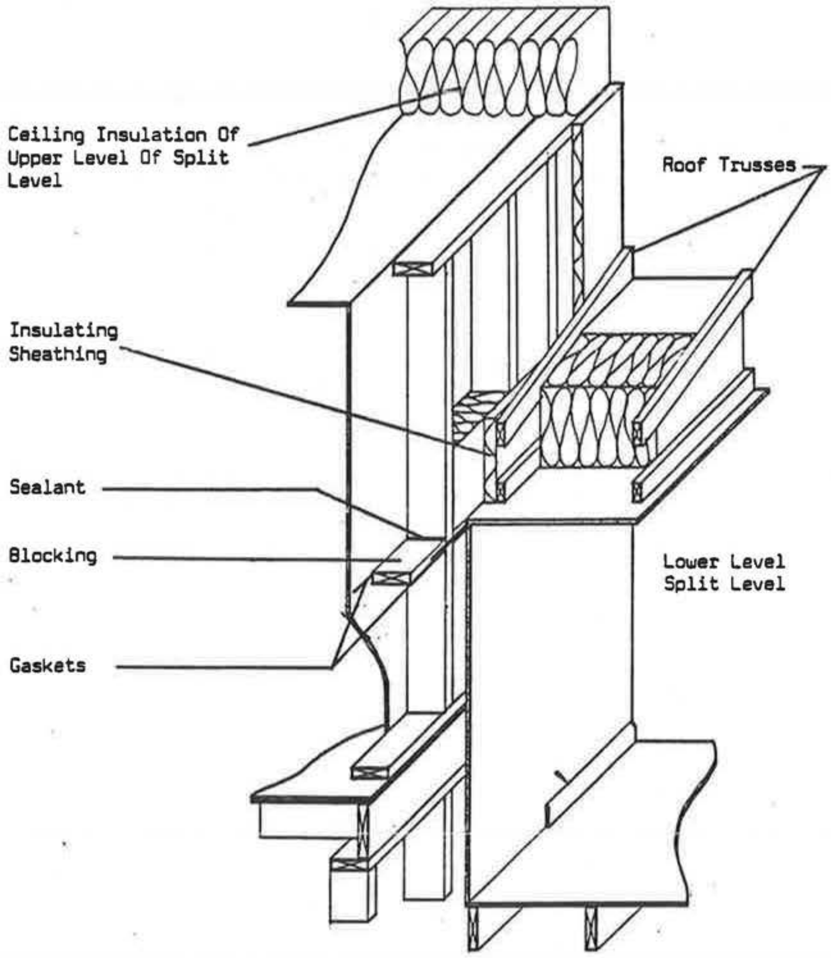


Figure 3-29 — Split level detail

blocking behind the drywall and the pipe, then sealed to the wood top plate. Where large-diameter vents penetrate a ceiling, an expansion joint is recommended. With smaller pipe, any movement can be accommodated by offsetting the pipe horizontally a few feet in the stud bays before penetrating the roof (Figure 3-30).

It is recommended that electrical outlets and wall switches be placed, where possible, on interior walls. Where it is necessary to place electrical switches and outlets on exterior walls, these are installed in a conventional manner. The gypsum board or drywall air barrier is sealed to the electrical outlet by mudding the gypsum board directly to the electrical outlet and by installing a compressible gasket directly underneath the cover plate of the outlet or switch (Figure 3-31). Such gaskets are currently being used in the retrofit air sealing industries. It is also recommended that outlet boxes without openings be selected, such as sealed plastic outlet boxes. Wires penetrating these boxes should also be caulked to the box.

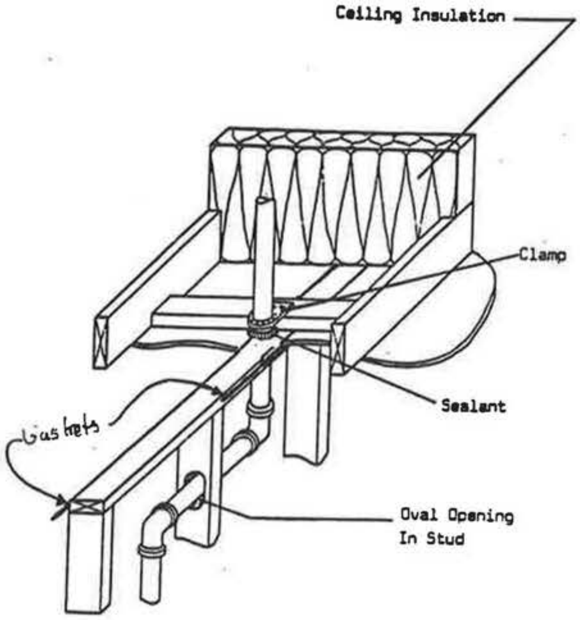


Figure 3-30 — Plumbing vent pipe

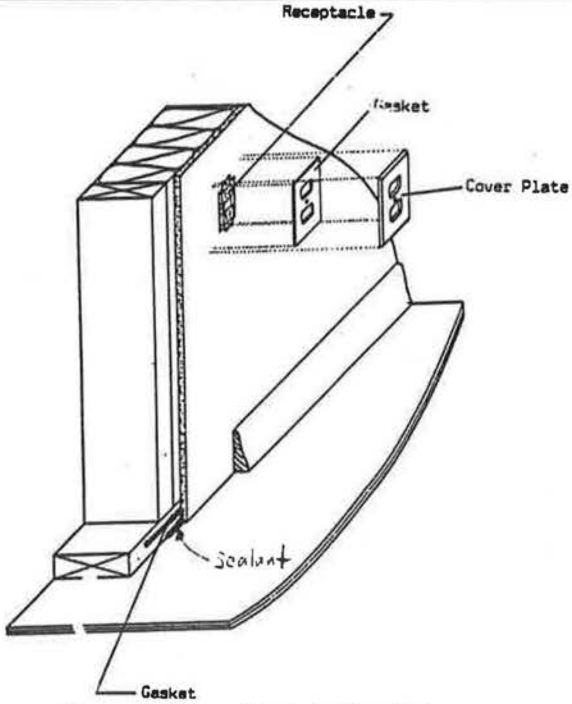


Figure 3-31 — Electrical outlet

Alternatively, it may not be necessary to penetrate the gypsum board or drywall on exterior walls if low-profile, surface-mounted boxes are located at baseboard level. Electrical wires are run directly down from the surface-mounted electrical box, through the floor sheathing and into the floor joist above. In this manner, no wiring penetrates the gypsum board or drywall air barrier. Local code requirements may limit the applicability of this surface-mounted approach.

Where possible, it is recommended that the number of ceiling fixtures be limited in insulated ceilings. It may be possible to replace switched ceiling lights in upper story bedrooms with switched wall plugs, placing the wall plugs on interior partitions. Should ceiling outlets on insulated ceilings be necessary, a wire can be dropped through a pre-positioned piece of wood blocking. A single hole is then left in the gypsum board for this wire, and the penetration is sealed with an appropriate sealant. A surface-mounted, low-profile, shallow saucer electrical box is then installed (Figure 3-32). When using this approach, only one wire can be installed in each saucer outlet and switching connections must be done at the wall-mounted boxes. This requires minor

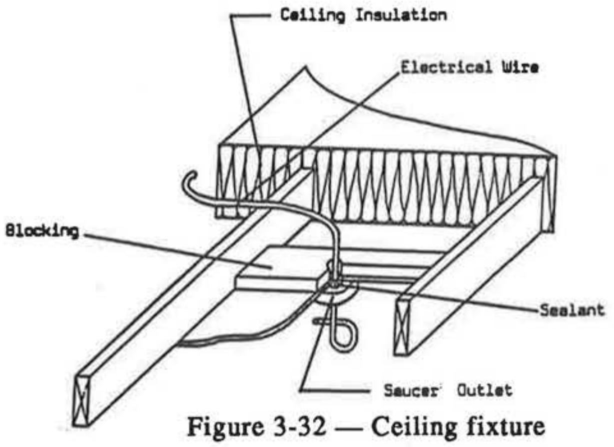


Figure 3-32 — Ceiling fixture

modification of conventional electrical wiring procedures.

Electrical panels installed in basements are mounted on a plywood or waferboard sheet. The basement gypsum board or drywall is installed to form a butt joint between this plywood or waferboard backing for the electrical panel and the resulting seam is sealed. Electrical wires running to interior partitions are run to the interior surface of this plywood or waferboard backing. The wiring for electrical outlets placed in the exterior walls in the perimeter basement walls is run through the plywood or waferboard backing. Sealing is required only where the electrical wire penetrates the plywood backing at this location. It is also recommended that an appropriate sealant be installed both in the main conduit supplying electrical power to the building and around the exterior of the pipe conduit itself.

It is recommended that electrical wires running from switches or outlets found on interior walls should not be run through exterior walls to the electrical panel. Instead, these wires should be routed down inside the interior walls and into the subfloor. In this manner they never penetrate the air barrier, and hence, do not need to be sealed.

Where electrical wires penetrate the top plates of partition walls, intersecting insulated ceilings at the first stud of an interior partition wall intersecting an exterior perimeter insulated wall, they must be caulked in order to maintain air barrier continuity.

Exterior Air Barriers (Housewrap)

The term "housewrap" was introduced by Dupont in 1982 when it first put Tyvek brand housewrap on the market. Tyvek was a "first of its kind" product, but not any more. Today there are several brands of housewrap, manufactured in different ways. The following section includes three articles that describe first Tyvek, then Parsec Airtight Wrap, and finally the variety of products that were introduced into the marketplace during 1986 and 1987.

What Is Tyvek?

If you ever read building trade magazines, you have probably seen advertisements for Tyvek house wrap from Dupont. Claimed to be a remarkable new energy-saving air infiltration barrier, it has been mentioned several times in Energy Design Update and is probably one of the most important energy-saving building products to come out in the past few years.

Actually, Tyvek is not new. Produced by Dupont as early as 1962, its largest application market has been envelopes. You have probably received a Tyvek envelope — the white slippery one that was impossible to tear with your hands. Other Tyvek applications include mattresses, furniture, protective clothing, banners, medical packaging, and computer floppy disk envelopes. While at the superinsulation conference in Minnesota, this editor purchased a "disposable" bathing suit from the hotel.

What was it made of? Right — Tyvek!

The Tyvek literature describes it as a "spun-bonded olefin" — an esoteric-sounding term to non-chemists. Actually Tyvek is made of common polyethylene — the same material used to make sheeting for vapor barriers and storm windows. "Olefin" is a generic term for a group of organic compounds. Polyethylene is one of many "olefins."

One note of clarification: there are two broad categories of polyethylene — high-density and low-density. High-density polyethylene is stronger, more resistant to oxidation, and more expensive to produce. Low-density polyethylene degrades more quickly due to molecular branching. Tyvek is high density. Common polyethylene sheeting purchased from a building materials supplier may be either high- or low-density. The polyethylene products you can buy from suppliers differ widely in many other ways as well. Some products are made from recycled materials, while others are made from virgin materials; some are treated with anti-oxidants, others not.

Tyvek sheets are formed by "spinning" polyethylene into short threads which are then sprayed into a mat and "bonded" together. Through careful process control, the mat is spun tightly enough to make a good air barrier while still remaining porous to water vapor. The "spun-bonded" polyethylene mat is also extremely strong. Evidently the process is very difficult to control; Dupont holds the process patent and is the sole manufacturer at this time. (Another product, "Parsec Airtight White," by Parsec Inc., Dallas, Texas, is actually Tyvek, manufactured by Dupont.)

What is Tyvek used for?

Dupont calls it a "house-wrap" or "air-infiltration barrier." When wrapped around the outside of a house, over the sheathing, Tyvek helps to prevent air from moving into or out of the wall insulation system. In attics, Tyvek laid down over loose-fill insulation prevents the insulation from blowing around in addition to preventing air flow into or out of the insulation.

An effective barrier makes the building envelope more thermally efficient in the following three ways:

1) It decreases air leakage through the building skin (infiltration). This is the most obvious benefit. Infiltration often accounts for 25 to 50 percent of the total heating/cooling load of a house. By sealing the outside of the building skin, the barrier reduces infiltration heat loss.
2) It prevents "one-sided" air intrusion. When air penetrates into and out of one side of an insulation system, as when attic ventilation air circulates over the top surface of the attic insulation, the thermal performance of the insulation can be degraded. The extent of the degradation is uncertain and there are conflicting research reports about the seriousness of the problem in houses. In any case, an effective air barrier should prevent any thermal degradation of the insulation system due to air intrusion.
3) It helps to keep moisture out of the insulation. The prime mechanism by which moisture gets into wall insulation is convective transport (see the September/October 1982 issue of EDU). Water vapor is carried into the insulation system by interior air leaking through the wall. Even with the air barrier installed on the outside, air leakage through the wall from the inside is reduced. With the outside of a wall sealed, air can't pass through in either direction — it has nowhere to go!

Why is Tyvek such a good product?

1. It is an air barrier but not a vapor barrier.

This is the number one advantage of this material. If Tyvek were a vapor barrier, like common polyethylene sheeting, it couldn't be used on the outside (cold side) of walls and ceilings.

According to Dr. Ronald Smorada, research chemist at the Spun-Bonded Division of Dupont, Tyvek has a "moisture vapor transport rate" of 795 grams per square meter per 24 hours. According to Smorada, roofing felt, when measured the same way, has a transport rate of only 11 grams per square meter per 24 hours.

Note: The actual amount of water vapor which can be passed through Tyvek depends on environmental conditions such as temperature and dew point. Also, different testing methods will give different results. The important point here is the relative transport rate of Tyvek compared to roofing felt — 77 times as high.

The following description of an experiment run by Dupont gives a more graphic illustration of Tyvek's vapor transmission properties:

A 20'x12' test room was built inside another enclosed building. The ceiling of the test room consisted of gypsum board with 6 inches of fiberglass insulation. No vapor barrier was installed. The test room was heated to 70°F and kept at 45% relative humidity. The temperature in the larger containment building ranged from 37° to 50°F.

Two experiments were run. First the top of the test room was covered with polyethylene sheeting, forming a vapor barrier on the wrong (cold) side of the insulation. Condensation built up very quickly on the polyethylene and wetted the insulation. This was as expected. Next, the polyethylene was removed, the insulation dried out, and the test room covered with Tyvek. Condensation never occurred. Evidently the Tyvek was able to pass all of the water vapor which was coming up through the insulation. Thus it was not acting as a vapor barrier.

2. It is very strong.

It is literally impossible to tear with bare hands and even difficult to puncture with a pencil.

3. It is inexpensive.

Prices range from 5 to 7 cents per square foot.

4. It is durable.

The life expectancy of Tyvek is at least 30 years.

Although it is sensitive to ultra-violet light, Smorada claims it won't degrade significantly unless left in the sun for a full year — not a severe problem. We've seen builders use Tyvek in sub-freezing weather. It gets a little stiff, but not brittle.

How much energy is saved by using Tyvek?

This is almost like asking "how tall is a house?" If you wrap a very loosely built house with Tyvek, you will probably reduce the infiltration rate and air intrusion considerably. On the other hand, in a superinsulated house with a good interior vapor barrier, the Tyvek is mostly "insurance" and may even be redundant (but still recommended). Predictions of exact savings from using Tyvek will probably never be possible. But given its low cost and ease of installation, it makes sense to use it in almost any new construction or re-siding project.

For more information

Tyvek is available in most areas of the U.S. through retail lumber yards. For technical information, contact: Richard D. Weimar, Jr., Dupont, Christina Laboratory, Wilmington, DE 19898; Tel: (302)774-0529.

A New Housewrap — Competition for Tyvek?

The first company to give Dupont any competition was Parsec, Dallas, Texas, and the product was Parsec Airtight Wrap. Parsec has been in the air-sealing product business for a long time. In fact, Nickey Naumovich, Jr., president of Parsec, holds a patent for sealing a house with an external membrane and pressure sensitive tape (Patent #4,328,652, issued May 11, 1982, for an "Insulated Structure and Method for Insulating a Structure"). The Parsec system for sealing exterior air barriers using its "Thermo-Brite" tape is definitely good. It also used to sell another product — Airtight White — which was actually Tyvek, produced by Dupont.

Airtight Wrap is completely different from Tyvek. Tyvek is a "spun bonded" material composed of thin plastic threads bonded into a mat that is porous enough to allow moisture transmission but tight enough to prevent excessive air leakage. Airtight White is a microperforated polyethylene film. It is made from 3-mil Valeron, a very tough laminated polyethylene film that is also sold (without the perforations) as Tu-Tuf and Ruffco vapor barriers.

The perforations are easily visible and are spaced about 3/16-inch apart from each other. According to Parsec, the microperforations allow a small amount of air and water vapor to pass through the film, retarding air flow enough to serve as an air barrier, yet allowing enough water vapor to pass through so as not to serve as a complete vapor barrier.

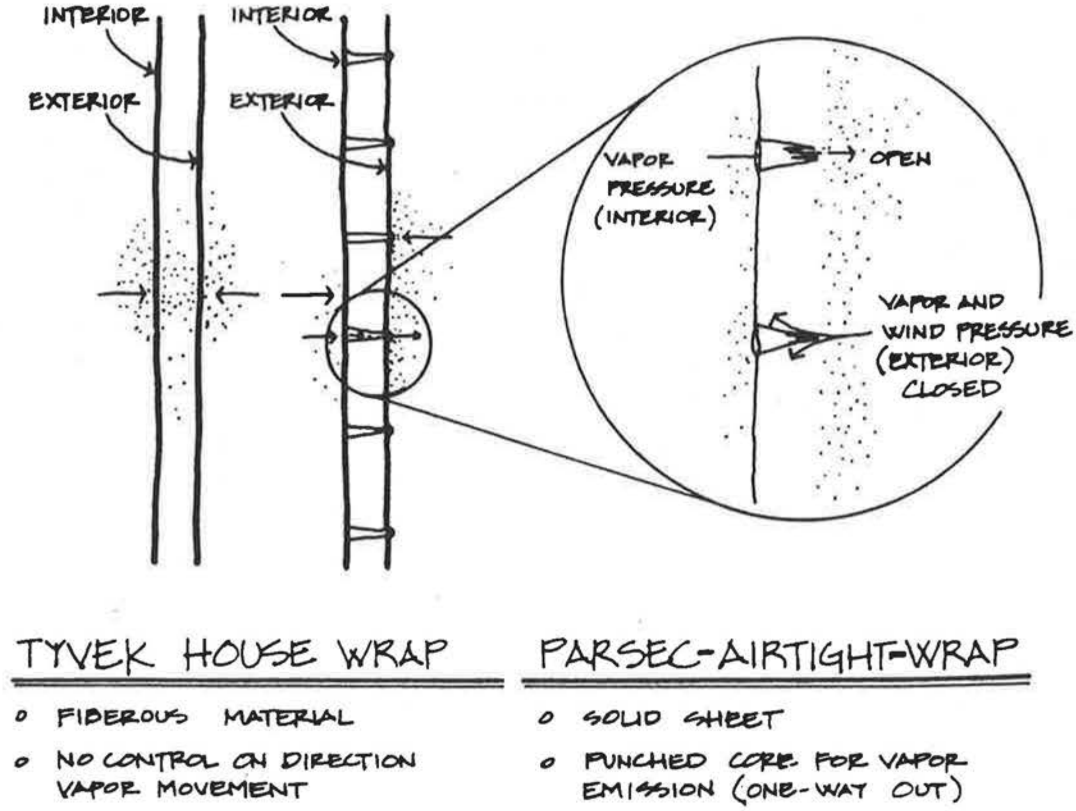


Figure 3-33 — Parsec Airtight Wrap "one-way valves."

One way valves?

When the holes are created in Airtight Wrap, the pins push the plastic up on one side, forming tiny "volcano-like" shapes. (You can feel them with your hand; one side is rough; the other side smooth). Parsec's theory is that those tiny volcanoes act as one-way valves which are forced closed by external wind and vapor pressure, but pushed opened by internal pressures (see Figure 3-33), thus allowing air and water vapor to move from inside to out, but not from outside to in.

While the idea of wrapping houses with a continuous one-way valve for moisture and air sounds great, we're a bit skeptical as to how well it really works. The diagram from the Parsec brochure (Figure 3-33), suggests that vapor pressure is partially responsible for opening and closing the valves. That's hard to swallow. According to Jesse Trevinio, product manager for Valeron at Van Leer, airflow through Airtight Wrap is equal in both directions.

UV degradation

Valeron is subject to ultraviolet degradation (as are almost all available polyethylene products). Parsec is well aware of this and recommends that it "not be exposed to weather and ultraviolet rays more than one week before it is covered with siding."

Compared to Tyvek

How good is the Parsec product and how does it compare with Tyvek? The most important properties for an air-barrier material are water vapor transmission rate, air leakage rate, and strength. All of these are measured by several different methods and unfortunately we weren't able to get good test results that allowed us to compare apples with apples. Tyvek is a strong material, but one of the problems encountered with it has been wind damage on site. The "new" Tyvek was produced to correct that problem (see the October 1985 issue of EDU). Valeron is also very strong and has been used successfully as a vapor barrier — as Tu-Tuf or Ruffco — by many builders with little or no damage problems.

In its promotional literature, Parsec challenges Tyvek head-on. First there are photos of Tyvek ripped and hanging loose from houses (in every case, the Tyvek name is visible, but upside down). Then there are laboratory test results comparing leakage rates of three test wall sections — one with just fiberboard sheathing, one with Tyvek, and a third with Parsec Airtight Wrap sealed at the joints with Parsec Thermo-Brite Tape. The wall with Tyvek showed almost six times as much air leakage as the wall with the Parsec product. But are those results due to the housewrap or the taping of the seams? What if the Tyvek had also been sealed with the Parsec tape? Chances are that both products would have worked about equally well. All in all, Airtight Wrap looks like a good idea and is probably just as good and possibly better than Tyvek (but certainly not six times better). The permeability is high enough to avoid forming an exterior vapor barrier and its tear resistance is very good. One possible disadvantage to this product is that it is available only in 54-inch widths. But to those who don't like Tyvek's cumbersome 8-foot or 9-foot rolls, that may be a welcome feature.

Price and Availability

Airtight Wrap is available either through Georgia Pacific or directly from Parsec. According to Naumovich, it sells for about 7-1/2 cents per square foot. For more information, contact Parsec, Inc., P.O. Box 38527, Dallas, TX 75238; (800)527-3454.

The Housewrap Wars

In the beginning there was Tyvek. Then came Parsec Airtight White, which was really Tyvek under a different name, followed by Parsec Airtight Wrap, then Rufco-Wrap, then VersaWrap and Air Seal. Finally Barricade and Typar.

One thing is certain. There is definitely a strong demand for housewrap. In fact, Dupont can't keep up with current orders for Tyvek and won't be able to meet demand until its new manufacturing facility in Luxembourg comes on line in 1988. No surprise then that competition has moved in. So what are these new housewrap products and how do they compare to Tyvek?

Three basic types

All the housewrap products currently available fall into three basic categories — spun-bonded polyethylene, perforated polyethylene, and spun-bonded polypropylene.

1. Spun-bonded polyethylene

This is Tyvek, the original housewrap. Thin filaments of polyethylene are "spun-bonded" into a mat through a patented Dupont process. The resultant mat is extremely strong, relatively impervious to airflow, yet highly permeable to water vapor. Tyvek, introduced in 1980, is the only product of this type.

2. Perforated polyethylene

As the name implies, perforated polyethylene is polyethylene film with holes. At last count, four companies were selling perforated polyethylene housewrap: Parsec Inc., Dallas, Texas, (Parsec Airtight Wrap); Raven Industries, Sioux Falls, South Dakota, (Rufco-wrap); Sto-Cote Products, Richmond, Illinois, (Tu-Tuf Air Seal); and Diversifoam Products, New Brighton, Minnesota, (VersaWrap).

All the perforated polys are actually the same product — Valeron, an extremely tough laminated polyethylene film manufactured by Van Leer Plastics, Houston, Texas. (See the November 1983 issue of EDU for a complete description of how Valeron is manufactured.) Regular Valeron, without perforations, is sold as a vapor barrier material under the names Tu-Tuf (Sto-Cote Products) and Rufco (Raven Industries). Perforated Valeron has been used in applications such as fruit sacks, where high strength and breathability are required.

3. Spun-bonded polypropylene

The latest material to hit the housewrap market is spun-bonded polypropylene. The only products of this type currently available are "Barricade," introduced in early 1987 by Simplex Industries, Adrian, Michigan, and Typar, by Intertech Group, Charleston, South Carolina. (Note: Typar was released just before this version of the EDU Workbook went to press and is, therefore, not reviewed in detail.) Like Tyvek, Barricade is formed by spin-binding plastic fibers into a mat. The main difference between Barricade and Tyvek is that the fibers in Barricade are polypropylene rather than polyethylene.

The bonded polypropylene mat used in making Barricade is relatively weak for stapling and probably not dense enough to effectively stop air infiltration. To overcome those problems, Simplex has done two things. First, it has incorporated reinforced edge and center strips for stapling. Second, it has applied a treatment to the polypropylene mat to decrease its air porosity. We were told by one source that the treatment consists of spraying with a polypropylene solution, but a spokesperson at Simplex would not confirm that, claiming that the treatment process is proprietary and as yet unprotected. Finished Barricade is translucent when in contact with a surface.

Which Housewrap Is Best?

Comparing Apples with Apples

Confronted with a growing variety of housewrap materials, the discriminating buyer will certainly want to carefully compare each product's physical properties and performance characteristics. Permeability, air porosity, tear resistance, cost, and ease of installation — all are important. The problem is that for each important characteristic, there are several test methods and, for some test methods, there are several ways for reporting the results. The situation makes it very difficult to compare "apples with apples."

Water Vapor Transmission

Housewrap material should have a high water vapor transmission rate (WVT) (high perm rating) to avoid creating an exterior vapor barrier (at least in cold climates).

The standard method for measuring WVT is ASTM E-96. A sample of the material to be tested is sealed over a large shallow dish containing either a desiccant (Procedure A) or water (Procedure B). The dish is placed in a chamber with controlled temperature and humidity. The amount of water vapor passing through the test material into the dish (Procedure A) or out of the dish (Procedure B) is measured through repeated weighings.

Here's the problem. Measured water vapor transmission will not be the same with Procedures A and B. Therefore, any comparison between two products will only be valid if the same procedure is used to test both of them. Unfortunately, not all manufacturers use the same test procedure. Even worse, some manufacturers don't even indicate which procedure was used for the tests of their products. The problem is exacerbated by the fact that, in addition to Procedures A and B, ASTM E-96 includes four other procedures (Procedures BW, C, D, and E)! Each differs as to test temperature and cup configuration and each will produce different results for the same material. Raven Industries, for example, publishes results for Procedure C which measures WVT at 90°F (Procedures A and B call for 73.4°F.)

Finally, not everybody expresses the results of the ASTM tests in the same units. The standard unit is the perm (grains per hour per square foot per inch mercury vapor pressure). But Dupont, for example, expresses the permeance of Tyvek in units of grams per 100 square inches per 24 hours. Unless you know the proper conversion factor, a comparison between Tyvek and a product rated in perms is extremely difficult.

The following table should help. In it, we have compared published WVT results for various types of housewrap products. All units have been converted to perms. When known, we have listed the test method used.

Technically, all these materials have high enough water vapor transmission rate to allow walls to "breathe" to the outside. In fact, all of them are several times more permeable than exterior grade plywood sheathing. However, given the possibility of excessive moisture buildup in walls due to air leakage and, unlike with plywood, the lack of open seams (particularly when taped), we believe the use of perforated polys in cold climates should be carefully evaluated because of their relatively low water vapor transmission rate.

Air Porosity

To effectively reduce air leakage, a housewrap product should have low air porosity. Unfortunately, comparing the air porosity of these products is even more difficult than comparing water vapor transmission. An examination of manufacturers' literature will show two basic test reports — ASTM E-283 and the "Gurley-Hill Porosity Test."

TABLE 1
Listed Water Vapor Transmission Rate In Perms for Various Housewrap Products

Product	WVT (perms)	Test Procedure (ASTM E-96)	Source
Tyvek	48	A	Dupont wallet factsheet
"	85-95	Unknown	Dupont Technical Update
Parsec Airtight Wrap	12	Unknown	Dupont wallet factsheet
"	15	A	Parsec brochure
"	17	B	Parsec brochure
"	26	C	Parsec brochure
Rufco-Wrap	26	C	Raven factsheet
"	12	Unknown	Dupont wallet factsheet
Barricade	33	Unknown	Dupont wallet factsheet
"	37	A	Simplex (personal communication)
"	70	B	"

ASTM Test Results Are Often Meaningless

ASTM E-283 is the "Standard Test Method for Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors." A wall assembly to be tested is fitted into one side of a test chamber. The chamber is pressurized to simulate some predetermined amount of wind force against the test wall. Air leakage through the test wall assembly is calculated by measuring the amount of air required to maintain pressure in the test

TABLE 2
Air Leakage Reduction Test Results (ASTM E-283.)

Product	Measured Air Leakage (cfm) Without Housewrap	Measured Air Leakage (cfm) With Housewrap	Percent Reduction	Source
Parsec Airtight Wrap	243.5	18.5	92.4% (sealed at seams)	Parsec brochure
"	243.5	77.5	68.2% (not sealed)	Parsec brochure
Rufco-wrap	56.8	21.4	62.3%	Rufco-Wrap brochure
Tyvek	NA	NA	88.2 to 98.9%	BOCA Report #79-34
"	NA	NA	61%	Raven Industries factsheet

chamber. To evaluate housewrap, a wall assembly is tested with and without the housewrap installed. The reduction in air leakage after applying the housewrap is typically expressed as a percent. Table 2 shows some results published by housewrap companies for ASTM E-283 tests of their products.

Here's why comparative results from this test are often meaningless. If the test wall is initially very leaky, then the housewrap will cause an enormous reduction in air leakage. But if the test wall is initially tight, then the housewrap will have little effect. (Compare the difference in leakage of the wall without housewrap in the Parsec and Rufco-Wrap test.) Since there is no "standard" base case wall in the ASTM procedure, the test can be configured to produce almost any result. Furthermore, the test is measuring the seal at joints, seams, and penetrations as well as tightness of the housewrap material itself.

The NAHB tests

The NAHB Research Foundation was commissioned by Dupont to perform comparative tests on Tyvek and Parsec using the ASTM method. Under the supervision of Christopher Mathis, research engineer at the Research Foundation, an extensive bank of carefully controlled tests were performed. (The testing was actually performed by a third-party independent certified laboratory.)

TABLE 3
NAHB Research Foundation Air Leakage Test Results.
(All measurements are at 50 pascal pressure)

Test Configuration	Init (cfm)	Final (cfm)	Reduction (%)
Tyvek, untaped	46.2	21.2	54%
Parsec, untaped	46.2	19.2	58%
Tyvek, taped	46.2	9.5	79%
Parsec, taped	46.2	15.2	67%
Tape without housewrap	61.4	15.4	75%

Forty separate tests were run on three identical wall sections. Some of the most illuminating results are shown in Table 3. Notice that when the window flange and ends were not taped, Tyvek stopped about 54% of the air leakage compared to the base case wall. With taping, the reduction jumped to 79%. Parsec was slightly more effective than Tyvek when untaped, but less effective when taped. But look at the result of the test wall with no housewrap. Taping alone reduced the total air leakage by 75%!

What do these test data mean? If taken at face value, they might indicate that taping alone is almost as good as housewrap, so why bother with the housewrap? But notice that the actual leakage through the wall with tape alone is about 63% higher than the wall with taped Tyvek. (Two different test panels were used for these tests, but they were of identical size and construction.) Do any of the percent reduction figures have meaning? If so, which ones? Does Tyvek perform better than Parsec? Does tape alone perform better than Parsec?

The Gurley-Hill Porosity Test

The Gurley-Hill porosity test is a laboratory test that evaluates the air porosity of a material by measuring the time required to pass a given volume of air through a sample of the material under a specified pressure. Used mostly by the paper industry, it is prescribed as Method T-460 of the Technical Association of the Pulp and Paper Industry (TAPPI). The results are expressed in seconds per 100 cc of air or just seconds. The higher the measured time in seconds, the better the material as an air barrier. A brief examination of manufacturers' published values for measured Gurley-Hill tests shows several contradictions:

TABLE 4 — AIR POROSITY MEASURED WITH GURLEY-HILL POROSIMETER

Product	Porosity (sec/100cc-sq.in.)	Source
Tyvek	17.6	Tyvek brochure
"	7.6	BOCA Report #79-34
Barricade	10.5	Barricade brochure
"	5.0	Dupont wallet factsheet
Parsec Airtight White	7.0	Dupont Technical Update
"	8.7	Dupont wallet factsheet

The most noticeable contradictions are those values listed by Dupont and Simplex comparing each other's product. Simplex's promotional literature emphasizes the very poor 7.6 porosity listed for Tyvek in the BOCA Research Report. But Dupont claims that the 7.6 figure is a typographical error, that the "1" was left off before the 7.6 and that the actual value is 17.6 seconds, as listed above. You might wonder, however, why Dupont hasn't had a new report generated, since the date of the BOCA listing is 1979! According to Mark Vergnano, marketing specialist at Dupont's Fibers Marketing Center, they are in the process of having new tests performed.

On the other side, Dupont lists a poor 10.5 seconds for Barricade compared to Simplex's claim of 5.0. No explanation was available for that discrepancy.

[NITPICKER'S DELIGHT — For those technical folks who delighted in renaming vapor barriers to vapor retarders, since no material was a complete vapor barrier, there is now a new opportunity. As shown by the Gurley-Hill tests, none of these housewrap materials are complete air barriers. That's right — air retarders.]

Strength

Gathering comparable laboratory measurements for the strength and tear resistance of these products is even more difficult than getting WVT and air porosity data. We finally gave up.

Roughly speaking, Tyvek and the perforated polys are about equally tear resistant, although the polys might be slightly stronger. Barricade is definitely weaker, except at the reinforced stapling strips.

Ease of Installation

Tyvek and Barricade come in 3-foot, 4.5-foot, and 9-foot rolls. The perforated polys come in 4.5-foot rolls and J-folded 9-foot rolls. Which is easiest is pretty much a matter of personal preference.

The Envelope Please

Given the available data, our recommendation at this time is to stick with Tyvek, but keep an eye on the new products, particularly Barricade. Regarding the perforated polys, we are concerned about the long-range permeability. Will the tiny perforations close up over time? When the holes are created in Valeron, pins push the plastic up on one side, forming tiny "volcano-like" shapes. What happens when the material is tightly sandwiched between sheathing and siding? Might the "volcanoes" get crushed shut?

Our main reservation about Barricade is strength. To be fair, we must admit that our evaluation is based on a very small test sample and we were not able to interview any builders in the field who have used the product yet. However, based on the quick and dirty hand-tear test, Barricade is nowhere near as strong as Tyvek. If it can withstand normal jobsite abuse without damage, then it would be as attractive as Tyvek.

For More Information

Barricade
Simplex Products Division
Anthony Industries
P.O. Box 10
Adrian MI 49221-0010
(517)263-8881

Tyvek
Dupont Company
Textile Fibers Department
Wilmington, DE 19898

VersaWrap
DiversiFoam Products
1901 13th Street, N.E.
New Brighton, MN 55112
(800)752-4306

Parsec Airtight Wrap
Parsec, Inc.
P.O. Box 38527
Dallas, TX 75238
(800)441-0324

Rufco-Wrap
Raven Industries, Inc.
P.O. Box 1007
Sioux Falls, SC 57117-1007
(800)227-2836

Moisture Principles — Supplemental Information

The following three articles contain important practical information for understanding the principles and practice of moisture control in housing.

Yes You Do Need A Vapor Barrier, Sometimes

Is vapor diffusion an important mechanism of moisture transport?

In the February 1986 issue of EDU's Research & Ideas section, we mentioned that some researchers are beginning to suggest that vapor barriers (retarders) may in fact be superfluous. We cited studies performed by Dr. George Tsongas at Portland State University that showed no evidence of moisture damage in walls without vapor barriers, even in cold climates. This new thinking falls in line with the recent popularity of the Airtight Drywall Approach, developed by Joe Lstiburek, in which painted drywall serves as the vapor barrier and air barrier; the polyethylene vapor barrier is eliminated. But a research project just completed by the Manville Service Corporation sheds some new light on the issue, suggesting that an effective vapor barrier, whether it be polyethylene or some other material, may in fact be very important to prevent moisture problems. Over the past ten years, it has become apparent to the building research community that air leakage is the dominant mechanism by which water vapor is transported into wall and ceiling cavities. Whenever the air pressure indoors is positive relative to outdoors, moist air is forced into wall cavities. Vapor diffusion — the transport of water vapor through solid vapor-permeable surfaces such as plaster and drywall — is now known to be minor in most cases compared to air leakage. Thus, to stop water migration into walls, the important building component is an air barrier, which stops air leakage. Of secondary importance is the vapor barrier, which stops vapor diffusion.

Vapor diffusion CAN cause moisture problems.

In 1985, the Manville Service Corporation, under a grant from the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), conducted a series of lab experiments to test the magnitude of vapor transport by air leakage and by vapor diffusion.

A test wall was built of 2x4 framing insulated with fiberglass batts. The interior surface was 0.5-inch gypsum board. Aluminum siding over 0.5-inch asphalt saturated wood-fiber sheathing board constituted the exterior surface. Three series of tests were run with different types of vapor barriers:

1. "Excellent" vapor barrier

Polyethylene film was installed under the gypsum board. There were no penetrations in the poly.

2. Poor vapor barrier

No polyethylene film was installed. Instead, the gypsum board was painted with two coats of ordinary latex paint.

3. Point-source air leak in vapor barrier

Polyethylene film was installed under the gypsum board and was penetrated by a single electrical box with receptacle and cover plate.

The test wall was installed in an apparatus that simulated winter conditions in a northern winter climate. Air on the warm side was maintained at 70°F, at 50% relative humidity. Air on the cold side was kept at 20°F.

The test was repeated several times with different relative air pressures between the warm and cold side. The purpose of varying the air pressure was to see the difference in rate of moisture transport under positive pressure (air leaking outward) and negative pressure (air leaking inward). Outward leakage should result in moisture deposition in the wall; inward air leakage should have a drying effect. Each day, the test wall was weighed to measure how much moisture had accumulated. (Those results are shown in Figure 3-34.) The thermal conductivity of the insulation was also measured to check for any decrease in R-value.

Results of the Manville Vapor Barrier Experiment

Excellent vapor barrier

With the excellent vapor barrier, there was a measurable but insignificant accumulation of moisture in the wall when the indoor air pressure was positive or neutral. Under negative pressure, there was actually a slight decrease in moisture content in the wall. According to the principal investigator in the project, the slight moisture loss was probably due to air leakage around the gypsum board screws (the gypsum board was unpainted for this test).

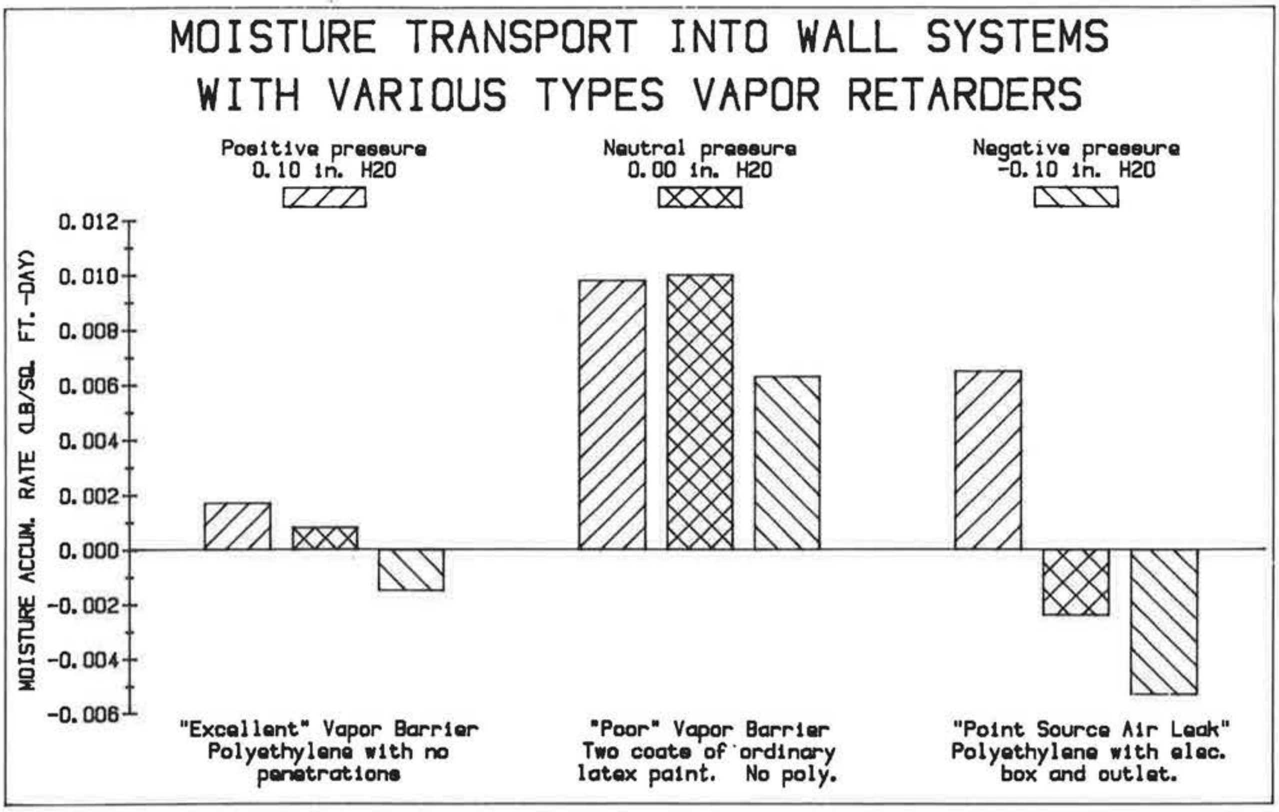


Figure 3-34 — Results of the Manville experiment

Poor vapor barrier

This is the most important result of the study. Without a polyethylene vapor barrier, there was considerable moisture transport into the wall, even when the room was under negative pressure! This is moisture transport by diffusion and is not stopped by an air barrier. The two coats of latex paint did not provide enough resistance to vapor diffusion. When the wall was disassembled after this test, there was more than 500 percent moisture by weight in the coldest insulation layer, next to the sheathing. The moisture increased the heat flux an estimated five percent.

Point-source air leak in vapor barrier

This test held little surprise. Under neutral or negative pressure, the wall lost moisture due to the drying effect of infiltrating cold air. Under positive pressure, the wall gained moisture due to the exfiltrating high humidity air. However, the moisture gain under positive pressure was not as great as that in the wall with the poor vapor barrier.

Observations and Conclusions from the Manville Study

1. Vapor diffusion through painted gypsum board can be significant.

Under the test conditions in the Manville study, 0.01 lbs of water per square foot per day accumulated in the test walls. That means that in a 1000-square-feet wall, 10 pounds of water would accumulate per day!

2. Polyethylene vapor barriers significantly retard vapor diffusion.

The results shown in Figure 3-34 indicate that with a polyethylene vapor barrier installed, vapor diffusion is insignificant.

3. Regular latex paint is not a good vapor barrier.

Although low-permeability paints probably serve very well as a vapor barrier, the ordinary paint used in this study did not. If paint is to serve as the vapor barrier, then it should be stressed by the designer that low-permeability paint be used. This could present a problem, since in some situations interior paint selection may be out of the control of the designer or builder.

The Obvious Question

The question you've probably already asked is "If the absence of a good vapor barrier results in such a high rate of moisture transport, why don't we see more moisture condensation problems in houses without vapor barriers?" The answer has partly to do with the relative magnitude of the "vapor drive" in the Manville tests. The high temperature and humidity on the warm side of the test wall, together with the cold temperature on the cold side, create a strong pressure differential "driving" moisture into the wall.

A full copy of this paper (ASHRAE #85-2914) was published in the 1985 ASHRAE transactions. For more information, contact ASHRAE, 1791 Tullie Circle, N.E., Atlanta, GA 30329; (404)636-8400.

Psychrometrics for Builders and Designers

With the advent of more-sophisticated envelope design for houses, it has become increasingly important for residential designers and builders to understand psychrometrics — the behavior of moist air under various temperature and humidity conditions.

One basic tool is the "psychrometric chart." A full psychrometric chart includes hundreds of lines, which describe the physical properties of air over a broad range of temperatures. Most people get dizzy just looking at a complete chart and to master its use is a challenge even for many engineers. Figure 3-35 is a simplified version of the psychrometric chart. The horizontal axis represents dry-bulb air temperature (dry-bulb temperature is what we're all used to, measured with an ordinary thermometer). The curved lines represent relative humidity.

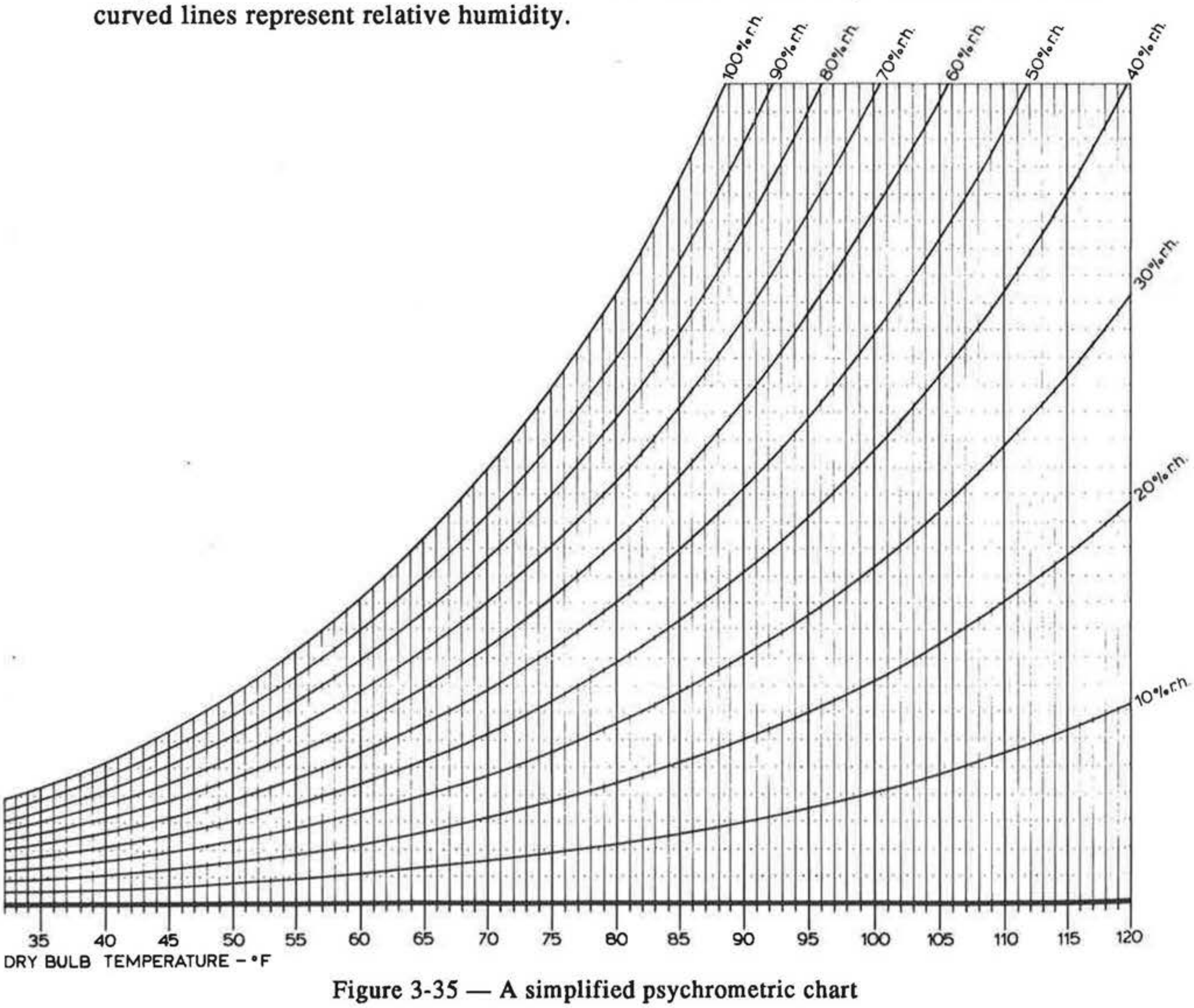


Figure 3-35 — A simplified psychrometric chart

In this article we will show how this simplified chart can be used by designers and builders to address several practical moisture-related design issues.

Predicting Moisture Condensation with the Psychrometric Chart

Some common questions.

1. During summer, will condensation occur on an uninsulated basement floor in a warm climate if the basement is ventilated with outdoor air?
2. During winter, will condensation occur on ventilation intake ducts located in a heated basement?
3. Under what conditions will condensation occur on cold water pipes?
4. If a wall is insulated with R-19 fiberglass batts plus R-7 exterior foil-faced foam sheathing, will condensation occur on the inner foil face of the sheathing?

Finding the Answers

To predict whether or not moisture condensation will occur on a certain surface, you need to know three things:

1. The temperature of the air.
2. The relative humidity of the air.
3. The temperature of the surface in question.

Moisture condensation occurs when air is cooled below a certain critical temperature called the "dew point temperature."

If the Temperature of a Surface Is Below the Dew Point Temperature of the Air, Condensation Will Occur

If we know the temperature and relative humidity, it is easy to determine the dew-point temperature of an air mass by using the psychrometric chart. The following four examples show how to use the chart to determine dew point temperature and to predict condensation conditions. The first three examples deal with surface condensation on basement floors, ventilation ducts, and cold water pipes. Example 4 is a slightly more complex situation, in which we look at the possibility of concealed condensation inside a wall section.

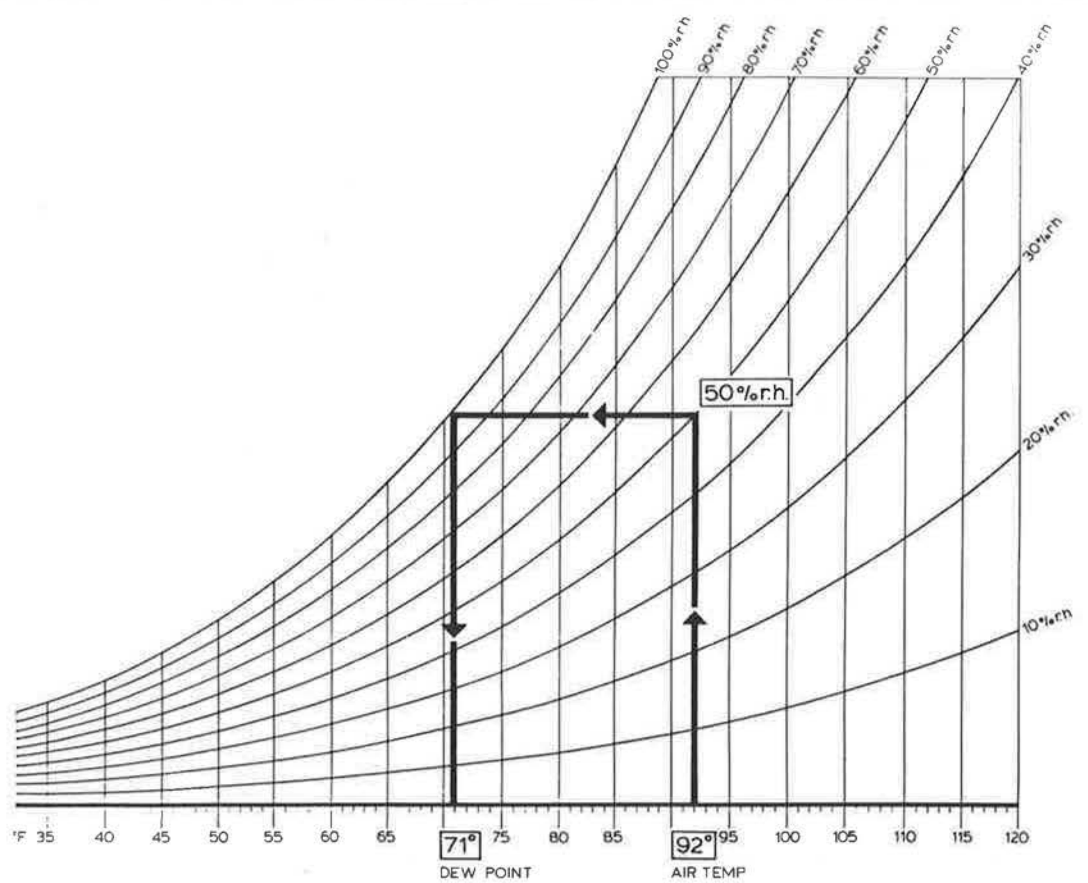


Figure 3-36 — Finding the dew point temperature of air at 92°F and 50% rh.

Example 1: Condensation on basement floors

In warm climates, some designers intentionally avoid sub-slab insulation under basement floors to derive some benefit from ground-coupled cooling. But sometimes those slabs get wet and although the first suspected culprit is groundwater, moisture condensation from interior air may actually be the source. In those cases, it may be advisable to insulate the slab to prevent surface condensation.

As an example, let's look at Houston, Texas, where summer design conditions are about 92°F and 50% relative humidity. If a basement in Houston is ventilated with outdoor air during the summer, is condensation likely to occur on the uninsulated basement floor? The average ground temperature at 2- to 12-foot depth is about 79°F in summer.

Solution (Figure 3-36)

To answer the question, we use the psychrometric chart to determine the dew-point temperature of the air. If the surface temperature of the floor is below the dew-point temperature of the air, condensation will occur.

Here's how to use the chart:

1. Find 92°F on the horizontal axis.
2. Follow the line vertically up to the intersection of the curved line marked 50% rh.
3. Proceed horizontally to the left to the intersection with the curved line marked 100% rh.
4. Finally, proceed vertically down to the horizontal axis and read the dew-point temperature — about 71°F.

In this instance, the dew-point temperature of the air is 71°F. Since the average ground temperature in summer, about 79°F, is not below the 71°F dew-point temperature, condensation should not occur.

Example 2: Condensation on ventilation ducts

If fresh air intake ducts for a ventilation system are located in a heated basement, will moisture condense on the outer surface? If so, what should be done?

Solution (Figure 3-37)

To answer the question, we first determine the dew-point temperature of the indoor air using the psychrometric chart. Next, we estimate typical duct surface temperatures to see if they fall below the air dew-point temperature. Let's assume the indoor air is at 70°F and 40% rh. The method for determining dew-point temperature is the same as in Example 1.

1. Using the chart, find 70°F on the horizontal axis.
2. Proceed vertically to the curved line marked 40% rh.
3. Proceed horizontally to the left to the intersection with the curved line marked 100% rh.
4. Finally, proceed downward and read the dew-point temperature — 44°F — on the horizontal axis.

Under these indoor conditions, condensation will occur on any surface with a temperature below 44°F. If winter outdoor air temperatures are often below 44°F for extended periods of time, then condensation on the duct surface will definitely be a problem.

To alleviate the problem, the fresh air intake duct should be insulated.

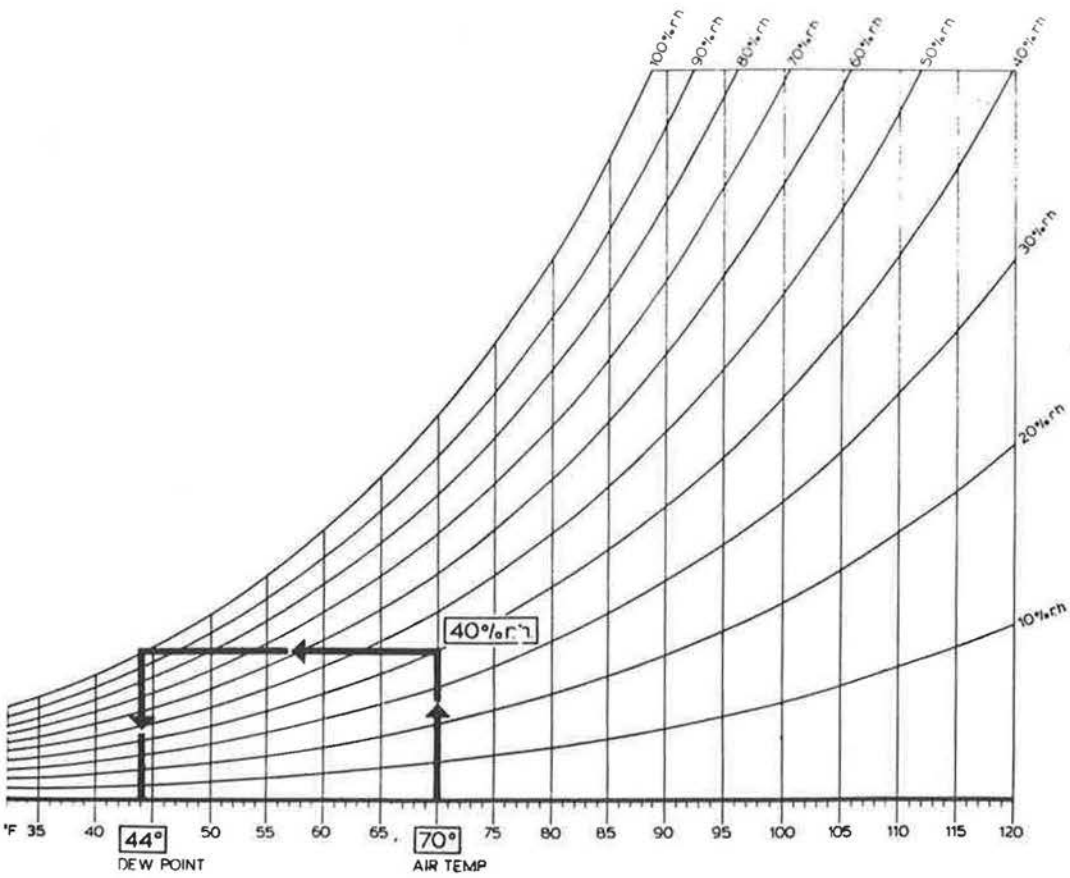


Figure 3-37 — Finding the dew point temperature of air at 70°F and 40% rh.

Example 3: Condensation on cold water pipes

Suppose one of your customers discovers water in the plumbing wall behind the bathroom. He suspects a plumbing leak, but there doesn't seem to be enough water for that. He is an elderly man and keeps the house at about 78°F. When you visit the house, you measure the relative humidity at 50%. Could the problem be condensation on the cold water pipes? The house uses well-water from a deep well. The water temperature is about 45°F.

Solution (Figure 3-38)

Using the psychrometric chart (Figure 3-38), we see that the dew-point temperature of air at 78°F and 50% rh is about 58°F. Since the cold water temperature is below that (45°F), condensation is probably occurring on the pipes. To remedy the situation, either the relative humidity of the house should be reduced and/or the cold water pipes should be insulated.

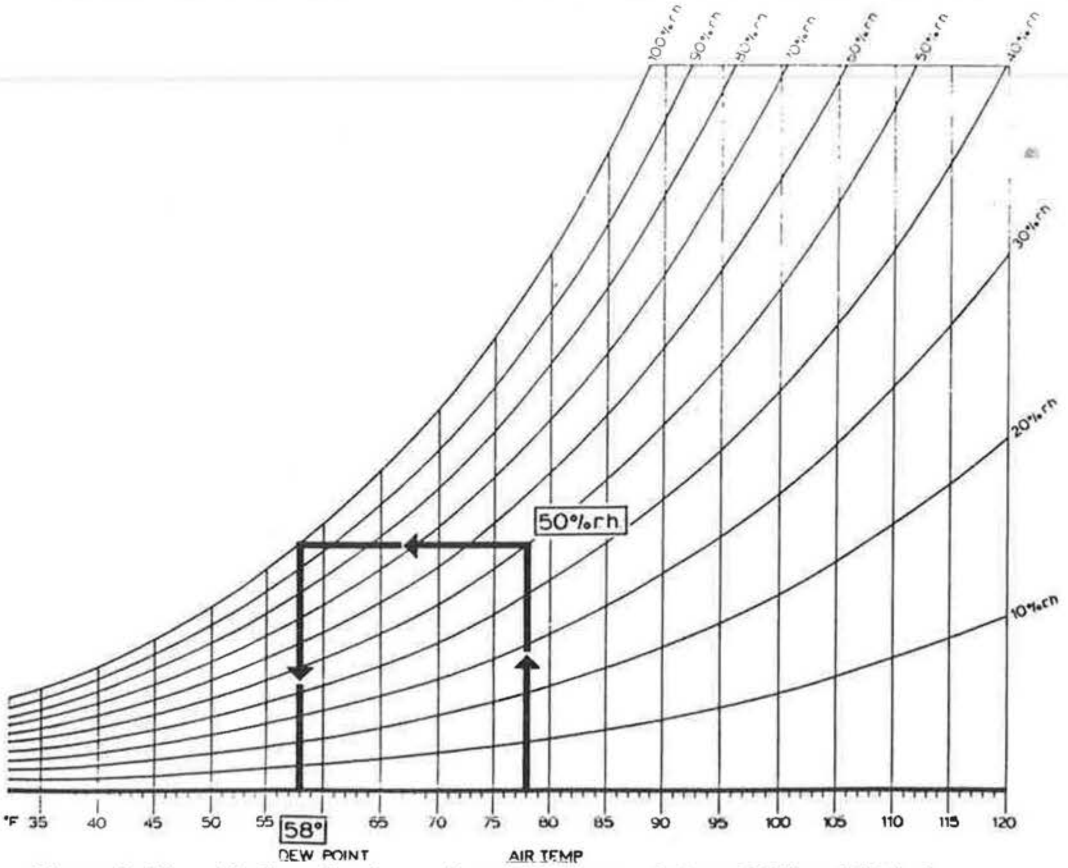


Figure 3-38 — Finding the dew point temperature of air at 78°F and 50% rh.

Example 4: Concealed condensation in an insulated wall

Suppose you have designed a wall with 6-inch (R-19) fiberglass batts plus foil-faced exterior foam sheathing (R-7). Since the foil-faced sheathing creates a vapor barrier on the cold side of the fiberglass insulation, there is some concern that condensation might occur on the foil if moist indoor air leaks into the wall cavity. (No condensation will occur if the temperature of the foil is above the dew-point of the air.) Under average winter conditions, say 35°F outdoor air temperature, will the temperature of the foil facing be above or below the dew-point temperature of the indoor air?

Solution

This example is slightly more complex because you need to calculate the temperature of the foil. Since there is insulation on both sides (foam on the outside; fiberglass on the inside), the foil temperature will be somewhere between the indoor and outdoor air temperatures.

The following simple procedure can be used to calculate the temperature at any point (P) inside a wall.

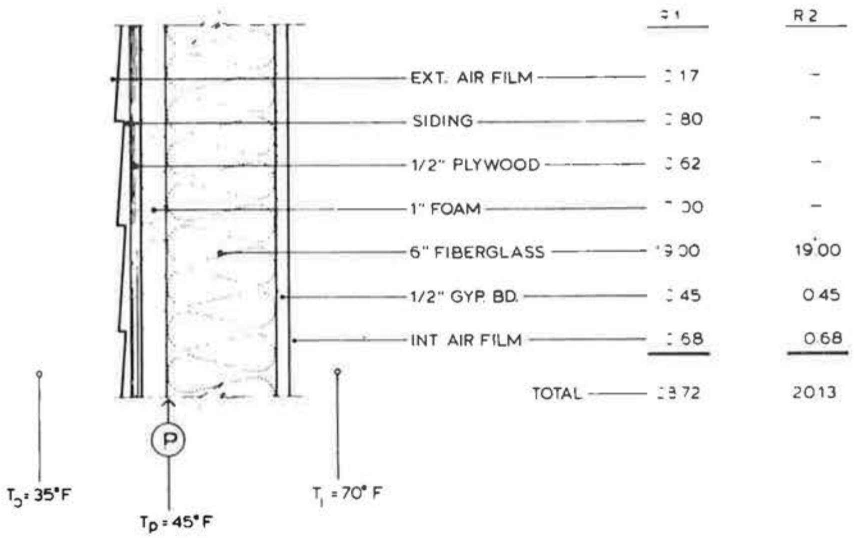


Figure 3-39 — Finding the temperature at a point P in a wall

1. Calculate the total R-value of the wall. Call this R1.
2. Calculate the R-value of the wall from the inside air to the point (P) that you are interested in. Call this R2.
3. Ti = Indoor temperature
   To = Outdoor temperature
4. Tp = Temperature at point P.

To find Tp, use the following equation:

$$Tp = Ti - ((Ti - To) \times (R2/R1))$$

For this example, we need to find the temperature of the foil when the indoor temperature (Ti) is 70°F and the outdoor temperature (To) is 35°F. The R-values are taken from Figure 3-39.

1. R1 = 28.72
2. R2 = 20.13
3. Ti = 70°F
   To = 35°F
4. Tp = 70 - ((70-35) x (20.13/28.72)) = 45°F

Thus the temperature of the foil surface will be 45°F when the outdoor air is 35°F and the indoor air is 70°F.

In Example 2, we found that the dew-point temperature of air at 70°F and 40% rh is about 44°F (Figure 3-37) — slightly below the 45°F foil temperature. Thus, no condensation should occur under these temperature conditions. It is, however, a borderline case; if the outdoor air temperature were to drop, condensation might occur.

You can perform this calculation for any wall design and temperature regime. Keep in mind that it cannot exactly predict when condensation will occur because of complicating factors such as parallel heat flow through studs, insulation imperfections, air leaks etc. (see Design & Construction Tips, in the February 1985 issue of EDU). Also, keep in mind that moisture condensation in walls with exterior sheathing is quite complex and not fully understood. In many cases, no evidence of condensation is found even though calculations show that it should occur. But the calculations are good insurance. If they show that condensation will not occur under average winter conditions, then you can confidently assume that no moisture problems from condensation will occur.

Understanding "Dry Winter Air"

At an EDU superinsulation seminar in Cleveland, one builder in the audience asked why outdoor air could be used to lower the humidity in a house even though the outdoor air may have a relative humidity as high as 70% and the indoor air may have a lower relative humidity of say only 50%.

The explanation is actually quite simple. "Relative humidity" is a measure of "percent saturation" of water vapor in air. Cold air can hold less water vapor than warm air. For example, air at 35°F can hold a maximum of 0.0043 pounds of moisture per pound of dry air at saturation. If outdoor air at 35°F has 70% of that amount of moisture (0.0030 pounds per pound dry

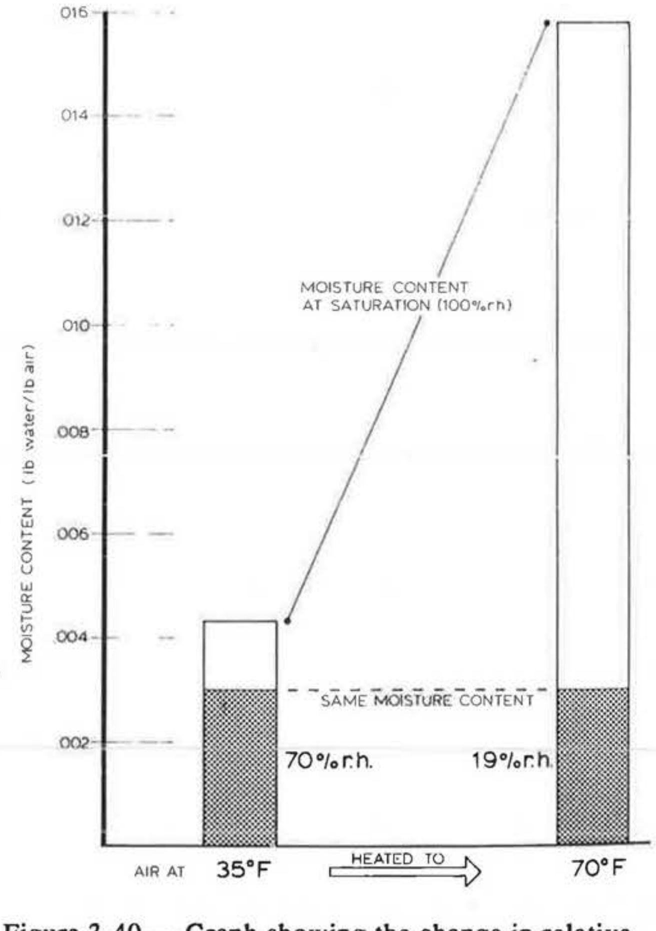


Figure 3-40 — Graph showing the change in relative humidity of air at 35°F and 70% rh when heated to 70°F with no moisture added or removed.

air), we say it is 70% saturated and has a relative humidity of 70% (see Figure 3-40). Now suppose we bring outdoor air at 35°F and 70% rh into a house and heat it to 70°F. Let's assume no moisture is added or removed from the air. At 70°F, air can hold 3.4 times as much moisture as air at 35°F (0.0158 lb per lb dry air). Thus, even though this air was nearly saturated when it was outside (70% rh), it is nowhere near saturated when it is brought indoors and heated. In fact, the relative humidity is now only 19% (see Figure 3-40).

The change in relative humidity when dry winter air is brought into a house is easy to determine using the psychrometric chart. Here's a quick example:

Example 5

If outdoor air has a temperature of 40°F and a relative humidity of 60 percent, what will be its relative humidity if it is brought into a house and heated to 75°F?

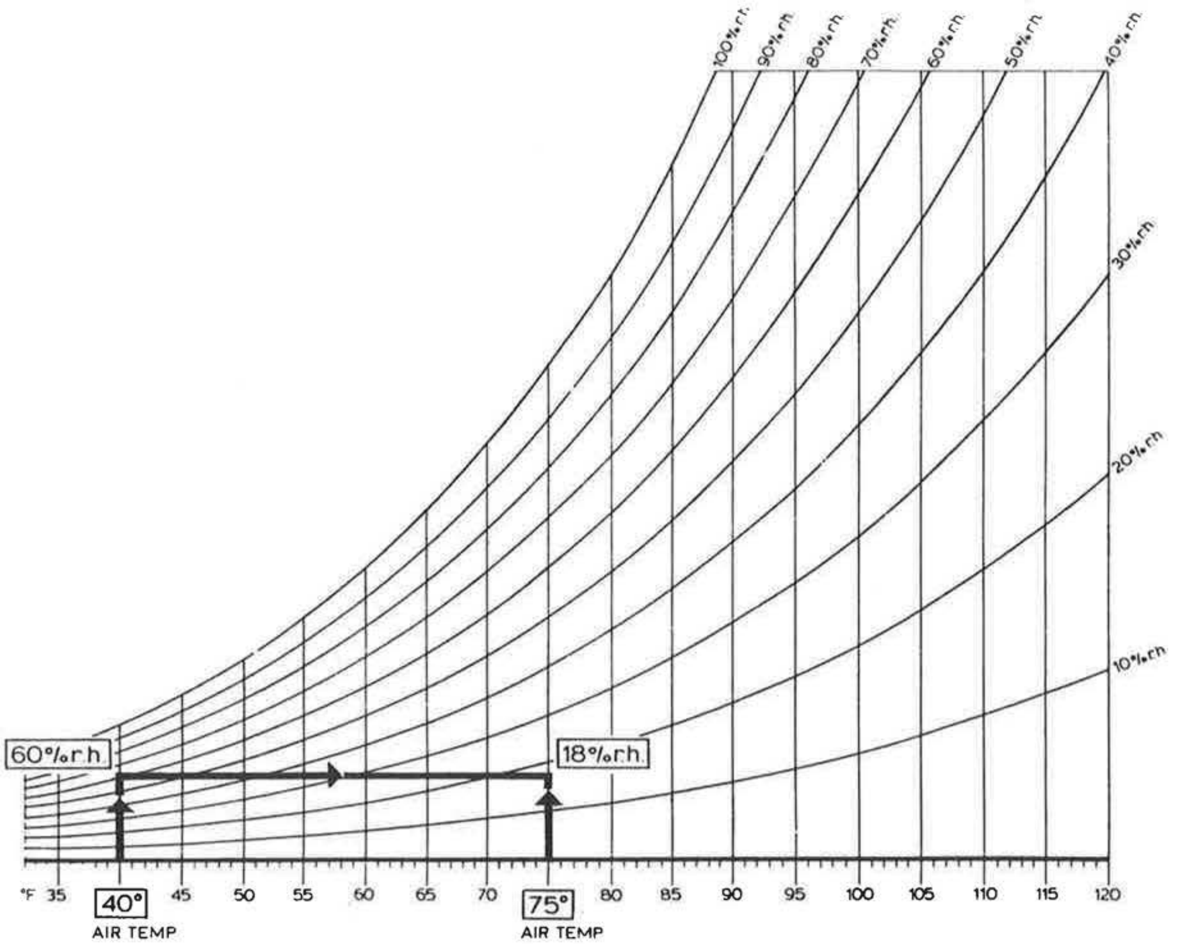


Figure 3-41 — Finding the relative humidity of air at 40°F and 60% rh when heated to 75°F.

Solution: (Figure 3-41)

1. Find 40°F on the horizontal axis.
2. Proceed vertically to the intersection of the curved line marked 60% rh.
3. Proceed horizontally to the right to the intersection with the vertical line marked 75°F.
4. The relative humidity of the air is read from the curved lines. In this case, it is between 10% and 20% — about 18%.

In this situation, if no moisture were added to the air from indoor sources, the indoor relative humidity would be 18%. Of course if the house is occupied, quite a bit of moisture is given off from occupant activity and the actual indoor relative humidity will be somewhat higher, depending upon the rate of indoor moisture generation and outdoor air leakage and ventilation.

For more information on the use of the psychrometric chart, see the ASHRAE Handbook of Fundamentals, published by ASHRAE, 1791 Tullie Circle N.E., Atlanta, GA 30329.

Wood and Water

How much moisture does "dry" lumber contain? How does the moisture content change after installation in a building? Does the relative humidity of the air control wood moisture content? Can high relative humidity cause wood decay and structural damage? What other effects does moisture content have on the physical properties of wood? These and other questions continuously arise as modern building techniques, especially energy-efficient construction, proliferate. Although several mysteries still surround moisture dynamics in buildings (see the November 1984 issue of EDU), the effects of moisture on wood are fairly well known. The following article draws on information contained in The Wood Handbook, published by the U.S. Department of Agriculture. It addresses the several questions mentioned above, with emphasis on applications in highly-insulated structures.

What is meant by "wood moisture content"?

Moisture content of wood is defined as the weight of water in wood, expressed as a percentage, of the weight of oven-dry wood. This is sometimes confusing. If a sample of wood has 20 percent moisture content, then the weight of water in the sample is 20 percent of the weight of the dry wood in the sample, not 20 percent of the total sample weight. For example, 100 pounds of wood with a moisture content of 20 percent contains 17 pounds of water and 83 pounds of dry wood (17 is 20% of 83). In trees, wood moisture content may range from about 30 percent to more than 200 percent. (At 200 percent moisture content, the weight of the water content is twice the weight of the dry wood content.)

Before it is sold commercially, lumber is dried using any of several acceptable methods. The American Softwood Lumber Standard requires that, to be classified as dry lumber, moisture content shall not exceed 19 percent. To be grademarked KD (kiln dry), the maximum moisture content permitted is generally 15 percent.

How does wood moisture content change after installation in a building?

Wood moisture content is determined by the relative humidity and, to a lesser extent, the temperature of the surrounding air. As you might guess, as relative humidity increases, so does wood moisture content; as temperature increases, wood moisture content decreases. Figure 3-42 shows the moisture content of softwood in equilibrium with air at 30°, 70°, and 110°F. Notice that moisture content only exceeds 20 percent when the relative humidity is 90 percent or greater.

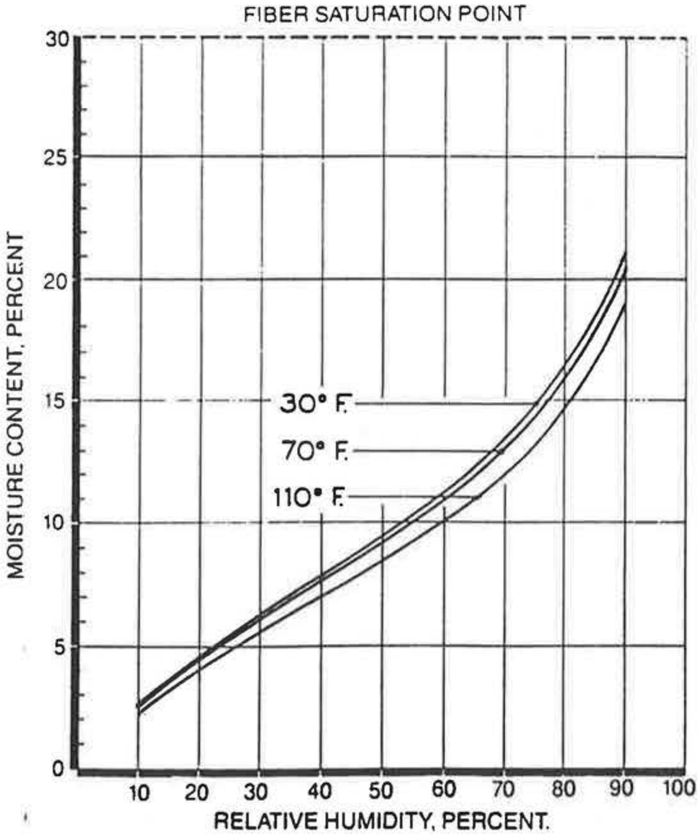


Figure 3-42 — Plot of wood moisture content vs. relative humidity at 30°F, 70°F, and 110°F.
Source: U.S. Forest Products Laboratory

What conditions are conducive to wood decay?

Most decay can progress rapidly at temperatures that favor growth of plant life in general. Generally, decay is relatively slow at temperatures below 50°F and above 90°F. Decay essentially ceases when the temperature drops as low as 35°F or rises as high as 100°F.

Serious decay occurs only when the wood moisture content is above the fiber saturation point (about 30 percent). No combination of temperature and relative humidity will result in an equilibrium wood moisture content of 30 percent. Therefore, the water vapor in humid air alone will not wet wood sufficiently to support significant wood decay, although it can permit development of some superficial mold growth. Only when previously dried wood is contacted by liquid water from rain, wet ground, or water vapor condensation will the fiber saturation point be reached.

The primary concern in insulated houses is water vapor condensation. If the temperature of the vapor barrier in a wall or ceiling is below the dew point temperature of the indoor air, condensation can occur (see the previous article for methods of determining dew-point temperature and predicting condensation conditions). If that temperature is also conducive to fungal growth, wood rot might ensue. (In certain circumstances, condensation can also come from outdoor air — see the article on "Moisture Mysteries" in the November 1984 issue of EDU.)

The most common type of wood decay is brown, crumbly rot, commonly referred to as "dry rot" — somewhat of a misnomer, since wood must be damp to decay, although it may dry out later.

Shrinkage

Upon drying, wood tends to shrink across the grain. This is common knowledge to any builder and all too familiar to those who have built with green lumber, which can shrink up to 7 percent upon drying.

