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The Air Drywall Approach

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ABSTRACT

THE TECHNICAL AND ECONOMIC FEASIBILITY OF BUILDING ENVELOPE AIRTIGHTNESS HAS BEEN THE MAJOR FACTOR PREVENTING THE WIDESCALE CONSTRUCTION OF LOW ENERGY HOUSING BY TRACT/PRODUCTION BUILDERS IN NORTH AMERICA. THIS PAPER DOCUMENTS THE DEVELOPMENT OF THE AIR DRYWALL APPROACH (ADA), AN APPROACH WHICH MAKES BUILDING ENVELOPE AIRTIGHTNESS PRACTICAL FOR TRACT/PRODUCTION BUILDERS.

ACKNOWLEDGEMENTS

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I. BACKGROUND

Building envelope airtightness became one of the major techniques employed in the reduction of high residential heating bills brought on by the energy crisis of the 1970's. An airtight building envelope could be shown to significantly reduce or eliminate energy losses due to the mechanism of air exfiltration/infiltration (Besant,Dumont,Schoenau; 1979). In addition, it was recognized that air leakage was a significant moisture transport mechanism that lead to interstitial moisture accumulation and the subsequent deterioration of walls and ceilings (Latta; 1976).

In the early 1980's, airtightening of the building envelope was thought to be a significant factor in reducing wall and attic moisture problems. Unfortunately, modest airtightening of the building envelope in heating climates was often found to lead to an increase in moisture problems rather than the expected reduction. This was due to the interrelated effect that airtightening of the building envelope has with the interior moisture dilution due to natural airchange.

As natural airchange is reduced as a result of building envelope airtightening, interior relative humidity levels rise since the production of moisture within the building enclosure or the transport of moisture into the building enclosure is unchanged. Interior air which exfiltrates after building envelope airtightening has occured, does so at a much higher moisture content at fewer and fewer locations. Where previously, air at a relatively low moisture content exfiltrated over large building envelope surface areas, air now exfiltrated at a much higher moisture content, concentrated at fewer leakage openings leading to localized moisture shocks.

Where sufficient drying potentials did not exist to compensate for these moisture shocks, moisture problems became commonplace. Reductions of wall and attic moisture problems in heating climates occur only when airtightening of the building envelope is comprehensive and coupled with controlled ventilation systems which dilute interior relative humidity levels. Alternatively, moisture can be controled by installing controlled ventilation systems which both dilute interior relative humidity levels and slightly depressurize the building enclosure (See APPENDIX A: MOISTURE MOVEMENT).

Here was the heart of the problem. Significant degrees of airtightness were desired for both energy conservation reasons and as a method of controlling and possibly eliminating interstitial moisture problems. In fact, airtightness and airtightening strategies were heavily promoted by governmental policy and regulatory agencies and some building codes. The strategy promoted by authorities having jurisdiction and other agencies to achieve the required degrees of building envelope airtightness was the use of a sealed, continuous or integral polyethylene film air/vapour barrier. This approach can be shown to have a number of weaknesses (See APPENDIX B: CONCERNS ABOUT THE USE OF POLYETHYLENE FILM IN RESIDENTIAL CONSTRUCTION). Problems exist with high labour and supervision costs, chemical degredation, fragility, incompatibility with production techniques of tract housing and the inability of the sheet polyethylene, when unsupported, to resist air pressure differences arising out of the influences of wind, stack action and mechanical equipment. These problems have resulted in tract house builders resisting low energy construction practices. In fact, the problems with sheet polyethylene low energy house construction techniques have resulted in not more than small numbers of low energy homes being built across North America. No major production builder in North America is building or contemplating building any significant numbers of low energy homes on a production basis. Only one-of-a-kind custom homes, built and sold at premium prices, are currently being constructed using the sealed, integral polyethylene film approach to achieve high degrees of airtightness.

As such, alternative strategies were required which could achieve building envelope airtightness meeting the requirements of air barriers and which are cost effective and capable of being employed by the residential construction industry.

The development of the Air Drywall Approach (ADA) as a strategy to achieve building envelope airtightness was, similar to the evolution of polyethylene film as an air barrier, a result of the concerns of the cost of heating energy resulting from air leakage as well as moisture impacts on the durability of the building enclosure. However, the historical beginnings of the Air Drywall Approach predate the use of polyethylene as an air barrier by almost a decade. The recent recognition of the inadequacies of polyethylene films as air barriers has simply accelerated the development of the Air Drywall Approach rather than be responsible for its origins.

The origins of the Air Drywall Approach lie with the Mark VII Experimental House built in 1971 by the Housing and Urban Development Association of Canada (now called the Canadian Home Builders' Association). This house utilized 10 mm (3/8") fir plywood as both an air barrier and a vapour diffusion retarder. The plywood was installed in a continuous manner on the interior of the exterior frame walls. A secondary interior finish of painted gypsum board was installed over the plywood (Kempthorne, Kohli; 1972). The system was uneconomical to build because of the double interior cladding.

In 1981 G.O.Handegord, then affiliated with the Division of Building Research, National Research Council of Canada, proposed a significant modification of the approach used in the Mark VII Experimental House. Handegord proposed using the airtightness properties of gypsum board sheets together with plywood or waferboard strips incorporated in a modified balloon wood framing technique (Handegord; 1984) thereby eliminating the double interior cladding. A modified version of this technique was demonstrated by the author in the construction of nine demonstration houses in Brampton, Ontario during the winter of 1982 and the spring of 1983. These houses exhibited high degrees of airtightness, averaging less than 1 airchange per hour at a 50 Pascal negative pressure differential (Lstiburek; 1983) as tested by the Canadian General Standards Board Standard, "Determination of the Equivalent Leakage Area of Buildings By the Fan Depressurization

Method", CAN2-149.10-M84. The plywood or waferboard strips coupled with the modified balloon framing technique employed in these houses was still sufficiently cumbersome and time consuming to render this approach uneconomical.

As a result of the construction of the Brampton houses, the author proposed the elimination of the plywood or waferboard strips and to rely only on the interior gypsum board and existing framing members to achieve building envelope airtightness. This approach was demonstrated by the author in two houses in Ontario in the summer of 1983: the Shelburne House and the Lawrence Park House (Lstiburek; 1983). These two houses were the first houses to be called Air Drywall Approach houses.

However, these two houses still employed a modified balloon framing technique and substantial amounts of caulking to achieve low infiltration rates which were felt to be a significant disincentive to the adoption of the approach by the building community.

In an attempt to address these concerns a third house, the London House, was built in the fall of 1983 and was the first to use standard platform framing and gasket materials to replace caulking (Lstiburek; 1983). A further ten houses, similar to the London House, were built in Ottawa in late 1983 and early 1984 as part of a two year moisture research and monitoring project sponsored by the Canada Mortgage and Housing Corporation.

In July, 1984 a feasibility study titled: "A New Approach to Low Energy House Construction" was published by the Alberta Department of

Housing summarizing the research and development relating to the Air Drywall Approach to that date. In this publication, a proposed second generation approach to the Air Drywall Approach was presented (Lstiburek, Lischkoff; 1984), building on the construction experience of the London House as well as the Brampton, Shelburne, and Lawrence Park Houses. This second generation approach was subsequently demonstrated in the construction of three houses in Edmonton, Alberta during the summer of 1984 and documented in another report published by the Alberta Department of Housing titled: "Construction Experience Using The Air Drywall Approach" (Lstiburek; 1985). The three houses built in Edmonton, Alberta were completed in the summer and early fall of 1984. However, several difficulties with the approach remained, namely trade scheduling, notching of gypsum board sheets around cast-in-place floor joists, concerns regarding gasket durability, cost and long term performance. The latter two concerns became the major focus of a ten house ADA demonstration and research project in Winnipeg, Manitoba jointly funded by the Manitoba Department of Energy and Mines, and the Federal Department of Energy, Mines and Resources, Canada. Construction of the ten Winnipeg houses began in September, 1984 and was completed by January, 1985 (Lstiburek; 1985).

The remaining concern with the ADA concept, trade scheduling, became the major focus of two American research and demonstration projects, a sixteen house demonstration project in the State of Oregon and a six house demonstration project in the State of Idaho. Both of these two projects were funded by the Bonneville Power Administration as part of their Residential Standards Demonstration Project. The Oregon houses were administered by the Idaho Department of Water Resources. Construction of the Oregon and Idaho houses commenced in August and September of 1984 and was completed by December, 1984 and January, 1985 respectively. The author supervised the construction of the twenty-two houses involved in both projects.

II. ALBERTA AIR DRYWALL APPROACH DEMONSTRATION PROJECT

A. Introduction

Three houses were built in Edmonton, Alberta in 1984 according to the proposed second generation approach to the Air Drywall Approach. These houses were identified as follows:

	House	Floor Area	Built
a)	Bearspaw Show Home	140 m2 (1506 sq.ft.)	March-May 1984
b)	River Ridge Show Home	204 m2 (2206 sq.ft.)	April-July 1984
c)	Meadows Show Home	178 m2 (1911 sq.ft.)	June-Oct. 1984

B. Technical Outline of Project

The three houses, in addition to demonstrating the Air Drywall Approach concept, were designed using the R-2000 standards of Energy, Mines and Resources Canada as a guide. The Bearspaw and River Ridge Show Homes met the R-2000 standards. The Meadows Show Home did not, as it did not utilize any form of heat recovery on ventilation (had an ATAHE or other heat recovery device been installed, it would have also met the R-2000 standards).

Briefly, technical requirements were as follows:

1. Energy Budget: The maximum amount of energy to be used for space heating for the three unit types was based on the following formula:

Maximum Space
Heating Consumption = (5 kWh/m2 + (45 kWh/m2 x DD/6000)) x EFA
for a House (kWh)

where: DD = annual Celsius degree-days for the location

EFA = the heated volume of the house in cubic metres calculated from interior dimensions divided by 2.5 metres to arrive at the equivalent floor area in square metres.

