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NEW RESIDENTIAL BUILDING CONSTRUCTION IN THE UNITED STATES

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Abstract

This paper summarizes the information obtained, concerning new residential construction in the United States and points out important differences between U.S. and Swedish technology and construction methods for energy-efficient housing.

Selected building components for U.S. housing are described and compared with corresponding Swedish techniques.

The most important differences are:

a. Differences in ventilation strategies; almost all new Swedish houses have continuous mechanical ventilation.
b. The airtightness of building envelopes.
c. Wall constructions and standard insulation practices.

There are energy-efficient U.S. houses, especially in the colder parts of the country, that have the same features as the most energy-efficient houses in Sweden, but the variations from standard construction are much greater in the United States.

Keywords: construction details, new construction, ventilation systems, energy efficiency

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Introduction

There are, at the moment, on-going discussions about technology transfer between Sweden and the United States in new energy-efficient housing construction. This paper summarizes information obtained during the spring of 1983 concerning new residential construction in the United States and points out important differences between U.S. and Swedish technology and construction methods for energy-efficient housing. The focus is on new construction, although many of the techniques are applicable to retrofits.

Because wood-frame construction is the most common residential form in both countries, and requires special methods to achieve airtightness, it is the primary focus of this paper. Concrete and brick constructions are not treated; however, ventilation problems, etc., also apply to these types of constructions.

The comments and comparisons given below are based on information obtained from builders and persons involved in building research and information (see Acknowledgements). The examples of energy-efficient U.S. building practice are valid mostly for the northern states, although basically the same materials and technology, with regional variations, are common throughout the country.

The northern midwest is influenced by Canadian technology, and some of the details shown are of Canadian origin. However, Canadian details are not directly discussed in this paper.

Notes and figures from site visits are given in Appendix A.

Comments on New Construction

The most important energy-related differences found between U.S. and Swedish construction are those concerning ventilation systems, airtightness, wall constructions and standard insulation practices. The following is an effort to describe current U.S. construction mostly in terms of energy efficiency. It briefly compares U.S. and Swedish building technology for selected components of new residential housing to point out differences between the countries. The components discussed are:

a. Ventilation
b. Airtightness
c. Insulation
d. Windows
e. Doors
f. Walls
g. Roofs and Ceilings
h. Foundations

a. Ventilation

In Standard 62-81, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) specifies minimum ventilation requirements for acceptable indoor air quality. For a typical detached house the ventilation required is about 0.4 air changes per hour (ac/h), see Table 1. (This standard, however, is not yet in the building codes.) The dominant process is ventilation from infiltration with intermittent manually-operated fans in bathrooms and kitchens. The bathroom fan is, in some cases, connected directly to the attic, and the kitchen exhaust fan is sometimes replaced with a charcoal filter. In new construction, ventilation systems with "air-to-air heat exchangers" are becoming more common because infiltration is not always enough to supply the ventilation needed in airtight structures, and also not controllable.

Table 1. Outdoor air requirements for ventilation of residences, according to ASHRAE Standard 62-81. Operable windows or mechanical ventilation shall be provided for use when occupancy is greater than usual conditions or when unusual contaminant levels are generated within the space. Ventilation rates given are independent of room size.

	Outdoor Air Requirements per room	
	ft^3/minute	liters/second
General living areas	10	5
Bedrooms	10	5
All other rooms	10	5
Kitchens[1]	100	50
Baths, toilets[1]	50	25

1. Installed capacity for intermittent use.

Natural gas furnaces and water heaters are very common in the United States. These require air for combustion and a flue, which in some cases increases the ventilation rate by depressurizing the building. If a mechanical exhaust fan ventilation system is to be installed, special consideration must be given to the fact that the exhaust fan also depressurizes the building and that therefore the flow of combustion air could be reversed. Builders who have switched to electrical heating, which does not require a flue for combustion, have noticed lower ventilation rates; as a result some have abolished vapor barriers in ceilings.

The Swedish Building Code[4] requires 0.35 l/sm^2 (approx. 0.5 ac/h in dwellings with normal ceiling height) of continuous ventilation in the entire living space. This has resulted in two basic types of mechanical ventilation: exhaust fan ventilation, and a "balanced" ventilation system with both supply and exhaust fans, see Fig. 1. Heat recovery devices taking exhaust air energy are installed in most new houses more because of favorable governmental loan regulations than because of cost-effective energy savings (i.e., on a private basis).

Proper ventilation is also a security for builders, in order to avoid excessive internal moisture built-up and related problems. The warranty period for Swedish houses is normally two years for obvious errors, but claims can be made for hidden faults up to 10 years after the completion date. Moisture problems are the most common cause for complaint in Swedish houses.

Heat recovery on the exhaust ventilation air in Sweden is by means of heat pumps or heat exchangers. Heat pumps heat domestic hot water and sometimes also the radiator water in hydronic heating systems. They are used mostly in connection with exhaust fan ventilation systems. Heat exchangers are generally used with balanced ventilation systems to heat incoming ventilation air. There are units available in combination with forced-air heating systems, although these systems are uncommon in new Swedish dwellings.

b. Airtightness

Unlike Sweden, the United States has no standard or requirement on the airtightness of whole buildings. However, an ASHRAE committee is working on a leakage standard. A first draft is being prepared, in which the airtightness requirement varies with the number of degree days.

Some U.S. builders are aware of techniques to make buildings airtight, and have achieved good results according to pressurization tests. A typical method of achieving airtight seams in the air/vapor barrier, in these cases, is by caulking with e.g. acoustical sealant, see Fig. 2.

For more design details on airtight construction in the United States and in Sweden, see Appendix A and references.

The Swedish Building Code's performance requirement for airtightness of entire buildings, measured with pressure testing (3 ac/h at 50 Pascals pressure difference in detached houses), has leveled out variations in construction quality and forced less advanced builders to learn necessary techniques. The normal technique for sealing seams in the air/vapor barrier in Sweden would be approximately 200 mm (8 inches) overlap joints over studs clamped by the interior sheathing, often with seams allowed in only a few specified places.

There are, in practice, two types of materials used for achieving airtightness in new wood-frame houses: air/vapor barriers (mostly polyethylene), and air barriers that allow vapor to diffuse through them. Polyethylene air/vapor barriers are different in terms of thicknesses and stability against UV-radiation and oxidation, both between and within the U.S. and Sweden. "Tu-Tuf" is a new polyethylene product not yet introduced in Sweden. Vapor-permeable air barriers will normally be installed on the outside in colder climates and do not exclude the use of a vapor barrier. These air barrriers (e.g., "Tyvek" and "Parsec") are available in large sheets but not yet in common usage in the United States. Tyvek has just been introduced in Sweden.

c. Insulation

Levels of insulation in the U.S. and Sweden naturally differ because of codes and climatic differences. Especially within the U.S., with its wide range of climate and not so strict building codes, one would expect big differences in installed insulation thicknesses for comfort reasons, but this does not seem to be the case. Table 2 shows requirements on U-values for different countries. It should be noted that the U.S. requirement, here exemlified by the ASHRAE Standard 90-80, is not mandatory and only adopted in some of the U.S. building codes.

In Sweden, as of 1984, special regulations apply to single-family houses in which direct electrical heating is to be installed. These houses must be designed for lower energy consumption, including lower maximum U-values for outer walls and roofs, 0.17 and 0.12 W/m^2K, respectively (R-33 and R-47 $hrft^{2\circ}F/Btu$, respectively). Heat recovery from ventilation air will also be required.

Table 2. Maximum permitted heat transfer coefficients (U-values) in W/m^2K for outer parts of dwellings for countries affiliated to the Air Infiltration Centre (from Ref. 1). Note: In Canada, Netherlands and United States the requirements often are given as R-values (Here: RSI=1/U; R=5.67*RSI).

	Canada 1978	Denmark 1979	Netherlands 1978	Norway 1980	Sweden 1980	Switzerland 1980	United Kingdom 1982	United States ASHRAE 1980
Roof	0.14-0.40[1]	0.20	0.78	0.23	0.17-0.20[1]	0.50	0.35	0.14-0.28[1]
Exposed outside wall	0.27-0.40	0.30-0.40[3]	0.78	0.25	0.25-0.30	0.60	0.60	0.60-1.60[5]
Exposed floor structure	0.21-0.40	0.20	0.78	0.23	0.17-0.20	0.60	0.60	
Floor structure above crawlspace	0.21-0.40	0.30	1.92	0.30	0.30	0.60		0.25-2.00
Floor structure on earth	0.21-0.40[2]	0.30	1.92	0.30	0.30	0.80		0.34-3.33
Floor structure above cellar	0.21-0.40	0.40	1.92	0.30	0.50	0.80		0.25-2.00
Windows	2.2-3.3	2.90	2.80[4]	2.10	2.00	3.30		
Doors	0.7	2.00		2.00	1.00			

1. Numbers vary depending on climate zones (Sweden) or number of heating degree days (United States, Canada).
2. Perimeter insulation required if floor <600 mm below ground level.
3. Depends on wall density, the higher demand on light-weight walls.
4. Only in living room and kitchen.
5. Includes windows and doors.

The most common materials for above grade insulation are mineral wool batts (both rockwool and glass fiber) in Sweden and glass fiber in the United States. Different qualities of polystyrene are popular as insulation for foundations. Blown-in mineral wool or cellulose fiber is used for attic insulation in the United States. Cellulose is sometimes even used in walls, especially for retrofitting buildings. Measures should be taken to ensure that the cellulose fibers are blown in to the right density, since this is greatly affects the performance.

Densities in glass fiber batts are different between the countries. The bulk density for standard wall insulation is about 10 kg/m^3 in the United States, compared to about 22 kg/m^3 for Swedish A-quality batts. The "R-13" batt has a bulk density of about 15 kg/m^3.

The double-wall design, shown later in the section on walls, along with special roof trusses, are sometimes used in the United States to allow for installing greater thicknesses of insulation. These are, however, representative only of the relatively few "super-insulated" houses built in the northern states.

Composite studs are becoming common in Sweden, especially in manufactured housing. This is because of increased insulation thicknesses installed to meet the more stringent 1984 code requirements. Homogeneous studs in thick dimensions tend to be very expensive, as are multi-layer walls with crossing studs. The same U-value can be maintained with thinner walls that use composite studs. There are at least three types of composite studs available on the Swedish market, see Fig. 3a. An American relative to these, though not structural, is the "Larsen truss", which is used especially when adding thick wall insulation to existing houses, see Fig. 3b.