One important consideration concerning lumber shrinkage in superinsulated houses has to do with double-wall construction. If you build a "Saskatchewan" type double wall, where the inner wall framing is inside the air/vapor barrier and the outer wall framing is outside the air/vapor barrier, the two walls will be exposed to different temperature and humidity conditions (see Figure 3-43). Assuming that indoor conditions are fairly constant at 70°F temperature and 40 percent relative humidity, the inner wall framing should reach an equilibrium moisture content of about 7.7 percent. If the wood moisture content at the time of installation was 15 percent, then the total shrinkage for a two-story house would be about three-tenths of an inch. The outer wall, on the other

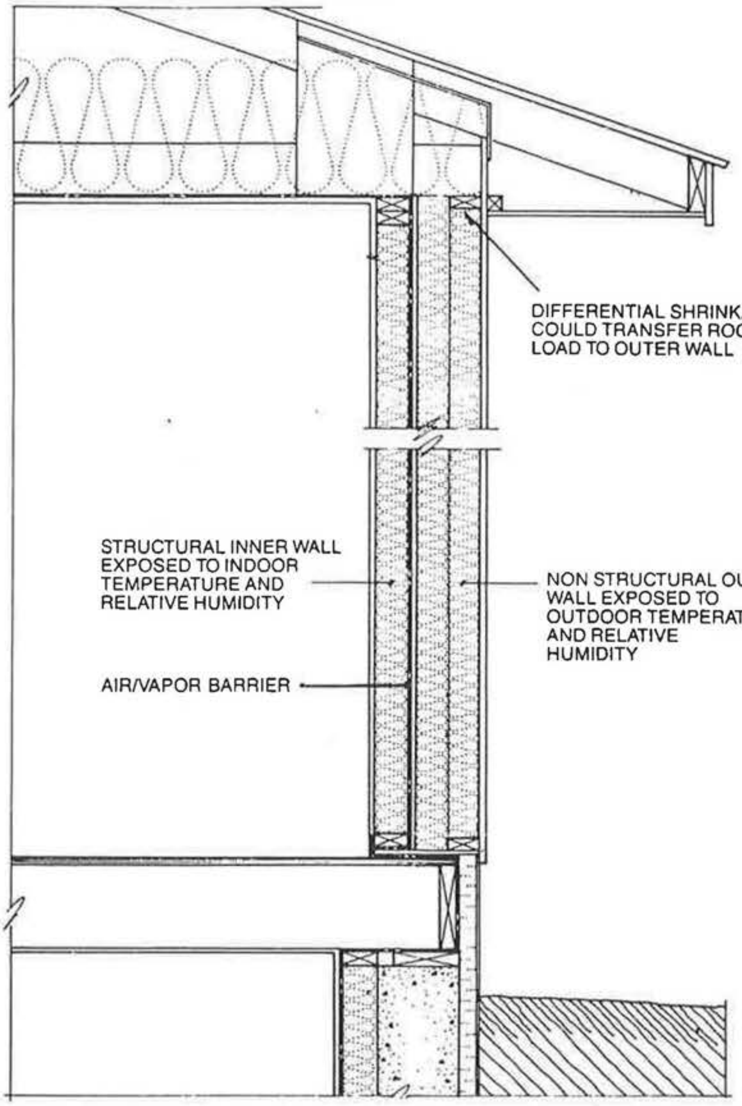


Figure 3-43 — Differential shrinkage of walls in double wall structure could shift roof bearing load to nonstructural wall.

hand, will be isolated from the house interior air and will be exposed to fluctuating weather conditions. It may dry out and shrink differently from the inner wall, depending on the climate.

One practical implication of this comes from Professor Howard Faulkner of the University of Southern Maine. Faulkner helped develop the "Roki Double-wall System" used by Roki Associates, Standish, Maine (see the February 1984 issue of EDU). Originally, Roki Designed the inner wall to be load-bearing. But the local building inspector objected. What if the inner wall were to shrink more than the outer wall? Trouble. The solution is either to design the wall system so that either wall can carry the roof load or to leave a gap between the non-structural wall and the roof trusses, so that the roof load will never contact the non-structural wall.

Thermal conductivity

Here's a relatively unimportant piece of building science trivia to impress your friends with. What's the R-value of softwood? R-1.25 per inch. Right? Pretty much, but actually it varies about 25 percent under normal conditions. For example, Western White Pine has an R-value of R-1.1 per inch at 24 percent moisture content, but R-1.4 per inch at 5 percent moisture content.

For more information on the effects of moisture on wood, see The Wood Handbook, published by the U.S. Forest Products Laboratory, available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402; Stock Number 0100-03200.

SECTION 4

Walls

In this section we look at seven types of superinsulated wall construction:

1. Single 6-inch wall with spray-in-place urethane foam insulation.
2. Single 6-inch wall with urethane skim coat plus fiberglass insulation.
3. Strapped wall.
4. Double-framed wall.
5. Walls with exterior foam sheathing.
6. Sandwich panel or "stressed skin" walls.
7. Non-structural trusses (The Larsen Truss).

Selection Factors

1. R-Value

All of the designs presented in this section have R-values of at least R-27 and some can be built with much higher R-values at relatively small incremental cost. For example, with a double wall, increasing the wall R-value is simply a matter of spacing the walls farther apart. The only extra cost is for the insulation.

2. Thermal Bridging

Thermal bridging was discussed in Section 1. An ideal wall system would be a continuous blanket of insulation with no thermal bridges. Some of the wall designs, such as exterior foam sheathing, foam sandwich panels (including stressed skin panels), and the Larsen Truss system approach this; others, such as urethane filled 6-inch walls, have considerable thermal bridging through framing. Although this shouldn't be the only selection criteria, it should be considered when choosing a wall design.

3. Airtightness

All of the wall types presented can be made equally airtight, but some are easier than others. Some require several small sections of air/vapor barrier to get around floor joists; others allow it to be done in one piece. If you are building a single-story house it may not matter, while with a multi-story or split-level house, it should be an important consideration.

4. Cost

Obviously a consideration in any design selection, cost is also important when selecting a superinsulated wall design. The extra cost for superinsulation is not always easy to assess.

5. Ease of Construction

The relative overall ease of construction of the different wall types will vary considerably from one builder to the next. Often it is difficult to assess how easy or hard a system is to build until you actually get out there and try it. Typically the first house is always difficult, but it's always easier after that.

1. Single 6-inch Wall with Spray-in-place Urethane Foam Insulation.

This wall design is gaining popularity among superinsulated home builders. Urethane foam is sprayed into wall cavities before the interior sheathing goes up. Urethane sticks to vertical surfaces, making it possible to spray it onto walls and neatly fill the stud cavities. Listed R-value for urethane varies somewhat, but assuming a conservative R-6.5 per inch, the 5.5-inch deep stud cavity will have an R-value of about R-36, not counting sheathing, air films, etc.

One of the reasons many builders prefer this wall system is that the foam forms an airtight and vapor-tight seal in the wall cavity. Keep in mind, however, that even though the foam seals the stud cavities, an air/vapor barrier is still necessary to seal the joints between wall, ceiling, and floor.

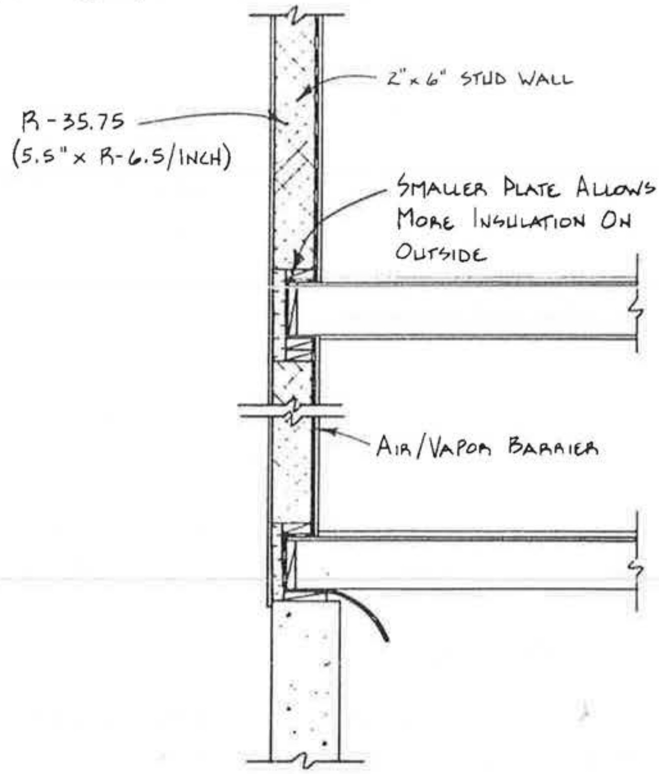


Figure 4-1 — Single 6" wall with spray-in-place urethane foam insulation

Furthermore, some builders have expressed concern that the foam seal might be broken if the framing lumber deforms over time. The air/vapor barrier is insurance against any air leaks that might develop. The urethane insulation should always be outside the air/vapor barrier.

Notice the air/vapor barrier installation in Figure 4-1. The wall studs are cantilevered 2 inches out over the platform and 2 inches of rigid foam are set in outside the rim joist. A strip of polyethylene is installed around the joist header and joined to the wall air/vapor barriers above and below. The polyethylene strip is laid over the first-floor wall before the second-floor platform is installed. A protective layer of felt or tarpaper is placed over the polyethylene to protect it during joist installation.

One advantage of this system is that it allows you to build a high R-value wall with virtually no added labor costs for carpentry. Those savings must, of course, be balanced against the extra cost for the urethane installation, which is considerably more expensive than other insulation materials.

A final consideration is fire-safety. Although urethane is approved for indoor use, it must be covered with fire-rated gypsum board.

2. Single 6-inch Wall with Urethane Skim Coat Plus Fiberglass Insulation

The Airtight Urethane Approach

Spray-applied urethane insulation has recently gained popularity for residential sidewall applications. A 2x4 stud wall insulated with spray urethane has an R-value of roughly R-25. One of the advantages of this insulation material, aside from its excellent insulating properties, is that it forms a good airtight seal between building components. It also imparts structural rigidity to a wall assembly.

But spray urethane also has some drawbacks. It's expensive and somewhat messy. The trick is to completely fill the stud cavities without overfilling. Any overspray must be planed down and stud faces must be scraped before putting up the drywall.

To exploit the advantages and avoid the drawbacks of spray-applied urethane, inventor/builder Bill Brodhead of Buffalo Homes, Riegelsville, Pennsylvania, developed an alternative to the common 2x4 urethane wall. Despite the fact that it uses three different types of insulation material (four if you count the cellulose attic insulation), Brodhead's design simplifies superinsulation in that it provides a highly-insulated airtight wall assembly using relatively standard framing techniques with no polyethylene and no drywall gaskets. According to Brodhead, this wall design is better and less expensive than a 2x4 urethane wall. For lack of a better name, we'll call it the "Airtight Urethane Approach" (AUA).

The Basic Design

Walls are framed with 2x6s in a more or less standard fashion. One important variation is that top and bottom plates are 2x4s, not 2x6s. We'll get into the advantages of that variation in a moment. Since there is no structural exterior sheathing, diagonal tee braces are installed on the interior stud surfaces.

The outside of the wall is sheathed with 1-inch insulative sheathing (R-Max, Energyshield, Styrofoam, etc.). Next, 1-1/2 inches of urethane are sprayed into the wall cavities from the inside. Finally, R-13 batts are installed in the stud cavity.

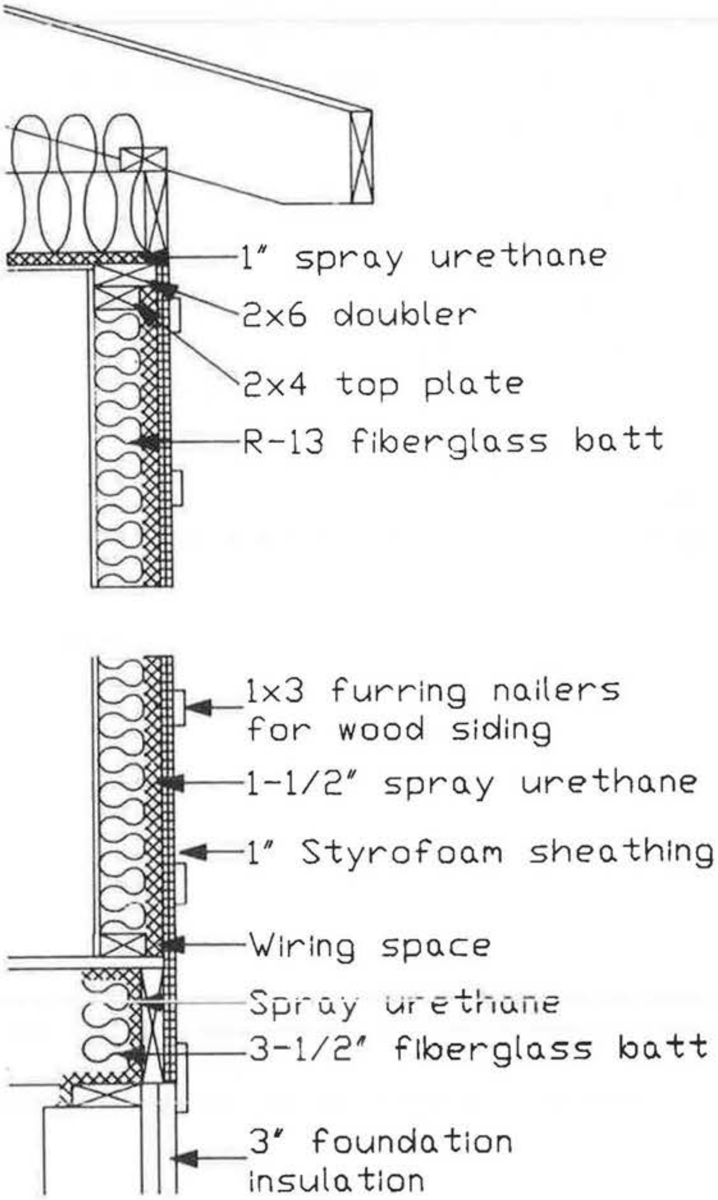


Figure 4-2

Urethane is also sprayed onto the ceiling drywall from above and into the header joist cavities between floors.

That's basically it. The result is a wall system with the following advantages:

1. High R-value.

Assuming the exterior sheathing is polyisocyanurate (R-7.0), the total R-value of the wall insulation is roughly R-29 (1-1/2 inches urethane = R-9; 1 inch Thermax = R-7.2; fiberglass = R-13). Add on the miscellaneous items such as drywall and siding and you have about an R-32 or R-33 wall.

2. Airtightness without bother.

Here's where the importance of the 2x4 top and bottom plates comes in. The 2-inch spaces behind the top and bottom plates allow the urethane to seal the joint between the sheathing and subfloor below and between the sheathing and the 2x6 cap plate above. That simple design variation eliminates the need for drywall gaskets or polyethylene air barrier (the drywall will still serve as a vapor barrier).

For window and door framing, full 2x6s are used for floor to header jacks, but 2x4s are used for the side kings and cripple studs. This again allows the urethane foam to make an airtight seal between the rough framing and exterior sheathing.

3. Urethane goes in easily and neatly.

Since the stud cavities are not being filled, the spray job is very easy — no need to form a smooth even surface. Stud faces should stay clean.

4. Wiring.

One side advantage of the 2x4 bottom plates is that they leave a convenient chase for wiring.

[NOTE: Recently, researchers in Canada have expressed concern about possible hazardous heat buildup when long runs of electrical wiring are embedded in foam insulation. Make sure wiring is properly sized for this type of installation.]

5. Using 6-inch studs, the urethane easily penetrates behind electrical boxes.

According to Brodhead, when spraying urethane in a 4-inch wall, sometimes the foam won't penetrate fully behind and around the electrical boxes because the space between the boxes and exterior sheathing is too narrow.

6. Cost.

Brodhead claims this wall design costs less to build than a 2x4 urethane wall. By reducing the thickness of the urethane two inches, he saves $1.20 per square foot of wall (at

$.60 per board foot for urethane). That saving is not eaten up by the 6-inch studs, fiberglass batts, and insulative sheathing.

7. Because of the exterior insulative sheathing, they get very good yield from the urethane.

This is an interesting advantage. When urethane is sprayed onto a surface, it gives off heat as it sets up (an exothermic reaction). The warmer the surface onto which it is sprayed, the better it sets up. According to Brodhead, depending on outdoor temperature, they get 10 to 20 percent better yield from their feedstock spraying against Styrofoam than they would against plywood.

Update on the Airtight Urethane Approach

Like so many innovative construction systems, AUA had a few kinks that needed to be worked out. When his first AUA house was pressure-tested for air leakage, Brodhead was surprised to find quite a bit of air leakage around window frames and at the rim joist area. To avoid those leaks, he suggests a few changes.

In general, the idea is to avoid double 2x6 framing members wherever possible. For example, around windows — where studs, cripples and/or jacks are typically doubled up — the framing should by installed as shown in Figure 4-3. With that configuration, the spray urethane can get behind each 2x4 member and seal the 2x6 to the wall sheathing. Notice also the 2x4 window sills and the 2x4 doublers over the wall top plates.

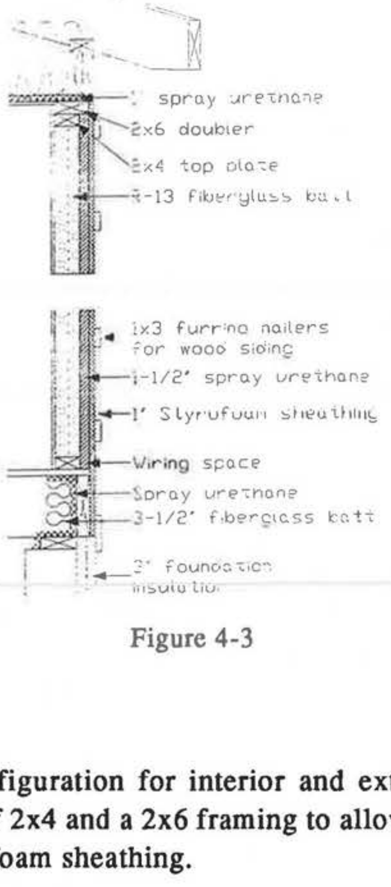
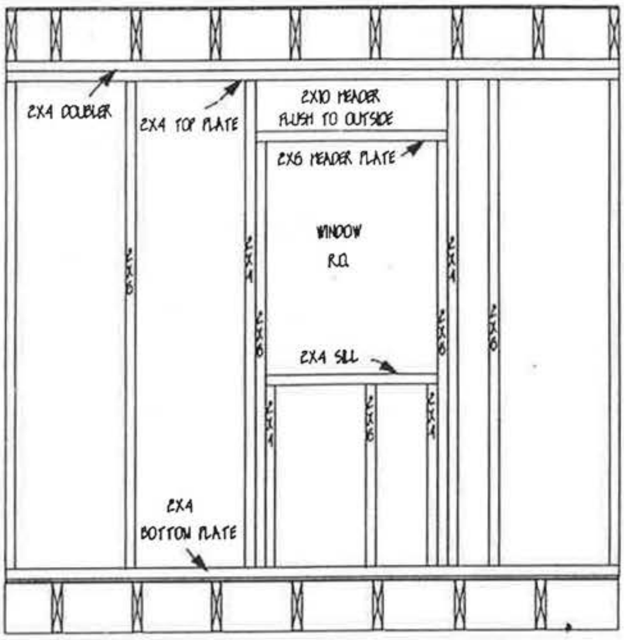


Figure 4-3

Figure 4-4 shows the framing stud configuration for interior and exterior corners. Again, the idea is to use a combination of 2x4 and a 2x6 framing to allow the urethane to seal each 2x6 member to the exterior foam sheathing.



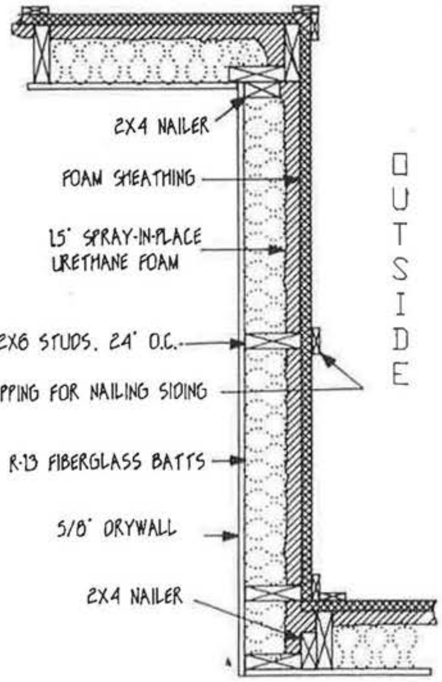


Figure 4-4 — Corner framing details of AUA system

Figure 4-5 — Detail showing clipped corners of upper 2x6 window frame

One final detail recommended by Brodhead is to cut the corners off the 2x6 header plates to allow the spray urethane to get on top of the 2x6 cripple and seal it (Fig 4-5).

Ten Points to Remember

The following are a few practical tips concerning the use of spray urethane and the AUA system:

1. All things of value must be protected, i.e., windows, doors, vehicles outside open windows, eyes, lungs, etc.
2. Urethane rises by heat. The warmer the building the better. In cold weather, spraying against foam sheathing gives better yield than just plywood, especially if only applying 1.5 inches of foam.
3. Urethane tends to roll over itself in layers that can leak. Quality control is crucial.
4. Urethane is not effective as an air seal unless it is continuous and thorough. Always inspect sprayers' work closely for missing spots and defects.
5. If you plan to fill a whole cavity, figure in extra in the estimate for scraping excess foam off studs.
6. Pre-caulk wire holes before spraying urethane. It won't get into very tight areas.

7. If using recessed ceiling light fixtures that are approved for direct burial in insulation, cover them with site-built drywall boxes and spray over the top of the boxes to create a tight air seal.
8. Install all penetrations through outside walls — i.e., dryer outlets, air conditioning freon lines, spigot pipes, etc. — before urethane is installed so that the foam can seal them to the wall.
9. Don't let spaces get too small just because you are keeping the framing on certain centers. Plan your centers to avoid framing traps where urethane can't be sprayed.
10. Remember: Any joint or connection of two pieces of wood without urethane between or behind them is a potential point of leakage and defeats the system.

For more information, contact Bill Brodhead, Buffalo Homes, RD#1, Box 209, Riegelsville, PA 18077; (215)346-8044.

3. The Strapped Wall

The strapped wall is one of the most popular superinsulated wall designs. Horizontal 2x3 strapping is applied to the inside of a standard 2x4 or 2x6 wall. The strapping cavities are usually filled with insulation. In the wall shown in Figure 4-7, the main wall is filled with R-19 fiberglass batts; the strapping cavity is filled with R-7 fiberglass batts. Thus the total R-value of the wall insulation is about R-26 (not counting sheathing, air films, etc.).

Other dimension strapping can also be used. Some builders use 2x3s set on end to get a 2.5-inch depth in the strapping cavity.

An advantage of the strapped wall is that it allows the air/vapor barrier to be installed deep in the wall, between the strapping and the main wall framing (see Figure 4-7). Wiring and plumbing can be installed in the strapping cavity without touching the air/vapor barrier. (If the cavity is only 1.5 inches deep, then shallow electrical boxes will have to be used.) This not only saves quite a bit of time from not having to seal the air/vapor barrier at each electrical

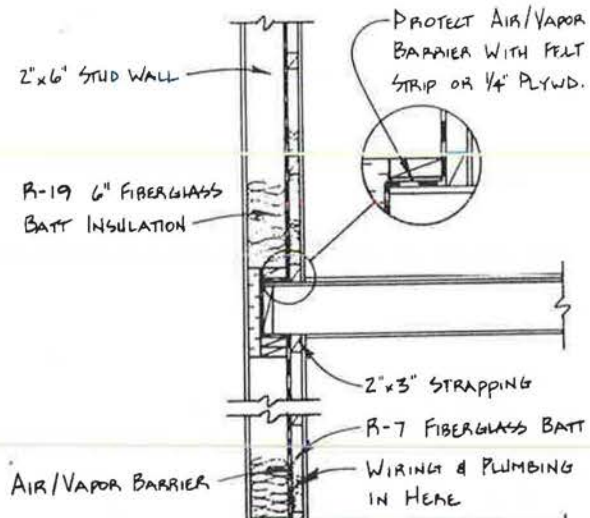


Figure 4-7 — Strapped wall

box, but the house will also probably be more airtight.

Another good aspect of the strapped wall is that thermal bridging is significantly reduced. The only place where wood extends from inside to outside, through the wall, is at the intersection of the strapping and framing members.

4. The Double-framed Wall

Sometimes referred to as the "Canadian" double wall, this type of wall consists of two identically framed walls attached together with plywood top and bottom plates. Figure 4-8 shows a section through this type of wall. The two walls are built with 2x4s, 24 inches on center, with a 5.5-inch space between the walls. The inner wall is structural. (The space between the walls can be any thickness.)

This wall is insulated with three layers of fiberglass batts: one layer of 3.5-inch R-13 batts installed in the inner stud cavity, one layer of the same material in the outer stud cavity, and a third layer of 6-inch R-19 fiberglass batts installed horizontally in the space between the walls. The total R-value of the wall insulation is R-45.

The air/vapor barrier is on the outside of the inner wall. This is an example of using the 1/3-2/3 rule. With R-32 outside the air/vapor barrier (R-19 + R-13) and R-13 inside, this design falls well within the 1/3-2/3 boundaries. Structural sheathing is installed over the air/vapor barrier, on the outside face of the inner wall.

In Figure 4-8, the double wall assembly is cantilevered 2 inches out over the foundation to allow space for 2 inches of extruded polystyrene foam (R-10.0). Inside the basement, a 2x4 wall is built out 2 inches from the foundation wall and R-19 fiberglass batts are installed. Total foundation R-value is R-29 (insulation only).

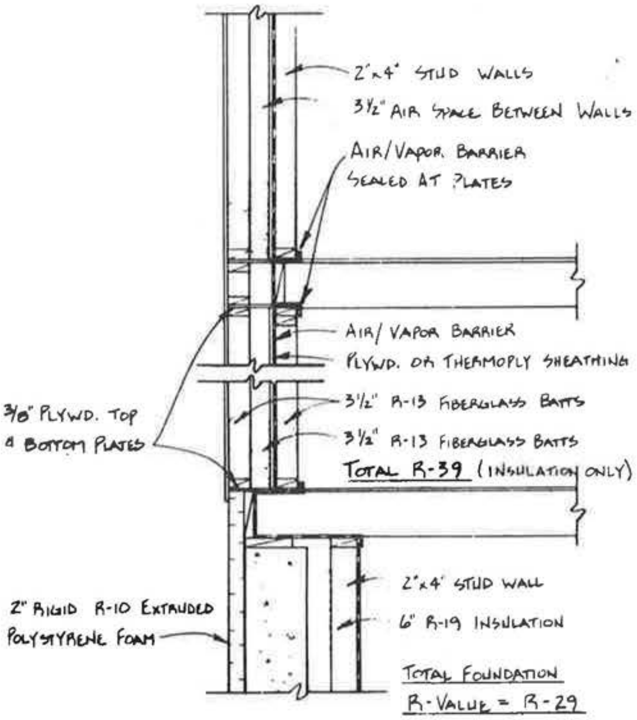


Figure 4-8 — Canadian double wall

There are several advantages to the Canadian double wall. First and most obvious is the high R-value. Second is that the air/vapor barrier is 3.5 inches away from the inside surface of the wall, leaving plenty of room for electricians and plumbers to work. Third is that thermal bridging is reduced to a minimum. The only wood which extends from inside to out are the plywood top and bottom plates and plywood frames which are installed in window rough openings. Also, although the illustration doesn't show it, the outer wall needn't have structural framing under and over windows, since it doesn't carry the second floor or roof weight. The inner wall is structural and requires full structural design.

Canadian Double Wall — Construction Sequence

1. Inner wall is assembled on deck. Since final wall assembly is heavy, wall should be assembled in place, ready to lift up.
2. Air/vapor barrier is laid over completed inner wall and stapled in a few spots. Windows openings are left covered.
3. Sheathing is installed over air/vapor barrier.
4. Outer wall is assembled over inner wall. (This step can be done before steps 2 and 3, which allows the inner wall to be used as a template. The assembled outer wall is then removed while steps 2 and 3 are performed.)

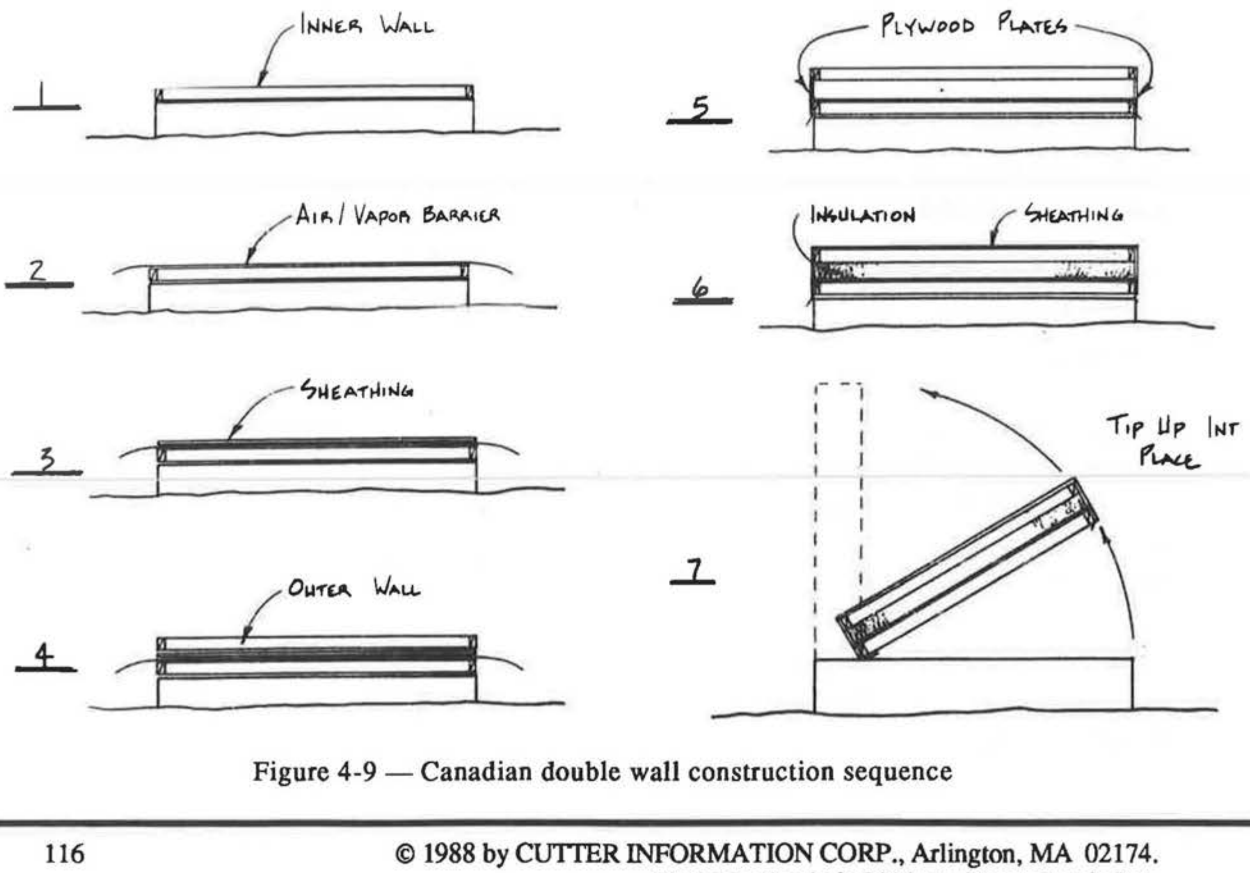


Figure 4-9 — Canadian double wall construction sequence

5. The two walls are separated using temporary spacers made from scrap 2x6. The plywood top and bottom plates are installed.
6. The central layer of insulation is installed between the two walls. The outer layer of insulation is installed in the outer wall stud cavities; outer sheathing is installed. The last two parts of this step can be postponed until after the wall is put into place. This may be desirable when building large wall sections, which might be too heavy.
7. The wall is tipped into place.

The completed wall needs no straightening and will stand up by itself.

Double Wall Variations

This illustration shows three common variations of the double wall design. Figure 4-10a is a plan view of the Canadian double wall discussed above. Figure 4-10b shows a double wall with the air/vapor barrier installed on the inner surface of the inner wall. This design is not as good as the 4-10a, since the air/vapor barrier is subject to damage. Figure 4-10c shows a staggered stud arrangement. The main reason usually stated for building staggered stud walls is to reduce thermal bridging by increasing the distance between studs. Although technically true, the difference in performance between staggered studs and non-staggered studs is insignificant and not measurable. Non-staggered stud walls have the advantage that the two walls are exactly the same; one can serve as a template for the other during construction.

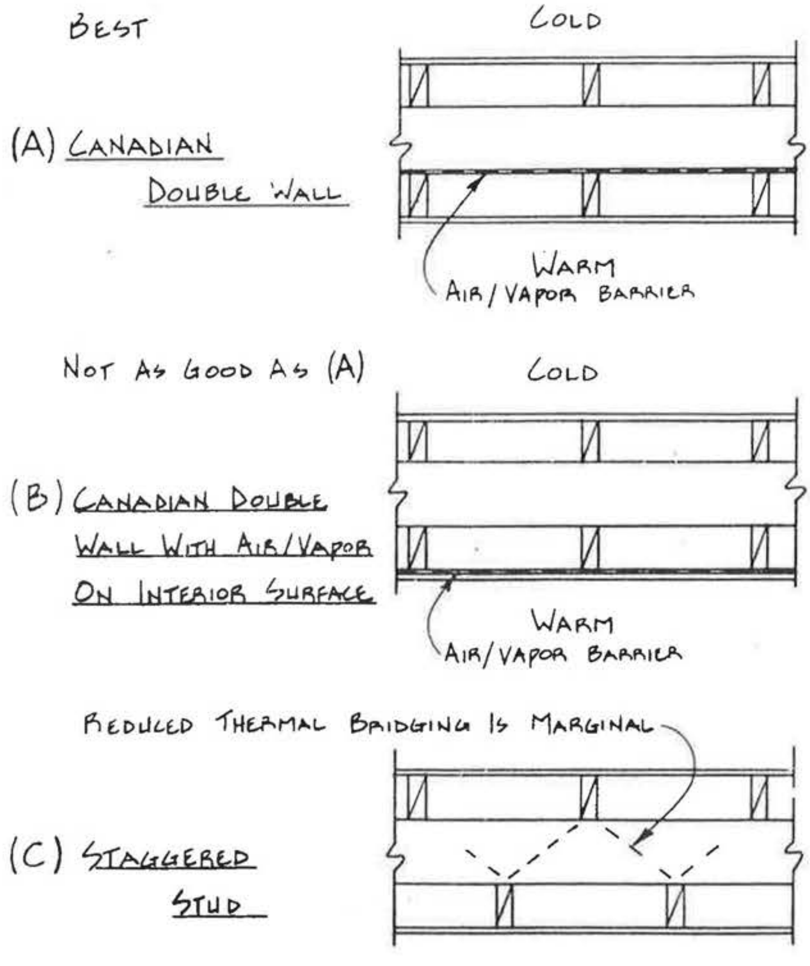


Figure 4-10 — Double framed walls

Balloon Framing at Outer Wall

This is another common double-wall design variation. With this design, the inner and outer wall are built and installed separately. The inner wall is built and installed on the platform, as with conventional platform framing. The joists and platform are pulled back 4 to 8 inches from the outer edge of the foundation. (Obviously to come back 8 inches requires a 12-inch foundation.) The outer wall is then set right on the foundation sill plate, as with conventional balloon framing.

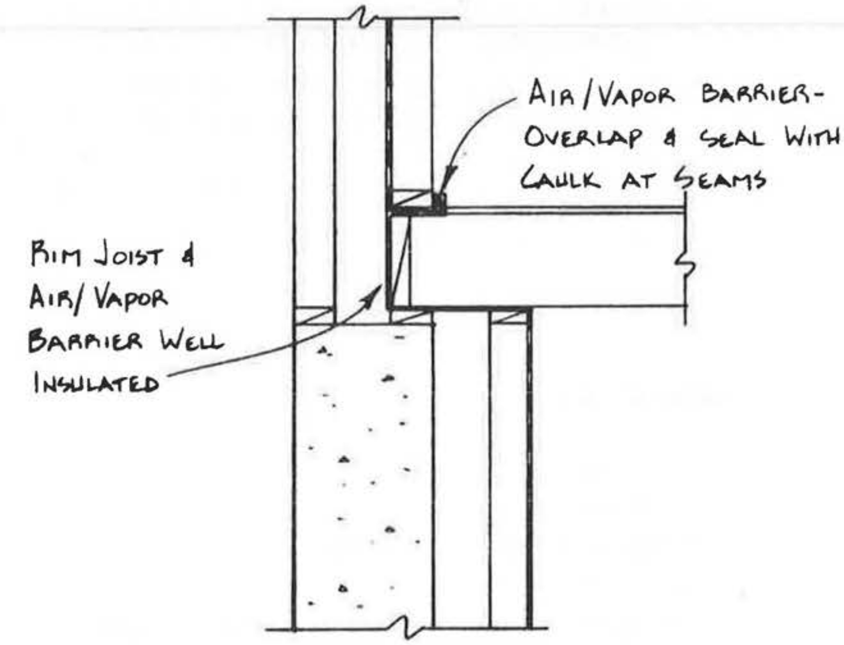


Figure 4-11 — Balloon framing at outer wall

The advantage of this design is that the entire joist area is very well insulated on the outside. There is almost no thermal bridging near the wall-floor intersection. The air/vapor barrier is easily installed around the joists and can even be run as one sheet from foundation to top plate. (In Figure 11, we show the air/vapor barrier installed as two pieces, sealed with caulk at the wall bottom plate.)

One possible disadvantage, compared to the Canadian double wall, is that the outer and inner wall studs are not the same length. More precision cutting is necessary on the site.

The Roki Double Wall

The Roki double wall is a double wall design variation and construction sequence developed jointly by Roger Beaulieu, president of Roki Associates, Gorham, Maine, and Professor Howard Faulkner of the University of Southern Maine.

A hybrid balloon/platform framing system, the Roki wall has no top plates or bottom plates between the inner and outer walls. The two walls are tied together with 16-gauge metal spacer plates (see Figure 4-12). One advantage of this system is efficiency of the construction sequence (described below). Another advantage is that the walls can be easily insulated with blown-in insulation from the top of the upper wall; there is a clear space (except for the metal plates) from attic to foundation. The attic insulation is blown in on top of the wall insulation, leaving almost no thermal bridging and almost no danger of voids resulting from insulation settling in the walls.

The construction sequence is as follows:

1. Set and bolt 2x8-inch sill plate.
2. Set in a sheet of polyethylene air/vapor barrier to go around rim joist. Allow enough excess to fold, caulk, and staple to basement wall below and to inner stud wall bottom plate above.
3. Set joists and use 1/2-inch CDX plywood as rim joist rather than 2x10s. Allow joists to set 3 inches onto sill plate.
   NOTE: Check with local code for acceptability of plywood rim joist.
4. Attach plywood deck.
5. Bring air/vapor barrier up onto deck and staple.
6. Set exterior wall onto sill and nail.

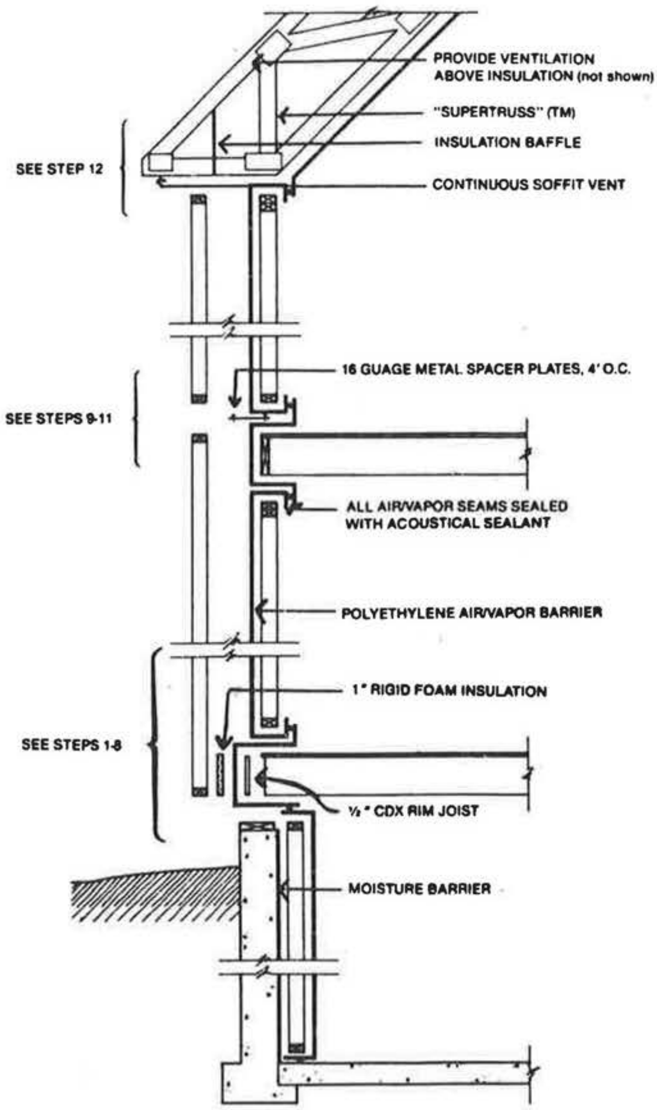


Figure 4-12 — The Roki double wall

7. Set 1-inch rigid insulation between exterior wall and CDX rim joist.
8. Set interior wall in place with air/vapor barrier on exterior face. Wrap air/vapor barrier around top and bottom plates with enough excess to seal to air/vapor barriers above and below.
9. Set in air/vapor barrier to go around second-floor joists, leaving enough excess to attach to wall air/vapor barriers above and below.
10. Add second-floor joists and plywood deck. Bring air/vapor barrier around rim joist and staple to deck.

    NOTE: Deck will come level with exterior wall top plate.

11.Add 16-gauge metal spacers, 4-foot on center.

12.Continue second floor walls as per drawing, nailing truss to both walls. Seal wall air/vapor barrier to ceiling air/vapor barrier with acoustical sealant.

Double Wall Corner Details

Figure 4-13 shows details for inside and outside corners with double wall construction. Notice the outside corner where wall A meets wall B. The 2x4 top plates of wall B must end at the point indicated to allow the air/vapor barrier to wrap around the wall without getting close the cold exterior surface of the wall. At the inside corner where wall B meets wall C, the top plate can extend all the way to the end of the wall. Notice the air/vapor barrier installation at this point.

The walls are tied together at the corner one of two ways: either metal straps are nailed over the plywood top plates, or 2x6 blocking is laid over and parallel to wall B, but hanging out enough to nail down into wall C. This blocking also serves as nailbase for attaching ceiling drywall.

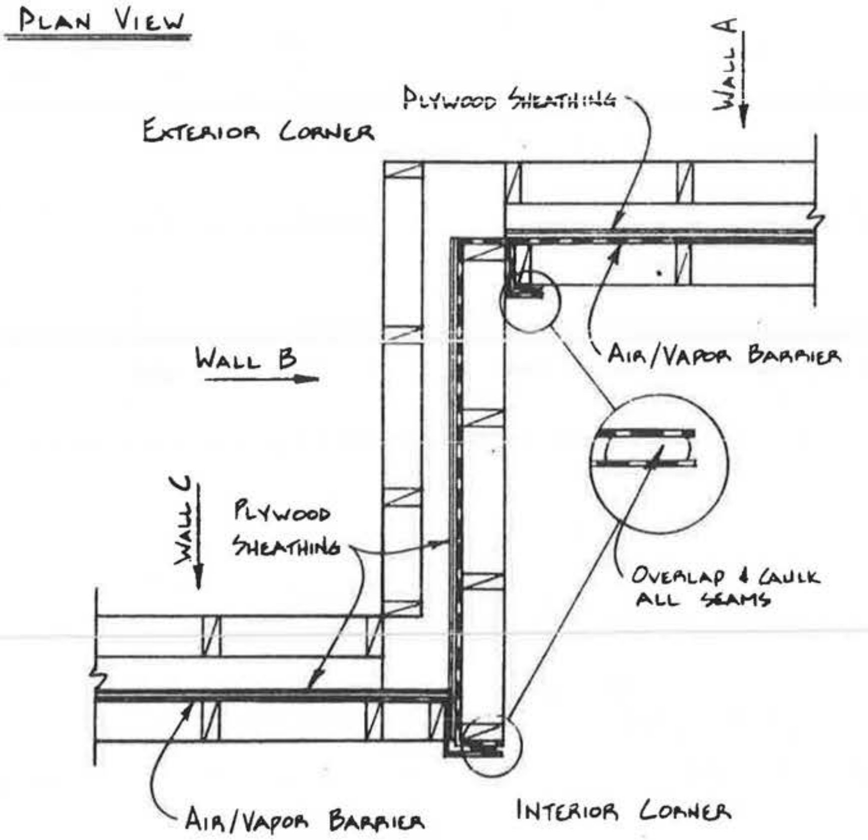


Figure 4-13 — Double wall corner detail — plan view

5. Exterior Insulative Sheathing

Exterior rigid foam sheathing can be used to add R-value to any of the wall types described above. Urethane, isocyanurate, expanded polystyrene (beadboard), and extruded polystyrene are all commonly used.

There are several advantages to this system. First, the wall framing is basically standard, usually using 2x6 studs. Second, the foam covers the entire wall, including joists. There is no thermal bridging since the foam is continuous. Finally, exterior foam sheathing is quite easy to install and is already common practice in many areas of the country.

The wall section illustrated in Figure 4-14 has R-19 fiberglass in the main wall plus 2 inches of extruded polystyrene (R-5 per inch), which gives a total insulation R-value of R-29 (insulation only).

A possible problem with exterior foam sheathing is moisture condensation. Most foam sheathing, particularly foil faced products, act as a vapor barrier. By installing it on the outside surface of a wall, you are putting a second vapor barrier on the cold side of the insulation. Theoretically, this should cause condensation, but for whatever reason, there have not yet been any reported problems with this system.

One manufacturer of rigid foam recommends that in certain cases, venting strips should be installed between the foam and framing to allow moisture to escape from the wall cavity. This is not recommended for superinsulated houses because it will degrade the performance of the insulation in the wall cavity. In one recent experiment, it was found that installing those strips actually increased air leakage into the wall, aggravating moisture problems. The following article summarizes that research, published by the U.S. Forest Products Laboratory in Madison, Wisconsin.

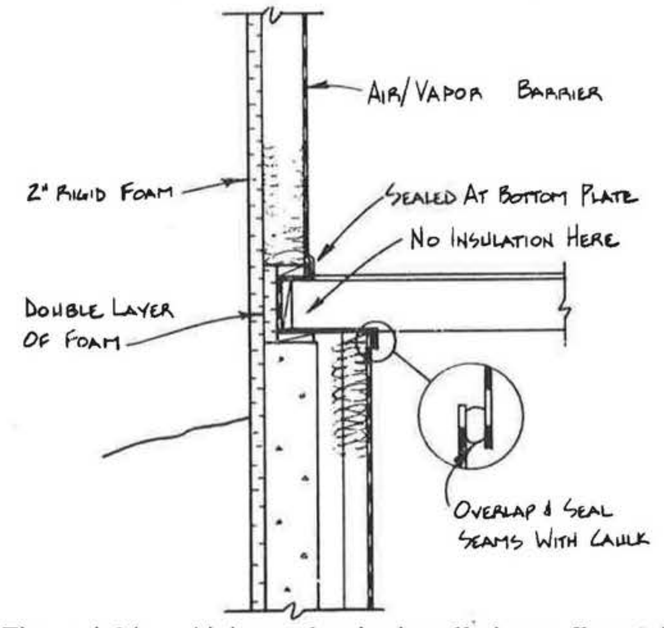


Figure 4-14 — Air/vapor barrier installation at floor joists

Exterior Foam Sheathing And Cold-side Vapor Retarders

Moisture dynamics in insulated buildings may be the most poorly understood area in building technology today. One critical concern involves the practicc of using low-permeability rigid-foam sheathing (Styrofoam, Thermax, etc.) on the outside of insulated walls. Exterior foam sheathing is a cold-side vapor retarder and violates the traditional recommendation that vapor retarders be placed only on the warm side of an insulated wall.

The professional building community has been generally frustrated in its search for technical approval of this common but seemingly dangerous practice but definitive new work in this area has been lacking. The situation has been worsened by widespread misinformation.

However, a 1983 study performed at the U.S. Department of Agriculture's Forest Products Laboratory (FPL) in Madison, Wisconsin, did produce concrete evidence that cold-side vapor retarders are not as critical as was once believed and that with proper precautions, exterior foam sheathing should cause no moisture problems. The study also produced other valuable information concerning moisture in building construction.

The FPL built an experimental structure with eight test rooms, each with a different wall structure:

Wall #	Sheathing	Insulation	Vapor Barrier
1	Fiberboard	R-13 fiberglass batt	6-mil polyethylene
2	Fiberboard	R-11 fiberglass batt	Asphalted paper
3	0.5-inch plywood	R-11 fiberglass batt	Asphalted paper
4	Fiberboard	R-19 fiberglass batt	6-mil polyethylene
5	1-inch extruded polystyrene foam	R-11 fiberglass batt	6-mil polyethylene
6	1-inch extruded polystyrene foam	R-11 fiberglass batt	Asphalted paper
7	1-inch foil-faced isocyanurate foam with vent strip	R-13 fiberglass batt	6-mil polyethylene
8	1-inch foil-faced isocyanurate foam (no vent strip)	R-13 fiberglass batt	6-mil polyethylene

Interior room conditions were maintained at constant 70°F and 40 percent relative humidity. Moisture and temperature sensors were placed in twelve locations in each wall. Measurements were taken for two full years.

During the second year, a standard duplex wall outlet was placed in each wall to examine the effect of minimal air leakage on condensation.

Observations and Conclusions

1. **Low-permeance foam sheathings present no greater condensation hazard in cold weather than the other types of sheathing studied.**

   When the vapor barrier was punctured by electrical outlets, condensation occurred in all of the test walls, but the walls with foam sheathing did not show any worse conditions than those with fiberboard or plywood sheathing. Cavity moisture content was more associated with sheathing temperature than with permeability.

   Condensation itself is not necessarily a problem. It only becomes a problem when it has detrimental effects on the building. Potential adverse effects include: 1) decreased effectiveness of the cavity insulation; 2) structural damage to wood components due to rotting; and 3) buckling or warping of siding or paint peeling. Condensation probably occurs to some extent in every wall of every house in the northern U.S. (except perhaps some of the newer houses with integral vapor barriers); but in most cases, there is little or no detrimental effect.

   When condensation occurs in a wall, three things can happen: 1) it can be absorbed by the wood members in the wall; 2) it can reevaporate and move out of the wall either by diffusion or convection; or 3) it can remain in the wall as excess wetness. Only the third possibility causes structural damage and only if it persists for an extended period of time. Furthermore, for rot to occur, the "wetness" condition must not only persist long enough, but must also coincide with warm enough temperatures to allow fungal growth. According to Gerald Sherwood, author of the FPL study, the moisture content of the wood framing in the test walls never rose above 12 percent. Evidently the wood members have a sizeable capacity to temporarily "buffer" excess moisture in the wall cavity. In the FPL study, all the test walls were completely dry by April, even when condensation was severe during the winter months.

   Sherwood further stated that FPL receives numerous reports of moisture damage in houses, but in every case the damage has been traced to excessively high relative humidity in the house. In those cases, the most severe damage is around window framing, since condensation occurs on the windows before it occurs in the walls. He stressed the need for humidity control through ventilation or other means.

2. **With a continuous polyethylene vapor retarder, no condensation occurred, regardless of sheathing type.**

3. **Punctured vapor barriers performed no better than asphalt-coated paper.**

   The installation of a single-wall outlet in each 4-foot by 8-foot wall section caused condensation in the cavities. This finding strongly supports the recommendation that all electrical outlets and other penetrations through the vapor barrier should be tightly sealed.

4. **A cold-side vapor retarder, such as the glue joint in plywood sheathing, reduced the hazard of condensation at the sheathing-siding interface without unduly increasing the cavity moisture content.**

   In walls with permeable sheathing (fiberboard), condensation occurred first between the sheathing and the siding, sometimes producing streaks on the siding. In the wall with plywood sheathing (#4), the impermeable plywood prevented the moisture from getting to the siding, thus preventing the streaking effect. Even though the plywood was acting as a cold-side vapor retarder, it did not cause excessive moisture buildup inside the cavity. Note that the wall section with plywood sheathing (#4) did not even have a polyethylene vapor barrier.

5. **The use of "vent strips" at the top of walls with foam sheathing resulted in greater air leakage with no apparent benefit in moisture control.**

   Vent strips are sometimes recommended to avoid condensation problems; Celotex Corporation recommends them in certain cases for its Thermax sheathing. But wall #8, with vent strips, actually had higher cavity moisture content than wall #9, which did not have strips.

6. **Whenever condensation did occur in a wall, it formed on the back of the siding or on the back surface of the sheathing and did not wet the bulk of the cavity insulation.**

   This same phenomenon was noticed during a study by Doug Burch at the National Bureau of Standards (see the July/August 1982 issue of EDU). It suggests that even when condensation occurs, there is probably no significant thermal degradation of the insulation material. It should be noted that both studies looked at fiberglass insulation only.

What About Warm-Climate Applications?

Moisture problems should probably be viewed very differently in warm, humid climates. First of all, there is the possibility of condensation on the inner wall surface during the cooling season. Second, if condensation should occur, there is a greater danger of fungal growth and rot due to the warmer temperatures. Unfortunately there is a scarcity of practical information in this area.

Conclusions and Recommendations

1. The application of exterior rigid-foam sheathing should not cause hazardous condensation problems and is probably acceptable in most U.S. climates.
2. A complete and well-sealed vapor retarder on the warm side of the insulation is the best guarantee of prevention of condensation in walls.

Two qualifications. First, these results cannot be confidently extended to climates which are colder than Madison (7,800 degree days). In colder climates, condensation could be more severe and might persist for a longer period of time. Second, the FPL study did not test walls with more than R-19 insulation in the cavity. With higher R-values, the foam sheathing could possibly get cold enough to cause more troublesome condensation.

For More Information

Copies of the report are available for $7.00 from the National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161; (703)487-4650. The order number is ADA 129452.

Super Thick Exterior Sheathing — The "Styro House"

The "Styro House" is a type of wall design developed by Bill Brodhead of Buffalo Homes, Riegelsville, Pennsylvania. The walls are 2x4 framing with 5.25 inches of expanded polystyrene (beadboard) on the outside. This unusual design attains high R-value at relatively low cost and has several additional advantages as well.

Construction Details

The walls are 2x4 studs, 16 inch on center, with Aspenite sheathing. The framing is almost totally conventional with a few minor exceptions: the first-floor band joists are recessed 5 1/4 inches from the outside of the foundation insulation to leave room for the foam sheathing. Similarly, the ceiling joists are cantilevered out 5 1/4 inches over the wall. Window and door frames must naturally be deeper in the thicker wall. So during rough framing, an extra 3 inches is added to all exterior window and door rough opening heights and the side jacks are not installed. Later, after the exterior insulation is installed, 2x10 headers, sills, and jacks are installed (see below).

After the house is completely rough framed and sheathed, the exterior insulation system is installed in the following sequence:

1. A continuous polyethylene vapor barrier is installed over the sheathing from foundation footings to soffit.
2. Two layers of 2 5/8-inch expanded polystyrene foam (EPS or "beadboard"), with overlapping seams, are applied over the vapor barrier, giving a continuous R-21 over all framing members.
3. Window and door openings are cut out through the foam with a hand saw from the inside. 2x10-inch jacks, headers, and sills are nailed together as a "boxes," which fit into the oversized rough openings and flush up with the outside of the beadboard and the inside of the framing.
4. A layer of Tyvek housewrap is placed on the outside of the EPS. It's hard to imagine air leaking through this wall even without the Tyvek, but it's pretty cheap insurance and will prevent any possibility of air circulating around the seams of the foam sheets. (Brodhead claims that improperly aged EPS can shrink, leaving gaps between the sheets.)
5. 1x3-inch furring is installed over the foam using 8-inch aluminum gutter spikes nailed through the foam into the studs and Aspenite. The furring is also attached directly to the 2 x 10 window and door frames. There is definitely some art involved in using such long nails and since the foam is compressible, you must be careful not to hammer the furring in tighter in one spot than another.
6. The siding is attached directly to the furring with small galvanized nails.

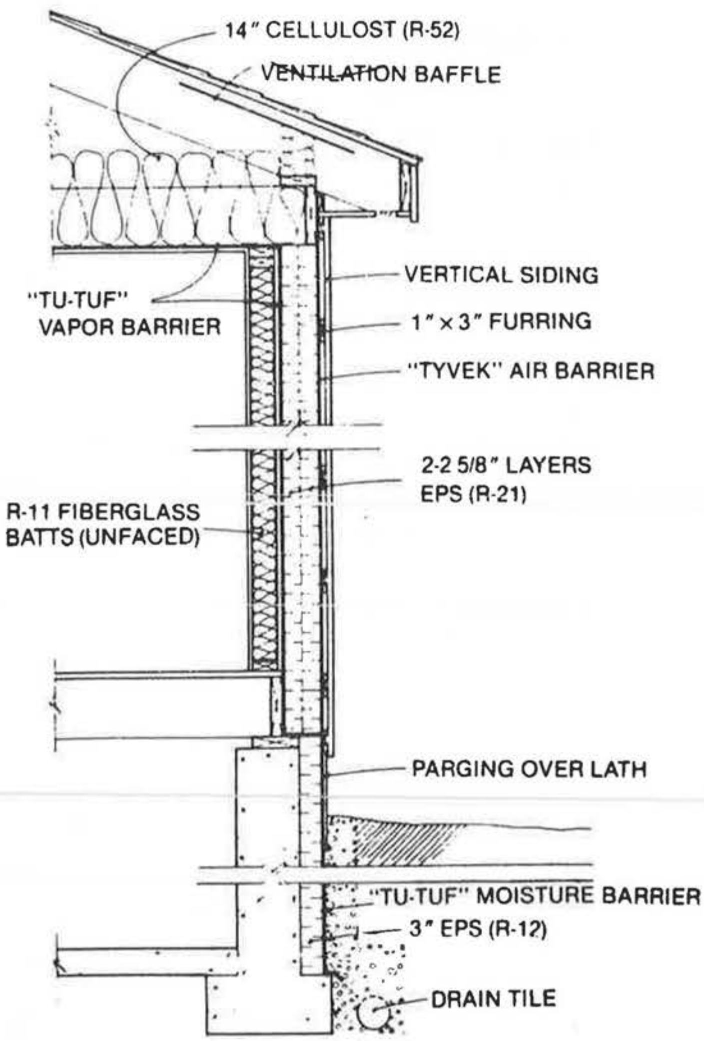


Figure 4-15 — The "Styro House" double wall

The 2x4 stud wall is insulated with unfaced R-11 fiberglass batts. Before the insulation goes in, all the plumbing and wiring is installed and all holes that lead to an exterior space (including holes in top and bottom plates which lead to attic or basement) are caulked. No interior vapor barrier is necessary.

There are two main advantages to the Styro house wall design: 1) The house is framed using <u>conventional</u>

2x4 framing techniques with only a few minor modifications, allowing the use of standard framing subcontracting crews without any special training; and 2) The vapor barrier is easy to install, involving very little "cutting and pasting." This was the main factor which motivated the Styro House design. In fact, the reason the foam is 5 1/4-inches thick is to get twice as much R-value outside the vapor barrier as inside. It is OK to put insulation on both sides of a vapor barrier as long as two-thirds of the R-value is on the outside. The Styro house has R-21 on the outside of the barrier (5 1/4 inches of foam) and R-11 on the inside (3 1/2 inches of fiberglass).

6. Sandwich Panel or "Stressed Skin" Construction

"Sandwich panels," sometimes referred to as "stressed-skin" panels, consist of foam insulation sandwiched between two layers of sheathing material. The foam may be either expanded molded polystyrene (beadboard) or urethane. The sheathing material may be almost anything, including plywood, waferboard, gypsum board, or steel.

Although both terms are usually used interchangeably, there is actually a technical distinction between sandwich panels and stressed-skin panels. Sandwich panels are designed to withstand axial loads (force applied to the edge of the panel) and stressed-skin panels are designed to withstand bending loads (force applied to the face of the panel).

Although the most common application of sandwich panels has been as a sheathing on post and beam houses, structural panels that need no supportive framing are also available and are gaining popularity.

The following is a list of manufacturers of insulating sandwich panels:

Advance Energy Technologies, Inc.
P.O. Box 387
Clifton Park, NY 12065
(518)351-1155

Alchem, Inc.
3617 Strawberry Road
Anchorage, AK 99502

Andrews Building Systems, Inc.
225 South Price Road
Longmont, CO 80501
(303)722-3516

Arco Building Products
1500 Market Street
Philadelphia, PA 19102
(215)557-2000

Associated Foam Manufacturers, Inc.
P.O. Box 246
Excelsior, MN 55331
(800)255-0176

Atlas Industries
6 Willow Road
Ayer, MA 01432
(800)343-1437

Branch River Foam Plastics, Inc.
15B Thurbers Boulevard
Smithfield, RI 02917
(401)232-0270

Chase Panel Systems
2755 S. 160th St.
New Berlin, WI 53151
(414)784-9634

Clark Industries
375 E. Fifth Avenue
Columbus, OH 43201
(614)294-3761

Concept 2000 Homes
3003 N. Highway 94
St. Charles, MO 63301
(314)947-7414

Delta Industries, Inc.
1951 Galaxie Dr.
Columbus, OH 43207
(614)445-9634

Drew Foam of Colorado, Inc.
1450 West Colfax Avenue
Denver, CO 80204

Enercept, Inc.
3100 9th Ave. S.E.
Watertown, SD 57201
(605)882-2222

Foam Products Corp.
2525 Adie Road
Hazelwood, MO 63043

Foam Laminates of Vermont
Box 102
Hinesburg, VT 05461
(802)482-2534

Foam Products Corporation
2525 Adie Road
Maryland Heights, MO 63043
(314)739-8100

Foam Plastics of New England
P.O. Box 7075
Prospect, CT 06712
(203)758-6411

Futurebilt
A-104 Plaza Del Sol
Wimberley, TX 78676
(512)847-5721

Homasote, Co.
P.O. Box 7240
West Trenton, NJ 08628

Insul-Wall
11 Mosher Dr.
Dartmouth, N.S. B3B 1E5
(902)465-7470

J-Deck, Inc.
2587 Harrison Road
Columbus, OH 43204

Korwall Industries, Inc.
326 N. Bowen Road
Arlington, TX 76012
(817)277-6741

Panel Building Systems, Inc.
431 Second St.
Reynolds Industrial Park
Greenville, PA 16125
(412)646-2400

Pond Hill Homes, Ltd.
Westinghouse Road
RD4 Box 330-1
Blairsville, PA 15717

Riverbend Timber Framing, Inc.
P.O. Box 26
Blissfield, MI 49228

Therm-L-Tec Systems
119-A Osage
Kansas City, KS 66105
(913)621-1916

Thermapan Industries, Inc.
2514 Highway 20, Box 479
Fonthill, ON L0S 1E0
(416)892-2675

Unijoint International
Division of R.J. Rydeen & Associates
107 Main St.
P.O. Box 107
Fremont, NH 03044

Winter, Inc.
Main St.
West Groton, MA 01472
(617)448-3077

6. Non-structural Trusses — The Larsen Truss

The Larsen Truss was developed by John Larsen of Sunscape Builders Ltd., Edmonton, Alberta, and John Hughes of Passive Solar Designs Ltd., also of Edmonton. It is a non-structural truss made of 2x2 chords and intermittent plywood webs, somewhat similar to commercially available structural trusses used for floors and roofs. Its total depth is 8.25 inches and it comes in prebuilt lengths of 10, 12, 14, and 16 feet. The trusses can be easily fabricated on site following detailed instructions available from Larsen and Hughes.

How Is it Used?

The trusses are applied vertically on the outside of a 2x4 frame wall. The 2x4 wall is built using conventional framing techniques, except horizontal blocking is inserted between the studs for attaching the trusses. The wall is usually set back a few inches from the edge of the floor to allow one chord of the truss to rest on the floor. Standard sheathing is installed and a continuous air/vapor barrier is applied over (on the outside of) the sheathing.

The trusses are usually mounted 24 inches on center and are nailed approximately every 48 inches along their length using four 3.5-inch spikes at each nailing point. On tall walls or gable ends it is usually necessary to butt join several trusses to gain sufficient height. This is easily done.

If horizontal or diagonal wood siding is to be used, it can go directly onto the trusses. Vertical siding will, of course, need horizontal strapping. Stucco, lightweight vinyl siding, or metal siding require some sort of sheathing to be applied to the trusses for support.

The truss depth can be insulated using any type and method of insulation.

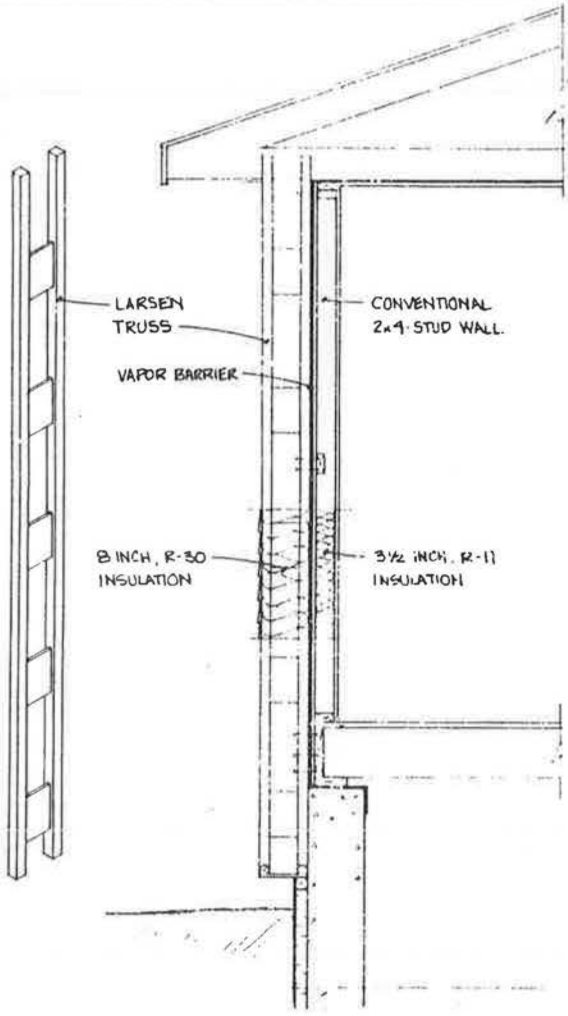


Figure 4-16 — The Larsen Truss

The Larsen Truss system has three main advantages: 1) as with the Styro House, it is easy to install a continuous air/vapor barrier without a lot of cutting and pasting, particularly on a two-story house. The air/vapor barrier is wrapped around the sheathed 2x4 wall after it is finished and up; there is no interruption of the framing process; it is not necessary to wrap the membrane out and around joist headers; 2) The structural 2x4 wall is standard construction. Regular framing crews can be used without much special instruction; and 3) tall walls are no problem. The trusses can be butt joined to span any length. Since they nail right to the wall, you don't need attachment points at the top from which to hang them.

The main disadvantage of this system is its newness. Although it has proven itself well in limited application, it is still relatively new and untested

SECTION 5

Roofs and Ceilings

Requirements for Ceilings and Roofs

The design requirements for ceilings and roofs are relatively straightforward. First, the framing structure must allow enough space for adequate insulation plus room for ventilation above the insulation. Second, the structure should allow full thickness of insulation to be applied over the wall top plates, a weakness in conventional rafter or truss construction where the roof comes down too close to the wall plates to allow full insulation. Finally, the insulated ceiling must be airtight.

In this section, we first look at houses with attics, then at houses with cathedral ceilings, discussing ways to achieve adequate levels of insulation and proper ventilation. Then we discuss ways to deal with ceiling penetrations, such as electrical fixtures and plumbing stacks, so that the roof or ceiling stays airtight.

Ceiling Air/Vapor Barrier — Yes Or No?

Some building consultants recommend that no vapor barrier be installed in house ceilings. The general reasoning behind that is that you need to allow water vapor to diffuse through the ceiling to prevent excessively high humidity levels inside the house. If the attic is well ventilated, then the moisture should be removed from the attic, avoiding condensation problems. This practice is not recommended. Why? First of all, tightly built houses must have mechanical ventilation which not only brings in fresh air, but also exhausts stale air and excess humidity from the house. There is no need to rely on haphazard diffusion of moisture through the ceiling for humidity control when you have a controllable ventilation system. Second, eliminating the vapor barrier could create serious condensation conditions in the attic. Superinsulated attics are much colder than attics in conventional houses. Even with properly installed attic vents, moisture may condense and even freeze before it can be ventilated out. The third reason to install an air/vapor barrier in ceilings is to maintain airtightness. Gypsum board alone cannot be relied upon to make a permanent airtight seal at the ceiling.

What About an Air Barrier Over Attic Insulation?

This is somewhat of a tricky question to answer. Some researchers recommend installation of an air barrier, such as spun-bonded olefin, over attic insulation to prevent air intrusion and to prevent loose-fill insulation from blowing around in the attic. Theoretically, this is a good idea, but some researchers have expressed concern that if any water vapor gets through the insulation, it may condense on the air barrier. Also, recent research has shown that air intrusion in attics is not a serious problem. Therefore, we recommend that no air barrier be installed over attic insulation, except perhaps around the perimeter 2 feet, near soffit vents, to prevent wind gusts from blowing loose fill insulation around in the attic.

Attic and Roof Ventilation

The main purpose of attic and roof ventilation is to remove moisture. A secondary purpose is to remove excess heat during hot weather. Both of these functions are less important in superinsulated houses, particularly moisture removal. However, as positive insurance and to comply with building codes, attics and roofs should be ventilated according to conventional guidelines. The most effective type of attic and roof ventilation is continuous ridge and soffit vents. Gable vents are less reliable because they are sensitive to wind direction and speed. Install 1 square foot of "free area" ventilation for every 150 square feet of attic floor area. Make sure that the ventilation pathway is kept open. In attics, insulation baffles should be installed on the underside of the roof, near the eaves, to make sure the insulation doesn't touch the roof and block the ventilation.

A Fallacy — Ceilings Need More Insulation than Walls

Literally all guidelines for insulation recommend higher R-value insulation in the ceiling than anywhere else. Why? The given answer is usually: "Because heat rises." Right? Actually no, wrong! First of all, heat doesn't rise; warm air rises. In any house, heated air will tend to rise, creating slightly higher temperatures near the ceiling, but that slight temperature differential is not enough to warrant significantly higher insulation in the ceiling. Furthermore, in a superinsulated house, unless there is considerable solar gain into a space, the temperature differential between floor and ceiling is rarely more than 2 or 3 degrees. The reason to put more insulation in the ceiling than in walls is simply because it usually costs much less to install lots of insulation in a ceiling than in a wall.

If ceilings cost the same as walls to insulate, then the insulation levels in ceilings should be the same as the insulation levels in walls. In reality, this rarely happens. Ceilings

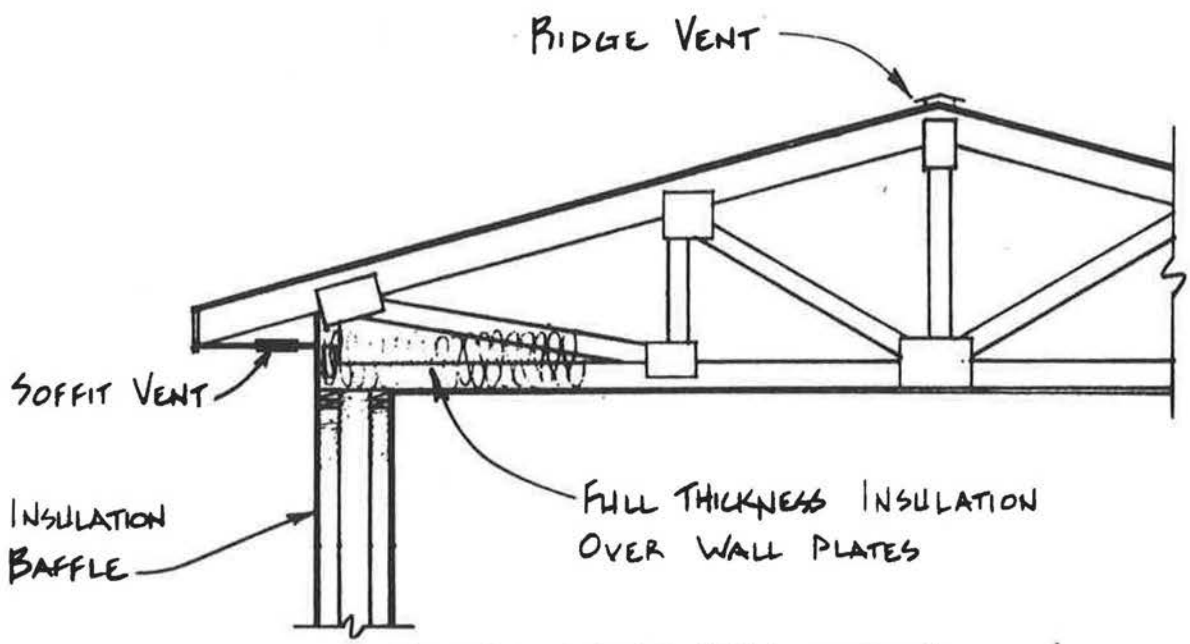


Figure 5-1 — Raised-Heel ("Arkansas Truss")

are almost always less expensive to insulate than walls. In houses with attics, installing thicker insulation in the ceiling usually only entails buying and installing the extra insulation — a relatively minor cost — no special framing, no extra wide window casings, or other special features as with walls. In houses with cathedral ceilings, extra thick insulation is a little more complex, but still not as expensive as extra thick insulation in walls. When designing a ceiling insulation system, you should start with an R-value equivalent to walls and then look at the extra cost for increasing it. If the cost is minimal, then add more.

Attics

Attics are relatively easy to design for superinsulation. Whether the roof is built with site-built rafters or trusses, attaining high R-values is no problem. The only area requiring special attention is the section over the wall plates. In this section, we present several alternatives for treating that area.

The Raised-Heel Truss

Commonly referred to as the "Arkansas Truss" or "Energy Truss," the raised-heel truss is specially engineered to allow extra height over the wall plates. The truss in Figure 5-1 has about 18 inches clearance over the wall plates. Thus 16 inches of insulation can be installed, leaving an additional 2 inches for ventilation above the insulation.

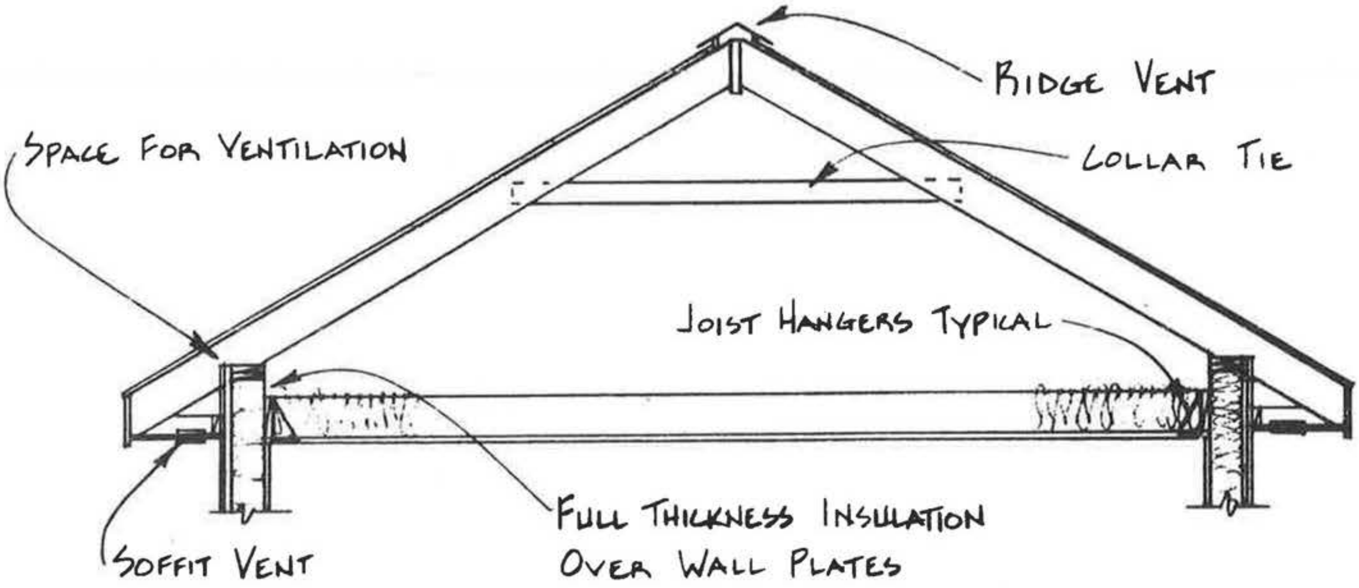


Figure 5-2 — Site-built rafters with dropped ceiling joists

Site-built Rafters with Dropped Ceiling Joists

With site-built rafters, one way to get adequate insulation over the wall plates is to drop the ceiling joists and install them with joist hangers or by nailing to the wall studs. The design in Figure 5-2 uses joist hangers. With this method, the joists don't provide structural strength against the walls bowing outward. Collar ties or other structural support is necessary.

Notice that with this design configuration, there is no thermal bridging through the wall top plates at the wall-ceiling joint. The entire corner is surrounded with insulation.

Elevated Roof Rafters

Another way to get more insulation over the wall plates with site built rafters is to install the ceiling joists over the wall in usual fashion, but instead of resting the rafter birdsmouth on the wall top plate, add an extra plate over the ceiling joists and seat the rafter

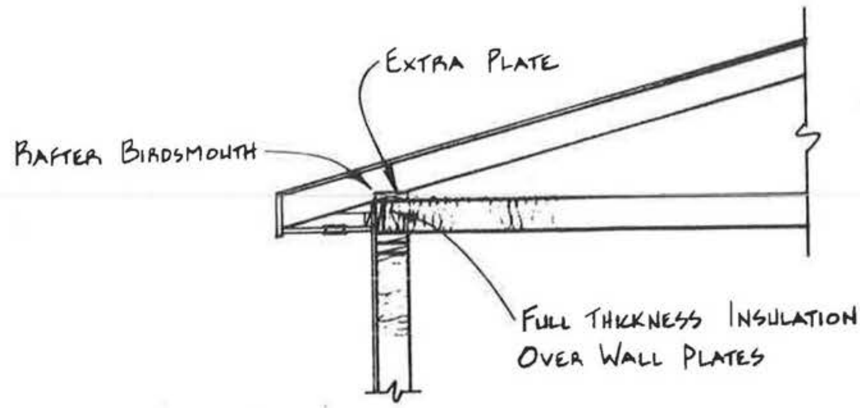


Figure 5-3 — Elevated roof rafters

birdsmouth on the new plate (see Figure 5-3). This design allows for full thickness insulation over the top of the wall. There are no structural uncertainties, as with the dropped joist technique in Figure 5-2.