The HOTCAN computer program was used to verify design compliance with the energy budget.

2. Airtightness: Each house was constructed sufficiently tight in order to meet the requirements of 1.5 air changes per hour (ach) or less at a pressure differential of 50 Pascals. Each house was tested as per the Canadian General Standard Board's Standard for the Determination of the Equivalent Leakage Area of Buildings by the Fan Depressurization Method, CAN2-149.10-M84. For heat loss calculations in the design stage, a natural infiltration/exfiltration rate of 0.05 ach was assumed.

3. Mechanical Ventilation: There was to be a minimum of 0.5 air changes per hour ventilating CAPABILITY (emphasis by author) that was to be provided and controlled by mechanical means. Where heat recovery equipment was used, a maximum efficiency of 50 percent was assumed for design purposes.

4. Wall Construction: Walls were constructed to have a thermal resistance equal to or greater than RSI 3.5 (R-20).

5. All combustion appliances were aerodynamically uncoupled from the building enclosure. Sealed furnace rooms were not used.

6. Temperature Swings: Each house was constructed such that temperature swings within the building's livable area were limited to 5.5 Celsius degrees(10 Fahrenheit degrees). Normal indoor tempertures were defined as 21 degrees Celcius (70 degrees Fahrenheit) for living spaces and 18 degrees Celcius (65 degrees Fahrenheit) for basement spaces.

7. Design combinations which met these technical criteria and the Alberta Building Code were used.

The building envelopes of the three houses were constructed with an air barrier as defined in APPENDIX B: CONCERNS ABOUT THE USE OF POLYETHYLENE FILM IN RESIDENTIAL CONSTRUCTION. The air barrier was the interior cladding or gypsum board installed in a continuous manner and joined with appropriate gasket material to wood framing members and the concrete floor slab in the basement. No polyethylene film was used anywhere as part of the air barrier system.

Some simplified wood framing techniques were incorporated including: nail-on window headers which eliminated many of the short studs or cripples prevalent in standard framing.

Innovative heating and ventilating strategies were also demonstrated including a multiple inlet fresh air supply and distribution system coupled with a fan-coil system attached to an induced draft gas domestic hot water heater. However, in the latter system, back-up heat was required due to code requirements and the large heat demand of the house involved (current hot water heaters are only capable of providing 5 to 6 KW).

C. Documentation of Construction

The three Edmonton ADA houses, in order to achieve significant degrees of airtightness, incorporated the construction details proposed in the previously mentioned feasibility study, "A New Approach to Affordable Low Energy House Construction". These details along with additional construction details developed to deal with previously unencountered building geometries arising out of the construction of the three Edmonton ADA houses will now be discussed.

1. Foundation Details

The footing detail (Figure 1, Pg. 13) utilized dampproofing on the top of the cast concrete footing to provide for a capillary break in addition to the standard dampproofing applied on the exterior of the cast concrete perimeter basement foundation wall. A dampproofing coating was also applied to the interior surface of the concrete basement foundation wall to grade level to act as a vapour diffusion retarder in order to meet local building code requirements.

Considerable disagreement exists regarding the necessity of installing a vapour diffusion retarder in this location as well as the logic of running it only to grade level. The proponents of installing this interior vapour diffusion retarder argue that by stopping it at grade any moisture which may have migrated into the interstitial space between the finished interior gypsum board surface and the concrete perimeter wall will be able to diffuse to the surrounding atmosphere through the exposed concrete above grade level. These same proponents, however, typically have no argument for installing a vapour diffusion retarder in this location in the first place, but they insist that if one is to be installed, it must stop at grade level.

One of the few arguments for installing a vapour diffusion retarder on the interior surface of a concrete perimeter foundation wall is to try to prevent or reduce the migration of the large quantities of moisture found in freshly cast concrete into the interstitial spaces. Presumably this argument implies that if the concrete is allowed to dry before an insulated interior frame wall is installed, then no

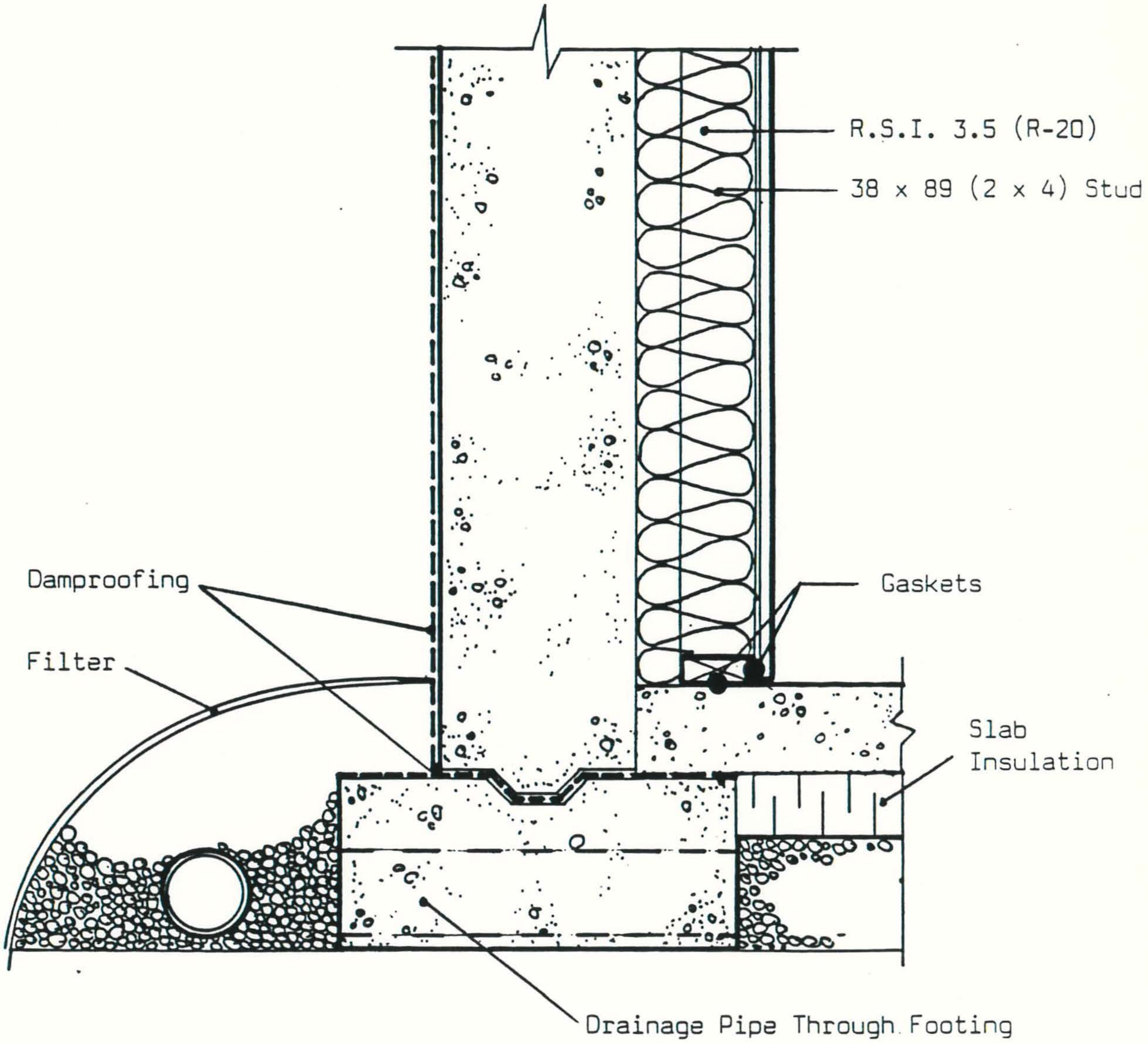


Figure 1: Footing Detail

vapour diffusion retarder is required at this location.

If a vapour diffusion retarder is installed to prevent moisture from migrating into the interstitial space of a perimeter frame wall, then, logic should dictate that the vapour diffusion retarder be installed to the top of the foundation wall. Also, an additional capillary break should presumably be installed at the top of the cast concrete wall between the concrete and the framing materials, thus ensuring that the only drying of the concrete occur to the surrounding atmosphere through the exterior exposed concrete above grade level. Moisture which migrates from the house interior into the interstitial space between the gypsum board surface and the concrete wall will condense on the interior surface of the concrete if its surface temperature is below the dew point. The installation of a vapour diffusion retarder at this location will not prevent this from occuring. The condensation will merely occur on the interior surface of the vapour diffusion retarder instead of directly on the surface of the concrete. This condensed moisture will run down the surface of the concrete (or the surface of the vapour diffusion retarder) to the basement floor slab level. It is unlikely that any appreciable amounts of moisture will diffuse above a vapour diffusion retarder terminated at grade level through the basement concrete to the surrounding atmosphere. It may be appropriate to simply allow this moisture, likely to be in liquid form and located at the floor slab level, to drain through the slab into the granular material typically located below. This strategy was not implemented due to local code restrictions and builder unease, although it was recommended.

2. Crack Initiators for Basement Walls

A strategy which was recommended and adopted was the use of crack initiators to control concrete perimeter foundation wall cracking. This strategy employed the use of prism shaped pieces of forming material inserted into standard forms to in essence pre-crack the concrete foundation wall (Figure 2, Pg. 17). The use of crack initiators induced the concrete to crack at these pre-determined locations rather than elsewhere in a random manner. Since the location of basement wall cracks was now predictable, the cracks could be pre-fixed before backfilling. This pre-fixing was accomplished by the use of a strip of rigid, draining fiberglass insulation, tied into the perimeter drain system. A mastic or sealant was not relied upon exclusively to seal the exterior of such initiated cracks as it was felt that the mastic would dry and eventually crack, leading to potential moisture ingress. The location of crack initiators was determined by the CSA Standard, "Concrete Construction for Small Buildings", which recommends crack initiators spaced at 5 metre (15 ft.) and at stress concentrations such as under basement windows.