When installing insulation batts, it is important to avoid gaps that form convection paths. Friction-fit batts fill the space between studs better than foil- or paper-faced blankets, which are stapled to the framing members, see Fig. 4.

In Sweden, great care is taken to protect insulation from air movements, both from internal convection that could be caused by poor wind protection and from blow-through. This means a good wind barrier on the outside must complement the air/vapor barrier on the inside. Attic insulation is also protected from wind by building paper.

d. Windows

Sliding windows (horizontal and vertical) seem still to be the most common type in the U.S. In milder climates single-glazed windows are generally used, while in the more severe climates double-glazed windows, sometimes with an additional storm window, are used. The glazing distance in insulating panes is commonly about 1/8 inch, although some manufacturers use a wider gap. Even in "super-insulated" houses having double-wall construction one often sees only double-glazed windows.

Severe thermal bridges exist in metal windows where the metal is continuous from inside to outside. Some of them have a vinyl coating, which is not sufficient to prevent surface condensation, etc.

The typical window installed in Swedish houses is a triple-glazed wooden casement window, with two panes of insulating glass about 12 mm

(1/2 inch) apart on the inside of the third pane. All windows are factory-made with integral frame and weather stripping. Storm windows are not used in Sweden, although the space on the inside of the outer pane normally is ventilated to prevent surface condensation.

e. Doors

Metal doors with foam cores are gaining popularity in the U.S. Some types use metal from inside to outside, which seems to cause a severe thermal bridge, while others use wood edges. Advantages claimed for metal doors are that magnetic weather stripping could be used ("refrigerator type"), and that they warp less than wooden doors. However, some builders interviewed stated that some of these doors also warped.

Swedish doors are mostly wood-frame construction with insulation in accordance with the requirement in the building code. Metal doors are rarely used in Swedish dwellings other than in air-raid shelters.

f. Walls

Standard wall construction in the U.S. is 2 by 4 (1.5 by 3.5 inches) studs spaced 16 inches on center. According to the National Association of Home Builders (NAHB), 76% of all new walls built in 1980 in single-family houses were of this construction. However, 2 by 6 construction, 16 or 24 inches on center, is becoming more common. (Some builders commented that 2 by 6 studs sometimes were difficult to get.) Double walls comprised of two insulated 2 by 4 frames with about 4 inches of insulation in between are becoming popular among some groups in the northern states, see Fig. 5. Walls with crossing studs are very uncommon, as are composite studs, both commonly used in Sweden.

Materials for wind barriers are in principle not much different between the countries, although plywood is not used in Sweden. Both countries use insulating sheathing outside the framework, the difference being that polystyrene is used in the U.S. while rigid paper-faced mineral wool is used in Sweden.

g. Roofs and Ceilings

To allow moisture diffusion through ceilings, the ceiling vapor barrier is sometimes left out in certain areas of the United States. Much time is then spent caulking seams between gypsum boards and in top plates inside internal walls to avoid convection into the attic, see Fig. 6. These measures are merely to prevent internal moisture problems caused by uncertain ventilation rates. However, they put a heavier moisture load on the attic, which then must be well ventilated. New Swedish houses always have vapor barriers in ceilings.

Traditional differences in roofing materials exist, the most common being shingles in the U.S. and usually concrete tiles in Swedish houses. In Sweden, the secondary roof, below the tiles, used to be asphalt paper on top of wood paneling. Today, particle board and HDpolyethylene film are more common. When using tiles, the alternative to the secondary roof is to caulk beween tiles with mortar. This technique is used in Denmark, but not in Sweden.

h. Foundations

Based of claims of lower cost and U-values, wood foundations are sometimes used in the midwest. Pressure-treated wood is used for the foundation. Plywood sheathing, covered by a polyethylene moisture barrier, is used outside foundation walls, see Fig. 5. Wood foundations are very uncommon in new Swedish construction.

Crawl spaces in the United States tend to be unventilated and insulated on the ground and around the perimeter wall. A moisture barrier on the ground prevents the soil moisture from entering the crawl space, see Fig. 7. In Sweden, crawl spaces are normally well ventilated, with the insulation between the floor joists.

Perimeter insulation at slab-on-grade is done in several different ways. One example from Sweden is shown in Fig. 8, in which a prefabicated edge beam of light clinker concrete also functions as the form for pouring the slab. The slab insulation could be placed either above or below the slab; it is most commonly above, for comfort reasons.

Earthquake forces are not considered in Swedish foundation design. In U.S. areas with a high earthquake risk, mudsills are bolted to the foundations with 10" by 1/2" anchor bolts to the foundations.

Termites are a problem in some parts of the U.S.; as a result, metal flashing or a minimum distance between mudsills and ground surface is required.

References

1. Elmroth, A., and Levin, P., Air Infiltration Control in Housing - A Guide to International Practice. Swedish Council for Building Research No. D2:1983, Stockholm, 1983.

2. Ryan Homes, Specifications for Standard Energy Package, Ryan Homes, Pittsburgh, Pennsylvania, 1979 (to be updated in 1983).

3. Yanev, P., Piece of Mind in Earthquake Country, Chronicle Books, San Francisco, California, 1974.

4. SBN 1980, The Swedish Building Code 1980, The National Swedish Board for Physical Planning and Building, Stockholm, 1980.

5. ASHRAE Standard 90, Energy Conservation in new Building Design, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia, 1980.

6. ASHRAE Standard 62, Ventilation for Acceptable Indoor Air Quality, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia, 1981.

7. ASTM Standard E 779, Measuring Air Leakage by the Fan Pressurization Method, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1981.

8. ASTM Standard E 741, Measuring Air Leakage Rate by the Tracer Dilution Method, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1980.

9. Uniform Building Code 1982, International Conference of Building Officials, Whittier, California, 1982.

10. The BOCA, Basic Energy Conservation Code 1977, Building Officials and Code Administrators International Inc., Chicago, Illinois, 1977.

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Owens/Corning Fiberglas, Granville, Ohio
Dave Robinson, Consultant, Saint Paul, Minnesota
RoKi Associates, Standish, Maine
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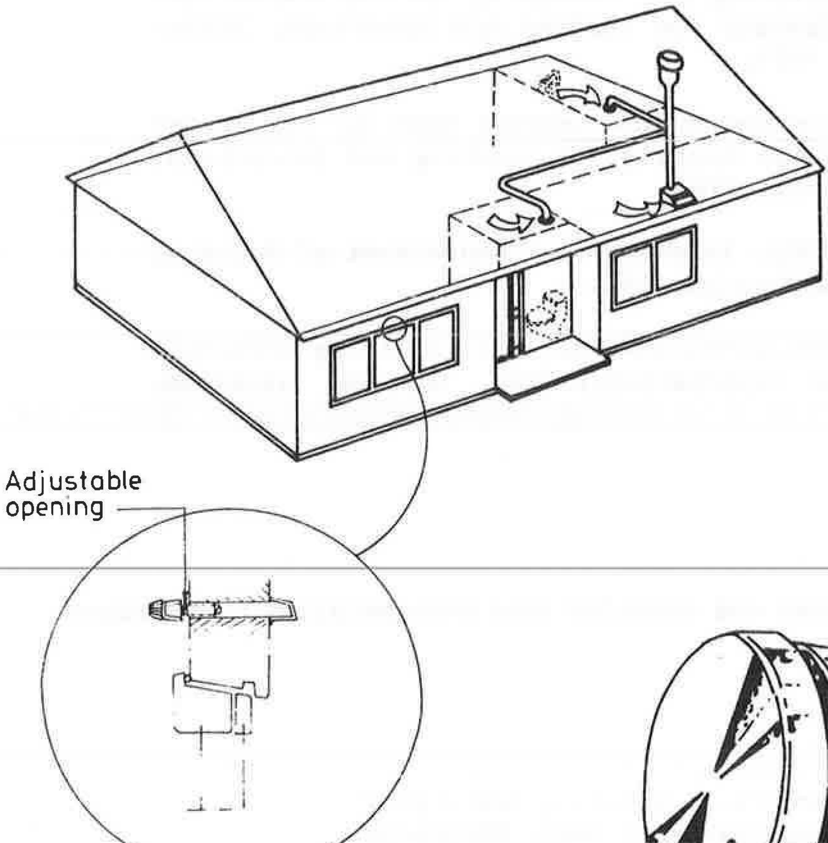
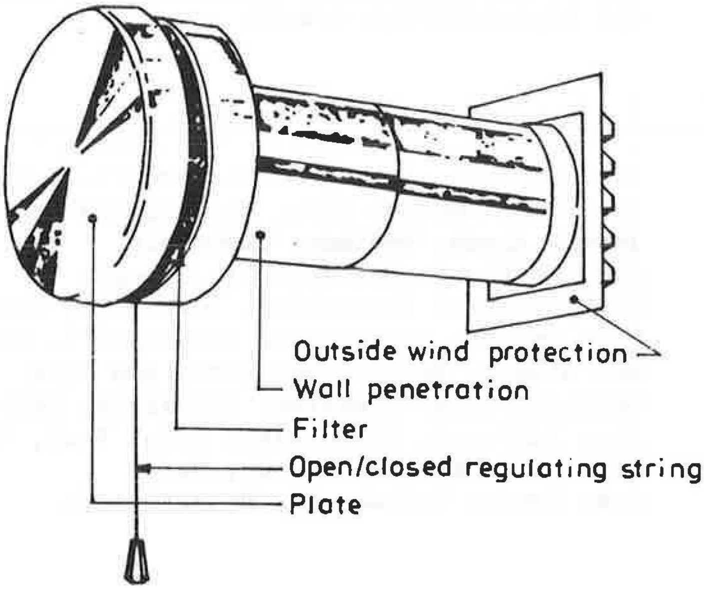


a.



b.

Figure 1. a. Principle of mechanical exhaust fan ventilation system, where the fan is mounted on the roof. Air is removed from kitchen, bathroom, and laundry room and unconditioned air is supplied to bedrooms and living room. The supply air enters through slot or plate openings in walls or windows. Openings are normally adjustable to provide the amount of ventilation desired. The "balanced" ventilation system includes, in addition to the exhaust fan system, a supply fan and ducts to bedrooms and living room.

b. Example of plate vent with noise-reducing properties, for use in an exhaust fan ventilation system.