Cathedral Ceilings

Cathedral ceilings are somewhat more difficult than unheated attics because of limited space between the ceiling and roof skin. There are, however, several good options for creating a superinsulated cathedral ceiling using trusses or exterior foam sheathing.

Scissors Truss

The common scissors truss is a good option for superinsulated cathedral ceilings. As can be seen in Figure 5-4, ceiling slope is not as steep as roof slope, but the cathedral effect is still somewhat maintained.

The easiest way to insulate this type of roof is with loose-fill insulation, but care must be taken to prevent the insulation from blocking ventilation through the ridge-soffit vent system. Notice the ventilation baffle in Figure 5-4. It is not necessary to install the baffle all the way up the entire roof; only where insulation reaches the roof skin. Notice also the insulation stop at the soffits.

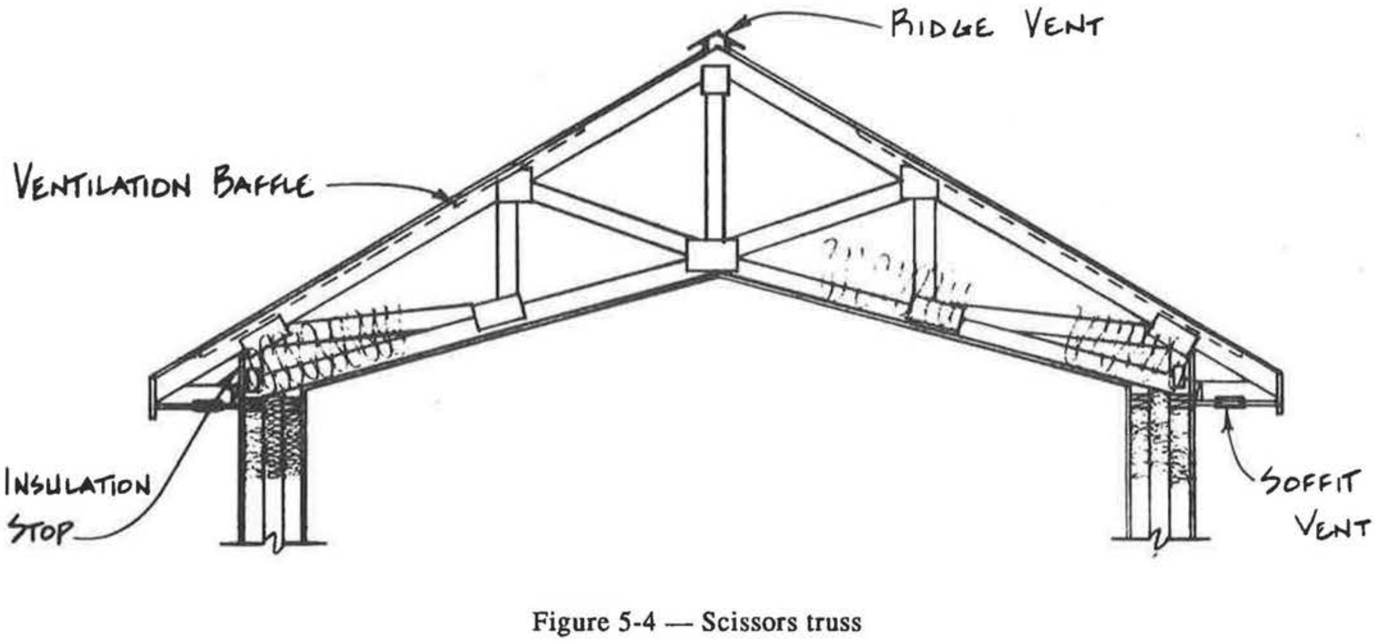


Figure 5-4 — Scissors truss

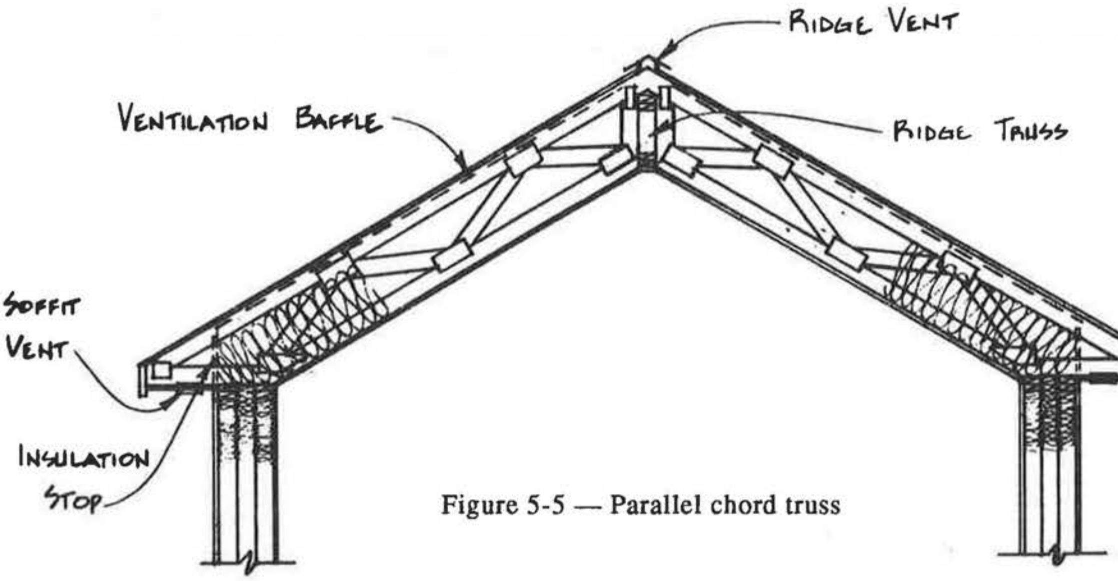


Figure 5-5 — Parallel chord truss

Parallel Chord Truss

The parallel chord truss is another good alternative for superinsulated cathedral ceilings. One advantage of the parallel chord truss over the scissors truss is that it allows the ceiling to follow the roof line, creating a better cathedral ceiling effect. A disadvantage is that it must be installed in two pieces, with a ridge beam or truss at the center (see Figure 5-5). With parallel chord trusses, it is necessary to install continuous ventilation baffles on the underside of the roof skin, extending from soffits to ridge.

Cathedral Ceiling With Rigid Insulation (Bonded Panel)

One way to achieve high R-value with site-built rafters is to install exterior rigid foam sheathing over the roof. This can be done using special bonded panels consisting of foam prebonded to a particleboard nailbase, or by separately installing foam and nailbase on site. The advantage of the prebonded panels is that one construction step is eliminated. The advantage of separate installation of foam and nailbase is that there is less waste; the insulation can be installed using odd-size pieces which are covered over by large sheets of sheathing. Another advantage of separate installation is that the seams of the foam and sheathing can be overlapped, ensuring good airtightness. Figure 5-6 shows a cathedral ceiling with 4 inches of foam insulation on a prebonded panel. Notice the structural sheathing on the roof rafters. The nailbase on the prebonded panel does not provide structural strength because of the separation by the foam — separate structural sheathing is required.

Notice also the placement of the air/vapor barrier and the optional insulation installed between the rafters. This is an important design variable which should be carefully

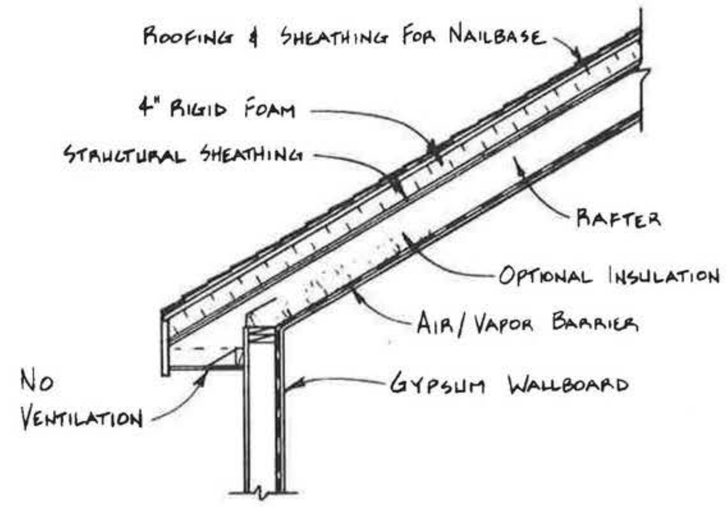


Figure 5-6 — Cathedral ceiling with rigid foam insulative sheathing (pre-bonded panel)

considered. The foam sheathing and roof skin act as a vapor barrier, but a separate air/vapor barrier is still installed on the underside of the rafters to ensure airtightness. If 4 inches of urethane foam are used, the R-value will be between R-26 and R-28 (R-value of urethane varies). To increase the R-value of the roof system, you may opt to install fiberglass batts between the rafters. This is OK, but you must adhere to the 1/3-2/3 rule; the R-value of the insulation between the rafters must be less than one-half the R-value of the foam sheathing. In the roof in Figure 5-6, that would be R-13 or less. Thus, it would be OK to install R-11 or possibly R-13 batts between the rafters, but not R-19 or R-30. If you did install R-19 or R-30, you would be risking condensation problems in the insulation. It wouldn't make sense to ventilate the rafter cavity with ridge-soffit vents because that would reduce the effectiveness of the foam insulation.

Special Trusses — The Supertruss™

Three special trusses for superinsulated houses are illustrated on the following page. A patented design called Supertruss™, they are particularly useful for cape, saltbox and gambrel-roof houses. These trusses allow up to 22 inches of space for insulation plus ventilation over the insulation. Although not shown in the illustration, insulation stops and ventilation baffles are, of course, necessary.

Making Ceilings Airtight

As discussed at the beginning of this section, the roof or ceiling of a superinsulated house must be airtight. All penetrations through the ceiling must be effectively sealed to the air barrier. The best approach is to eliminate as many ceiling penetrations as possible. Light fixtures, for example, can be placed on interior walls instead of ceilings. Bathroom and kitchen vent fans can be exhausted down through a partition wall and out through the basement rather than up through the ceiling. However, penetrations, such as plumbing stacks, are unavoidable.

For specific details on making ceilings airtight, see Section 3 on air and vapor barriers.

Three Tips Concerning Ceiling Air/Vapor Barriers

1. Install the ceiling air/vapor barrier before the interior partitions.

The advantage of this sequence is that the air/vapor barrier can be installed quickly and easily, in a few large pieces, with little or no cutting and sealing around partition top plates. The obvious disadvantage is that the construction sequence is interrupted; first the exterior framing is put up, then the air/vapor barrier, then the framing crews must come back again to put in the interior partitions. However, we know many builders who have adopted this technique and find that it saves time and money in the long run. It is especially practical in houses with long-span roof trusses and no-load-bearing partitions.

Some builders also install the ceiling gypsum board before putting in the interior partitions. This is a fine idea, but there are two considerations to take into account. First, the interior partitions will have to be cut

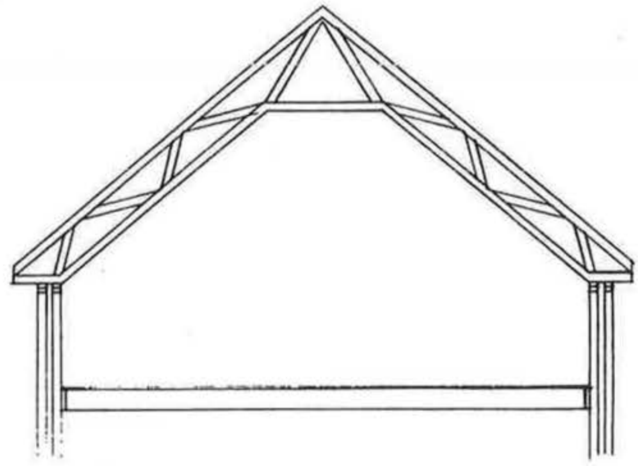


Figure 5-7 — Cape Supertruss™

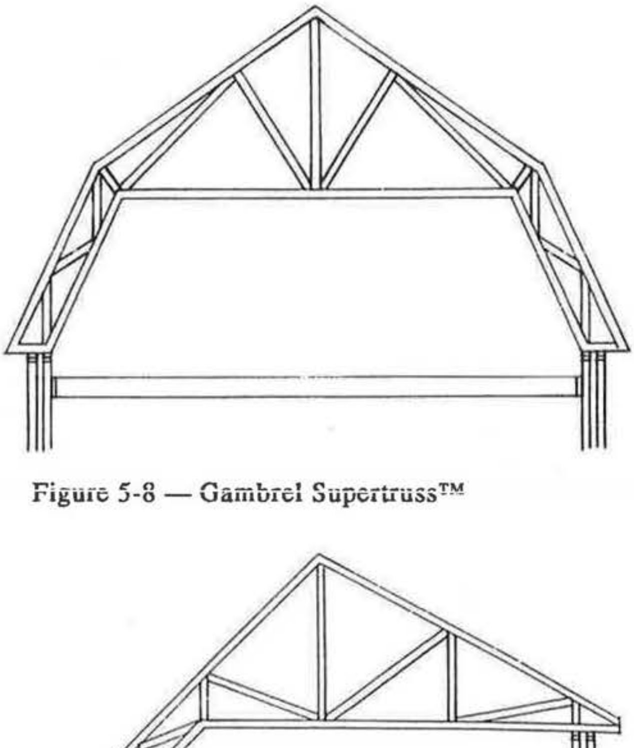


Figure 5-8 — Gambrel Supertruss™

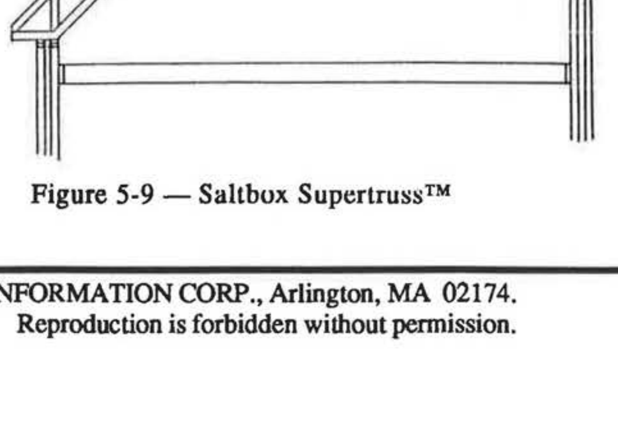


Figure 5-9 — Saltbox Supertruss™

short to allow space for the gypsum board. Second, with the ceiling gypsum board in place, the nailbases for the interior partitions are not visible. Nailing points should, therefore, be marked ahead of time. Also, be sure to install blocking where needed between trusses or ceiling joists before putting up the gypsum board.

2. Unless the gypsum board will be installed soon after the air/vapor barrier, leave out a 10-x10-foot section of the air/vapor barrier to prevent wind damage.

High winds blowing over the top of a house create a negative pressure in the attic, which can tear a polyethylene air/vapor barrier. Leaving out a section prevents this from occurring. The missing section can be easily installed by the drywall contractor later.

3. Insulate the ceiling as soon as possible after air/vapor barrier installation.

Here's a common problem. You install the ceiling air/vapor barrier and gypsum board but not the ceiling insulation, which will be installed by a separate sub-contractor later. You proceed to complete the interior work including taping the gypsum board seams and possibly some painting. It's cold out, so you run a few "salamander" propane heaters to keep the crews warm and to dry the gypsum-board seams. All of these processes produce water vapor which diffuses through the unpainted ceiling, condenses on the cold, uninsulated air/vapor barrier, and causes a mess. We have heard reports of condensed water actually puddling above the ceiling gypsum board and pulling it down, especially where the ceiling is coated with a textured finish.

The problem is not the ceiling air/vapor barrier; the problem is the cold ceiling air/vapor barrier. The solution is to insulate it and keep it warm. As a general rule, once the ceiling air/vapor barrier is up, the ceiling insulation should be installed before any type of heat is put into the house.

The Ceiling Is an Important Part of the Heating Distribution System

You won't find it mentioned much in HVAC handbooks, the ceiling of a room is a definite part of the heat distribution system, whether the room is heated with baseboards, warm air, or even sunshine. Let's look at the mechanisms at work in a typical room (see Figure 5-10). Sun shines through the window, warming the floor (1). Air near the floor is heated by the warm floor and the baseboard heater (2). The warm, buoyant air rises to the ceiling, where it loses some of its heat to the mass of the gypsum board.

When the temperature of the ceiling is raised slightly, it gives off radiant energy (3) which is absorbed by the floor and other objects in the room. Assuming that the floor and walls are as well insulated as the ceiling, this dynamic heat exchange will tend to equalize temperatures on all surfaces. The system is automatically self-balancing; the warmer the ceiling gets, the more it radiates to the floor. Unless there are large expanses of windows or the house is poorly insulated, there will be very little temperature stratification.

Radiant ceiling heating systems use the ceiling directly as the heat distribution system. Electric cables heat the ceiling surface to between 94° and 110°F; the ceiling then radiates to and warms other surfaces in the room.

What about ceiling fans?

Since warm air rises in a room, doesn't it make sense to blow it down again to recapture some of that heat? Although the suggestion sounds sensible, the answer is generally no. Here's why:

1. If the house is well insulated, the ceiling should distribute heat effectively and automatically with little or no stratification and no need for destratifying fans.

Even in a room with lots of sunshine (i.e., a sunspace), where there might be stratification due to high solar gain, a destratifying fan is not needed. The well-insulated ceiling should effectively radiate heat energy to other room surfaces just like a radiant ceiling heating system does.

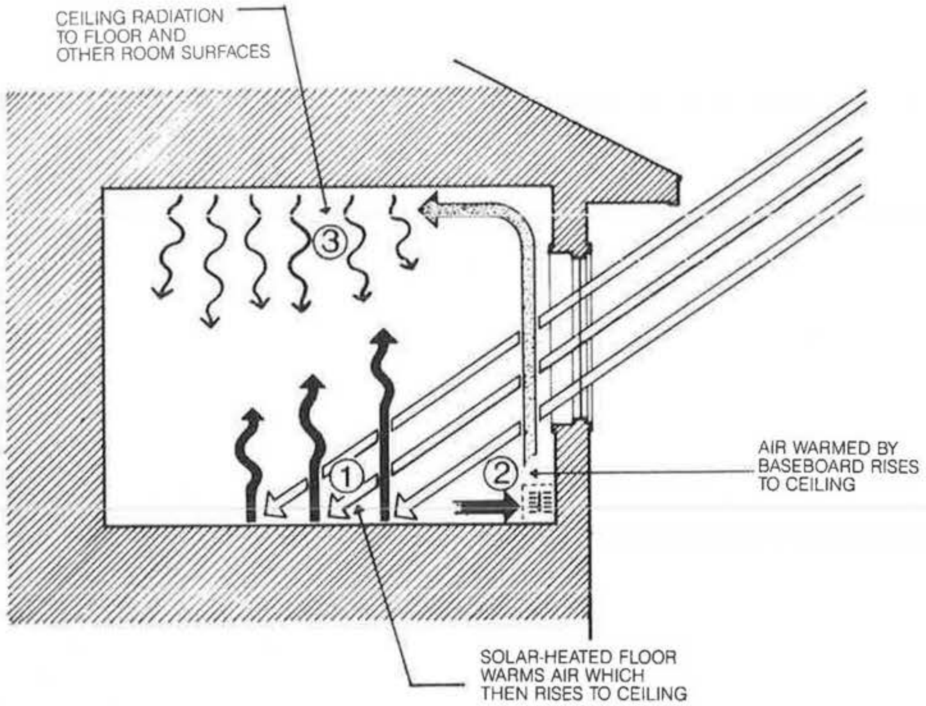


Figure 5-10 — The ceiling as a heat distribution system

2. Moving air cools people.

Although an advantage in summer, air movement in winter can make people feel uncomfortably cool and possibly cause them to raise the thermostat setting, resulting in increased energy use.

3. Moving air also causes increased heat loss through windows.

Much of the thermal resistance of window glass is due to the thin film of air which clings to the inner surface of the window. The R-value of that air film is assumed to be R-0.68 if the air in the room is still. If a ceiling fan moves air across the window, it will reduce the effective R-value of that air film, thus increasing heat loss.

4. Fans consume electricity.

If there are no energy savings from using them, destratifying fans are net losers.

Two Qualifications:

This discussion about the uselessness of ceiling fans during the heating season refers only to well-insulated, well-sealed houses. In poorly-insulated, leaky houses, floors may be uncomfortably cold due to air leaks and poor floor insulation. In those cases, a destratifying fan could increase thermal comfort and save energy by equalizing temperatures throughout the room.

Also, this discussion refers to winter use only. Warm weather use is a different story.

Hot Roofs and Cold Roofs

What's a "Hot Roof"?

The first time we heard the term "hot roof" was while conducting seminars in Alaska. One attendee came up to us during a coffee break and asked whether there was any problem with building a hot roof in the Juneau area. By that time in the workshop, we had already heard numerous tales of peculiar Alaskan building problems, such as building on permafrost and muskeg, so we patiently awaited an explanation of some new type of heated roof that is used only in Alaska.

As it turned out, what she meant by "hot roof" was simply an unvented insulated cathedral ceiling. It's called a "hot" roof simply because the outer surface of such a roof is technically warmer than a vented roof system ("cold roof"), in which the outer roof surface is isolated from and thermally decoupled from the warm roof insulation.

Since that time, we've received inquiries from subscribers in the "lower 48" who are also considering hot roofs. It seems that some designers and builders are seriously questioning the traditional recommendation that all insulated cathedral ceilings must have ventilation above the insulation. And possibly for good reason. Given the complexity of the issue and its relationship to moisture dynamics in houses, we suspect that this article won't be the last on this topic.

Cold Roofs Are the Norm

The ventilation between the insulation and roof skin in a cold roof serves three functions:

1) Removes water vapor that passes into the rafter cavity from the heated living space;

2) Keeps the outer roof surface cold, thus preventing snow melt and ice damming; and

3) Helps to cool the roof during hot sunny weather in warm climates.

Typical cold roof design includes a 1- to 2-inch airspace between the insulation and roof sheathing, with continuous soffit and ridge vents for air entry and exit.

But Not Necessarily the Rule

Although it is often assumed that ventilation over insulation in cathedral ceilings is a universal code requirement, we were surprised to find that according to the CABO One and Two Family Dwelling Code it's actually up to the discretion of the local inspector. Section R-707 of the Code states that *"When determined necessary by the building official due to atmospheric or climatic conditions, ... rafter spaces formed where ceilings are applied direct to the underside of roof rafters shall have cross ventilation for each separate space by ventilating openings protected against the entrance of rain or snow."*

The Effectiveness and Even the Necessity of Roof Ventilation Has Been Questioned

In the old days, roof ventilation in cathedral ceilings was necessary because the ceilings were insulated with minimal insulation and nobody paid any attention to air leakage through ceiling penetrations. So much water vapor leaked into the rafter cavities that it had to be vented out to prevent condensation damage — it was called the "flow through principle."

Those old ceilings not only leaked water vapor, but also heat, keeping the insulation and roof sheathing warm enough to avoid excessive condensation (Figure 5-11).

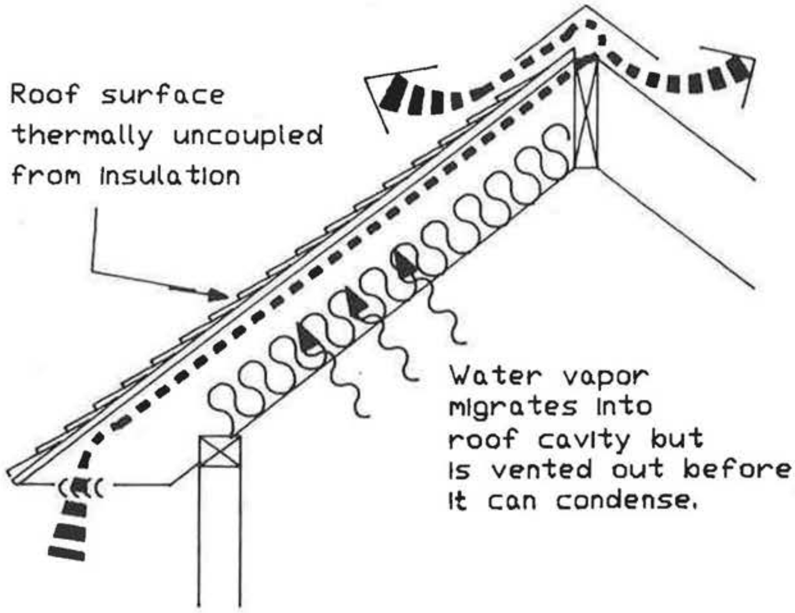


Figure 5-11 — A typical "cold" roof

But what about newer heavily-insulated cathedral ceilings, with say R-30 or more insulation? One effect of the thicker insulation is to cause the airspace above the insulation to run colder, thus increasing the potential and speed at which condensation can occur. In a very cold climate, water vapor passing through a ventilated cathedral ceiling may condense and even freeze before it can be ventilated out (Figure 5-12). That problem often shows up directly above ceiling light fixtures and other roof penetrations — ice builds up on the underside of the roof sheathing until spring, when the ceiling fixture becomes an indoor waterfall.

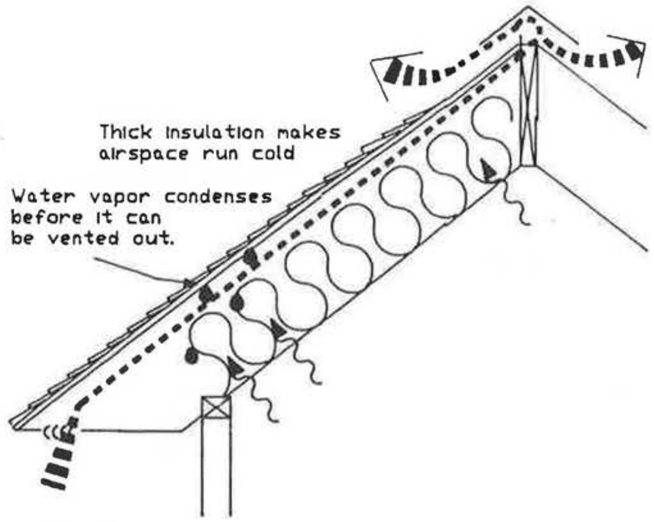
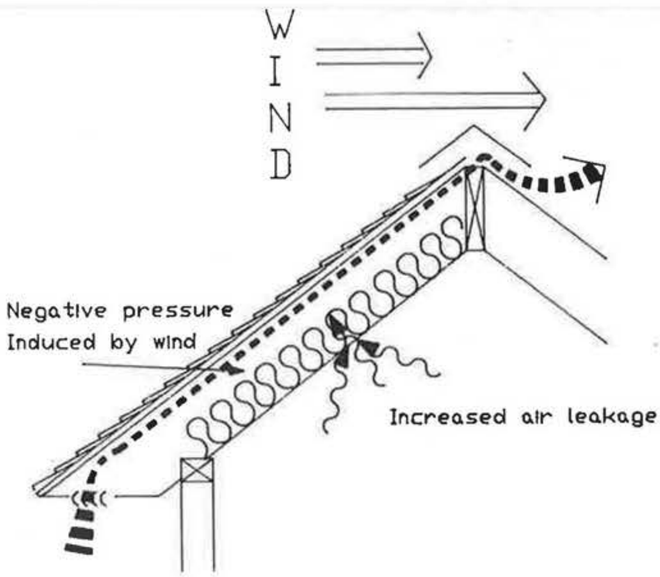
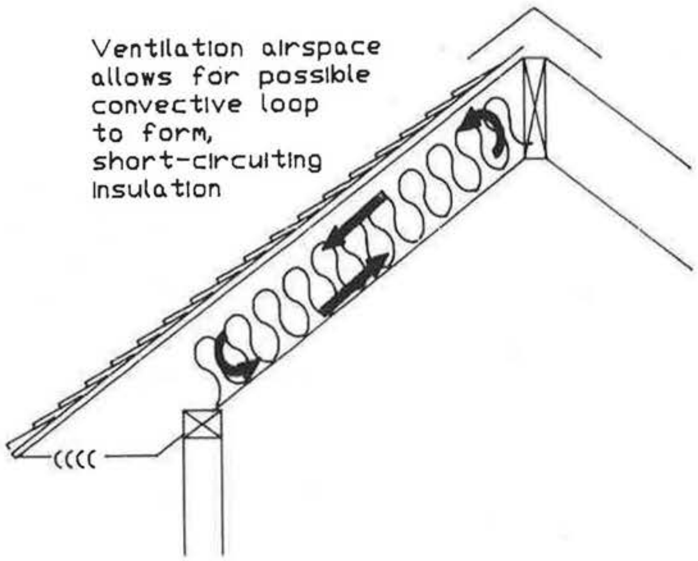


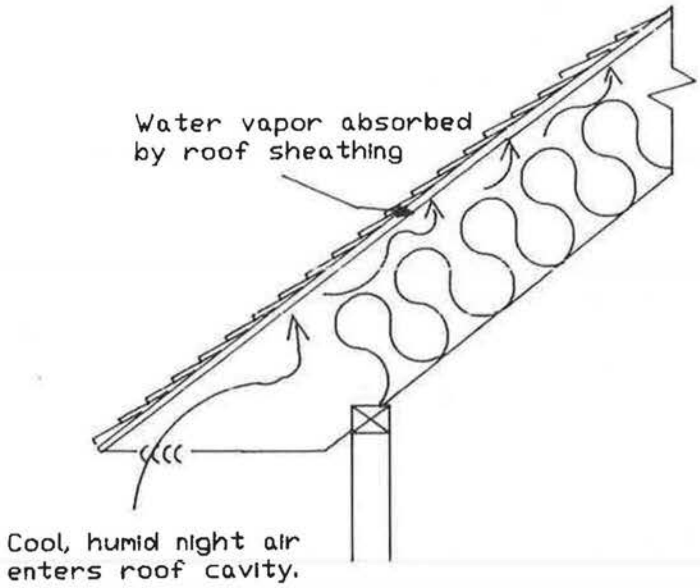
Figure 5-12 — With thick insulation, the ventilation in a cold roof may not be adequate to remove all moisture before it condenses into water or ice.



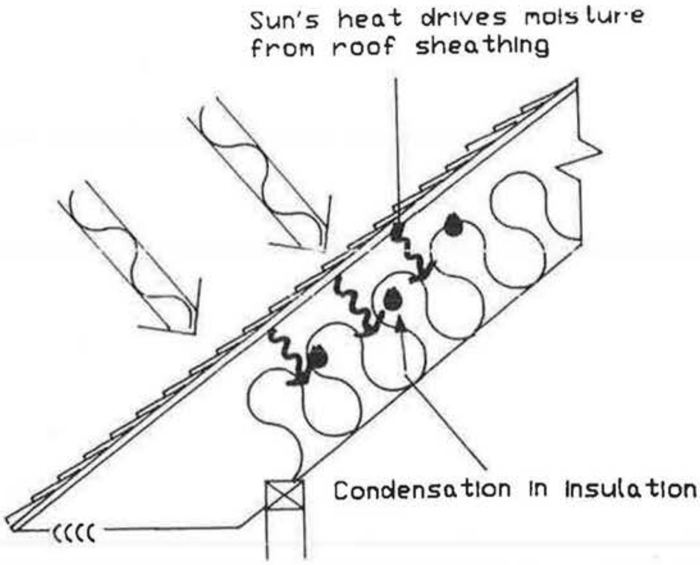
A — Negative pressure caused by wind may increase air leakage into roof from living space



B — Ventilation airspace can allow convective loop to be set up within rafter cavity, short-circuiting the insulation



C — During periods of high outdoor humidity (at night), roof sheathing may absorb moisture from outside air



D — Moisture in roof sheathing is driven out by sun's heat, possibly resulting in condensation on cool insulation

Figure 5-13 — Possible problems with ventilated roofs

Roof Ventilation May Even Cause Problems

The inclusion of a ventilated airspace in an insulated cathedral ceiling can cause three problems:

1. Increased air leakage. During periods of high winds, it is possible that a negative pressure created within the ventilation airspace could induce or increase air leakage through the ceiling (Figure 5-13A).
2. Convective degradation of the insulation thermal resistance. The inclusion of an airspace adjacent to an insulation component, such as a fiberglass batt, can create a convective air loop around and within the insulation (Figure 5-13B).
3. Introduction of moisture into the insulation system from outdoor air. A study on attic moisture dynamics, performed by Peter Cleary at Lawrence Berkeley Laboratory suggests that in some cases, the source of moisture condensation in attics is from outdoor air, not indoor air. At night, the wood components of the roof sheathing and framing absorb moisture from the cool, humid outdoor air. The following day, solar heat drives the moisture from the sheathing, raising the humidity of the air in the attic to the point where condensation can occur on the cool surface of the attic insulation. A similar phenomenon may occur in cathedral ceilings (see Figures 5-13C and 5-13D).

Why Build a Hot Roof?

There are two primary reasons why some builders are turning to the concept of hot roofs. Both have to do with foam insulation. One application involves spraying a skim coat of foam, about 1.5 inches thick, onto the underside of the roof sheathing in a cathedral ceiling.

Fiberglass batts are then installed to fill the rest of the rafter cavity (Figure 5-14). In addition to creating a watertight boundary, the urethane foam also forms an extremely good air barrier. With 8-inch rafters and R-19 fiberglass batts, the result is a good airtight R-30 roof assembly.

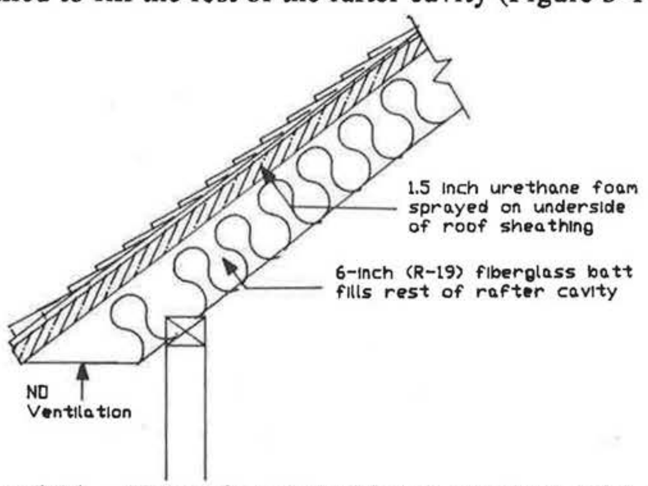


Figure 5-14 — Hot roof created with spray urethane skim coat under roof sheathing.

The other popular type of hot roof design uses rigid foam sheathing boards on top of roof rafters (Figure 5-15). Several products are now available, which include isocyanurate or polystyrene foam, with a laminated nail-base for attaching roof shingles. An example of such a product is TUPS from Homasote. As with the spray urethane approach described above, the rigid foam insulation is usually supplemented with fiberglass installed in the rafter cavity.

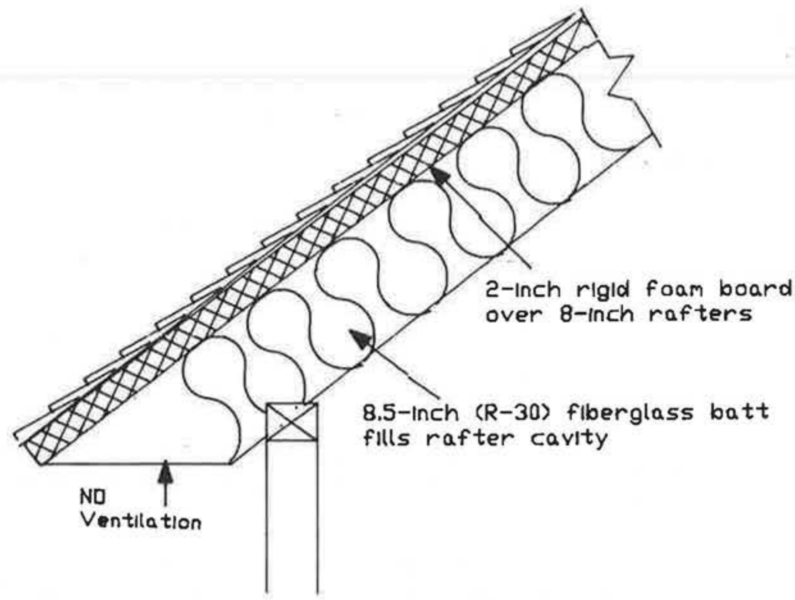


Figure 5-15 — Hot roof with rigid foam sheathing over rafters.

Both of the above designs must remain unvented. If you ventilate under the foam, you are isolating it from the rest of the insulation system. You might as well put the foam in the back yard!

What about Moisture Condensation in Hot Roofs?

The hot roof configurations in Figures 5-14 and 5-15 are similar to walls with exterior foam sheathing — not exact, but similar. Both have exterior air and vapor barriers (the foam insulation) with fiber insulation in the framing cavity. The main differences between hot roofs and walls with exterior foam sheathing are that hot roofs are likely to be more air and vapor tight on the cold side and are also likely to have more insulation in the framing cavity than most walls (R-19 to R-30 in the roofs vs. R-11 to R-19 in walls). Walls with exterior foam sheathing have become quite common in cold climates, generally with no moisture condensation problems. So hot roofs shouldn't have problems either. The reason that walls don't have problems is probably a combination of:

1) air and vapor barriers keeping water vapor out,
2) the foam maintaining the stud cavity at a warmer temperature, reducing condensation potential and suppressing internal air convection within the stud cavity,
3) absorption of condensed water by the building framing members, and
4) possible ventilation of the stud cavities through wiring holes and other building defects.

Will the same factors be evident in hot roofs? Probably yes, but we should still be cautious. The best assurance to protect against moisture problems is to install effective air and vapor barriers to prevent moisture from getting into the rafter cavities in the first place. The colder the climate, the more important the air and vapor barriers.

The Ice Damming Problem — It's Not Just Temperature that Counts

In order for ice damming to occur, the roof surface temperature must be above freezing over heated spaces and below freezing at the eaves (over unheated spaces). With a very poorly insulated roof, the roof surface temperature over heated spaces could easily be over 32°F when the outdoor air temperature is, say, 25°F (even if the roof is vented). Under those conditions, ice damming could occur after a light snowfall (Figure 5-16).

But with a well-insulated hot roof with an R-value of, say, R-40 or R-50, the temperature of the roof skin will be almost the same as the temperature of the outdoor air. If the outdoor air is 25°F, the temperature of the R-40 roof will theoretically be about 26°F. The snow should not melt anywhere on the roof surface.

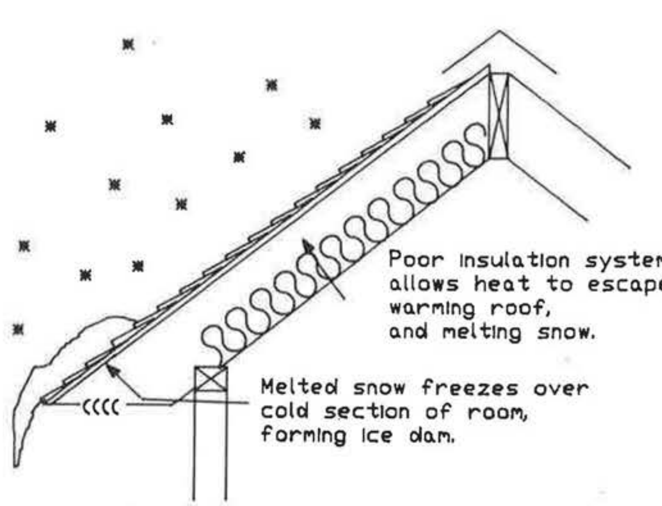


Figure 5-16 — Ice damming on a poorly insulated roof

But what happens as the snow accumulates?

Here's the problem. Snow is an insulator. As it builds up on a hot roof, it holds some of the heat in, raising the roof surface temperature. If enough snow builds up and remains on the roof, it can raise the surface temperature above the freezing point, creating ice-dam conditions.

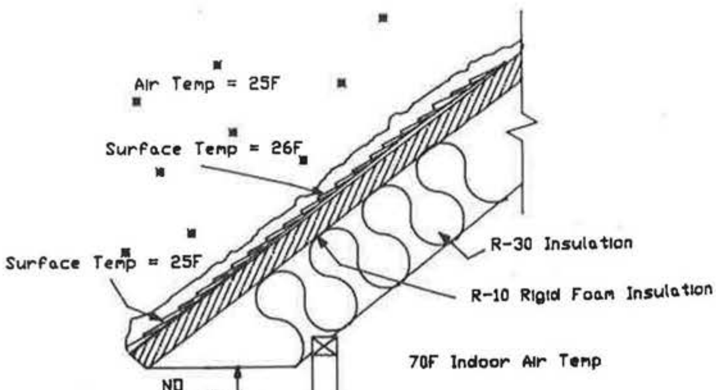


Figure 5-17 — On a heavily insulated, unvented roof, the roof surface temperature will be nearly the same over the heated space as over the eaves.

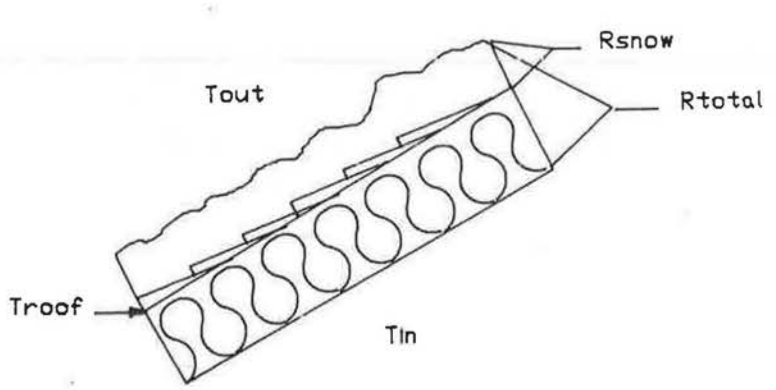


Figure 5-18 — Calculation of roof surface temperature

Whether or not the above-described problem occurs with a hot roof depends on the R-value of the roof, the thickness of snow on the roof, and the outdoor air temperature. The R-value of snow varies with age of the snow and outdoor air temperature, but as a rough estimate, fresh falling snow has an R-value of about R-1 per inch. Given that, the roof surface temperature can be easily calculated using the following equation:

Troof = Tout + ((Tin-Tout) x (Rsnow / Rtotal))

where:

Troof =temperature of the roof surface,
Tout = outdoor air temperature
Tin = indoor air temperature;
Rsnow = R-value of the snow alone; and
Rtotal = total R-value of the roof PLUS snow.

Figures 5-19 through 5-21 show the effect of snow buildup on hot roofs insulated to various R-values. The greater the R-value of the roof, the greater the snow buildup that can be tolerated before melting conditions occur at the roof surface. The worst-case situation (of the three presented) would be the R-20 roof (Figure 5-19). At 20°F outdoor air temperature, the surface of the R-20 roof will rise above freezing with as little as 6 or 7 inches of snow on it. The R-30 roof (Figure 5-20) is better, requiring over 8 inches of snow buildup before melting conditions occur on the roof surface (assuming 20°F outdoor air temperature), while the surface temperature of the R-60 roof (Figure 5-21) won't rise above freezing until over 16 inches of snow accumulates. At colder outdoor air temperatures, the thickness of snow necessary to cause melting increases.

The bottom line is that if a house is located in a climate where 8 inches of snow or more commonly collects on sloping surfaces for extended periods of time, then a hot roof may lead to ice damming problems.

Cold temperatures alone should not preclude the use of hot roofs. For example, in Alaska hot roofs are common in Anchorage — about 11,000 degree days. But travel north to Fairbanks (14,000 degree days) and you'll find that hot roofs are never used. Not because of the cold, but because Fairbanks experiences very little wind during the winter and snow accumulations of two feet or more on roofs is not uncommon. (According to Fairbanks residents, even 40 inches of snow on roofs is sometimes seen.)

But farther north at Barrow, (20,000 degree days), hot roofs should not be a problem. According to Harold Orr of the Canadian National Research Council, hot roofs can be successfully used in places like Barrow because the high winter winds prevent buildup of insulating snow layers on roofs.

NOTE: Keep in mind that all these calculations ignore the roof framing. The R-value of an 8-inch rafter is only R-10. At the rafters, the roof surface temperature will be somewhat warmer than the temperatures predicted in the Figures 5-19 through 5-21.

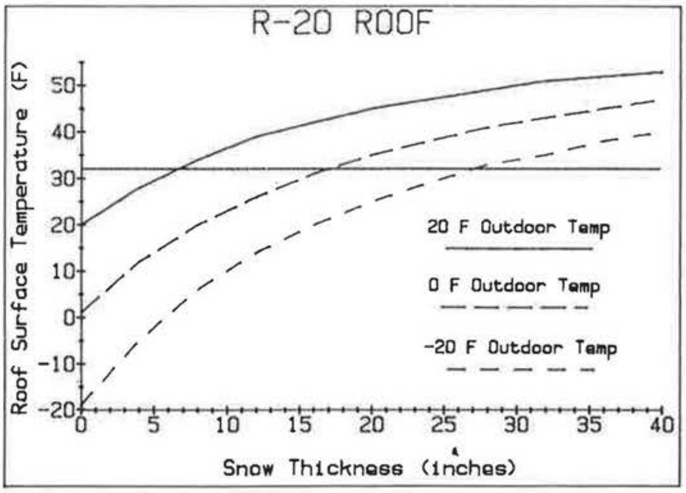


Figure 5-19 - Roof surface temperature vs snow thickness for R-20 roof.

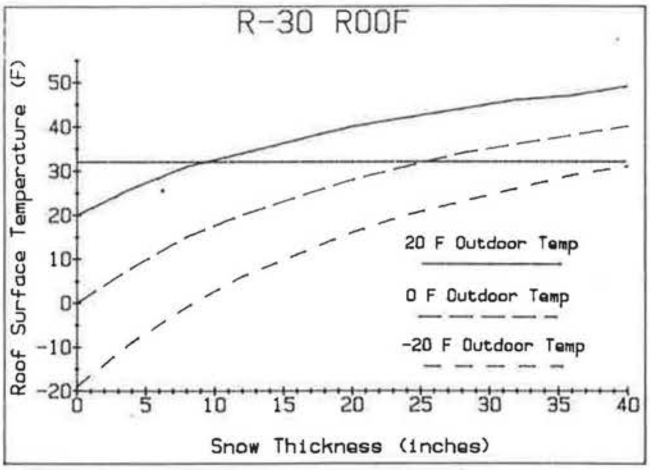


Figure 5-20 - Roof surface temperature vs snow thickness for R-30 roof.

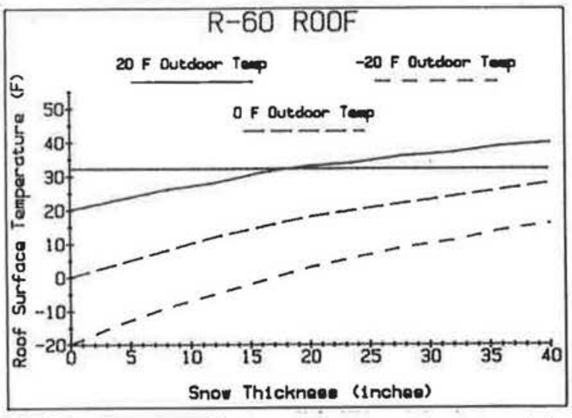


Figure 5-21 - Roof surface temperature vs snow thickness for R-60 roof.

A Hot Roof to Avoid

What about the roof assembly in Figure 5-22? No foam sheathing, just a fiber-filled rafter cavity with the air and vapor barriers installed on the warm side of the insulation. Theoretically, this design will work fine as long as the air and vapor barriers are flawless. It has certainly been done. One well documented example is a superinsulation retrofit performed in Saskatoon under the supervision of Harold Orr. But unless you are assured of extremely high quality control in air and vapor barrier installation, a fiber-filled hot roof is a risk. Our recommendation is to avoid that type of design unless you are confident that the air and vapor barriers will be essentially flawless (and will stay that way over the years).

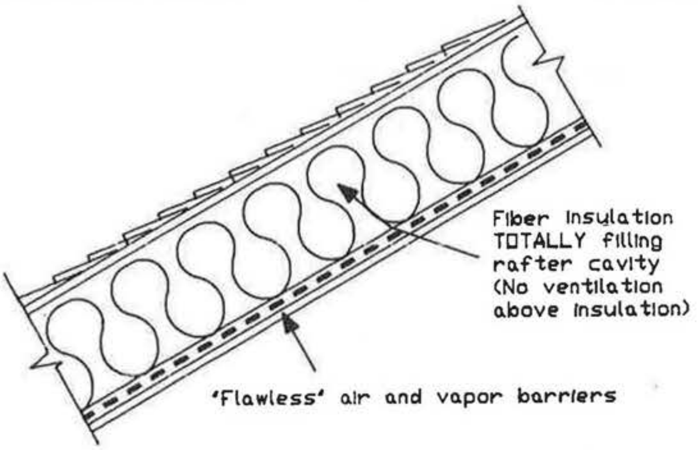


Figure 5-22 — Hot roof with fiber insulation only

What about Overheating of Hot Roofs in Warm Climates?

Without ventilation beneath the roof sheathing, will a hot roof overheat to the point of damage to the shingles? Unfortunately, we were unable to get a conclusive answer to that question from shingle manufacturers, but we suspect that it could be a serious problem with dark-colored roofs in warm climates.

The Best of Both Worlds?...

The design in Figure 5-23 is a way to gain all the advantages of both hot and cold roof designs. The roof is insulated with some type of exterior foam insulation (either a skim coat of urethane or a layer of rigid foam over the rafters) as with regular hot roof design. But in this design, sleepers are laid over the rafters and are then covered with a second sheathing onto which the shingles are attached. The

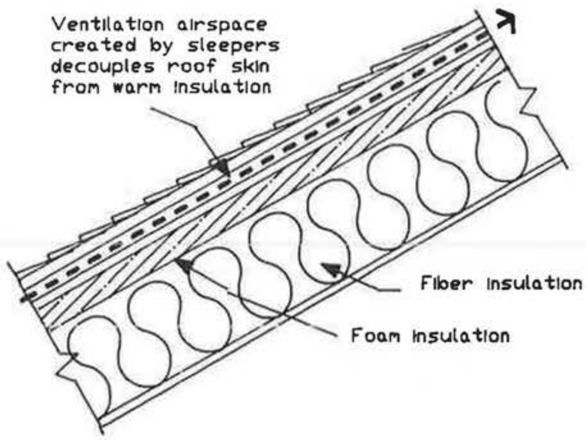


Figure 5-23 — Hot roof with ventilation between sheathing sleeper cavities provide ventilation of the outer skin, reducing the risk of ice damming in cold climates and roof overheating in hot climates.

CONCLUSIONS

1. Hot roofs are OK in most situations if:

   A. Exterior foam insulation is used — not just fiber insulation.

   B. Good air and vapor barriers are installed.

   C. Snow buildup does not exceed 7 or 8 inches on sloping surfaces.

SECTION 6
FOUNDATIONS

Foundations Lose Heat in Two Directions

The ground is a heat sink. In cold climates, the temperature of the ground at almost any depth is always cooler than room temperature. Thus, houses are always losing heat to the ground through their foundations. Foundations lose heat in two directions — downward to the "deep earth," and upward toward the ground surface.

Deep below the surface, at a depth ranging from 10 to 20 feet, the temperature of the earth never changes. That temperature, referred to as the "deep ground temperature," is roughly equal to the average annual air temperature. (Actually it is usually slightly higher than the average annual air temperature because snow cover in winter tends to reduce heat loss from the ground and solar gain in summer tends to increase heat gain.) The foundation of a house constantly loses heat downward toward the deep earth. In Minneapolis, the average deep ground temperature is between 46 and 50 degrees Fahrenheit. Heat loss from a foundation to the deep ground is not terribly great since the temperature difference between the foundation and the deep earth is not more than 20 or 25 degrees. Furthermore, over time, a house tends to warm the soil beneath the foundation, further decreasing heat loss.

The second direction of heat loss from foundations is upward toward the ground surface. This is a much more significant source of heat loss and requires more attention when designing foundation insulation systems. Near the ground surface, soil temperatures roughly track outdoor air temperatures, with a slight lag. At depths of 1 or 2 feet, the time lag is on the order of a few days; at greater depths, the time lag ranges up to six weeks. However, at all depths, the ground temperature is always lower than typical room temperature. For example, in Minneapolis, even in July, the average ground temperature at 0- to 6-feet depth is 62 degrees; at 2- to 12-foot depth, it is 53 degrees. In January, the average ground temperature at 0- to 6-feet is 33 degrees; at 2- to 12-feet, it's 42 degrees. Thus, the portion of a foun-

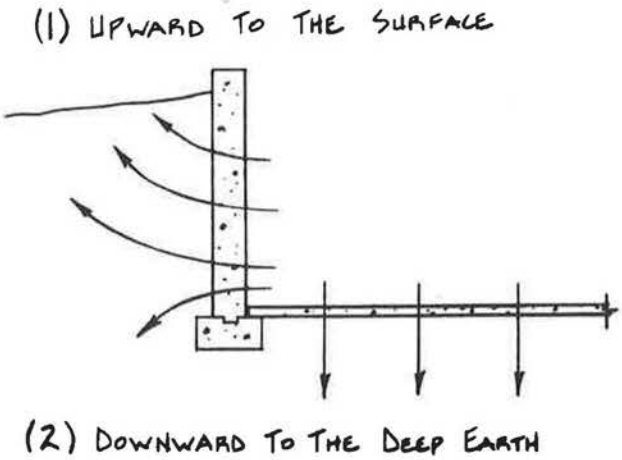


Figure 6-1 — Foundations lose heat in two directions dation which is near the ground surface loses a considerable amount of heat in winter.

Whether it is built with slab on grade, crawl space, or full basement, a superinsulated house foundation must have an effective insulation system to reduce heat loss, both to the deep earth as well as to the ground surface.

Foundation Materials for Superinsulated Houses

Any of the common foundation materials — poured concrete, concrete blocks, or wood — can be used for superinsulated house foundations. However, to properly design the foundation insulation system, you should have a basic understanding and appreciation of the thermal characteristic of the various materials.

1. Poured Concrete

Concrete is a poor insulator. With an R-value of R-0.08 per inch, an 8-inch concrete wall has an R-value of 0.64 — less than that of a single glazed window. An uninsulated concrete foundation would be a thermal disaster. When designing an insulation system for a concrete foundation, you must be careful to avoid any thermal bridging. Even if the heat flow path is 2 feet long, the R-value of a concrete thermal bridge is only R-1.92 (0.08 per inch x 24 inches).

2. Concrete Blocks

Concrete blocks have R-values ranging from R-0.70 to R-2.00, depending upon the material from which they are made. Although the R-value is slightly higher than poured concrete, concrete block foundations still must be well insulated to avoid excessive foundation heat loss. In addition to their low thermal resistance, concrete blocks also cause high heat loss — due to convection cells — which can form within the hollow cores. If the cores are connected, air can circulate within the block wall, carrying heat from the inner foundation surface upward and outward to the cold outdoor air. To prevent this, hollow concrete blocks should be filled with a water-resistant insulation material, such as vermiculite or perlite. Core insulation, however, does not provide enough thermal resistance for a superinsulated foundation. Additional insulation must be installed either on the inside or outside of the wall, in the same manner as with poured concrete foundations.

3. Wood Foundations

Wood foundations are quickly gaining popularity. From a thermal standpoint, wood foundations are significantly better than either concrete or block foundations. First of all, wood is a better insulator than concrete; it has an R-value of about R-1.25 per inch.

Secondly, a wood foundation is basically a 6- or 8-inch stud wall, the hollow cavities of which can be easily insulated with fiberglass batts or other suitable insulation material.

Wood Foundations on Concrete Footings — Yes or No?

From an energy conservation standpoint, wood foundations are superior to poured concrete or block foundations. Not only is wood itself a better insulator than masonry materials, but the hollow wall cavities of wood foundations can be easily insulated with almost any type of standard insulation material. Although opinions vary, most builders agree that the total cost of a heavily insulated foundation is lower using wood than it is using concrete or block. Partly because of the above reasons, wood foundations are gaining increasing popularity within the energy design community.

Standard practice for installing an All Weather Wood Foundation (AWWF) calls for a composite footing, consisting of a wood footing plate over a layer of gravel or crushed stone. One of the advantages of this system, compared to using a concrete footing, is that concrete is completely eliminated; no hold-ups waiting for the concrete truck. Recently, however, we heard from several builders who are using concrete footings under wood foundations. Their stated reason is that leveling crushed stone is too time-consuming; concrete is easier. Also, some builders are still skeptical about a crushed-stone footing supporting a house without settling. The latter concern is unfounded: washed pea gravel and 3/8-inch crushed stone are both excellent footing materials, classified as non-compressive soil. The wood footing plate distributes the design load from the framed wall to the gravel layer, which in turn distributes it to the supporting soil. As for the first concern — the excessive time required to level gravel or stone — most builders we've spoken with find it difficult to level larger-size crushed stone, but relatively easy to level 3/8-inch crushed stone or river-run pea gravel.

However, aside from ease of construction and supportive strength, there is another very important factor to keep in mind when considering concrete footings — drainage. One of the purposes of a gravel footing is to provide a path for water drainage under the footings and slab. If you look in the "Design, Fabrication, Installation Manual" for the AWWF system, published by the National Forest Products Association (NFPA), you will not see footing drains. The gravel footings are a natural drain to the porous fill under the slab. We asked Gerald Koenigshof at the U.S. Forest Service's Forestry Sciences Lab in Athens, Georgia, about using concrete footings instead of wood. (Koenigshof took part in much of the original research on wood foundations at NAHB during the late 1960s. As a contractor, he also built hundreds of homes with wood foundations.) According to Koenigshof, concrete footings may cause water leakage into a basement if the footings are situated on low-permeability soil and are not properly

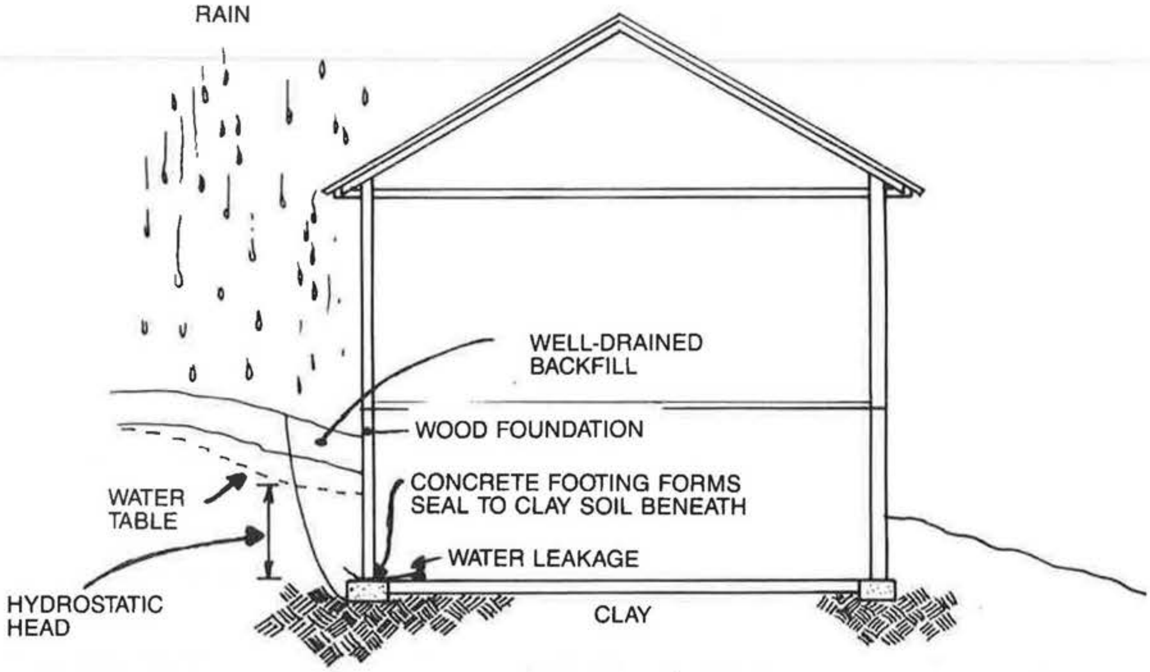


Figure 6-2 — Concrete footings on clay soil create conditions that lead to basement leakage.

drained. The foundation wall and footing form a dam, sealed to the clay substrate. Depending on the level of the water table, hydrostatic pressure can build up behind the "dam" and eventually force water through the foundation wall into the basement (see Figure 6-2).

On the other hand, if the foundation and slab are underlain with a permeable material such as crushed stone, water can easily drain under the house (see Figure 6-3). (The AWWF manual calls for crushed stone or gravel under a floor slab, brought to a level with the top of the footing plate.) At flat sites, a sump pump must be installed.

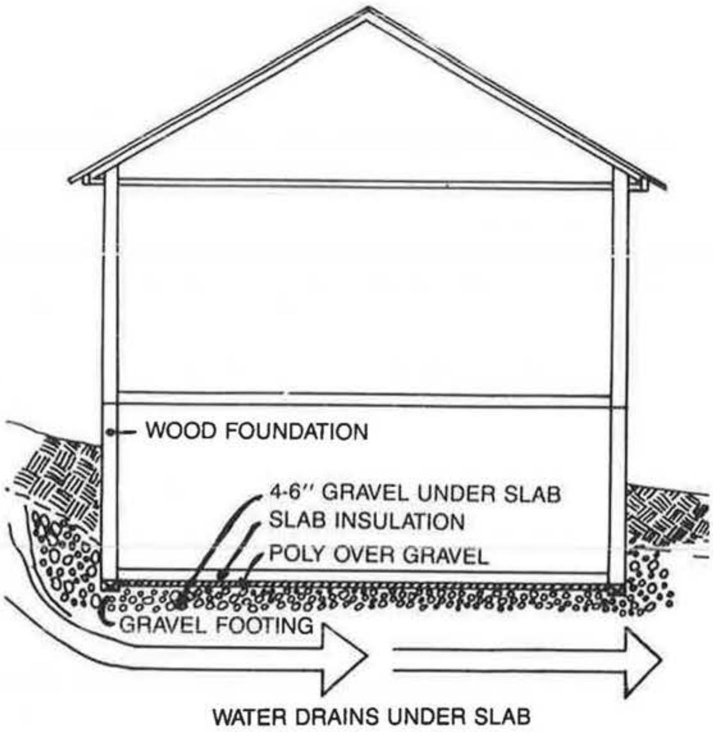


Figure 6-3 — Gravel footings allow drainage beneath house

This approach to foundation drainage is not new and has not been limited to AWWF applications. An article written by Koenigshof in 1978 shows a design where drainage channels are installed on top of concrete footings to relieve water pressure outside the wall (Figure 6-4). Crushed stone or gravel is filled in under the floor slab to receive water coming through the drainage holes.

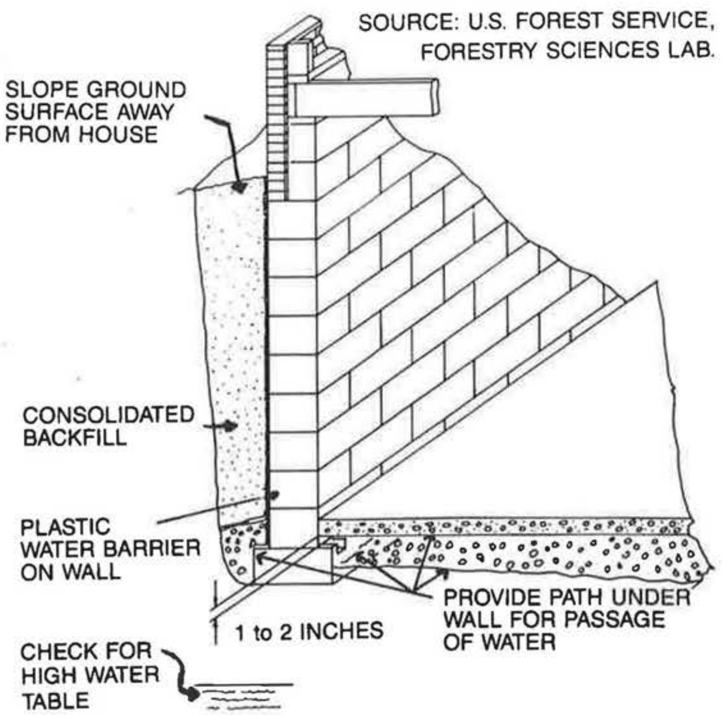


Figure 6-4 — Notched footing allows water drainage over footing, under slab

What about footing drains? Fine, says Koenigshof. As long as they are properly installed and never clog, footing drains can replace the subslab drainage system. (We know of one builder, Oliver Drerup, of Allen, Drerup and White, Toronto and Ottawa, who installs double drain tiles around concrete footings under wood foundations.)

How about well-drained soils? Also fine. When building on sandy soils or other soils with high permeability, water drainage will almost never be a problem, with or without concrete footings.

In Summary

If you install concrete footings under a wood foundation, you may be removing part of the foundation drainage system: the concrete footing forms a dam, blocking the water drainage path under the house. The problem is not necessarily severe, since it shouldn't occur in well-drained soils. Plus, it can be easily rectified by installing a proper alternative drainage system such as drain tiles.

For more information, contact Gerald Koenigshof, U.S. Forest Service, Forestry Sciences Lab, Carlton St., Athens, GA 30602; (404)546-2445.

Foundation Design Types

The three basic foundation design types — slab-on-grade, crawl space, and basement — can all be successfully incorporated into a superinsulated house. However, superinsulation design requires some extra thought about where to position the insulation system. The important concept to consider is: Where is the boundary of the thermal envelope? For example, a crawl space can either be insulated in the overlying floor or on the ground surface. In the first case, the floor is the boundary of the thermal envelope and the crawl space is outside (unheated); in the second case, the crawl space is essentially a heated space and lies within the thermal envelope. A similar situation applies to basements. Should insulation be placed in the basement ceiling, on the basement walls, or both?

In this section, we look at methods for insulating slabs, crawl spaces, and basements, including discussion on locating the boundary of the thermal envelope.

Slab-on-grade Insulation

Since the concrete slab of a slab-on-grade house is the floor of the living space, it is particularly important that it be well insulated, not only to reduce foundation heat loss, but also to prevent the uncomfortable feeling of cold floors. The most effective insulation system is a minimum of 2 inches of foam insulation on the outside of the foundation wall and 2 inches of foam under the slab.

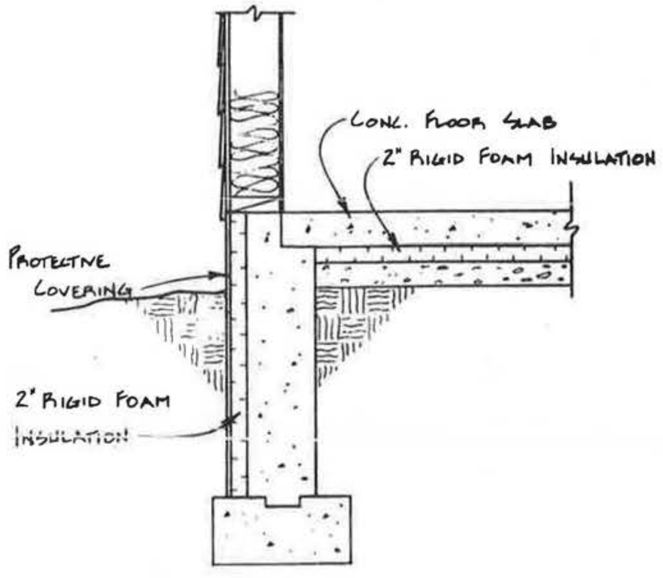


Figure 6-5 — Slab-on-grade insulation

Not Recommended Slab-on-grade Insulation Design

Many architectural texts show slab-on-grade insulation installed as in Figure 6-6. This is not recommended for superinsulated houses for two reasons. First, if installing thick insulation, as in the illustration, there is a problem with the floor finish; the foam is interior to the house wall. Second, it is almost impossible to install a continuous air/vapor barrier under the slab and connected to the wall air/vapor barrier.

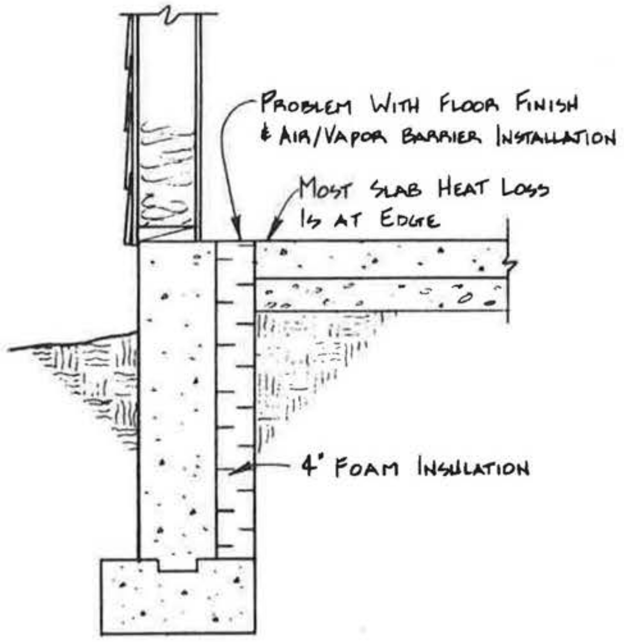


Figure 6-6 Slab-on-grade insulation design — not recommended

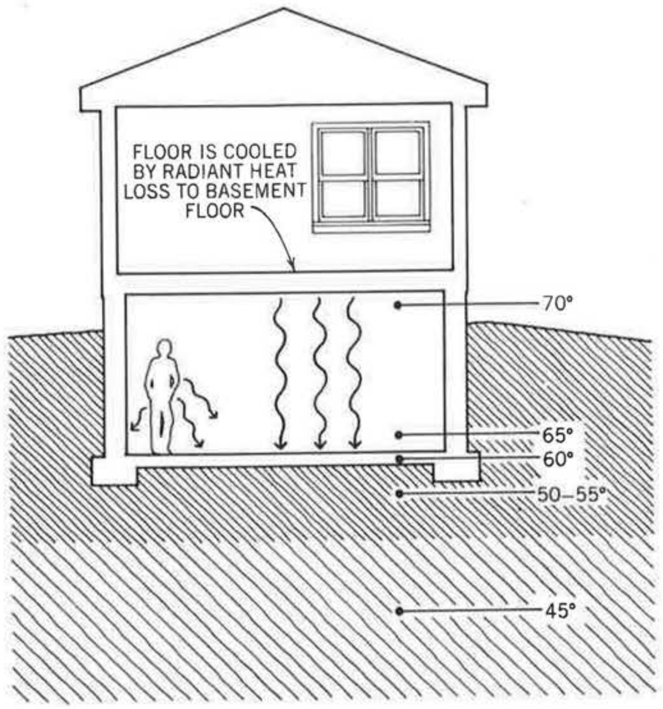


Figure 6-7 —An uninsulated basement slab will be at or near the temperature of the ground below, causing thermal discomfort and possibly cooling of floor above.
Source: The Superinsulated Home Book, by Ned Nisson and Gautam Dutt, John Wiley & Sons, New York, 1985.

Foam Insulation Under Basement Slab Floor

Two reasons why some builders and designers are reluctant to insulate under a concrete slab floor are: 1) they don't feel the savings in heating and cooling energy will justify the cost of the insulation; and 2) their concrete contractor is unfamiliar with or apprehensive about pouring concrete over rigid foam insulation. Both of these objections are quite understandable.

1. Cost-effectiveness of basement slab insulation.

Heat-loss and energy savings calculations for insulated slabs are difficult to verify. (A recent comparative study of foundation heat-loss calculation methods showed nearly 100 percent variation between generally accepted methods.) However, no matter what calculation method is used, basement slab insulation, at $.20 to $.40 per square foot is only marginally cost-effective except possibly in the most severe climates.

The main reason to insulate beneath a basement slab is to create a warm floor for thermal comfort rather than energy savings. Without insulation, the floor will be cold (see Figure 6-7). Cold floors cause thermal discomfort due to radiant heat loss from people's skin to the floor. For that reason, many finished basements go unused. Even if the basement is initially intended to be a living space, future use might change, and retrofit insulation is prohibitively expensive. (Another undesirable effect of a cold basement floor is that the basement ceiling loses heat by radiation to the cold floor, possibly cooling the floor above.)

2. Pouring concrete over rigid foam.

Problems commonly associated with pouring a concrete slab over rigid foam are: 1) reduced drainage downward, resulting in water floating to the surface and lengthened setup time; 2) differential settling of the concrete, particularly if the foam is installed only around the perimeter of the floor; and 3) damage to the foam by crews, wheelbarrows, etc. while pouring the concrete.

Figure 6-8 shows one simple design variation that addresses the above problems. With this technique, instead of pouring the concrete directly over the foam, a layer of sand, 1.5- to 3-inches thick, is spread over the foam and polyethylene moisture barrier (the polyethylene can be either on top of or beneath the rigid foam). The main advantage of this scheme is that it provides downward drainage during curing. This should help the problem of water floating to the surface and will also slightly shorten setup time. Differential settling is avoided because the sand presents an even surface for the pour. Damage to the foam is reduced somewhat due to protection by the sand.

Tell your contractor to use as stiff a mix as possible, and to expect to spend almost twice as long finishing the floor compared to a pour without foam or poly beneath it.

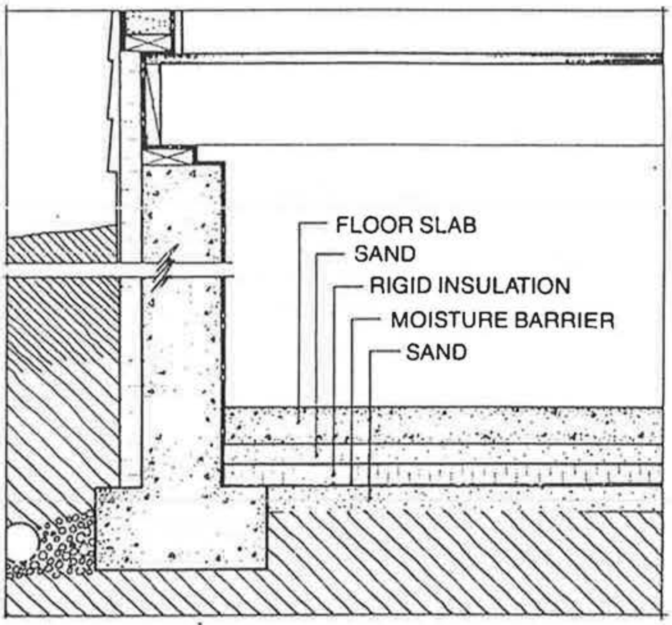


Figure 6-8 — A layer of sand over the moisture barrier reduces problems associated with the construction of insulated basement floors.

Crawl Space Insulation In Overlying Floor

As mentioned above, crawl spaces can either be insulated in the floor above the crawl space or on the crawl space floor. Figure 6-9 shows a crawl space insulated in the overlying floor with exterior foam insulation on the foundation walls. Notice that there is also a moisture barrier on the floor of the crawl space to keep out ground moisture.

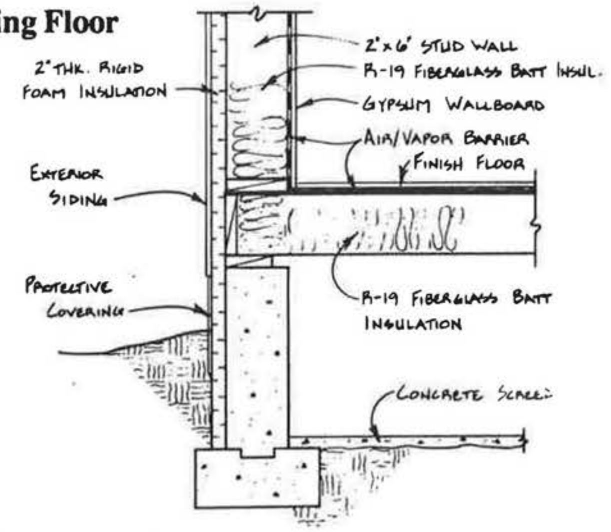


Figure 6-9 — Crawl space insulation in overlying floor

This insulation design may not be as effective as insulating the crawl space floor (discussed in next subsection). First of all, the crawl space is outside the thermal envelope; it is unheated. Any pipes or ducts in the crawl space must be well insulated to reduce heat loss and/or freezing. Also, all penetrations through the floor must be completely sealed to the air/vapor barrier in the floor — a tedious job. Finally, it is sometimes difficult to get good insulation coverage between the floor joists. Cross ties, plumbing, and wiring all get in the way.

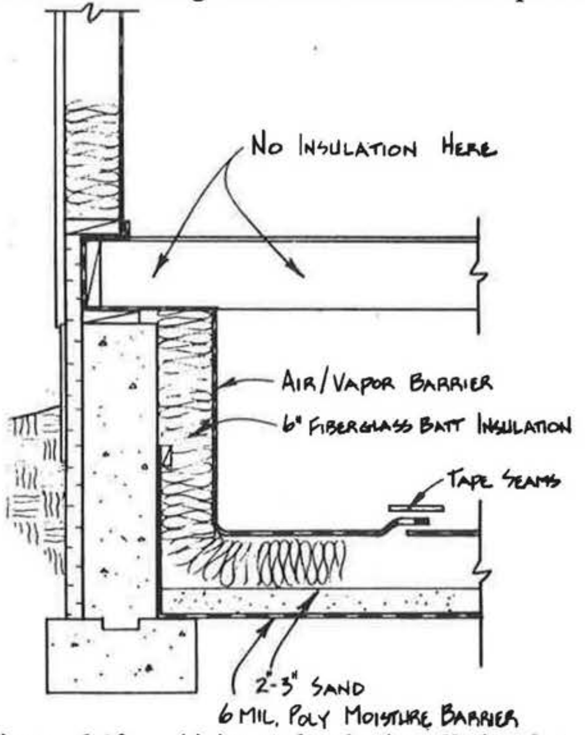


Figure 6-10 — Air/vapor barrier installation for heated crawl space

Insulation On Crawl Space Floor — Heated Crawl Space

This insulation design for crawl spaces was discussed in Section 3 on air/vapor barriers. The most important and most obvious requirement of this design is that the insulation be kept dry. It should not be used in areas with high water table or where there is danger of flooding in the crawl space. Except for those instances, it is a very effective crawl space insulation system, eliminating many of the drawbacks of installing insulation in the overlying floor. Notice in the illustration that, in addition to the crawl space floor insulation, there is also a layer of rigid foam applied to the outside of the foundation wall. The reason for this is to reduce thermal bridging through the floor and foundation. Also, it adds to the overall R-value of the crawl space insulation system.