3. Air Barrier Detail at Grade

Air barrier continuity at grade, when utilizing ADA with standard platform framing, is typically achieved as described in Figure 3, Pg. 18. However, in Western Canada it is usual to utilize cast-in-place floor joists at grade. As such, the standard approach to ADA at this location was not possible. For the three Edmonton ADA houses, two details were employed to provide air barrier continuity at grade through the cast-in-place subfloor framing when siding or brick cladding was utilized (Figure 4, Pg. 19 and Figure 5, Pg. 20). Central to this strategy was the notching of gypsum board sheets around the floor joists and sealing the resultant seams with a sealant (Figure 6, Pg. 21). This approach provided satisfactory performance with respect to air barrier continuity, but ultimately proved unsatisfactory with respect to time, labour and monetary considerations. It proved to be too time consuming and labour intensive to be practical in the long term. It may also prove not to be durable over the long term due to joist shrinkage. Unfortunately an alternative strategy was not proposed in time to be field evaluated in the Edmonton project. A more acceptable strategy was subsquently developed and is described in SECTION III: SUBSEQUENT EVOLUTIONARY DEVELOPMENT OF THE AIR DRYWALL APPROACH.

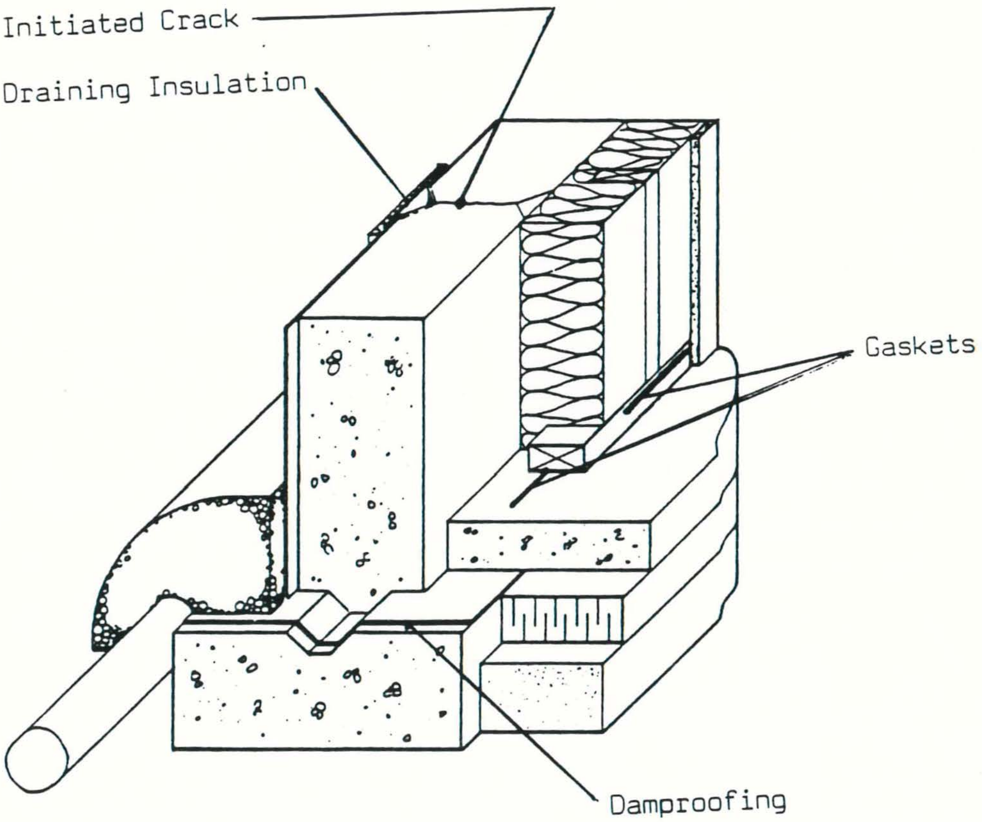


Figure 2: Footing Detail-Crack Initiator

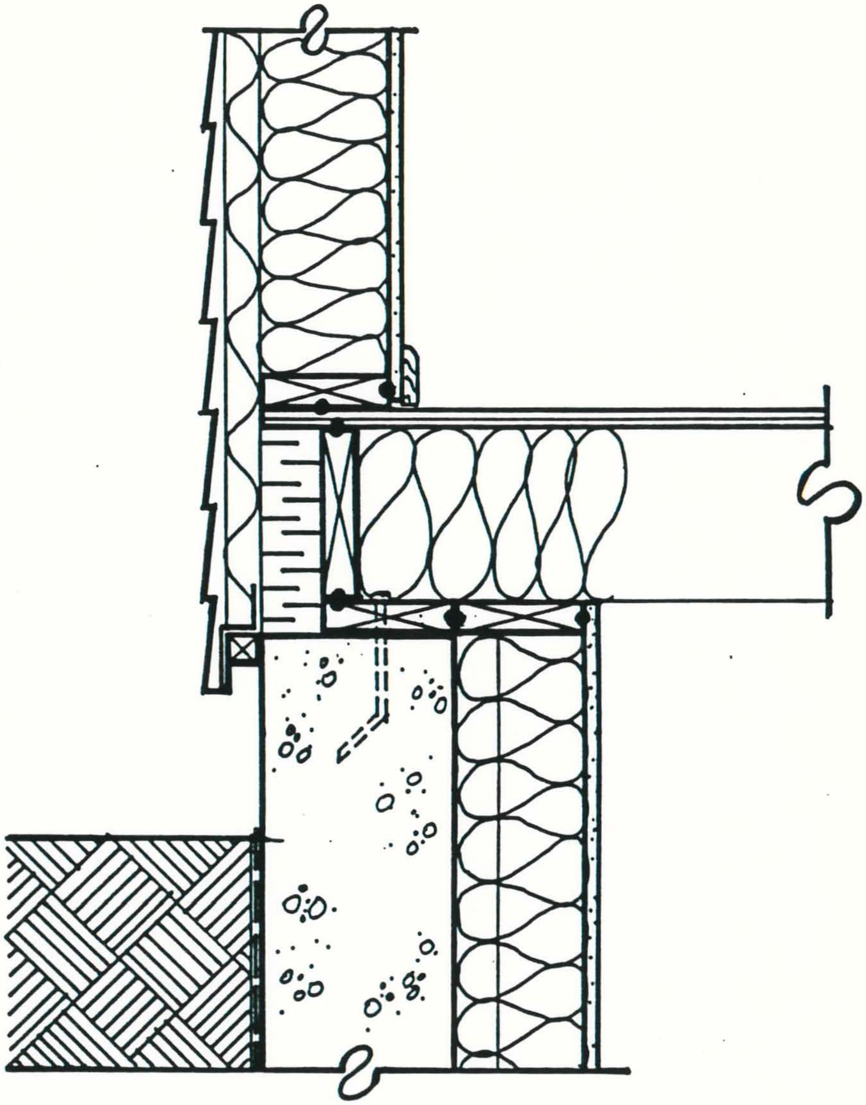


Figure 3 : Subfloor at Grade

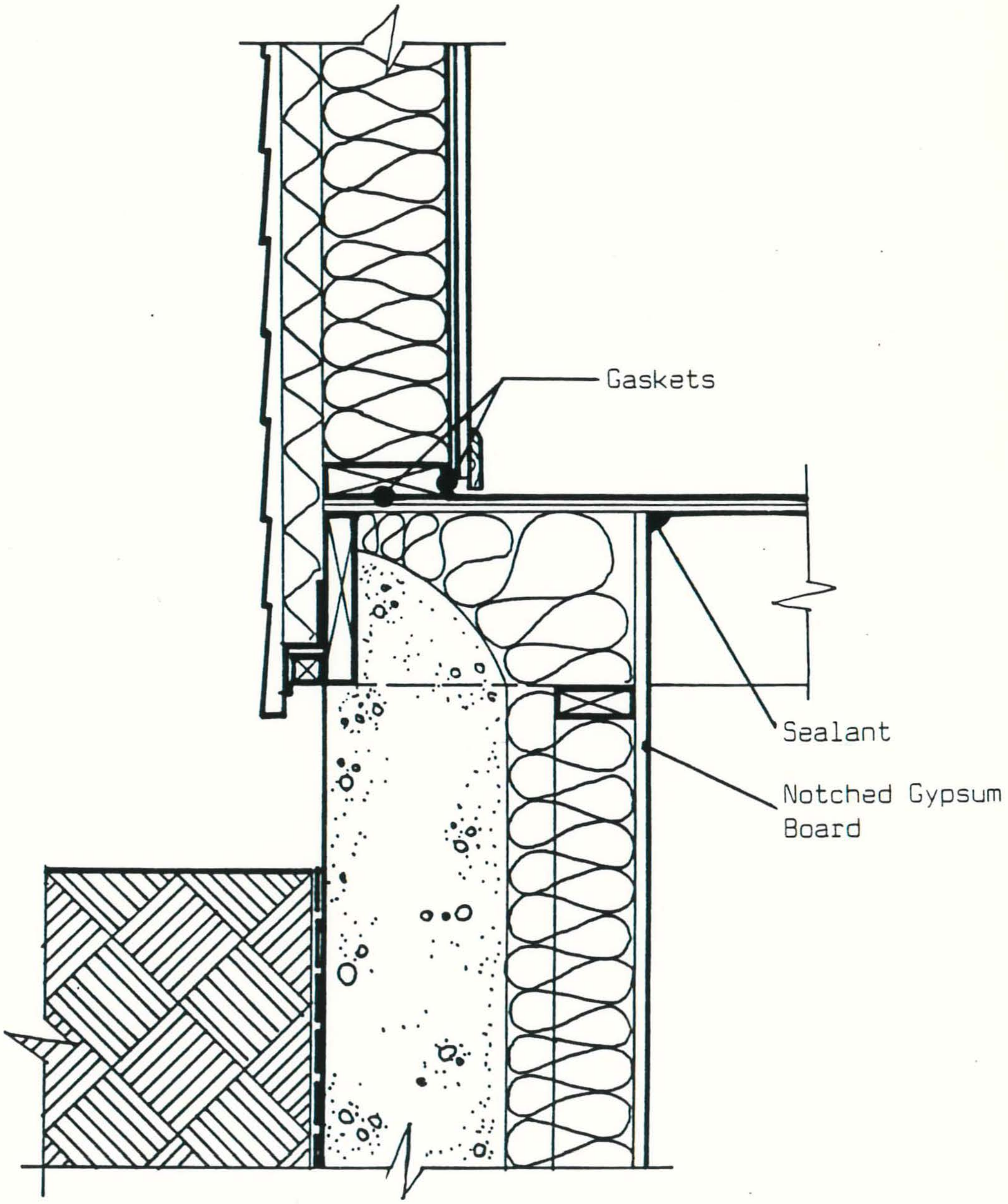


Figure 9 : Subfloor at Grade

Cast-in-place Floor Joists

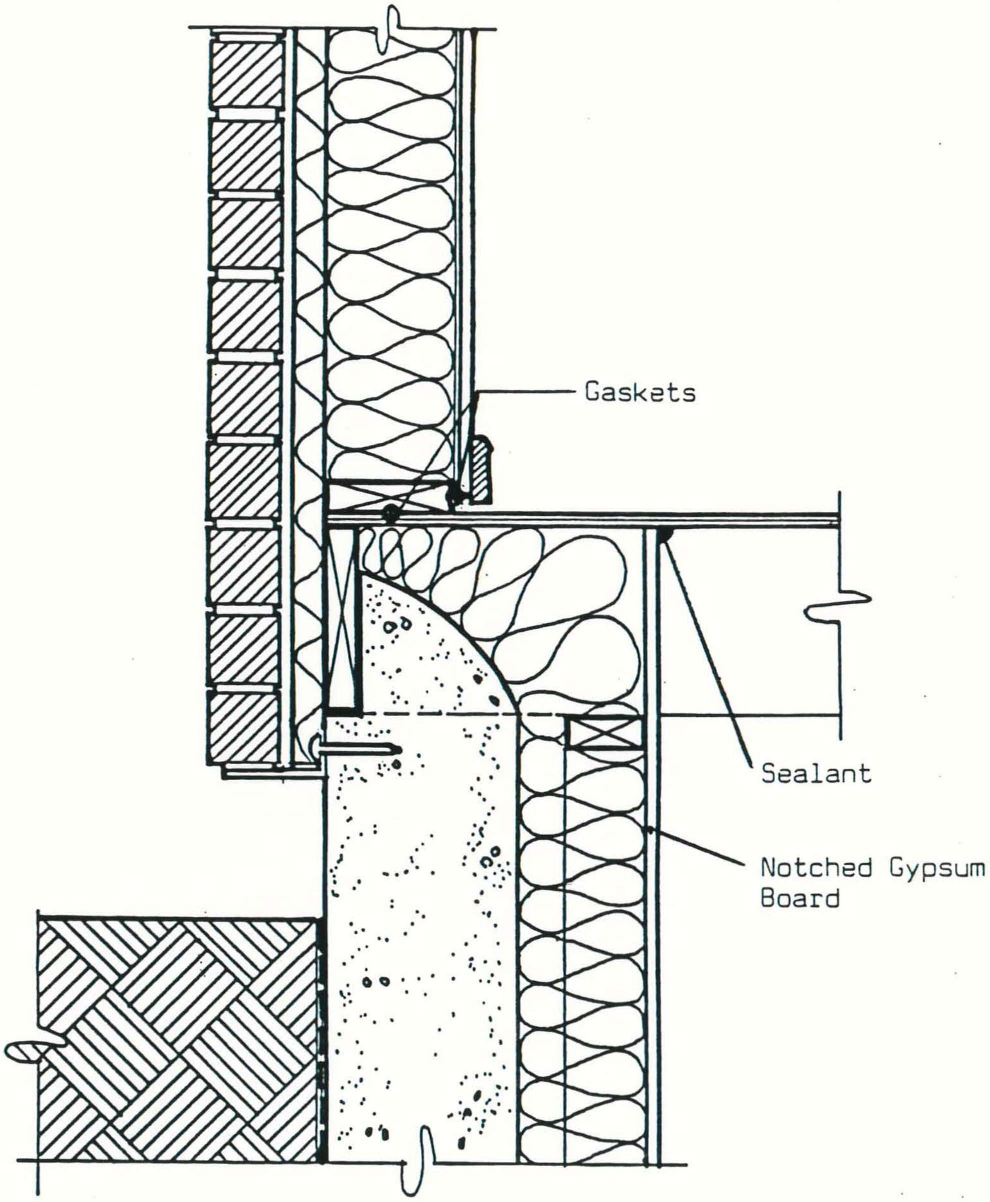