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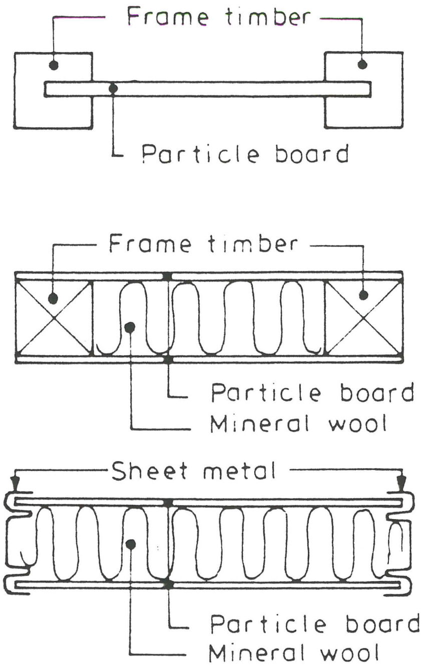
Figure 2. Caulking of seams in air/vapor barrier around a window, with a non-hardening sealant.

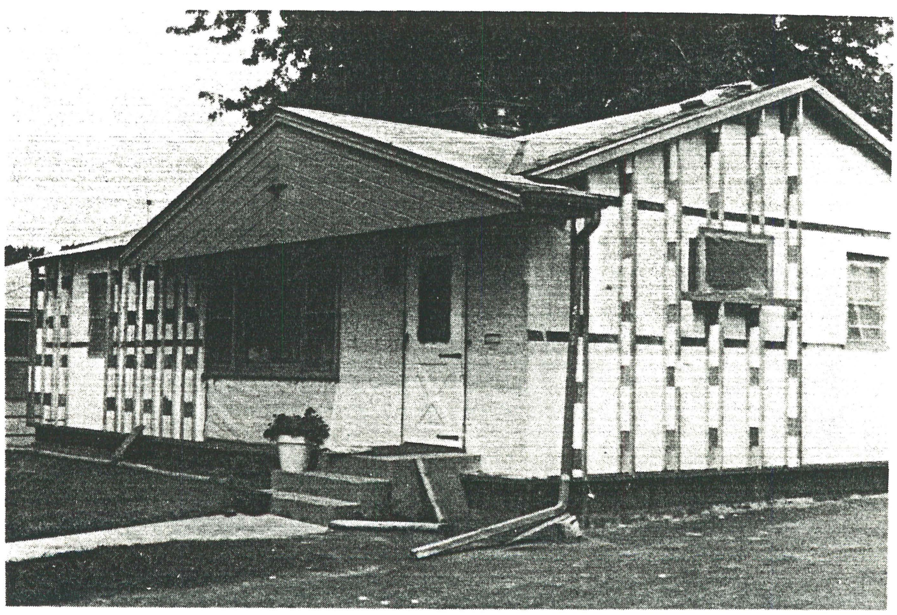


a) "The Masonite beam" is constructed of two frame timbers, approx. 45 x 45 mm, which are joined together with particle board. Jointing is achieved by glueing and pressing according to a specially developed method.

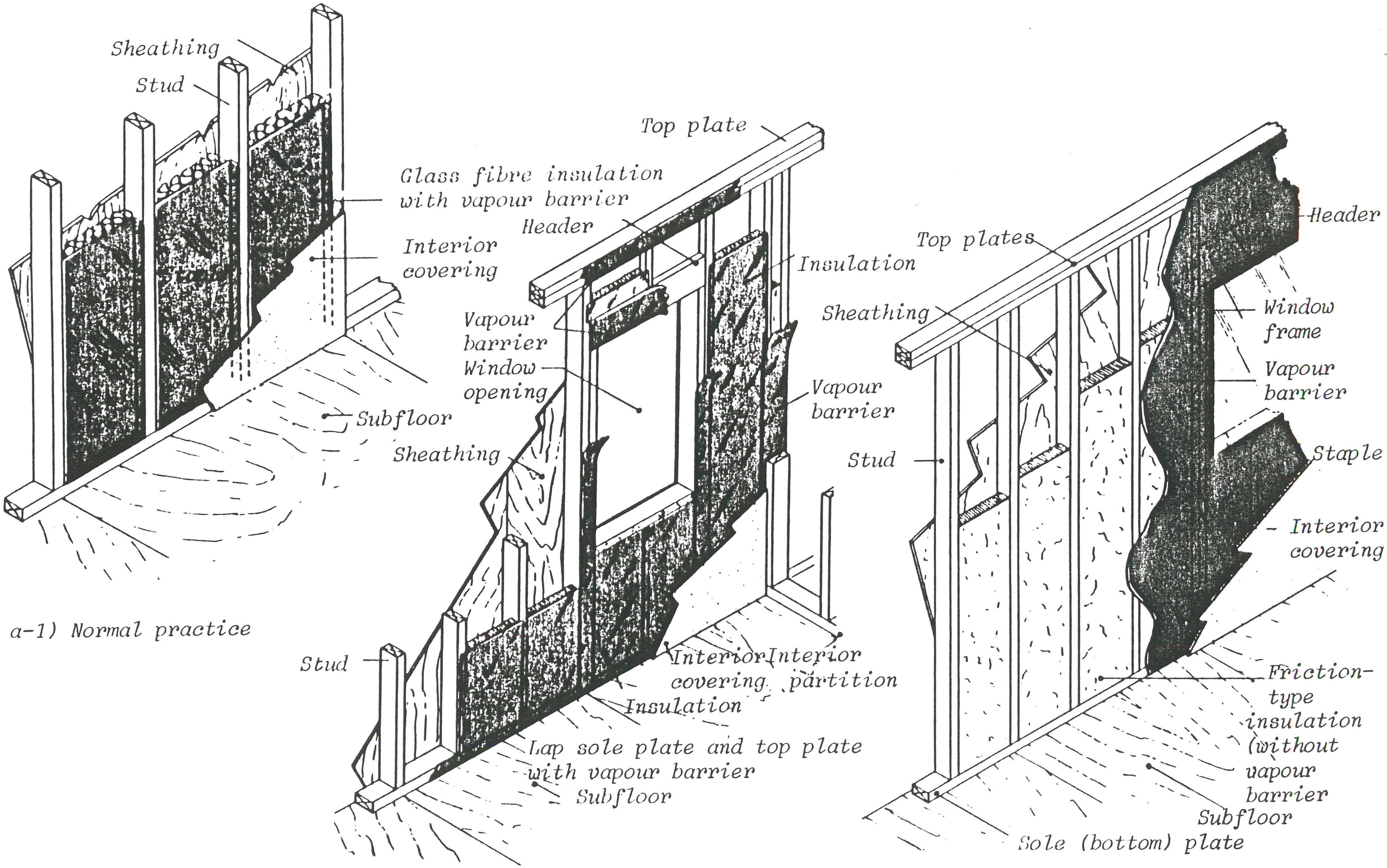
b) In this construction, two frame timbers are joined with two thin particle boards with mineral wool between.

c) This construction employs galvanised steel sheeting instead of frame timbers.

Figure 3. a. Examples of light frame constructions used for walls with thick insulation in Sweden. Types a and b are also used as floor joists and in roof trusses.



b. House in Minneapolis adding insulation, using the "Larsen truss".



a-1) Normal practice

a-2) Improved practice

b) Best practice

Figure 4. Methods of attaching insulation in the United States: a. stapling vapor barrier paper on insulation blanket to studs. b. using a separate vapor barrier with friction-fit glass fiber insulation.

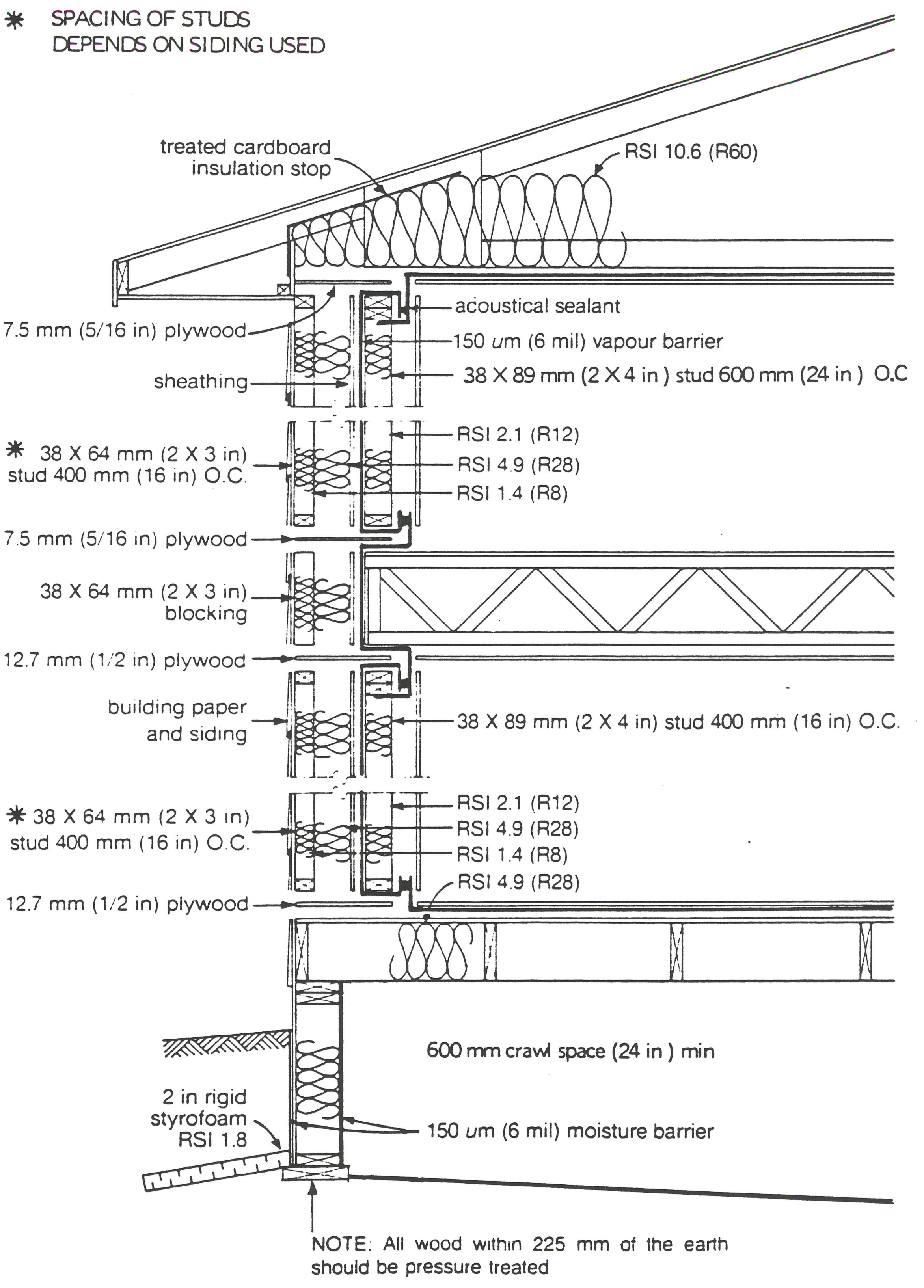


Figure 5. Section of a double-wall design over a wood foundation.