Basement Walls — Exterior Foam Insulation

Exterior foam insulation is an excellent system for insulating basement walls and has several distinct advantages over interior wall insulation (discussed in the next section). First, the concrete wall is inside the thermal envelope and is not subjected to the stresses of severe outdoor temperature swings. Thus, it is less likely to sustain damage. Second, the foam can be extended up over the joist area and possibly up over the above-grade wall (as in Figure 6-11). This reduces thermal bridging at the sill plate and joist areas. Third, the concrete mass, being inside the thermal envelope, can serve as thermal mass, smoothing out temperature swings in the house and possibly storing a moderate amount of passive solar gain. Finally, this design avoids problems with moisture which may arise with interior foundation insulation (see next section).

Notice in Figure 6-11 that the air/vapor barrier is terminated and sealed at the top of the foundation wall. This is necessary to maintain house airtightness. Notice also, that extra polyethylene is stapled to the underside of the floor joists. The purpose of this is to provide a means for continuing the air/vapor barrier down the inside of the foundation wall, should the basement ever be finished.

Exterior foam insulation must be protected above grade against sunlight, rain, and physical damage. A variety of foundation coatings are available, including rigid fiberglass panels and cementitious coatings.

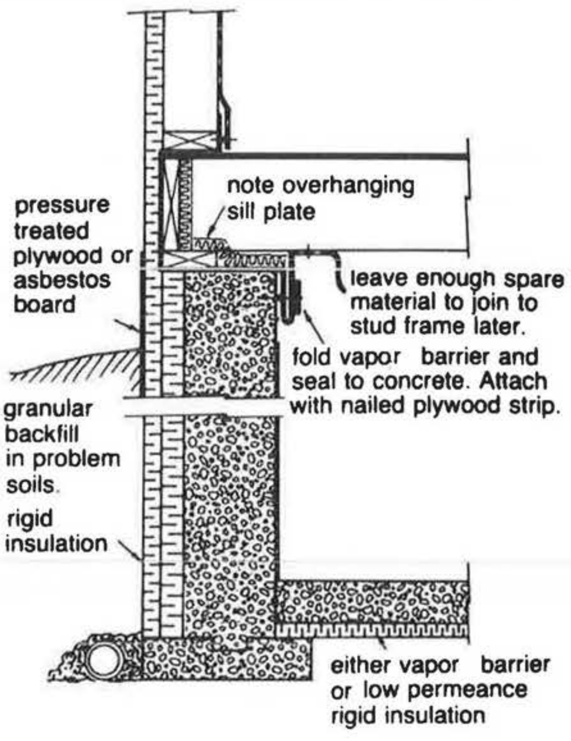


Figure 6-11 — Basement walls — Exterior foam insulation

Some builders express concern that insulating a foundation wall increases the hazard of damage from frost heave because there is no longer enough heat escaping from the foundation to keep the ground from freezing. There is absolutely no evidence to support this fear. First of all, frost heave acts mostly in a vertical direction, not laterally. It is possible, however, for frost to cause lateral pressure if the ground is saturated with water when it freezes. The way to prevent this problem, however, is not to warm the soil with heat from the house, but rather to properly drain the soil around the foundation. If, for example, the house is built in clay soil, the clay should be removed and replaced with gravel or other soil with good drainage characteristics. Footing drains should always be installed. After backfilling, grade the surface so that it slopes away from the house for good drainage.

Shallow Horizontal Foam Insulation

The insulation configuration shown in Figure 6-12 is a "selective" system. The horizontal foam insulation retards the flow of heat from the foundation to the ground surface, but not from the foundation to the deep earth. Some designers prefer this system because it allows the foundation to stay "coupled" to the earth, possibly deriving some benefit for summer cooling. One definite advantage of this system is that the soil beneath the horizontal fin of insulation will never freeze.

The foam should be installed as close to the surface as possible. Since foundation plantings usually need at least 12 inches for roots, place the foam 12 inches down near the foundation and slope it down to about 20 inches at the outer edge. The foam should be about three feet wide for most climates. In very cold climates, additional optional insulation can and should be applied to the lower section of the foundation wall.

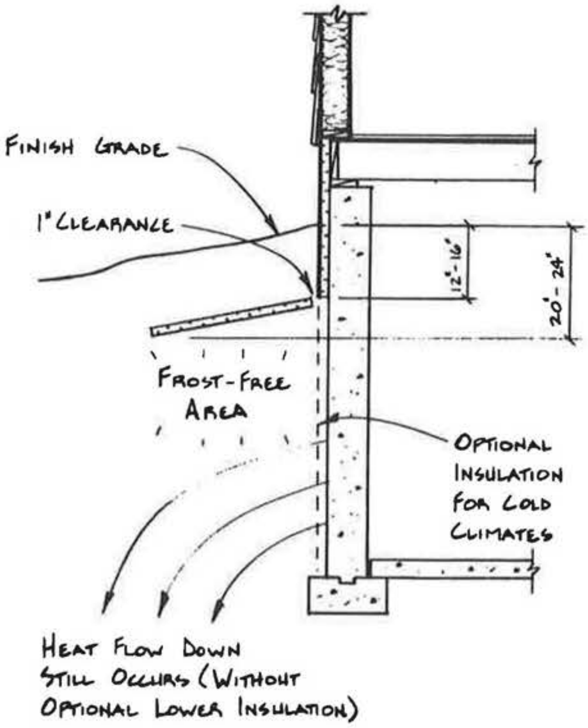


Figure 6-12 — Shallow horizontal insulation

Basement Walls — Exterior High-density Fiberglass Insulation

High-density, semi-rigid fiberglass has been used as exterior foundation insulation for some time in Canada. Until recently, there was no commercially available product for this application in the U.S. One company, Owens-Corning, now manufactures a high-density fiberglass foundation insulation called Warm-N-Dry.

Great News from Owens-Corning

One of the hottest debates in the energy-efficient design community is over what type of foam insulation to use on foundation walls below grade; the issue has centered on moisture absorption, loss of R-value, and possible physical degradation. The debate may subside in the wake of a new product announcement from Owens-Corning; Warm-N-Dri is a semi-rigid medium-density fiberglass foundation insulation with several distinct advantages over the plastic foams.

Fiberglass foundation insulation is not new. Fiberglas Canada, an Owens-Corning affiliate, has been marketing a product called "Base-Clad" since 1981. Furthermore, according to Mark Bomberg at the Canadian National Research Council (NRC), fiberglass foundation insulation has been used in Canada for almost thirty years. Evidently, Owens-Corning considered releasing this product in the U.S. several years ago, but shelved it after receiving a poor test marketing reaction. Now it's back and we highly recommend it for superinsulated houses.

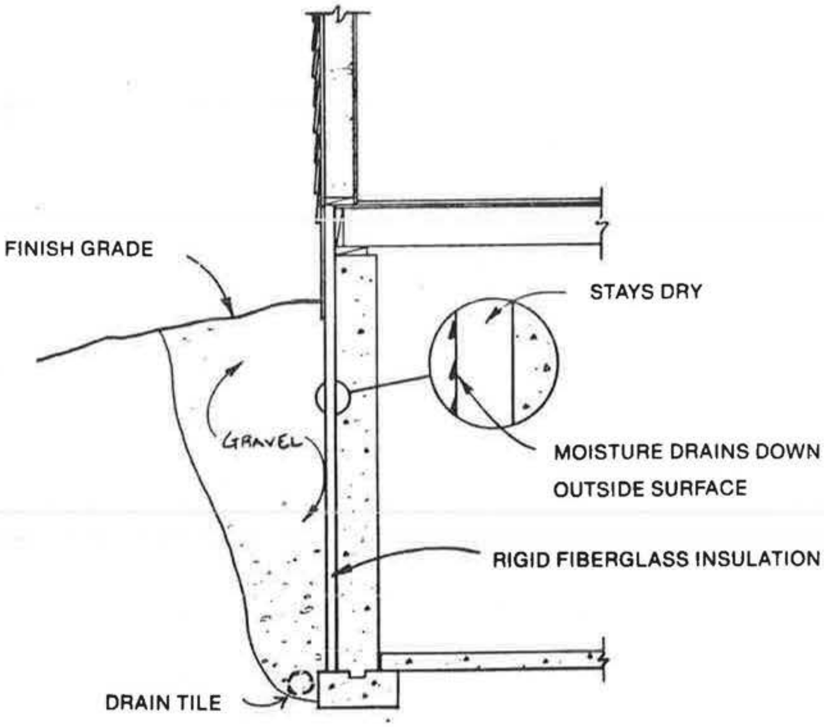


Figure 6-13 — Warm-N-Dri

One of the strongest advantages of this material is that it also acts as a drainage layer, protecting the foundation from ground water. According to Harold Orr of the Canadian NRC, their tests show that even in wet soil conditions, water does not penetrate the insulation more than one-eighth of an inch. The glass fibers serve as drainage pathways, conducting water down the outer surface of the insulation to drainage tiles at the footings (see Figure 6-13). Thus there is no water pressure build-up against foundation walls. According to Orr, this drainage ability alone makes the product worthwhile for house foundations.

Warm-N-Dri is also good insulation. With an R-value of 4.5 per inch, it is comparable to expanded polystyrene and almost as good as extruded polystyrene. Since it sheds rather than absorbs moisture, there should be little or no R-value degradation, even under adverse soil moisture conditions. According to Bomberg at the Canadian NRC, samples of fiberglass insulation which were buried for five years showed no degradation in R-value per inch.

Since it is basically an inorganic material, Warm-N-Dri should be less subject to chemical attack and insect or vermin infestation than the plastic foams. The only organic constituent of the material is the binder applied to the glass fibers, and according to Bomberg, samples of similar material which were dug up after twelve years showed no loss of binder.

Our only concern about this material is possible compression and loss of total R-value over time. Bomberg stated that some semi-rigid fiberglass may lose between 40 and 70 percent of its compressive strength when exposed to high humidity over long periods of time. According to Paul Shipp, Senior Engineer at Owens-Corning, their tests show slight compression at the bottom half of foundation walls, but it was limited to maximum 1/8- to 1/4-inch compression with 2-inch thick material. Maintenance of compressive strength is partly dependent on density. Warm-N-Dri is produced at a higher density than Base-Clad (6.5 pounds per cubic foot compared to 4.0 pounds per cubic foot for Base-Clad). According to Shipp, the higher density is intended to provide insurance against compression. Harold Orr of the Canadian NRC tells us that their tests of Base-Clad showed no measurable compression under installed conditions.

In conjunction with Warm-N-Dri, Owens-Corning is introducing its new foundation coating — Tuff-N-Dri — a polymeric material which provides a highly elastomeric waterproof membrane when applied to concrete foundations. Even though Warm-N-Dri alone should theoretically keep a foundation dry, a waterproof coating is still recommended to protect the foundation from water which may leak through seams or defects in the insulation. Tuff-N-Dri is spray-applied and also serves as the adhesive for attachment of Warm-N-Dri.

To install the waterproofing/insulation system, you spray the foundation with Tuff-N-Dri and also apply a light rectangular pattern on the insulation boards. (According to Owens-Corning, a properly trained 2-man crew can easily apply over 1,500 square feet of Tuff-N-Dri per hour.) The coating is allowed to dry for 3 hours, then the insulation boards are stood up on the foundation footings and pressed into place vertically. The insulation is trimmed at corners and around doors and windows using a utility knife or hand saw.

Since Warm-N-Dri acts as a water drainage system, it is important to install proper drainage at the foundation footings to carry water away. It should not be installed only on the top half of a foundation because it would deposit drainage water at that point. The insulation should be installed full height, down to the footings, in close proximity to the footing drainage system.

No protection for the insulation is needed below grade. (In fact it would defeat the purpose of the drainage layer.) Above grade, the insulation must be covered with a rigid covering such as Insul-Guard (see the February 1984 issue of EDU) or a cementitious foundation coating such as Thoroseal or Thermaseal.

Warm-N-Dri comes in 4x8-foot sheets of 1-inch or 2-inch thickness (R-4.5 and R-9.0 respectively). For more information, contact Owens-Corning Fiberglas, Protective Coatings Business, Box 415, Granville, OH 43023; (614)587-7916.

Interior Basement Wall Insulation

The most common way to insulate foundation walls on the inside is to build a 2x4 or 2x6 frame wall set off from the foundation wall. Figure 6-14 shows such an installation insulated with fiberglass batts. Notice the installation of the air/vapor barrier, continuous from basement floor, all the way up to first floor walls.

Although this design is good from a thermal standpoint, and has been successfully used in many superinsulated houses, there are some potential moisture problems. If the interior air/vapor barrier is properly installed, any

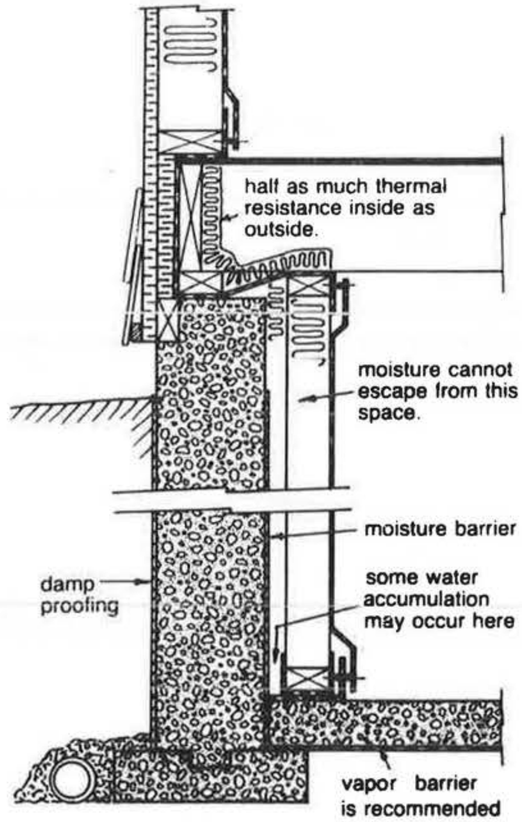


Figure 6-14 — Basement walls — interior insulation moisture coming from the concrete cannot escape to the indoors; it becomes trapped in the insulation and may wet it. Green concrete gives off considerable amounts of water during curing. Also, any imperfections in the exterior foundation waterproofing may also allow groundwater to penetrate the wall. There is no perfect solution to this problem. One safeguard is illustrated in Figure 6-14. A separate polyethylene moisture barrier is installed against the inner surface of the basement wall. It begins at the floor but only extends up as far as grade level. The idea is that any trapped moisture may rise up in the wall cavity and vent out through the upper portions of the basement wall or through irregular air spaces between the top of the wall and the sill plate.

Another suggestion which should help avoid problems arising from water given off from curing concrete is to delay installing the interior basement insulation for several months, giving the concrete time to completely cure first. (This will probably not be practical for contractors because of scheduling interruption, but should be a good idea for self-contracted jobs.)

Insulated Wood Foundations

As mentioned above, wood foundations are gaining increasing popularity. From a thermal standpoint, they are far superior to concrete or block foundations because they are easy to insulate and, since wood has a higher R-value than concrete, thermal bridging is much less of a problem. Figure 6-15 shows a wood foundation insulated with 6-inch R-19 batts plus 1 inch of extruded polystyrene foam on the inner surface. Notice that the foam must be covered with fire-rated gypsum board.

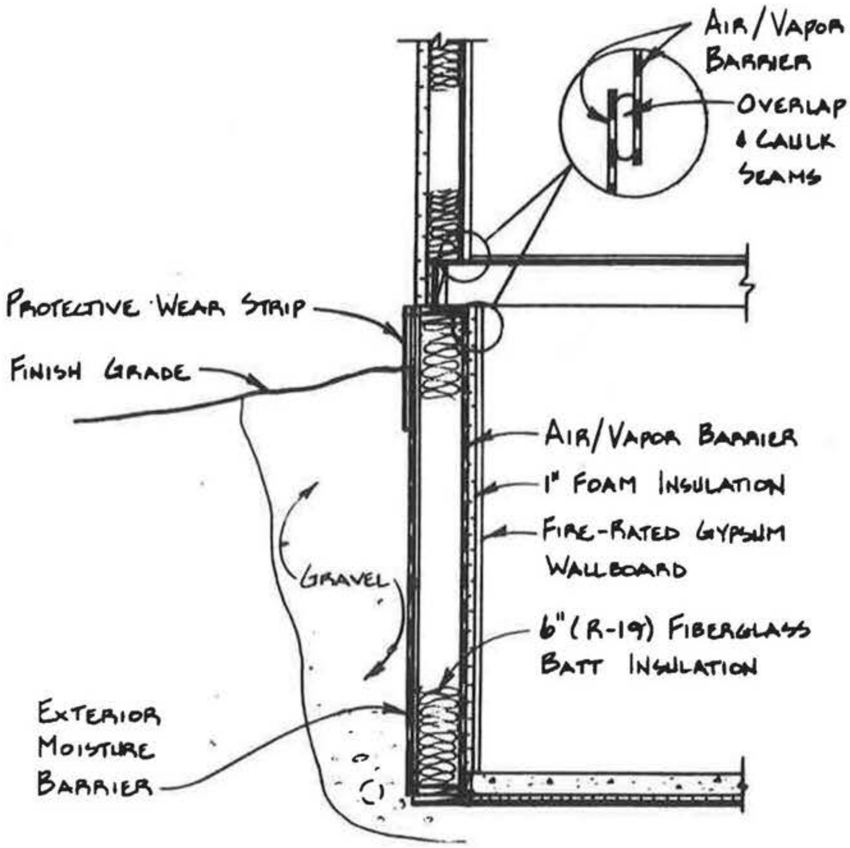


Figure 6-15 — Insulated wood foundation

Wood Foundation with Additional Stand-off Wall

In a previous figure, the R-value of a wood foundation was increased by adding a layer of foam to the inner wall surface. An alternative is to build a separate 2x4 wall inside the foundation and insulate it with fiberglass batts or other suitable insulation material.

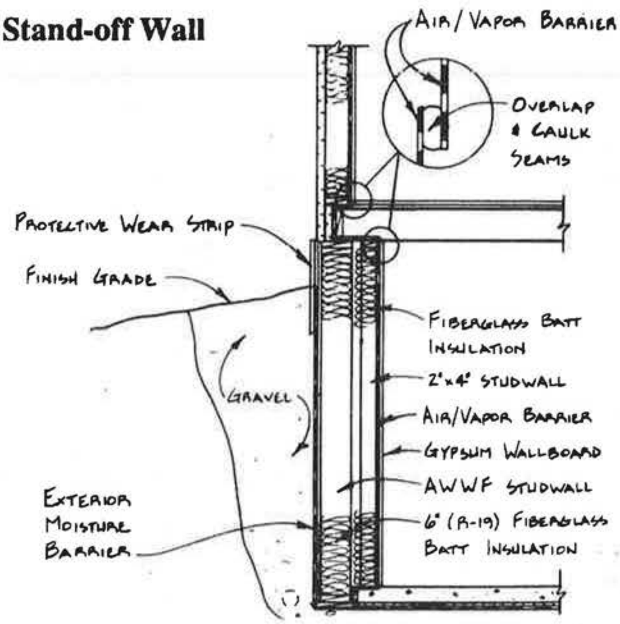


Figure 6-16 — Wood foundation with stand-off wall

Basement Floor Insulation

There is some debate within the energy design community over whether or not it is cost effective to insulate basement floors. Because heat loss through basement floors and energy savings from insulation are very difficult to calculate accurately, it is difficult to settle the issue. Most builders of superinsulated houses choose to install at least 1 inch and often 2 inches of extruded polystyrene foam beneath basement floors. Although it is uncertain whether or not this is cost effective, it does have the additional advantage of creating a warm basement floor. Even if the basement is not planned to be used initially as a living space, it may be finished off some time in the future and retrofitting the floor with insulation is much more expensive than installing insulation during construction.

SECTION 7
Windows

A dominant design element constituting from 15 to 40 percent of the total wall area in typical houses, windows serve several important functions:

1. They allow visual communication with the outdoors, giving the occupants of a room first-hand information about weather and events occurring outside. Outdoor views also provide relief from monotony and claustrophobia.
2. They admit sunshine for light and heat.
3. They allow natural ventilation.
4. They provide emergency egress in case of fire.
5. They enhance the appearance of the building exterior.

Because they are so transparent to energy flow into and out of a house, windows have always been a prime focus for energy-conserving building design and modification, sometimes resulting in houses with almost no windows and other times resulting in houses with no windows on one side but giant glass walls on the other. To increase thermal performance, windows have been covered with polyethylene, fiberglass, quilts, shutters, and shades. During the past few years, new energy-efficient glazing systems with double and triple the energy efficiency of older "insulating" windows have come on the market.

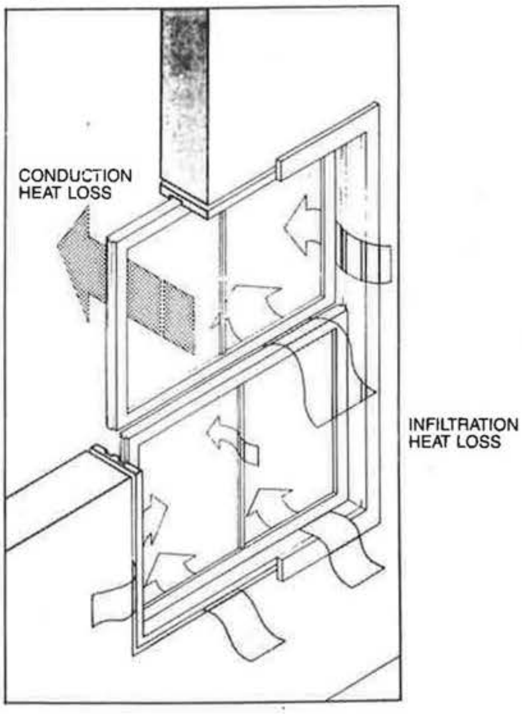


Figure 7-1 — Windows are the weak spot in the house thermal envelope.

Windows are "holes" in the insulation system (Figure 7-1). Glass, with an R-value of R-0.014 per inch, conducts heat about 90 times faster than wood and about 500 times faster than urethane insulation of the same thickness. Even double-pane insulating glass conducts heat 10 to 20 times faster than typical insulated walls. Windows are also "patches" in the air barrier. A difficult patching job, the wooden window frame must be carefully sealed to the air barrier; movable sashes must make a tight seal against the wooden frame; and glass lites must be well sealed against the wooden sashes. Although high-quality windows usually have good seals around lites and sashes, the most important air leakage path — between window frame and rough opening — must be carefully sealed during construction.

Selecting Windows

There are two things to consider when selecting windows — the type of glazing system, and the window style. The type of glazing system — double-glazed, triple-glazed, low-E, etc. — determines the R-value and light transmission properties of the window. Window style — double-hung, casement, slider, etc. — is important with respect to airtightness. The following sections discuss important energy-related selection criteria with recommended options for energy-efficient houses.

R-value

Determined by the type of glazing system and frame construction, window R-values range from about R-1.0 to R-5.0. When selecting R-value for windows, the most obvious consideration is relative heat loss and its effect on overall house energy consumption. Another consideration, discussed later in this report, is the effect of R-value on glass interior surface temperature.

The thermal resistance of a single glazed window — about R-1 — is almost entirely due to the air films which naturally hug the glass surfaces (Figure 7-2). The following sections describe various glazing systems with higher R-values, including multiple glazings, selective "low-E" coatings, interpane baffles, gas-filled airspaces, and ventilated glazing systems.

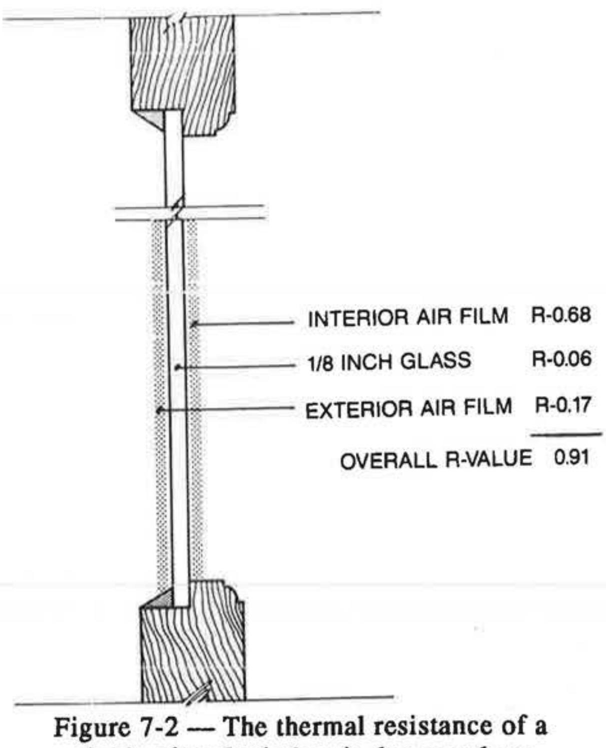


Figure 7-2 — The thermal resistance of a single-glazed window is due mostly to air films on glass.

How Accurate Are Listed R-values for Glass and Windows?

You will notice throughout this report that listed R-values for windows are only listed to one decimal point, i.e., R-2.1 rather than R-2.13. Why? Because the actual R-value of a window that you purchase from a lumber yard may vary 10 to 20 percent from the manufacturer's listed R-value. The second decimal place is, in most cases, meaningless. For further discussion of the reliability of published window R-values, see the EDU feature article reprint at the end of this section.

Multiple Glazings

The first multiple-pane window unit was patented by Thomas Stetson in 1865. Sealed double-pane insulating glass units became commercially popular during the 1950s. With the advent of the "energy crisis" during the 1970s, triple-pane windows began to appear and, more recently, quadruple-pane.

Multiple glazing increases thermal resistance by entrapping air spaces, each with an effective R-value ranging from R-0.7 to R-1.0, between the glass panes. Heat is transferred across the air spaces by infrared radiation and conduction (Figure 7-3). Infrared radiation from the warm interior glass pane is transmitted successively across each air space, absorbed by each pane of glass, and reradiated outward and inward, with the largest loss toward the cold outer glazings. Heat is also conducted across the air space by the entrapped air, which acts as insulation. Each additional air space created by adding another pane of glass increases the overall R-value.

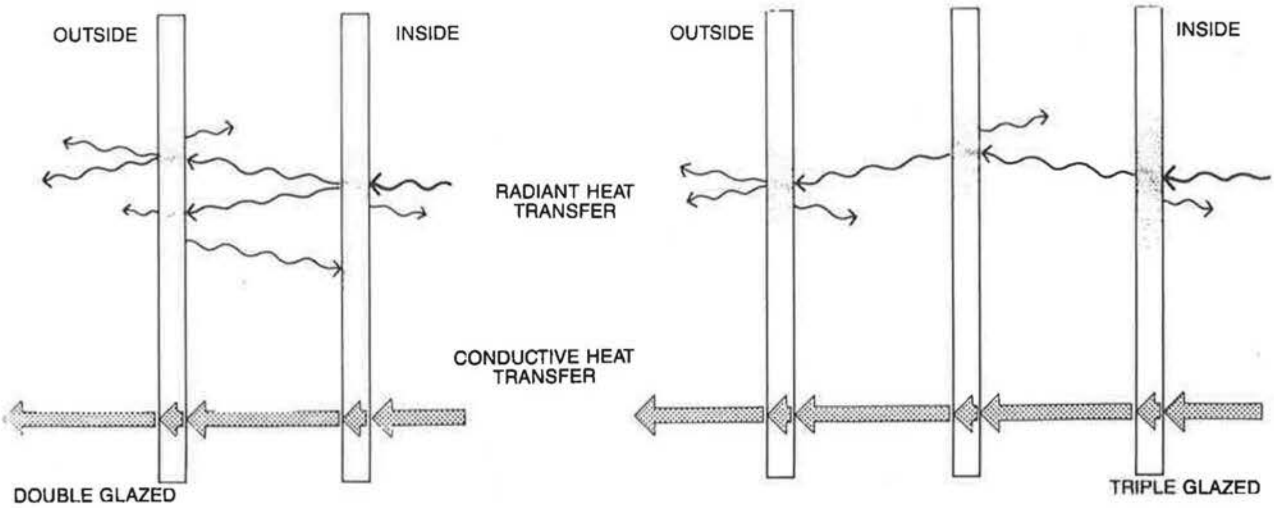


Figure 7-3 — Heat transfer through multiple-glazed windows

Since the "insulation" in multiple glazed windows is the entrapped air, increasing the air space thickness increases overall R-value; multiple glazed units with 1/2-inch air space(s), for example, have higher R-value than those with 1/4-inch air spaces. But the effect of increasing the thickness of the air space is limited. Beyond a certain thickness — about 3/4-inch — interpane convection increases, carrying heat from the inner to outer pane through air circulation (Figure 7-4). Further increases in air space thickness do not result in increased R-value. The exact thickness at which convection becomes a dominant heat transfer mechanism depends on the height of the glass unit and the temperature differential between indoors and outdoors.

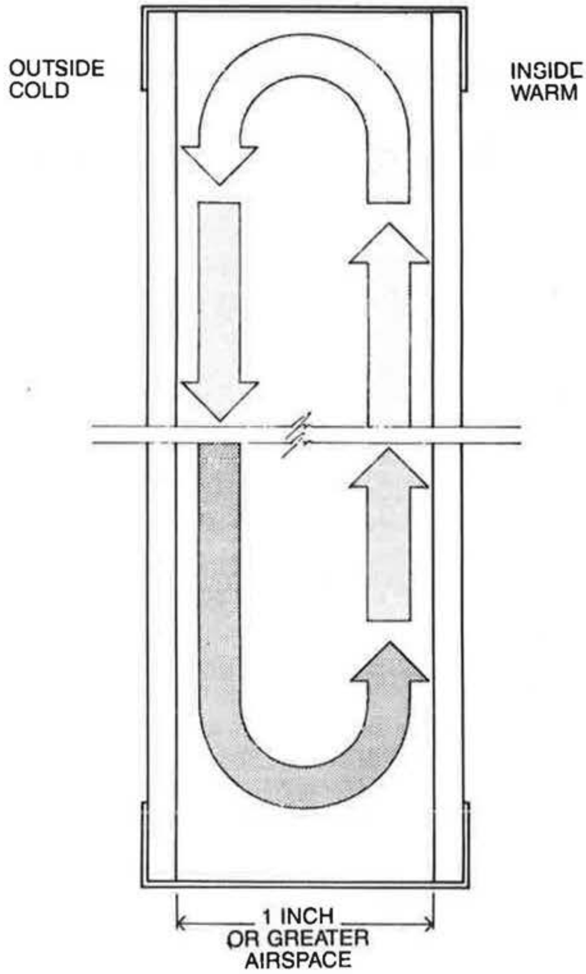


Figure 7-4 — Connective heat transfer becomes dominant with wide interpane airspaces.

Double glazing with a 3/16-inch air space has an R-value of R-1.69. With a 1/2-inch air space, the R-value is about R-2.0. Triple glazing with two entrapped air spaces provides R-values ranging from R-2.5 to R-3.2, depending on the thickness of the spaces. Quadruple glazing, with three air spaces, provides R-values ranging from R-3.5 to R-4.0.

Double glazing usually comes as a sealed unit commonly referred to as "insulating glass." The two panes of glass are sealed at the edges with some type of synthetic rubber sealant. Edge spacers keep the proper spacing and a desiccant is usually included to absorb moisture between the panes. Triple glazing is also available in sealed units consisting of three panes of glass, but it is more commonly supplied by window manufacturers as a double-glazed sealed primary unit plus an additional removable glass panel (RGP) that is installed either on the inside or outside of the primary unit. Almost all window manufacturers offer double and triple glazing options. There are no manufacturers we know of that supply all-glass quadruple pane windows, but a few manufacturers make quad-pane glass units and windows using plastic film interpanes instead of glass (see Appendix B, Products Directory, for listings).

Plastic Interpanes

An all-glass, triple-glazed window weighs almost 50 percent more than a double-glazed window; quadruple glazing is, naturally, even heavier. The heaviness of multiple glazing can be somewhat of a problem.

Plastic interpanes offer a solution. Several U.S. glass and window manufacturers produce triple- and quadruple-glazed units with plastic interpanes. Because the thermal resistance of multiple glazing is due to entrapped air rather than the glazing material itself, plastic sheeting can be just as effective as glass. A quadruple-glazed window with two plastic interpanes between two outer glass panes weighs little more than conventional double-glazed windows, yet it still has the R-value of quadruple glazing.

The only brands of plastic films currently being used in commercially produced windows or glass units are 3M Sungain™ and Southwall Heat Mirror™ (see below). Appendix B of this report lists manufacturers of glass units and windows which use both those films.

Low-E Glass

Low-E glass is quickly becoming very popular for residential applications, providing remarkable energy-efficiency with no extra bulk or weight.

What is low-E glass; How does it work?

We have already seen (Figure 7-3) that "radiant heat transfer" is one of the mechanisms by which heat is transferred across the space(s) between the panes of glass in multipane windows. About half the heat transfer across the air space of a double-glazed window is caused by long-wave infrared radiation from the warm inner pane to the cooler outer pane.

The amount of heat transferred by radiation across the air space depends on the relative temperature difference between the two panes of glass and the emissivity of the glass surface. Emissivity is a measure of the amount of radiation of a specific wavelength given off by a surface, at some temperature, when compared to a perfect "black body" at the same temperature. It is expressed as a fraction between 0 and 1. Most building materials and common room surfaces have high emissivities (0.9 or greater). Shiny surfaces, such as aluminum foil, have low emissivities (0.1 or less).

If the surface of an object has a low emissivity, heat loss from that object by radiation will be correspondingly low. For example, suppose you have two cans filled with hot water. One has a polished aluminum surface (low emissivity) and the other has a flat black surface (high emissivity). Both cans are set at room temperature to cool. What happens? The black can will cool faster than the shiny can because its surface emits more long-wave radiation, causing it to lose heat faster.

Regular float glass has an emissivity of about 0.84. Thus, a great deal of heat energy is transferred across a double-pane insulating glass unit due to long wave emission from the inner pane to the outer pane. With Low-E glass, a special low-emissivity (about 0.15) coating is applied to the outboard surface of the inner pane of glass (number 3 surface) (Figure 7-5a). The low-E coating reduces the surface emissivity of the glass and thus reduces the radiant heat transfer across the space. The result is that the effective R-value of the glass unit is increased. For example, Sungate 100, a low-E double-glazed unit produced by PPG, has an R-value of R-2.9, which is equivalent to that of most triple-glazed units — but without the extra weight or bulk.

In addition to low emissivity, another important characteristic of low-E glass is high reflectivity. The special coating also makes the glass surface highly reflective to long-wave infrared radiation. Thus low-E glass also helps to reduce summer heat gain; the coated inner pane reflects long-wave infrared radiation from the warm outer pane of glass (Figure 7-5b). It does not, however, reflect visible light and does not appear shiny. The coatings on low-E glass are "wavelength selective." That is, they reflect long-wave infrared radiation, but are transparent to visible light. Sungate 100, for example, transmits about 90 percent as much visible light as standard clear double-glazed units.

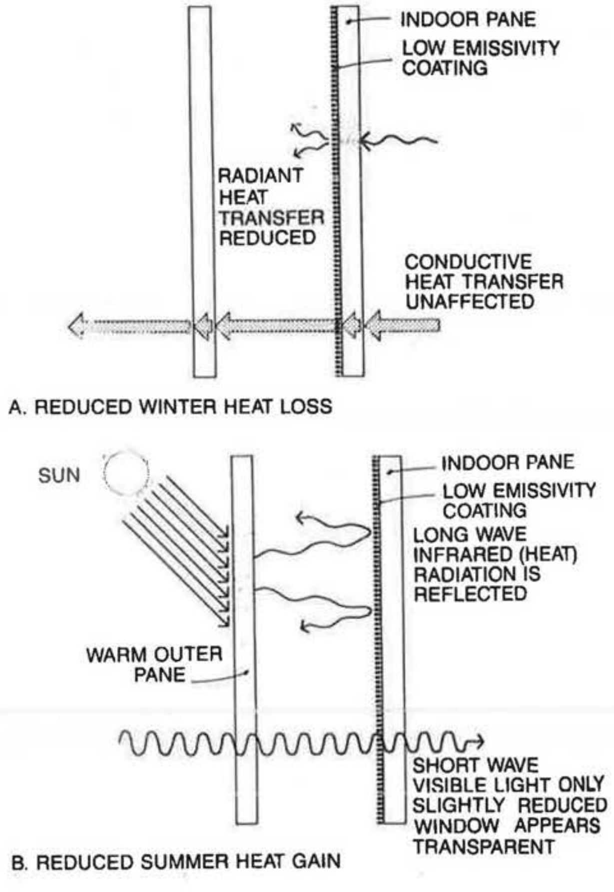


Figure 7-5 — Coated "Low-E" glass increases thermal resistance by reducing radiation heat transfer

One disadvantage of low-E glass is that even though it transmits most visible light, it cuts down transmission of the near infrared portion of the solar spectrum, resulting in lowered total solar transmittance (see next section). This is a disadvantage for passive solar heating. The total solar transmission of Sungate 100, for example, is considerably lower than regular double-pane insulating glass and slightly lower than regular triple-pane glass.

Solar Transmittance

Sungate 100	55%
double-pane insulating glass	71%
triple-pane insulating glass	59%

Hard Coat and Soft Coat

When low-E glass first came out in the U.S. and Canada, it was all produced by a process developed by Airco Temescal in California. The coating produced with that process is commonly referred to as "soft coat." In 1986, a different type of coating was introduced into the market. Using a process developed by Interpane Glass, the new coating, referred to as "hard coat," is more durable but has a higher emissivity and thus somewhat poorer performance. The advantage of the hard coat is that it is easier to work with because it is not as delicate as the soft coat. To the consumer, however, unless there is a significant price break, hard coat has no advantage.

Gas-filled Windows

Another way to increase the thermal resistance of a multiple-glazed window is to suppress convection between the panes by substituting a heavier gas for air. Argon, sulfur hexafluoride, and carbon dioxide are three commonly used gases. The combination of gas filling and low-emissivity coatings (see below) has produced double-glazed windows with R-values as high as R-5.9. In addition to thermal efficiency, gas filling is also used for sound attenuation.

Although several types of gas-filled windows are commercially available in Europe, and sold in large quantities, highly energy-efficient gas-filled windows are still relatively rare in the U.S. and Canada. Three U.S. companies currently produce gas-filled window units — Interpane, makers of I-Plus glass; Alpen, makers of Alpenglass; and Floral Insulating Glass Products, makers of Insula glass units (see Appendix B for addresses). All of these companies use a combination of gas-filling and low-emissivity coatings to produce exceptionally energy-efficient glass units. (Alpen makes a glass unit with a calculated R-value of R-5.0.) (Actually, two other U.S. companies produce double-pane insulating glass filled with carbon dioxide, but they are specialty products with very thin interpane spaces, and are not more energy-efficient than conventional double-glazed windows.)

At the time of this writing, the only nationally distributed window with gas-filled low-E glass is made by Marvin.

Heat Mirror

Although "heat mirror" has become something of a generic term for low-emissivity coatings, it is also the trade name of a specific product consisting of a 2-mil polyester film with a low-emissivity coating, manufactured by Southwall Inc. The coating on Heat Mirror works basically like the coating on low-E glass, but instead of being applied directly to the glass surface, the low-emissivity film is suspended between two panes of glass. Long-wave infrared radiation from the inner pane of glass is reflected back by the Heat Mirror, reducing heat loss and increasing effective R-value (Figure 7-6). In addition to acting as a radiation barrier, the plastic film also serves as a third glazing, reducing the heat loss even further. The R-value of a glazing system with heat mirror suspended between two panes of glass is about R-4.3 (with 0.5-inch air spaces).

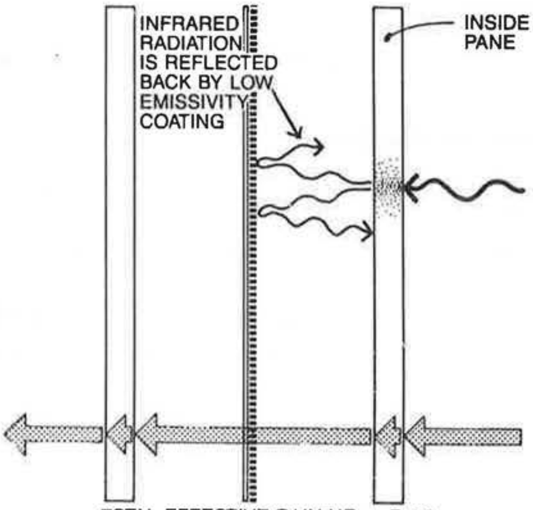


Figure 7-6 — Triple-glazed window with low-emissivity plastic film as central glazing.

Heat Mirror is now being used by several U.S. window manufacturers including Hurd, Louisiana Pacific, Warm-Lite, Stang, and Delabro. It is also being incorporated into insulating glass units by about seven other manufacturers (see Appendix B). The listed R-values range from R-3.2 to R-4.0, depending on air space thickness and possibly the type of frame construction.

Interpane Baffles

Another system that increases window thermal resistance is "interpane baffles" (Figure 7-7). But although research has shown that baffles can significantly improve window thermal efficiency, available manufactured units with baffles are actually only slightly better than regular double-glazed windows. For example, the Pella Slimshade™, with venetian blind-type baffles between the panes, has an R-value of R-2.56, compared to R-2.43 for the regular double-glazed unit. A variation of that window is the

"E Slimshade"™ which has a low-emissivity coating on the baffles. When the baffles are in the closed position, they act as low-emissivity thermal shutters, reflecting infrared radiation and providing an overall R-value of R-4.35.

Air Curtain Windows

An air-curtain window is actually a type of air-to-glass heat exchanger. There are several types of designs and configurations, but all work on the principle of using room exhaust air to intercept heat loss through the window. In Figure 7-8, house exhaust air is passed between the two inner panes of a triple-glazed unit. Since the exhaust air is the same temperature as room air, no heat is lost across the inner pane and the inner glass is therefore kept

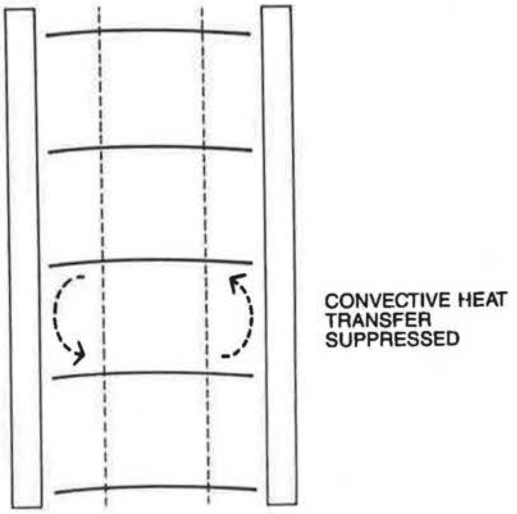


Figure 7-7 — Double-glazing with interpane baffles

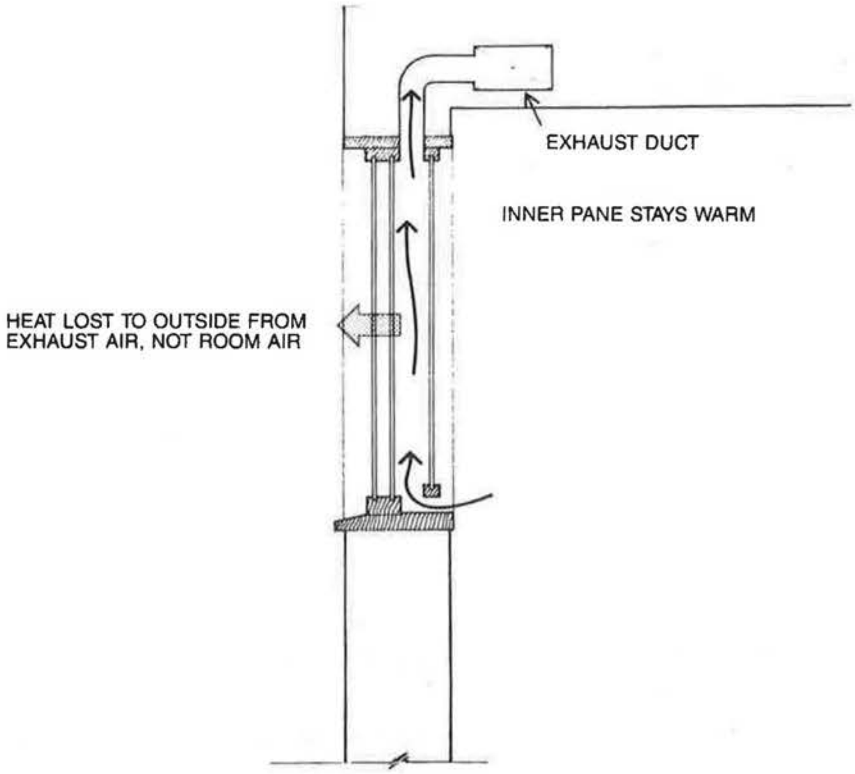


Figure 7-8 — Air curtain window — schematic warm. The exhaust air loses heat to the two outer panes before being vented to the outdoors. A complicated and expensive system, the air curtain window is only practical for commercial applications at this time. One manufacturer, Ekono, has several air curtain window installations in commercial buildings and schools in the U.S. (see the March/April 1983 issue of EDU, p. 8).

Window Frames

Window frames are typically made of wood, aluminum, steel, or vinyl. Wood frames are generally the most energy efficient with overall R-values ranging from R-2.0 to R-4.0. Aluminum frames may or may not have thermal breaks. Aluminum or other metal frames without thermal breaks have extremely low R-values and should never be used in an energy-efficient house.

Published R-values for manufactured windows are usually an average of glass and frame areas, calculated according to guidelines set forth by ASHRAE. The ASHRAE guidelines provide only a rough approximation, based on a set of assumptions about frame R-value and relative areas of glass and frame. Between 1977 and 1981, ASHRAE changed those guidelines, causing some manufacturers to alter the rated R-values of their windows. The discrepancies are typically very small, usually plus or minus R-0.2.

Window frame R-value and its effect on overall window performance is an issue that is receiving focussed attention by the research and manufacturing communities. For more information on this topic, see the EDU feature article on window R-values reproduced at the end of this Section.

TABLE 5 — R-values for Windows with Various Frame Types

Frame Type	Glazing System		
	single glass	double glass (0.5" air space)	triple glass (0.5" air space)
All Glass	0.91	2.04	3.20
Wood Frame	1.00 - 1.07	2.04 - 2.28	3.20 - 3.40
Metal Frame	0.83 - 0.91	1.57 - 1.70	2.15 - 2.48
Thermally Broken Metal Frame	0.91 - 1.01	1.77 - 2.15	2.58 - 3.20

Source: American Society of Heating, Refrigerating, and Air Conditioning Engineers Handbook — 1981 Fundamentals.

Movable Insulation

Although typically not an integral part of the window proper, movable insulation is an obvious way to increase the R-value of a window system. Window insulation can be installed on the exterior, interior, or between the panes of a window system. The most common placement is inside the window; scores of commercially produced interior thermal shutters and shades are available. A potential problem with interior window insulation is that the glass, being outside the insulation, is cold and subject to condensation. Unless the insulation makes a tight seal with the window frame, interior air may leak around the insulation and condensation may form on the glass. In extremely cold climates, another problem is thermal shock. When window shutters are opened after a very cold night, warm room air hitting the cold glass can actually cause crackage. Another potential problem — when the shutters are left shut, solar energy can heat the air between the exterior glass and shutter to the point where the glass may crack.

Between-the-panes systems are less common. One product, the Pella Slimshade, was mentioned above. Another system called "Beadwall," manufactured by Zomeworks Inc., uses tiny polystyrene beads that are blown between two widely spaced panes of glass. While attractive, Beadwall is costly and has practical problems, which have precluded its widespread acceptance.

External shutters are an attractive option because the window glass, being on the inside of the insulation, stays warm. Another side-benefit is security. The difficulties with external shutters are making them weatherproof and providing a mechanism for operating them from the inside. One good external window insulation system was recently developed by the Syracuse Research Foundation (see the May/June 1983 issue of EDU), but it has not yet been put into commercial production.

Effect of R-Value on Interior Glass Surface Temperature

Interior glass surface temperature is drastically affected by window R-value. Notice in Figure 7-9 that when the outdoor temperature is 0°F, the indoor surface of an R-1.0 window is 22°F. By comparison, an R-4.0 window under the same conditions has an indoor surface temperature of about 58°F. (The values in the figure assume an indoor air temperature of 70°F.) Glass surface temperature is important with respect to comfort, moisture condensation, and the design of the heat distribution system.

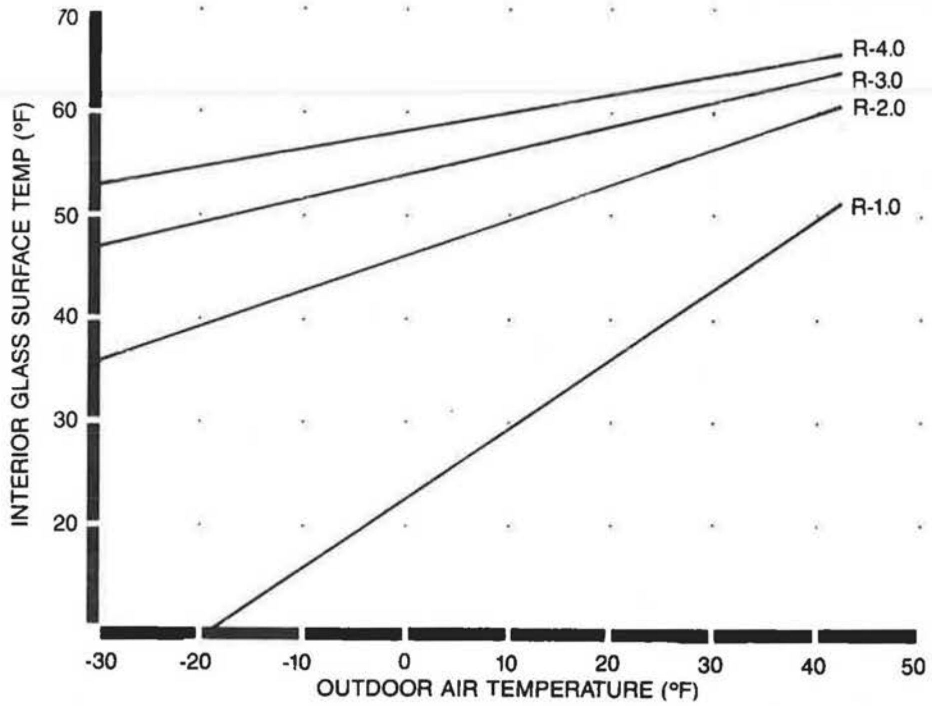


Figure 7-9— Interior glass surface temperature vs. outdoor air temperature for windows of different R-values (70°F indoor air temperature).

Comfort

Nobody likes to sit next to cold glass. Radiant heat loss and drafts created by cold glass have an obvious and significant effect on thermal comfort. The extent of the chilling effect depends on window size as well as R-value.

Moisture Condensation

The most noticeable effect of cold windows is moisture condensation. Condensation occurrence depends on the temperature of the interior surface of the glass and on the relative humidity of the room air. Figure 7-10 shows a method for determining at what indoor and outdoor temperatures, and at what indoor relative humidity, condensation will occur on windows of various R-values. It can serve as a useful design tool for selecting window R-values to avoid condensation.

Example 1: At what indoor relative humidity will condensation occur on a window with an R-value of R-2.0, when the indoor temperature is 70°F and the outdoor temperature is 0°F.

In Figure 7-10, find 70°F on the bottom of the right-hand chart. Proceed vertically to the intersection of the sloped line marked "to" = 0°F ("to" is outdoor temperature).

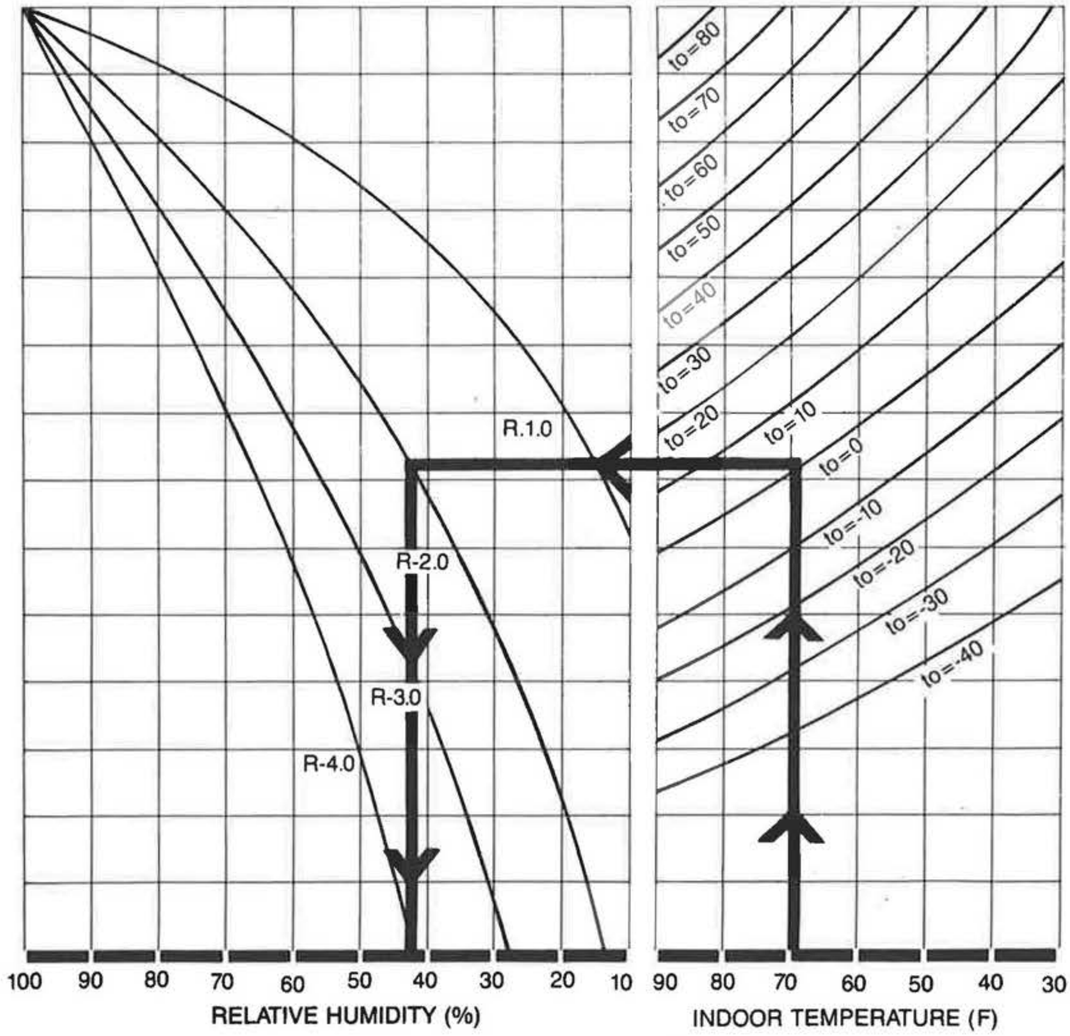


Figure 7-10 — Condensation prediction chart

Proceed horizontally to the left-hand chart to the intersection of the sloped line marked R = 2.0. Descend vertically and read 40 percent relative humidity at bottom.

Under these temperature conditions, this window will have condensation whenever the indoor relative humidity is 40 percent or above.

Example 2: Assuming that the indoor relative humidity is 40 percent, what R-value windows are necessary to prevent condensation in an area where the winter design temperature is -10°F?

Using the charts in Figure 7-10, find 70°F on the bottom of the right-hand chart, proceed vertically to the to = -10°F curve. Proceed horizontally to the left-hand chart to the intersection of the vertical line at 40 percent relative humidity. The necessary R-value is about R-2.25.

In airtight houses with controlled ventilation, indoor relative humidity is usually easily controllable. Most health guidelines place optimum winter humidity between 30 and 40 percent. When selecting R-values, you should assume approximately 40 percent humidity and select the appropriate R-value according to the graph in Figure 7-10.

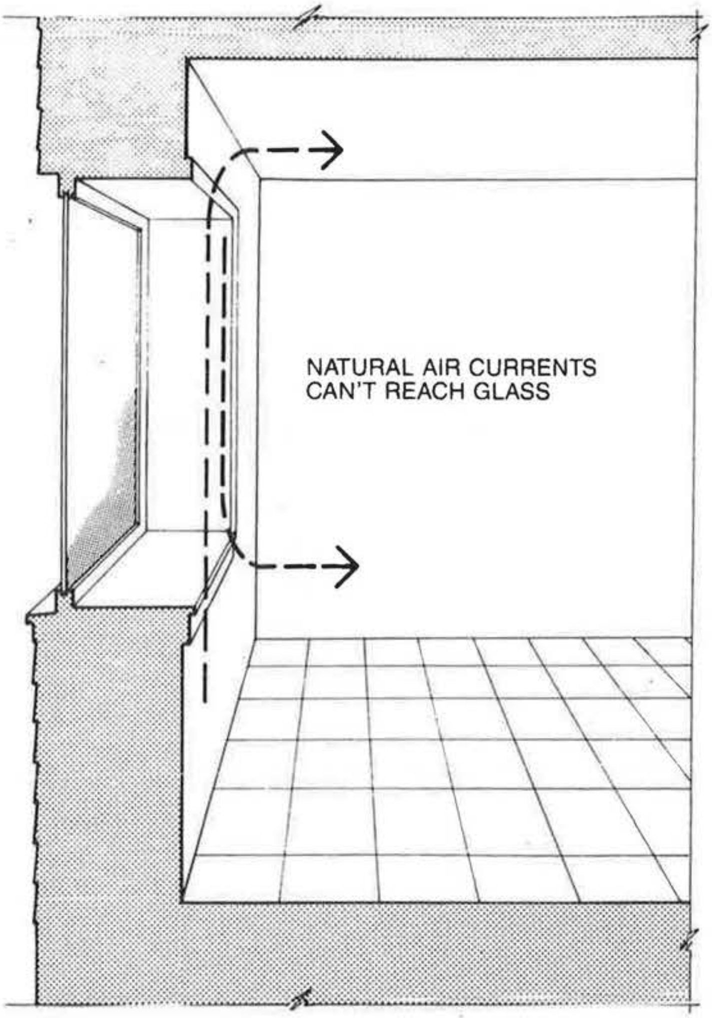


Figure 7-11 — Recessed glass is more prone to condensation

In spaces with high indoor relative humidity, such as kitchens, bathrooms, and especially recreation areas with a hot tub or pool, higher R-values are necessary to prevent condensation. In very humid spaces, even the most efficient windows may still have condensation. In those cases, air circulation is the only way to keep windows dry. When air moves over the inner panes of glass, the R-value of the air layer on the window is reduced, so that the temperature of the glass surface becomes closer to that of the room air. Avoiding condensation by increasing air movement does not save energy; in fact it wastes energy by decreasing window R-value. But if R-value alone cannot prevent condensation, then air circulation is recommended. Another recommendation, developed by Swedish researchers, is to avoid the recessed glass common in thick-walled superinsulated houses (Figure 7-11) because it is less exposed to natural air currents, which help keep glass defrosted.

The Effect of Window Temperature on Heat Distribution System Design

Windows with low heat loss can affect the design of a house's heat distribution system. In conventional houses, baseboards or supply registers are often located under windows to counteract the chilling effect of drafts and radiant heat loss to window glass. But if the walls and windows are not extremely cold, perimeter heaters — or "draft heaters," as they are sometimes called — may possibly be eliminated; heat distribution may be from a central core. For example, a dropped ceiling in a central hallway can be used as a supply plenum for all the perimeter rooms of the house.

However, before eliminating perimeter heat distribution, you should carefully consider the need for air circulation for comfort reasons.

AIRTIGHTNESS

Options

Windows are tested and rated for air leakage using a standard ASTM test procedure (ASTM E-283; Air Leakage of Residential Windows). The window is exposed to a pressure differential of 1.57 pounds per square foot, which is equivalent to a 25-mph wind. Air leakage through the unit is measured and recorded in units of cubic feet of air leakage per lineal foot of crack (cfm/ft) between sash and frame.

The industry standard is 0.50 cfm/ft, but most modern manufactured windows have leakage rates well below that. Windows with compression seals, casements, and awnings typically have the lowest leakage rates. Those with sliding seals, such as double-hung or sliders, usually have considerably higher leakage. For example, Pella lists a leakage rate of only 0.03 cfm per foot of crack for its casement window, but 0.15 cfm per foot of crack for its double-hung window. (Double-hung windows have the further disadvantage of more crack length per unit area of glass because of the central joint, where the two sashes meet.) Figure 7-12 shows

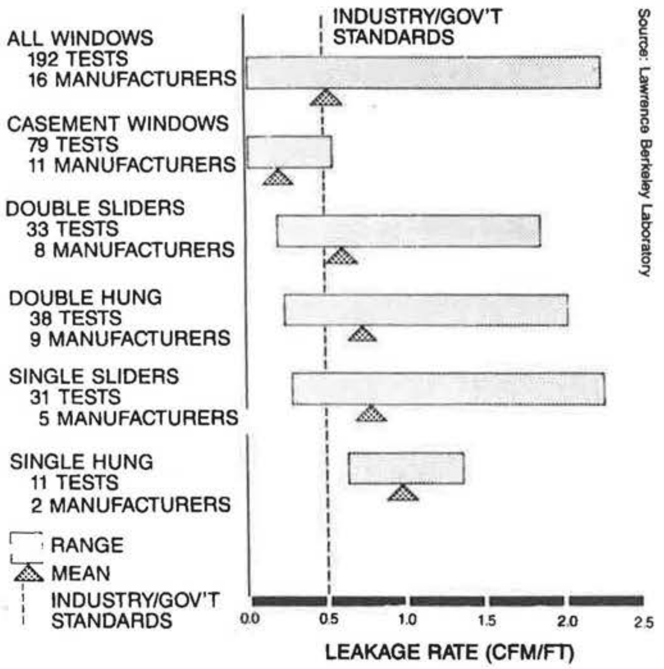


Figure 7-12 — Comparative leakage rates of several common window types laboratory-tested leakage rates for several common types of windows. For more information on window air leakage, see the EDU articles reprinted at the end of this section. Also, specific leakage rates for several manufactured windows are given in Appendix B.

Selection

Obviously, from an energy standpoint, windows with the lowest air leakage rate are the most desirable. Architectural aesthetics notwithstanding, casement windows are the best choice. As for selecting between brands, manufacturers' catalogs usually list air leakage rates for their products. In some cases, listed rates are the "best case" for the tightest unit measured; in others, an average value is used. Common judgment and reliable references are sometimes the most helpful input.

Solar Transmission Properties

Proper selection of glazing systems for solar control depends on climate and house orientation. For example, in northern climates, west-facing windows may be candidates for sun control; south- and east-facing glass, on the other hand, should be clear to allow maximum solar gain. Except for glare control, reflecting or heat-absorbing glass are rarely necessary on north or near-north orientations.

In warm southern climates, some type of sun control should be considered for north-, east-, and west-facing windows to reduce the cooling load. (South-facing windows are less of a problem in southern latitudes because the summer sun is high enough to be easily shaded by moderately-sized overhangs.)

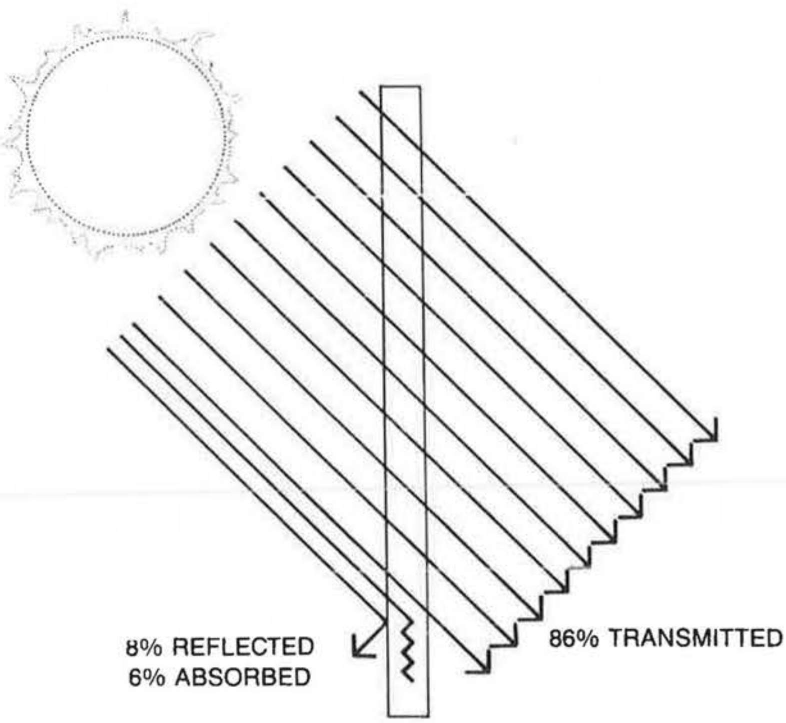


Figure 7-13 — Sunlight striking regular double-strength glass

Of the total solar radiation reaching the earth's surface, approximately 3 percent is ultraviolet (UV), 44 percent is visible, and 53 percent is infrared. Different glazing types selectively transmit, absorb, and reflect each component of the solar spectrum, resulting in varying overall light and heat transmission characteristics. Manufacturers' specifications list several properties of glazing systems that are useful for characterizing their effectiveness for controlling heat gain and light transmission. The most useful specifications are "total solar transmittance," "shading coefficient," and "visible light transmittance."

"Total solar transmittance" is the percent of total incident solar energy — UV, visible, infrared — which passes through a glazing system when the incident light is perpendicular to the glass surface. For passive solar heating applications, the total solar transmittance is a key characteristic. Double-strength sheet glass has a total solar transmittance of 86 percent. Of the rest of the incident solar radiation, about 8 percent is reflected, and 6 percent is absorbed by the glass (Figure 7-13). The actual transmittance varies with incident angle, but the above values are used as a reference for comparative purposes. Multiple glazings, tinted glass, and reflective coatings all reduce total solar transmittance. Solar transmittance values for several types of glass and glazing systems are listed in Table 6.

"Shading coefficient" is the ratio of total solar heat gain through a specific window to the total solar heat gain through a single sheet of double-strength glass under the same set of conditions. Shading coefficients range from 0 to 1. Clear double-strength glass has a shading coefficient of 1.00; double-pane insulating glass has a shading coefficient of about .84; reflective and heat-absorbing glasses have shading coefficients ranging from .10 to .90. Table 6 lists shading coefficients for various glazing systems.

Shading coefficient is the most useful characteristic for evaluating a window's ability to admit or repel solar radiation. Calculation methods for estimating solar gain through windows use the shading coefficient and the Solar Heat Gain Factor (SHGF) published in the ASHRAE Handbook of Fundamentals. SHGF is the amount of solar energy that strikes and penetrates a single sheet of double-strength glass. SHGF varies with latitude and takes into account both solar intensity and angle of incidence of the sunlight. To estimate the solar energy gain through any particular type of glazing, you multiply the shading coefficient times the SHGF. The lower the shading coefficient, the less the solar heat gain. The HOTCAN computer program (see the January/February 1983 issue of EDU) uses the shading coefficient of all windows to calculate the solar contribution to the annual heating load.

"Visible light transmittance" is the percent of total incident visible light transmitted through a glazing system. Obviously, for providing natural lighting and views of the outdoors, light transmittance is a very important factor.

Options

Solar transmission through windows is selectively controlled through the use of reflective coatings and films, heat absorbing glass, high-transmittance glass, and moveable shading devices.

Reflective Glass and Reflective Films

The most effective glazing system for excluding sunlight is reflective glass or reflective films that are applied to the glass surface. Scores of reflective glass types and hundreds of reflective films are commercially available. Typical shading coefficients range from .10 to .90. Most commonly used on commercial buildings, reflective glazing has not been widely accepted for residential application because of its shiny exterior appearance and limited visible light transmittance. However, some newer products specifically targeted for the residential market, provide a reasonably low shading coefficient without high visible reflectivity. To identify those products, you should look for low shading coefficient and high visible light transmittance.

Reflective coatings reflect not only visible light but also, like the Low-E coatings, longwave infrared radiation. Therefore, in addition to excluding solar heat, they create increased winter and summer R-values. Advertisements for reflective glass usually promote the combined merits of decreased winter heat loss as well as reduced summer solar gain; in other words, warmer in winter, cooler in summer. It should be remembered, though, that unlike low-E coatings, reflective glass often has a noticeably shiny appearance.

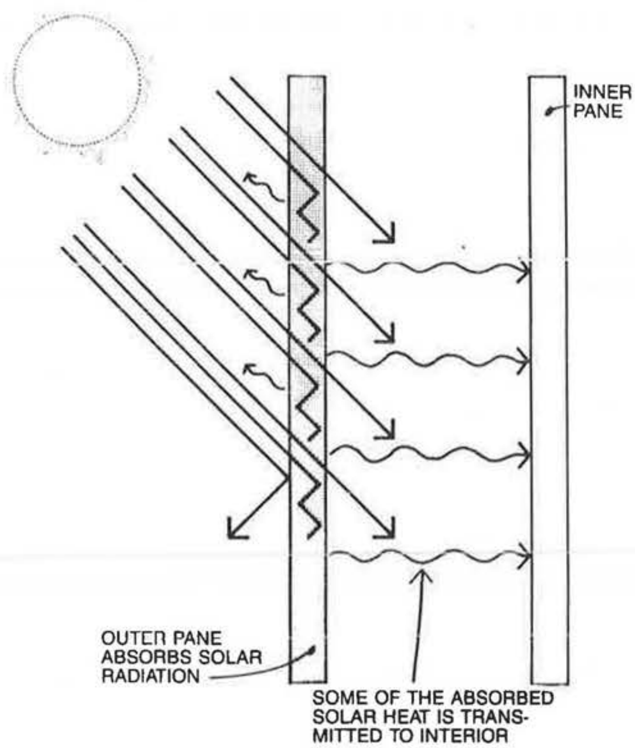


Figure 7-14 — Sunlight striking heat absorbing (tinted) glass

Heat Absorbing Glass

Heat absorbing glass is manufactured with special tints that absorb visible and near infrared light. Available in a variety of colors and having shading coefficients ranging from 0.20 to 0.60, heat absorbing glass is not as effective as reflective glass for reducing solar gain because the absorbed light warms the glass; absorbed heat is then transferred into the house by conduction and convection (Figure 7-14). For residential applications, however, non-reflective heat absorbing glass is gaining popularity. For example, Ford Sunglas, when produced in a double-pane unit (with the outer pane clear), has a shading coefficient of 0.25, but reflects only 8 percent of visible light, thus providing excellent sun exclusion without shiny appearance.

High-transmittance Glass

We have been discussing the selection of glazing to reduce unwanted solar heat gain in order to keep a house cooler. The opposite requirement — maximizing solar gain — is obviously important for south- and/or east-facing windows intended to supply useful solar heat.

Special glasses, sometimes referred to as "water white" or "low iron" (because iron impurities found in regular glass are reduced), have solar transmittance greater than 90 percent for 1/8-inch thicknesses. Two commercially available products are Solarkleer by General Glass and Solatex by AFG Industries (see Appendix B for listings).

Movable Shading Devices

Just as window R-value can be increased with movable insulation, the window shading coefficient can be decreased with movable interior or ex-

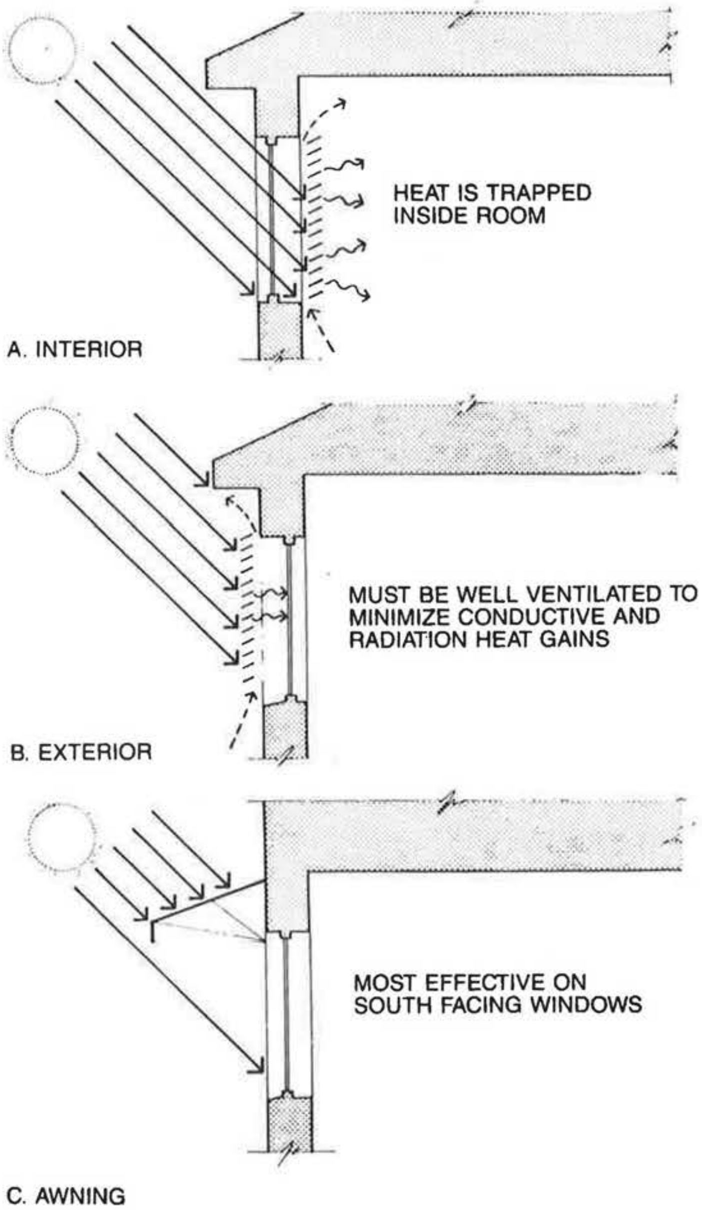


Figure 7-15 — Movable shading devices

terior shading devices such as blinds, curtains, screens, and awnings (Figure 7-15). Although movable shading devices are not part of the window proper, they may preclude the need for special low-shading coefficient glass to reduce solar load. However, like window insulation, their effectiveness depends on occupant action; if they are not used, they don't work.

Interior Movable Shading Devices

Indoor shading devices affect not only the shading coefficient, but also many other factors that contribute to the indoor environment, such as outward vision, privacy, brightness, and sound control. Methods for selecting draperies and other indoor shading devices for sun control are described in detail in the ASHRAE Handbook of Fundamentals. When considering interior shading devices, keep in mind that they intercept solar heat only after it has penetrated through the glass. Unless the shading device has a reflective outer surface, the solar heat is absorbed and partially fed into the interior space.

Exterior Movable Shading Devices

Exterior shading reduces the solar load on windows by intercepting solar radiation before it reaches the glass. Types of movable exterior shading devices include awnings, insect screening, specially woven fiberglass screening, and sun screens made of miniaturized fixed metal louvers. Perhaps the greatest advantage of such devices is that they work with the window open, reducing solar gain, while allowing outdoor air to circulate through the house.

Shade screens are particularly useful because they filter out ground-reflected sun as well as direct solar radiation. The disadvantage of screens, of course, is that they decrease visibility. One interesting product is "Shadescreen" by Kaiser Aluminum. Composed of small angled fixed metal louvers, the shading coefficient of this product changes with sun altitude angle. At 15 degrees solar altitude, the shading coefficient is 0.72, but decreases to nearly 0 at 31 degrees solar altitude.

INSTALLING WINDOWS

The key to proper window installation is the creation of a continuous airtight seal between the window frame and the air barrier.

Conventionally, the air barrier is terminated at the rough opening, but this leaves a major channel for air leakage between the rough opening and the window frame (see Figure 7-16). Many builders attempt to seal this area by stuffing in fiberglass insulation. While intuitively this may seem an effective sealing method, fiberglass insulation is not an air barrier. Under continuous pressure differential, air will leak through, no matter how tightly the fiberglass is installed.

Caulking is the most common method for sealing the joint between the window frame and rough opening. The best caulking material is expanding urethane caulk, available in small cans or bulk dispensers. The best seal is attained when the crack to be filled is at least 1/2 inch wide; narrower cracks are difficult to seal effectively. One good tip is to oversize the rough opening by 1 inch to provide sufficient crack width around the window frame for good caulking.

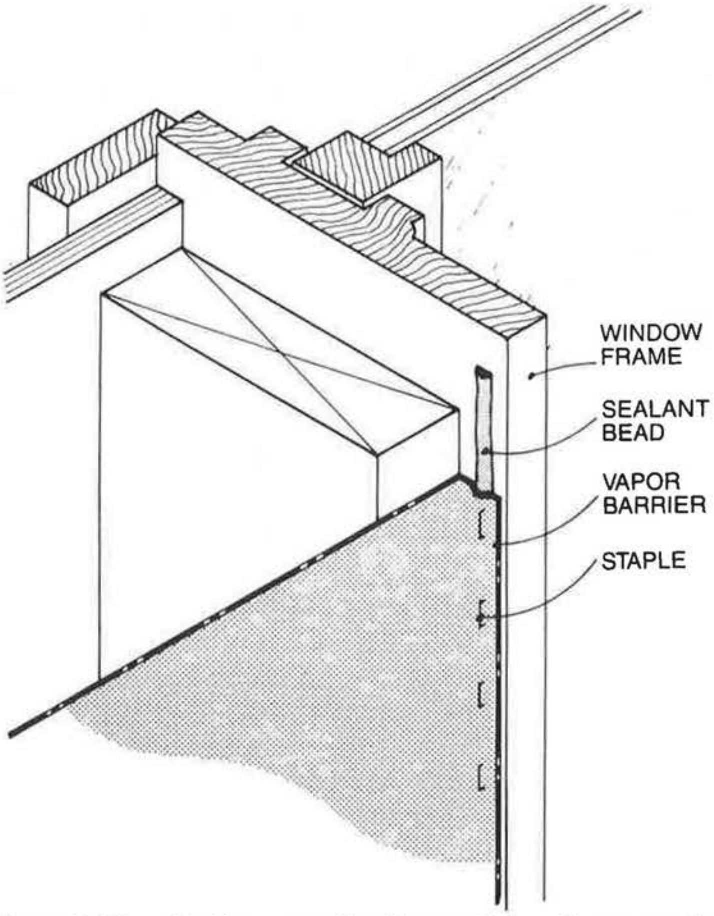


Figure 7-16 — Sealing vapor barrier to window frame at edge

A note of caution: When applied around double-hung or other types of sliding windows, the expanding caulk can actually deform the frame slightly, causing the window to bind. Care should be taken to avoid overfilling cracks.

When a polyethylene air/vapor barrier is used, another approach is to extend the air/vapor barrier to the edge of the window frame and seal it to the frame as shown in Figure 16. If done properly this is a good technique but there is not much exposed frame to work on.