Figure 5: Subfloor at Grade
Cast-in-place Floor Joists,
Brick Veneer

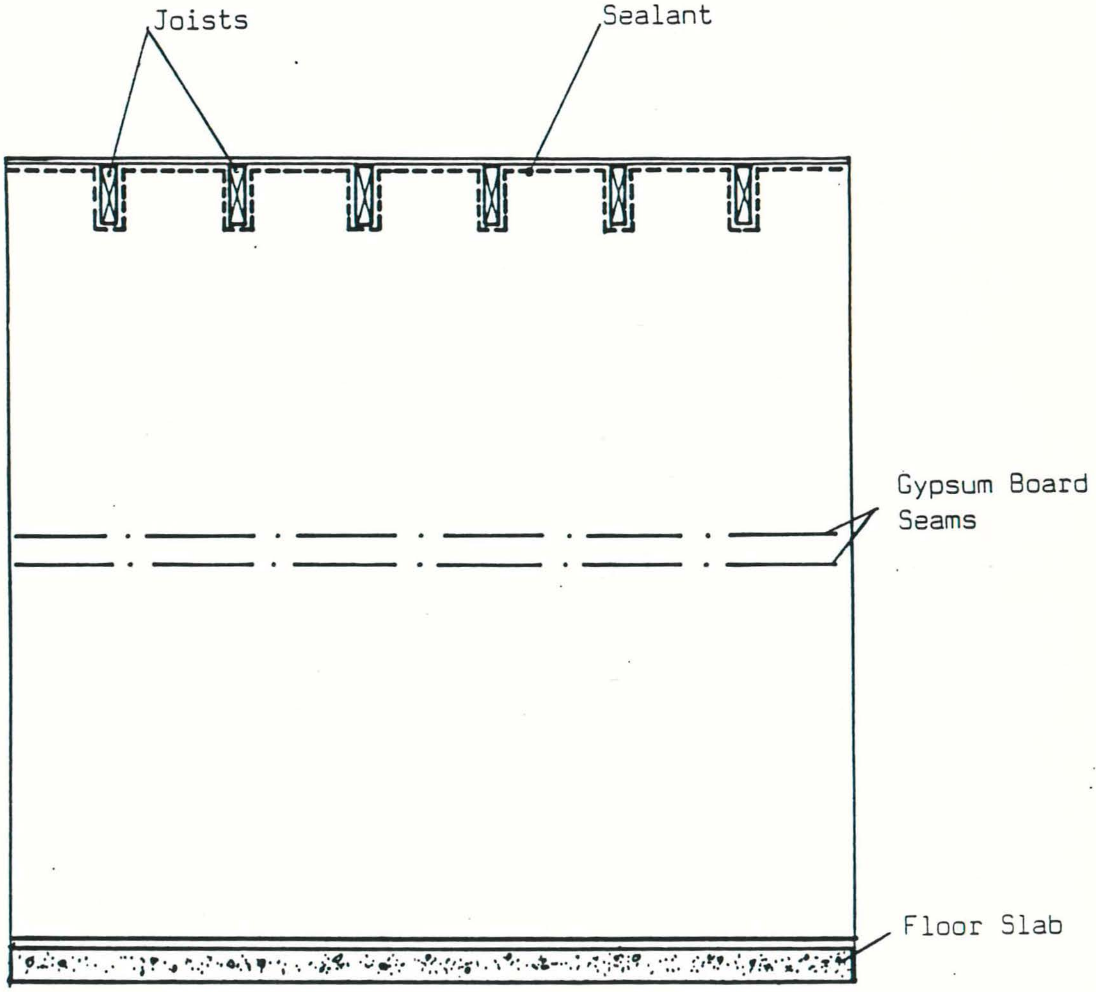


Figure 6: Notched Gypsum Board

4. Air Barrier at Second Floor

In the two multi-storey Edmonton ADA houses, air barrier continuity between storeys at subfloors was accomplished as shown in Figure 7, Pg. 24, for standard subfloor framing and as shown in Figure 8, Pg. 25, where floor trusses were employed. The major difference between the two is the use of plywood as a rim joist, (header or band joist) in place of a standard wood joist. This was to compensate for differential shrinkage rates between waferboards, plywoods and floor trusses as compared to typical floor joist material. Floor trusses, which practically do not shrink, are combined with a waferboard or plywood rim joist or header. Standard floor joists, which do shrink as moisture contents decrease, are combined with standard rim joist or header materials which shrink at the same rate. A minor difference to note, between Figure 7, and Figure 8, was the use of a construction adhesive to provide a seal between the top of the plywood rim joist and the plywood subfloor in Figure 8, as opposed to a gasket in this location in Figure 7. A gasket was judged to be too difficult to install in this location. A wide gasket, of rectangular profile (Dow Sil Seal) was used at the bottom of the plywood rim joist in Figure 8, as it would have been too difficult to accurately position a narrow gasket directly under a narrow rim joist. A sealant was not used in this location in order to allow for building frame movement.