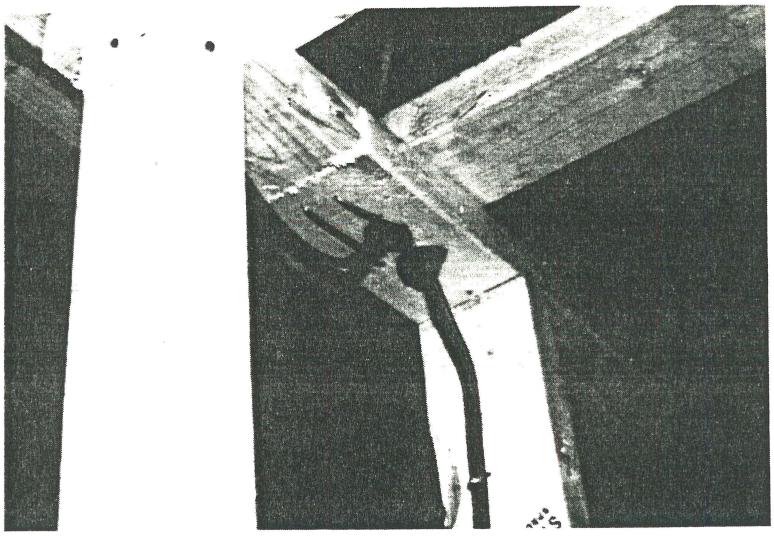


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Figure 6. Sealing air leaks into attic is important for avoiding condensation problems, especially if the ceiling vapor barrier is abolished.

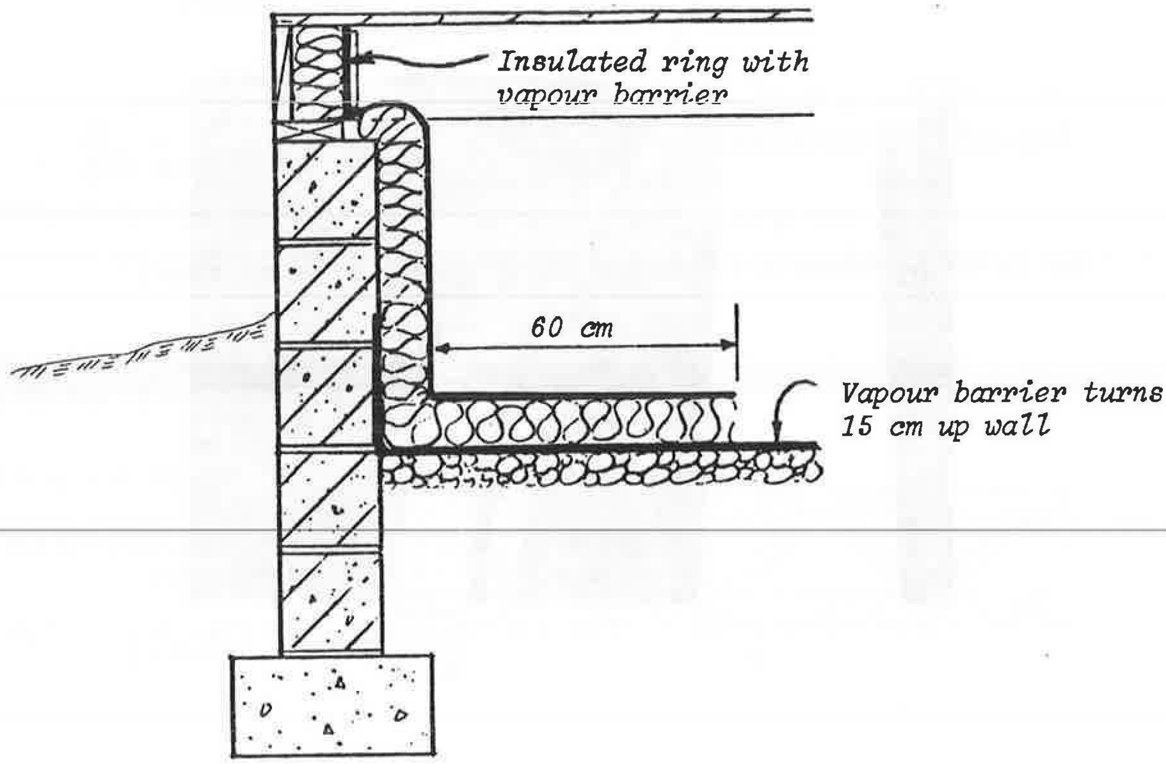


Figure 7. Example of an unventilated crawl space from the U.S. with insulation on the ground and around the perimeter walls. A moisture barrier is used to eliminate moisture penetration into the crawl space.

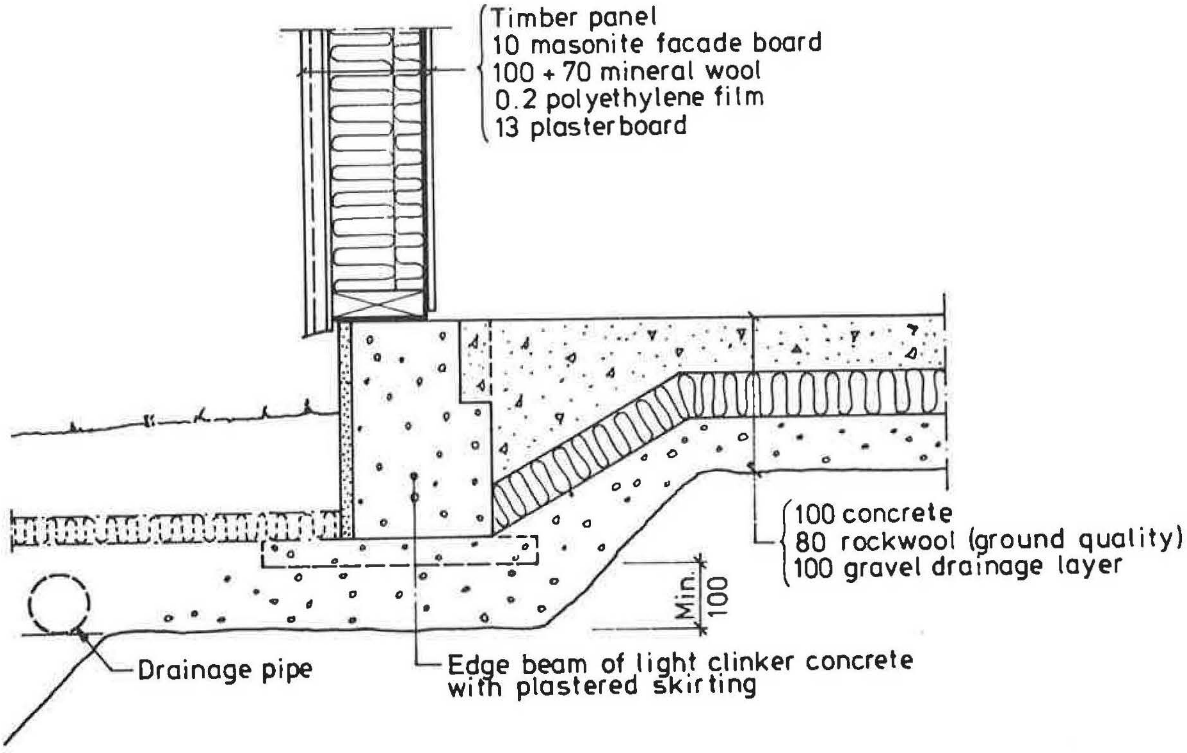


Figure 8. Example of a slab-on-grade from Sweden, showing wall and slab junction detail. A double-tube-profile rubber strip is used as a sill sealer to achieve an airtight joint. The light clinker concrete, used as the edge beam, has approximately the same thermal resistance as wood.

Appendix A

Building Site Visits in the United States

Travel notes / March 1983.

I. Minneapolis area, Minnesota

Contact: Gary Nelson

a.Cedar-Riverside

Super-insulating retrofits were performed on a group of low-income houses from the end of the last century. Some new, similar, infill houses were also under construction. Most of the houses are duplexes and triplexes. The work was carefully controlled by the supervisor on the site.

Old houses:

Figure A-1 shows the exterior of one of the retrofitted houses. Old interior sheathing was taken out and fiberglass batts installed in the old 2 by 4 framework. Interior sheathing of aluminium foil-covered polyurethane foam batts (3 inches) was added before the gypsum board was installed.

An air/vapor barrier of polyethylene film was used, and seams were caulked with acoustic sealant.

A Canadian method was used, in which a strip of polyethylene film is secured around the window frame; the film is folded out on the wall and overlapped and caulked to the wall film, see Fig. A-2 and A-3. This requires that the windows be taken out. In this case, new windows were installed. Figure A-4 shows a window after gypsum board was installed.

The ceiling air/vapor barrier was installed separately in each room and caulked to the top plates of all walls, which seemed to be difficult to do well. Polyurethane foam was used for sealing penetrations inside interior walls. Penetrations in ceilings (for ductwork, etc.) were not sufficiently sealed to the polyethylene air/vapor barrier because of poor planning, which was the case for many of the most difficult details.

Polyurethane foam boards were fitted between floor joists inside the rim joist and caulked to the floor joists and the flooring above for continuous air sealing. The air/vapor barrier was not installed between floor joists, Fig. A-5.

There is, at the moment, no plan to install mechanical ventilation other than bathroom exhaust fans. Fresh air intakes for combustion air into basements are provided, one for each furnace (i.e., if a basement has two furnaces, two holes will be made in the basement walls).

New houses:

The exterior of one of the new houses is shown in Fig. A-6.

The north, east and west walls are of double-wall construction, which is comprised of two 2 by 4 frames, spaced about 4 inches apart. The polyethylene film was installed on the outside of the inner framework. At the gable walls, a strip of film was installed for continuity in the air/vapor barrier, Fig. A-7. The overlap joints were clamped with the weight of the wall. The same system was used as in the retrofitted houses to seal and insulate between joists in the floor structure (polyurethane foam boards and caulking).The south walls are made of 2 by 6 studs, spaced 16 inches on center.