Another sealing technique involves attaching the air/vapor barrier to the window frame prior to window installation (Figure 7-17). A skirt of polyethylene is caulked and stapled to the window frame with about 6 inches of excess material extending toward the inside. When wrapping the plastic around the frame, the corners are pleated (see inset) so that when the window is installed, the polyethylene skirt can be flared out flat against the wall without having to cut the polyethylene at the corners. After the window is installed, the polyethylene skirt is sealed to the main wall air/vapor barrier. Figures 7-17b and 7-17c show installation in a single and double wall respectively. Although time-consuming, this method — when properly done — provides the best possible seal between window and wall.

(Illustrations and text excerpted from The Superinsulated Home Book by J.D. Ned Nisson and Gautam Dutt, John Wiley & Sons, New York.)

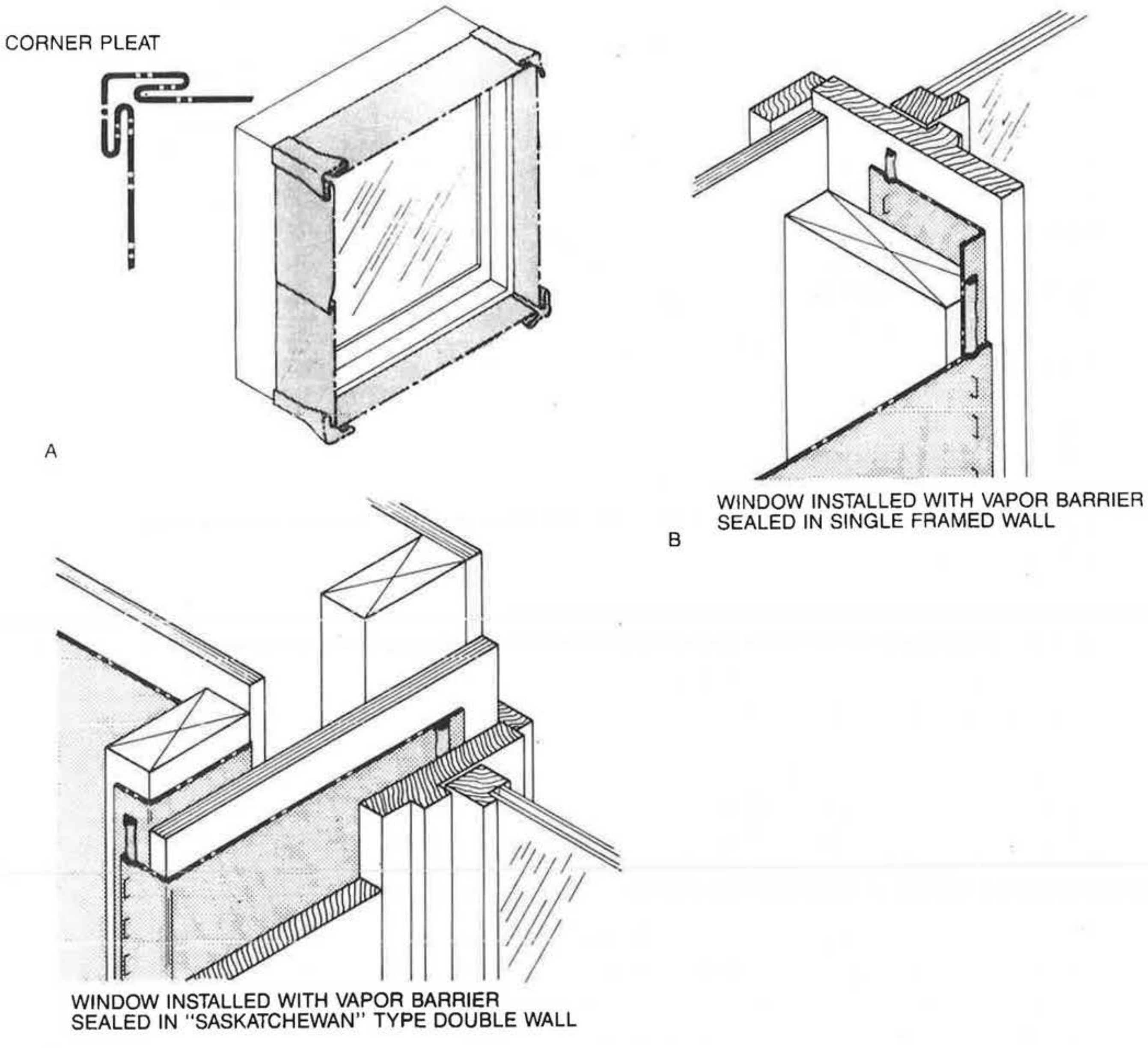


Figure 7-17 — Attaching vapor barrier to window frame prior to window installation

The Measured Performance of Windows

The July 1986 issue of EDU featured an article that focused on window airtightness ratings and how representative they are of the actual field performance of windows. In response to that article, we received a flurry of inquiries asking about other window performance ratings. Specifically, how accurate and valid are manufacturers' listed U-values and R-values for windows?

[NOTE: Although U-value is the more proper term for expressing window thermal performance, we will also use R-value in this article because of its familiarity. R is simply the reciprocal of U (R=1/U).]

Since window R-value is critical to overall building performance and moisture condensation control, and since building codes, energy codes, and various lending programs commonly specify minimum R-values for windows, manufacturers' published performance figures should certainly not go unquestioned.

So we questioned. And we found some startling surprises. We found several Low-E windows that performed well below the common claims for Low-E products, including one Marvin Low-E window with an R-value of R-1.5! On the other hand, we found Andersen windows that actually performed better than the manufacturer's claims in the brochure. We also found comparative lab tests showing that window size alone can cause the R-value to vary up to 40%! Perhaps the most noteworthy discovery was that ASHRAE's published U-values and R-values for windows and the accepted test procedures for testing windows are both clouded with uncertainty.

All in all, we found that listed values for window performance factors are not necessarily accurate representations of actual field performance. The good news is that work is under way to improve the situation. But in the meantime, we should be aware of the areas and degree of uncertainty in calculated and measured window performance.

The Survey of Laboratory Test Data

To evaluate published ratings, we examined laboratory measured performance data for over 300 windows. We eliminated any data that was not from a certified laboratory and then selected that data which was useful for practical comparison and evaluation. A summary of the compiled test data is tabulated in Table 7 at the end of this article. Although we would have liked to limit our analysis to include only nationally distributed windows that would be familiar to all our readers, some of the most illuminating information came from results of tests of windows from regional manufacturers.

Calculated vs. Measured R-value

Pick up any window catalog. For this discussion, let's select the 1986 Pella catalog. On page two are illustrations of the various Pella glazing systems along with rated U-values and R-values. In the lower left corner of the page is the following note:

> *"U values shown are calculated for a 2048 casement using ASHRAE methods and factors. Compare with other calculated ratings. Testing will probably result in higher U values. When comparing test results, methods, conditions, and sizes should be identical. Actual results may vary due to differences in environment, exposure, or management." [underline our emphasis]*

This disclaimer, which appears in similar form in many window catalogs, is the first hint that even though U-values and R-values are often expressed to the second decimal place, the numbers are not gospel and "actual results may vary."

Figure 7-18 compares the laboratory-measured R-value of a Pella 36"x48" casement with the R-value listed in the Pella catalog for an identical window. Notice that the agreement between the Pella calculated value and the laboratory-measured value is actually quite good.

Now let's look at Marvin windows. The Marvin "Product Performance and Information" fact sheet lists an R-value of R-3.57 for its MG2448 Casemaster with Low-E glass (PPG Sungate 100). Unlike Pella, Marvin doesn't explain where that number comes from. We compared Marvin's listed R-value against lab test results for a 35"x48"

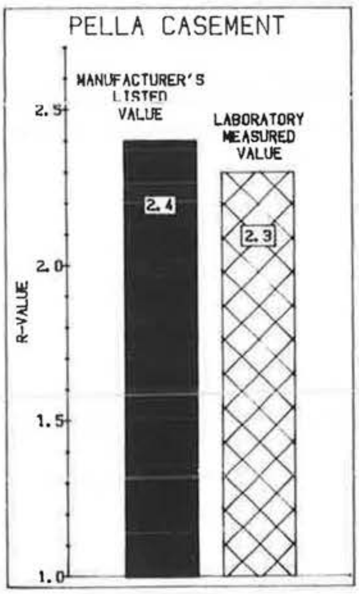


Figure 7-18 — Listed vs. measured R-value of Pella casement window.

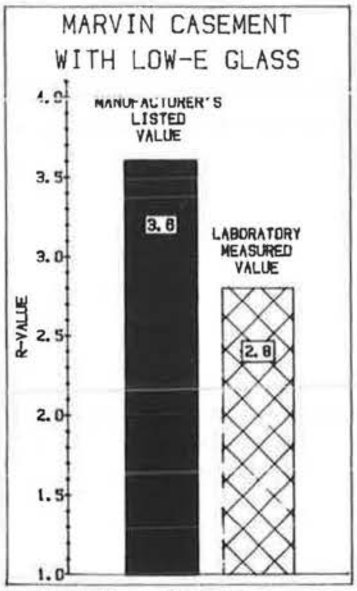


Figure 7-19 — Listed vs. measured R-value, Marvin casement window with Low-E glass.

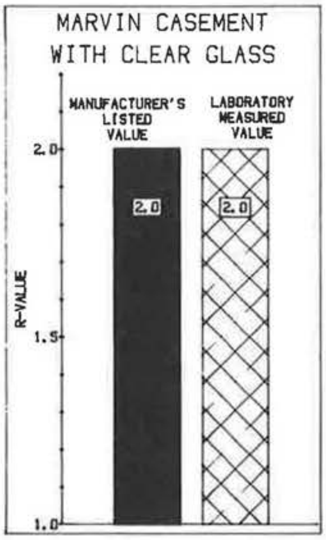


Figure 7-20 — Listed vs. measured R-value, Marvin casement window with clear double glazing; 1/4-inch airspace.

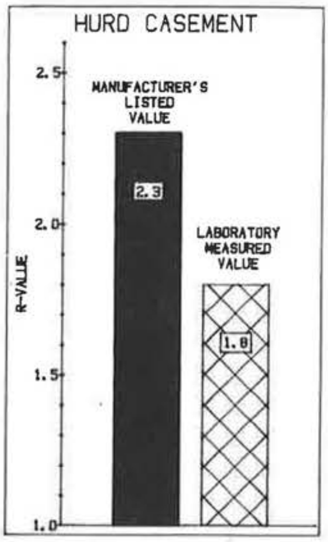


Figure 7-21 — Listed vs. measured R-value, Hurd casement window with clear double glazing

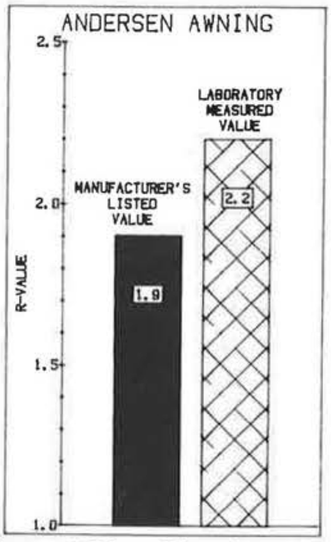


Figure 7-22 — Listed vs. measured R-value, Andersen awning window with clear double glazing

Casemaster (slightly smaller than the MG2448). The lab measured R-value was only R-2.8, 21% lower than the R-3.57 claimed by Marvin (Figure 7-19).

What gives? Is Marvin simply inflating its R-value figures? Probably not, since listed values for other Marvin window models agree quite well with lab test data. For example, Figure 7-20 compares listed vs. measured R-values of a Marvin casement window with clear double insulating glass. The two values agree perfectly.

More sampling from our window files produced more discrepancies between listed and measured R-values. For example, Figure 7-21 shows listed vs. measured R-value for Hurd's double-glazed casement with 13/16-inch interpanel airspace. The measured value is more than 25% below the listed value.

Not all of the discrepancies are disappointing. In the case of Andersen's double-glazed awning window, the measured R-value is higher than Andersen's listed R-value (Figure 7-22).

Why so much discrepancy between listed and measured performance data for windows? Let's look at the major problems.

Problem #1 — The Uncertain Effect of Edge Spacers and Frames

Perhaps the most important problem is the simple fact that windows are very complex building components, consisting of much more than just glass. Ignoring for the moment gaskets, weatherstripping, and locking hardware, windows consist of three basic areas that effect heat transfer — the glass center, the glass edge, and the frame/sash areas.

A. Glass Center Area

The glass center area comprises the bulk of the total window area. The R-value of this area is affected by the number of glazing layers, the width of the interpane airspace(s), and the emissivity of the glazing surfaces. To illustrate the actual effect of these factors, Figure 7-23 shows the measured R-value of various configurations of Interpane Iplus Neutral Low-E glass (glass only, no frame). These lab-measured R-values agree exactly with the performance claims listed by Interpane in its literature.

[NOTE: It is important to note here that the tests of Interpane glass which we examined were performed by measuring conductivity through the center of the glass units only. None of the test thermocouples were near the edge of the glass. The significance of this fact will become more obvious when we discuss "edge effect" below.]

Given the fact that high-performance glazing systems do in fact work (as shown in Figure 7-23), the next logical question is: What impact do they have on whole window performance? Since the glass center area comprises the largest portion of the total window area, there is a tendency to falsely assume that the R-value of the whole window is more or less the same as the R-value of the glass center area. But take a look at Figure 7-24. The leftmost pair of vertical bars compares the R-value of clear double glazing with Low-E double glazing (glass only). Notice that the Low-E R-value is about 63% higher. The other four pairs of vertical bars compare the actual measured difference in R-value between whole window assemblies with and without Low-E glass. In no case is there anywhere near a 63% greater R-value with Low-E glass. The Marvin window showed no difference at all between clear double glazing and Low-E double glazing!

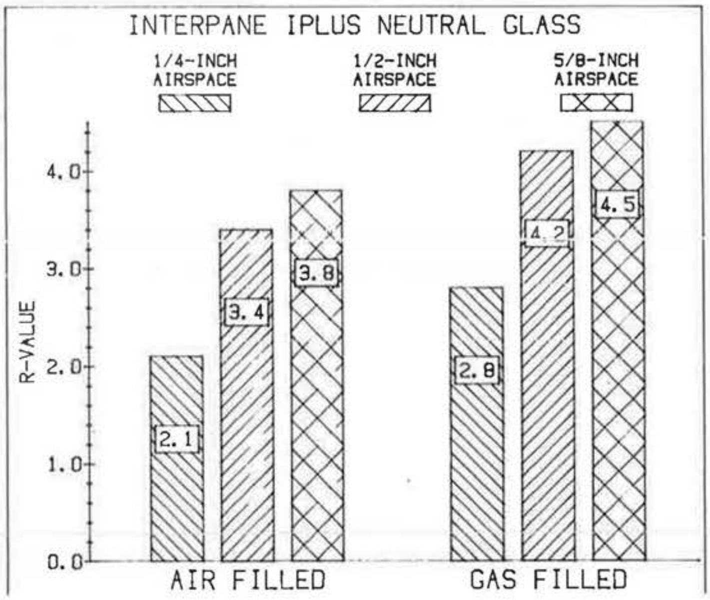


Figure 7-23 — Measured R-value of Interpane Iplus Neutral Low-E glass with and without gas filling.

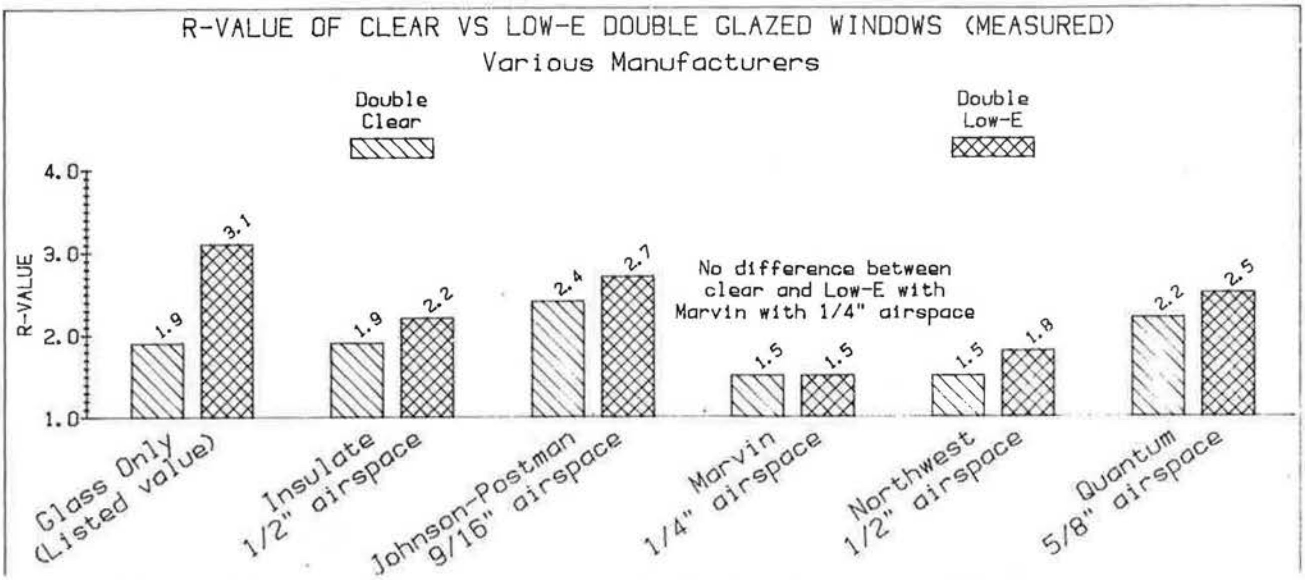


Figure 7-24 — R-value of clear vs. Low-E double-glazed windows; various manufacturers.

Equally astonishing are the data shown in Figure 7-25. Here we see a comparison of clear double glazing, Low-E double glazing, clear triple glazing, and triple glazing with Heat Mirror. Again the leftmost set of vertical bars shows R-values for glazing alone without framing. The other four sets of vertical bars are for awning, casement, fixed, and single-hung windows produced by Fentron. In these tests, the effect of Low-E glazing on whole window performance is insignificant. Bear in mind that all the triple-glazed Fentron units have only 1/4-inch airspace between the glazing. Even so, the R-value of Heat Mirror with that spacing is supposed to be R-3.2, yet none of the Fentron units tested higher than R-2.4!

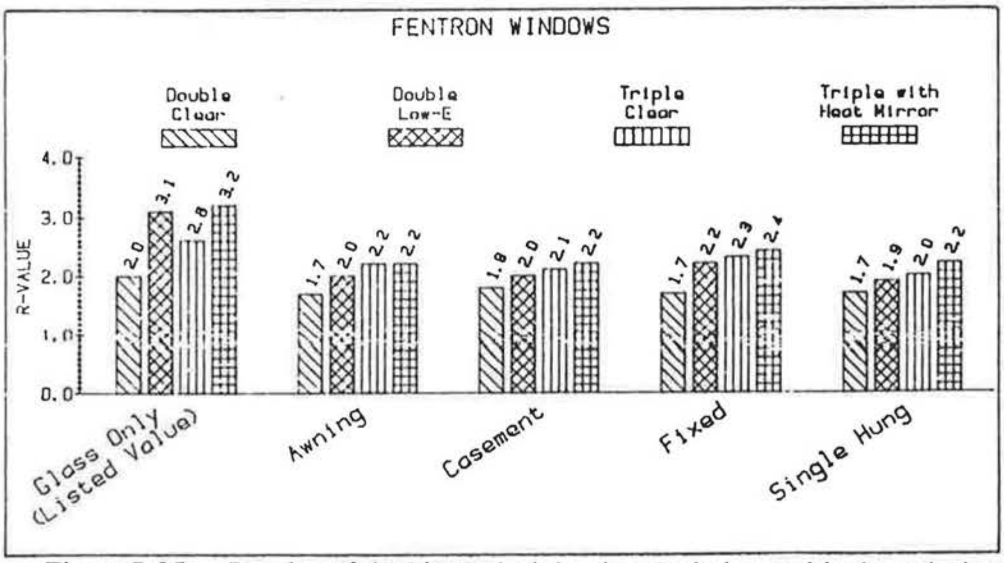


Figure 7-25 — R-value of double- and triple-glazed windows with clear glazing, Low-E glazing, and Heat Mirror interpane.

Why do these Low-E windows test out so poorly? One possibility is that some Low-E glass is not all that it's cracked up to be. Another possibility is that the test procedures themselves are faulty. The third and most likely possibility is that the R-value of whole window assemblies is seriously degraded by high conductivity through the edge seals and window frames.

B. Glass Edge Area

In a sealed insulating glass unit, the spacing between the panes is typically maintained by a hollow aluminum edge spacer (Figure 7-26). Because of aluminum's high thermal conductivity, the R-value at the edge of a sealed insulating glass unit is considerably higher than the R-value at the center of the glass. This is commonly referred to as "the edge effect."

Figure 7-26 — Hollow aluminum edge spacer filled with desiccant.

The edge effect is important not only with respect to overall window R-value, but also with respect to glass surface temperature and condensation potential.

Figure 7-27 shows measured indoor surface temperatures of a 36"x48" Peachtree "Ariel" picture window with 3/4-inch double insulating glass. In this test (AAMA 1502.7-1981), the window was exposed to 18°F air on the cold side and 68°F air on the warm side. The temperature at the center of the glass is 50.6°F — almost exactly what it should be according to theoretical calculations. But the temperature near the edge ranges from 35.5 to 41.8°F — far below what you would expect from an R-2.0 window.

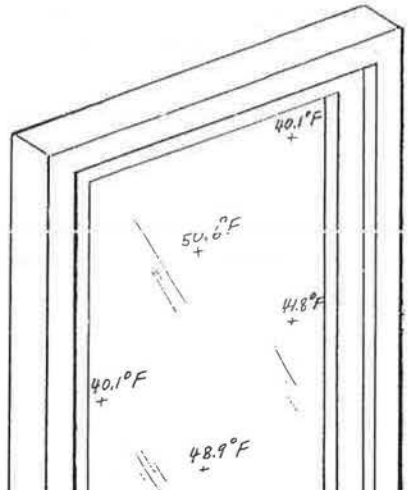


Figure 7-27 — Surface temperature measurements of Peachtree Ariel picture window during Condensation Resistance Factor test (AAMA 1502).

The impact of the edge effect on overall window R-value has not been well quantified, but research performed by PPG shows that aluminum edge spacers can cause a 30% reduction in R-value over a 2.5-inch band around the entire perimeter of the window. In a presentation to the Sealed Insulating Glass Manufacturers Association (SIGMA) last summer, Charles Peterson of PPG estimated that in a 36"x48" window, the edge area constitutes 21% of the total window area, and that the net effect of the spacer is to reduce the overall R-value of a Low-E window by 14%. Despite PPG's estimate, the impact of the edge effect on the performance of assembled windows is variable and quite uncertain.

Methods For Reducing Edge Effect

Some European window manufacturers decrease the edge effect by recessing the glass edge deep in the window sash. Most American window manufacturers are reluctant to do that since it decreases the total clear lite area. Andersen, for example, recesses the glass unit only 1/2-inch into the sash of its casement windows. An exception, however, is the Alaska Window Company, which incorporates a 1-inch-deep glazing well into its vinyl framed windows (Figure 7-28). [In Alaska, a serious concern is the danger of windows freezing shut due to interior condensation and icing, preventing egress during fire or other emergencies. In tests performed by the Alaska Department of Transportation and Public Facilities, the Alaska Primo window was found to perform better than similar Caradco or Rockwell units in this respect.]

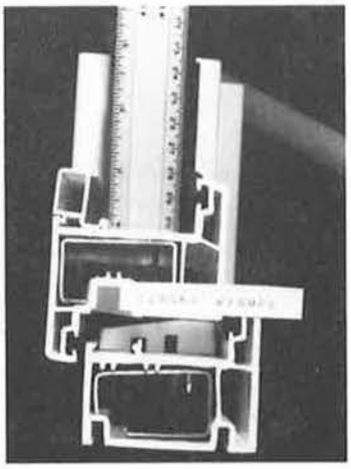


Figure 7-28 — The Alaska Window PVC frame. The glass cavity is 1 inch deep to reduce the effect of thermal short circuiting through the edge spacer.

Some manufacturers are replacing the hollow aluminum edge spacers with alternative spacers having lower conductivity. One example is a relatively new spacer called "Swiggle Stick," a corrugated aluminum spacer produced by Tremco, Inc. Although no measurements are available yet, windows with Swiggle Stick should experience less edge effect than those with conventional aluminum spacers.

Another attractive alternative on the horizon is fiberglass spacers, developed and produced by Fibertherm as part of its fiberglass frame system (see the September 1986 issue of EDU). Since fiberglass has a much lower conductivity than aluminum, these new components will significantly reduce heat transmission through the edge area in windows. Fiberglass spacers are expensive and not yet available in the U.S. They are available in Canada, however, and are being considered by PPG for distribution in the U.S. as part of its Sunsash fiberglass framing system.

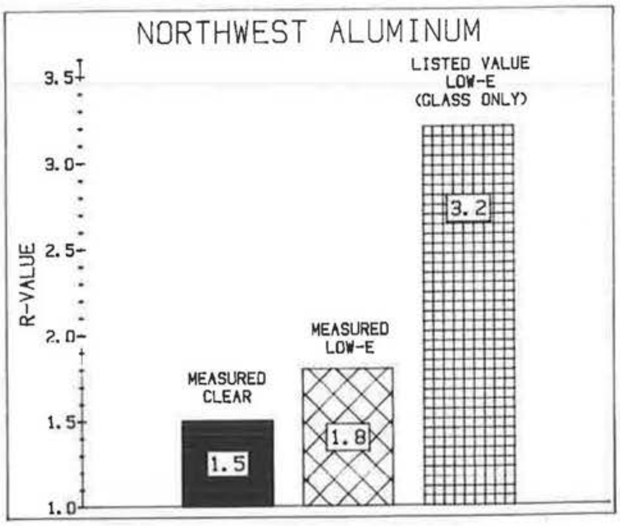


Figure 7-29 — R-value of Northwest windows with thermally unbroken aluminum frames; double clear and double Low-E glazings.

C. Frame and Sash Area

Last but certainly not least are window frames and sashes, whose effect on overall window performance is usually underestimated. A good demonstration of their impact is shown by test results of two aluminum-framed windows produced by Northwest Aluminum (Figure 7-29). One window has clear double glazing and the other has Low-E glass (both with 1/2-inch airspace). Neither window has thermal breaks in the aluminum frame. Clear double glazing has an R-value of about R-2.0 and Low-E glass

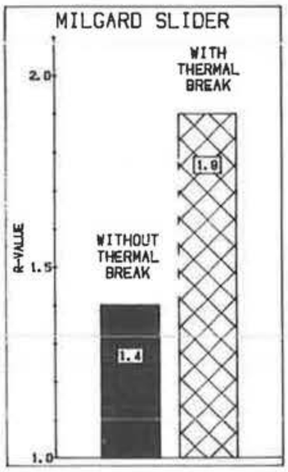


Figure 7-30 — R-value of Milgard sliders with and without thermal breaks in aluminum frames; clear double glazing.

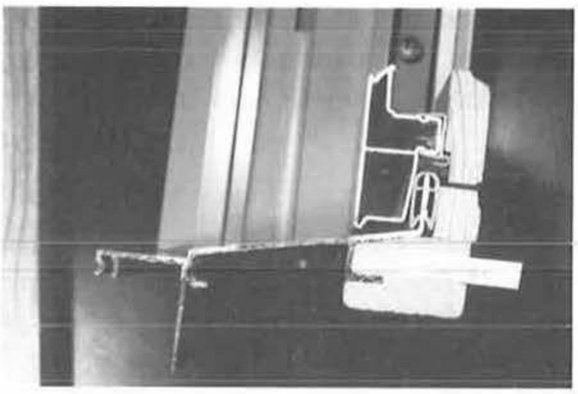


Figure 7-31 — Cross section though Peachtree casement window frame.

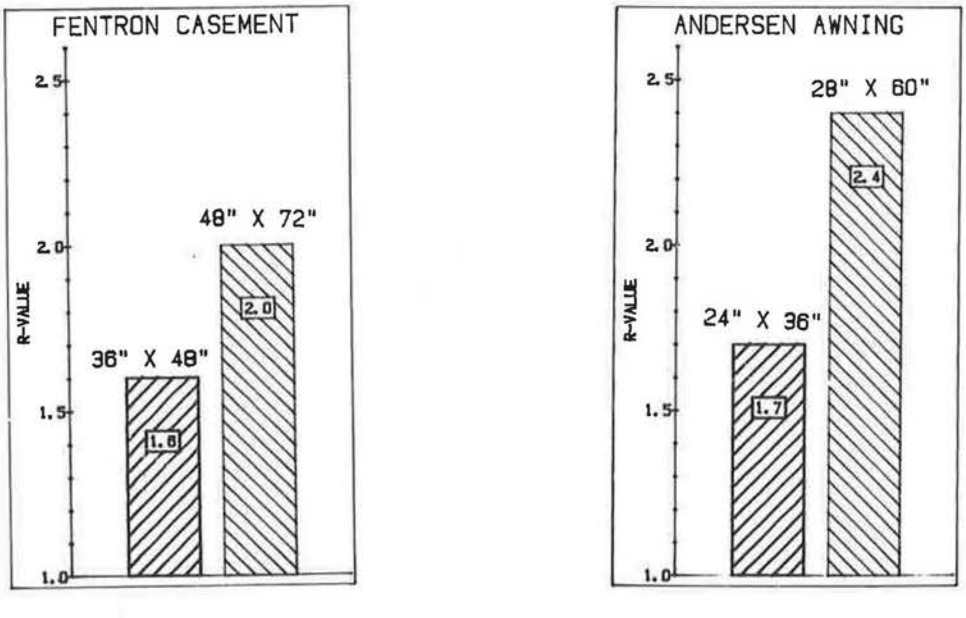
has an R-value of R-3.2, but the measured R-values of the Northwest windows are only R-1.5 and R-1.8! Without thermal breaks, the aluminum frames almost completely nullify the advantage of the low-E glass.

How much improvement do thermal breaks make in aluminum framed windows? To answer that question, let's look at some comparative test data for two Milgard sliders, one with and one without thermal breaks in the frame (Figure 7-30). The R-value of the window with thermal break is 36% higher than a similar window without thermal break.

In addition to metal there are wood, vinyl, and now fiberglass window frames. Many modern windows use a combination of several materials, such as the Peachtree frame in Figure 7-31. The thermal performance of these composite frames has not been well characterized or documented.

Framing And Edge Effects Cause Window R-values To Vary With Window Size

As the glass-to-frame ratio decreases, the overall window R-value also decreases due to the edge effect and in some cases due to framing effects. In other words, large windows should have higher R-values than smaller windows of the same type. An example of this phenomenon is illustrated in Figure 7-32.



a. Fentron casement   b. Andersen awning

Figure 7-32 — Effect of window size on measured R-value

Figure 7-32a compares the R-value of two Fentron casements that are identical except for size. The R-value of the larger window is 25% higher than the R-value of the smaller unit. Figure 7-32b shows a similar comparison for two Andersen awning windows. Here the R-value of the larger window is 41% higher. The Andersen catalog is the only one we've found that explains this phenomenon. One of its catalogs contained the following note:

"The U values stated under this heading are for the indicated products and sizes and do not indicate the U-values of other products or sizes. Ordinarily, a unit with a smaller glass to frame ratio will have a lower U-value and a unit with a larger glass to frame ratio will have a higher U-value." [underline our emphasis]

Problem #2 — Window Performance Tests may not Accurately Reflect Field Performance.

Testing For U-value

The basic concept for measuring window U-value is relatively simple. A test window is placed between a warm chamber and a cold chamber. As heat flows through the window, the amount of energy required to maintain temperature in the warm chamber is measured. With that measurement, the overall transmission coefficient (U-value) of the window can easily be calculated.

Two standard ASTM methods are used for testing window U-value: the "Guarded Hot Box" test (ASTM C236), and the "Calibrated Hot Box" test (ASTM C976). Both tests are also used for measuring U-values of walls and other building components.

The problem arises in selecting the wind conditions under which the test should be performed. Since window R-value is very sensitive to wind speed and direction, wind conditions during the test are very important. If you look at listed R-values or U-values for windows, you will almost always see a footnote stating that the listed value is for a 15-mph wind. So the tests are typically run with a simulated 15-mph wind in the cold-side test chamber. But which way should the wind blow? Parallel or perpendicular to the window surface? ASTM procedures specifically state that the wind must be parallel to the test sample surface. But the window industry claims that is inappropriate for windows because muntins and other protrusions will interfere with the effect of the wind and the results will not be reproducible from lab to lab. So the American Architectural Manufacturers Association (AAMA), an industry trade group, has devised its own test method — AAMA 1503 — which is similar to the ASTM tests, but which includes a 15-mph wind blowing perpendicular to the window surface. The two tests give different results.

Even more serious than the parallel vs. perpendicular wind debate is suspicion that the AAMA test induces air leakage through the window during the test. These tests are not supposed to measure air leakage or its effect on thermal transmission. That's done by a separate test (ASTM 283). To prevent air leakage, the test procedure states that pressure on both sides of the test window must be equalized. (The warm side chamber is pumped up to neutralize the pressure created by the 15 mph wind in the cold side chamber.) A recent ASHRAE study report written by Michael McCabe of the National Bureau of Standards states that the wind conditions in the AAMA test may in fact cause air leakage. McCabe told us that R-values measured by the AAMA test may be erroneously low due to the added heat loss caused by the air leakage.

Figure 7-33 shows laboratory test data that support McCabe's claim. For each manufacturer, the windows represented are the same size and have the same type of framing and glazing. Why do the R-values vary so much? The most likely possibility is that tests of the more leaky windows, such as the double-hung units, are confounded by air leakage, resulting in falsely low R-value readings. This is only a hypothesis, but according to McCabe, a good possibility.

Another possible problem with the AAMA test is that the force of the 15 mph wind might actually cause the glass to deflect, reducing the width of the interpane airspace and thus reducing the R-value of the glazing. McCabe told us that in some instances (presumably with large windows), the panes have actually bent to the point where the panes touch!

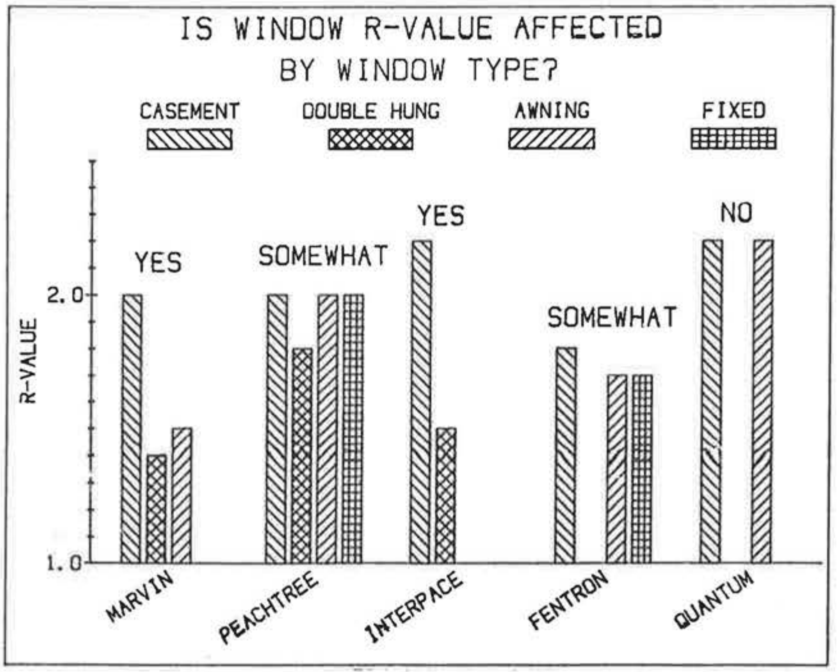


Figure 7-33 — Variation of measured R-value among window types

Problem #3 — The ASHRAE Numbers

The most widely accepted source of U-value and R-value information for windows is the ASHRAE Handbook of Fundamentals, published by the American Society of Heating, Refrigerating and Air Conditioning Engineers. Table 13 in Chapter 27 of the current handbook lists U-values for various glazing configurations.

There are lots of problems with the ASHRAE numbers and the way in which they are used. ASHRAE is well aware of the situation and has formed a subcommittee, headed up by Michael McCabe at NBS, to work on a new revision for the next edition of the handbook, which will be ready in 1989. Here are a few of the problems as outlined in the Work Statement for the ASHRAE subcommittee and/or as told to us by McCabe:

1. Experimentally determined U-values are often significantly different from handbook values. We've shown a few examples of this in this report.
2. Information on many newer and widely used products such as Heat Mirror are not included in the listings of U-value.
3. Nobody seems to know why ASHRAE lists window U-values for 15-mph wind conditions. It certainly is not the average wind speed for most places.
4. Published U-values for windows appearing in past editions of the handbook have changed over the years. The subcommittee does not have a rational explanation for those changes.
5. The ASHRAE-published values are typically misused by the design community. This last problem really shocked us: apparently the ASHRAE U-values as listed are supposed to be specifically excluded from use in annual energy consumption computations. The title of Table 13 clearly states that the table provides U-values "for use in peak load determination and mechanical equipment sizing only and not in any analysis of annual energy usage." Yet nearly every analysis of window options begins by computing energy consumption using the ASHRAE numbers. It stands to reason that, since no real sites have a constant 15 mph wind all year long, using the ASHRAE numbers wouldn't be accurate, yet it is commonly done anyway.

Table 14 in Chapter 27 of the Handbook provides conversion factors between U-values at 0, 7.5, and 15 mph but specific information is not provided on how to use these data to estimate seasonal energy performance.

Aside from the problem with wind speed, the ASHRAE U-values are for an infinite sheet of glass. The edge effect and/or framing effects are not considered. Although Part C of Table 13 lists "Correction Factors" for the effect of framing on overall U-value, there are no factors for combination wood and metal frames, vinyl frames, or fiberglass frames.

McCabe's subcommittee hopes to develop a simple procedure whereby design-day U-value data can be modified to estimate seasonal energy performance of windows. Also, Table 13 in the Handbook is now being revised with more realistic figures and the subcommittee has proposed that a new set of U-values be developed, based on actual laboratory test results.

FOR MORE INFORMATION:

To obtain copies of the ASTM standard test procedures, contact ASTM, 1916 Race Street, Philadelphia, PA 19103; (215)299-5400.

For copies of the AAMA test procedures, contact American Architectural Manufacturers Association, 35 E. Wacker Drive, Chicago, IL 60601; (312)782-8256.

For information on the ASHRAE subcommittee involved with window values, contact Michael McCabe, National Bureau of Standards, U.S. Dept. of Commerce, Gaithersburg, MD 20899.

Special thanks to Michael McCabe for his assistance in preparing this report and to the City of Seattle Department of Construction and Land Use for supplying much of the window test data used for our analyses.

Manufacturer	Sash Type	Glazing	Airspace	Type	Size (Inches)	U-value	R-value
Alaska Window Company	Vinyl	triple	1/2,1/2	casement	31×38	0.31	3.2
Andersen	Vinyl coated wood	double	3/8	awning	48×48	0.45	2.2
		double	3/16	awning	24×36	0.59	1.7
		double	3/16	awning	28×60	0.42	2.4
		double Low-E (Cardinal)	7/16	awning	24×48	0.41	2.4
		double Low-E (Cardinal)	7/16	casement	38×77	0.37	2.7
Fentron Bldg. Prod.	Alum. thermal break	double	5/8	awning	48×72	0.59	1.7
		double	5/8	casement	48×72	0.55	1.8
		double	5/8	fixed	36×48	0.58	1.7
		double	5/8	single hung	48×72	0.58	1.7
		double Low-E	5/8	awning	48×72	0.49	2.0
		double Low-E	5/8	casement	48×72	0.50	2.0
		double Low-E	5/8	casement	36×48	0.62	1.6
		double Low-E	5/8	fixed	72×48	0.46	2.2
		double Low-E	5/8	single hung	48×72	0.54	1.9
		triple	1/4+1/4	awning	48×72	0.45	2.2
		triple	1/4+1/4	casement	48×72	0.47	2.1
		triple	1/4+1/4	fixed	48×72	0.44	2.3
		triple	1/4+1/4	single hung	48×72	0.51	2.0
		triple Low-E (Heat Mirror)	1/4+1/4	awning	48×72	0.45	2.2
		triple Low-E (Heat Mirror)	1/4+1/4	casement	48×72	0.46	2.2
		triple Low-E (Heat Mirror)	1/4+1/4	fixed	48×72	0.41	2.4
		triple Low-E (Heat Mirror)	1/4+1/4	single hung	48×72	0.45	2.2
Hurd Millwork	Wood with ext. alum.	double	13/16	casement	28×60	0.56	1.8
Insulate Industries	Wood	double	1/2	single hung	36×48	0.54	1.9
		double Low-E (Ford Sunglas)	1/2	single hung	36×48	0.45	2.2
Interpace Wood Products	Wood	double	1/2	casement	36×48	0.45	2.2
		double	1/2	double hung	36×48	0.67	1.5
Johnson-Postman	Wood	double	9/16	casement	72×47	0.42	2.4
		double Low-E (Ford Sunglas HR)	9/16	casement	72×47	0.37	2.7
Marvin Windows	Wood	double	1/4	awning	35×48	0.67	1.5
		double	1/4	casement	35×48	0.50	2.0
		double	1/4	double hung	35×48	0.74	1.4
		double	1/4	slider	35×48	0.74	1.4
		double	3/8	double hung	35×48	0.50	2.0
		double	5/8	fixed	35×48	0.54	1.9
		double Low-E (PPG sungate 100)	1/4	double hung	35×48	0.67	1.5
		double Low-E (PPG sungate 100)	1/2	casement	35×48	0.36	2.8
		double Low-E (PPG sungate 100)	1/2	awning	35×48	0.49	2.0
	Wood with ext. alum.	double	1/2	double hung	35×48	0.53	1.9
		double	1/2	casement	35×48	0.45	2.2

Manufacturer	Sash Type	Glazing	Airspace	Type	Size (Inches)	U-value	R-value
Milgard Mfrg.	Aluminum	double	1/2	slider	72×48	0.69	1.4
	Alum. thermal break	double	1/2	slider	73×48	0.52	1.9
		double Low-E (Guardian)	7/16	slider	73×48	0.42	2.4
Northwest Aluminum	Aluminum	double	1/2	single hung	48×72	0.66	1.5
		double Low-E (Glaverbel)	1/2	single hung	48×72	0.55	1.8
Peachtree Windows and Doors	Wood with ext. alum.	double	9/16	double hung	36×48	0.55	1.8
		double	9/16	awning	36×48	0.49	2.0
		double	9/16	casement	36×48	0.49	2.0
		double	9/16	fixed	36×48	0.49	2.0
Pella Products	Wood with ext. alum.	single plus int. storm	13/16	casement	36×48	0.44	2.3
		single plus int. storm	13/16	double hung	36×48	0.47	2.1
		single plus double int. storm	13/16+1/4	casement	36×48	0.36	2.8
Quantum Wood Windows	Wood	double	5/8	awning	48×36	0.45	2.2
		double	5/8	casement	36×48	0.45	2.2
		double Low-E (For Sunglas HR)	5/8	awning	48×36	0.40	2.5
		double Low-E (For Sunglas HR)	5/8	casement	36×48	0.40	2.5
Viking Windows	Alum. thermal break	double	17/32	single hung	48×72	0.57	1.8
		double	17/32	slider	72×48	0.58	1.7
		double Low-E (PPG Sungate 200)	17/32	single hung	48×72	0.52	1.9
		double Low-E (PPG Sungate 200)	17/32	slider	72×48	0.48	2.1
Iplus Neutral Glass	No Frame	double Low-E; gas-filled	5/8	glass only	36×48	0.22	4.5
		double Low-E; air-filled	5/8	glass only	36×48	0.26	3.8
		double Low-E; gas-filled	1/2	glass only	36×48	0.24	4.2
		double Low-E; air-filled	1/2	glass only	36×48	0.29	3.4
		double Low-E; gas-filled	1/4	glass only	36×48	0.36	2.8
		double Low-E; air-filled	1/4	glass only	36×48	0.48	2.1
All Weather, Inc.	No Frame	Quad-pane; Glass outer panes with 3M SunGain inner panes	3/8,3/4,3/8	glass only	17×42	0.29	3.4
		Quad-pane; Outer glass had Low-E film applied to inner surface; two 3M Sun Gain inner panes	3/8,3/4,3/8	glass only	17×42	0.24	4.2
		Triple Glass	5/16,5/16	glass only	17×42	0.31	3.2
		Triple; 2 outer glass, 1 inner 3M SunGain	5/16,5/16	glass only	17×42	0.39	2.6
	Alum. thermal break	Quad-pane; Glass outer panes with 2 3M SunGain inner panes	5/16	casement/fixed combination	64×72	0.43	2.3
Wenco of Oregon JX-7	Wood	Triple glazed Low-E	1/4,1/2	slider	12×24	0.36	2.8
		Triple glazed low-E (PPG Sungate 200)	1/4,1/2	casement	23×38	0.25	4.0

Window Airtightness Ratings — How Good Are They?

Before plopping down a pile of money for high-quality windows, any wise consumer should check the air infiltration ratings listed on manufacturers' brochures and specifications sheets. Those numbers are usually derived from tests performed in accordance with ASTM (American Society for Testing Materials) E-283 — "Method of test for determining rate of air leakage through windows and gliding doors" — in which window units are exposed to 1.56 psf of air pressure (equivalent to a 25 mph wind) and the resultant air leakage is then measured. Expressed in units of cubic feet per minute per lineal foot of crack length (cfm/ft), the "industry standard" for air infiltration is usually listed as 0.50 cfm/ft. (It was actually recently lowered to 0.37 cfm/ft.)

Most manufacturers claim air infiltration rates between 0.03 and 0.20 cfm/ft, depending on the type of window. Those with compression seals (casement, awning, etc.) have typically lower infiltration rates than those with sliding seals (double hung, horizontal sliders, etc.).

But how representative of actual field performance are those published figures? Although not much is usually said about it, manufacturers' published values for air infiltration may not reflect real world conditions very well at all. For example, in a study conducted by the Minnesota Energy Agency for the U.S. Department of Energy, 40% of all windows tested had higher air leakages than the nationally accepted standard of 0.5 cfm/ft!

Why don't published test data represent actual field conditions? A few reasons. First of all, you must ask how the tested units were selected. Did someone at the factory select the very best looking unit off the line and carefully hand-carry it to the testing lab? Or were several units randomly selected at periodic intervals and shipped to a lab via the same route as production windows are shipped to suppliers and end-users? The first method would naturally produce better test results in most cases.

We checked through our library of window literature and found only one manufacturer — Andersen — that explained how windows are selected for testing. According to its brochure, Andersen windows are selected randomly at periodic intervals and the averaged results are what is printed in the brochure. If other manufacturers do the same, we wonder why they don't say so. In any case, except for that one manufacturer, we have no way of knowing how representative the published air leakage values are.

But there is a much more important problem with published window air infiltration rates. That problem is almost never mentioned, but was explained in a report presented by David Kehrli at the Thermal Performance of the Exterior Envelope of Buildings conference in Clearwater, Florida, in December 1985.

The Effect of Temperature Differentials and Aging on Window Air Leakage Performance

Think about it. The outer surface of a window frame and sash exposed to direct sunlight may be anywhere from 35 to 190 degrees hotter than the outdoor air. But the inner surface will be close to the indoor temperature. So in July, when it is 80°F or 90°F outdoors, the temperature differential across a solid window can be as much as 200°F! Maybe that represents an extreme, but under typical conditions, the differential could easily be 100°F to 120°F. During winter in cold climates, the temperature differential reverses, with as much as 100°F warmer temperature indoors than out.

Temperature Increase May Make Windows Tighter at First.

Particularly with aluminum and PVC windows, thermal expansion of the window frame can cause the windows to get tighter. Figure 7-34 shows measured air leakage of an aluminum window with four different types of seals under different temperature differentials. Notice that as the temperature differential increases, air leakage decreases.

But if the seals take on a "compression set," air leakage may eventually increase.

According to Kehrli's report, the majority of weatherseals used in residential and commercial windows are multifilament polypropylene fiber seals generically known as

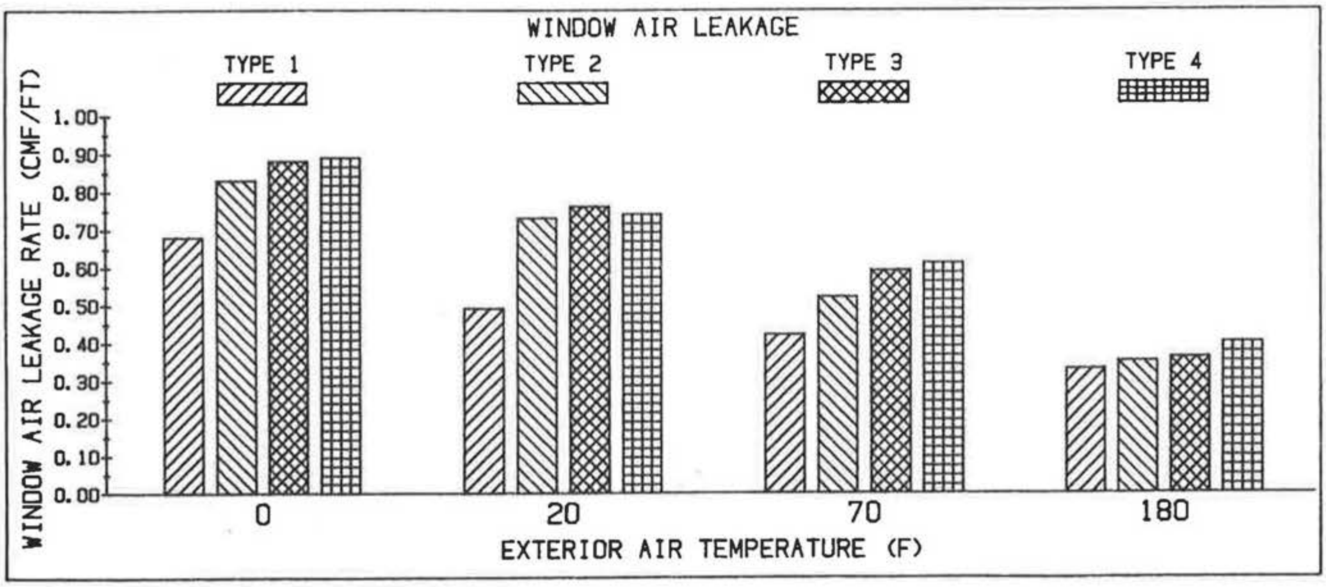


Figure 7-34— Window air leakage under various temperature differentials.

a. Multifilament polypropylene pile

b. Multifilament polypropylene pile with central appurtenanc

c. Polyethylene-clad polyurethane foam

Figure 7-35 — Tested weatherseals

"pile weatherstripping." Since polypropylene is a "thermoplastic" material, it softens upon heating and takes on a permanent "compression set" when compressed under elevated temperatures. In other words, it loses its ability to spring back to its original full thickness. If and when that happens to the weatherseals in a window, the air leakage of the window would increase.

To demonstrate that phenomenon, the following test was performed on three types of weatherseals: The seals were placed into a fixture that measures their ability to resist air leakage at a given air pressure. They were compressed 40% and the air leakage was recorded in cfm per linear foot. Next the seals were placed into an oven at 158°F for 22 hours at 50% compression. The purpose of the second procedure was to induce compression set in the seals. At the end of the 22 hours, the seals were removed and placed back into the air leakage testing device and the leakage was then measured again.

The three types of weather seals tested are shown in Figure 7-35. The results are shown in Figure 7-36.

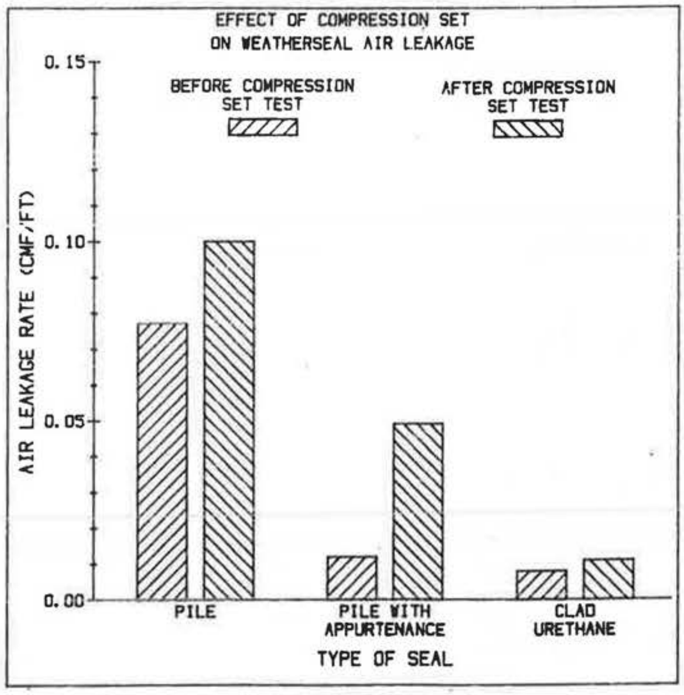


Figure 7-36 — Compression set effects on weatherseal air leakage.

Notice that with all three types of seals, the air leakage increased after the compression set test. The filament-pile weatherstrip with no appurtenance showed the greatest percentage increase in air leakage. The seal that showed the least amount of degradation was the polyethylene-clad polyurethane foam. The reason for that is probably because polyurethane is a thermoset material, not a thermoplastic material, meaning it does not soften and deform upon moderate heating.

An Accelerated Aging Test

One other experiment reported in Kehrli's study was an accelerated aging test performed on aluminum windows with pile weatherstripping and with urethane foam weatherstripping. In that test, complete windows were exposed to alternating cycles of 145°F and 0°F for varying lengths of time. Figure 7-37 shows what happened to the air leakage characteristics of those windows.

Again both types of weatherstripping degraded, but again the urethane foam product fared better.

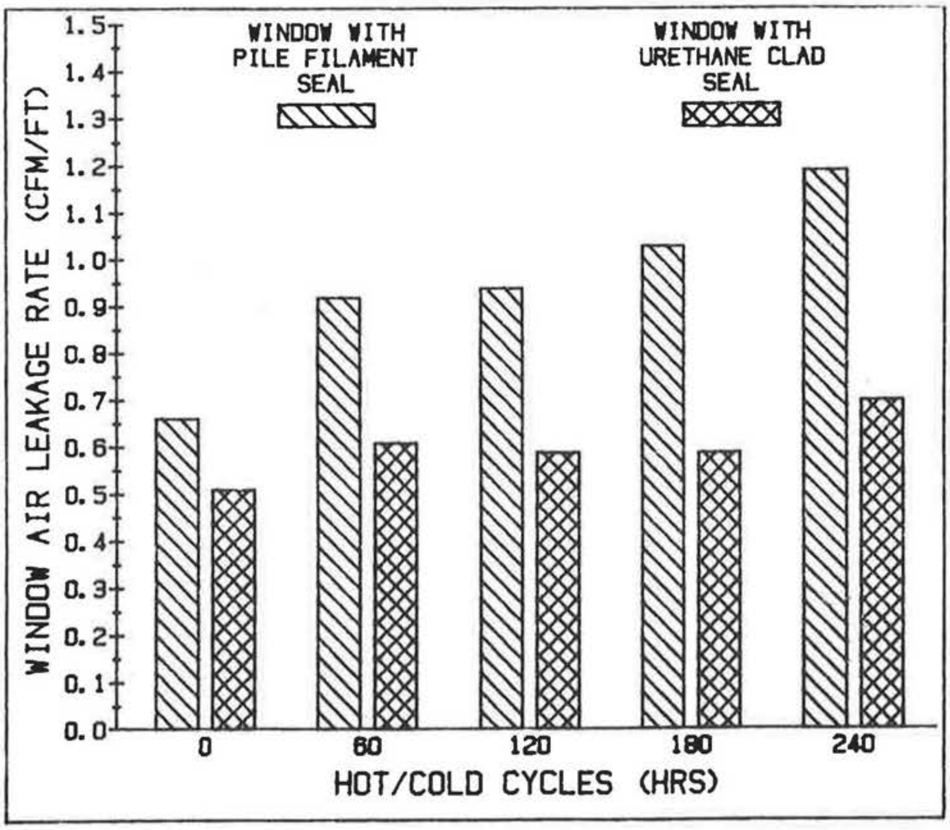


Figure 7-37 — Temperature cycling effects on window air leakage

The Good News:

This study emphasizes the need for more realistic testing of windows to simulate real world conditions over time. The good news is that is exactly what is happening. ASTM E-283 is now being revised to incorporate differential temperature testing. Also, a standard method for accelerated aging, or cycling test, is being explored. The other good news is that the Architectural Aluminum Manufacturers Association (AAMA), a trade group of window manufacturers, is initiating a program of random testing of window units for certification. Unfortunately, most wood window manufacturers don't belong to AAMA (they have their own trade group). All in all, we should see more representative and more reliable window performance data in the near future.

For more information, contact David Kehrli, Schlegel Corporation, Rochester Division, P.O. Box 23197, Rochester, NY 14692-3197.

SECTION 8

Ventilation and Indoor Air Quality

Airtight Houses Must Have Mechanical Ventilation Systems

1. To remove air contaminants and excess moisture.

A plethora of substances are continuously released into household air. Some of them, such as moisture and carbon dioxide, are not dangerous or even harmful in low concentrations, but can cause problems in higher concentrations. For example, carbon dioxide, a natural by-product of metabolism and respiration, can cause headaches and loss of judgement when present in elevated concentrations in the indoor air. Moisture is an even better example; humidity levels of 40 to 50 percent are desirable for health and comfort, but higher humidity levels are both unhealthy and dangerous to the structure of the house.

Even more important are noxious substances such as radon, formaldehyde, carbon monoxide, nitrogen dioxides, and others, which can be serious health hazards at even low concentrations. Some of those, such as radon, are naturally occurring substances emitted from the soil. Others, such as formaldehyde, are intrinsic to the building, being emitted from conventional building materials such as particleboard and plywood. Still others, such as nitrogen oxides and smoke, are given off during occupant activities such as cooking and smoking.

Since the average person spends 80 to 90 percent of his/her time indoors, indoor air quality is more important than outdoor air quality.

Residential indoor air quality did not receive significant attention until the advent of airtight, energy-efficient housing. Prior to that, it was assumed that leaky houses are well ventilated, thus there was no need for concern about indoor air quality. In fact, that is a false assumption. As one designer once put it: "You can't design an air leak." In other words, ventilation in leaky houses is haphazard, uncontrollable, and unpredictable. In an airtight house with a mechanical ventilation system, proper and adequate ventilation is assured to all parts of the house.

2. To bring in oxygen for respiration and combustion.

Supplying oxygen is actually not the most important reason for ventilation in superinsulated houses. First of all, fuel combustion is either carefully fed with outside air or else eliminated in superinsulated houses. Even gas cooking stoves should be avoided. Second, in the absence of fuel-burning appliances, oxygen depletion will never be a problem. People and pets consume oxygen and give off carbon dioxide during respiration. Carbon dioxide build-up is much more harmful and happens sooner than serious oxygen depletion. If you sealed yourself inside an airtight box, by the time you suffered from oxygen depletion, carbon dioxide levels would have already caused serious harm.

Indoor Air Contaminants and Their Sources

Contaminant	Sources
radon	mostly soil, but also from some well water and natural gas supplies.
formaldehyde	ureaformaldehyde foam insulation; medium-density particleboard; some plywood; carpets and upholstery; other household products.
carbon monoxide	furnaces, boilers, woodstoves; cigarette smoke; car exhaust.
nitrogen dioxides	gas stoves; furnaces; outdoor air.
particulates	smoke, dust, bacteria, asbestos, etc.; indoor activities; some building materials.

A full discussion of each of the above pollutants is beyond the scope of this manual. All are potentially dangerous and must be controlled in the indoor environment. There is still some uncertainty, however, as to how much of each contaminant is generated in typical houses, as well as what the safe limits are. Measuring most of the above contaminants is beyond the practical capability of the average designer or builder, but there now are organizations that provide those testing services.

Another approach to indoor pollutant control is to remove or reduce sources of pollutants. Certain precautions such as sealing basements to keep out radon and avoiding building materials with high formaldehyde emissions, are within the control of the designer and builder. Unfortunately, most of the more problematic substances are generated by occupants and can't be controlled during design and construction. Moisture especially, which can cause considerable structural damage, is best controlled through a properly designed and installed ventilation system.

Recommended Ventilation Rate

0.5 air changes per hour (acph)
or
67 cfm per 1,000 square feet of floor area

ASHRAE Ventilation Standards

General living areas	10 cfm per room
Kitchens	100 cfm per room (installed capacity)

The ASHRAE standards are the basis of several building codes including the BOCA 1983 Model Energy Code. They are developed from information generated over the past 40 or 50 years, but are based mostly on carbon dioxide and odor control. The following chart shows ventilation requirements for three houses of different size, based on the ASHRAE guidelines. Notice that according to this analysis, the required ventilation rate is only about 0.2 to 0.3 acph, about half the "0.5 acph recommended ventilation rate" for airtight houses. The recommended rate includes a margin of safety and should be followed until more definitive information is developed about indoor air quality and ventilation requirements.

Ventilation Requirements For Typical Houses (Based on ASHRAE Standard 62-1981)

CASES	1	2	3
Living space floor area (ft^2)	1,000	1,800	3,000
No. of rooms excluding kitchens and bathrooms	3	5	8
No. of bathrooms	1	2	3
Typical ventilation requirement (1,000 ft^3/day)	58	90	136
or			
(air change/hour)	0.30	0.26	0.29
Installed ventilation requirement (air change/hour)	1.35	1.04	0.88
Minimum ventilation requirement (air change/hour)	0.22	0.21	0.20

[Source: The Superinsulation Home Book, by J.D. Ned Nisson and Gautam Dutt, John Wiley & Sons, New York, 1984.]

Mechanical Ventilation Systems for Houses

[*The following section, written by James Lischkoff and Joseph Lstiburek originally appeared in "The Airtight House" (Iowa State University Research Foundation, Inc., Engineering Extension Service, EES Building, Haber Road, Ames, IA 50011.)*]

There are two basic types of ventilation systems. Both have an exhaust fan and ductwork to distribute the fresh air through the house — they differ in how they bring fresh air into the house. One type of system has no inlet fan. Simple inlet openings are located in all rooms except in bathrooms and kitchens. The exhaust fan pulls fresh air in as it exhausts air to the outside. The other type of system has a single inlet opening with an intake fan. The inlet fan pulls fresh air into the house. Heat recovery is optional in both of these systems.

Systems that have only an intake fan and no exhaust fan aren't very good choices; they're difficult to retrofit for heat recovery at a later date. Furthermore, such systems could lead to moisture problems in the wall and ceiling cavities. Any fresh air entering the house at one location has to push stale air out of the house at another location. If an intentional hole is not provided (as is the case with the systems mentioned above), the stale air will leave the house through whatever cracks and holes it can find in the building envelope.

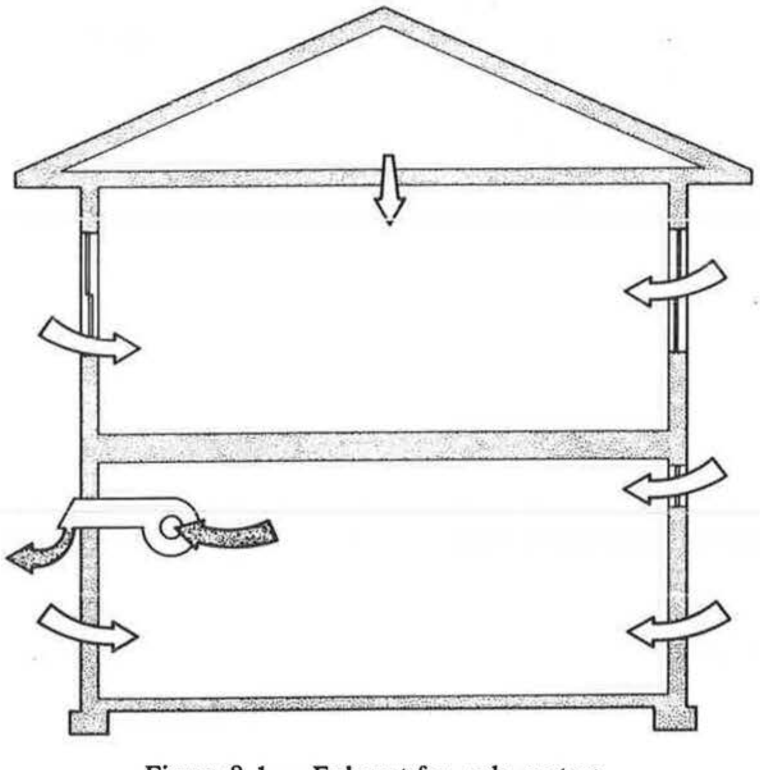


Figure 8-1 — Exhaust fan only system

We'd like to make a few comments about the two basic ventilation systems. A ventilation system which has an exhaust fan but no intake fan will probably draw fresh air into the house through cracks and holes in addition to any holes made intentionally. There's some concern that this will draw pollutants such as radon into the house from the basement area. It's important to remember, however, that the ventilation systems discussed here are designed for airtight houses. The major source of radon is soil gas leaking into the basement and in a tight house the basement area is sealed to prevent this. As far as we know, this should prevent any significant amounts of radon from being drawn into the house.

A ventilation system that has both an exhaust fan and an intake fan is called a balanced system. Because this type of system uses fans to both exhaust and draw air into the house, the air flow into the house is less affected by wind action than in an exhaust-only system. In exhaust-only systems, wind causes variable flow rates because it either hinders or assists airflow through the inlets. An intake fan maintains a more constant air flow. Intake fans can be located close to the exhaust fan (as in an air-to-air heat exchanger).

Every ventilation system must be able to provide at least two ventilation rates: one low-speed ventilation rate (to operate continually), and one high-speed ventilation rate, which will operate intermittently and at the homeowner's discretion.

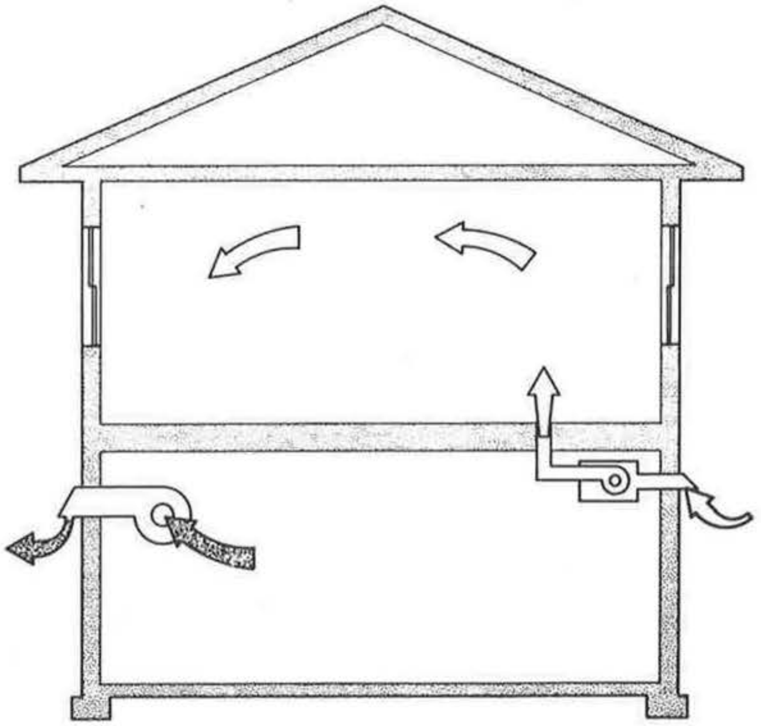


Figure 8-2 — Exhaust fan and intake fan

Fans

There are two types of fans: blade-type (as typically used in bathrooms), and squirrel-cage fans (also called blowers). Although blade-type fans consume about one-third less energy than blowers, blowers are recommended. This is because blade-type fans are more likely to vibrate. They require careful installation and flexible connections between the fan and all ducting to reduce noise. Although blowers are more expensive than blade-type fan units, they're more powerful and far better suited to the task of moving air through extensive duct work. The blowers should be of the variable-speed variety with at least 250 cfm capacity (at 0.3 inches of static pressure).

Install the exhaust blower anywhere in the building envelope (usually in the basement area) where noise will be minimal and where it will be easy to reach for maintenance. The exhaust fan should not be located within 6 feet of any intake openings (to avoid cross contamination), or within 3 feet of an outside corner (to avoid wind action). This blower draws air from all the bathrooms, the kitchen area, and possibly from the laundry room, thus, the need for conventional fans in the bathrooms is eliminated. The kitchen exhaust pick-up should be located as far as possible from the stove to avoid pulling in grease and odors. The stove must be equipped with either a recirculating charcoal filter or its own fan to remove odors. Ductwork is run from the exhaust fan to the pick up points.

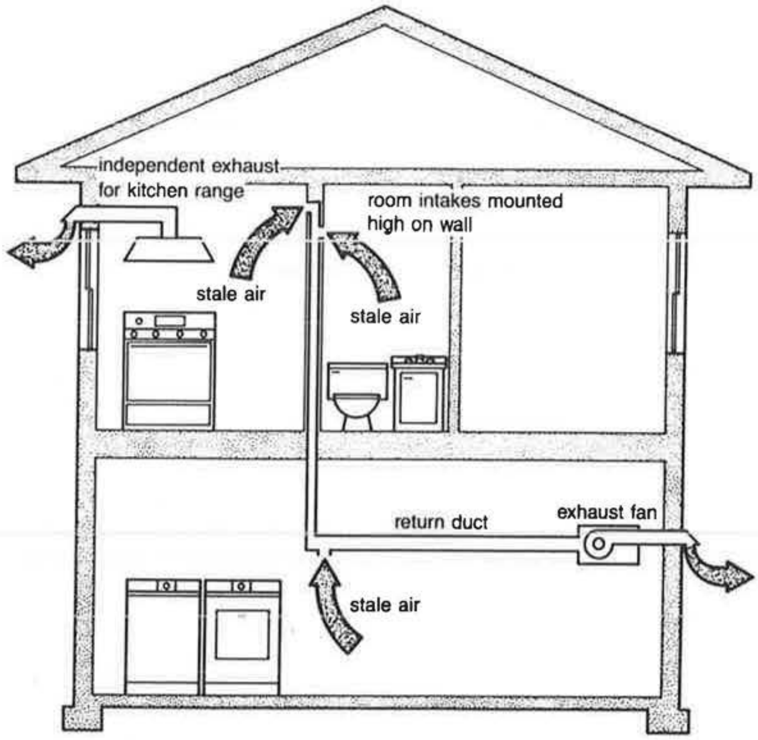


Figure 8-3 — Central exhaust fan and system

Electrical Controls

The objective of the ventilation system is to provide the necessary amount of fresh air when required. This objective is easily met by using a fan which can deliver a low ventilation rate that operates continually and a higher ventilation rate that can be activated whenever the homeowner thinks it's necessary.

The ideal exhaust fan should be of variable speed having a range of 0 to at least 250 cfm. Two-speed fans can be used. However, variable-speed fans make it easier for the installer to set the low rates in accordance with ASHRAE's recommendations. A variable-speed fan also allows the homeowner to pick exactly the ventilation rate that he and the house are comfortable with. The idea is to set the desired minimum speed by a manually-operated variable-speed switch located within easy reach. In addition, provision must be made for activating a higher speed when the homeowner requires it (for example, when the kitchen or bathroom areas are in use). This can be done easily with mechanical switches in the bathrooms or kitchen. When the homeowner turns on one of these switches, the exhaust fan is activated to its highest speed. If a 250-cfm fan is used, then the fan would operate at 250 cfm. The switches in the bathrooms that activate the high-speed operation of the fan should automatically return the fan to its low-speed after a set time interval. Switches called interval timers have a variable time setting (0 to 15 minutes) and are readily available.

In addition to the mechanical switches in the bathrooms or kitchen, the fan's high speed can also be activated by a dehumidistat which will automatically turn up the fan when the indoor relative humidity becomes excessive. If a variable-speed fan is used, then a dehumidistat isn't necessary because the homeowner can adjust the speed of the fan to keep the house comfortable at all times.

In summary, the basic requirements are a variable-speed fan with a variable-speed controller that can be manually operated to run continuously at low speed, and switches in the kitchen and bathroom areas that will kick in the high-speed operation of the fan when the homeowner requires it. A dehumidistat may also be used to automatically activate the high speed of the fan when indoor humidity levels become excessive.

DUCTWORK

All ductwork should follow standard HVAC guidelines. In order to reduce friction losses, the ductwork should have as few turns and elbows as possible and should consist of ducts that are as large as possible and with a smooth inside surface. If it's your first time, you'll be wise to consider hiring an experienced air-conditioning and heating contractor to install the entire ventilation system.

Inlet openings

If the ventilation system has an exhaust fan only and no intake fan, then one or more openings can be provided as a fresh air intake. The amount of air that enters through an inlet is affected by wind as well as the operation of the exhaust fan. Depending on its direction, wind will either help push more air through the opening or will decrease the amount of air entering the opening. Thus, it may be difficult to control the amount of air entering through an opening; an inlet fan overcomes most of the wind problems.

One advantage of placing an opening in each room of the house is that a duct system then isn't needed to distribute the fresh air. The exhaust fan will draw air in through all the intentional openings around the building envelope. In this way, fresh air will enter each room and then be drawn through the house to be exhausted as stale air through the exhaust fan. However, it may be difficult to control the amount of air each room receives.

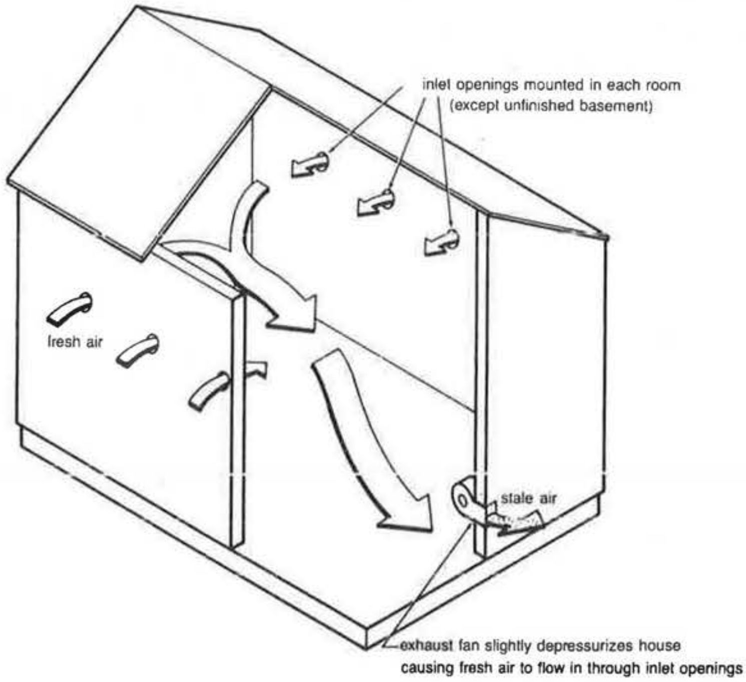


Figure 8-4 — Individual inlet openings

Whether one or more inlet openings are being provided, the inlets should be located away from pollutant sources. That is, they shouldn't be located near where a car will be parked, near a dryer vent, or near a vent for an induced-draft furnace or hot water tank.

The incoming fresh air may have to be heated up to prevent cold drafts. This may be done by installing a small resistance heater in the ductwork.

If one opening is used, it is usually made in the basement area and special provisions must be made for cold drafts or other problems. In addition, a duct system must be provided for the distribution of fresh air throughout the house.

Distribution system

It's very important that the fresh air entering the house be distributed throughout the house. If more than one inlet is used (as previously mentioned), then ductwork isn't needed to move the fresh air from room to room. If only one inlet is used, then either a ductwork system must be provided to move the fresh air around, or (if the house has a forced-air furnace) the existing ductwork can also be used to distribute the fresh air. If separate distribution is provided, air is drawn from the bedroom areas through registers mounted high on the walls and is returned via one or two registers mounted in the floor. Attention must be given to the location of the fresh air registers to prevent cold drafts. The following is recommended:

1) If possible, locate the fresh air registers high on the wall to allow mixing of the air above occupant level. If this isn't possible, use perimeter registers which direct the air along the wall up to the ceiling level.