5. Air Barrier at Ceiling

Air barrier continuity where exterior perimeter walls met insulated ceilings was provided for as described in Figure 9, Pg. 26. 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 gypsum board. It should be noted that treated paper baffles were installed between the roof trusses directly in line with and above the exterior perimeter wall top plates. This limits the deleterious effects of wind washing or blow-through in which wind can serve to short-circuit thermal insulation and lead to local chilling of the interior cladding, which often results in high surface relative humidities and attendent mould and mildew growth. It is important to note that a perfect air barrier located on the interior of an exterior wall will not eliminate mould and mildew formation as it does not prevent wind washing.

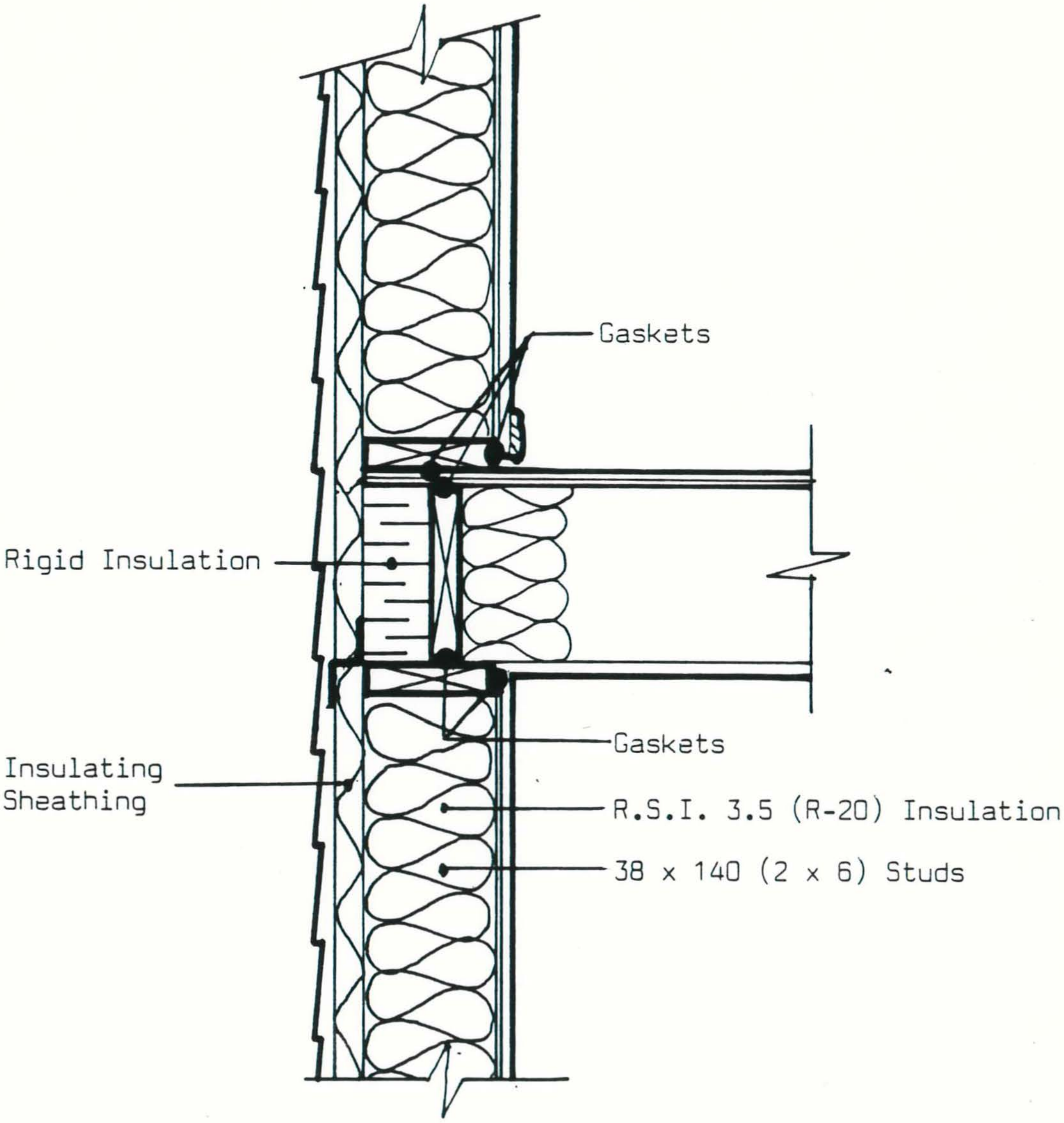


Figure 7: Second Floor Subfloor

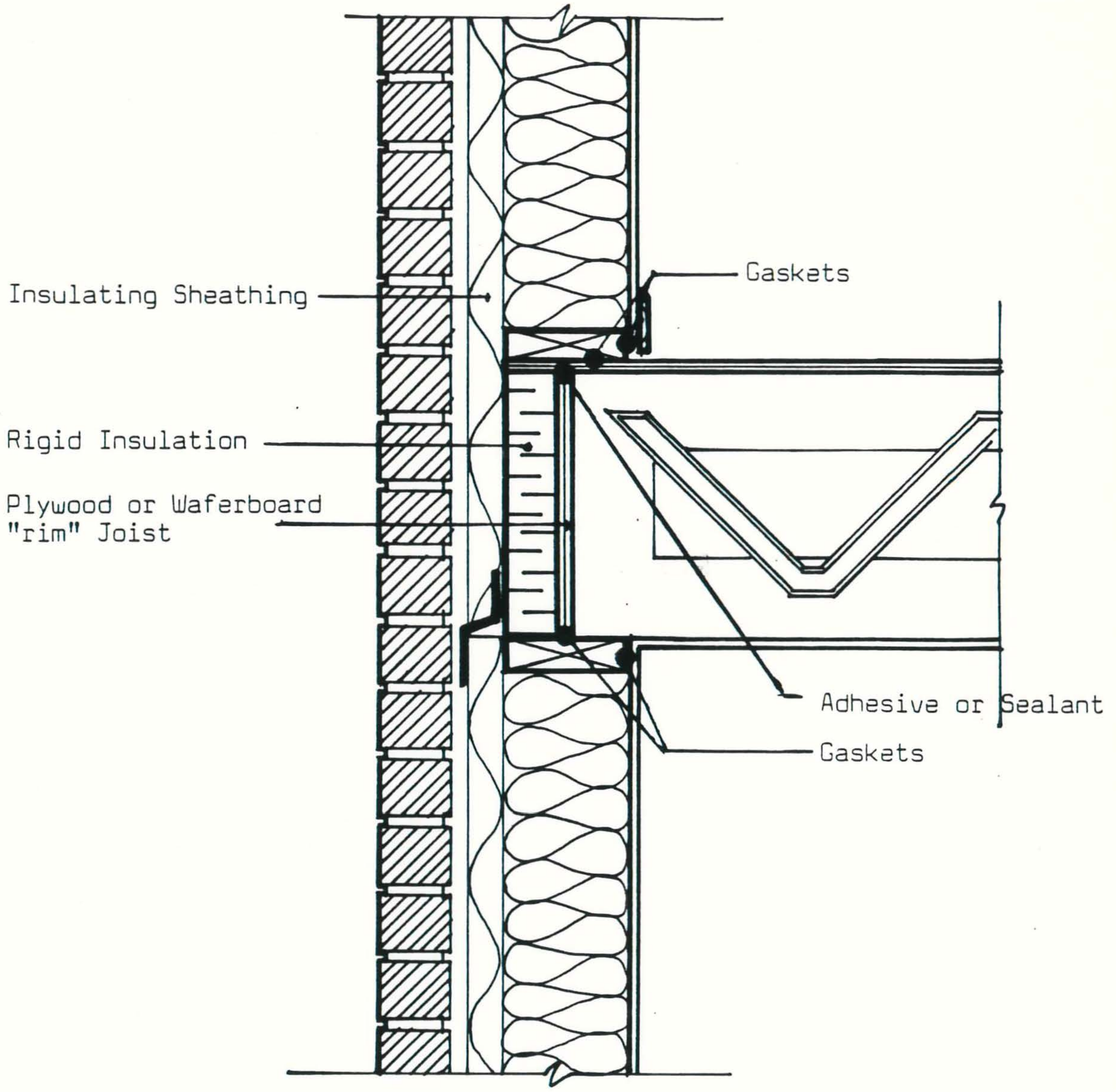


Figure 8: Second Floor Subfloor - Floor Tr sses

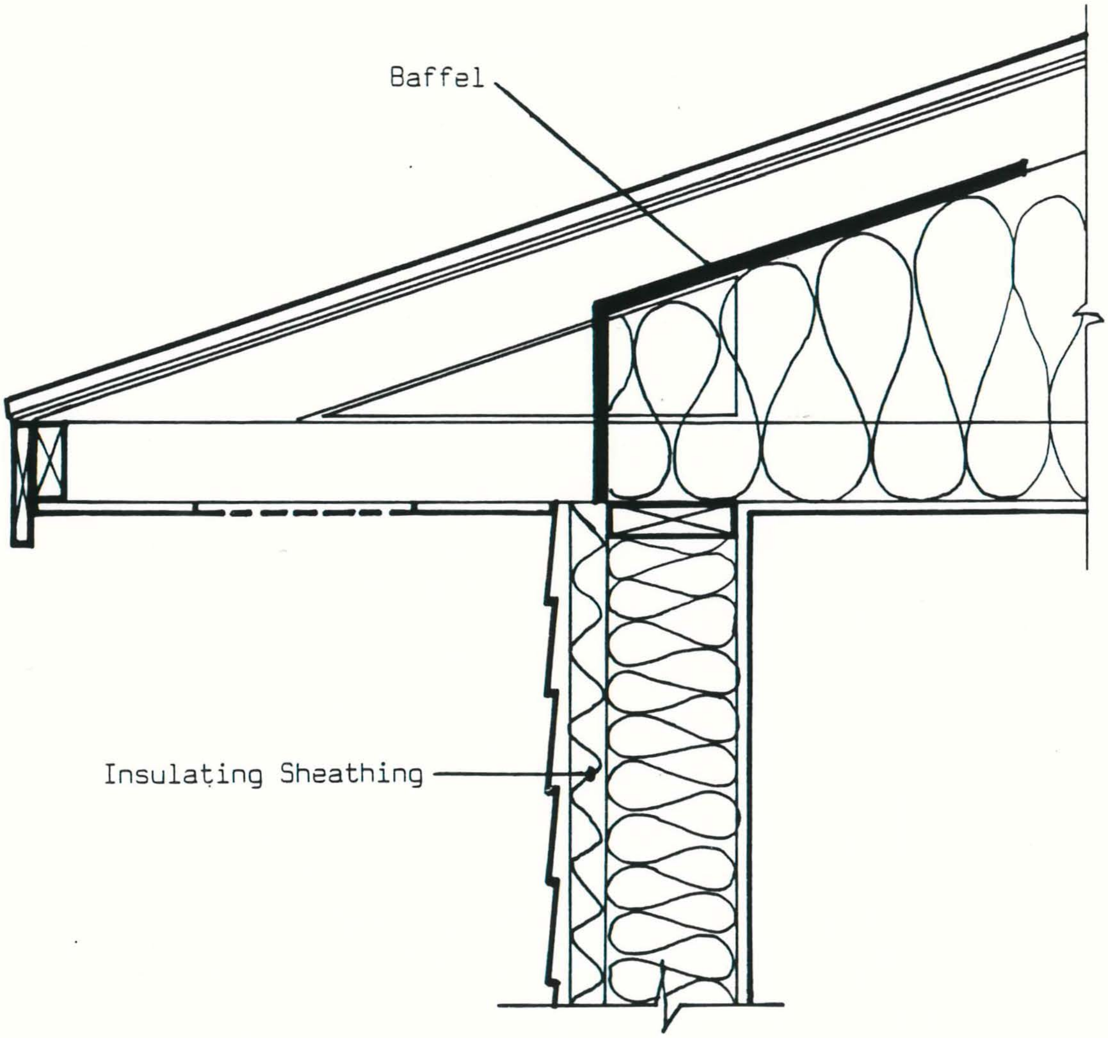


Figure 9 : Roof/Ceiling Interface

6. Windows

Window installation was facilitated as described in Figure 10, Pg. 29, in which the interior gypsum board surface was returned to the window frame and the seam was sealed with an appropriate sealant, typically paintable caulking. A gasket was not utilized here for obvious practical reasons. Where a wood jamb was desired, the detail in Figure 11, Pg. 30, was employed. In this detail the gypsum board is sealed directly to the wood jamb extension with caulking and this seam is hidden with standard trim. For this detail to work in a satisfactory manner, the wood jamb extension must be sealed to the wood window with a continuous bead of adhesive. Windows often come with wood jamb extensions factory installed. In such cases, it should be specified that factory applied adhesives be applied in a continuous manner.

7. Cantilevered Floor Construction

Cantilevered floor construction, typically encountered at second floor subfloors and at bay windows, was facilitated with the use of the construction details presented in Figure 12, Pg. 31 and Figure 13, Pg. 32. In Figure 12, where intersection floor joists crossed over a perimeter exterior wall, wood blocking or blocks of rigid, non-air permeable, insulating sheathing were inserted into the joist spaces and sealed around their edges with caulking to provide for air barrier continuity. The air barrier over the cantilevered portion of the subfloor therefore became the actual subfloor sheathing. Seams in the subfloor sheathing material were therefore sealed with a subfloor adhesive. In Figure 13, where floor joists are aligned parallel to a lower perimeter exterior wall, a floor joist is positioned directly over the lower perimeter exterior wall and gasketed similar to a typical rim joist. Again, the subfloor sheathing was the air barrier over the cantilevered portion of the subfloor with the seams sealed.