Windows were installed using the Canadian design, similar to that used in the retrofits, Fig. A-8.

A strip of film was installed over the top plates in interior walls to achieve a continuous ceiling air/vapor barrier, Fig. A-9.

The foundation is slab-on-grade. Plastic heating ducts are placed inside the slab, insulated except on top. Perimeter insulation is 2 inches of extruded polystyrene. The only drainage provision is, normally, that the soil next to the house slopes away from the house. Gutters to carry water from the roof are not always provided.

b. Hand Construction Inc.

Dick Hand makes custom-built super-insulated houses, see Fig. A-10. He uses a double-wall construction consisting of two 2 by 4 frames, with a 4 inch gap between them. The outer frame extends lower than the inner, providing insulation outside the rim joist, see detail in Fig. A-11. The frames are shifted 8 inches so that members in the inner and outer frame are at different places in order to reduce thermal bridging. The air/vapor barrier is on the inside of the inner frame. The top plates are not in one piece so an air/vapor barrier strip seals the top to prevent convection from walls to the attic, see Fig. A-12. The air/vapor barrier goes down to the basement on the outside of the rim joist, Fig. A-13.

Details were good except at electrical outlets, which were sealed with tape of unknown durability. A new type of air/vapor barrier of cross-laminated polyethylene film ("Tu-Tuf") was used, which was supposed to be stronger than ordinary polyethylene film. Tears were seen in the film, however, at staples in the earlier mounted strips around interior walls.

The house was equipped with electric heat and an air-to-air heat exchanger, which was set up to function as a simplified balanced mechanical ventilation system that is typical for an airtight and "super-insulated" house in Minnesota. Exhaust ventilation systems are not used because of the natural gas combustion devices.

Pressurization tests have shown good results. According to Hand, 2.5 ac/h at 50 Pa were measured in a house built some years ago. A new house showed 1.75 ac/h at 50 Pa (measured by Gary Nelson in the spring of 1983). In these results the volume of the basement was included.

A set of drawings from an older house was obtained, together with an economic analysis to justify the double-wall system.

c. North Hennepin Area Vocational Technical Institute

Bill Te Vogt, who is a teacher at the institute, showed us a super-insulated house made by the students in the school backyard. The house was pre-sold and moved to the buyer's lot when finished.

Walls were made with 2 by 6 construction. 1 inch of Styrofoam sheathing was added externally and a 2 by 2 horizontal insulated framework internally. The air/vapor barrier was placed on the inside of the load-bearing structure, giving no penetration in the walls.

A polyethylene bag was fitted around ceiling light fixtures to avoid air leaks.

The interior sheathing was already erected at the time of the visit, which prevented inspection of details, except for the windows, where tape was mounted between the window frame and gypsum board, Fig. A-14. The tape was supported by the molding.

II. Madison, Wisconsin

Impala Homes, Edwin Gehl

Impala Homes has a small factory for prefabricating wall elements and window and door frames. Walls were made 2 by 6, 16 inches on center, Fig. A-15.

Owens/Corning's demonstration home (EPDS) was built by Impala Homes in 1981, see Fig. A-16. It has double-wall construction with the air/vapor barrier on the inside. Other differences from standard practices characteristic of that time are that heating ducts were sealed and an electric furnace was installed for easier monitoring of space heating.

The EPDS house is currently rented by Owens/Corning; in it a family of four is simulated with lightbulbs and moisture evaporation. The internal moisture seemed very high during the visit and condensation appeared on windows, epecially on the upper floor. This is probably caused by a low ventilation rate.

Energy consumption between July 1981 and March 1983 was, according to the kWh-meters, about 36000 kWh of which about 50% was for appliances. Heating, hot water, and heat pump used 10800 kWh. Airtightness was 0.4 ac/h at 50 Pa, according to Gehl (including volume of basement).

Visits were made to two houses under construction, which were to be equipped with gas forced-air furnaces and gas hot-water heaters. An interesting way of supplying combustion air had been developed: A vent in the basement wall that is connected to a duct guides the incoming air down to an open box from where air is "drawn when needed"; probably when the bottom of the house is at negative pressure (when bathroom fans or the furnace are working).

Figure A-17 shows mineral wool packing around a window and good insulation installation. The edges of floor structures were insulated with paper-backed fiberglass batts, which were folded instead of cut to fit, leaving cavities that allow air circulation, Fig. A-18. The polyethylene air/vapor barrier was located on the outside of the rim joist covered by only an inch of polyurethane foam. Locating the polyethylene air/vapor barrier here has caused frost problems in other (not much colder) parts of the country. Recessed lights were sealed, Fig. A-19.

The air/vapor barrier installation technique was good, except for penetrations in walls, which were basically left unattended. Thin polyethylene air/vapor barrier was used.

Good insulating windows were used with about a 0.5 inch air gap between panes.

External basement walls were insulated with extruded polystyrene boards on the outside down to 2 meters (6 feet) below grade.

Internal wall penetrations were sealed with polyurethane foam.

III. Pittsburgh, Pennsylvania

Ryan Homes, Richard Tracey

Ryan Homes manufactures about 10000 homes per year in more than 20 states. The wall elements are made in a factory, with or without siding or insulation.

There are about 60 models to choose from. A computer-aided design system is used for drawings (2-dimensional). Only the floorplans and drawings necessary for building permits are stored. A computer program is used for manufacturing the houses. Surprisingly enough, it is very difficult to change wall thicknesses, because wall thickness affects so many other things.

Ryan Homes cooperates with land developers, and agrees to build a certain number of houses per month. All houses except the models are sold in advance. They seem to be selling well, claiming good energy performance. A 10-year warranty is given.

Ryan Homes developed its own Standard Energy Package in 1978, which is currently under review. The standard describes in great detail how different details for insulation and airtightness are to be performed.

Figure A-20 shows exteriors of recently erected houses and Fig. A-21 shows a split-level house being erected.

No vapor barrier is installed in the ceiling, to permit vapor diffusion through the ceiling, see Fig. A-22. Ridge and soffit attic ventilation is provided and careful caulking and sealing is made to avoid air leaks from the inside to the attic, Fig. A-23. A special cardboard box is used at the soffit to provide both proper insulation (normally blown-in cellulose fiber) and ventilation to the attic, Fig. A-24. Attics are inspected 6 months after erection and no condensation problems have been noted so far. Ceilings are insulated to R-30 ($U=0.19\ W/m^2K$).

Bathroom fans ventilate to the outside through the roofs. The kitchen stove has only a charcoal filter.

Some of the windows are of vinyl coated metal, which has a severe thermal bridge. Better "Andersen" wood windows are used in some locations.

Walls are constructed of 2 by 4 studs, 16 inches on center. Insulation is normally well installed. Recently, a change to a higher-density glass fiber batt was made (R-13 instead of R-11). Sill sealing is performed with an open-cell foam strip, Fig. A-25. The wall air/vapor barrier overlaps 1 inch against the ceiling gypsum boards and more at the floor. At windows, the air/vapor barrier is drawn past the gap between frame and wall and clamped with a molding piece, Fig. A-26. Metal backup clips are used as backing for the gypsum board, to avoid an extra floor joist, see Fig. A-27. Insulation at rim joist fills the whole space between joists, Fig. A-28. The upper floor is mostly cantilevered. A paper is installed on the outside as an air barrier in these locations.

Basement walls in living spaces are insulated on the inside with insulation as thick as the external walls, Fig. A-29. In non-living spaces, the insulation batts are hung from the ceiling, Fig. A-30. Ducts through unheated spaces are in a sealed box to reduce the effect of duct leaks, Fig. A-31. Figure A-32 shows the separation between garage and living space on the second floor.

The roofs and floor structures to the townhouses are built right on the first-floor structure, lifted off during erection of the walls and then lifted back in place, Fig. A-33.

A continuous wind barrier is achieved with thin boards (1/8 inch) with overlapped joints over studs and extra wrapping around corners and cantilevered floors, Fig. A-34. Currently used paper, "Ply-dry", was sometimes damaged during construction which is why Ryan Homes considered switching to a "Tyvek" type instead.

The placement of the heating registers was recently changed, after some research, to be close to the interior walls instead of the exterior. This change is said to make houses more energy-efficient by reducing the temperature difference across the external walls, Fig. A-35.

Literature

Design Heat Loss Analysis, Prepared by the Mid-American Solar Energy Complex for Hand Construction Inc., Final report, August 1981.

Ryan Homes, Specification for Standard Energy Package, Ryan Homes, Pittsburgh, Pennsylvania 1979 (being revised).

CBB 837-6318

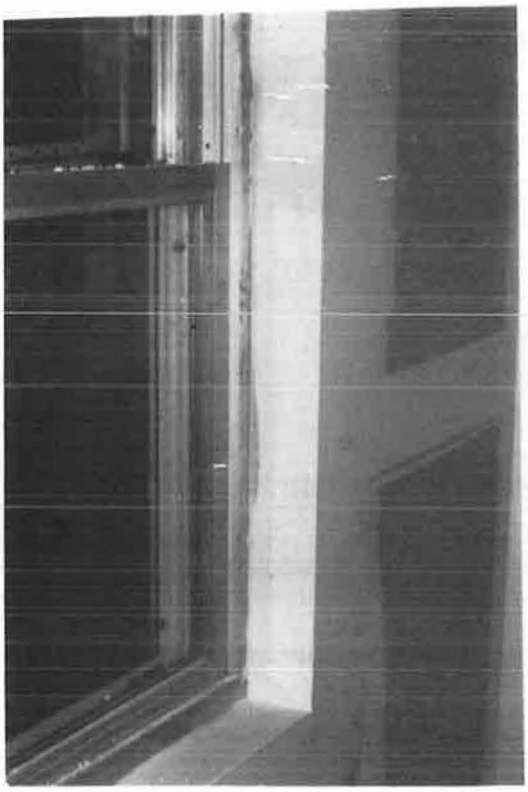
Figure A-1. Exterior of house during retrofit in the Cedar-Riverside area.

CBB 837-6320

CBB 837-6322

Figure A-2. Replacing windows. A strip of polyethylene is sealed around the window frame before the window is installed.

Figure A-3. The window film strip is connected to the wall film by caulking with a non-hardening sealant.