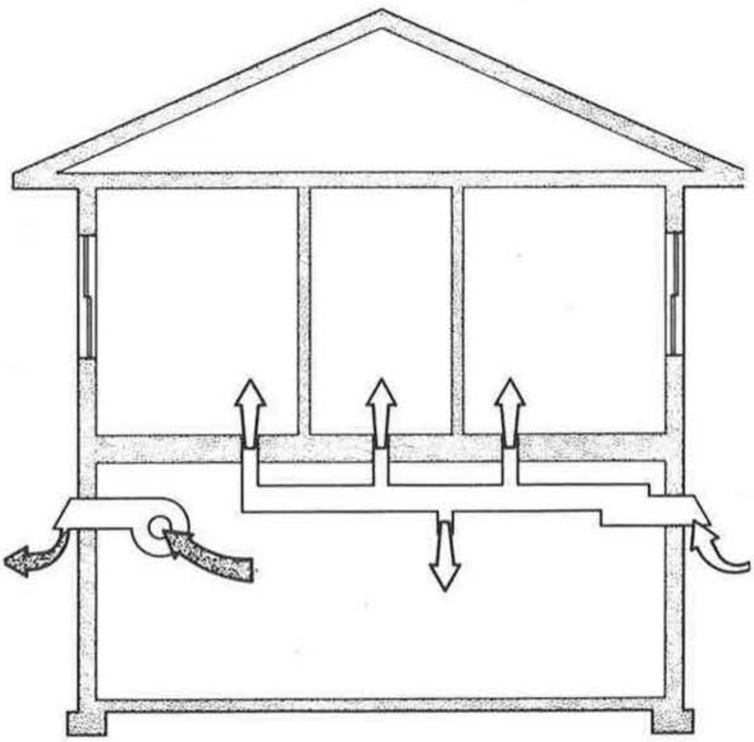


Figure 8-5 — Fresh air distribution system

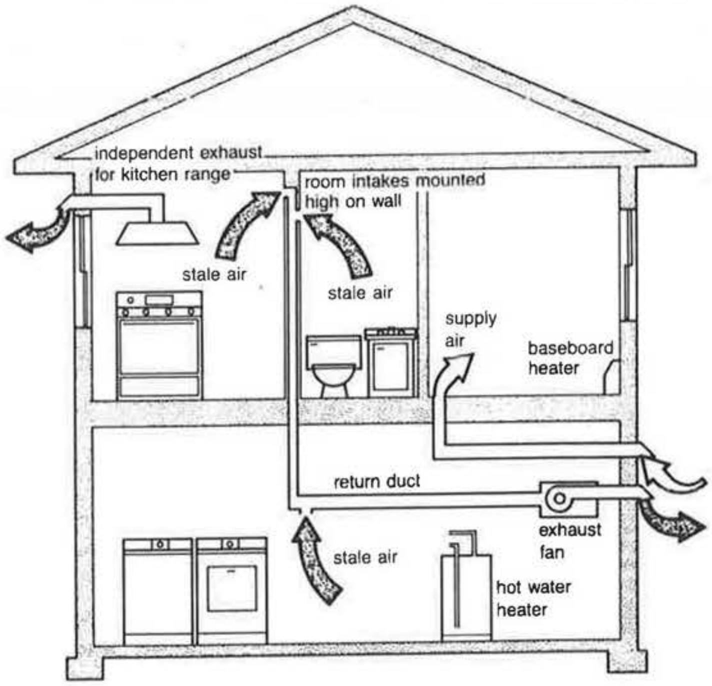


Figure 8-6 — Independent ventilation and heating systems

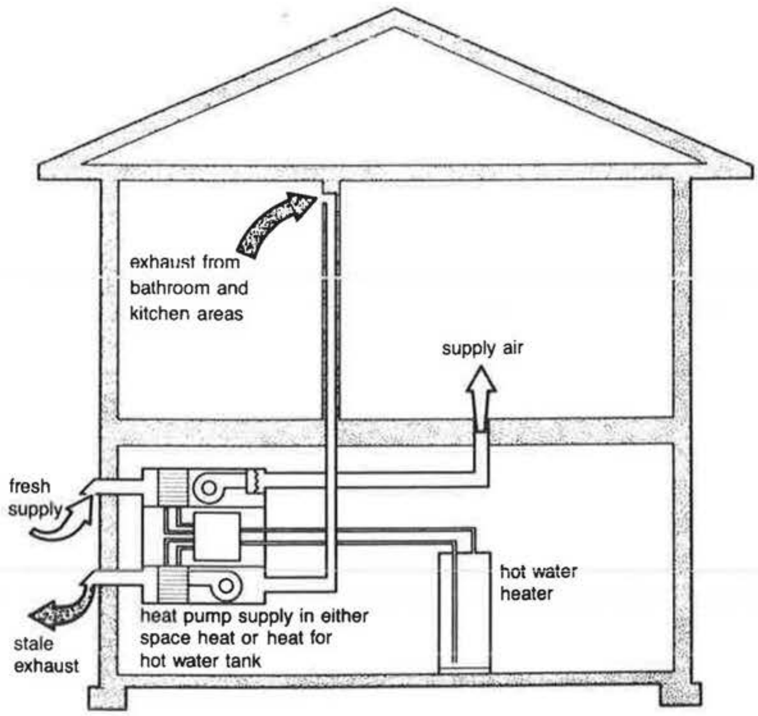


Figure 8-7 — Fully integrated system

2) Fresh air registers should not be located in bathrooms or kitchen areas from which the exhaust fan draws air. The fresh air registers can be located in living room or bedroom areas. If fresh air registers are placed in closets or hallways, then proper air circulation must be monitored to make sure that the bedroom and living room areas are sufficiently ventilated.

Instead of using ductwork to supply fresh air directly to individual rooms, fresh air may be fed directly into an overhead plenum which extends throughout the entire house. Registers placed in the overhead plenum will allow fresh air to enter selected rooms.

Regardless of the distribution system used, it may be necessary to cut all interior doors at the bottom, thereby allowing the easy movement of air from room to room.

Types of Ventilation Systems

Although ventilation systems come in many possible varieties, the ones discussed here all have the following features: an exhaust fan (sometimes an intake fan as well), an intentional inlet opening or openings, and some kind of distribution system to move the fresh air around the house. In an airtight house, the basic controlled ventilation system is relatively easy to design if it is independent of the heating and air-conditioning system.

It is also possible to integrate the controlled ventilation system with existing heating and air-conditioning equipment. This eliminates the duplication of fans and/or ductwork. While integrated systems are more efficient, they have one disadvantage. An integrated ventilation, heating, and air-conditioning system is much more complicated to design and is dependent on the degree of the house's energy efficiency (i.e., the amount of exterior insulation). Conventional heating and air-conditioning equipment has airflow rates that are incompatible with required ventilation rates. It may be difficult to obtain heating and air-conditioning equipment specifically designed for low-energy houses. Professional help is needed to integrate all three functions. A simple controlled ventilation system installed independently, on the other hand, only requires an airtight house and not a superinsulated house.

Ventilation Systems without Heat Recovery

The balancing of ventilation systems to provide the proper amount of air flow in each room is more art than science. The return grills are manually adjusted in order to damper the intake flow until the occupant feels comfortable. The only way the actual flow rates can be determined is to measure them in the house after all the ductwork is in place.

Fresh Air Duct with Forced-air Furnace

If the house has a forced-air furnace (it doesn't matter whether the furnace uses electricity, oil, or gas), the furnace ductwork can be used to distribute fresh air throughout the house. In order to use the existing ductwork of a forced-air furnace, two modifications are required. The Canadian R-2000 program suggests the following procedure: install a 6-inch insulated inlet duct with a damper to bring fresh air to within one foot of the opening in the return air duct system.

It's also recommended that the duct be at least 6 feet from the furnace itself. If this procedure is used then the furnace fan must run continuously, whenever the house is closed up. When heat is required, the furnace fan will move warm air mixed with fresh air throughout the house. When heat isn't required, the furnace fan will move only fresh air throughout the house.

More Than One Inlet

If there is no existing duct system, as in a house with electrical baseboard heaters, then installation of a distribution system can be avoided by using inlet openings located in each of the rooms.

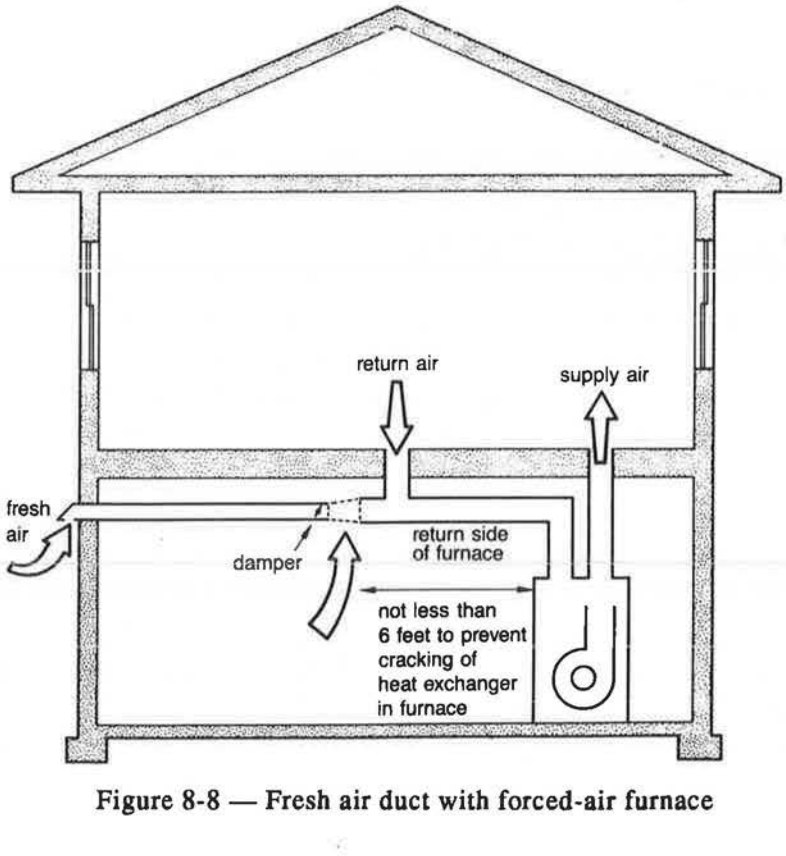


Figure 8-8 — Fresh air duct with forced-air furnace

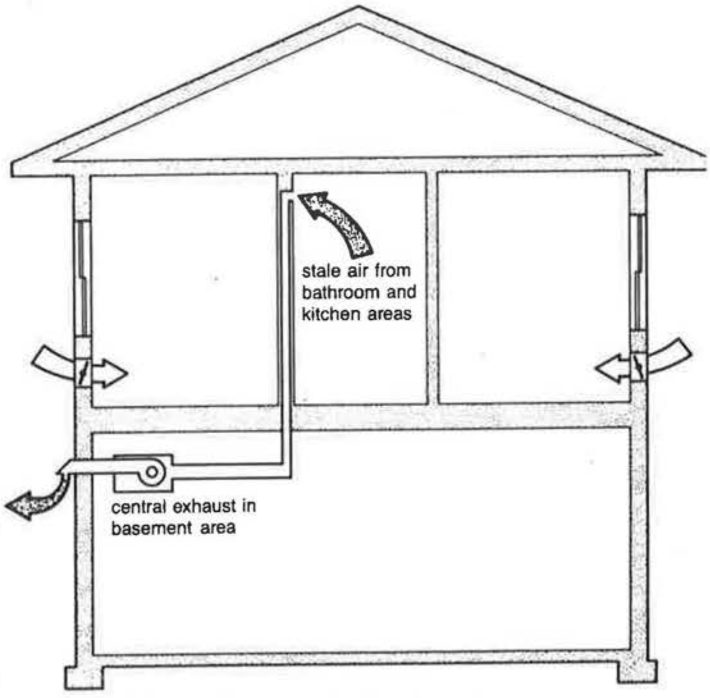


Figure 8-9 — Individual fresh air inlets

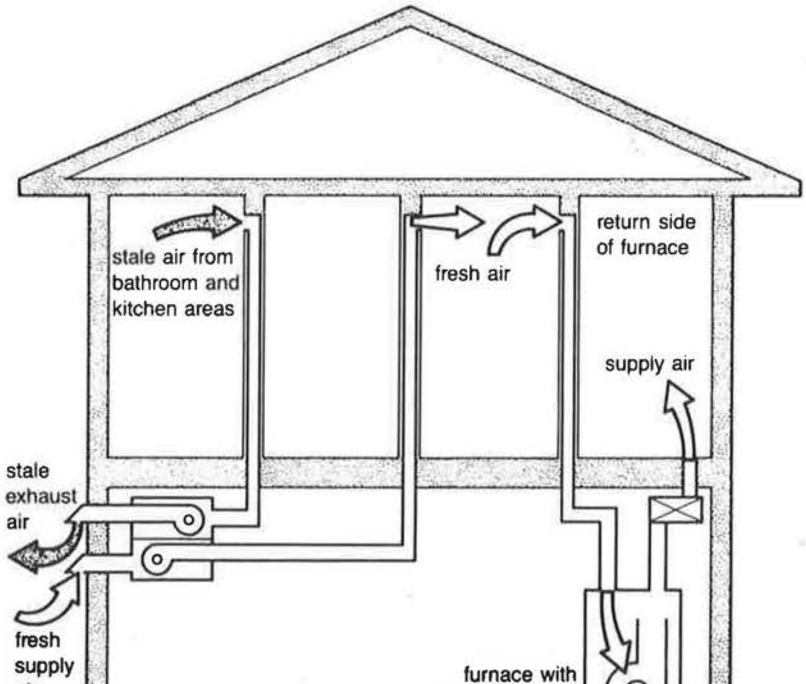


Figure 8-10 — Individual fresh air inlets

Many types of inlet vents are available. There are several through-the-hole vents which are basically 3-inch diameter pipes with adjustable openings and insect screens. In Sweden, these vents are placed high in the wall (similar to an air-conditioning vent) and enable the cool air to slowly sink and mix properly.

Special devices are also available which are inserted through the window frame. Their openings are automatically adjusted by wind conditions; when the wind blows, the opening shrinks, and when the wind stops blowing, the opening expands. Fresh air may also be brought in at floor level, allowing the use of conventional floor registers. If the opening is brought in through the wall in this way, the interior appearance of the house won't be disturbed. However, it may be necessary to pre-heat the air in order to prevent cold drafts. Remember that, regardless of how fresh air is brought into and distributed throughout the house, an exhaust fan is always needed.

Exhaust fan and an inlet fan

In this system, an intake fan is provided in addition to an exhaust fan. The intake fan can be located near the exhaust fan to facilitate the addition of a heat recovery device later on. If the house doesn't have a forced-air furnace, then a duct system to distribute the fresh air must be installed.

Ventilation Systems with Heat Recovery

Air-to-air heat exchangers are also commonly referred to as heat recovery ventilators (HRVs) because they're designed to perform two functions. First, they bring fresh air into and exhaust stale air out of the house and, secondly, they recover some of the heat in the exhaust air and transfer it to the colder incoming fresh air.

Air-to-Air Heat Exchangers

In addition to transferring some of the sensible heat from the exhaust air to the incoming air, HRVs can also transfer some of the latent heat released when water vapor in the exhaust air condenses. The air-to-air heat exchanger replaces the need for an exhaust and intake fan because it includes both. All that remains is to distribute the pre-warmed fresh air throughout the house. This can be done by hooking up the HRV to existing ductwork, such as a warm air distribution system, or installing a separate system.

The "efficiency" of an HRV (which may range from 30 to 80 percent) refers to how effectively it transfers heat from the exhaust air to the incoming air. There are several

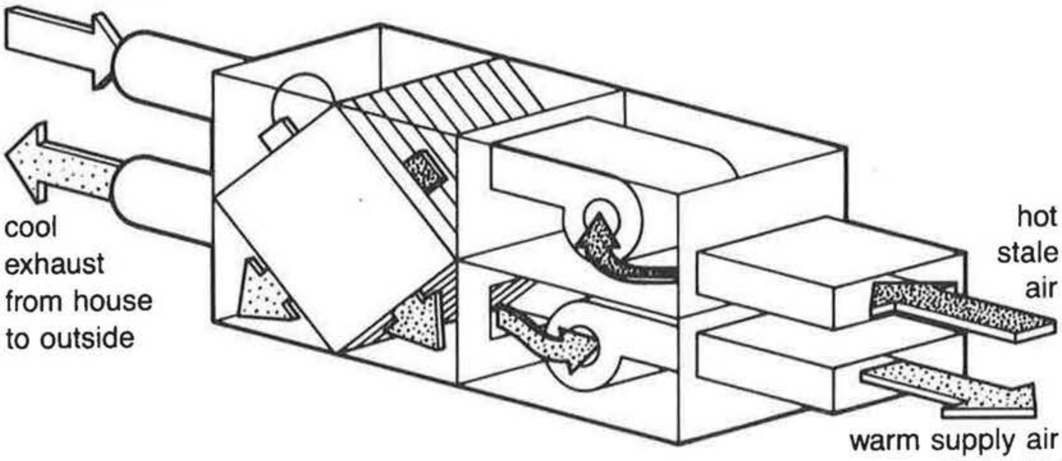


Figure 8-11 — Air-to-air heat exchanger

different types of HRVs, including flat plate heat exchangers, finned-tube devices, and rotary wheel heat exchangers.

Here are some factors to take into consideration after deciding to install an air-to-air heat exchanger.

- The unit should be located in a heated environment where the temperature will not fall below freezing.
- The unit should be located within easy reach for control adjustment, repair, and maintenance.
- A provision should be made to drain away any condensate which may form in the unit.
- The unit should be installed in a way which reduces noise to a minimum. This can be done by using rubber or cork mountings and a canvas collar or short-length flexible ductwork to prevent transmission of noise between the air-to-air heat exchanger unit and the ductwork.
- Ducts leading from the air-to-air heat exchanger to the outside should be insulated and carefully wrapped in a vapor barrier to prevent condensation on the ducts.

The range hood or the clothes dryer shouldn't be hooked up directly to the air-to-air heat exchanger. These will clog it up with grease and lint respectively.

Heat Exchanger performance

The exact performance of air-to-air heat exchangers (and other heat recovery devices as well) can only be assessed in the field. The actual flow rate must be measured after installation when all the ductwork is in place. This can be done by measuring the flow rates between the outside and the air-to-air heat exchanger box. Most air-to-air heat exchangers are designed as balanced systems. That is, the amount of air exhausted from the house is theoretically equal to the amount of fresh air drawn into the house. The ductwork on the cold side of the air-to-air heat exchanger should have dampers so that the flow rate of the incoming fresh air can be adjusted within 10 percent of the outgoing exhaust air. This balancing of the air-to-air heat exchanger is critical to its performance. If more fresh air is being drawn in than stale air is being exhausted, then the incoming cold air won't be heated sufficiently and the unit will frost up, causing inefficient performance. In addition, the house will tend to be pressurized and interstitial moisture problems can result. If more air is being exhausted than is being drawn in, then additional air leakage may cause high energy bills.

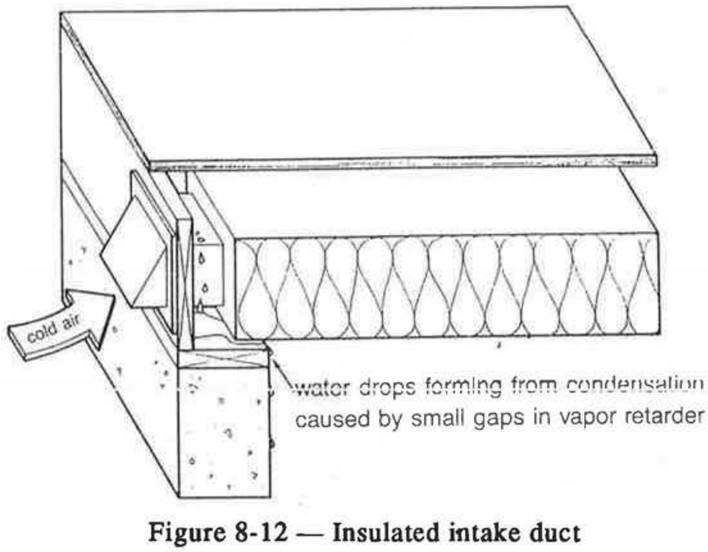


Figure 8-12 — Insulated intake duct

Heat pumps

Heat pumps work like refrigerators, withdrawing heat from the air in one location and pumping that heat to another location. Unlike refrigerators, though, heat pumps can run backwards. That is, in the summer a heat pump can remove heat from the air inside the house and cool it, and in the winter it can take heat from the outside air and pump it indoors. A heat pump can also reclaim heat from warm inside exhausted house air for ventilation purposes.

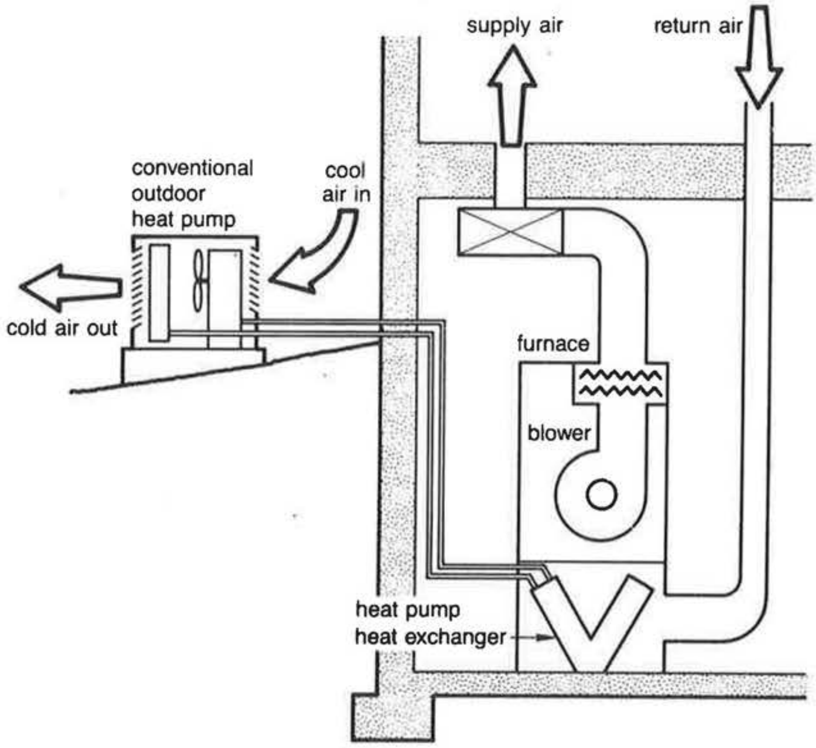


Figure 8-13 — The outdoor heat pump

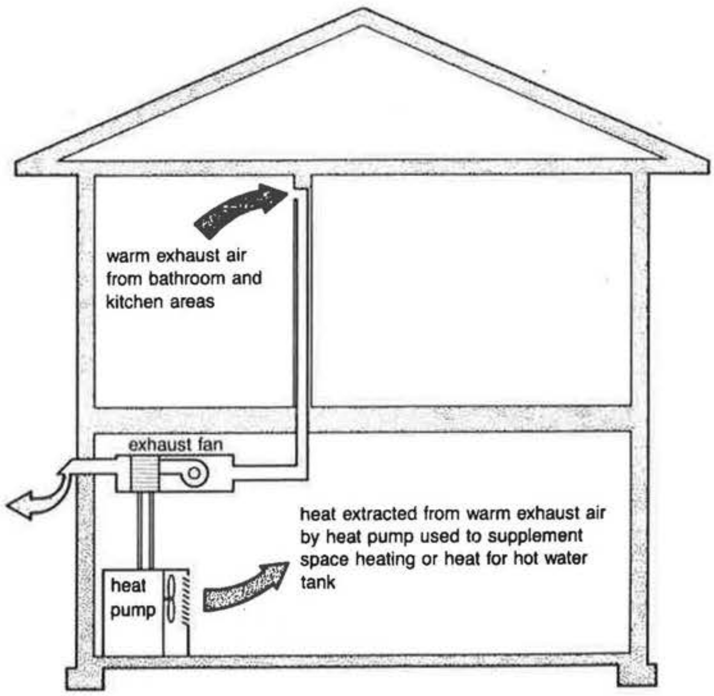


Figure 8-14 — The indoor heat pump

There are two types of heat pumps: those located outside the building envelope and suitable for relatively hot climates, and those situated inside the building envelope and suitable for colder climates.

The first type of heat pump, suitable for hot climates, is commonly an air-source heat pump and is located adjacent to the building. The colder the outside air, the less efficient the heat pump. In addition, if the temperature drops below freezing, the compressor is susceptible to freezing. Because of this inefficiency, the outdoor air source heat pump is generally considered uneconomical in colder climates or in regions where air-conditioning is not prevalent. In winter, heat can be extracted from sources other than outside air, for example, from well water or from the ground.

A heat pump's efficiency depends on the difference between the heat source and the discharge. When this difference is minor, the heat pump can deliver two to three times more heat energy than the electrical energy it consumes while operating. This ratio is called its coefficient of performance (COP).

If the air source heat pump is located inside the thermal envelope, all of the problems associated with air-source heat pumps located out of doors are eliminated. Heat pumps can be set up to extract heat from the warm exhaust air which, in turn, can be used to heat domestic hot water and/or incoming fresh air. The exhaust air is warm year round, thereby allowing these heat pumps to continually work at peak efficiency. Unfortunately, while the outdoor air-source heat pump for hot climates is well developed, the indoor air-source heat pump isn't.

Heat pumps have two advantages over air-to-air heat exchangers: they generate greater savings and reduce payback periods because heat can be recovered year round and can be used to heat water; and, they can be incorporated in an air-conditioning system to reduce cooling costs.

Ventilation system with air-to-air heat exchangers

If an air-to-air heat exchanger (or heat recovery ventilator — HRV) is used, a separate exhaust fan isn't required. An air-to-air heat exchanger contains both an exhaust fan and intake fan.

Fresh air enters the house at one location, passes through the air-to-air heat exchanger, and then either enters the return air duct system of a forced-air furnace (if one exists) or is ducted to individual rooms, as described earlier. If a forced-air furnace doesn't exist, then the fresh air may have to be preheated before it's ducted to the individual rooms. This can be done by installing a heating coil in the duct system. The stale air

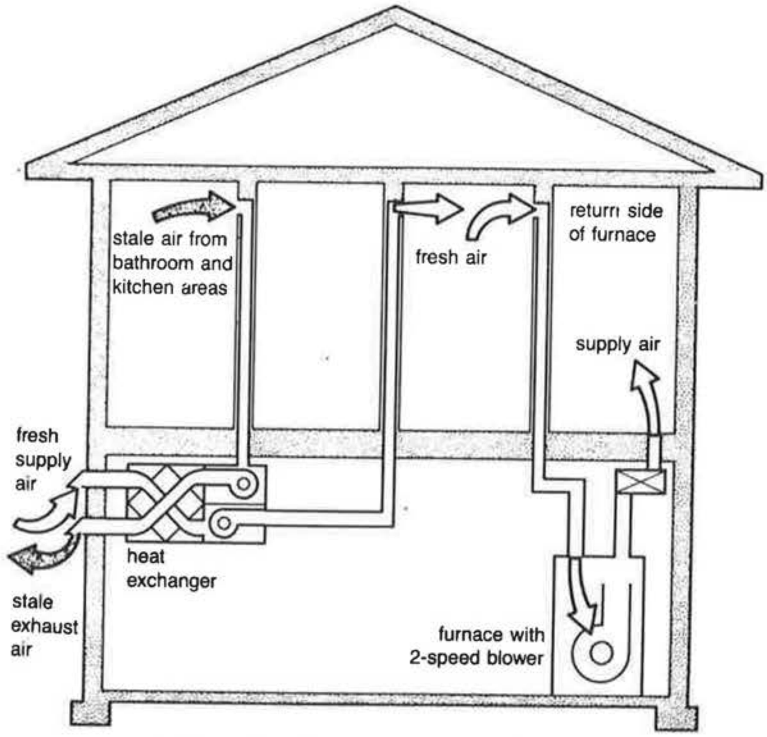


Figure 8-15 — Ventilation system with heat exchanger

is then drawn from the bathroom and kitchen areas, passes through the air-to-air heat exchanger, and is exhausted to the outside.

Ventilation system with heat pump

A heat pump can be used instead of an air-to-air heat exchanger. In this case, the heat pump extracts heat from the exhaust stream of air and heats the incoming fresh air, the hot water tank, or both. The ductwork for the exhaust air and fresh air is installed in the usual way. The fresh air supply may also be incorporated into a forced-air furnace if one is available. A heat pump is also a possible choice for cooling in the summer. It will be more cost-effective than a conventional air-conditioning system.

Available Air-to-Air Heat Exchangers

There are currently almost thirty brands of air-to-air heat exchangers sold in the U.S. and Canada with over 80 different models. For a complete cross reference listing of all brands and models, see the EDU Air-To-Air Heat Exchanger Directory & Buyers' Guide.

SECTION 9

Heating and Cooling

The way we heat and cool houses is changing dramatically. The equipment now being installed in new and existing houses bears little resemblance to that which was installed 20 years ago. If current trends continue, the next 20 years may bring similar advances. Some of the changes that have taken place are simply the result of advancing technology, where engineering innovation has created the ability to provide environmental control with greater efficiency, safety, and economy. But many of the changes are the result of shifting demands of occupants and changing characteristics of houses.

Comfort and Health

The primary new occupant demand with regard to residential mechanical systems pertains to indoor air quality. With all the media attention to the issue of radon entry into houses plus latent concern over formaldehyde, nitrogen oxides, and other potentially harmful air contaminants, there is a growing demand among the consuming public for a means to provide clean, healthy air indoors.

In response to this demand, whole-house ventilation systems and high-efficiency air treatment systems — including filtration, electrostatic precipitation, humidification, and dehumidification — are being developed and incorporated into new and existing houses. While these systems are not heating systems per se, they do interface with and affect the design of the house heating system. For example, air treatment of any kind obviously requires air circulation — thus a tendency toward forced-air heating distribution.

New Improved Mechanical Systems for New Improved Housing

New housing is better insulated and more tightly built than that of twenty years ago. Most new houses don't need 150,000 Btu/hr heating systems. Even in the northern U.S. and Canada, houses with design heating loads of 15,000 to 25,000 Btu/hr are not uncommon. Sometimes the required space heating capacity is not much greater or perhaps even less than the required domestic water heating capacity. To avoid discomfort and off-cycle efficiency losses of oversized systems, small central-heating systems are needed. One important trend has been toward integration of space heater and water heater into a single unit.

Tightly-built houses also need heating systems that are immune to backdrafting and that don't have to fight with other appliances for combustion air. The heating system must be able to work together with a mechanical ventilation system. Although for the most part, major appliance manufacturers have not yet joined in, integrated heating and ventilation appliances have made a successful penetration into the residential marketplace.

Selecting the "Best" Heating System

Amidst all the changes in residential heating equipment, designers and builders continue to search for the "best heating system." But is there such thing?

Probably not; at least not yet. First of all, people's values vary. To some, installation cost is the most important factor; to others, annual operating costs may be more important. Some like the feel of radiant heat, while others complain that it is uncomfortable. Some are concerned about indoor air quality and prefer to have mechanical ventilation; others don't care. Houses are also different. Some are conventionally insulated, while some are "superinsulated;" some have significant solar gain, others don't. Some are large and sprawling; others are compact with open floor plans. These and other variables all affect the design of a residential heating system.

How do you select the best (or maybe we should say "most appropriate") heating system for a particular house? Let's look at a sequence of questions and a logic process that should lead you toward that goal. We should keep in mind, however, that this technology is moving fast: the best system today will probably be improved upon tomorrow.

1. Calculate the Design Heating Load

The design heat load is the theoretical maximum amount of heat that will be needed during the coldest weather in a particular climate. As a very rough guideline, in a climate with a winter design temperature of 20°F, a typical new 2,000-square-foot house will have a design heat load between 10,000 and 50,000 Btu/hr. In a climate with a design temperature of -10°, typical design heat load will range from 16,000 to 80,000 Btu/hr. The design load is important not only for sizing the heating unit, but also for selecting the type of system. For example, with a design load of say 20,000 Btu/hr you could easily use a fan coil with domestic water heater or in-space electric convection heaters. But with a design load of 50,000 Btu/hr, you would need to look at more heavy-duty systems.

2. Calculate a Rough Annual Energy Consumption

The purpose of looking at predicted annual energy consumption is mainly to weigh annual heating energy costs against system installation costs.

[NOTE ON CALCULATION ACCURACY AND THE USE OF COMPUTER PROGRAMS: A plethora of programs for personal computers are available that perform heat load and annual energy consumption calculations. These programs have the enormous advantage of allowing the designer to perform "what if" analyses, in which he or she can modify one or more components in a house and then recalculate the heat load almost instantly. Other advantages of these programs include sophisticated solar calculations, below-grade heat loss calculations, and elaborate report presentation formats. But, as far as accuracy goes, keep in mind that the basic heat loss calculations are only accurate to within 10 or 20 percent at best and, for the purposes of selecting and sizing a heating system, hand calculations can be just as accurate as computer programs.]

3. Select Fuel Type

Thanks to recent efforts from Madison Avenue, choice of heating fuel has become as much an emotional issue as a practical one. In the Northeast, we hear radio ads warning us of the insidious dangers of gas heat. Counter advertising by the gas industry tells us about the foolishness of storing expensive and dirty oil underground, wasting our money. In the Southeast, a masked rider on a white horse chases the evil electric heat pump guys from the neighborhood, replacing their systems with clean-burning gas furnaces. In any area of the country, some people will object to any form of electric heating because of the inherent inefficiency of the system of electric power generation and its overall negative impact on our national energy picture.

There is little question that gas is the least expensive fuel per Btu of delivered heat. But electric heating is usually the least expensive to install. If the choice between those two fuels is based on economics alone, then you need to weigh installation cost against annual fuel cost. For example, if the predicted annual energy consumption for a house is 50 million Btu, then electricity will cost $600 to $700 more per year than gas and a high-efficiency gas system may be justified. If, on the other hand, the predicted annual energy consumption is only 10 million Btu, then the annual cost for electricity will be somewhere around $150 more than the annual cost for gas. It may not be worthwhile to install a high-efficiency gas system. Of course, the actual numbers depend on the relative price of fuel and equipment in your area.

Oil heat is a special case. At present, oil is more expensive than gas (per delivered Btu of heat). But we are beginning to see high-efficiency oil equipment (Yukon and

Dornback furnaces) and oil prices are dropping on the world market. If those trends continue, oil may become a very economical alternative to gas as a primary fuel.

4. Decide on Ventilation

This editor believes that every house should have some type of mechanical ventilation system that distributes fresh outdoor air to each room of the house. However, that opinion is not held by all in the industry and the decision whether to include a ventilation system must be made by each individual designer.

If the house is to have a ventilation system, then a warm air heating distribution system will make sense because the ductwork will be in place. Keep in mind, however, that ventilation ductwork is not necessarily the same size as traditional heating ductwork.

5. Decide on central air conditioning

As with ventilation, the presence of air conditioning ductwork will lead you toward warm air heat distribution. Nothing new there.

6. Select system configuration

This is the end of the road. Having determined heating load, annual energy consumption, fuel type, ventilation, and air conditioning requirements, you should be able to select the most appropriate system. In selecting systems for consideration, we have not looked at every possible configuration, but rather stuck to those that in our opinion are most practical for today and the very near future. One important assumption was that natural-draft atmospheric combustion equipment is unacceptable for new housing. All heating equipment should be either direct vent, induced draft, or power vented. (Power-vented devices are those that use fans to expel flue gases outdoors, but not to draw combustion air through the appliance.)

A. Central Heating with Warm Air Distribution

If any system can be classified as an all around "best" for modern housing, this is it. The main reason is because warm air distribution allows for the most latitude in environmental control. As the public consciousness of the indoor environment increases, demand will probably rise for air cleaners, humidifiers, and other air treatment systems in addition to outdoor ventilation. Those components will probably be treated as marketing features for new housing.

As pointed out above, if a house has mechanical ventilation or central air conditioning, then warm air heating makes sense because the ductwork is already in place. Let's look at three alternatives for forced warm air heat.

1. Conventional furnace

When you think of warm air heating, a gas or oil furnace is usually the first system to come to mind. The past few years have seen a variety of new high-efficiency direct vent and induced-draft gas furnaces.

The one disadvantage of conventional furnaces is that, except for two brands of gas furnaces, none are capable of water heating. The two exceptions are the Amana Energy Command and the GlowCore. With any other furnace, a separate water heater will be necessary. With oil furnaces, the situation is pretty much the same. If atmospheric combustion heaters are eliminated, the only acceptable oil furnaces are the Yukon EX-95 (see the January 1986 issue of EDU) and the Dornback (November 1986 EDU), both of which are power vented. Neither oil furnace has water heating capability.

2. Hydronic furnace powered by domestic water heater

This system is very attractive if the heating load of the house is low enough to be satisfied by a domestic water heater. Most domestic water heaters have energy input in the range of 35,000 to 40,000 Btu/hr, although a few have input ratings as high as 60,000 or 70,000 Btu/hr. Since most water heater manufacturers don't list output, it is difficult to evaluate the actual capacity of these units. Also, the output of a water heater varies with the temperature of the water in the tank. A reasonable guideline is to assume that the output is roughly 60 to 70 percent of the input. Thus, as a rule of thumb, this type of system will work well if the design heating load is 25,000 Btu/hr or lower. Of course higher loads can be accommodated with one of the higher capacity water heaters, or possibly with a commercial heater.

3. Hydronic fan coil powered by boiler

Using a boiler instead of a water heater to power a fan coil provides higher efficiency, greater capacity, and more durability at a higher cost. The distinction between water heater and boiler begins to get hazy in light of new appliances such as the Mor-Flo Polaris heater.

B. Central Heating with Hydronic Baseboard Distribution

The main advantage of a hydronic baseboard heating system is ease of zoning. The disadvantage is that it lacks the potential for air treatment that forced warm air distribution has. Also, if the house has a ventilation system, then it will have two separate and parallel distribution systems — one for heat and one for air. That redundancy is not likely to be cost-effective.

C. In-space Heating (Area Heating)

As the term implies, "in-space" heating systems are those in which the heat source is located within the space to be heated. It is also referred to as "area heating."

In-space heating has two primary advantages: 1) it can be inexpensive to install; and 2) it allows easy and effective zoning. A recent study at Oak Ridge National Laboratory showed that zoning can cut energy costs as much as 30 percent.

When considering in-space heating, a primary decision will be fuel choice — electric versus gas. Electric area heating is less expensive to install, allows more flexibility, and is aesthetically more acceptable than gas area heating. Gas heating, on the other hand, typically has faster pickup and is less expensive to operate.

1. Electric radiant ceiling heat

In the past, the most common types of ceiling radiant heat were electric cables or hot water pipes embedded in plaster or between two layers of gypsum board. Those systems enjoyed only limited popularity because they were expensive to install and because people sometimes complained of the "cold feet syndrome." Both those problems have been all but eliminated. First, with the new plastic laminates, the cost for electric radiant ceiling heat has been reduced to a fraction of the cost of the old type of systems. Second, cold feet should not be a problem in new, well-insulated houses. The reason for the cold feet syndrome was that radiant heat warms people and objects before it warms the room air. If your feet are under a table, then the radiant heat can't reach them and they get cold against the cold floor. But in an energy-efficient house, the floor is well-insulated and not cold. Feet should stay warm, even if not directly exposed to the radiant heat.

Radiant heat has several distinct advantages. Many people find it very comfortable. Since it warms people and objects, not air, it can create a feeling of warmth even when the room air temperature is low. Also, hidden behind the ceiling gypsum board, it is invisible and silent. The main disadvantage of electric radiant heat is the high cost of electricity.

2. Electric convective heat

Electric convective heaters have never been popular in residential applications, except in bathrooms. But a new product, the Cadet, (see the March 1985 issue of EDU), deserves consideration. The Cadet is a recessed heater that installs in a 2x4 stud bay. The reason we mention it here is because it is extremely quiet and not particularly expensive (around $100).

If your annual energy requirements are low enough to allow electric heat, the Cadet is a viable alternative to electric baseboards and electric radiant ceiling heat.

3. Electric baseboard heat

Of all the options discussed, electric baseboard heating is the least expensive to install. This is clearly the "low cost alternative" when electric heat is economically acceptable and the prime decision factor is installation cost.

4. Gas heaters

Approximately twelve manufacturers produce small wall-mounted, direct-vent gas space heaters, ranging in output from 8,000 to 50,000 Btu/hr (see the December 1985 issue of EDU for listings). The main drawbacks of these heaters are appearance (not out of sight like radiant ceiling heat) and sometimes noise (some are fan-forced, others not). The advantages are fast pickup and low cost of operation compared to electric heating.

Cooling the Energy-Efficient House — Energy vs. Comfort

Builders of energy-efficient houses in warm, humid climates have a problem — dehumidification. Why is it a problem? Because many conventional air conditioners, even if they have adequate capacity and high energy efficiency, don't always remove enough moisture from indoor air to create comfortable indoor conditions. Ironically, the problem is often worst with high-efficiency air conditioners. Although more experimentation is necessary to develop the optimal solution, this article presents a few recommendations which can help to lessen the problem.

The Cooling Load

The cooling load of a house consists of two components: sensible load and latent load.

Sensible cooling load refers to the need to remove heat energy by lowering the temperature of the indoor air. Sources of sensible cooling load are solar gain through windows, heat conduction through the house skin, and intrinsic heat gain from lights, appliances, and people. The sensible cooling load is relatively easy to calculate.

Latent cooling load refers to the need to remove water vapor from the indoor air. Water vapor is added to indoor air from household activities such as cooking, bathing, and cleaning; from humid outdoor air which leaks into the house; and from water vapor, which diffuses through the building skin from outdoors. The latent cooling load is more difficult to calculate than sensible cooling load. First of all, it depends heavily upon occupant activity and behavior, which is hard to predict. Second, it also depends not

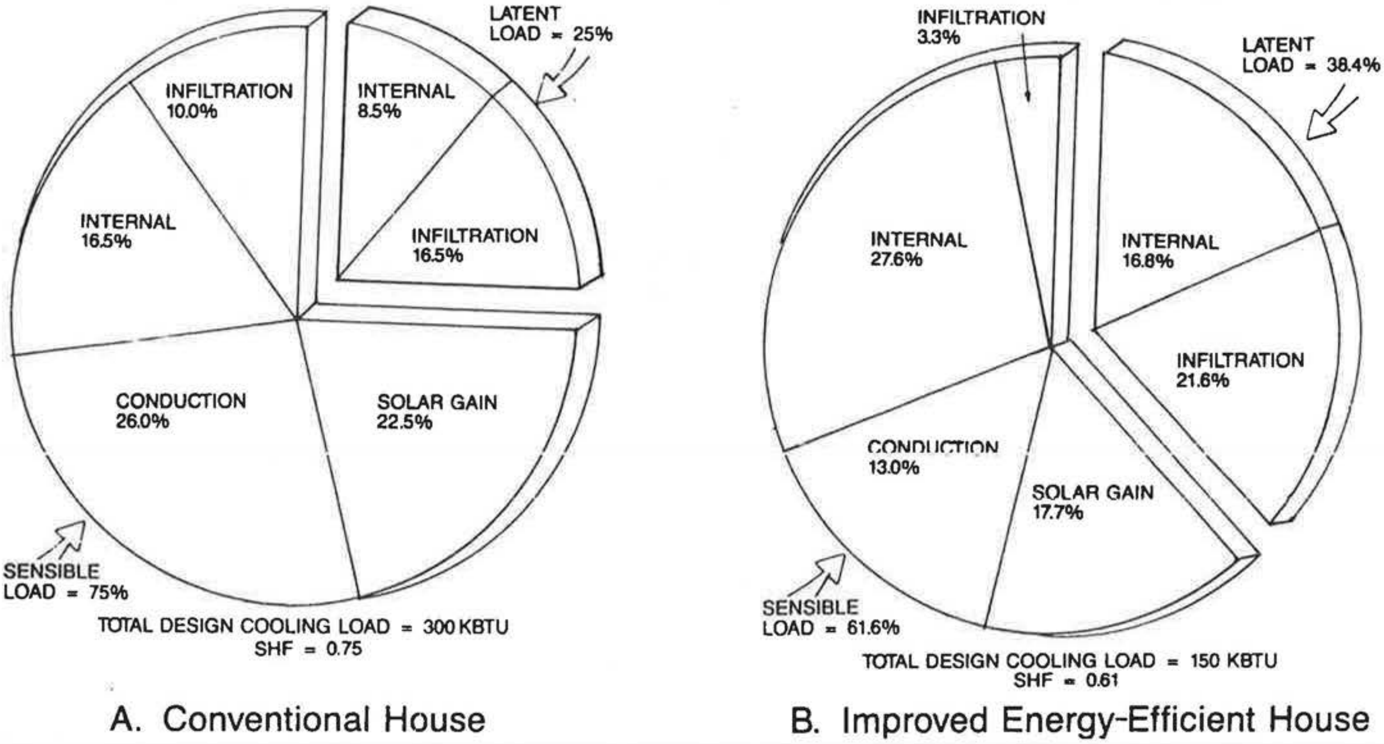


Figure 9-1
Figure 9-1A shows the breakdown of cooling load for a typical house located in Orlando, Florida. (The calculations were performed by Philip Fairey at the Florida Solar Energy Center using the TARP computer program developed by the National Bureau of Standards.) Notice that the sensible load is 75 percent of the total load. The ratio of sensible cooling load to total cooling load is sometimes referred to as the Sensible Heat Factor (SHF). For this house, the SHF is 0.75.

only on infiltration rate, but also on outdoor humidity conditions. In a dry climate, infiltration may reduce the latent cooling load because air leaking in may be drier than air leaking out. In a humid climate, on the other hand, outdoor air should add to the latent cooling load. In some climates, infiltration will add to the latent load sometimes, yet decrease it at other times. Many residential HVAC contractors don't even attempt to calculate the latent load. In fact, until recently, Manual J (Load Calculations) of the Air Conditioning Contractors of America recommended that to estimate the latent cooling load of a house, you should simply multiply the sensible cooling load by 0.30. In other words, if a house has a calculated sensible cooling load of say 15,000 Btu/hr, then the latent load would simply be 0.30 x 15,000 or 4,500 Btu/hr. (The latest version of the manual has a more rigorous procedure.)

An important question is "What happens to the SHF when a house is made more energy-efficient?" (The reason for the importance of this question will become clear in a moment.) The house represented in Figure 9-1B is an improved energy-efficient version of the house represented in Figure 9-1A. Through increased insulation and airtight construction, the total cooling load is reduced by about 50 percent compared to the house in Figure 9-1A. But notice the relative size of the latent load; it has grown to over 38 percent. The sensible load is only about 62 percent of the total cooling load and the house SHF is only 0.62.

Thus one possible consequence of energy-efficient construction is a lowering of the SHF.

The Cooling Machine

Without going into the guts of a typical air conditioner, let's picture it simply as a cold coil located in an air duct (Figure 9-2). As long as the coil is cooler than the house air, it will remove sensible heat and partially satisfy the sensible cooling load. By increasing the size of the surface area and/or decreasing the coil temperature, the amount of

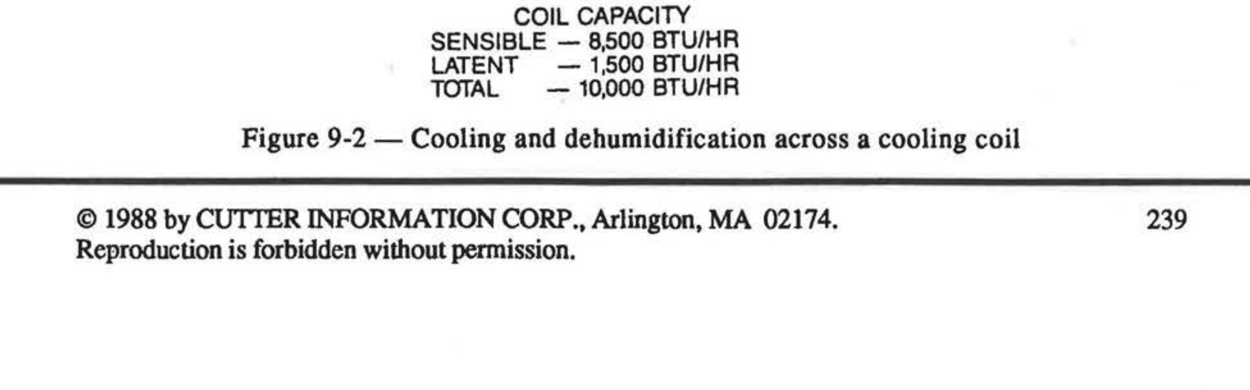


Figure 9-2 — Cooling and dehumidification across a cooling coil sensible heat removal is increased. But to get good moisture removal, the coil must be well below the dew point temperature of the room air — typically 20 to 25 degrees below room air temperature.

Here's the key to the problem: every air conditioner has an operational SHF — a ratio of sensible heat removal to total heat removal. The machine SHF depends on the size and surface area of the coil, the operating temperature of the coil, and certain characteristics of the compressor and other components in the machine. If the SHF of the air conditioner is higher than the SHF of the house, the machine won't adequately dehumidify the air.

[Note: The SHF of any particular air conditioner is not a constant. It varies with entering air temperature and relative humidity.]

Air conditioners are operated to satisfy sensible cooling load, not latent load — the control mechanism is a thermostat, not a humidistat. The unit comes on when the house is too warm, runs until the indoor temperature is reduced to the thermostat setpoint, then shuts off. But how much humidity was removed from the air during the cooling cycle? Was it enough to bring down the indoor humidity to comfortable levels? The answer depends on what the SHF of the air conditioner is. Look at Figure 9-2. In this example, we assume that the total cooling load is 10,000 Btu/hr, broken down into 7,000 sensible and 3,000 latent. (The house SHF is therefore 0.70.) Now let's assume that the air conditioner has a total cooling capacity of 10,000 Btu/hr, but that its SHF is 0.85, providing up to 8,500 sensible cooling and 1,500 latent cooling. What happens? The air conditioner runs until the sensible cooling load is satisfied, but that still leaves an excess latent load — about 1,500 Btu/hr. The house becomes cooled to the thermostat setpoint, but the humidity may be uncomfortably high.

Energy-efficient Cooling Machines

The problem gets worse in the name of energy-efficiency. Air conditioner efficiency is usually measured in terms of the Seasonal Energy Efficiency Ratio (SEER), calculated as the cooling output in Btu divided by the electricity consumption in kilowatts. The higher the SEER, the more energy-efficient the unit. Most air conditioners have an SEER between 6.0 and 9.0, but some are considerably higher. (You may have noticed recent advertisements for the Lennox Power Saver with a SEER of 15.0.)

High SEER can be achieved in a number of ways — including efficient compressors, fans, and other components — but the easiest and least expensive way to boost efficiency is to increase the size and/or surface area of the cooling coil. This normally causes the coil to operate at a higher temperature, and even though the total sensible heat removal might be increased, the latent heat removal is usually decreased. In a humid climate, the super energy-efficient units may not provide adequate dehumidification unless the unit is run for extra-long periods of time. (According to Bill Dickson, an engineer at Lennox, their Power Saver unit, when operating at a SEER of 15.0 provides very little dehumidification.)

THE SOLUTIONS

As mentioned above, there is no perfect solution to the problem, but there are some good design approaches you can take. Ideally, the SHF of the air conditioner would match the SHF of the house, but since both vary considerably, that is not possible. For an energy-efficient house in a humid climate, the best course is to install an air conditioner with high latent cooling capacity. This in itself is difficult because manufacturers' literature only list total cooling capacity without breakdown into latent and sensible components. The following are a few suggestions you may follow to help solve the problem:

1. Don't oversize the cooling system.

If an air conditioner is oversized it will cycle more frequently. Every time it starts up, the coil must be cooled below the dew point of the indoor air before it begins to condense out humidity. During startup, sensible heat reduction is greatest and dehumidification is least. With a slightly undersized unit, the system runs more often and dehumidification will be higher.

2. Stay away from the very high SEER units unless the manufacturer can assure you of adequate latent cooling capacity.

As a rule of thumb, air conditioners with SEER above 9.0 or 10.0 will have considerably less latent cooling capacity than lower SEER units. This may not hold true for some newer models that achieve high SEER through improvements other than evaporator coil upsizing. Check with the manufacturer.

3. Decrease the fan speed at the evaporator coil.

By decreasing fan speed at the evaporator coil, the coil will operate at a lower temperature, thus increasing latent heat removal. According to Mukesh Khattar at the Florida Solar Energy Center, most fan motors can be easily wired to run at a slower speed. Khattar is now working on a control device which will allow for variable fan speed control. A note of caution — air conditioners are complex machines. You must be careful when modifying them in any way. For example, if the fan speed is decreased too much, the coil could run too cold and possibly freeze.

One system, the Lennox Power Saver, is available with an optional "Latent Load Discriminator," which senses humidity in the airstream and automatically reduces fan speed whenever more dehumidification is necessary. To our knowledge, this is the only residential air conditioner with this type of feature.

4. Install a Dinh heat-pipe unit.

What's a Dinh heat-pipe unit? It's a simple but ingenious device developed by the Dinh Company, Alachua, Florida, and tested by the Florida Solar Energy Center. Using simple heat-pipe technology, the Dinh system creates an air conditioning system with an SHF of about 0.50. Here's how it works:

Instead of an "A-coil" evaporator, which is commonly used with standard air conditioners, Dinh uses a "Z-coil" consisting of three components (Figure 9-3): 1) a row of evaporator heat pipes at the incoming air side; 2) the air conditioner evaporator coil; and 3) a row of condenser heat pipes at the outgoing air side.

The two rows of heat pipes are connected, forming a heat exchanger loop. The evaporator heat pipes absorb heat by evaporating a refrigerant fluid. The refrigerant vapor travels to the condensing heat pipes where it condenses and gives off the absorbed heat.

Return air from the house enters the unit at about 80°F. When it passes over the evaporator heat pipes, it is precooled about 10 degrees. No dehumidification occurs at the evaporator heat pipe. Next, the air passes over the air conditioner evaporator coil, where it is dehumidified and "overcooled" to about 55°F. The evaporator coil operates at approximately 45°F. After leaving the evaporator coil, the overcooled air passes over the condenser heat pipes, which reheat it back to about 65°F.

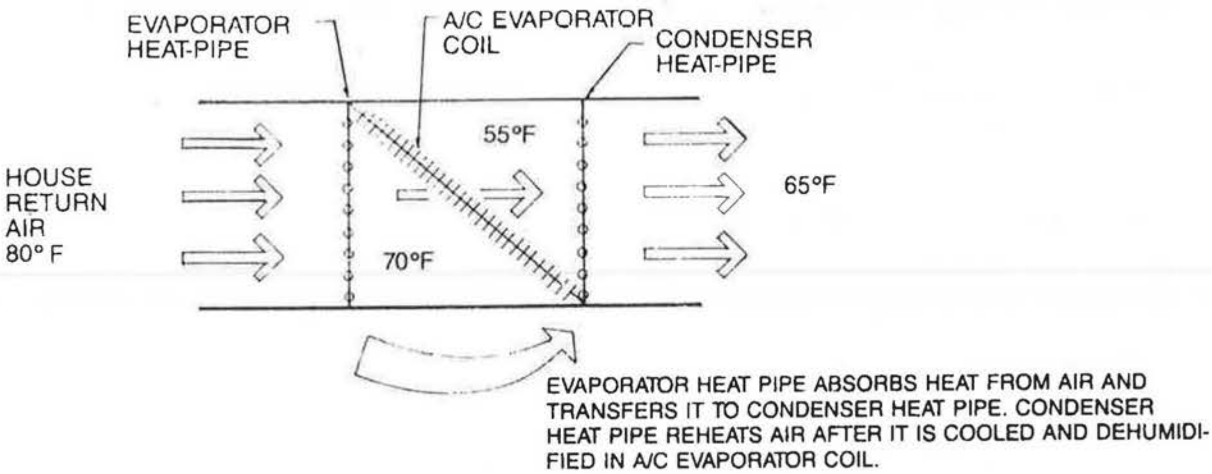


Figure 9-3 — DINH heat-pipe cooling/dehumidification system

In other words, the heat pipe serves as a sensible heat bypass around the air conditioner evaporator coil, allowing the air conditioner to use more of its cooling capacity for dehumidification. The result is an SHF of about 0.50: 50% sensible cooling and 50% latent cooling.

The Dinh Z-coil unit with heat pipe and evaporator coil will sell for around $400. It can be purchased as an option with the Dinh two-speed central air conditioner. (By the way, the Dinh air conditioner is partly powered by photovoltaics. According to Kanh Dinh, its inventor, it has an SEER of 0.50 — perfect, except possibly for the price — $8,000.) For more information, contact: The Dinh Company, P.O. Box 999, Alachua, FL 32615; (904)462-3464.

What about using a separate dehumidifier?

This always seems like a natural solution. If the air conditioner can't handle the dehumidification load, why not simply use an auxiliary dehumidifier? But a mechanical dehumidifier is a poor compromise at best.

The problem is that a dehumidifier actually adds to the total cooling load even though it reduces humidity. Figure 9-4 shows a schematic of a standard vapor compression dehumidifier. It is basically the same as an air conditioner except the evaporator and condenser coils are both indoors. Humid air is first cooled and dehumidified as it passes over the evaporator coil; then it is reheated as it passes over the condenser coil. For each pound of water removed from the air, 1,150 Btu of latent heat is transformed into 1,150 Btu of sensible heat. The air is dehumidified, but heated. In addition to the 1,150 Btu per pound of water removed, additional waste heat from the compressor and fan is added to the discharge air, resulting in a net gain of approximately 2,000 Btu per pound of moisture removed.

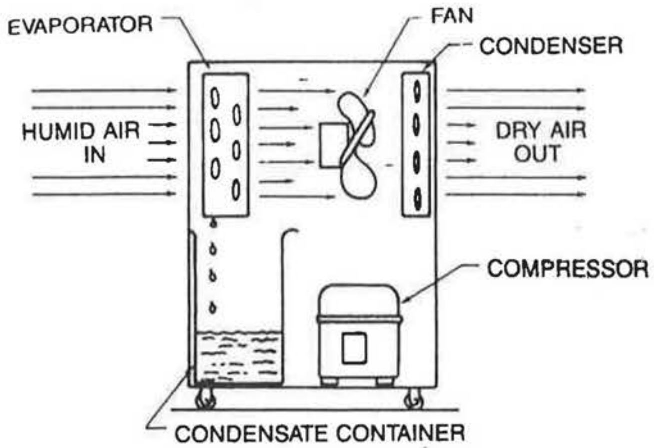


Figure 9-4 — Typical mechanical dehumidifier

Is desiccant dehumidification practical?

Not yet, although the picture is promising. One air-to-air heat exchanger may offer some degree of desiccant cooling, but its effectiveness is unknown. A more promising possibility is a complete desiccant cooling and dehumidification system. The Gas Research Institute and the Solar Energy Research Institute are working on such a system (see the January 1984 issue of EDU) and according to industry spokespeople, we can expect something on the market in the near future.

Comfort vs. Efficiency

All the recommendations mentioned above address the problem of attaining adequate dehumidification, not energy efficiency. If indoor humidity is properly controlled at low levels, people will feel comfortable at warmer temperatures ("It's not the heat, it's the humidity").

Theoretically, if humidity is low in a house, occupants might set their thermostat higher. According to Khattar at the Florida Solar Energy Center, each 2 degree rise in thermostat setting will result in about 14% savings in total cooling energy consumption. Khattar cautions however, that he knows of no documented cases of energy savings through humidity control.

Water Heaters for Superinsulated Houses

Are there special considerations to be taken when selecting a water heater for a superinsulated house? Yes, a few. First, the "superinsulated" characteristics of the house warrant some consideration, and second, if the object is to build an energy-efficient house, then some attention should generally be given to the selection of an efficient water heating system.

To avoid any confusion, let's assume that by "superinsulated house" we are talking about a house that:

1) is relatively airtight (3 to 5 acph at 50 pascals);
2) has very low heating and cooling demands due to its airtightness and high levels of insulation; and
3) includes some form of controlled mechanical ventilation.

How do these factors affect the water heater selection process?

1) Tight construction

Atmospheric combustion (natural draft) water heaters — those that rely on natural buoyancy to draw hot flue gases through the heater — are potential hazards in tightly-built houses. Exhaust fans, central vacuum cleaners, clothes dryers, or imbalanced ventilation systems can cause hazardous flue backdrafting. Particularly worrisome is the possibility of slight backdrafting, which would probably go unnoticed, yet could seriously affect indoor air quality. The recommendation, therefore, is to select a water heater that is resistant to backdrafting or, if that's not possible, to install an outdoor air intake, close to the water heater, to supply combustion makeup air. The second solution is less desirable because it depends on the dubious assumption that nobody will ever close off the outdoor air intake.

There are several selection options for non-backdrafting water heaters:

A. Electric resistance heaters;

B. Electric heat-pump water heaters;

C. Solar water heaters;

D. Induced-draft or sealed-combustion gas water heaters;

E. Integrated water heating / space heating systems.

A few years ago, no sealed-combustion storage-tank water heaters were available. Now there are at least two — the State (see the December 1984 issue of EDU) and the Rheem (see the April 1985 issue of EDU). There are also two sealed-combustion instantaneous water heaters — the Hydrotherm Celtic and the Thermar. Chances are that we will be seeing more sealed units on the marketplace as demand for them increases.

In an integrated system, water heating may be accomplished by drawing heat from a sealed-combustion or induced-draft boiler or furnace. (The Amana Energy Command and Glow Core are the only furnaces that have water heating capability.)

2) Low space heating and cooling load

If the heating load of a superinsulated house is low enough, the domestic water heater could be used to supply hot water for space heating. The Apollo Hydroheat is an example of a system designed for that purpose. Cooling and dehumidification can be provided by a heat pump water heater (HPWH). Some HPWH's have nearly one ton of cooling capacity. Although some creative control strategy would be called for, one of those units could serve as the primary air conditioner in an energy-efficient house in a moderate climate. (We'd welcome hearing from anyone who has tried it.)

While we're discussing heat pump water heaters, we should mention that they will generally work at a higher net efficiency in a superinsulated house (in cold climates) than in a conventional house. Here's why:

Heat pump water heaters boast coefficient of performance (COP) of up to 3.4. Generally speaking, that's equivalent to an efficiency of 340 percent! You might therefore assume that a heat pump water heater would be nearly three times as efficient as an electric resistance water heater, using only one-third as much energy. However, that's a bit of an oversimplification because from one-half to two-thirds of the heat delivered by a heat pump water heater comes from the air surrounding the unit. If the heat pump is located in a heated space, then you are simply robbing Peter to pay Paul; i.e, taking space heat and putting it into the hot water. One study conducted by Mair Perlman at the Ontario Hydro Research Division showed that with a 60-gallon-per-day hot water draw, a heat pump water heater will increase the space heating load by 7%. Larger water draws will cause proportionately larger space heating penalties.

But the more energy efficient a house is, the better a heat pump should look. Why? Because the heating season is shorter. For example, the Ontario Hydro study assumed that the heating season is 250 days long. For some superinsulated houses, the time when heat is needed is much shorter than that and there is often excess heat in the house during winter months. At those times, the energy taken by the heat pump is waste heat. It would be thrown out by Peter if the heat pump didn't take it to give to Paul.

Finally, the energy efficiency of the house affects the cost-effectiveness of desuperheaters. Sometimes called "heat reclaimers," desuperheaters are heat recovery devices that reclaim waste heat from the hot gas discharged by the compressor of an air conditioner (or heat pump heater). The recovered energy is then used to heat domestic water. Several manufacturers sell desuperheaters for retrofit application and a few equipment manufacturers are offering desuperheater water heaters as options for their central air conditioners and heat pumps.

Since the desuperheater only collects heat when the air conditioner or heat pump is running, the cost-effectiveness of the system depends somewhat on how the space cooling or heating system runs. The more energy-efficient a house is, the less those systems run. In very hot climates, the effect of the house energy-efficiency is probably negligible because the air conditioner will still run more than enough to generate all the hot water needed. But in moderate climates, the effect might be substantial and the desuperheater may not supply enough hot water to justify its installation.

For those interested in further information about desuperheaters, an excellent analysis of their cost effectiveness can be found in a recent ASHRAE paper. See "Economic Viability of Heat Pump Desuperheaters for Supplying Domestic Hot Water," by M. Olszewski, ASHRAE Transactions 1984, Volume 90, Part 1B, p. 169.

3. Ventilation system

The main consideration surrounding the presence of a ventilation system, other than combustion air supply and backdrafting, is the potential for using a heat pump heat recovery ventilator for heating domestic water.

Selecting Water Heater Capacity

What size water heater will a proposed house need? When considering capacity, you should look at what is called the "first hour rating" of the water heater. The first hour rating is the amount of hot water that the heater can supply during the first hour of operation. It depends on more than just storage tank size as we shall see later.

The Gas Appliance Manufacturers Association has devised a method for calculating required first hour capacity. The following is a summary of that method:

1. Determine during what general time of day (morning, noon, evening) there is usually the most use of hot water in the home.
2. Use the following table to determine the required first hour capacity or peak demand:

Use	Average Gallons of Hot Water per Usage	x	Times used during 1 hour	=	Gallons used in 1 hour
Shower	20		________		________
Bath	20		________		________
Shaving	2		________		________
Hand washing	4		________		________
Hair shampoo	4		________		________
Hand dishwashing	4		________		________
Automatic Dishwasher	14		________		________
Food preparation	5		________		________
Automatic Clothes washer	32		________		________
Total Required First Hour Capacity					________

Example

A typical household morning routine might include 2 showers, 2 shampoos, 4 hands and face washing, and 1 food preparation between 7 and 8:00 A.M. The peak water demand will therefore be:

2 showers 20 x 2 =	40
2 shampoos 2 x 4 =	8
4 hand/face wash 4 x 4 =	16
1 food prep 1 x 5 =	5
TOTAL =	69

REQUIRED FIRST HOUR CAPACITY = 69 gallons

The first hour rating of a water heater (listed on the "Energyguide" label on all water heaters except heat pump water heaters), depends upon the size of the storage tank and the heat output of the burner or heating element. This is important. Many people simply choose a water heater by tank size. But the more powerful the water heater, the less storage required to achieve equivalent first hour rating. Gas heaters typically have higher energy output than electric heaters and the first hour rating of gas heaters will therefore usually be considerably higher than the first hour rating of electric water heaters with equal storage capacity. For example, State Industries' 50-gallon electric water heaters have first hour ratings of about 55 gallons, while the State 50-gallon gas water heaters have first hour ratings ranging from 69 to 77 gallons. Ruud has a 50-gallon gas heater with a first hour capacity of 95 gallons. (By the way, even though they are not very common, oil water heaters typically have the highest first hour rating for a given storage capacity. For example, the Ford Products Corp. Model CF50E 50-gallon oil-fired water heater has a first hour rating of 121 gallons. This is not unusual for oil-fired heaters.)

What about instantaneous water heaters?

Instantaneous water heaters are a different story. With these heaters, since there is no storage, the first hour capacity is the same as the overall recovery rate (amount of hot water a heater can supply continuously) and depends completely on the output of the burner or heating element.

Here's a guideline: To supply a single bathroom (one shower at a time), an instantaneous water heater should be capable of supplying 2.75 to 3.0 gallons of water per minute at a temperature rise of 80 to 100 degrees. If the temperature of the water coming into the house is warm (above 60°F), an 80 degree rise is sufficient; if the incoming water is less than 50°F, a 100 degree rise is needed.

Some manufacturers of instantaneous heaters list the recovery rate in their literature, some don't. However, if you know the heat output in Btu/hr, the recovery rate is very easy to calculate using the following equation:

Recovery rate = heater output / (60 x 8.34 x temperature rise)
(gallons per minute) (Btu/hr) (degrees F)

Example What is the recovery rate of an instantaneous water heater that has an output of 80,000 Btu/hr if the desired temperature rise is 90°F?

Solution Recovery Rate = 80,000 / (60 x 8.34 x 90)
= 1.8 gallons per minute

Thus this water heater would probably not assure adequate hot water for bathing, especially if other water-consuming activities are going on in the house.

NOTES: The 60 constant in the equation converts gallons per hour to gallons per minute. The 8.34 constant is the number of Btu required to raise the temperature of 1 gallon of water 1°F.

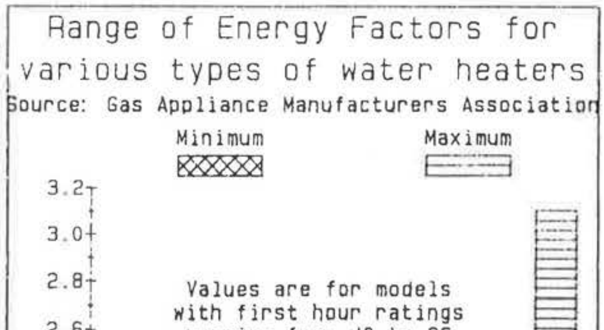


Figure 9-5

Selecting for Energy Efficiency and Cost Effectiveness

Three terms are commonly used when referring to efficiency of water heaters — "recovery efficiency," "standby loss," and "energy factor." Recovery efficiency refers to the efficiency with which heat is transferred from the flame or heating element to the water during "cold start" operation. The recovery efficiency is essentially 100% minus whatever is lost up the flue. (In electric heaters, the recovery efficiency is 100%). Standby loss is the percentage of heat lost from the stored water per hour compared to the heat content of the stored water. Typical standby losses range from 1% to 3%. The most important yardstick of water heater efficiency is the Energy Factor (EF). Similar to the AFUE for furnaces and boilers, the EF is a measure of the overall efficiency of a water heater based on recovery efficiency and cycling losses. It is expressed as a decimal where 1.00 would be equivalent to 100% efficiency. The EF is used for comparing the cost-effectiveness of various types of heaters.

Figure 9-5 shows the range of energy factors for the various types of water heaters.

Calculating Annual Energy Cost

The U.S. Department of Energy, in its procedures for evaluating water heater performance, assumes that the average household uses 64.3 gallons of hot water per day. That figure is supported somewhat by the BECA-D study by Lawrence Berkeley Laboratory — a compilation of data of approximately 11,000 water heater installations — which shows an average household usage of about 60 gallons per day. If we assume that the DOE figure is correct and we further assume that on the average, the temperature of incoming water is raised 90 degrees, then it is easy to calculate the annual cost for water heating using the following equation:

For natural gas heaters:

Annual energy cost = (176 / EF) x [price for gas ($/ccf)]

For electric heaters (resistance or heat pump):

Annual energy cost = (5162 / EF) x [price for electricity ($/kWh)]

Example: Let's compare the annual energy cost of the following three water heaters:

A. A.O. Smith 50-gallon gas water heater	EF = .51
B. A.O. Smith 52-gallon electric water heater	EF = .88
C. DEC International Thermastor 80-gallon heat pump water heater	EF = 3.4

Gas price — $.65/ccf

Electricity price — $.08/kWh

Solution

A. A.O. Smith gas	Annual cost = (176/.51) x $.65	= $224/year
B. A.O. Smith electric	Annual cost = (5162/.88) x $.08	= $469/year
C. DEC	Annual cost = (5162/3.4) x $.08	= $121/year

Which unit is most cost effective? As shown in Figure 9-6, the heaters with the higher prices have the best efficiency. No surprise there. But is the heat pump efficient enough to warrant the large initial investment? Table 8 shows an economic comparison between the various options.

Table 8

Comparison	Extra Cost (Difference in list cost)	Savings (Difference in annual energy cost)	Simple Payback
A. Gas vs. electric	$178	$245	0.7 years
B. Heat pump vs. gas	$907	$103	8.8 years
C. Heat pump vs. electric	$1,085	$348	3.1 years

A Few Qualifications

1. The three heaters illustrated in the above example are all expensive high-quality units. Naturally, other heaters with different prices will give different results. For example, Sears makes a 50-gallon gas water heater with a slightly higher EF than the A.O. Smith but sells for only $229.
2. The COP of any heat pump water heater is not constant; it varies as the temperature of the water in the tank varies. The COP is highest when the water in the storage tank is cold. As the water in the tank is heated, the COP drops. This is important because with some types of usage patterns, the actual COP will be significantly lower than the rated COP of the unit. Consider this example: Suppose a heat pump water heater is installed in a small office building where the only hot water usage is for hand washing. The average draw is a gallon or two, which lowers the storage tank temperature only a few degrees. The heat pump would always be operating at a low COP because the tank temperature would always be high.

Now consider an opposite situation: Suppose a heat pump water heater is located in a small dormitory where it is used only three times per day for dishwashing. During each usage, the tank is drained almost completely. When the heat pump comes on, it will be operating at its highest COP because the tank will be filled with cold water.

This phenomenon is illustrated in another study performed by Perlman at Ontario Hydro. In that study, he monitored the actual performance of five heat pump water

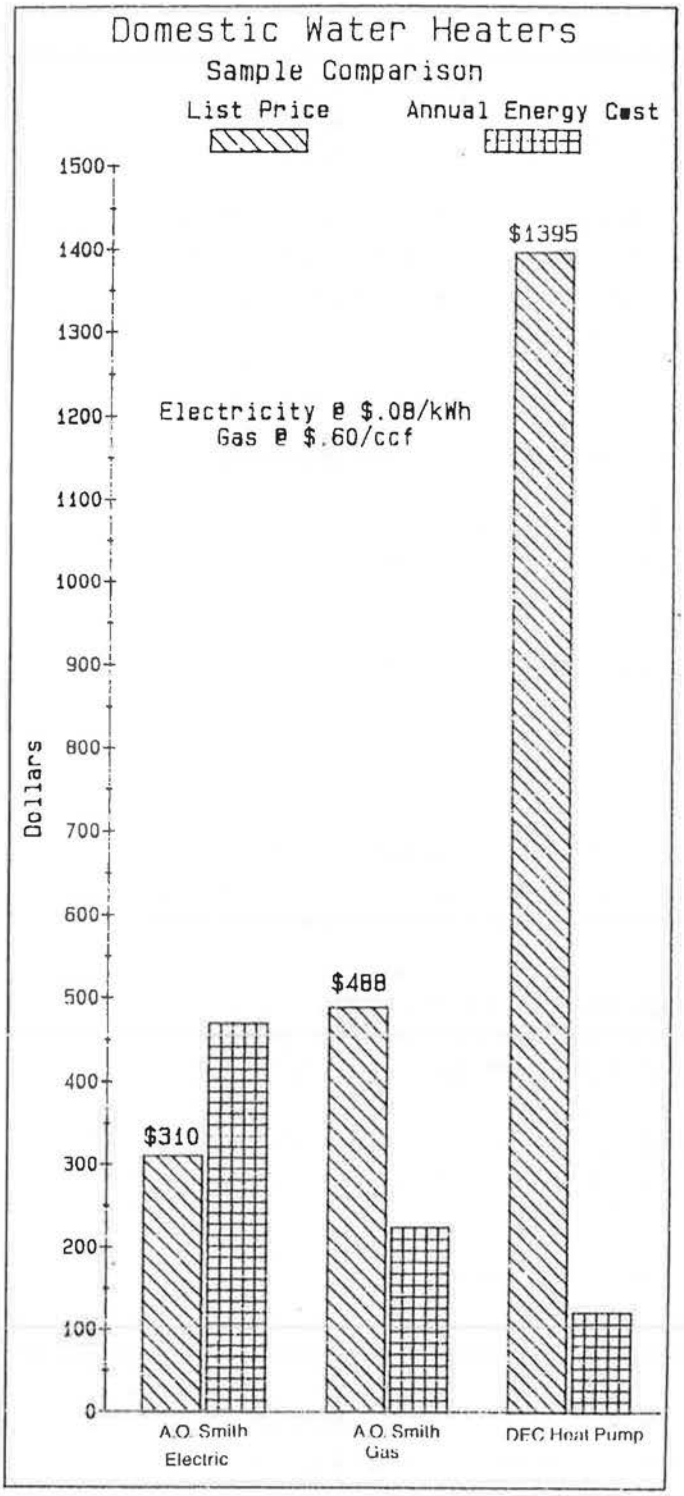


Figure 9-6 — Comparison of first cost and annual energy consumption for three water heaters

heaters — four in residences and one in a restaurant. Figure 9-7 shows the results of that study. Notice that in three of the residences, the actual measured COP ranged from 1.4 to 1.7, even though the rated COP's were all 2.54. In the restaurant installation, the measured COP was closer to the rated COP of the unit.

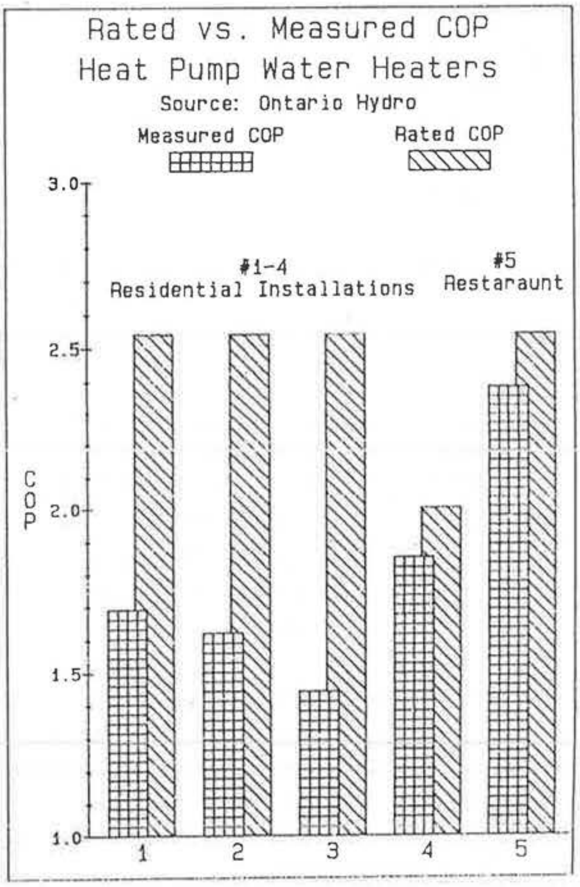


Figure 9-7

APPENDIX A

Insulation Materials

[This section includes edited excerpts from "An Assessment of Thermal Materials and Systems for Building Applications," published by the U.S. Department of Energy and prepared by Brookhaven National Laboratory with Dynatech R/D Company; and The Superinsulated Home Book, by J.D. Ned Nisson and Gautam Dutt, John Wiley & Sons, 1986; and selected articles from Energy Design Update.]

History

Techniques and materials for separating man from the heat and cold in his external environment are as old as civilization itself. Thatched roofs of tropical settlers and adobes developed by American Indians were early versions of insulation. They performed, to some degree, their intended functions — isolating man from the heat of the sun in summer and the cold of winter winds and snow.

In the 1800s, insulations used were natural materials — largely vegetable, principally wood and its derivatives. Early in the 20th century, the beginning of what is today the insulation industry — the development and manufacture of materials specifically designed to retard the movement of heat — was started.

The first materials manufactured on a large scale were rock and slag wools. Natural rocks or industrial slags were melted in a furnace, fired with coke, and the molten material was spun into fibers and formed into felts or blankets. These were used in buildings of all types and also for industrial processes but on a very limited basis, where temperatures of an "extreme" nature existed. The use of these materials gradually increased during the first half of the 20th century and, at the end of that period, they were being used in most houses as well as industrial/commercial buildings, although still limited in terms of the quantities and thicknesses used. In 1928 there were about 8 plants manufacturing these products in the U.S. This number increased to 25 by 1939 and 80 to 90 in the 1950s, but has since declined to about 15 to 20 today.

Glass fibers were successfully developed on a commercial scale in the U.S. in the 1930s by Owens-Illinois, Corning Glass Company, and Owens-Corning Fiberglas Company (formed by the first two companies). Fiberglass insulations were developed during the 1940s and 1950s by melting inorganic materials — principally sand — and fiberizing the molten glass into blanket-type material. Owens-Corning Fiberglas was the only producer of fiberglass insulation in the U.S. until 1950. An anti-trust action filed in 1949 by the U.S. Department of Justice resulted in a settlement in which Owens-Corning Fiberglas agreed to license qualified companies to produce fibers. In addition, alternative processes have since been developed and are now being used to produce glass fiber.

In the mid-40s, the domestic perlite industry began. The crude perlite, when processed and expanded, was used as thermal insulation. At the same time, some entrepreneurs in various parts of the United States began grinding waste paper into a fibrous state for use as an insulating material. This was the origin of the cellulose insulation industry.

The commercial production of plastic foams began in the mid-40s with extruded, foamed polystyrene, originally developed by Dow Chemical Company. It was followed in the late fifties by the commercial production of urethane foams, polystyrene foams manufactured from beads, and ureaformaldehyde foams. Phenolic foam, which was never significant commercially in the U.S., has been produced in Europe since the 1950s and in Canada since about 1972. In the first 10 to 15 years of production, it was primarily used in particularly severe insulating applications, such as in low-temperature space facilities, because of its moisture resistance and high stable thermal resistance. Phenolic foam is just now gaining popularity as a building insulation in the U.S. The major manufacturer is the Koppers Company. Over the last 10 to 15 years, the uses for plastic foams, particularly the polystyrenes and polyurethanes, have expanded rapidly into building insulation applications.

The 1960s saw a rapid development of fiberglass as an insulating material. As fiberglass use grew, rock wool (and slag wool) declined. The small rock-wool plants, approximately 80 to 90 in number in the 1950s declined to about 15 to 20 today, their product being replaced by fiberglass.