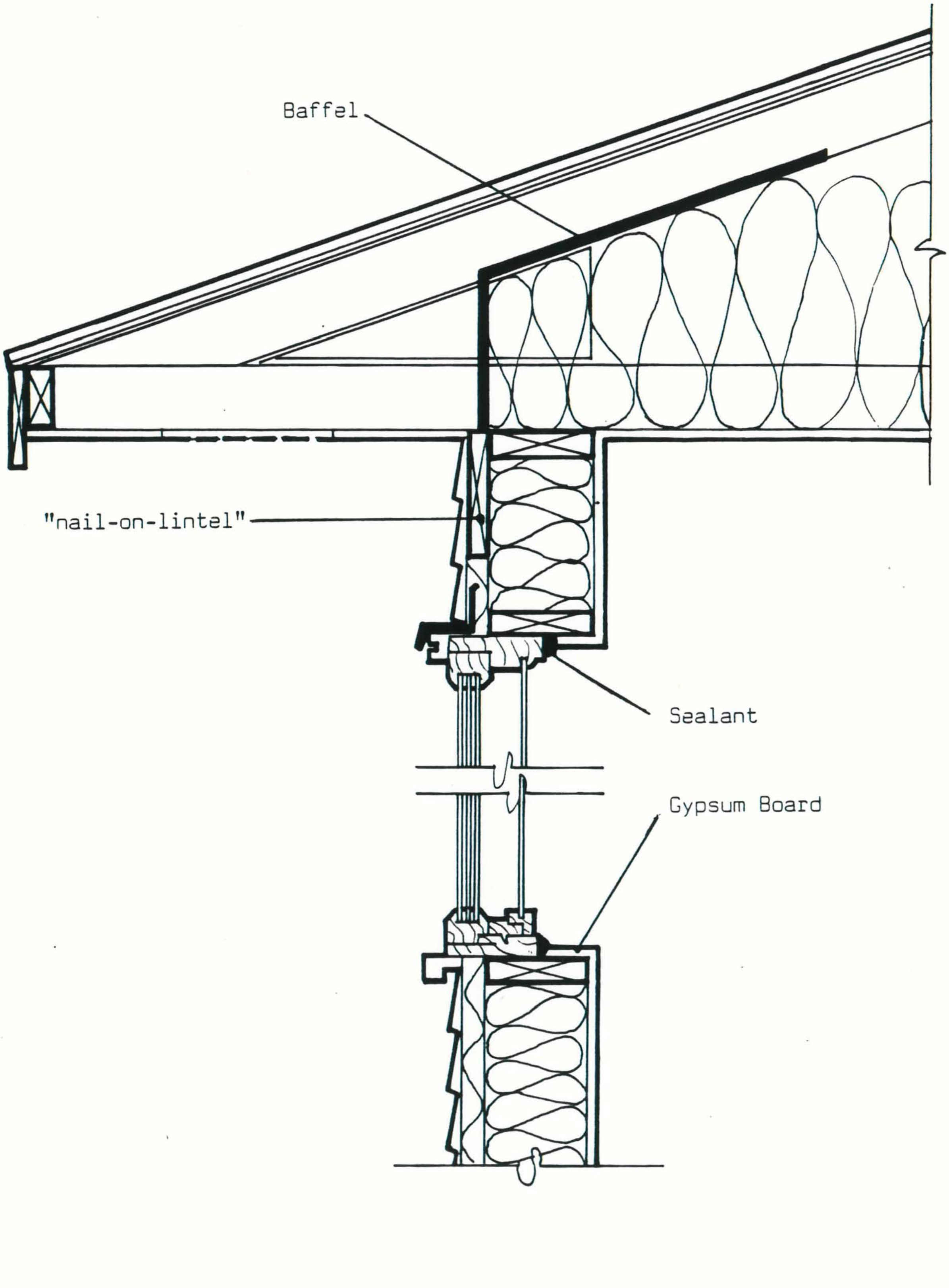


Figure 10: Window Detail - Drywall Return

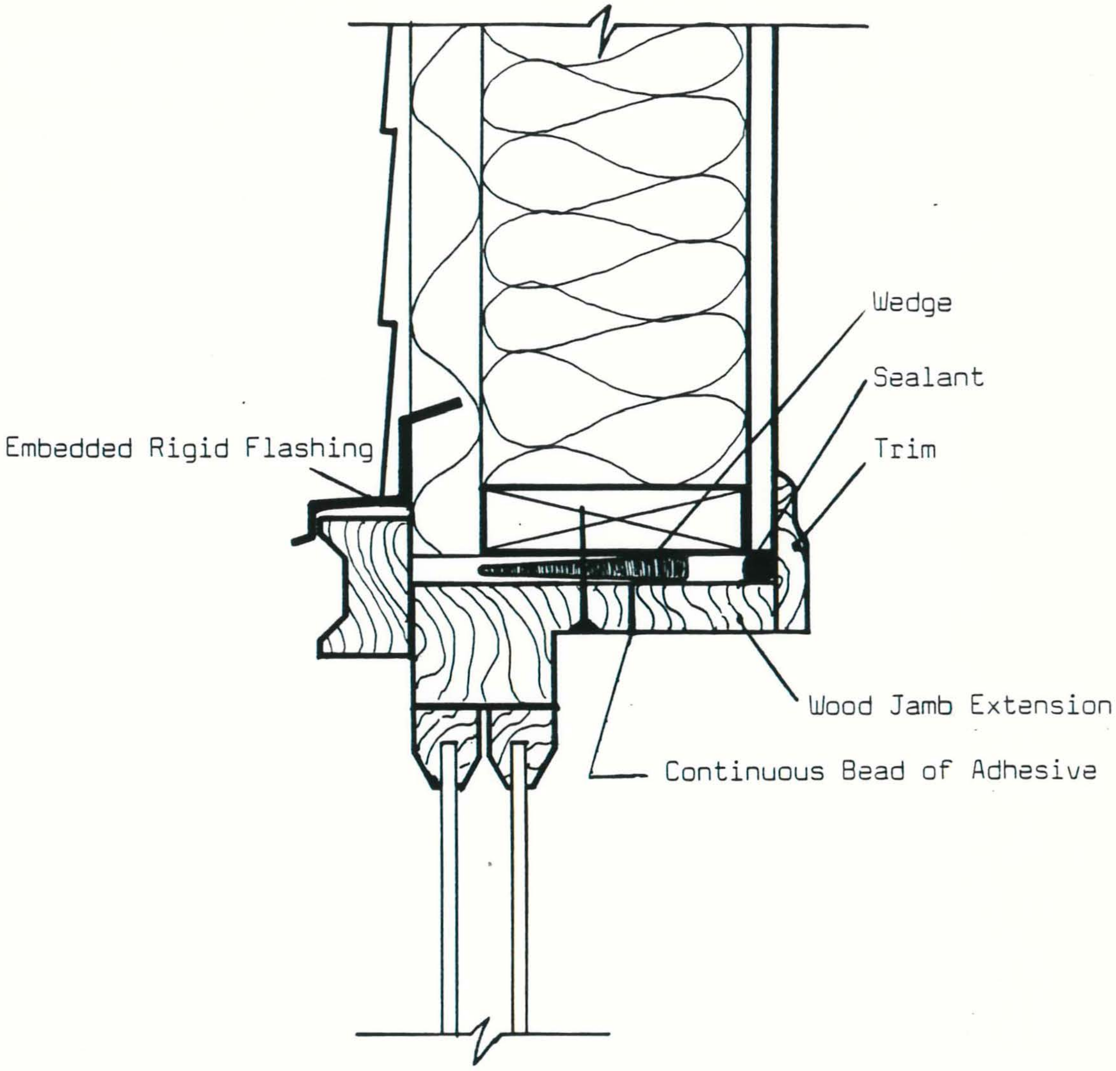


Figure 11 : Window Detail - Wood Jamb Extension

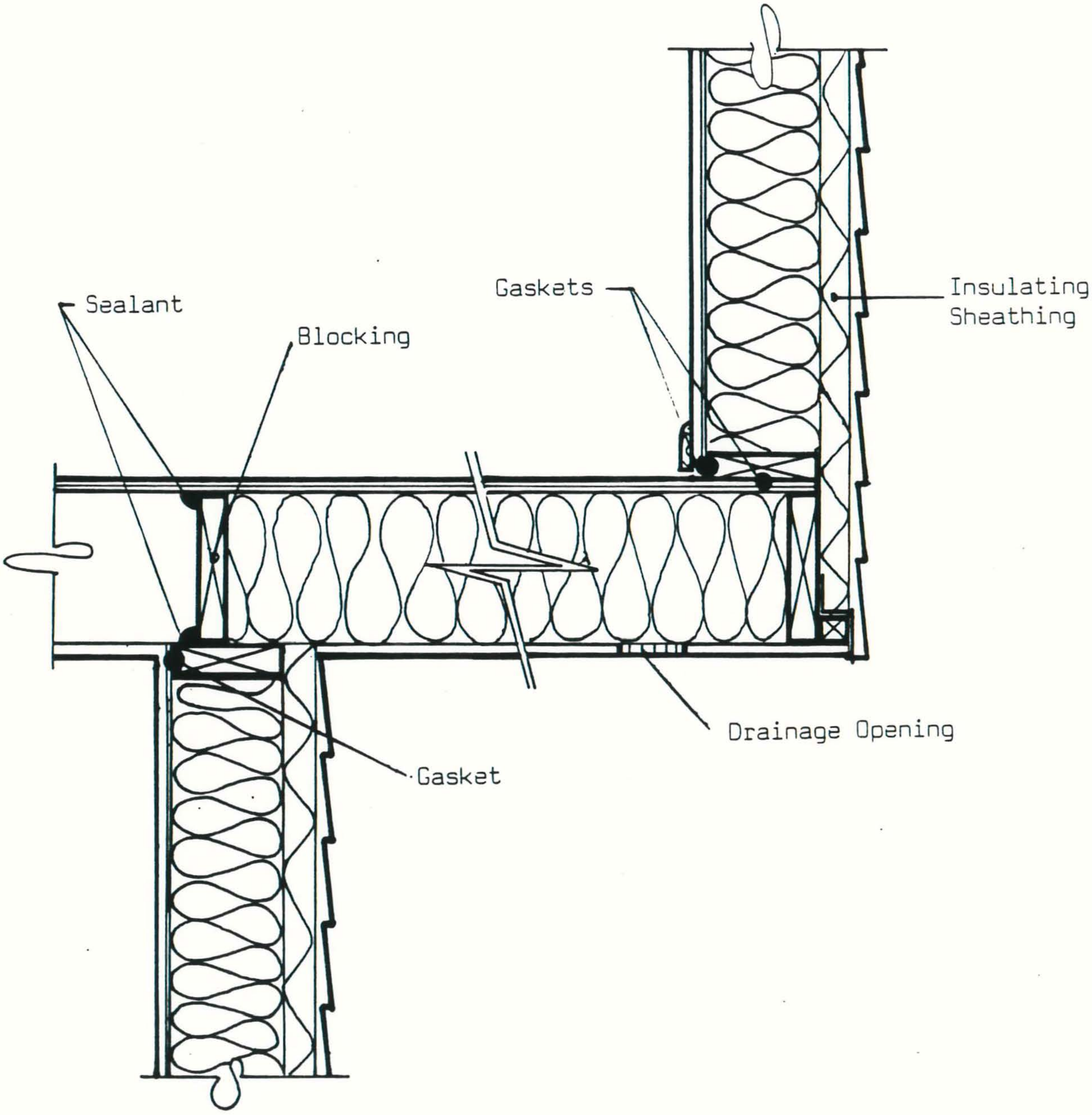


Figure 12: Cantilever Floor - Intersecting Joists

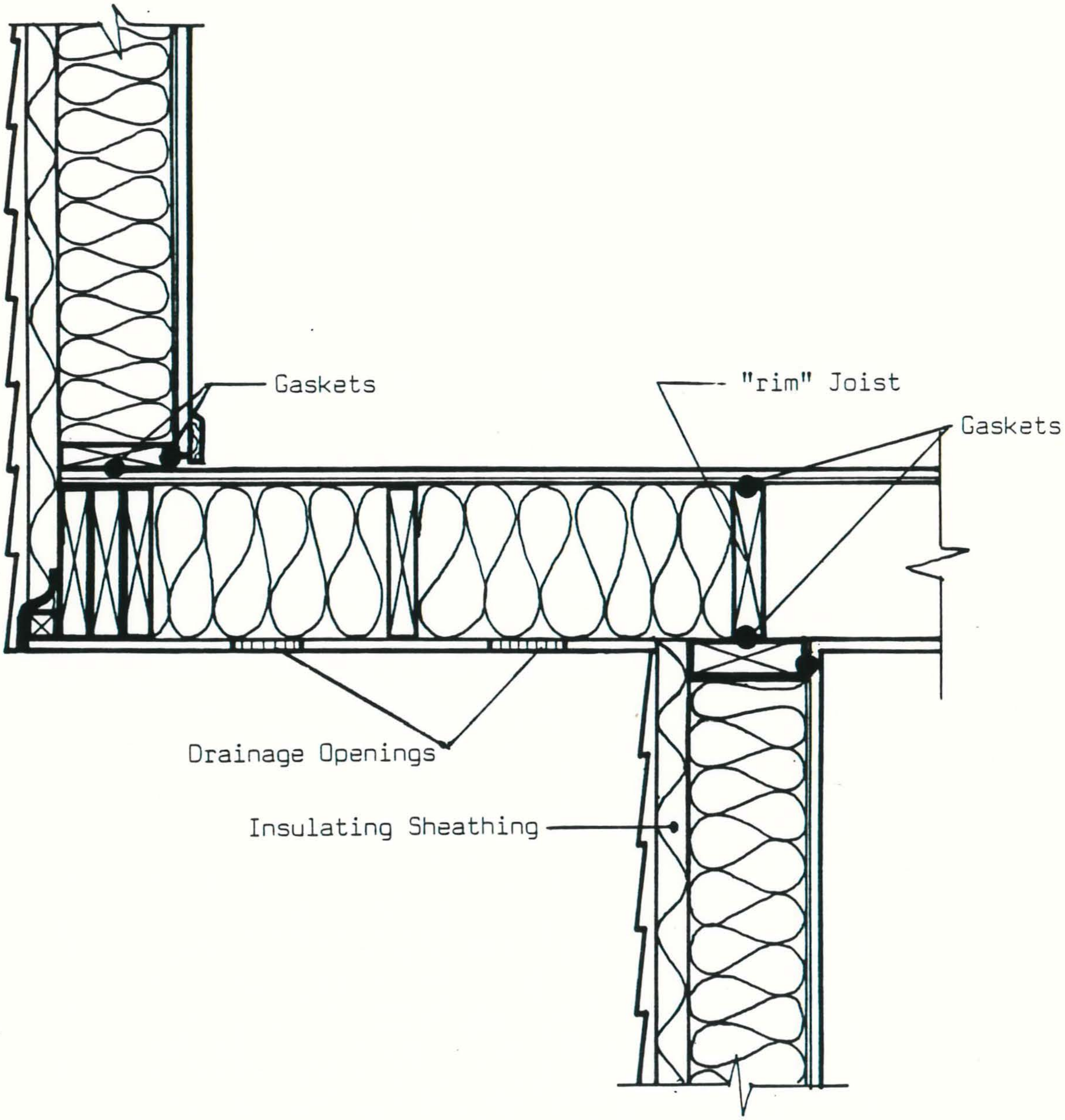


Figure 13: Cantilever Floor - Parallel Joists

8. Interior Partitions

Interior partition walls located under insulated ceilings in the three Edmonton ADA houses were constructed after ceiling gypsum board was installed. This was possible due to the use of roof trusses. However, as the complexity of floor plans and roof construction increased due to the need for client customization, occasional interior load bearing walls under insulated ceilings were required. Air barrier continuity in such a situation was accomplished as detailed in Figure 14, Pg. 35. Gaskets were installed on both sides of the load bearing top plate providing for air barrier continuity between the ceiling gypsum board sheets on either side of the load bearing partition wall.