CBB 837-6326

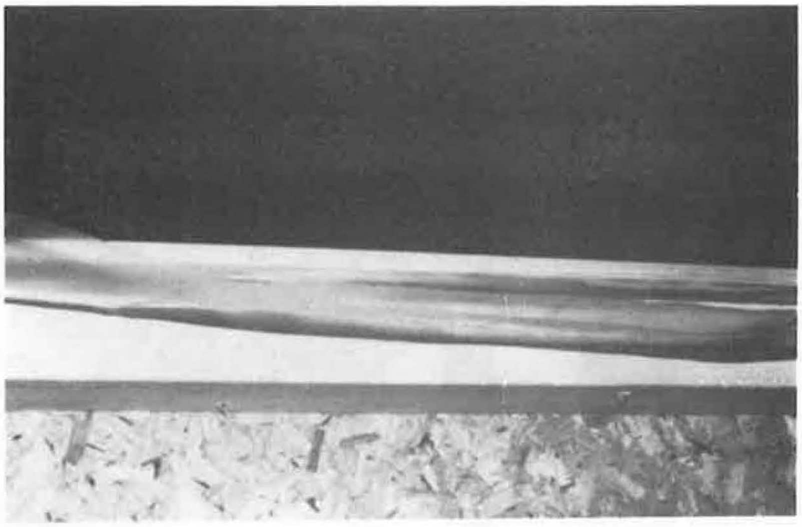
Figure A-4. Window after gypsum board installation.

CBB 837-6324

Figure A-5. Air/vapor barrier between floor joists. Polyurethane boards were put between joists and caulked to them and to the flooring above. The wall air/vapor barrier ends on the bottom of the floor joists.

CBB 837-6328

Figure A-6. Exterior of new house with redwood siding (in background). A house being retrofitted is shown to the right.

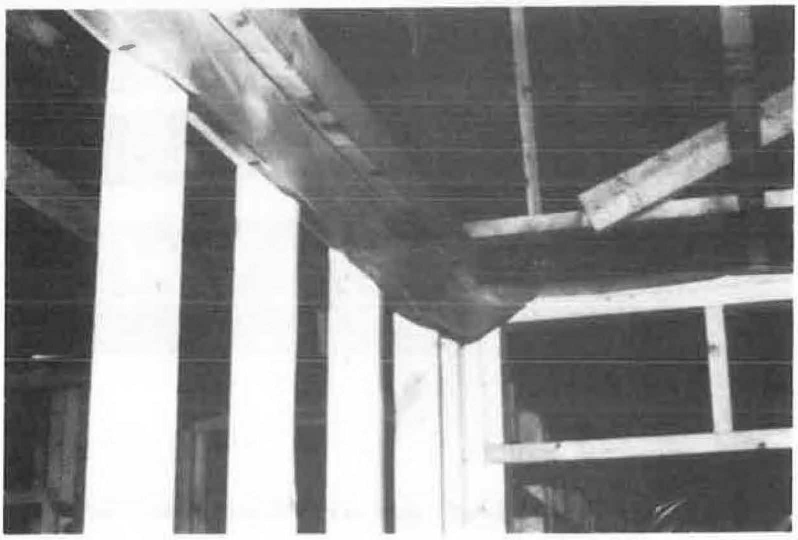


CBB 837-6330

Figure A-7. Continuity of the air/vapor barrier at the middle floor structure's junction at gable is achieved by an overlapping joint clamped by the weight of the wall.

CBB 837-6332

Figure A-8. New houses use the same principle as retrofitted houses for making windows airtight. Note the chipboard used to cover the cavity in the double wall.

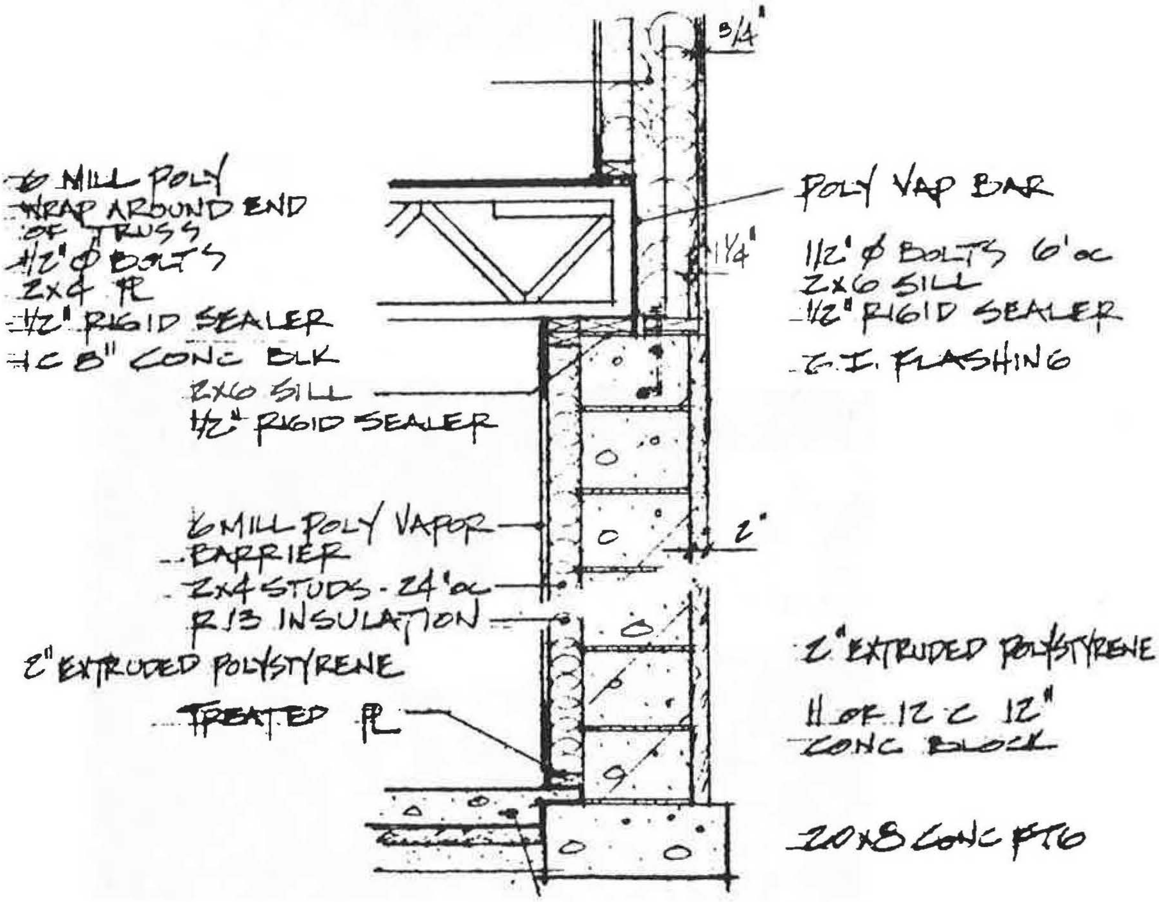


CBB 837-6334

Figure A-9. A strip of film is installed over the top plates in internal walls to achieve a continuous air/vapor barrier in the ceiling.

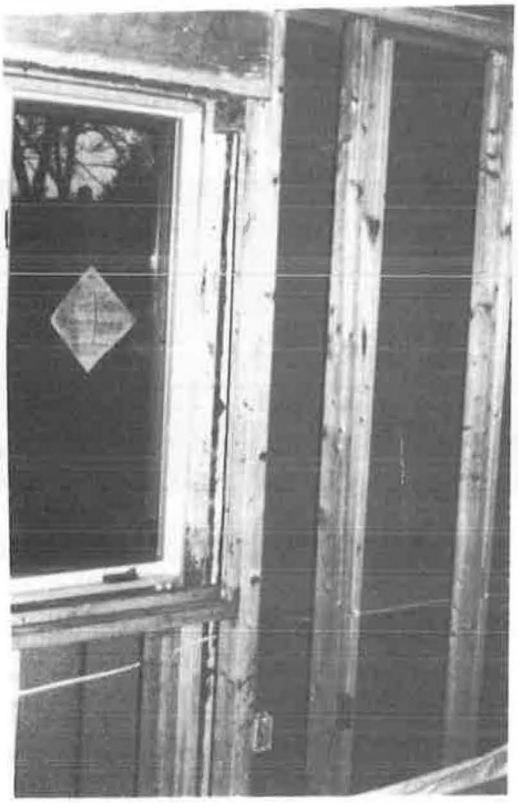
CBB 837-6336

Figure A-10. Exterior of a "super-insulated" house during construction in Saint Paul, Minnesota.



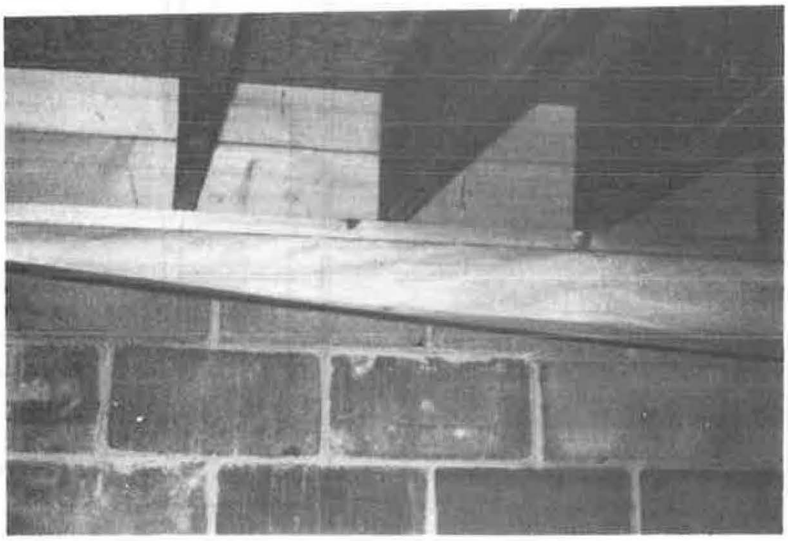
Source: Hand

Figure A-11. Detail of rim joist solution and basement wall construction.



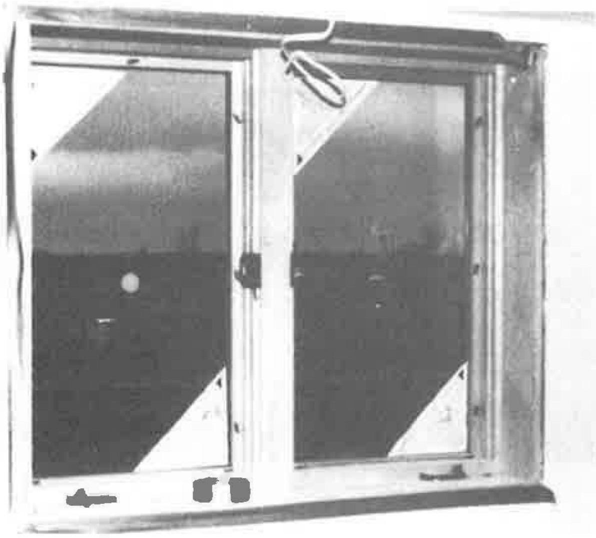
CBB 837-6338

Figure A-12. Air/vapor barrier connection at floor and ceiling. Note the staggered studs in the double wall.