Although patents for cellulosic fiber insulation were issued in the 1800s, the product did not find a firm foundation in the marketplace until late in the 1950s. The primary use of the material was for retrofitting attics, and to a lesser degree, insulating existing wood-frame sidewalls.

Spurred by the economic pressures of the "energy crisis" of the 1970s, the insulation industry grew considerably, not only in quantity of material, but also in types and brands. New insulation materials are still being introduced into the residential and commercial market and future years are sure to see continued expansion of the industry.

Types of Insulation Materials

Rock or Slag Wool

Rock or slag wool are terms that are used commonly to denote glassy fibrous substances made by melting and fiberizing slags obtained from smelting metal ores including iron ores ("slag wool"), or by melting and fiberizing naturally occurring rock ("rock wool"). (Mineral wool is a generic term which includes fiberglass and rock and slag wool.)

The overwhelming majority of this product manufactured in the United States is made from steel, copper, or lead slag, as opposed to natural rock, as raw material, which is used extensively in Europe. The slag is melted using coke as a fuel, then spun into fibers by pouring the molten material onto rotating discs. The fibers are attenuated with steam, and rapidly cooled to room temperature. The fibers are sprayed with a phenolic resin, which serves as a binder, compressed, and then cured by passing through an oven. The resulting "slabs" are cut to desired sizes to make batts. Another additive is mineral oil, which serves to seal the surface against dust production and provide water-repellency.

Fiberglass

Fiberglass insulation is made of thin glass fibers felted in batts or nodules. It falls into two major classifications as a result of different manufacturing processes. In the first process, the fibers are produced by melting glass marbles into primary fibers, which are attenuated into relatively long fibers. The second process, known as the rotary process, produces fibers by flowing molten glass into a spinning perforated disc, thus projecting glass fibers. This process produces shorter fibers. For both processes, the fibers are sprayed with a binder and collected into wool-like mats. The process is controlled to produce mats of varying densities. The matts are formed into batts, with or without kraft paper or foil facings.

Fiberglass itself is an inorganic, non-combustible material, but flammable organic binders are used in the production of batts and blowing wool. Facings on fiberglass building insulation usually consist of an asphalt-coated kraft or foil-kraft paper laminate, which is also flammable.

Glass-fiber loose-fill insulations (for blowing and pouring) are usually produced by hammer milling glass-fiber blanket material, thereby retaining the bonded fiber quality which ensures good loft and R-value.

Fiberglass Batts - Thickness and R-value

Inquiry from an EDU Subscriber:

"Most fiberglass manufacturers now show their 6-inch glass insulation to be 6-1/4 inches thick with an R-value of R-19. As this is installed in a 5-1/2-inch cavity it is compressed 3/4 inches and I understand insulation will lose an R of 1 for each 1/8-inch of compression. Are we actually installing insulation with an in-place value of R-13?"

Editors Reply:

No, you're not installing batts with R-value of R-13. But neither are you installing R-19. When you compress a 6-1/4-inch fiberglass batt into a 5-1/2-inch stud cavity, the R-value of the batt is reduced to about R-18. However, if you compressed that 6-1/2-inch batt into a 2x4 stud cavity (3-1/2-inch actual depth), then the R-value of the batt would be R-13. The 1-R per 1/8-inch is but another creative energy myth.

Discussion

Long ago, before the energy crisis, when most builders had little or no idea of how insulation worked, it was commonly believed that if you compress a 6-inch R-19 fiberglass batt into a 3-1/2-inch stud cavity, you still get R-19! Most people now know better, yet there is still confusion and misunderstanding about what actually happens when fiberglass is compressed. Let's look at a few basic facts which should clear up the whole mystery.

1. The R-value per inch of fiberglass insulation depends on density (and, to a lesser degree, other factors such as fiber diameter and coatings). The higher the density, the higher the R-value.

Fiberglass batts and blankets are typically manufactured and sold at a 1 pound per cubic foot density, at which the R-value is roughly R-3.2 per inch. But it varies with product and manufacturer. That's why you can get R-11 batts and R-13 batts of the same thickness (actually the R-13 batts are 1/8-inch thicker, but let's not split fibers). Table 9 lists several commonly available fiberglass batts along with their thickness, overall R-value and R-value per inch. Notice that the R-values per inch range from R-2.75 to R-3.59.

TABLE 9
Thickness and R-Value of Fiberglass Batts

Manufacturer	Thickness (inches)	R-value (overall)	R-value (per inch)
Manville	1-1/8	R-3.4	3.02
Knauf	1-1/2	R-5	3.33
Georgia Pacific	2-3/4	R-7	2.55
Owens Corning	3-1/2	R-11	3.14
Owens Corning	3-5/8	R-13	3.59
Georgia Pacific	4	R-11	2.75
Owens Corning	6-1/4	R-19	3.04
Georgia Pacific	6-1/2	R-19	2.92
Knauf	6-1/2	R-22	3.38
Owens Corning	6-3/4	R-22	3.26
Georgia Pacific	7-1/2	R-22	2.93
Georgia Pacific	9-1/2	R-30	3.16
Knauf	12	R-38	3.17
Manville	13	R-38	2.92

Several high-density fiberglass products are available with R-values over R-4.0 per inch. Owens Corning Series 700 insulation and Warm 'n Dri foundation insulation both have R-values over R-4.0 per inch; Manville's Type IV glass fiber insulation has an R-value of R-4.5 per inch at a density of 6 pounds per cubic foot. The reason that similar materials are not sold for residential sidewall application is simply economics. Batts are designed to maximize the R-value per dollar rather than per-inch thickness.

2. When fiberglass batts are compressed during installation, such as when a 6-1/4-inch batt is compressed into a 5-1/2-inch wall cavity, the density and R-value per inch both increase, but the overall R-value decreases.

This is sometimes confusing. Even though the R-value per inch increases as the batt is compressed, that does not compensate for the loss in thickness. The resultant overall R-value of the compressed batt is therefore lower.

Figure A-1 shows what happens to a 6-1/4-inch R-19 batt when it is compressed. At full thickness (6-1/4 inches), the R-value per inch is R-3.04. When compressed to 5.5 inches (as in a 2x6 stud wall), the R-value per inch rises to R-3.27, but the overall R-value drops to R-18. When compressed to 3.5 inches (as in a 2x4 wall), the R-value per inch rises to R-3.71, but the overall R-value drops to R-13. The maximum R-value per inch occurs when the R-19 batt is compressed to about 1/2-inch thickness.

Figure A-2 shows the effect of compression on other types of fiberglass batts.

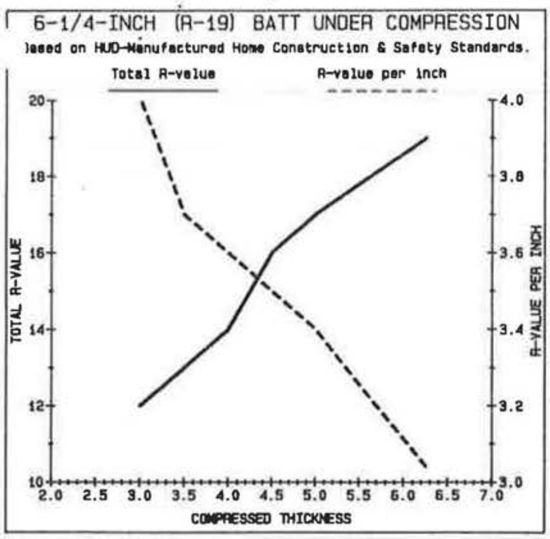


Figure A-1 — Changes in R-value caused by compression of a 6-1/4 inch fiberglass batt

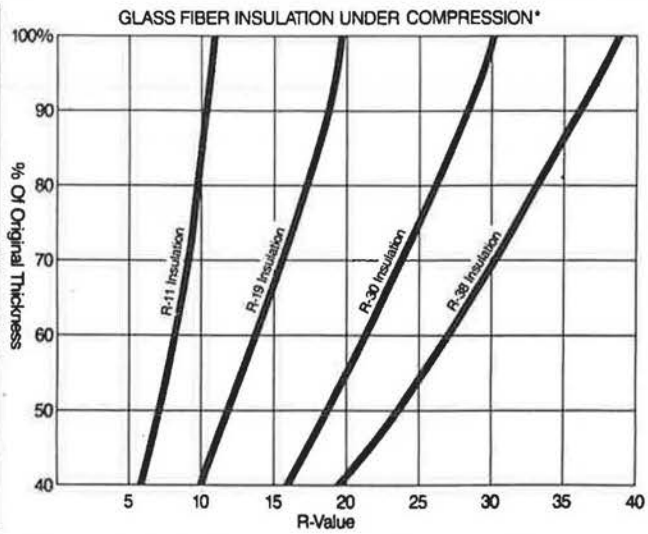


Figure A-2 — Changes in R-value caused by compression of various types of fiberglass batts.
Source: Owens Corning Fiberglas

Table 10 shows the changes in R-value caused by compressing batt insulation into various size stud walls.

One final note: Have you ever wondered why R-11 batts are made 3-1/2 inches thick — fitting nicely into a 2x4 cavity — but R-19 batts are either 6-1/4 or 6-1/2 inches thick — thicker than a standard 2x6 cavity? According to Paul Shipp at Owens Corning, the answer is simply because R-19 batts were originally designed for use in attics, where thickness and compression are not issues. However, regardless of the roots of the convention, slight compression is probably a plus for fiberglass batts, in that it reduces voids in corners and inhibits internal air circulation within the batt.

Acknowledgment: We'd like to thank Dr. Paul Shipp, formerly with Owens Corning Fiberglas Research Laboratory, for supplying much of the information contained in this article.

Table 10

Nominal Lumber Sizes	Actual* Depth Of Wall Cavity	Insulation "R" Values When Insulated In A Confined Wall Cavity								
2"×12"	11¼"	37	—	—	—	—	—	—	—	—
2"×10"	9¼"	32	30	—	—	—	—	—	—	—
2"×8"	7¼"	27	26	—	—	—	—	—	—	—
2"×6"	5½"	—	21	20	18	—	—	—	—	—
2"×4"	4"	—	—	15	14	—	—	—	—	—
2"×4"	3½"	—	—	14	13	13	—	—	—	—
2"×3"	2½"	—	—	—	—	9.8	8.8	—	—	—
2"×2"	1½"	—	—	—	—	6.3	6.0	5.7	—	—
2"×1"	1½"	—	—	—	—	—	—	—	3.2	3.0
"R" Values Standard Thicknesses		**R-38 12"**	**R-30 9½"**	**R-22 6¾"**	**R-19 6¼"**	**R-13 3¼"**	**R-11 3½"**	**R-8 2½"**	**R-5 1½"**	**R-3 ¾"**

R-value of fiberglas batts that are compressed in various depth wall cavities.
Source: Owens Corning Fiberglas

In Defense of Fiberglass Batt Insulation

Every now and then we receive a brochure or news release that cites research showing that fiberglass batt insulation has much lower actual R-value than what is listed on the manufacturers' labels. The most frequently cited study, performed in 1977 by Dynatech Labs, found that between 85 and 93 percent of the batts tested had R-values below the manufacturers listed R-value (see the April 1986 issue of EDU).

Aside from claims that fiberglass batts don't really have the R-value claimed for them, another common criticism of that insulation product is that when installed in the field, the thermal performance is seriously degraded by convection in and around the batts. One research study, performed by Schuyler and Solvasson and reported in the February 1985 issue of EDU, showed that the R-value of a wall insulated with fiberglass batts could be degraded 34% by air convection around the batts.

In addition to the two studies mentioned above, other field tests have shown that measured R-values of assembled building components insulated with fiberglass batts can be lower than theoretical R-values as calculated using manufacturers (and ASHRAE) values.

These research findings make interesting magazine (and newsletter) articles and, of course, also provide great advertising copy for non-mineral fiber insulation manufacturers. But what about the other side of the coin?

Are there good objective data showing that fiberglass batts do in fact have the R-value claimed for them by manufacturers and that they do in fact perform as expected in the field? If so, then how can we explain the fact that some research indicates that fiberglass insulation works and some research indicates that it doesn't?

How Do You Know Whether An R-19 Fiberglass Batt Is Really R-19?

You open up a fresh package of 6-inch R-19 fiberglass batt insulation. You roll out a batt and it slowly expands to roughly six-inch thickness. As you put it up into your wall stud cavities you wonder — "Is this really R-19?"

Unfortunately the 1977 Dynatech study, a government-funded project in which randomly sampled insulation batts were tested for R-value, has not been repeated. And since thermal testing is an expensive proposition, it is not likely to be repeated soon by the government, since the DOE energy conservation budget has been severely cut. But fortunately, there is at least one good source of quality verification — the NAHB Research Foundation labelling program.

The National Association of Homebuilders Research Foundation (NAHBRF) Labeling Program.

The National Association of Homebuilders Research Foundation (NAHBRF) is a wholly-owned not-for-profit subsidiary of the National Association of Homebuilders. In addition to practical research and development projects, the NAHBRF conducts a quality inspection and labelling program for certain products. One of the products included in the labelling program is fiberglass batts.

1. The NAHB Research Foundation certification seal.

The NAHBRF label is neither a promotional stunt nor a gratuitous arrangement between major insulation manufacturers and the national housing trade association. In fact, license to display the NAHBRF label on insulation packaging is granted only after a rigorous program of testing and quality control inspections.

Not only are the qualifications requirements strict, but in order to maintain certification, the manufacturer must allow the Research Foundation to select random samples for testing from each facility where the insulation is produced. Three samples are selected every 30 to 60 days (depending upon manufacturer's production volume). Each sample is tested for recovered thickness (according to ASTM C665-84) and R-value (according to ASTM C-518-76). The manufacturer's license to display the NAHBRF label is revoked if any one of the following occurs:

1) The running average thermal resistance of the most recent thirty samples tested does not equal or exceed 98 percent of the manufacturer's stated R- value.
2) The average thermal resistance of the three samples taken during any periodic visit is less than 94 percent of the manufacturer's stated R-value.
3) The R-value of any single sample tested is less than 90% of the manufacturer's stated R-value.

In addition to the periodic tests performed by NAHBRF, the labelling program requires that the manufacturer also take samples for testing every four hours. Those samples are tested for density and recovered thickness or for measured R-value. The results of the manufacturers' tests must be kept on file and are in-

Figure A-3 — NAHB Research Foundation certification seal spected every 30 to 60 days by Research Foundation staff.

In other words, the NAHBRF label is almost an absolute guarantee that the R-value of the labelled product is at least 90 percent of the manufacturer's listed R-value.

The only reason we say "almost" is because it is conceivable that the batt you buy could be an oddball that varied from all the rest. To find out how likely that is, we requested to see some of the actual test results from two manufacturers (Owens Corning and Certainteed) to see how much variation actually is typically found. Unfortunately, both companies refused our request due to the proprietary nature of the information. However, given the well-defined and rigorous requirements of the Research Foundation labelling program, it is reasonable to assume that the listed R-values of NAHBRF-labelled products are reliable. In fact, the greatest likelihood is that the fiberglass batt you purchase will have an R-value equal to or greater than the manufacturers listed R-value.

What About Performance In An Assembled Wall?

OK, so we know that an R-19 batt is really R-19 in the lab (assuming it bears the NAHBRF label). But what about in the field? The Schuyler and Solvasson study (see the February 1985 issue of EDU) showed that air circulation around unfaced fiberglass batts can degrade R-value up to 34%. Is this happening in all walls? Let's look at some recent test data:

Calibrated And Guarded Hot Box Tests

Two accepted methods for measuring the R-value of an assembled wall are the Calibrated Hot Box method (ASTM C-976) and the Guarded Hot Box method (ASTM C-236). In the calibrated hot box method, the wall to be tested is sandwiched between two chambers — the "indoor" or "metering" chamber and the "outdoor" or "climatic" chamber. The indoor chamber is controlled to simulate indoor conditions and is typically held at constant temperature and humidity. The outdoor chamber is controlled to simulate either winter or summer outdoor conditions. It can be kept at constant temperature and humidity for measuring steady-state heat flow, or can be cycled to simulate real dynamic weather conditions.

The temperature differential between the two walls drives heat into or out of the metering chamber. By measuring the amount of energy used to power the heating and cooling equipment in the metering chamber, you can calculate the amount of heat energy transmitted through the wall and thus the effective R-value of the wall. (The top, bottom, and sides of the two chambers are very heavily insulated so most of the heat flow into or out of either chamber is through the test wall.)

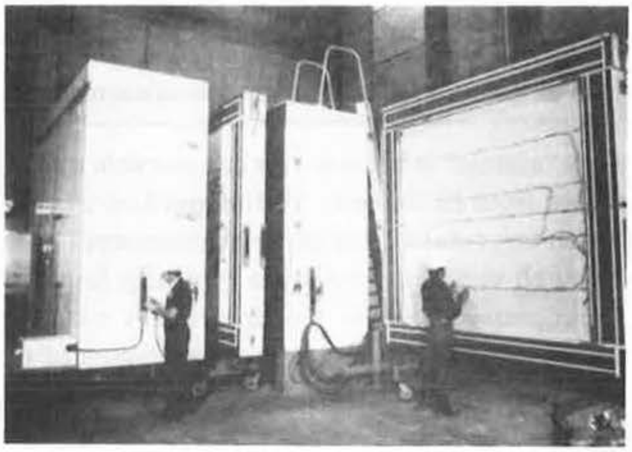


Figure A-4 — Calibrated hot box apparatus

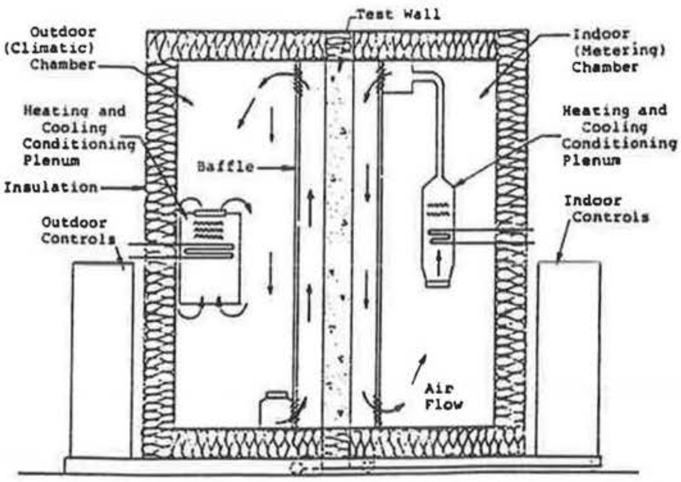
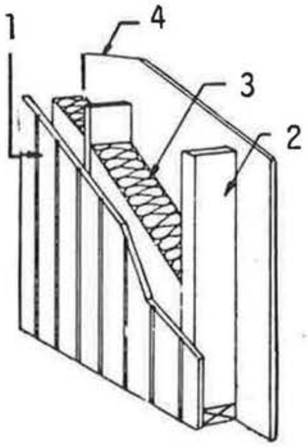


Figure A-5 — Calibrated hot box apparatus

The Guarded Hot Box test is similar to the Calibrated Hot Box except that the metering chamber is smaller and is surrounded by another chamber which is temperature controlled to eliminate side losses from the metering chamber.

A Wall Insulated with R-11 Batts Tested OK

A wood-frame wall constructed as shown in Figure A-6 was tested at Construction Technology Laboratories, Skokie, Illinois. The calculated R-value of the wall assembly, including correction for framing, was R-11.36 (see Table 11). The wall was tested in a calibrated hot box at four different outdoor temperatures ranging from -8°F to 124°F. The results are shown in Figure A-7. Notice that in every case the measured



1. 5/8-in. (16-mm) Plywood Cedar Siding
2. 2x4-in. (51x102-mm) Wood Studs spaced 16 in. (406 mm) on centers
3. 3-1/2-in. (89-mm) R-11 Fiberglass Blanket Insulation faced with kraft paper
4. 1/2-in. (13-mm) Gypsum Wallboard

Figure A-6 — Wall insulated with R-11 fiberglass

R-value of the wall exceeded the theoretical calculated R-value. In this test, there is little question that the fiberglass batts were performing as expected.

So Did a Wall Insulated with Double R-11 Batts

Recently, the National Bureau of Standards (NBS) initiated an effort to evaluate the thermal performance of an energy-conserving wall system that was suitable for automated assembly during manufacture. The design selected was a double 2x3 staggered stud wall insulated with two layers of R-11 fiberglass batts (Figure A-8). The 3.5-inch batts were compressed one inch to fit into the 2.5-inch stud space. The exterior side of the wall was sheathed with 0.75-inch polyisocyanurate sheathing, wrapped with Tyvek infiltration barrier, and sided with 0.5-inch wood siding. The interior surface was sheathed with gypsum board.

Component	R, Thermal Resistance	
	Between Framing hr·ft²·°F/Btu (m²·K/W)	At Framing hr·ft²·°F/Btu (m²·K/W)
1. Outside Air Film	0.17 (0.03)	0.17 (0.03)
2. 5/8-in. (16-mm) Plywood Siding	0.78* (0.14)	0.78 (0.14)
3. 2x4-in. (51x102-mm) Wood Stud	--	4.35* (0.77)
4. 3-1/2-in. (89-mm) Fiberglass Blanket Insulation	11.00* (1.94)	--
5. 1/2-in. (13-mm) Gypsum Wallboard	0.45* (0.08)	0.45 (0.08)
6. Inside Air Film	0.68 (0.12)	0.68 (0.12)
Total R	13.08 (2.30)	6.43 (1.14)
Total U	0.08 (0.43)	0.16 (0.88)

*Source: ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., New York, 1977, Chapter 22.

Table 1 — R-value calculations

Since the fiberglass batts were compressed to 2.5-inch thickness, their overall R-value was less than R-11.

Owens Corning publishes R-values for its batt insulation under various degrees of compression (see the previous article for a listing of OCF values). For R-11 batts compressed into a 2.5-inch stud cavity, OCF claims an overall R-value of R-8.8. In the NBS tests, they found the measured R-value of the compressed batts to be R-8.91.

Assuming that the foam sheathing has an R-value of R-7.2 per inch and, using ASHRAE values for the siding and gypsum board, the calculated R-value of the wall assembly was between R-22.5 and R-23.5 (depending on whether you use the ASHRAE parallel-path method or the ASHRAE isothermal-plane method of calculation). The measured R-value, as measured in a calibrated hot box, was R-22.2 at 40°F. The NBS researchers found that the R-value of the wall varied considerably with temperature, from R-18.5 at a mean wall temperature of 21°F, to R-22.8 at a mean wall temperature of 101°F.

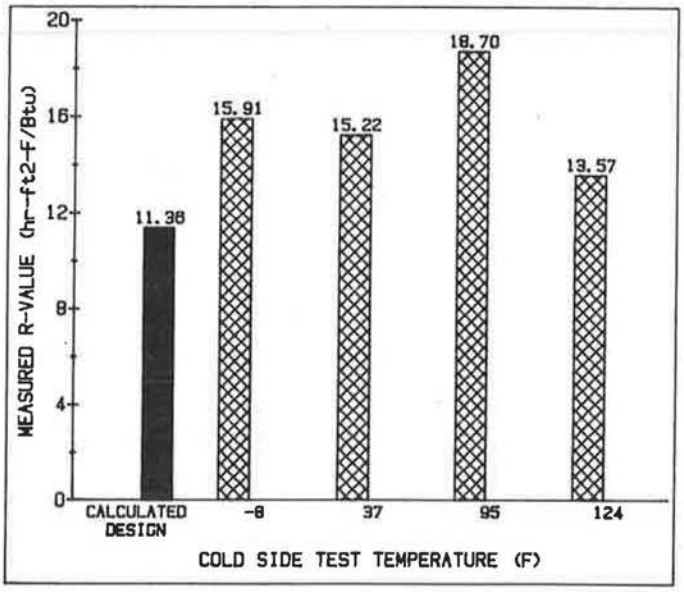


Figure A-7 — Results of themal testing of wall insulated with R-11 fiberglass batts

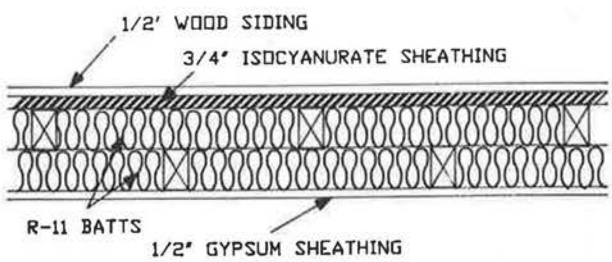


Figure A-8 — Wall insulated with double R-11 batts

And a "Superinsulated" Wall Insulated with Triple R-11 Batts

NBS also tested what it called a "superinsulated" wall, which was basically identical to the double stud wall described above except that the two stud frames were separated by a 3-inch space, and which was insulated with a third R-11 fiberglass batt. The calculated overall R-value at 40°F mean temperature was between R-32.5 and R-33.5. When tested in a calibrated hot box, the measured R-value ranged from R-32.7 at 50°F mean wall temperature to R-34.6 at 22°F mean wall temperature.

Thus again, the performance of a fully-assembled wall insulated with fiberglass batts was found to be equal to or better than the predicted performance based on manufacturers listed R-values.

So What About the Tests that Showed 34% Loss in R-value Due to Air Convection?

Air movement around fiberglass batts in a wall can short circuit the insulation by carrying heat from the warm side of the insulation over to the cold side. The amount of air convection, if any, depends on the size of the air spaces and the difference in temperature between indoor and out. The temperature differential is the driving force — the greater the temperature difference, the more convection that will occur.

When we reported Schuyler and Solvasson's results in the February 1985 issue of EDU, we failed to notice the conditions of their experiment. The temperature difference between the indoor chamber and metering chamber of their guarded hot box was 100°F. Although their findings are significant and important, you should bear in mind that the loss in R-value observed — 34% — was at an extremely high temperature differential that would only occur in a real house when the outdoor temperature drops to -30°F. Any statement that cites the Schuyler Solvasson study as proof that fiberglass batts always lose 34% of their insulating value is incorrect and misleading.

R-value Degradation Due to Air Convection Can Be Significantly Worse than 34%

An ASHRAE research report by W.C. Brown showed even worse R-value degradation of a wall system insulated with fiberglass. Brown looked at the performance of sheet steel walls insulated with fiberglass batts. These walls are typically constructed from a sheet steel V-rib inner liner and corrugated exterior cladding (Figure A-9). Since the fiberglass insulation can't conform to the channels formed by the V-ribs and corrugated cladding, vertical air channels are formed on both sides of the insulation, creating an easy path for airflow around the batts. This is truly a "worst case" situation.

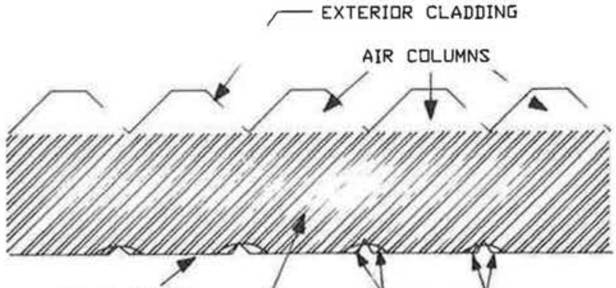


Figure A-9 — Sheet steel wall insulated with fiberglass batt

Brown tested 6-inch and 1-inch sheet steel walls in a calibrated hot box at two different temperature differentials. The results are shown in Figure A-10. At a 100°F temperature differential, the loss in R-value was 54 percent for the 6-inch wall and 65 percent for the 10-inch wall! Reducing the temperature differential in the hot box to 50°F reduced the R-value degradation somewhat, but it still was 25 and 40 percent for the 6- and 10- inch walls respectively.

Thus in this type of worst-case situation, it is possible to severely reduce the effective R-value of a wall insulated with fiberglass. But this is a defect in the installation, not the insulation. Brown found that by installing a proper air barrier to suppress convection within the wall section, the degradation due to convection was reduced.

Insulated Roofs Are Very Sensitive to Installation Defects

A common type of commercial roof insulation technique is wired-up batts, where the contractor strings wire across or along the roof trusses. These wires support batts above them and between the trusses. The batts are usually faced (in northern climates). The facings may or may not be sealed at the seams.

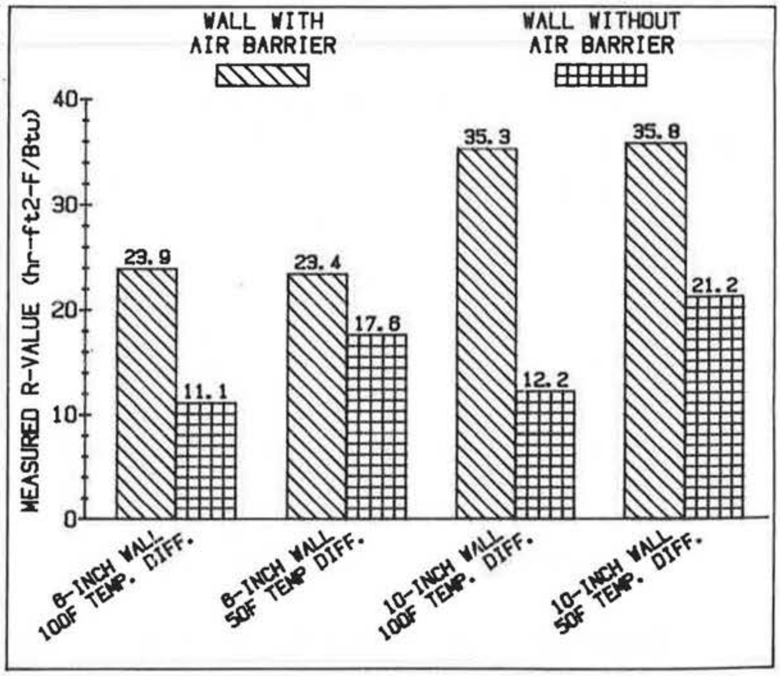


Figure A-10 — Results of thermal testing of sheet steel wall insulated with fiberglass batts.

The Owens Corning Fiberglas Thermal Research Facility at the Technical Center in Granville, Ohio, includes a large environmental chamber that can be used like a calibrated hot box to test full-scale attic and roof insulation systems. This very sophisticated facility is capable of maintaining temperatures from -50°F to 150°F.

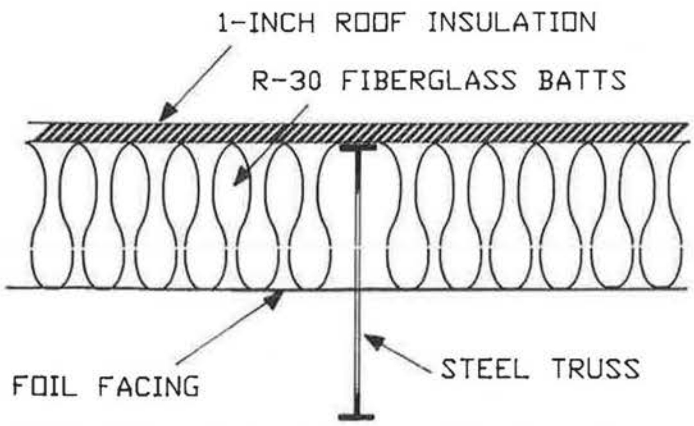


Figure A-11 — Roof with wired-up fiberglass batt insulation

Using the environmental chamber, T.B. Broderick ran a series of measurements to test the thermal performance of a roof with wired-up R-30 fiberglass batt insulation (Figure A-11). Several common defects were intentionally incorporated into the installation to evaluate the impact of the defects on the performance of the system. The defects consisted of various combinations of gaps between the batts and/or unsealed facings. The results are shown in Figure A-12.

The most astounding result is represented in the rightmost bar. With gaps between the batts amounting to 2% of the total area and with the foil facings unsealed, the total measured value of the roof system was about R-12.4! Since the same roof without batt insulation had a measured R-value of R-5.0, the addition of R-30 batts with the stated defects only increased the overall roof R-value by R-7.4! In other words, 75% of the added R-value was lost! Even when the size of the gaps was reduced to only 0.5% of the total ceiling area (second bar from the right) — certainly not an extraordinary defect for typical construction — the R-value of the total roof system was only R-21.1, well below the expected R-30 to R-35.

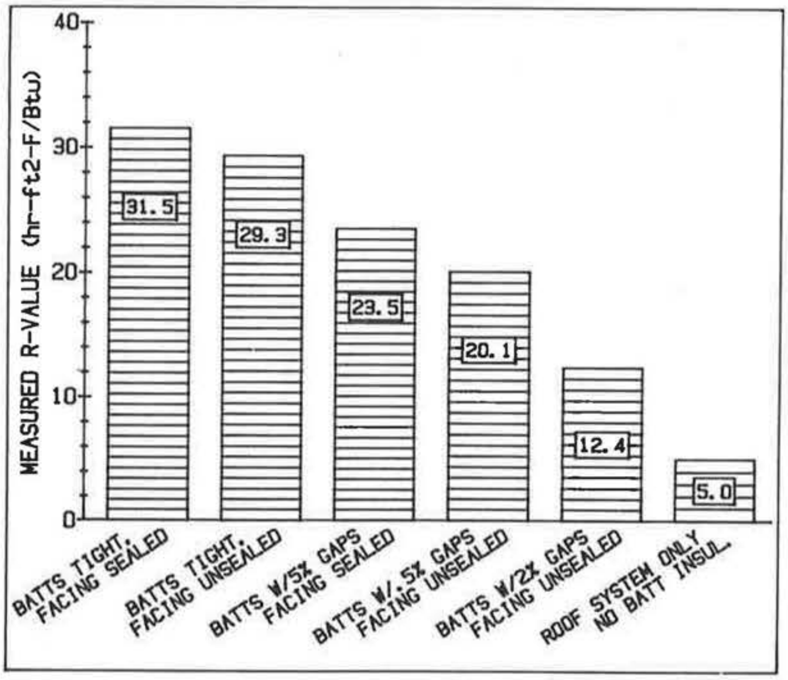


Figure A-12 — Thermal performance of roof with wired-up R-30 batts with and without installation defects.

The low R-values measured in Broderick's experiments are due partially to thermal bridging of the steel trusses and partially to air convection through and around the batts.

And Insulated Attics

Up to this point, all the information presented leads to the conclusion that fiberglass batt insulation systems work pretty much as expected as long as air convection is suppressed. But the following study, performed at the Owens Corning Technical Center, showed that other factors can also work to degrade the thermal performance of those systems.

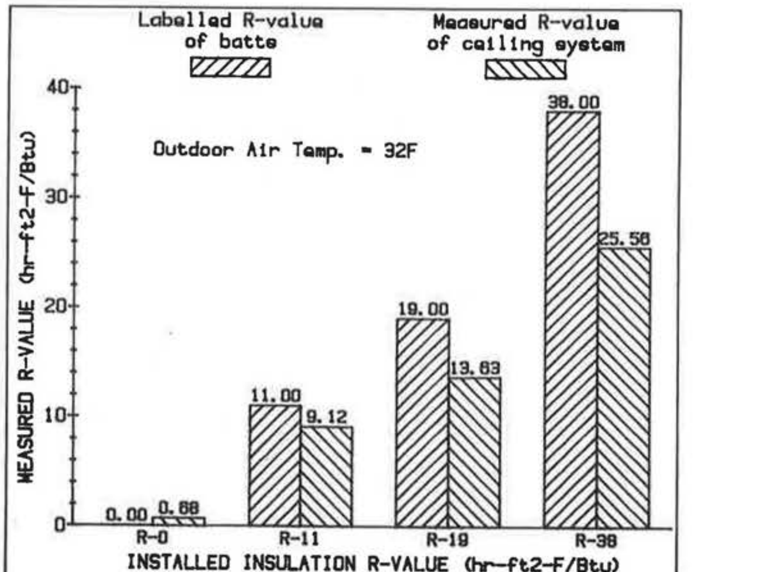


Figure A-13 — Results of thermal tests of ceiling insulated with fiberglass batts.

In a research project conducted by Kenneth Wilkes and James Rucker of Owens Corning, a simulated attic was built in the OCF environmental chamber. The attic included a system of standard trusses, plywood sheathing on the roof, and gypsum sheathing on the ceiling below the attic.

Tests were run with three levels of attic insulation — 1) R-11 batts, 2) R-19 batts, and 3) double R-19 batts (R-38). The results, shown in Figure A-13, don't look great. The ceiling with R-19 batts measured less than R-15 and the ceiling with double R-19 batts measured less than R-28.

In their report on the project, Wilkes and Rucker attributed the lower R-value to several factors, such as multi-dimensional conduction through the vertical edges of the insulation. However, regardless of whether or not it can be explained, the fact remains that this particular attic, insulated with fiberglass batts, showed actual measured R-values 21 to 26% less than expected. Do these test results indicate that we are overestimating the R-value of attics insulated with fiberglass batts? If so, by how much? The answer to the first question is probably yes, but since attics differ as to edge/area ratios and other factors, the answer to the second question may be hard to get.

Conclusions

1. Fiberglass batts can be reliably produced with specified R-values. Claims that most fiberglass batts have R-values lower than those listed by the manufacturers are mostly based on a single study, no longer applicable, performed by Dynatech labs in 1977.
2. Those fiberglass batts bearing the National Association of Homebuilders Research Foundation (NAHBRF) label can be relied upon to have actual R-values within 10% or less of the R-value listed on the package.
3. With proper installation, walls insulated with fiberglass batts can perform as expected according to the R-values listed on the batts.
4. The performance of fiberglass batts installed in a wall or roof can be significantly degraded by air convection around the batts. The degree of R-value degradation from convection is a function of the installation, namely the nature and size of air gaps and passages around the insulation. Also, the amount of degradation from convection depends on the temperature difference across the insulation assembly. The greater the temperature difference, the more the degradation in R-value.
5. Even without convection around the batts, ceilings insulated with fiberglass batts may have actual R-values significantly less than that calculated from R-values listed on the batts.

NOTE: The fact that ceilings insulated with fiberglass batts display low R-values does not necessarily mean that other types of insulation will work better or are preferable.

Similar tests of other materials, performed with the same level of sophistication as the Owens Corning tests, would have to be performed in order to make a valid comparison. To our knowledge, no such tests have yet been published.

For More Information

The following research papers provide further background and information about the tests cited in this article:

"Thermal Performance of Residential Attic Insulation," by Wilkes and Rucker, Energy and Buildings, Vol. 5 (1983), pp. 263-277.

"Heat Transmission Tests on Sheet Steel Walls," by W.C. Brown, ASHRAE Transactions 1986, Vol. 92, Part 2.

"Summary of Calibrated Hot Box Test Results for Twenty-One Wall Assemblies," by M.B. Van Geem. ASHRAE Transactions 1986, Vol. 92, Part 2.

"Measurements of Energy Flows Through Commercial Roof/Ceiling Insulation Systems," by T.B. Broderick, ASHRAE Transactions 1986, Vol. 92, Part 2.

"Thermal Resistance Measurements of Well-insulated and Superinsulated Residential Walls Using a Calibrated Hot Box," by R.R. Zarr, D.M. Burch, T.R. Faison, and C.E. Arnold, ASHRAE Transactions 1986, Vol. 92, Part 2.

Fiberglass Insulation and Cancer

In October 1986, the World Health Organization (WHO) held a symposium in Copenhagen on man-made mineral fibers. At that meeting, data was presented showing that workers in glass fiber manufacturing facilities suffered an excess mortality from lung cancer. This data confirms similar suggestive evidence that was presented at another meeting four years ago.

With such an explosive issue, it is important to take a sober look at what was actually observed, how any conclusions were drawn, and what questions still remain regarding those conclusions. For example, several research studies have shown that fibrous glass can induce tumors in rats if it is surgically implanted in their lungs. From those studies, one can truthfully say that fiberglass has been shown to cause cancer in rats. But does that mean it can also cause cancer in humans through inhalation of the fibers? If so, does the risk depend on the concentration of fibers in the air and/or the length of exposure?

During the past several months, EDU has pursued its own investigation of this issue. Our bottom-line questions have been: "Is there proof that fiberglass can cause cancer in humans?"; "Is fiberglass too dangerous to be installed in homes?"; "If so, is it dangerous to the installer only, or is it also dangerous to the homeowner?"

The 'Victims of Fiberglass' Campaign

Beginning in 1986, an anti-fiberglass information campaign supported by an organization called Victims of Fiberglass (VOF) was launched. Organized by Richard Munson, president of National Consumer Products Marketing, Inc., Auburn, California, the VOF campaign has been impressive and convincing. It includes several important research papers by respected scientists, together with copies of letters from government officials and other influential people expressing serious concern over the possible hazards associated with exposure to fibrous glass. Munson claims that there is absolutely no doubt that fiberglass insulation is carcinogenic. A full-page ad placed by VOF in the December 7, 1986 edition of the Auburn Journal carries the headline:

CONSUMER ALERT — FIBERGLASS INSULATION IN YOUR ATTIC CAUSES CANCER.

It further warns that "fiberglass must be handled as carefully as asbestos" and that if it is installed in your attic, you should have it removed. As we will see in a moment, Munson is not alone in his belief that fiberglass should be treated as cautiously as asbestos, but in all our research, we could not find anybody who agrees with him that homeowners are at risk from fiberglass in their attics.

Munson has announced that by the end of 1987 he will have reached every builder and architect in the U.S. with his message. We were told that VOF intended to place a full page ad in USA Today. In that ad, fiberglass is referred to as "man-made asbestos"!

Munson's credibility regarding this issue is usually questioned because he is a confessed "rabid hater of the fiberglass industry." But more than that, he is closely connected to the cellulose insulation industry, and would probably benefit from any bad press given to fiberglass. Despite some skepticism about his motives, Munson is making his mark. He has gained the ear of officials in the federal government and is probably responsible, at least to some extent, for current investigations into this matter now being carried out by the Occupational Safety and Health Administration (OSHA).

Perhaps the most convincing evidence of Munson's success was a statement made before a group of builders at the annual convention of the National Association of Homebuilders (NAHB) in Dallas in January 1987. A successful Colorado builder told the audience that in view of recent research evidence connecting fiberglass with serious health problems, he would no longer use that material in any of his houses.

Evidence that Fiberglass May Cause Cancer

1. Similar particle size to asbestos.

Several research studies, most notably one published by Dr. Mearl Stanton at the National Cancer Institute in 1977, have suggested that the carcinogenicity of a material depends on fiber size rather than physical or chemical properties. Long, thin fibers seem to present the greatest hazard. In general, the literature relates the degree of carcinogenicity to the proportion of fibers with diameters between 0.5 and 2.5 micrometers and with lengths between 10 and 80 micrometers.

Ironically, to increase the thermal performance of fiberglass insulation, some manufacturers have reduced the diameter of the fibers. The most notable example of this is Certainteed's Insul-Safe III. Munson's group funded a research study by Dr. William T. Lowry to characterize the particle size distribution in Insul-Safe III. Lowry's report shows that 80% of the fibers in Insul-Safe III have a median diameter between 0.6 and 0.9 micrometers and lengths between 10 and 20 micrometers.

Dr. Richard Lemen, director of the Division of Standards Development and Technology Transfer in the Center for Disease Control at the National Institute of Occupational Safety and Health (NIOSH), stated in a letter to Munson that "There is good evidence to support the theory that the physical dimensions of fibers are the critical factors which determine their chronic biologic effects, namely pulmonary fibrosis and cancer. Based upon that, we share your concern regarding potential exposures to Insul-Safe III Fibrous Glass Insulation."

Even though Insul-Safe III has the smallest average particle size, all fiberglass products probably have some fibers that are in the range considered dangerous.

But...

Although all the researchers we spoke with agree that particle size and geometry affect the carcinogenicity of a material, several researchers claim that other factors come into play and that just because some glass fibers are the same size and shape as asbestos fibers doesn't necessarily mean that the glass fibers will cause cancer. For example, Dr. William Moorman at NIOSH told us that certain electrophysical properties of the fiber may be just as important. Dr. Philip Enterline, a biostatistician at the University of Pittsburgh whose research work is often cited as supporting the connection between fiberglass and cancer, agrees with Moorman. Enterline believes that in cases where fiberglass does seem to induce cancer, it may be the binder on the fibers as well as other factors that come into play.

2. Fiberglass has been shown to cause lung cancer in rats.

Several studies have shown that glass fibers can induce tumors in the lungs of rats and other animals. Some of the literature distributed by VOF includes reports on those studies.

But...

With only one exception, the lung cancer in rats was induced either by surgical implantation or direct injection of the glass fibers into the lungs of the animals. The only exception we could find, where lung cancer was induced in rats by inhalation of glass fibers, was a study performed by a Dr. Potts in Germany. Potts' study has never been replicated.

3. Rats exposed to fiberglass through inhalation developed leukemia.

In a study sponsored by NIOSH and performed at Battelle labs by Ralph Mitchell, David Donofrio, and William Moorman, rats exposed to glass fibers in the air showed an increase in the incidence of mononuclear cell leukemia compared to control rats that were not exposed. According to Dr. Trent Lewis, chief of the Experimental Toxicology Branch at NIOSH, "The finding of increased leukemia in F-344 rats exposed to fibrous glass is accurate. The likelihood that such results would occur in each of the aerosol exposed groups, but not in the controls, is highly unlikely."

But...

The strain of rats used in these experiments, known as Fisher 344, typically show an increased spontaneous incidence of this disease. Bill Moorman, who conducted the experiments at NIOSH, told us that there are other explanations for how exposure to glass fibers may have indirectly caused the increased leukemia. His alternate hypothesis, if valid, would suggest that the increased incidence of leukemia would be specific to that animal species and not necessarily transferrable to humans.

The Copenhagen Symposium

The most important evidence suggesting a link between fiberglass and cancer in humans was presented at a symposium on man-made mineral fibers sponsored by the World Health Organization in Copenhagen last October. Three studies performed in Europe, Canada, and the United States showed an excess mortality from lung cancer among workers in fiberglass manufacturing facilities compared to the general population.

The conclusions from the three studies were summarized by Sir Richard Doll, a renowned epidemiologist. According to Philip Enterline, who presented one of the three studies, Doll stated that "If man-made fibers are regulated at the same level as asbestos, they will be perfectly safe." Doll's statement carries particular seriousness in that it puts fiberglass in the same class as asbestos. According to Enterline, current thinking in Europe is heading in that direction. He told EDU that Europeans seem to be convinced that fiberglass is dangerous and that man-made fibers behave very much like asbestos. "In fact," said Enterline, "the Germans are about to issue regulations that will regulate man-made fibers exactly like asbestos, and the rest of the countries in Europe will probably follow." Does this mean that fiberglass won't be used in Europe? "No," said Enterline, "but they will regulate the exposure levels of man-made mineral fibers the same way as they regulate asbestos."

But...

Usually when a disease is caused by contact with a substance, the incidence of that disease is related to the length and intensity of exposure to the substance. No such relationship was established in the studies presented at the Copenhagen symposium. In fact, in the American study, the relationship between exposure level and cancer went backwards: the higher the exposure, the lower the incidence of lung cancer.

Furthermore, according to Dr. J. Corbett McDonald of the MRC Cardiothoracic Epidemiology Group at Brompton Hospital in London, "the question of causes and effect is still uncertain." McDonald stated in a letter to Richard Munson that the excess in cancer reported at Copenhagen "was largely confined to men working during a period when the production process probably entailed exposure to a variety of other carcinogens."

Statements by Owens Corning Fiberglas and TIMA

The Occupational Safety and Health Administration's (OSHA) Hazard Communication Standard, 29 CFR 1910.1200, otherwise known as the "Workers' Right to Know" rule, requires chemical manufacturers to evaluate chemicals produced in their workplaces to determine if they are hazardous. If that determination indicates that a substance is in fact hazardous, then it must be so indicated on a Material Safety Data Sheet (MSDS), which must be transmitted to all affected employers and employees within the manufacturing sector.

In response to the findings presented at the Copenhagen symposium and other studies mentioned above, Owens Corning Fiberglas has modified its MSDS to include the following statement:

The Owens Corning Material Safety Data Sheet
(excerpted portion)

"Many studies have been conducted to determine the potential long-term effects of fibrous glass inhalation. Although inconclusive, some research supported by the industry indicates that manufacturing plant employees who were first employed more than 30 years ago in factories that manufactured glass wool and mineral wool have an increased rate of lung cancer as compared to certain other reference populations. Further study is planned to identify those factors associated with the reported increased rate. Similar findings were not reported regarding employees in textile-fiber manufacturing plants. Animal studies have not demonstrated an increased rate of lung cancer when the animals breathed large quantities of glass fibers. Artificial implantation or injection of fine glass fibers into the chest, abdominal cavity, or trachea of laboratory animals has produced cancer."

Evidently other fiberglass insulation manufacturers are following OCF's lead. According to Betty McDonald at Certainteed, they are now in the process of revising their MSDS, but the new version is not yet available.

The Thermal Insulation Manufacturers Association (TIMA) also produced a statement concerning the potential carcinogenicity of fiberglass. The Federal Toxic Substances Act requires that any suspected carcinogen be reported to the EPA. In compliance with that rule, TIMA submitted its statement to the U.S. Environmental Protection Agency in November 1986.

What About Product Labeling?

According to John Pendergrass, assistant secretary for occupational safety and health at the U.S. Department of Labor, if studies include positive human evidence of carcinogenicity, then the label of the product must contain a hazard warning for carcinogenicity. We were unable to determine whether OSHA would require such a label on fiberglass products at the time.

What About Installers and Homeowners?

We know a lot about rats and we know a little about people who worked in factories 30 years ago. But what do we know about people who install fiberglass insulation in houses today? And how about the people who then live in those houses?

According to Enterline at the University of Pittsburgh, the risk to house occupants is zero. And the risk to installers of batts in walls is very close to zero. We might have a problem, he told us, with installers of blown insulation in attics.

The workers studied in the Copenhagen reports were exposed to relatively low concentrations of glass fibers. An insulator blowing fiberglass in an attic is surrounded by much higher concentrations. According to Dr. John Konzen, vice president of medical and health affairs at Owens Corning, studies have been performed to measure the exposure of insulators in attics. We were not able to get copies of those studies, but subjective observations indicate that the concentration of fiberglass in the air is considerably higher than what one sees in a manufacturing facility. On the other hand, the time of exposure is less. At this point, there are no data indicating the level of risk or the incidence of lung cancer among insulation installers. (Even with no cancer risk, insulators should always wear protective facemasks to avoid irritation to the respiratory tract.)

What Next?

The Occupational Safety and Health Administration is reviewing the data from the NIOSH study and the information presented at the Copenhagen conference to see whether further action on its part is warranted. According to Dr. Edward Baier, OSHA director of technical support, no decisions have been made yet.

On July 22 1986, Margaret Seminario, associate director of the Department of Occupational Safety, Health and Social Security at the AFL/CIO, presented a statement to the Environmental Protection Agency (EPA) requesting that it reassess the potential hazards of "asbestos substitutes" before they further regulate public exposure to asbestos. One of the substitutes that would have to be considered is fibrous glass.

The fiberglass industry is confronting the issue responsibly. The Thermal Insulation Manufacturers Association was one of the sponsors of the Copenhagen symposium and has supported much of the research to date. In our research for this article, we received extensive cooperation from sources at Owens Corning Fiberglas Corporation and Certainteed Corporation.

Meanwhile, Munson and the Victims of Fiberglass will continue their campaign. At the time this article was published there had been no major media coverage of the issue. Since that thime, however, articles have appeared in the New York Times, the Wall Street Journal, and most building-related magazines.

Unfortunately, cancer research is generally complex and often confusing to the general public. We saw saccharin banned as a carcinogen and then saw the ban reversed. The building community will remember a similar situation with ureaformaldehyde foam insulation; first banned, then the decision reversed. On the other hand, there is the tragic reality of asbestos, which is known to have caused thousands of cases of cancer in humans.

EDU will continue to track this issue and will present the important developments as they occur.

For more information, the following is a partial listing of people mentioned and documents cited in this article.

Richard Munson, Victims of Fiberglass, 11143 Lakeshore North, Lake of the Pines, Auburn, CA 95603; (916)268-0480.

Margaret Seminario, Associate Director, Department of Occupational Safety, Health and Social Security, AFL/CIO, 815 Sixteenth St. N.W., Washington, DC 20006; (202)637-5000.

Dr. William T. Lowry, William T. Lowry, Ph.D., Inc., Fielder Professional Park, 733 B North Fielder Road, Arlington, TX 76012; (817)469-1115.

Dr. Richard A. Lemen, Director, Division of Standards Development and Technology Transfer, National Institute for Occupational Safety & Health, Robert A. Taft Laboratories, 4676 Columbia Parkway, Cincinnati, OH 45226; (513)533-8302.

Thermal Insulation Manufacturers Association (TIMA), 7 Kirby Lane, Mt. Kisco, NY 10549.

Dr. William J. Moorman, Chief, Chronic Toxicology Section, Experimental Toxicology Branch, Div. of Biomedical & Behavioral Science, Centers for Disease Control, National Institute for Occupational Safety & Health, Robert A. Taft Laboratories, 4676 Columbia Parkway, Cincinnati, OH 45226; (513)533-8275.

Dr. Trent R. Lewis, Ph.D., Chief, Experimental Toxicology Branch, Division of Biomedical & Behavioral Science, Centers for Disease Control, National Institute for Occupational Safety & Health, Robert A. Taft Laboratories, 4676 Columbia Parkway, Cincinnati, OH 45226, (513)533-8392.

Publications

"Carcinogenicity of Fibrous Glass: Pleural Response in the Rat in Relation to Fiber Dimension," by Mearl F. Stanton et. al., Journal of the National Cancer Institute, V. 58, No. 3, March, 1977.

"Vitreous Insulations: Are They Hazardous?," ASHRAE Journal, March 1980.

"Respiratory Disease Among Workers Exposed to Man-made Mineral Fibers," by Philip Enterline et. al, American Review of Respiratory Disease, 1983; 128:1-7.

"Mechanisms of Mesothelioma Induction with Asbestos and Fibrous Glass," by Mearl F. Stanton and Constance Wrench, Journal of the National Cancer Institute; 48:797-821.

"Peer Review: Mortality of Workers Exposed to MMMF — Current Evidence and Future Research," by Dr. J. Corbett McDonald, proceedings of conference on biological effects of man-made mineral fibres, Copenhagen, April 20-22, 1982.

Cellulose

Cellulose insulation is made by converting used newsprint or other paper feedstock or virgin wood to fiber form by shredding and milling to produce a fluffy, low-density material. Chemicals are then added to provide resistance to fire, water absorption, and fungal growth. The most common chemicals used are borax, boric acid, ammonium sulfate, calcium sulfate, and aluminum sulphate at a loading of approximately 20 percent by weight.

Cellulose Insulation and Airtightness

The following letter is one of several we have received asking or commenting about the effect of cellulose fiber insulation on building airtightness:

To the Editor:

I have heard two claims for cellulose insulation that I would like to confirm if possible. The first is that because of its density and compactness, cellulose insulation significantly reduces air leakage through the exterior skin of a house. In other words, houses insulated with cellulose insulation are tighter than houses built with fiberglass batts. The second claim is that unlike fiberglass batts, blown cellulose does not allow convective air loops to form within the insulation layer. If these claims are true, then cellulose seems to have some distinct advantages over fiberglass batts.

Any information you have supporting or refuting these claims will be appreciated.

Cynthia Wells, Chicago.

Research has shown increased building tightness with cellulose insulation.

A 1979 study performed by Seton, Johnson, and Odell for the Oregon Department of Energy found the measured air leakage of homes insulated with cellulose fiber insulation (CFI) to be 15 to 20% less than the air leakage of homes insulated with other insulation materials. Blower door tests of 71 homes found the average leakage for cellulose homes to be 10.6 air changes per hour at 50 Pa, compared to 13.0 ach for homes insulated with rock wool (Figure A-14). Only limited conclusions can be drawn from these data since the houses differed in other ways in addition to insulation type, but the trend for greater tightness with cellulose is probably valid.

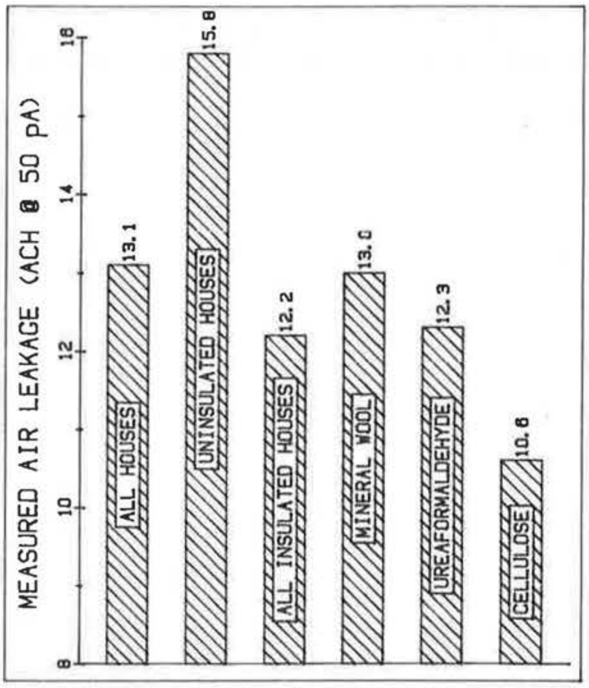


Figure A-14 - Measured air leakage of homes insulated with various types of insulation
Source: Oregon Dept. of Energy.

A more formal investigation on this topic was conducted in 1984 by David Jacobson, David Harrje, and Gautam Dutt at Princeton University. They built a simulated attic floor consisting of a test platform with intentional cracks in it. Using a controlled pressure device, air was forced through the cracks in the platform, first with no insulation on it, then successively with cellulose, fiberglass batts, fiberglass blowing wool, and finally vermiculite on it. The relative reduction in airflow caused by the various insulation

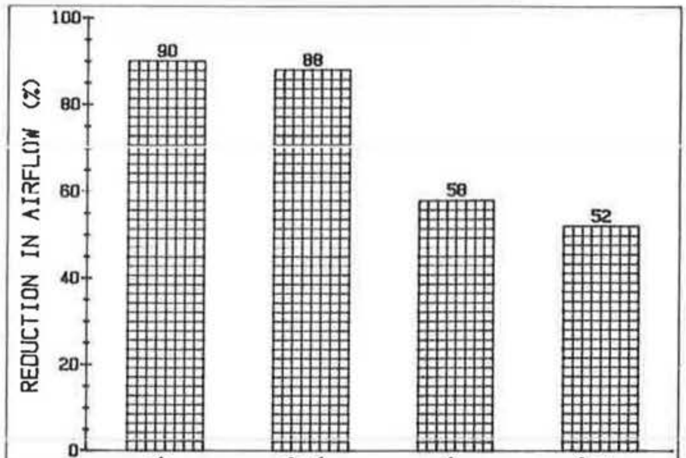


Figure A-15 - Percent air leakage reduction in test chamber with various types of insulation.
Source: Princeton University

materials was measured. The results are shown in Figure A-15. The greatest reduction by far was caused by the cellulose insulation.

The Princeton researchers also performed three field tests to measure the reduction in air leakage in houses retro-insulated with blown cellulose. Three houses were pressure tested with a blower door before and after retro-insulating the walls with cellulose. The results are shown in Figure A-16. In two houses, the reduction was enormous, but in a third, the reduction was only 3.6%. (The two houses with high reductions in air leakage both had balloon framing, which was probably open to the attic.)

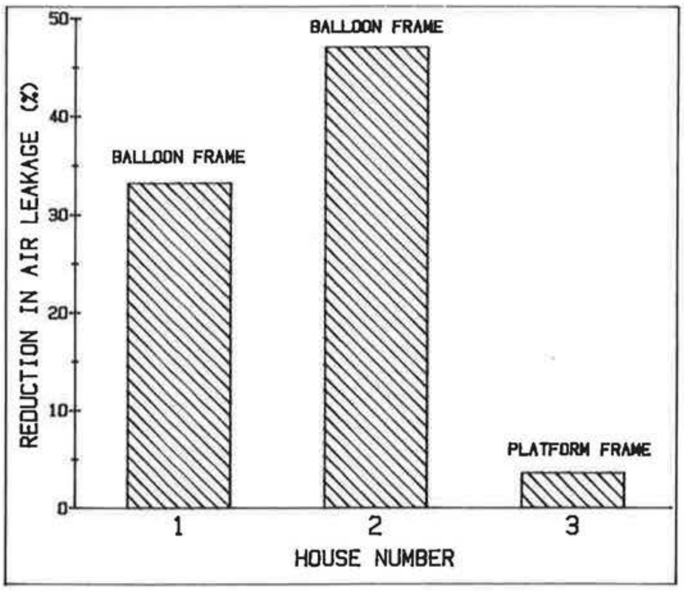


Figure A-16 - Percent reduction in air leakage after cellulose wall insulation retrofit.
Source: Princeton University.

Finally, a telling illustration of cellulose's ability to block air leakage is described in a report from the Minnesota Department of Energy and Economic Development:

During inspection of a group of energy-efficient houses built under the Minnesota Energy Efficient Housing Demonstration (EEHD) program, one defect noticed in many houses was air leakage into the attic through wiring holes and other penetrations in the top plates of interior partitions. In one house, the Minnesota research team was surprised to see almost no partition wall leaks into the attic during scanning examinations with an infrared camera. The initial conclusion was that the builder had been careful to plug those leaks during construction. However, when the cellulose insulation in the attic was removed, holes and cracks were in fact found around the interior partitions. The cellulose was actually sealing leakage points inadvertently left open by the builder.

Wet-spray cellulose is a different story

The most impressive air sealing effect of cellulose is seen when it is applied as a wet spray (see the September 1985 issue of EDU for a complete discussion of wet-spray insulation). We have received two reports from EDU readers about side-by-side comparisons of the air leakage characteristics of new houses built with wet-spray cellulose versus fiberglass batt insulation.

The first case is the Leominster Housing Project for the Elderly in Leominster, Massachusetts. Two of the buildings in the project have R-13 fiberglass batts in the walls and R-38 fiberglass batts in the ceilings. A third building is insulated with wet-spray cellulose in the walls and blown cellulose in the attic.

The three buildings were pressure tested with a blower door at the completion of construction. Some air sealing work was then done and the buildings were retested. Figure A-17 shows the results of the tests. The effective leakage area (ELA) of the building with cellulose was 40% lower than the average ELA of the two buildings with fiberglass before the air sealing work and 27% below the fiberglass buildings after the air sealing work.

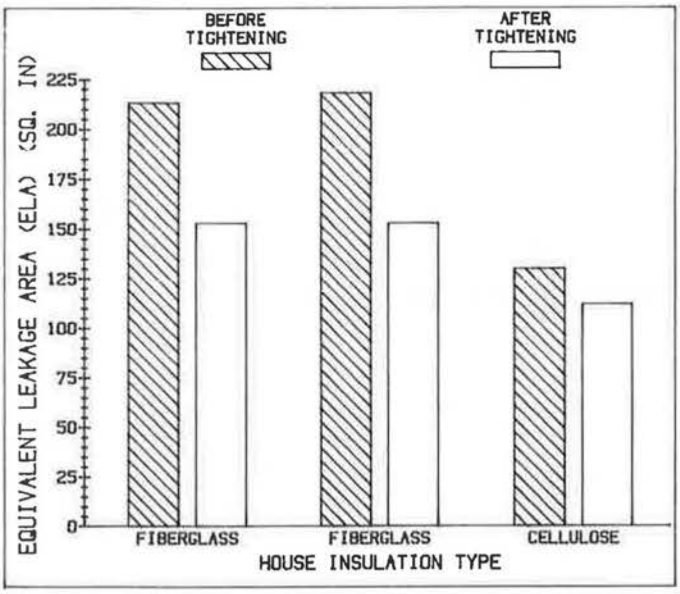


Figure A-17 - Comparison of measured air leakage of buildings insulated with fiberglass and buildings insulated with cellulose.
Source: Richard Piper, Mass. Exec. Office of Communities and Development.

The other case study was told to us by Bill Richardson, president of Columbine Homes, in Aurora, Colorado. Richardson is a volume builder who markets his homes largely on their energy efficiency. Last year Columbine built 250 homes. Each one built was tested for air leakage with a blower door.

Richardson compared the air leakage rates of homes insulated with fiberglass batts against the air leakage rates of homes insulated with wet-spray cellulose. He found that, all else being equal, the air leakage of the houses insulated with cellulose was generally about half that of the houses insulated with batts. The Columbine formula for achieving airtightness now includes cellulose insulation as an integral component, along with a system of gaskets and caulking similar to that used in the "airtight drywall approach" (ADA).

Air circulation within insulation is unproven

The second part of Cynthia Wells' inquiry letter, referring to the suppression of internal air movement within cellulose, is probably also true; to our knowledge, no one has demonstrated the presence of air circulation within cellulose. However, we have also not seen any discrete evidence showing the presence of air circulation within fiberglass batts either. We have seen, and have occasionally published, evidence of air circulation around and over fiberglass batts, but not within the batts. Air circulation around fiberglass batts is usually the result of gaps and spaces produced by imperfect installation. An advantage to cellulose in this respect is that gaps and spaces are less likely to occur.

Summary and Conclusion

Cellulose fiber insulation suppresses air leakage to a much greater extent than other types of insulation. In fact, when analyzing the cost-effectiveness of cellulose retro-insulation, you should probably factor in energy savings due to infiltration reduction. In new construction cellulose has the advantage, common to most loose-fill insulation materials, of complete filling of cavities, avoiding gaps and spaces which can lead to convective degradation of thermal performance. It cannot, however, be relied upon to correct flaws in the house air barrier.

Cellulose Fire Retardancy - Does Boric Acid Disappear Over Time?

During a 1986 workshop sponsored by the New Jersey Department of Energy, a contractor stood up and made the bold statement that through the process of sublimation, the boric acid and/or borax added to cellulose fiber insulation disappears completely within ten years, leaving the insulation with little or no fire retardancy. Our first reaction to his proclamation was total disbelief, but since that meeting, we received two more inquiries from subscribers who were concerned about "evaporation" of boric acid from cellulose insulation. After a little digging, we found that there is some concern within the industry over the permanence of the fire retardancy of cellulose, but the "ten year total disappearance" claim is an unfair and unfounded exaggeration, which probably refers to some very thin research performed at Oak Ridge National Laboratory a few years ago. Here's the story.

"Sublimation" is a common physical phenomenon similar to evaporation except that with sublimation, a material passes directly from the solid state to the gaseous state without first "melting" into a liquid. A common example of sublimation is dry ice — solid carbon dioxide which sublimes directly into gaseous carbon dioxide. Technically speaking, almost all chemicals can undergo sublimation to some degree and it is common knowledge that boric acid and borax (the common name for sodium borate), the two chemicals most commonly used as fire retardants in cellulose insulation, do sublime at elevated temperatures. The question is, how much?

The Oak Ridge Experiments

In 1982, Dave Yarbrough and others at Oak Ridge National Laboratory (ORNL) took a look at the problem of boron salt sublimation. They put a known amount of borax in a humidity cabinet and monitored it for four months, making very precise weight measurements. At the end of the four months, the borax had decreased in weight somewhat, but it was not clear whether or not any borax had been lost. Yarbrough could never convince himself that he had lost anything except water. (Borax contains some "water of hydration" which can be driven off under high temperature conditions.)

So he tried a second experiment. This time, he passed an air stream with known temperature and humidity across the surface of some boric acid. After passing over the boric acid, the air stream was bubbled through water and the water was then analyzed for boron. Some boron was found in the water, proving that some of the boric acid was being lost to the air stream. But how much? Based on the measured boron in the water and the airflow rates, Yarbrough projected that over a ten year period, they would have lost "some significant amount" of boric acid.

The results of that second experiment were reported in a single sentence of an Oak Ridge Report on cellulose insulation. Yarbrough told us that in his opinion, the experiment was "not real clean" and that the report included a lot of caveats and a lot of "ifs." When asked about the practical significance of those findings, he told us that he certainly would not back up the notion that you could take his results and apply it to a house and say that in ten years all the fire retardant would be gone.

As far as we could determine, Yarbrough's experiment is the sole source of all reports of boric acid disappearing from cellulose insulation by sublimation. For all practical purposes, therefore, those reports are unfounded.

The NBS Fire Study

In 1984, two researchers at the National Bureau of Standards (NBS), Sandy Davis and Randall Lawson, conducted some experiments to test "the sensitivity of the fire performance of cellulosic thermal insulation materials to selected environmental exposure conditions that are found in various parts of the continental United States." The final report of that study, written by Lawson, includes the following conclusions:

1. Test results show that environmental cycling can affect the fire performance of cellulosic thermal insulation materials.
2. Cycling through either high temperature/high humidity or high temperature/low humidity environments can adversely influence the protection provided by chemical fire retardants in cellulosic thermal insulation.

Sounds pretty bad, but...

According to Lawson, despite the above two published conclusions, the NBS tests produced no data that should cause alarm. "They don't necessarily relate to the real world of housing," he told us. That opinion was supported by Yarbrough at Oak Ridge who told us that "[NBS] made stronger statements in their report than they could actually support."

U.S. Borax

As a major vendor of boron products, U.S. Borax is naturally concerned about this issue and in 1983 it initiated a ten-year testing program to determine the permanency of borates in cellulose insulation. According to Bronson Schafer at U.S. Borax, as of the third year of the program, no negative effects had been observed. U.S. Borax intends to make the test results public at the completion of the experiment.

And finally, ASTM

That this whole issue is not just nonsense is evidenced by the fact that the American Society for Testing and Materials (ASTM) has an active task group on the permanency of the fire retardancy of cellulose insulation. According to task group chairman George Andrews, they have absolutely no evidence indicating that cellulose treated with boron salts loses its fire retardancy over time, but that the task group intends to seek evidence and formulate test procedures to prove that loss of boron is in fact not a problem. Another task group member, Sarfraz Siddiqui at the California Department of Consumer Affairs, told us that even though sublimation may not be a problem, other factors, such as settling out of the dry boron salts, could be a problem resulting in loss of fire retardancy. Siddiqui told us that they have performed tests in attics and found that in some cases, the concentration of boron salts is higher in the lower layers of insulation than in the upper layers, indicating that some of the salt had settled. He added, however, that there is still no conclusive evidence indicating that that phenomenon constitutes a fire hazard.

What to do?

At this point, we see no reason for concern about the long-term fire resistance of cellulose fiber insulation. The ten-year boron disappearing story is certainly a myth. Yes, there have been cases of fires in attics insulated with cellulose, but keep in mind that there was a time when a lot of cellulose insulation was made in garages by people with a grinding machine and some old newspaper. Times have changed and so has that industry.

On the other hand, we were told during our research that some fire retardant additives, such as ammonium sulfate, may be less stable than boron and may not provide adequate fire retardant permanency. The ASTM Task Group is considering this issue as well. We will stay in touch with them and report significant developments as they occur.

For more information

The NBS paper by Randy Lawson is available from the National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161; (703)487-4650. Ask for Report No. NBSIR 84- 2917, "Environmental Cycling of Cellulosic Thermal Insulation and Its Influence on Fire Performance," by J. Randall Lawson, August, 1984. The price is $8.50.

Dave Yarbrough may be reached at Oak Ridge National Lab, P.O. Box X, Oak Ridge TN 37831; (615)574-5978. The citation for his paper that includes information on boron volatility is: "Properties and Testing of Loose-Fill Cellulosic Insulation" [ORNL/TM-6433].

For information on the ASTM Task Group, contact George Andrews, Fiber Products, 21800 Main Street, Colton, CA 92324; (714) 783-0462.

Density and Settling of Cellulose Insulation

The photo below shows every cellulose manufacturer's nightmare. This embarrassing display was at the Boston Museum of Science. Incredible as it may seem, the wall is labeled with signs which tout the superior R-value of ureaformaldehyde foam (the white stuff with shrinkage at the top in the center four cavities) and cellulose (the grey stuff with the giant void spaces in the two rightmost stud cavities). The cellulose in this demonstration has obviously settled quite a bit. It may very well have been installed by someone with no skill or experience, but it illustrates the most common concern that builders and designers have about using cellulose in sidewalls and attics — settling.

Figure A-18 - A cellulose manufacturer's nightmare.
Source: Jon Slote, Acorn Structures Inc.

Walls

Is it Possible to Install Cellulose in Walls So that it Won't Settle?

Yes. Laboratory experiments by Mark Bomberg and C.W. Anderson at the National Research Council of Canada and Doug Burch at the National Bureau of Standards have demonstrated that cellulose can be blown into wall stud cavities in such a manner that it will not settle over time. Confirming field studies have been conducted by Dr. George Tsongas of Portland State University. In his recent "State-of-the-art Review of Retrofitted Wall Insulation," Tsongas states that settling of loose-fill materials does not occur in walls to any significant degree when the material is properly installed. "What is typically believed to be settling is probably incomplete filling of the wall cavity." Tsongas further states that "settling itself is not an issue of concern relative to the use and performance of retrofitted loose-fill wall insulation."

What Density Is Necessary to Prevent Settling?

The "design density" necessary to prevent settling of cellulose in walls can vary considerably. For example, Anderson examined cellulose settlement in walls filled at different densities with the same cellulose product. He found that once the density exceeded 3.0 to 3.5 lb/ft3, no settlement was observed. Similarly, Burch's studies at NBS showed no settlement at 3.55 lb/ft3. But experiments performed by Mark Bomberg at the Canadian National Research Council showed some settlement at 4.24 lb/ft3, although none at 4.4 lb/ft3.

The term "design density" is not an officially recognized variable and there is no standard test for determining it. Bomberg has proposed that it be calculated as 10% higher than the average density necessary to just fill a wall cavity without compaction. Using his proposed method, Bomberg found that the design density usually varies from one manufacturer to the next and can even vary considerably between different batches from the same manufacturer, with typical values falling in the range of 3.5 to 4.0 lbs/ft3.

Given a Prescribed Design Density, the Rest Is Simple. Right?

If you know the required density and the size of the wall cavity, proper installation should be simply a matter of a few basic calculations: Multiply the dimensions of the cavity in inches times the desired density and divide the result by 1,728 (the number of cubic inches in a cubic foot).

> **Example:** How much cellulose would be required to fill a 7'6" high, 24" wide, 5.5" deep stud cavity to a density of 4.0 pounds per cubic foot.
>
> **Solution:** [(90" x 24" x 5.5") x 4 lb/ft3)] / 1,728 in 3/ft3 = 27.5 pounds.

Thus assuming no obstructions, each stud bay should accept about 27.5 pounds of insulation.

No, Wrong.

What happens when you take your simple calculations into the field. You've got one worker holding the hose and the other worker operating the blowing machine. "Hey Joe, gimme 27.5 pounds for this stud bay. O.K.?" Sure.

There is no easy way for an installer to know how much is going into an individual stud bay. And even if the calculations are spread out for the whole job, it won't help. What if, at the end of the job, the crew finds that they have ten bags left over. Can they go back and distribute that material over the entire job? Obviously not.

So How Is the Proper Density Attained?

Skill and experience are the only ways to assure proper installation. So stated every contractor and manufacturer we interviewed for this article. A good installer can "feel" the required density during installation. In addition to the installer's skill, other variables such as machine air setting, number and location of installation holes used, nozzle diameter, and hose characteristics all affect final installed density.

The Bottom Line - Can Cellulose Be Installed in Walls with Assurance that it Won't Settle?

Yes. We know that if installed at sufficiently high density, the material won't settle. We also know that there are applicators who have practiced enough so that they can install the material at the proper density.

It should be noted however, that field studies have shown cellulose installations with large void spaces at the top of the stud cavity. In some cases, the voids may be due to incomplete filling; in others, however, it may be actual settling. Proper installation is certainly not universal; contractor selection is particularly important due to the required skill and integrity.

Attics

Can Cellulose Be Installed in Attics So that it Won't Settle?

No. Unlike wall applications, cellulose can't be compressed to a design density or "settled density in attics. Some settling always occurs.

How Does Settling Affect R-value?

As the material settles, the density increases and the overall thickness decreases. Both phenomena result in decreased R-value. (Although the effect is slight, the R-value per inch of cellulose actually decreases as the density increases (see Figure A-19).)

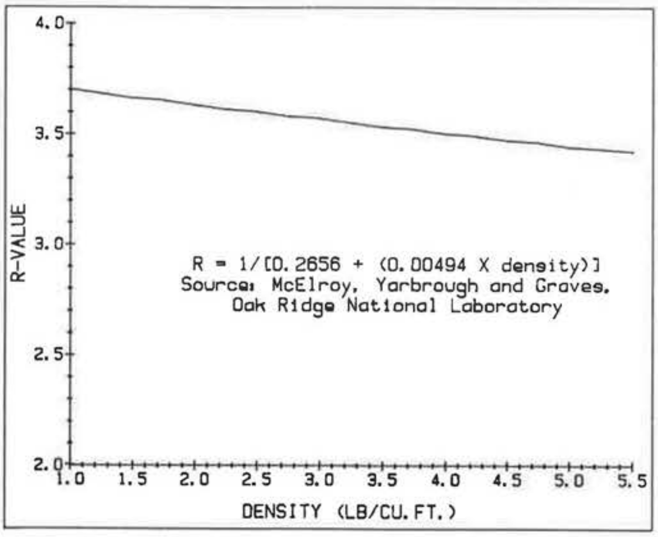


Figure A-19: R-value vs. Density for loose fill cellulose.

Source: ASHRAE.

Figure A-20 shows what happens when 15 inches of cellulose at a density of 2.5 lb/ft3 settles to 12.5 inches with a density of 3.0 lb/ft3. Notice that the total R-value drops from R-55.5 to R-43.8.

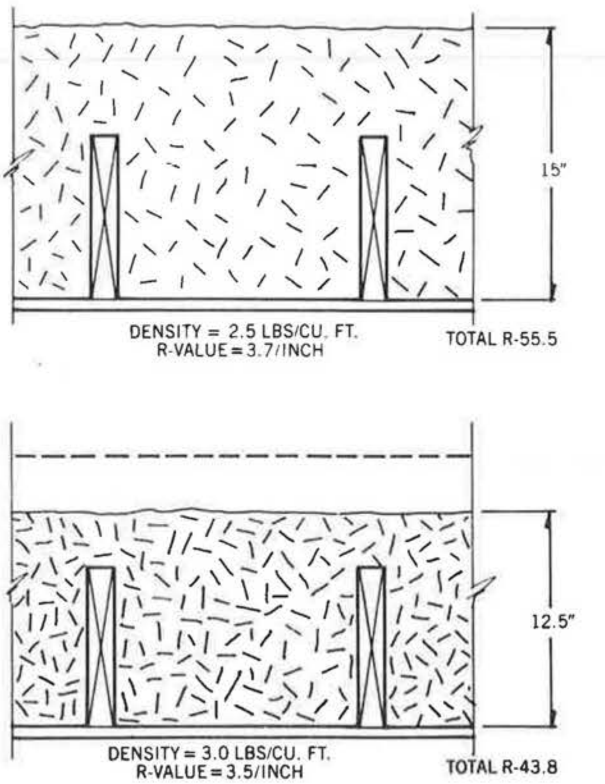


Figure A-20 - Effect of settling on overall R-value of cellulose installed in attic.

How Much Does Cellulose Settle in Attics?

The short answer

21% by thickness. (But it's not that simple. See the "long answer")

The long answer.