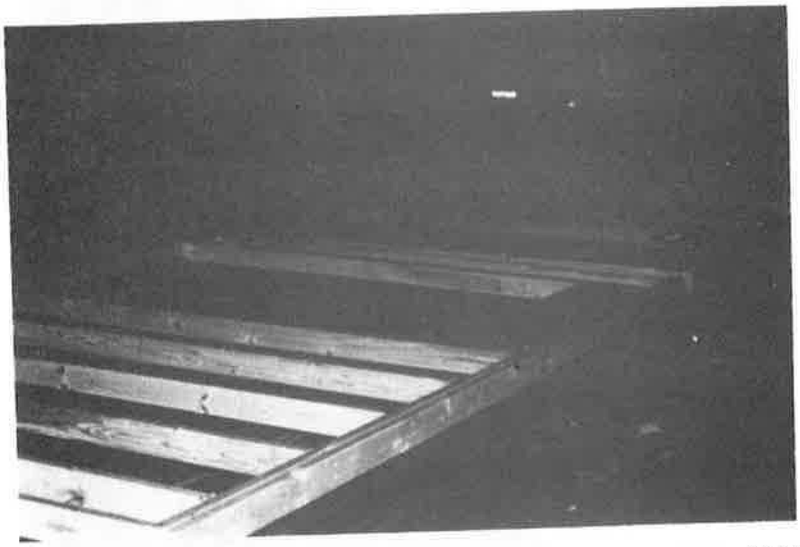
CBB 837-6340

Figure A-13. Air/vapor barrier from the floor above drops down into the basement, where it is connected to the basement air/vapor barrier.



CBB 837-6342

Figure A-14. Using tape seal between wall and window. The tape is clamped and supported by the molding.

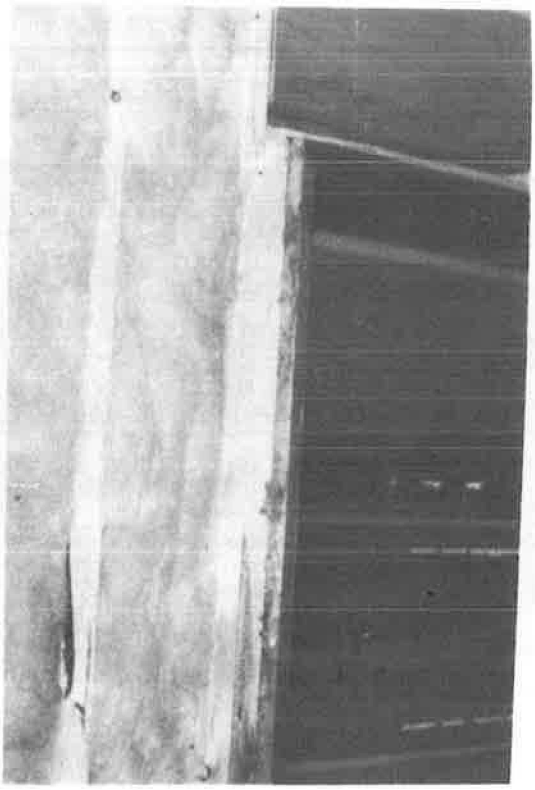


CBB 837-6308

Figure A-15. Wall section during assembly in factory in Madison, Wisconsin.

CBB 837-6310

Figure A-16. Owens/Corning Fiberglas demonstration home for energy performance in Madison, built by Impala Homes.

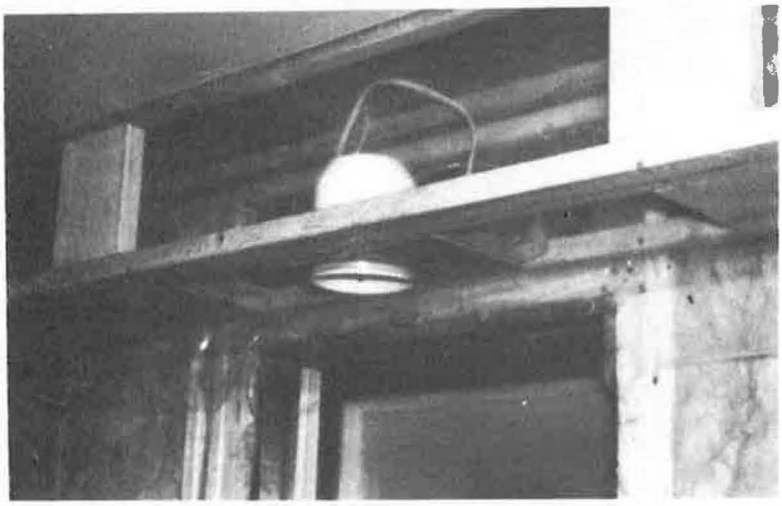


CBB 837-6312

Figure A-17. Mineral wool packing in wall-window joint.

CBB 837-6314

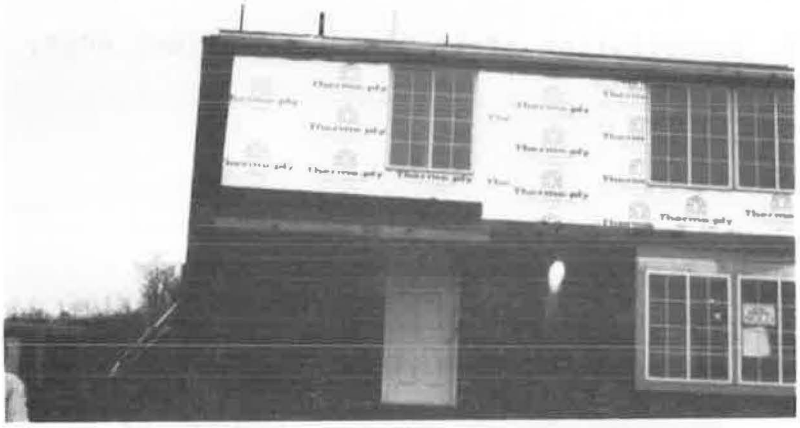
Figure A-18. Installation of insulation at floor edge, inside the rim joist.



CBB 837-6316

Figure A-19. Lowered soffit with recessed light, sealed with polyethylene film.

CBB 837-6270



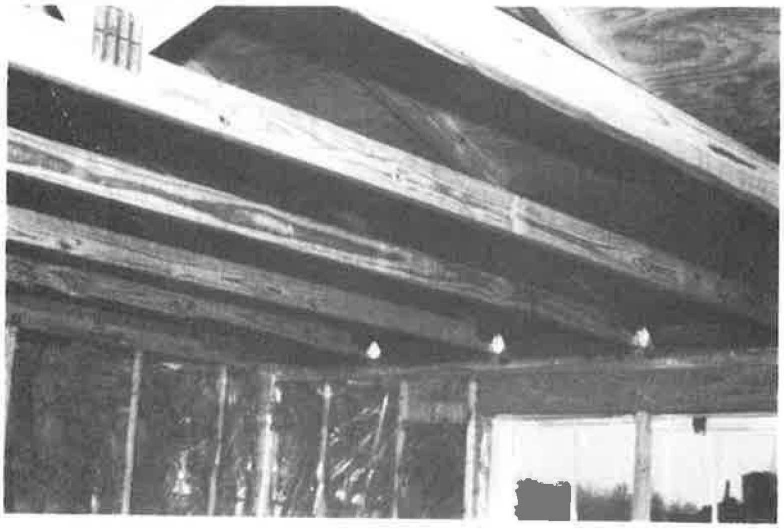
CBB 837-6272

CBB 837-6274

Figure A-20. Exteriors of recently erected houses in Pittsburgh, Pennsylvania.

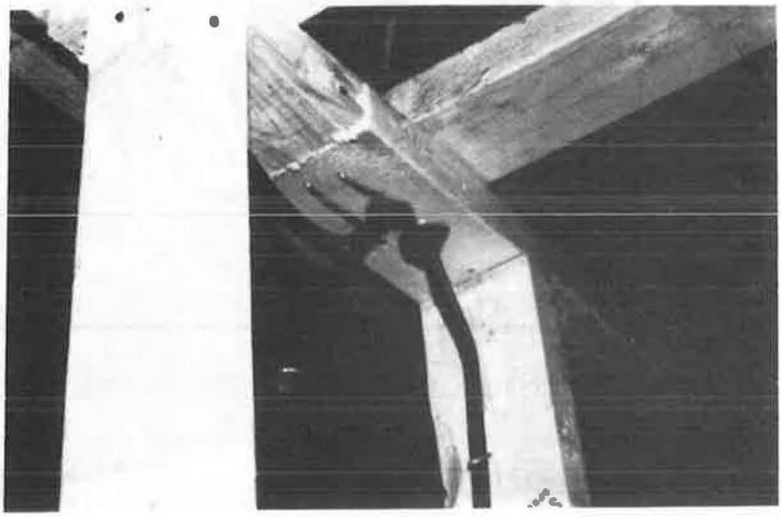
CBB 837-6276

Figure A-21. A split-level house during erection.



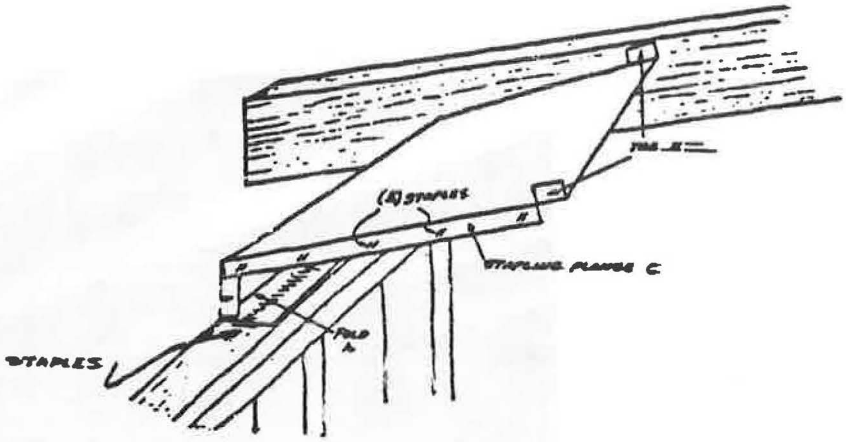
CBB 837-6278

Figure A-22. No vapor barrier is installed in ceilings. Note the cardboard boxes between rafters at the eaves.