This is one of the toughest issues plaguing not only the cellulose industry, but the rockwool and fiberglass blowing wool industries as well. The 21% figure listed in the above "short answer" comes from Specification 51-GP-60M of the Canadian Government Specifications Board (CGSB). Method "B" of that specification states that the design density of a cellulose product is 27% higher than the minimum blown density. The 27% increase is based on observed settlement of material in the field. If the density of the material increases 27%, then the thickness will decrease about 21%. Keep in mind however, that the 21% decrease in thickness only applies if the blown thickness is at minimum density, i.e. blown with machine adjustments set for maximum loft.

Theoretically, cellulose installed in an attic will settle until it reaches its "settled density," after which settling ceases. The U.S. Federal Trade Commission (FTC) requires that cellulose insulation manufacturers measure the settled density (sometimes called "label density") of their products by one of two tests — either the Canadian "Drop Box" test or the "Blower-Cyclone-Shaker" (BCS) test. The drop box test was developed in Canada in 1976 and adopted as a CGSB standard in 1977. Following the principle that settling is influenced primarily by humidity and vibrations, the drop box test subjects a sample to 28 days of humidity cycling followed by repeated dropping to induce settling. With the blower-cyclone-shaker test, settled density is determined by measuring the volumetric difference before and after applying concentrated vibration to a measured sample for approximately five minutes. The drop box test can be burdensome as an ongoing test because of the testing time requirements. In comparison, the BCS test is simpler and much faster.

Not everyone agrees on the validity and/or comparability of the two tests. In 1983, one cellulose manufacturer — Mono-Therm Industries — petitioned the U.S. Federal Trade Commission for a partial exemption from the "R-value" rule, claiming that the BCS test overestimated the settled density of cellulose products by about 10%. From the manufacturer's viewpoint, the lower the settled density the better, since the lower the settled density, the greater the R-value attained per unit weight of material. So it comes as no surprise that Mono-Therm complained about the suspected erroneous data produced by the BCS test. The petition was turned down by the FTC.

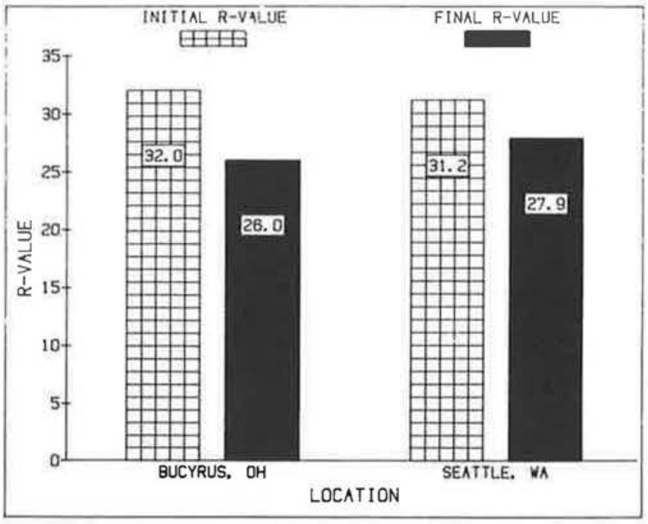


Figure A-21 - Initial and final R-value of cellulose in attics
Source: Oak Ridge National Laboratory

The Oak Ridge Experiments

The complexity of the problem is well illustrated by the results of a series of field experiments performed by Ron Graves, Dave McElroy, and Dave Yarbrough at Oak Ridge National Laboratory (ORNL).

The Oak Ridge researchers looked at 13 attic installations of cellulose in Seattle, Washington, and Bucyrus, Ohio, to see how much settling occurred over a two-year period. The Bucyrus houses lost about 19% and the Seattle houses lost about 11% in thickness and R-value (Figure A-21). The final density of the cellulose in the Bucyrus houses was about 12% greater than the manufacturer's label density. The final density of the Seattle houses was 24% higher than the manufacturer's label density. (Figure A-22).

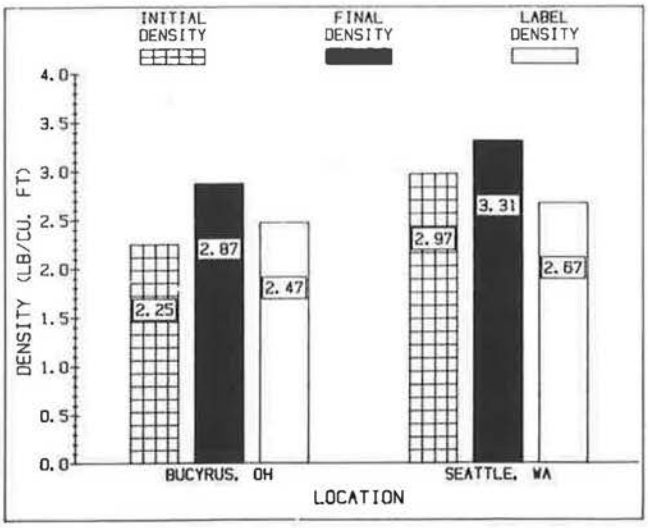


Figure A-22 - Initial, final, and label density of cellulose in attics
Source: Oak Ridge National Laboratory

How significant is the discrepancy between label density and the ORNL-measured density in terms of R-value? Let's look at the Seattle data. Suppose we want 12 inches of cellulose (to get about R-44.4 at an assumed R-value of R-3.7 per inch). According to the manufacturer's label density (2.67 lb/ft3), we would need 2.67 pounds of cellulose per square foot of attic floor area. But according to the measured final density in the Oak Ridge experiments (3.31 lb/ft3), 2.67 pounds would only provide a settled thickness of 9.7 inches [(2.67/3.31) x 12 inches)]. At R-3.7 per inch, that would provide an overall R-value of R-35.9 (3.7 x 9.7) — about 20% less than expected according to the bag label density.

R-14 Per Pound?

An imprecise but simple approach to the problem is to assume a settled density of 3 pounds per cubic foot and an R-value of R-3.5 per inch. Using those values gives an installed R-value of R-14 per pound per square foot.

To install any R-value, you would follow three steps:

1. Choose the desired R-value
2. Divide the total R-value by 14 to get the number of pounds per square foot needed.
3. Multiply the pounds per square foot by the area of the attic to get the total number of pounds to install.

For example, suppose we wanted to insulate a 1,000-square-foot attic to R-60.

1. Total R = 60
2. R-60 divided by 14 = 4.3 pounds per square foot.
3. 4.3 times 1,000 square feet = 4,300 pounds of cellulose.

Hey Joe, Gimme 4.3 Pounds!

The problem with installing by weight is that, as with walls, it is difficult for the installing team to know exactly how much weight is being installed per area. If after the job is done, too little material had been installed, it is very difficult if not impossible to go back and add more to the far reaches of the attic.

Again, however, a skilled installer will have a feel for the process and in many cases will be able to estimate with good accuracy just how much material is going in.

The Solution — "Inches Equals Rs"?

The ultimate solution to this problem will be to somehow simplify the process so that the installing contractor can install a certain thickness to obtain a certain R-value. That approach is already being taken by rockwool manufacturers and possibly by fiberglass blowing wool manufacturers.

According to Lee Edes, executive director of the Insulation Contractors Association of America (ICAA), the "Inches Equals Rs" approach is probably "do-able" for rockwool and fiberglass (Cassidy and Son and Mauulle already do it), because the material can be modified so that it won't settle.

But cellulose is a different story. It always settles. The only way to guarantee minimum R-value by thickness alone would be to install a prescribed extra thickness — say 20 to 25%. If that approach is taken, it is likely that in many cases the final R-value will be higher than expected. Of course, blowing extra inches also means extra cost.

For More Information

Contact the Insulation Contractors Association of America, 15819 Crabbs Branch Way, Rockville, MD 20855; (301)926-3083.

The Many Faces of Polystyrene

The Basic Ingredient

Polystyrene is made by reacting benzene with ethylene to form styrene monomer (single molecules of styrene). The monomer is then polymerized to form polystyrene — a chain of styrene molecules. Various additives are mixed into the foam for fire retardancy and other physical characteristics, but the basic polymer is the same for all the foams discussed below.

For thermal insulation, two distinctly different processes are used to make rigid polystyrene foam — molding and extrusion.

The Two Basic Kinds of Polystyrene Foam Insulation

1. Molded Expanded Polystyrene (MEPS) or "Beadboard"

MEPS production begins with "expandable beads" of polystyrene, which contain a small amount of liquid pentane. The expandable beads are heated with steam to about

200°F, causing the styrene to soften and the pentane to expand, puffing the beads to a low-density form commonly referred to as "pre-puff." The pre-puff is poured into a mold where the beads are further expanded and fused into a billet. The foam billet is then cut into boardstock.

MEPS is produced by roughly 175 manufacturers across the U.S and Canada, but most of the expandable beads come from six main manufacturers: Huntsman Chemical Corp., makers of Huntsman EPS (formerly Hostapor, produced by American Hoechst Corp.); Arco Chemical Company, maker of Dylite; BASF Wyandotte Corporation, maker of Styropor; Cosden Oil & Chemical Co., maker of Cospan; Huntsman-Russtek Polymers, Inc., maker of Styro-Ex; and Georgia Pacific Corporation.

2. Extruded Expanded Polystyrene (XEPS)

XEPS is manufactured by a completely different process than MEPS. EPS granules are fed into an extruder where they are melted into a viscous fluid. Then a blowing agent (usually a type of freon) is injected to make the mixture foamable. Under carefully controlled conditions, the foamable mixture is forced through a die, at which time foaming and shaping occurs. The rigid foam is then trimmed to the final product dimensions.

The original extruded polystyrene to be used as thermal insulation was blue Styrofoam brand, produced by Dow Chemical Company and commonly referred to as blueboard. Unfortunately (or maybe fortunately for Dow), people use the term Styrofoam to refer to all types of styrene foam products, for example "styrofoam cups." (The more accurate term would be beadboard cups.)

Three companies in addition to Dow now manufacture extruded polystyrene as thermal insulation: UC Industries, Inc., maker of Foamular (pink); Amoco Foam Products Company, maker of Amofoam (green); and DiversiFoam Products (formerly Minnesota Diversified Products, Inc.), maker of CertiFoam (yellow). Although the manufacturing process differs from one manufacturer to another, the basic chemical and physical properties of all the extruded polystyrene foams are the same.

NOTE: U.S. Plywood also sells an extruded polystyrene product — Thermowall. It is grey in color and was formerly sold by Champion Homes. Thermowall is made by Amoco and, except for the color, is identical to Amofoam. Monsanto also makes an extruded polystyrene called Foam-Cor, used mostly as an underlay for siding. It is not made in thicknesses exceeding 1/4-inch.

Type	MOLDED BEAD I	II	VIII	IX	EXTRUDED IV	V	VI	VII	X
R-value per inch	3.6	4.0	3.8	4.2	5.0	5.0	5.0	5.0	5.0
Density (lb/ft^3)	0.9	1.35	1.15	1.8	1.6	3.0	1.8	2.2	1.35
Compressive Strength (psi)	10	15	13	25	25	100	40	60	15
Flexural Strength (psi)	25	40	30	50	50	100	60	75	40
Water Vapor Permeability (perm-in)	5.0	3.5	3.5	2.0	1.1	1.1	1.1	1.1	1.1
Water Absorption (%)	4.0	3.0	3.0	2.0	0.3	0.3	0.3	0.3	0.3
Dimensional stability (%)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Oxygen Index	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0

The Nine "Types" of Polystyrene

In addition to the two physically distinct kinds of EPS, there are nine categories or "Types," defined according to ASTM Standard C 578-85, promulgated by the American Society for Testing and Materials (ASTM). The nine ASTM Types, designated by Roman numerals I, II, and IV through X (that's right, no III), are defined according to several specific physical properties including compressive strength, flexural strength, density, water vapor transmission rate, and R-value.

Table 10 lists the physical requirements of polystyrene foam according to the ASTM Standard.

For the extruded foams, the most significant property with respect to the Type classes is probably compressive strength. In applications with vertical loading, Type VI or VII foam may be required. In some situations, such as under a freezer warehouse slab, Type V foam, with a compressive strength of 100 psi may be specified.

On the other hand, for siding applications where compressive strength is less important, Type II (beadboard) or Type IV (extruded), both with compressive strength of 25 psi, would be fine. In fact, for siding applications, 10 to 15 psi compressive strength is OK, which is why UC Industries brought out its less expensive Type X low-density foams (Foamular 150) for siding.

NOTE: Dow also has a Type X foam, a grey product called PSF-002. However, PSF-002 is hard to find and Dow has evidently not yet made the commitment to push the product in the residential market.

Which Types Are Beadboard and Which Types Are Extruded Polystyrene?

The ASTM Standard does not specify whether any particular Types are molded or extruded polystyrene. Technically, any of the Types could conceivably be either kind of foam. But in reality, molded EPS as normally manufactured can only meet the minimum requirements of Types I, II, VIII, and IX.

The three requirements that set molded polystyrene apart from extruded polystyrene are R-value, water vapor permeability, and water absorption. Types IV, V, VI, VII, and X all require a minimum R-value of R-5.0 per inch (at 75°F). The only way to obtain that R-value with polystyrene is to use Freon or other low-conductivity gas as the blowing agent. Molded bead polystyrene, as normally produced, is always expanded with pentane. Thus it cannot be produced with an R-value as high as R-5.0. Water vapor permeability and water absorption are always higher with molded bead foam because of the nature of the material; water can migrate through the bead structure much more easily than through the continuous cell structure of extruded foam.

Notice, however, that with regard to compressive strength and flexural strength, Type IX beadboard can perform just as well as Type IV extruded foam and better than Type X extruded foam.

How to Tell the Type Class of a Particular Foam Beadboard

Beadboard

Beadboard is usually identified by density rather than ASTM Type classification. Unlike extruded foam, the R-value changes with density, so when looking for a certain Type beadboard foam, both R-value and density (and possibly compressive strength) should be checked.

Extruded Foam

The manufacturers of extruded foam each produce specific products that fall into various ASTM Type categories. The following is a partial listing:

Table 11

Type	Styrofoam	Foamular	Amofoam	CertiFoam
IV	TG, SM	250	Regular	Regular
V	HI 115	none	none	none
VI	HI 40	400	none	40
VII	HI 60	600	none	60
X	PFS 002 ?	150	none	none

The Bureaucratic Confusion

Before putting this topic to rest, those readers who encounter foam Type citations in building specifications should be aware of the fact that ASTM 578-85 is new. It replaced ASTM 578-83, which replaced ASTM 578-69. 578-69 had only two "grades" of EPS. The difference had to do with flammability. In 1983, the ASTM standard was revised. The revised version, ASTM 578-83, included five Type classes: I, II, and III were beadboard; IV and V were extruded polystyrene. ASTM 578-83 was the basis for Federal Specification HH-I-524C, which is often cited in building documents and building codes. In 1985 the standard was revised again to ASTM 578-85. The new standard eliminated one Type (III) and added five new ones (VI through X).

As of January 1, 1986, Federal Specification HH-I-524C was officially superceded by ASTM 578-85. Unfortunately, many building documents still carry reference to the old federal standard. This is sure to be a source of continuing confusion for some time.

A complete copy of the ASTM standard is available from ASTM, 1916 Race Street, Philadelphia, PA 19103; (215)299-5400.

Polyurethane And Polyisocyanurate Foams

Polyurethanes are plastics which are the reaction product of isocyanates and alcohols. Polyisocyanurates are made from isocyanates in the presence of a catalyst, resulting in the formation of a more thermally-stable isocyanurate ring structure. Originally, polyurethane foams were formed during the chemical reaction by release of carbon dioxide. However, halocarbons are now used as blowing agents, resulting in virtually 100 percent closed-cell foam. Either rigid or flexible foam can be produced, depending on the functionality of isocyanates and alcohols and the molecular weight. For thermal insulations, the rigid foam is used.

Polyurethane and polyisocyanurate foams are produced by several different processes. Continuous slab stock is made by mixing the necessary components and continuously metering the mixture onto a moving conveyor, where it forms a continuous foam that can be cut to various lengths. Laminates can be made by a similar process, dispensing the mixture between sheets.

Foamed-in-place polyurethanes and isocyanurates are prepared by mixing or metering the components and dispensing them either manually or automatically. Specially designed units are available for spray-on applications.

Perlite

Perlite is a naturally occurring, siliceous, volcanic glass containing between two and five percent water by weight. Perlite ore is composed primarily of aluminum silicate. Crushed ore particles are expanded to between 4 and 20 times their original volume by rapid heating to a temperature of 1000°C. which vaporizes the occluded water and forms vapor cells in the heat-softened glass.

Perlite is used primarily in industrial/commercial buildings as a roof insulation board material. The next largest use is in lightweight insulating concrete where expanded perlite is mixed with Portland cement. A wide range of density is possible. Perlite insulating concrete, both preformed and cast-in-place, is used primarily for roof decks, floor slabs, and wall systems. Low density expanded perlite is used as loose fill insulation.

Vermiculite

Vermiculite is a mica-like hydrated laminar mineral consisting of aluminum-iron-magnesium silicates with both free and bound water. When the mineral is subjected to high temperatures, it expands due to formation of steam which is driven off, thereby causing the laminae to separate. By controlling the degree of exfoliation, a density range of typically 4 to 10 pounds per cubic foot can be produced in the expanded material. The lower density material is commonly used as loose-fill insulation.

Vermiculite is non-combustible and melts at 1315 degrees Celsius. Being an inorganic material, it is resistant to rot, vermin and termites, and is not affected by age, temperature or humidity.

Reflective Foils (Radiant Barriers)

Reflective materials act as insulations by reflecting infrared radiation rather than by reducing conduction as conventional bulk insulations do. The most common types of radiation barriers are aluminum foils and aluminized mylar. They are most effectively used in applications where radiation heat transfer is dominant, such as the underside of roofs.

FIBERGLASS

Material Property	Value	Test Method
Density	0.6-1.0 lb/ft^3	
Thermal Conductivity (k factor)	varies with density	
Thermal Resistance (R-value) per 1" of thickness* at 75°F	3.16 hft^2F/Btu (batt) 2.2 hft^2F/Btu (loose fill)	ASTM C518, C653
Water Vapor Permeability	100 perm - in	
Water Absorption	<1% by weight	ASTM C553-70
Capillarity	none	
Fire Resistance	non-combustible	ASTM E136
Flame spread	15-20	ASTM E84
Fuel contributed	5-15	ASTM E84
Smoke developed	0-20	ASTM E84
Toxicity	Toxic fumes could develop due to combustion of binder	
Effect of Age		
a) Dimensional stability	none (batt) settling (loose fill)	
b) Thermal performance	none	
c) Fire resistance	none	
Degradation Due To:		
Temperature	none below 180°F	
Cycling	none	
Animal	none	
Moisture	none	
Fungal/bacterial	does not promote growth	
Weathering	none	
Corrosiveness	non-corrosive	Federal HH-I-558D
Odor	none	ASTM C553 - Sec. 16

*Derived from R19 and R11 products for 6" and 3.5" thickness respectively.

ROCK AND SLAG WOOL

Material Property	Value	Test Method
Density	1.5-2.5 lbs/ft^3	
Thermal Conductivity (k factor) at 75°F	0.31 - 0.27 Btu - $in/ft^2hr°F$ (batts) 0.34 Btu - $in/ft^2hr°F$ (loose fill)	ASTM C177
Thermal Resistance (R-value) per 1" of thickness at 75°F	3.2 - 3.7 hft^2F/Btu (batts) 2.9 hft^2F/Btu (loose fill)	ASTM C177
Water Vapor Permeability	100 perm - in	
Water Absorption	2% by weight	
Capillarity	none	
Fire Resistance	non-combustible	ASTM E136
Flame spread	15	ASTM E84
Fuel contributed	0	ASTM E84
Smoke developed	0	ASTM E84
Toxicity	none	
Effect of Age		
a) Dimensional stability	none (batt) settling (loose fill)	
b) Thermal performance	none	
c) Fire resistance	nonc	
Degradation Due To:		
Temperature	none	
Cycling	none	
Animal	none	
Moisture	transient	
Fungal/bacterial	does not support growth	
Weathering	none	
Corrosiveness	none	
Odor	none	

*Derived from R19 and R11 products for 6" and 3.5" thickness respectively.

CELLULOSE

Material Property	Value	Test Method
Density	2.2-3.0 lbs/ft^3	
Thermal Conductivity (k factor) at 75°F	0.27 to 0.31 Btu - in/ft^{2}hr°F	ASTM C177, C518
Thermal Resistance (R-value) per 1" of thickness at 75°F	3.2 - 3.7 hft^{2}F/Btu	
Water Vapor Permeability	high	
Water Absorption	5 - 20% by weight	ASTM C739
Capillarity	not known	
Fire Resistance	combustible	ASTM E136
Flame spread	15 - 40	ASTM E84
Fuel contributed	0 - 40	ASTM E84
Smoke developed	0 - 45	ASTM E84
Toxicity	develops CO when burned	
Effect of Age		
a) Dimensional stability	settles 0 - 20%	
b) Thermal performance	not known	
c) Fire resistance	inconsistent information	
Degradation Due To:		
Temperature	none	
Cycling	not known	
Animal	not known	
Moisture	not severe	
Fungal/bacterial	may support growth	
Weathering	not known	
Corrosiveness	may corrode steel, aluminum, copper	ASTM C739
Odor	none	ASTM C739

EXPANDED POLYSTYRENE (extruded)

Material Property	Value	Test Method
Density	0.8 to 2.0 lbs/ft^3	
Thermal Conductivity (k factor)	0.20 $Btu\text{-}in/ft^2hr°F$	ASTM C177, C518
Thermal Resistance (R-value) per 1" of thickness at 75°F	5 hft^2F/Btu	
Water Vapor Permeability	0.6 perm-in	ASTM D2842-69
Water Absorption	<0.7% by volume <0.02% by volume	ASTM D2842-69 ASTM C272
Capillarity	none	
Fire Resistance	combustible	ASTM E136
Flame spread	5 - 25	ASTM E84
Fuel contributed	5 - 80	ASTM E84
Smoke developed	10 - 400	ASTM E84
Toxicity	develops CO when burned	
Effect of Age		
a) Dimensional stability	none	
b) Thermal performance	increases to 0.20 after 5 years	
c) Fire resistance	none	
Degradation Due To:		
Temperature	above 165°F	
Cycling	none	
Animal	none	
Moisture	none	
Fungal/bacterial	does not support growth	
Weathering	direct exposure to UV light causes degradation	
Corrosiveness	none	
Odor	none	

EXPANDED POLYSTYRENE (molded)

Material Property	Value	Test Method
Density	0.8 to 2.0 lbs/ft^3	
Thermal Conductivity (k factor)	0.23-0.26 Btu-in/ft^{2}hr°F	
Thermal Resistance (R-value) per 1" of thickness at 75°F	3.85 to 4.35 hft^{2}F/Btu	
Water Vapor Permeability	1.2 to 3.0 perm-in	ASTM C355
Water Absorption	<4% by volume <2% by volume	ASTM D2842-69 ASTM C272
Capillarity	none	
Fire Resistance	combustible	ASTM E136
Flame spread	5 - 25	ASTM E84
Fuel contributed	5 - 80	ASTM E84
Smoke developed	10 - 400	ASTM E84
Toxicity	develops CO when burned	
Effect of Age		
a) Dimensional stability	none	
b) Thermal performance	none	
c) Fire resistance	none	
Degradation Due To:		
Temperature	above 165°F	
Cycling	none	
Animal	none	
Moisture	none	
Fungal/bacterial	does not support growth	
Weathering	direct exposure to UV light causes degradation	
Corrosiveness	none	
Odor	none	

POLYURETHANE/POLYISOCYANURATE FOAMS

Material Property	Value	Test Method
Density	2.0 lb/ft^3	
Closed Cell Content	90%	ASTM C591-69
Thermal Conductivity (k factor)	0.16-0.17 Btu - in/ft^{2}hr°F (aged & unfaced or spray applied) 0.13-0.14 Btu - in/ft^{2}hr°F (impermeable skin faced)	ASTM C177, C518
Thermal Resistance (R-value) per 1" of thickness at 75°F	6.2-5.8 hft^{2}F/Btu (aged & unfaced or spray applied) 7.7-7.1 hft^{2}F/Btu (impermeable skin faced)	
Water Vapor Permeability	2 to 3 perm-in	
Water Absorption	Negligible	
Capillarity	none	
Fire Resistance	combustible	ASTM E136
Flame spread	30-50 polyurethane 25 polyisocyanurate	ASTM E84
Fuel contributed	10-25 polyurethane 5 polyisocyanurate	ASTM E84
Smoke developed	155-500 polyurethane 55-200 polyisocyanurate	ASTM E84
Toxicity	produces CO when burned	
Effect of Age		
a) Dimensional stability	0-12% change	ASTM D-2126
b) Thermal performance	0.11 new, 0.17 aged 300 days	
c) Fire resistance	none	
Degradation due to:		
Temperature	above 250°F	
Cycling	not known	
Animal	none	
Moisture	limited information available	
Fungal/bacterial	does not promote growth	
Weathering	none	

POLYURETHANE/POLYISOCYANURATE FOAMS

(continued)

Material Property	Value	Test Method
Corrosiveness	none	
Odor	none	

UREA-FORMALDEHYDE AND UREA-BASED FOAMS

Material Property	Value	Test Method
Density	Wet — Approx. 2.5 lb/ft^3 Dry — 0.6 to 0.9 lb/ft^3	Weigh a foam-filled bag of known volume
Closed Cell Content	0.7 - 80%	
Thermal Conductivity (k factor) Mean temp. 75°F	0.24 Btu - $in/ft^2hr°F$	ASTM C177, 76
Thermal Resistance (R-value)	4.2 hft^2F/Btu	
Water Vapor Permeability	4.5 to 100 perm-in @ 50%rh 73°F	ASTM C355
Water Absorption	32% by weight (0.35% vol.) 95% rh 18% by weight (0.27% vol.) 60% rh 68°F 180 - 300% by weight (2-42% vol.) immersion	
Capillarity	slight	
Fire Resistance	combustible	ASTM E136
Flame spread	0-25	ASTM E84
Fuel contributed	0-30	ASTM E84
Smoke developed	0-10	ASTM E84
Toxicity	no more toxic than fumes from burning wood	
Effect of Age		
a) Dimensional stability	1 to 4% shrinkage in 28 days (curing) 4.6 to 10% shrinkage @ 100°F 100% rh for 1 week 30 to 45% shrinkage @ 158°F 90 to 100% rh 10 days	ASTM D2126 proc. C ASTM D2126-66
b) Thermal performance	no change	
Degradation due to:		
Temperature	decomposes at 415°F	
Cycling	no damage after 25 freeze/thaw cycles	
Animal	not a feed for vermin	
Moisture	not established	
Fungal/bacterial	does not support growth	ASTM G21-70 (1975)
Weathering		
Corrosiveness		
Odor	May exude formaldehyde until cured	

PERLITE (loose fill)

Material Property	Value	Test Method
Density	2-11 lbs/ft^3	
Thermal Conductivity (k factor at 75°F)	0.27 - 0.40 Btu-in/ft^{2}hr°F	ASTM C177
Thermal Resistance (R-value) per 1" of thickness at 75°F	3.7-2.5 hft^{2}F/Btu	
Water Vapor Permeability	high	
Water Absorption	low	
Capillarity		
Fire Resistance	non-combustible	ASTM E136
Flame spread	0	ASTM E84
Fuel contributed	0	ASTM E84
Smoke developed	0	ASTM E84
Toxicity	not toxic	
Effect of Age		
a) Dimensional stability	none	
b) Thermal performance	none	
c) Fire resistance	none	
Degradation due to:		
Temperature	none under 1200°F	
Cycling	none	
Animal	none	
Moisture	none	
Fungal/bacterial	does not promote growth	
Weathering	none	
Corrosiveness	none	
Odor	none	

PERLITE (Concrete)

Material Property	Value	Test Method
Density	20-40 lbs/ft^3	
Thermal Conductivity (k factor at 75°F)	0.5 - 0.93	ASTM C177
Thermal Resistance (R-value) per 1" of thickness at 75°F	2.0-1.08 hft^{2}F/Btu	
Water Vapor Permeability	high	
Water Absorption		
Capillarity		
Fire Resistance	non-combustible	ASTM E136
Flame spread	0	ASTM E84
Fuel contributed	0	ASTM E84
Smoke developed	0	ASTM E84
Toxicity	not toxic	
Effect of Age		
a) Dimensional stability	none	
b) Thermal performance	none	
c) Fire resistance	none	
Degradation Due To:		
Temperature	none under 500°F	
Cycling	none	
Animal	none	
Moisture	none	
Fungal/bacterial	does not promote growth	
Weathering	none	
Corrosiveness	none	
Odor	none	

VERMICULITE (loose fill)

Material Property	Value	Test Method
Density	4-10 lbs/ft^3	
Thermal Conductivity (k factor at 75°F)	0.33 - 0.41 Btu-in/ft2h°F	ASTM C177
Thermal Resistance (R-value) per 1" of thickness at 75°F	3.0-2.4 hft^2F/Btu	
Water Vapor Permeability	high	
Water Absorption	None	
Capillarity	None	
Fire Resistance	non-combustible	ASTM E136
Flame spread	0	ASTM E84
Fuel contributed	0	ASTM E84
Smoke developed	0	ASTM E84
Toxicity	none	
Effect of Age		
a) Dimensional stability	none	
b) Thermal performance	none	
c) Fire resistance	none	
Degradation Due To:		
Temperature	none under 1000°F	
Cycling	none	
Animal	none	
Moisture	none	
Fungal/bacterial	does not promote growth	
Weathering	none	
Corrosiveness	none	
Odor	none	

VERMICULITE (Concrete)

Material Property	Value	Test Method
Density	20-60 lbs/ft^3	
Thermal Conductivity (k factor at 75°F)	0.59 - 0.96 $Btu\text{-}in/ft^2hF$	ASTM C177
Thermal Resistance (R-value) per 1" of thickness at 75°F	1.7-1.0 hft^2F/Btu	
Water Vapor Permeability	high	
Water Absorption		
Capillarity		
Fire Resistance	non-combustible	ASTM E136
Flame spread	0	ASTM E84
Fuel contributed	0	ASTM E84
Smoke developed	0	ASTM E84
Toxicity	not toxic	
Effect of Age		
a) Dimensional stability	none	
b) Thermal performance	none	
c) Fire resistance	none	
Degradation Due To:		
Temperature	none under 1000°F	
Cycling	none	
Animal	none	
Moisture	none	
Fungal/bacterial	does not promote growth	
Weathering	none	
Corrosiveness	none	
Odor	none	

Wet Spray Insulation for Houses

Wet spray insulation has traditionally been used only in commercial buildings. Sprayed cellulose, fiberglass, and mineral wool are commonly left exposed on ceilings and walls to serve as soundproofing as well as thermal insulation. Other special spray-applied materials are also used for fireproofing. (The fuzzy coating you see on steel girders is a special type of spray insulation that prevents the steel from softening during fires.)

Although not yet common, wet-spray insulation can also be used as cavity wall insulation in new residential construction. Not many builders think of it as a primary option for new houses, but equipment manufacturers and materials suppliers of some spray insulation products are now looking to expand their penetration into the residential market.

Spray-applied insulation has some definite advantages, but also some drawbacks. One of the worst problems is the lack of consistent and reliable information. While researching this article, we were constantly presented with contradictory information and conflicting claims by manufacturers and end users. The more questions we asked, the more variety of answers we received. Certain issues, such as proper drying time and actual R-values of wet-spray insulations remain in question. Some of the claims for installed R-value would challenge even the most extreme gullibility. For example, witness the following excerpt from the promotional brochure for the Force/2 application equipment (our underlining):

"Imagine (if you can) being able to spray up the walls of three average size homes in a single day. From setup to cleanup. Completely filling every 2"x4" stud run like a mattress. That's faster than hanging batts, and far more effective. Especially when you consider you're achieving a wall with <u>an R-factor between R-19 and R-21</u>. That's a fact, as attested by certified laboratory documentation. That's what we call superinsulation."

R-21 in a 3-1/2-inch wall cavity? R-6.0 per inch? That's imagination, not superinsulation!

But wet-spray insulation should not be written off. We talked with several builders who swear by it and several insulation contractors who do very well installing it. Let's first look at the pros and cons of this insulation technique in general and then take a closer look at what's available.

What Is Wet-spray Insulation?

Basically wet-spray insulation is any insulation material — cellulose, fiberglass, mineral wool — that is wetted, usually mixed with adhesive, and sprayed onto an application surface using special blowing equipment. The adhesive may be either a dry powder that is premixed with the insulation, or a liquid that is introduced at the nozzle during application. When properly installed, the insulation can be applied up to six inches thick in one application. Upon drying, it forms a monolithic blanket of insulation that remains firmly attached to the application surface.

For cavity wall installation, the wet-spray process is typically modified somewhat since the material doesn't need the permanent adhesion qualities necessary in exposed applications. Usually less adhesive is used; sometimes the adhesive is eliminated altogether (cellulose only); and in the case of some manufacturers, a different fiber is sold for cavity wall insulation.

Advantages Of Wet-spray Insulation For Cavity Walls

1. Good coverage.

As with spray foam insulation, wet-spray insulation penetrates around obstructions and into odd-shaped cavities, completely filling most voids. Since the cavity is open, you can inspect the installation as it proceeds, reducing the chance of undetected voids.

2. No settling.

When properly applied, wet-spray insulation dries into a monolithic blanket of insulation that should never settle.

3. Reduced air infiltration.

Wet-spray insulation reduces air infiltration by forming an air seal between framing members and sheathing.

4. Reduced internal air convection.

Due to the monolithic structure of the dried insulation, air convection within the insulation is reduced.

5. Soundproofing.

Spray-applied materials have excellent sound attenuation properties. In residential applications, you can take advantage of this by spraying around plumbing supply and waste pipes in partition walls between bathrooms and bedrooms. Another idea is to spray the back side of fiberglass bath/shower enclosures to reduce the sound of impacting shower water.

Disadvantages

1. The Moisture Question

This is perhaps the most important issue surrounding the use of spray-applied insulation in enclosed wall cavities. No matter how well the water mix is controlled, the insulation is wet when installed. The obvious question is how long must the insulation be allowed to dry before closing in the wall and installing a vapor barrier? That question is evidently very difficult to answer and we received an extraordinary range of responses from the people we interviewed.

First of all, it depends on climate. We were told that in hot, dry climates, a 3-inch thick installation of spray cellulose should dry completely within 24 to 48 hours. But in humid climates, a much longer drying period may be necessary. Aaron Applegate of Applegate Insulation, a major cellulose manufacturer, told us that he endorses the use of wet-spray cellulose for cavity wall insulation in dry climates such as Arizona, but says it just takes too long to dry in places like Minnesota. Dick Williams, sales engineer at Unisul, the largest manufacturer of spray application equipment, says that in Florida, wet-spray insulation is often used to insulate furring cavities on concrete block walls. In those applications, he suggests a minimum of three days for complete drying.

H.B. Fuller manufactures latex adhesive for use with spray-applied fiberglass insulation. According to its fact sheet for Foster™ 86-60 adhesive, "Complete drying may require 3 to 6 days depending on the thickness and the temperature and relative humidity."

A spokesperson for National Cellulose Corporation told the audience at the ICAA Spray-Applied Insulation Seminar in Kansas City in June 1984 that "you can sheetrock immediately after applying the insulation as long as there is not a vapor barrier on both sides. But what is an effective vapor barrier? If the sheetrock is painted, is that a vapor barrier? A wet-spray applicator in Massachusetts told us that if a wall will have a double vapor barrier, he simply won't take the job.

The following is an excerpt from an installation manual for wet-spray insulation sent to us by Northern Cellulose Products Inc.: "In cavity construction, one side of the wall assembly should be erected; the plumbing and electrical components installed. Safe-T-Spray is then applied to the inner face to assure complete sealing of all cracks, pipes, and outlets. The wall may be closed (generally within a two-day curing time) at the discretion of the applicator. The Safe-T-Spray should be thoroughly dry before closure of the cavity. Open structures should be sprayed to a thickness not exceeding 2-1/2 inches."

The above citation is a perfect example of why the moisture issue is going to be a key problem for the wet-spray insulation industry's penetration into the residential market. If the evaluation of dryness is left up to "the discretion of the applicator," we are bound to see a lot of "seat of the pants" judgment going on. Who will be liable if the wall gets damaged from moisture?

2. Installation effectiveness is very sensitive to installer quality control.

Anyone can buy a machine, some insulation and adhesive, and start selling wet-spray insulation. But the material must be installed at the proper density, with the proper mix of water and adhesive. The installed density determines R-value and the water content affects drying time. The equipment for wet-spray insulation is more complex than that for dry blow-in application and the associated risk of failure is proportionately greater.

I had the opportunity to test various types of application machinery and insulation materials and found the application process generally easy; when I pointed the nozzle at the wall, the insulation came out and stuck to the wall just fine. It was no problem applying the material up to three or four inches thick. But when I grabbed a handful of insulation from the wall and squeezed it, several spoonfuls of water came out. Although I had succeeded in sticking three inches of insulation onto the wall, it was a lousy installation job. When properly applied, little or no water should come out of handful of freshly applied material.

Although it doesn't take extraordinary skill, a proper job requires a conscientious contractor who understands the equipment and takes care and pride in his/her work.

3. Messy.

The application process is noisy, messy, and somewhat wasteful. We saw a demonstration of various products applied using several different makes of blowing machines. The air was filled with "nuisance dust" as one contractor called it. Respirators were a must. Depending on the material and how it is applied, there is a good bit of "fly-off" which ends up on the floor. Although we talked to more than one enterprising contractor who actually shovels it up and puts it in the attic or saves it for the next job, for the most part it's waste. Also, the insulation must be scraped from the wall studs to present a clean working surface for drywall application — an easy job if done while the insulation is wet. But it takes time and creates more mess.

4. Expensive.

The installed cost of wet-spray insulation varies tremendously. For spray cellulose, product and adhesive costs are roughly $.16 to $.23 per square foot for a 3-1/2-inch wall cavity. Typical total installed costs range from $.35 to $.75 per square foot for a 3-1/2-inch wall cavity and $.60 to $.80 per square foot for a 5-1/2-inch wall cavity. Rockwool is more expensive than cellulose with a materials cost of $.27 to $.30 per square foot for a 3-1/2-inch wall cavity. Spray fiberglass is generally the most expensive. Material costs for Certainteed CertaSpray run between $.43 and $.45 per square foot for a 3-1/2-inch wall cavity. When labor, overhead, and profit are added, the cost can be as high as $.90 per square foot.

5. Temperature-sensitive installation.

Although it varies with product, most manufacturers recommend against installing wet-spray insulation when the outdoor temperature is 40°F or below. Evidently below 40°F, the adhesives won't cure properly. Some installers who install cellulose with water only (no adhesive) claim that they can successfully spray as long as the insulation doesn't freeze.

AVAILABLE PRODUCTS

1. Cellulose

For residential sidewall application, cellulose is probably the best bet. Although it is often sold with dry adhesive mixed in with the insulation, some manufacturers and contractors recommend spraying cellulose with water only, claiming that water alone provides enough adhesion and structural integrity for cavity wall applications.

R-value

The R-value of wet-spray cellulose remains somewhat of a mystery. ThermoCon International claims R-values as high as 4.7 per inch for its products (see the July 1985 issue of EDU for further discussion); National Cellulose claims R-4.17; but other manufacturers claim only R-3.7 per inch (the value listed in the ASHRAE Handbook).

Interestingly, the R-4.7 claimed by ThermoCon is at an applied density of 5.5 pounds per cubic foot. Literally every installer we spoke with stated that it was not possible to consistently install wet-spray cellulose at that density. Furthermore, since the R-value of cellulose decreases with density (after the maximum R-3.7), the R-4.7 seems even more incredible.

From what we could gather, the most reliable estimate of the R-value of wet-spray cellulose is about R-3.5 to R-3.7 per inch. However, proponents of wet-spray insulation insist that due to the added thermal advantage of reduced air convection in and through the insulation, wet spray will perform better, relative to fiberglass batts, than is indicated by standard tests for R-value alone. Whole-wall testing to support that claim is being performed at a testing laboratory in Texas. The results should be interesting.

Manufacturers

Although many spray applicators use regular cellulose for wet-spray application, we won't list all 200 U.S. manufacturers. The following three companies, however, distribute cellulose specifically for spray application.

1. National Cellulose Corporation
   12315 Robin Blvd.
   P.O. Box 45006
   Houston, TX 77245
   (713)433-6701

   National Cellulose makes K-13 and Celbar. K-13 is for exposed application, and Celbar is for cavity installation. According to a spokesperson at National Cellulose, Celbar is made with a different type of fiber, but we weren't able to get any specific explanation of how Celbar fibers and K-13 fibers differ. With the K-13, adhesive is added as a liquid during installation. Celbar contains a dry adhesive mixed in with the insulation.

2. ThermoCon International
   2508 New Marlin Highway
   Waco, TX 76705
   (817)756-3713

   Thermocon International makes ThermoCon Commercial Spray and ThermoCon Wall Spray. The Commercial Spray is for exposed applications and the Wall Spray is for cavity installations. With the Commercial Spray, adhesive is added as a liquid during installation. The Wall Spray contains a dry adhesive mixed in with the cellulose.

3. Northern Cellulose Products
Balch St.
P.O. Box 481
Beverly, MA 01915
(800)322-0419

Northern Cellulose sells a product similar to Celbar and ThermoCon wall spray. The claimed R-value is R-3.5 per inch.

2. Fiberglass

Certainteed Corporation
Insulation Group
P.O. Box 860
Valley Forge, PA 19482
(215)687-5000

CertaSpray, manufactured by Certainteed Corporation, is currently the only fiberglass product produced specifically for wet spray application (although we heard a rumor that Fiberglas Canada is developing a new product for wet-spray application). CertaSpray has been on the market since mid-1982. A white tufted fiberglass material, it is basically the same as Certainteed's Insul-Safe III (used for dry-blown application) except that it doesn't have the special fiber coatings which make Insul-Safe so soft and non-itchy. (The coatings evidently prevent the adhesive from binding properly with the glass fibers.) CertaSpray does not have dry adhesive mixed with the insulation. Liquid adhesive is added during installation.

Certainteed claims that CertaSpray has an installed R-value of R-4.0 per inch.

"Unapproved" products.

Some installers use regular fiberglass blowing insulation such as Certainteed's Insul-Safe III, Owens Corning's ThermaCube, and Manville's Rich-R for wet-spray application. According to Irvin Steltz at Foster Products [Division of H.B. Fuller Company, P.O. Box 625, Spring House, PA 19477; (215)628-2600], their adhesive is often used with all the fiberglass materials mentioned above, apparently with no problems.

This is a good example of the lack of reliable guidelines in the wet-spray industry. Owens Corning and Manville are probably not about to launch a campaign to discourage the use of their blowing insulation in wet-spray application, but spokespersons at both companies told us that in "no way, shape, or form" do they recommend the use of their products for wet spray application. Any R-value claims for wet-spray fiberglass (except for CertaSpray) are not from manufacturers' spec sheets.

3. Mineral wool.

Casco Mineral Wool
L.C. Cassidy & Son, Inc.
1918 South High School Road
Indianapolis, IN 46241
(317)241-6391

The most common brand of mineral wool promoted for spray application is Casco, manufactured by L.C. Cassidy & Son, Inc. As with CertaSpray, liquid adhesive is added during installation. Cassidy recommends using Foster 86-60 adhesive.

The Ark-Seal Blown-in-Blanket System

Ark Seal is an equipment manufacturer that advertises a unique system called "Blown-in-Blanket System" (BIBS). Probably due to its very aggressive advertising campaign, we receive lot of inquiries about this product and although it isn't exactly a "wet" spray insulation process, it should be mentioned here.

Basically, BIBS is somewhere between wet-spray and dry blow-in application. Any type of insulation can be used — fiberglass, cellulose, or rockwool. Less adhesive and water are used with BIBS than with conventional spray techniques and the insulation is applied with special application equipment that injects compressed air into the insulation as it leaves the nozzle, causing it to fluff up. The result is a semi-solid blanket with a lower density than wet-spray blankets. According to Jesse Aragon at Ark Seal, cellulose goes in at a density of about 3.0 pounds per cubic foot when properly installed. (With regular wet-spray application, cellulose goes in at 3.5 to 4.5 pounds per cubic foot.) Fiberglass goes in at 1.5 pounds per cubic foot.

Since insulation installed using BIBS won't stick to surfaces, it must be sprayed into a confined space. For new construction, a netting is stapled over the studs and the insulation is sprayed into the wall cavity through holes cut into the netting. Drywall could be used instead, but the advantage of using the netting is that the installation is visible; any voids are easily detected. The disadvantage is that installing the netting can be time consuming and, if improperly done, may result in bulging.

The Ark-Seal process looks good and we spoke to several builders who were quite enthusiastic about it. First of all it is less messy. Not only don't you end up with a pile of insulation on the floor, but the stud faces don't get covered with insulation and don't have to be scraped, as with regular wet-spray applications. Second, since less water and adhesive is added, drying time is shorter. How much shorter? According to Aragon, less than a one-day wait is necessary before closing in the wall. But according to Steltz at Foster Products (whose adhesive is among those recommended by Ark-Seal), two to four days are probably necessary to be completely safe.

According to Aragon, BIBS costs less than conventional wet spray because it uses less insulation and adhesive, and takes less time because there is less mess to clean up. Not everyone agrees. Some contractors told us that netting installation is time consuming and that they can wet-spray a house faster, even with cleanup.

According to Aragon, materials costs per square foot for a 2x4 wall are about \$.11 for fiberglass, \$0.13 for cellulose, \$.01 for adhesive, and \$.015 for the netting. One Texan Ark-Seal contractor gave us a price of \$.30 per square foot for a 2x4 wall and \$.40 to \$.45 per square foot for a 2x6 wall (fiberglass).

The one criticism we heard most was that the Ark Seal equipment was expensive and complicated and that the greater the complexity, the greater the risk of failure.

For more information, contact:

Ark-Seal Inc., International
2185 South Jason
Denver, CO 80223
(303)934-2174
(800)525-8992

Conclusions and Recommendations

Compared to fiberglass batts and blown fiberglass, wet-spray has the advantage of reduced internal air convection in the insulation. Unfortunately, the magnitude of that benefit has not been documented.

Compared to blown cellulose, wet spray has a tough time competing. Although it's a controversial topic, proponents of dry cellulose insist that when properly installed, dry-blown cellulose will not settle. If that's true, then why install wet-spray rather than dry loose fill? Perhaps the most practical advantage was suggested to us by Wayne Johnson of AAA insulation company in Utah. Johnson installs all types of insulation and told us that he personally prefers dry installation. But wet spray has the distinct marketing advantage because you can see it! No matter how competent the installing contractor, with dry blown insulation, a client needs to ride on faith that the insulation is completely filling a wall cavity and that it won't settle. Not so with wet-spray application.

At this point, perhaps the greatest cause for hesitation is the lack of consistent technical data and installation guidelines for these products. Is it really OK to use any type of fiberglass for wet-spray even though that use is not approved by the manufacturers? Does spray-applied cellulose need adhesive or not? How long does a 3-1/2-inch application of wet cellulose have to dry before it can be covered with gypsum board? What is the actual R-value of wet-spray cellulose? Until consistent and reliable answers are available to these and other questions, the future of wet-spray in the residential market is uncertain.

APPENDIX B

Glass and Window Manufacturers

I. GLASS AND ASSEMBLED GLASS UNITS

A. Low-E Glass

1. Interpane Glass
   Interpane Glass Ltd.
   550 Frontage Road
   Northfield, IL 60093
   (312)441-8155
   Contact: Leo Hadley

2. Sungate 100
   PPG Industries, Inc.
   100 Gateway Center
   Pittsburgh, PA 15222
   (412)434-3019
   Contact: Jean V. Wright

Sungate 100 was the first low-E glass to hit the market in the U.S. (see the May/June 1983 issue of EDU). It comes in both clear and bronze double-glazed units. In the bronze unit, the outboard lite is bronze and the inner lite is clear with low-E coating on the outer surface. Both units are made with 1/8" glass separated by a 3/8" air space.

According to a spokesperson at PPG, they are supplying glass to BiltBest, Twin-Pane, and Pella.

Thermal and light transmission properties of Sungate 100 are as follows:

Property	Sungate 100 Clear	Sungate 100 Bronze
R-value	R-2.9	R-2.9
Visible light Transmittance	73%	56%
Total solar Transmittance	55%	43%
Shading coefficient	0.80	0.57

3. Guardian Low-E Glass
   Guardian Industries Corp., Architectural Glass Division
   14600 Romine Road
   Carleton, MI 48117
   (313)962-2252; (800)521-9040

Guardian manufactures low-E glass in a variety of configurations including double-- and triple-glazed units with different width airspaces. It also produces units with tinted (green) outboard panes. Guardian sells in large quantities only, mostly to primary window manufacturers. It supplies the low-E glass for Marvin windows.

The thermal and light transmission properties of Guardian low-E glass are as follows (We have listed values for 1/2-inch air space):

Property	Double-Glazed		Triple-glazed
	Clear	Green	Clear
R-value	R-3.1	R-3.1	R-4.3
Visible light Transmittance	77%	69%	70%
Total solar Transmittance	56%	42%	48%
Shading coefficient	0.74	0.59	0.67

4. Northland Glass
   Northland Glass Industries
   5334 Barthel Drive
   P.O. Box 130
   Albertville, MN 55301
   (612)497-3212; (800)328-9749

Northland fabricates low-E insulated glass units using the Interpane coatings (see above). Thermal and light transmission properties for its clear 7/8-inch unit are as follows:

Property	
R-value	R-3.4
Visible light transmittance	70%
Total solar transmittance	62%
Shading coefficient	0.70

5. Insula Glass
   Floral Glass Industries
   895 Motor Parkway
   Hauppauge, NY 11788
   (516)234-2200

As with Northland low-E glass, Insula glass is made with the Interpane coating. Floral sells mostly to the commercial, high-rise building market. Thermal and light transmission properties are the same as for Northland glass.

6. Cardinal Glass Company
   6700 Excelsior Blvd.
   Minneapolis, MN 55426
   (612)935-1722

Cardinal is the major low-E glass supplier for Andersen windows. The following are the thermal and light transmission characteristics for its clear, double-glazed unit with 3/8-inch air space:

Property	
R-value	R-2.9
Total solar transmittance	55%
Total visible transmittance	76%
Shading coefficient	0.72

7. Ford Sunglas HR
   Ford Glass Division
   300 Renaissance Center
   P.O. Box 43343
   Detroit, MI 48243
   (800)521-6346; (313)568-2300

Sunglas HR (heat reflective) low-E glass.

8. Weathershield Low-E Glass
   Weather Shield Mfg., Inc.
   Medford, WI 54451
   (715)748-2100

B. Heat Mirror Products

Heat Mirror
The Southwall Corporation
3961 East Bayshore Rd.
Palo Alto, CA 94303
(415)962-9111

Southwall makes four grades of Heat Mirror: HM-44, HM-55, HM-66, and HM-88. HM-88 is the original Heat Mirror and is the one most commonly used for residential applications. The other three have lower emissivities than HM-88 and are used in warmer climates or in commercial buildings where cooling load is dominant. Southwall does not make glass units, but sells the Heat Mirror film to window manufacturers. The following data are typical thermal and light transmission characteristics for windows made with two panes of 1/8-inch glass with Heat Mirror film suspended in between, and separated from the glass by two 3/8-inch air spaces. (Note: This data is from Southwall. Some window manufacturers list higher R-values for their Heat Mirror equipped windows. That is probably due to wider interpane air spaces.)

Property	HM-88	HM-55
Film emissivity	.15	.05
R-value	R-3.8	R-4.2
Total solar transmittance	53%	28%
Total visible transmittance	71%	49%
Shading coefficient	0.70	0.41

SUPPLIERS OF HEAT-MIRROR-EQUIPPED WOOD WINDOWS

1. Hurd Millwork Company
   (see section on Window manufacturers)
2. Delabro Millwork
   2340 South 3270 West
   West Valley City, UT 84119
   (801)972-2383
   Contact: Tom DeLaHunt
   Distribution: Arizona, California, Colorado, Idaho, New Mexico, Montana, Nevada, Utah, Wyoming.
3. Louisiana-Pacific Corp.
   (see section on Window manufacturers)

4. Stang Windows
   230 North Central Ave.
   Columbus, OH 43222
   (614)276-8159
   Contact: Mark Denzer

5. Warm-Lite Co.
   P.O. Box 100
   Cornish, NH 03746
   (603)675-620
   Contact: Lawrence Berndt
   Distribution: New England states

SUPPLIERS OF HEAT-MIRROR-EQUIPPED ALUMINUM WINDOWS

1. Almetco of Santa Rosa
   P.O. Box 7251
   1733 Sebastopol Road
   Santa Rosa, CA 95401
   (707)545-6500
   Contact: Jim Kirkbride
   Distribution: California and Nevada

2. AMSCO
   1880 South 1045 West
   Salt Lake City, UT 84125
   (801)972-6444
   Contact: Noel Robertson
   Distribution: Arizona, Colorado, Idaho, Montana, Nevada, Utah, and Wyoming.

3. Belknap Industries, Inc.
   8462 S. 190th Street
   Kent, WA 98031
   (206)251-8210
   Contact: Bill Gomm
   Distribution: Nationwide.

4. A.B.P. Windows
   R.J. Grosso, Inc.
   1249 John Fitch Blvd.
   South Windsor, CT 06074
   (203)289-7986
   Contact: Ron Saunders
   Distribution: New England states, New York, New Jersey, Pennsylvania, North Carolina, and South Carolina.

SUPPLIERS OF HEAT-MIRROR-EQUIPPED VINYL WINDOWS

1. Thermo Systems, Inc.
   5012 Packinghouse Road
   Denver, CO 80216
   (303)295-2723
   Contact: Jim Crawford
   Distribution: Colorado.

2. TRACO (Three Rivers Aluminum Co.)
   P.O. Box 805
   CranberrIndustrial Park
   Warrendale, PA 15095
   (412)776-7000
   Contact: John Kalakos
   Distribution: East of the Mississippi.

SUPPLIERS OF HEAT-MIRROR-EQUIPPED INSULATING GLASS UNITS

1. Almetco of Santa Rosa
   (see above)

2. Alpen, Inc.
   7800 Highway 82
   Glenwood Springs, CO 81601
   (303)945-2445; (800)782-7822 (Colorado only)
   Contact: Robert Clarke
   Distribution: Nationwide

3. Belknap Industries, Inc.
   (see above)

4. Capitol Aluminum & Glass
   1276 West Main St. - U.S. 20
   Bellevue, OH 44811
   (419)483-7050
   Contact: Ray Robinson

5. Delabro Millwork
   (see above)

6. Enhanced Glass Corp.
   2901 Marlin Highway 6
   Waco, TX 76705
   (817)754-3581
   Contact: Arthur Acker
   Distribution: Nationwide

7. Louisiana Pacific Corp.
   (see section on Windows)

8. Temp-Seal, Inc.
   1317 W. El Segundo Blvd.
   Compton, CA 90222
   (213)636-8939
   Contact: Yolanda Wells
   Distribution: California

9. TRACO
   (see above)

C. Triple- and Quadruple-Glazed Units with 3M Sungain Film Interpanes

SunGain film, manufactured by 3M Company is a 4-mil polyester sheet film. As mentioned in Section 7 of this workbook, plastic interpanes have the advantage of reduced weight compared to all-glass triple- or quad-pane units. Sungain has two other advantages. First, it is very clear, thus it allows more sunlight to penetrate the window for passive solar gain. According to 3M, the solar transmittance of a single layer of SunGain is 93 to 96 percent compared to 84 percent for a single sheet of 1/8-inch glass. The high transmittance of the film is due to a special anti-reflective coating which is applied to both sides. The second advantage of SunGain is that it transmits less ultraviolet light than ordinary glass, thus it can help to reduce sun-induced fabric fading.

The following thermal and light transmission characteristics are for typical glazing units with SunGain interpanes. The triple-glazed units have two 3/8-inch air spaces; the quad-pane units have two 3/8-inch air spaces plus one 3/4-inch air space:

Property	Triple-glazed	Quad-pane
R-value	R-2.8	R-3.8
Total solar transmittance	66%	63%
Total visible transmittance	79%	78%
Shading coefficient	0.85	0.82

The following manufacturers produce glass units and/or windows with SunGain interpanes:

1. WeatherShield Windows
   (see section on Windows)

2. Northland Glass Company
   (see address in low-E glass section above)

3. All-Weather Inc.
   Box 3370, CRS
   Johnson City, TN 37601
   (615)282-1121

4. Air Seal Insulating Glass Company
   522 Powell Street
   Gloucester City, NJ 08030
   (609)456-3922

5. Rocky Mountain Solar Glass
   7123 Arapahoe
   Boulder, CO 80303
   (303)442-4277

D. TINTED AND REFLECTIVE GLASS

Many of the major window manufacturers produce insulating glass units with one pane of tinted or reflective glass. The following are two brands of tinted sheet glass specifically designed for residential application. Neither is reflective; they don't appear shiny from indoors or out.

1. Ford Sunglas
   Ford Motor Company, Glass Division
   30 Renaissance Center, P.O. Box 43343
   Detroit, MI 48243
   (313)568-2324

2. Koolvue Bronze
   AFG Industries, Inc.
   P.O. Box 929
   Kingsport, TN 37662
   (615)245-0217

Property**	Sunglas	Koolvue
color	green	bronze
shading coefficient	0.87	0.88
total solar trans.	70%	72%
total visible trans.	86%	74%
total solar reflected	7%	6%

*All data is for single-strength (3/32") single glass.

E. HIGH-TRANSMITTANCE GLASS

1. Solakleer
   General Glass International Corp.
   542 Main Street
   New Rochelle, NY 10801
   (914)235-5900

2. Solatex 1, Solatex 2
   AFG Industries Inc.
   P.O. Box 929
   Kingsport, TN 37662
   (615)229-7200

Solarkleer is a completely transparent low-iron glass, suitable for passive solar windows, sunspaces, etc. Solatex is a very high-transmittance glass used mostly for solar collector cover plates. Solatex 1 has a roughened surface to reduce glare; Solatex 2 is smooth, but translucent.

Glass	Iron oxide content	Total Solar Transmittance	Total visible transmittance
Solakleer1/8"	0.057%	90.1%	91.6%
Solatex 1"	0.04%	91.0%	not available
Solatex 2"	0.04	91.0%	not available

II. MANUFACTURED WINDOWS

The following list includes specifications and performance data for several energy-efficient residential windows. No attempt was made to list all manufacturers. Rather, we limited our scope to those windows produced by major manufacturers for residential application and/or those windows with notable energy-efficiency.

1. Andersen Windows
   Andersen Corporation
   Bayport, MN 55003
   (612)439-5150

Styles: casement, awning, slider, double-hung, patio door, skylight
Frame and sash construction: wood, primed or vinyl-clad
Glazing:

Double glazing:	double-pane insulating glass	R-1.9
	low-E double-pane insulating glass	R-3.3

Triple glazing:	double-pane insulating glass with additional removable glazing panel or combination storm window	R-3.1
	low-E double-pane insulating glass with additional removable glazing panel or combination storm window	R-4.5

Andersen did have a tri-pane insulating glass unit on the market for about a year, but it has been discontinued.

Air leakage:

casement (vinyl-clad)	0.09 cfm/ft
awning	0.15 cfm/ft
double-hung	0.20 cfm/ft
slider	0.20 cfm/ft

2. BiltBest Windows
   DG Shelter Products
   175 Tenth Street
   Ste. Genevieve, MO 63670
   (314)883-3575

Styles: casement, awning, double-hung, slider, patio door
Frame and sash construction: wood, primed or aluminum-clad
Glazing:

Double glazing:	5/8" double-pane insulating glass	R-2.0 to R-2.5
	low-E (PPG Sungate 100) double-pane glass	R-3.2

BiltBest was the first major window manufacturer to use PPG's Sungate 100 low-E glass. It has discontinued its line of triple-pane insulating glass units.

Air leakage:

casement	0.03 cfm/ft
double-hung	0.24 cfm/ft

3. Caradco Windows
   Caradco Corporation
   P.O. Box 920
   Rantoul, IL 61866
   (217)893-4444

Styles: casement, awning, double hung, slider, patio doors
Frame and sash construction: wood, aluminum-clad or primed

Glazing:

Double glazing:	double-pane insulating glass	R-2.0 to 2.3
Triple glazing:	double-pane insulating glass with additional removable glazing panel	R-3.0
	triple-pane insulating glass	R-2.7

Caradco uses Ford Sunglas for the outboard lite on its clad casement and awning windows and sliding glass doors. These windows therefore have relatively low shading coefficients — around 0.75. Casement windows have 3/32" Ford Sunglas outside lite, 3/32" clear inside lite, with 1/4" airspace. The 3-foot sliding glass door units have 1/8" Ford Sunglas outside lite, 1/8" clear glass inside lite with 3/4" airspace. The clad slider has two clear lites with 9/16" airspace.

Air leakage:

casement	0.03 cfm/ft
clad double-hung	0.09 cfm/ft
primed double-hung	0.22 cfm/ft
clad awning	0.03 cfm/ft
primed awning	0.05 cfm/ft
clad slider	0.07 cfm/ft
primed slider	0.15 cfm/ft
clad patio door	0.11 cfm/ft
primed patio door	0.05 cfm/ft

4. Ekono Windo
   Ekonowindo Inc.
   410 Bellevue Way S.E.
   Bellevue, WA 98004
   (206)455-5969

Styles: commercial "airflow" window
(see the March/April 1983 issue of EDU)

5. Hurd Windows
   Hurd Millwork Company
   520 S. Whelen Avenue
   Medford, WI 54451
   (715)748-2011

Styles: casement, awning, double-hung, slider, patio door
Frame and sash construction: wood, aluminum-clad or primed
Glazing:

Double glazing:	1" double-pane insulating glass		R-2.3
Triple glazing:	triple-pane insulating glass		R-3.1
	double-pane insulating glass plus additional removable glazing panel		R-3.3 to 3.7
	triple-pane insulating glass with Heat Mirror interpane	3/4" unit	R-3.2
		1" unit	R-4.0

The listed R-values of Hurd windows are different for clad units and primed units. Casement, awning, and patio doors come with 1" glass; double-hung windows come with the 3/4" glass.

Hurd used to manufacture a vinyl-clad window, it has discontinued it.

Air leakage:

clad casement/awning	0.04 cfm/ft
primed casement/awning	0.06 cfm/ft
clad double-hung	0.14 cfm/ft
primed double-hung	0.12 cfm/ft
patio door	0.10 cfm/ft

6. JX-7 Windows
   Jeld-Wen Inc.
   Commerce Drive
   Mount Vernon, OH 43050
   (614)397-3403

Types: casement, awning, double-hung, sliders, single-hung, patio doors
Frame and sash construction: wood, aluminum-clad or primed

Glazing:

Double glazing:	single glazing with combination storm unit	R-2.1
	double-pane insulating glass	R-2.0
Triple glazing:	double-pane insulating glass plus additional removable glazing panel	R-3.1

Unit width of JX-7 windows with double glazing is 1/2". Airspace thickness is 1/4".

Air leakage:

casement	0.01 cfm/ft
double-hung	0.04 cfm/ft
slider	0.23 cfm/ft
single hung	0.13 to 0.18 cfm/ft
patio door	0.24 cfm/ft

7. Louisiana Pacific Windows
   Louisiana Pacific Corporation
   32 Wooster Road N
   Barberton, OH 44203
   (216)745-1661

Types: casement, awning, double-hung, slider, patio door
Frame and sash construction: wood, primed or aluminum-clad frame; vinyl-clad sash
Glazing:

Double glazing:	3/4" double-pane insulating glass	R-1.9
Triple glazing:	3/4" triple-pane insulating glass	R-2.4
	3/4" triple-pane insulating glass with Heat Mirror interpane	R-3.3

Air leakage:

casement	0.11 cfm/ft
double-hung	0.31 cfm/ft
awning	0.08 cfm/ft
patio door	0.28 cfm/ft

8. Malta Windows
   Philips Industries Inc., Malta Division
   P.O. Box 397
   Malta, OH 43758
   (614)962-3131

Types: casement, awning, double hung
Frame and sash construction: wood, primed or vinyl clad
Glazing:

Double glazing:	double-pane insulating glass casement — 5/8" unit	R-2.2
	double hung — 1/2" unit	R-1.9
Triple glazing:	double-pane unit plus additional removable glazing panel	
	casement	R-3.2
	double hung	R-3.0

Air leakage:

clad casement	0.02 cfm/ft
primed casement	0.04 cfm/ft
double hung	0.16 cfm/ft

9. Marvin Windows
   8030 Cedar Ave. S., #228
   Minneapolis, MN 55420
   (612)854-1464

Styles: casement, double-hung, single-hung, slider, patio doors
Glazing (all values are for clad units):

Single glazing		R-1.1
Double glazing	single glazing plus additional removable glazing panel	R-2.2 to 2.3
	1/2" double-pane insulating glass	R-2.0
	1/2" low-E insulating glass	R-3.5
Triple glazing	double insulating glass plus additional removable glazing panel (casement and awning)	R-3.1
	double insulating glass plus combination storm (double-hung)	R-3.3

Air leakage (all values for clad windows):

casement	0.05 cfm/ft
double-hung	0.17 cfm/ft
slider	0.11 cfm/ft
patio door	0.22 cfm/ft

10. Norco Windows
    Norco Windows, Inc.
    Hawkins, WI 54530
    (715)585-6311

Types: casement, awning, slider, patio doors

Frame and sash construction: wood, aluminum cladding

Glazing:

Double glazing	3/4" double-pane insulating glass	R-2.1
	1/2" double-pane insulating glass	R-2.0
Triple glazing	double-pane insulating glass plus additional removable glazing panel	R-2.7
	double-pane insulating glass plus combination storm window	R-2.9
	3/4" triple-pane insulating glass	R-2.6

Norco casement and awning windows come with 3/4" glass units; double-hung windows come with 1/2" glass units. For triple glazing, the casement and awning units have the removable glazing panel; double-hung units have storm windows.

The above values are all for clad windows only.

Air leakage:

clad casement	0.06 cfm/ft
clad double-hung	0.18 cfm/ft

11. Nor-Guard Windows
    Noranda Building Products Co.
    7120 Kric Road
    Cleveland, OH 44146
    (216)232-5500

Types: casement, single-hung, patio door
Frame and sash construction: aluminum with thermal break
Glazing:

Double glazing:	double-pane insulating glass, 5/8"	R-1.5 to 1.7
Triple glazing:	double-pane insulating glass plus additional removable glazing panel	
	casement	R-2.1
	single-hung	R-3.8
	slider	R-3.0

The exceptionally high R-value of triple-glazed single-hung windows is very difficult to explain. We requested and received a copy of results of thermal testing performed by Architectural Testing Inc., York, Pennsylvania. That report listed the U-value of the triple-glazed single-hung window as 0.26, which translates into an R-value of R-3.8.

Air leakage:

casement	0.03 cfm/ft
single hung	0.05 cfm/ft
slider	0.46 cfm/ft

12. Peachtree Windows
    Peachtree Doors Inc.
    Box 700
    Norcross, GA 30091
    (404)449-0880

Types: casement, awning, fixed, patio door
Frame and sash construction: Ariel casement, awning, and fixed windows have aluminum extrusion exterior frame and wood interior frame. Sash is aluminum extrusion on exterior and vinyl on interior.

Glazing:

Single glazing:		R-1.2
Double glazing:	double-pane insulating glass	R-1.8 to 2.1
Triple glazing:	double-pane insulating glass plus additional removable glass panel	R-3.2 to 3.3

An alternative double-glazing option is available using a single-glazed primary unit plus an additional removable glass panel. Double-glazed unit and removable panel are available with tinted heat-absorbing glass.

Air leakage:

casement and awning windows	0.05 cfm/ft

13. Pella Windows
    Rolscreen Company
    Pella, IA 50219
    (515)628-1000

Types: casement, awning, double-hung, patio doors, skylights
Frame and sash construction: wood, aluminum clad or primed
Glazing:

Single glazing:		R-1.0 to 1.2
Double glazing:	single glazing plus additional removable glazing panel	R-2.2 to 2.5
	with white slimshade (slimshade closed)	R-3.0 to 3.3
	with Type E slimshade (low-emissivity) (slimshade closed)	R-4.0 to 4.4
Triple glazing:		R-2.9 to 3.2
	single glazing plus additional double-pane insulated glass panel	R-3.0 to 3.2
	triple-pane insulating glass	R-2.9

Pella's basic double-glazed unit consists of a single pane of glass plus a removable, interior-mounted second panel. The airspace width between the two panes is 13/16".

For triple glazing, there are two options. The first is a removable double-pane insulating glass unit (1/4" air space) added to the inside of a single-glazed sash. The other triple-glazing option is a sealed triple-pane unit with two 1/4" air spaces. The R-value of the sealed triple-pane unit is less than the R-value of the combination triple-glazed unit because of the thicker air spaces in the combination unit.

According to a spokesperson at Pella, they will also be producing a low-E window unit.

Air leakage:

casement	0.03 cfm/ft
awning	0.03 cfm/ft
doublc-hung	0.15 cfm/ft

14. SealRite Windows
    SealRite Windows Inc.
    P.O. Box 4468, Uni Place Station
    3500 North 44th Street
    Lincoln, NE 68504
    (402)464-0202

Types: casement, awning, double hung, slider
Frame and sash construction: wood, primed or aluminum clad
Glazing:

Single glazed (double hung and slider only:)		R-1.1
Double glazing:	double-pane insulating glass	R-2.0
Triple glazing:	double-pane insulating glass plus additional removable glass panel	R-3.1

Air leakage:

casement	0.01 cfm/ft
awning	0.01 cfm/ft
double hung	0.25 cfm/ft

15. The Sunflake Window
    Sunflake
    P.O. Box 28
    325 Mill Street
    Bayfield, CO 81122
    (303)884-9546

Sunflake is a unique window (see the November 1983 issue of EDU) consisting of two equal sections in one frame: a visible glazed opening and a concealed pocket that contains a sliding insulating shutter made of rigid insulation.

Types: casement, awning, patio doors
Frame construction: wood, primed
Glazing: single glazing plus removable double-glazing panel. R-value data for the glazing section alone is not available (see the above mentioned EDU article).
Air leakage: 0.03 cfm/ft

16. Weather Shield Windows
    Weather Shield Manufacturing Co., Inc.
    Medford, WI 54451
    (715)748-2100

Types: casement, awning, double-hung, sliders, fixed, patio doors
Frame and sash construction: wood frame, aluminum or vinyl clad. Sash of casement windows is aluminum or vinyl covered. Double-hung and slider sashes are factory finished with polyurea.
Glazing:

Double glazing:	5/8" double-pane insulating glass	R-2.1 to 2.2
	1" double-pane insulating glass	R-2.3 to 2.5
Triple glazing:	1" triple-pane insulating glass	R-3.0 to 3.1
	1" triple-pane insulating unit with two glass outer panes plus 3M Sungain film interpane	R-3.0 to 3.1
Quadruple glazing:	1-1/2" quad-pane insulating unit with two glass outer panes plus two Sungain interpanes	R-3.8 to 4.0

Air leakage:

casement windows	0.02 cfm/ft
awning windows	0.15 cfm/ft
double-hung windows	0.14 cfm/ft
sliders	0.17 cfm/ft

III. REFLECTIVE FILM FOR RESIDENTIAL APPLICATIONS

The following list includes manufacturers of reflective films suitable for residential applications. (Source: WES, April, 1984; see below)

1. Coolux
   3660 N.E. 3rd Ave.
   Fort Lauderdale, FL 33334
   (305)563-7991

2. ESM, Inc.
   82 Boston Post Rd.
   Waterford, CT 06385
   (203)444-6701

3. Energy Warehouse Inc.
   6523 E. 46th St.
   Tulsa, OK 74145
   (918)664-9491

4. 3M
   3M Center
   St. Paul, MN 55144
   (612)733-9093

5. Gila River Product
   6615 W. Boston St.
   Chandler, AZ 85224
   (602)961-1244

6. Madico, Inc.
   64 Industrial Pkwy.
   Woburn, MA 01888
   (617)935-7850

7. National Metallizing
   P.O. Box 5202
   Princeton, NJ 08540
   (609)443-5000

8. Optical Coating Laboratory, Inc.
   2789 Northpoint Pkwy.
   Santa Rosa, CA 95401
   (707)525-7540

9. Pro Marketing Associates
   1375 S. 33r
   Lincoln, NE 68510
   (402)474-1234

10. Solar-Screen Corp.
    53-11 105th Street
    Corona, NY 11368
    (212)592-8222

11. Sun Control Products, Inc.
    431 4th Ave. S.E.
    Rochester, MN 55904

12. Sun-X International, Inc.
    P.O. Box 7764
    Houston, TX 77270
    (713)869-8331

IV. SHADESCREENS

The following products are all frame-mounted shading materials that are installed on the outside of windows to reduce solar heat gain:

1. ShadeScreen and SunScreen
   Phifer Wire Products, Inc.
   P.O. Box 700
   Tuscaloosa, AL 35403
   (205)345-2120

2. Vimco Solar Shields
   Virginia Iron & Metal Co.
   P.O. Box 8229
   Richmond, VA 23226
   (804)266-9638

3. Sun Checker Solar Screen
   Sun Check, Inc.
   Chester, VA 23831
   (804)748-9035

4. 3S Haluscreen
   2664B Mercantile Drive
   Rancho Cordova, CA 95670
   (916)635-2440

V. SOURCES OF FURTHER INFORMATION

A. ORGANIZATIONS

1. National Woodwork Manufacturers Association
   205 West Touh
   Avenue
   Park Ridge, IL 60068
   (312)823-6747
   Trade association of manufacturers of wood-framed windows

2. Architectural Aluminum Manufacturers Association
   35 E. Wacker Drive
   Chicago, IL
   (312)698-3543
   Trade association of manufacturers of aluminum-framed windows.

3. Sealed Insulating Glass Manufacturers Association
   111 E. Wacker Drive
   Chicago, IL 60601
   (312)644-6610

4. Flat Glass Marketing Association
   3310 Harrison St.
   Topeka, KS 66611

B. BOOKS AND PERIODICALS

1. WES: The Voice of the Window Treatment Industry
   Industrial Fabrics Association International
   345 Cedar Building, Suite 450
   St. Paul, MN 55101
   (612)222-2508

2. Glass Digest
   Ashlee Publishing Company, Inc.
   310 Madison Ave.
   New York, NY 10017
   (212)682-7681

3. Windows: Performance, Design and Installation, by H.E. Beckett and J.A. Godfrey, Van Nostrand Reinhold, 1974.

4. Glass Engineering Handbook, by E.B. Shand, McGraw Hill, 1958

5. Thermal Shutters and Shades, by William A. Shurcliff, Brick House Publishing Co., 1980.

6. Movable Insulation, by William Langdon, Rodale Press, 1980.

7. ASHRAE Handbook of Fundamentals, 1981, American Society of Heating, Refrigeration and Air Conditioning Engineers, Atlanta.

APPENDIX C

AIR AND VAPOR SEALING PRODUCTS

VAPOR BARRIER MATERIALS

Cross-laminated polyethylene

Tu-Tuf

Sto-Cote Products, Inc.
P.O. Box 310
Richmond, IL 60071

Rufco 300 and 400

Raven Industries Inc.
Box 1007
Sioux Falls, SD 57117-1007
(800)227-2836

Swedish Vapor Barrier Polyethylene

Tenoarm

Resource Conservation Technology, Inc.
2633 N. Calvert Street
Baltimore, MD 21218
(301)366-1146

Acoustical sealant for sealing polyethylene air/vapor barriers

Tremco Acoustical Sealant

Tremco
10701 Shaker Blvd.
Cleveland, OH 44104

HOUSEWRAP MATERIALS (Exterior Air Barriers)

Barricade

Simplex Products Division
Anthony Industries
P.O. Box 10
Adrian, MI 49221-0010
(517)263-8881

Tyvek

Dupont Company
Textile Fibers Department
Wilmington, DE 19898

VersaWrap

DiversiFoam Products
1901 13th Street N.E.
New Brighton, MN 55112
(800)752-4306

Parsec Airtight Wrap

Parsec, Inc.
P.O. Box 38527
Dallas, TX 75238
(800)441-0324

Rufco-Wrap

Raven Industries, Inc.
P.O. Box 1007
Sioux Falls, SC 57117-1007
(800)227-2836

PLASTIC "POLYPANS" FOR SEALING AROUND ELECTRICAL BOXES

Solatech
7726 Morgan Ave. S.
Minneapolis, MN 55423
(802)229-4236

Energy Conservation Equipment
Box 161
Worcester, VT 05682

Acro Foam & Plastics Ltd.
1 Jidaro Valley
52109 Rge. Rd. 224
Sherwood Park, Alberta T8C 1B6, Canada
(403)922-5094

Lessco Air-Vapor Boxes
990 Mink Lane
Campbellsport, WI 53010
(414)533-8690

Iberville Products
100 Longtin
Saint-Jean-Sur-Richelieu
Quebec, Ontario J3B 3G5 Canada
(204)338-5960

N.R.G. Saver
Box 50, Group 32, RR 1B
Winipeg, Manitoba R3C 4A3 Canada

Commander Electrical Materials Inc.
100 Longtin St.
Saint-Jean-sur-Richelieu, Quebec J3B 3G5, Canada

TAPE FOR SEALING VAPOR BARRIERS AND FOAM SHEATHING

Parsec Thermobrite Tape

Parsec Inc.
Box 38534
Dallas, TX 75238

Contractor Sheathing Tape
3M Company
Minneapolis, MN

GASKETS FOR AIRTIGHT DRYWALL APPROACH CONSTRUCTION

Denarco Sales Company
P.O. Box 793
Elkhart, IN 46515
(219)294-7605

Log Home foam

Norton Performance Plastics
One Sealant Park
Drawer T
Granville, NY 12832
(518)642-2200

#7A Neoprene foam

Arlon
2811 S. Harbor Blvd.
P.O. Box 5260
Santa Anna, CA 92704
(800)854-0361

Emseal
3310 Elmbank Rd.
Mississauga, ON L4V 1A5 Canada

Illbruk USA
447 Elmwood
Troy, MI 48084

Gaska Tape Inc.
P.O. Box 1968
Elkart, IN 46515
(219)294-5431

Green Rod
Nomaco, Inc.
Hershey Drive
Ansonia, CT 06401

Swedish gasket system

Resource Conservation Technology, Inc.
2633 N. Calvert Street
Baltimore, MD 21218
(301)366-1146

Appendix D

Source Materials

Section 2 — Energy Dynamics

Section 3 — Moisture Control

Section 8 — Ventilation and Indoor Air Quality

Section 9 — Heating and Cooling

Appendix A — Insulation Materials

This section includes edited excerpts from "An Assessment of Thermal Materials and Systems for Building Applications," published by the U.S. Department of Energy and prepared by Brookhaven National Laboratory with Dynatech R/D Company; The Superinsulated Home Book, by J.D. Ned Nisson and Gautam Dutt, John Wiley & Sons, 1986; and selected articles for Energy Design Update.