CBB 837-6282

Figure A-23. Caulking of penetrations for installations in attic.



Source: Ryan

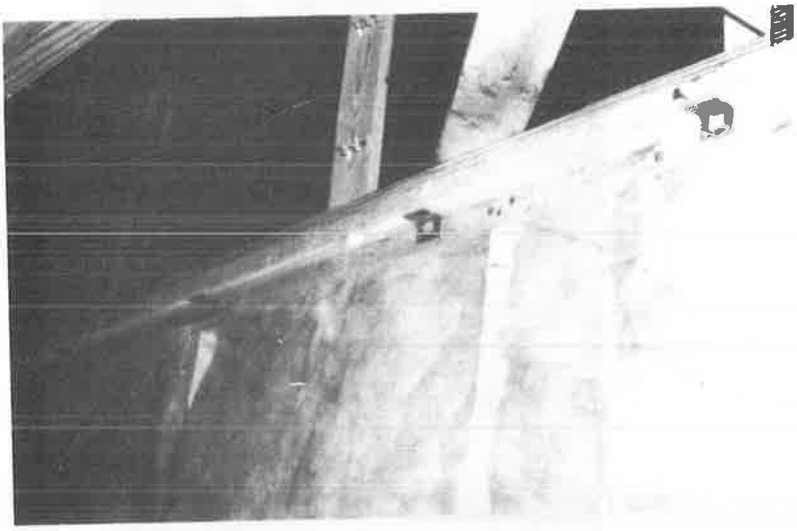
Figure A-24. A special cardboard box is stapled to rafters and top plate to allow good insulation installation at the eaves.

CBB 837-6284

Figure A-25. Sealing of sill with an open-cell foam strip, also used between construction elements. Note the air/vapor barrier's overlap into the floor.

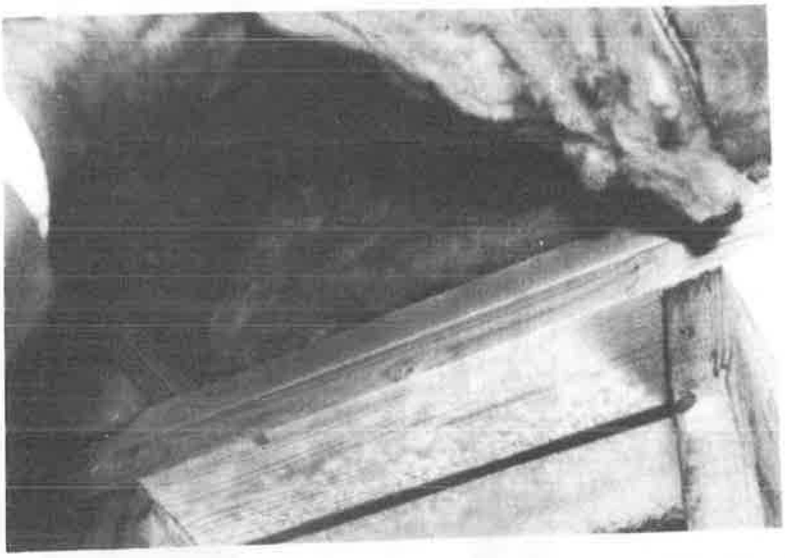
CBB 837-6286

Figure A-26. Technique for sealing air/vapor barrier to window by clamping with a molding piece.



CBB 837-6288

Figure A-27. Metal back-up clips are used instead of an extra floor joist, to support edges of ceiling gypsum boards.

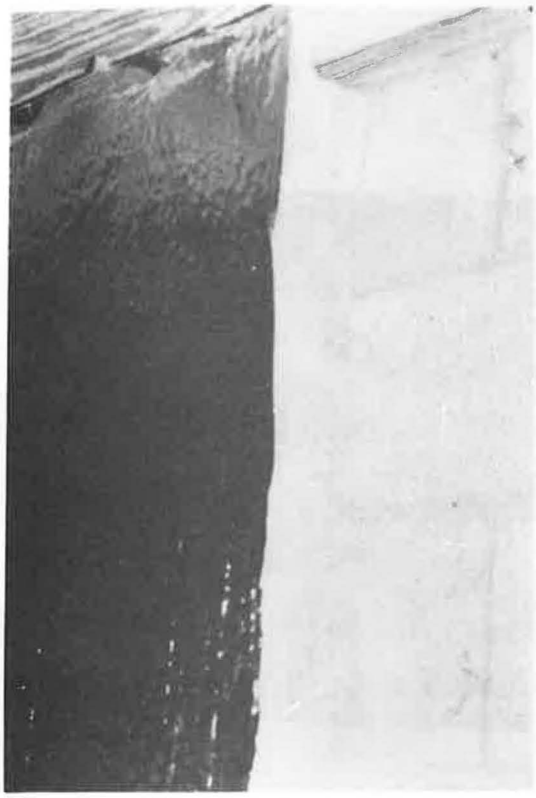


CBB 837-6290

Figure A-28. Insulation in full floor joist thickness fills the entire space between floor joists. In this case, the floor is cantilevered. The air barrier paper used on the outside in this location is visible at the top plate.

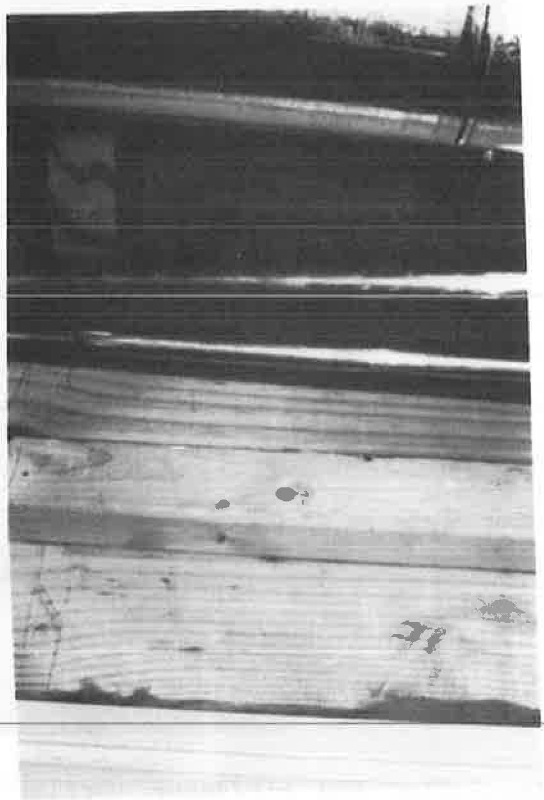
CBB 837-6294

Figure A-29. Insulation and air/vapor barrier inside basement wall, for living space.



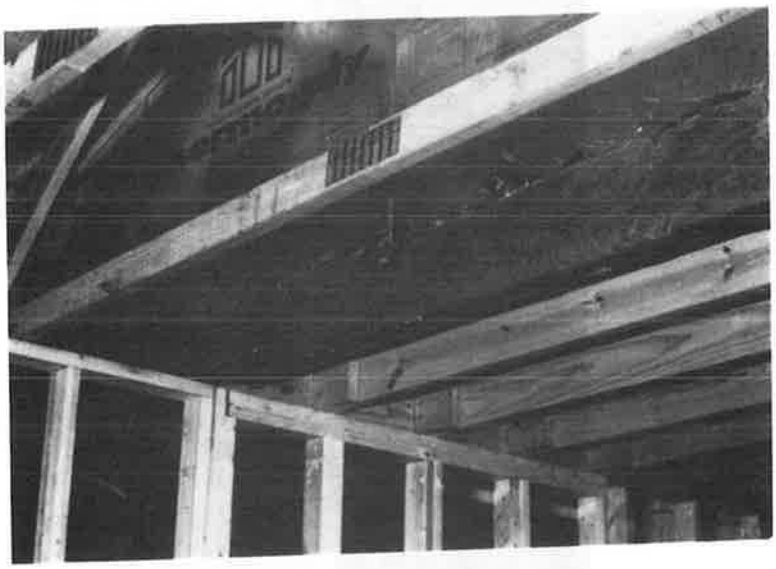
CBB 837-6292

Figure A-30. When the basement is not a living space, the insulation batts are hung from the ceiling.



CBB 837-6296

Figure A-31. Duct passing through unheated spaces are sealed to reduce the effect of leakage in heating ducts.



CBB 837-6298

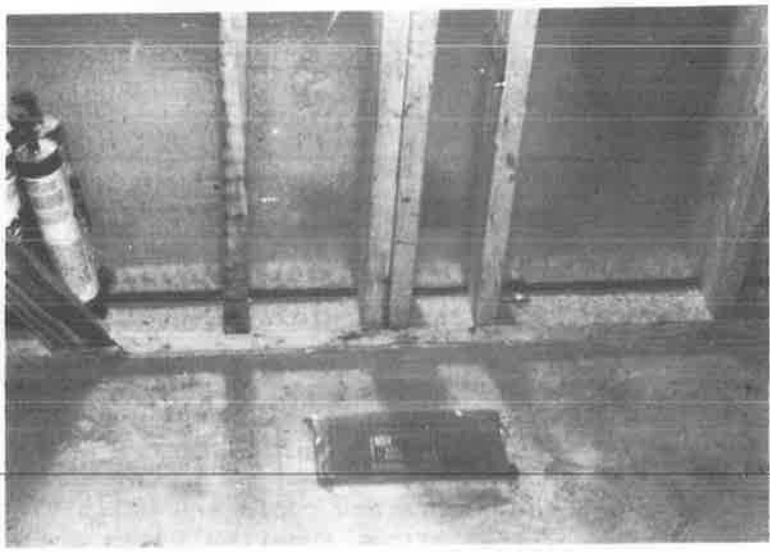
Figure A-32. Separation between the garage and second floor. 3 1/2 inch insulation is installed behind the sheathing.

CBB 837-6300

Figure A-33. Townhouse floors and roofs are built right on the foundation, lifted off at the time walls are erected, and then put back in place.

CBB 837-6302

Figure A-34. The wind barrier consists of thin (1/8 inch) sheathing, which is stapled to wall studs with overlap. Extra paper strips are mounted around corners and cantilevers to provide a continuous wind barrier.



CBB 837-6306

Figure A-35. Placing heating registers next to internal walls is a recent measure taken to improve energy efficiency.