Although it is possible to construct the vast majority of interior partition walls under insulated ceilings after ceiling gypsum board is installed, it was felt to be impractical as a long term strategy due to the increased complexity of trade scheduling. This approach requires additional trips for the framer, the electrician, the plumber, the gypsum board installers, and tapers. Furthermore, continuous gypsum board over the top of interior partion walls was also incompatible with standard techniques utilized for the control of "truss uplift" (although uplift was not a problem at this project). An alternative strategy was felt necessary. Unfortunately, an appropriate strategy was not available until after the three Edmonton ADA houses were constructed. One alternative strategy, which eliminated trade scheduling difficulties is presented in SECTION III: SUBSEQUENT EVOLUTIONARY DEVELOPMENT OF THE AIR DRYWALL APPROACH. Truss uplift concerns were not adequately addressed through ADA techniques until relatively recently, in which the ultimate strategy was to treat all interior partion walls as "load-bearing" with respect to air barrier continuity. This is described in SECTION IV: CURRENT AIR DRYWALL APPROACH TECHNIQUES.

9. Split-Level Detail

The first ADA split-level house was constructed as part of the Edmonton project and necessitated the development of the construction detail presented in Figure 15, Pg. 36. Wood fire blocking, which was caulked to wall stud framing, was the key component in providing air barrier continuity between the one storey portion of the split-level and the second storey of the two storey portion of the split-level. Gaskets were installed on both sides of the fire blocking before gypsum board was installed.

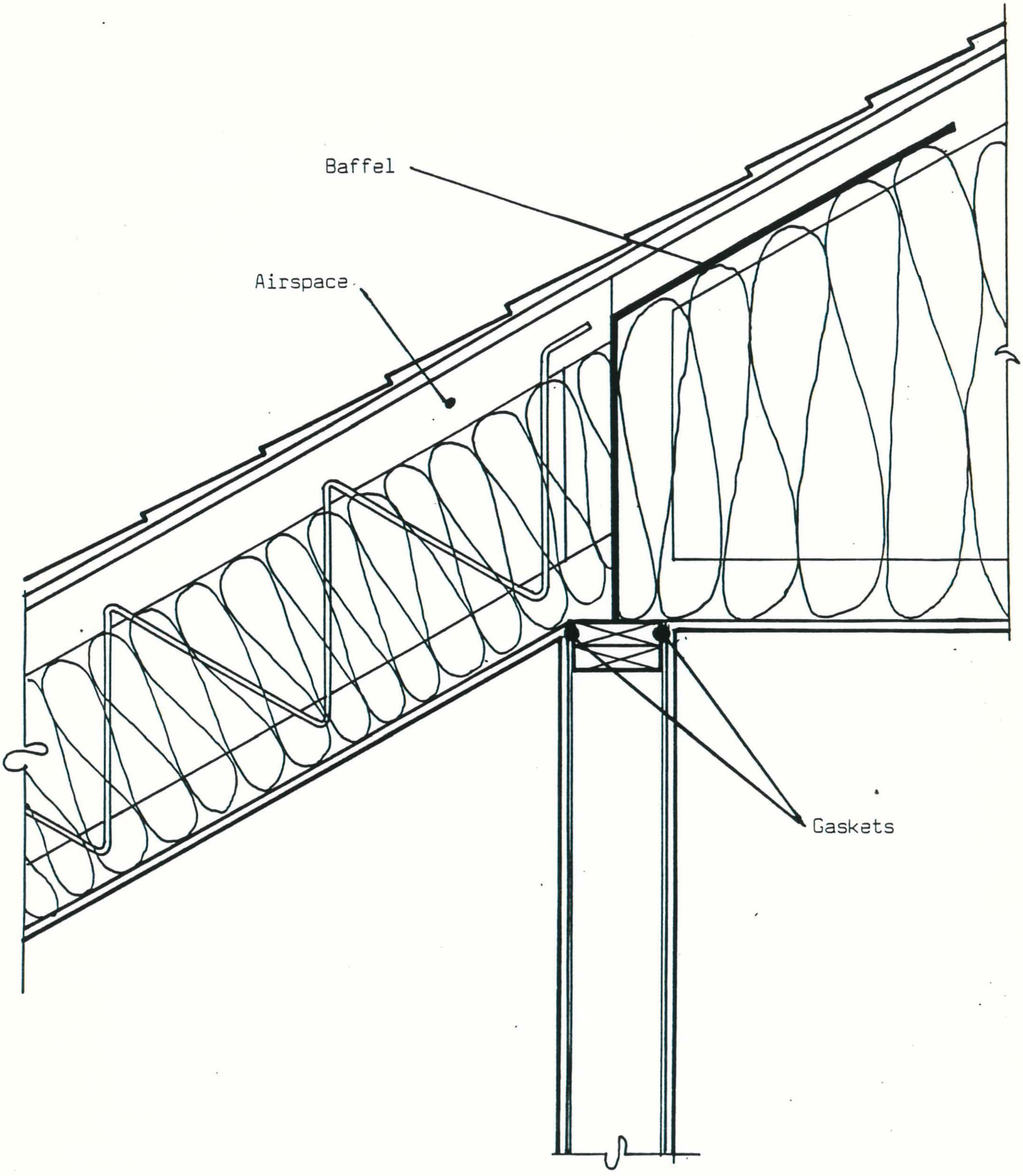


Figure 14: Load Bearing Wall - Sloped Ceiling

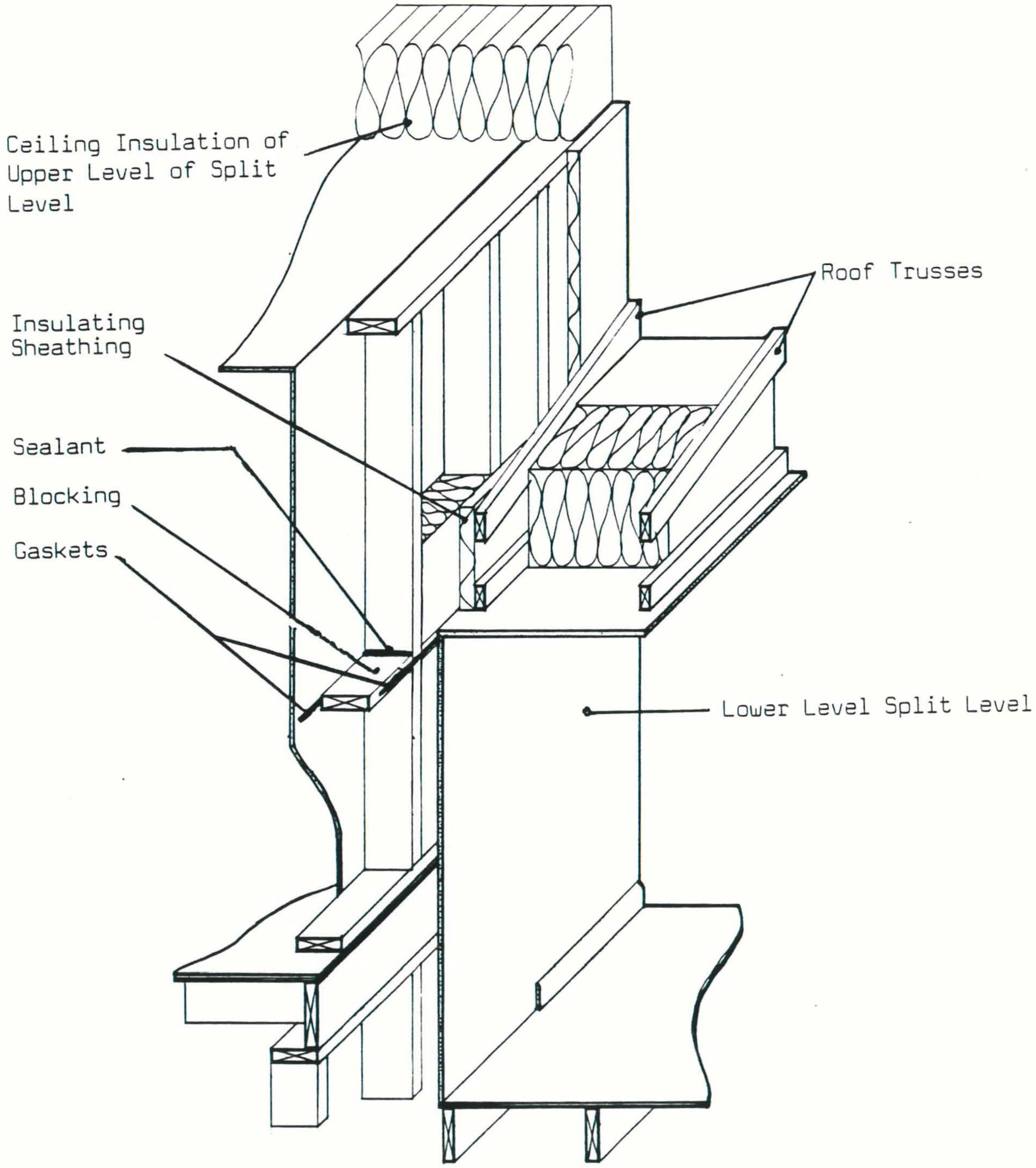


Figure 15: Split-Level Detail

10. Innovative Framing Details

Some innovative framing techniques were investigated with the intent of reducing the amount of framing materials in the buildings. The three major techniques investigated were:

1. The elimination of short pieces of framing material under window openings commonly referred to as cripples. These cripples can be shown to be redundant and their continued use only a hold over as a result of tradition.
2. The elimination of window lintels by relying on nail-on lintels.
3. Single top plate framing by lining up roof trusses directly over perimeter wall studs and floor trusses.

Of the three techniques, only the first two were incorporated into the three Edmonton ADA houses. The last technique was felt to have merit, however, it was felt that utilizing this technique in addition to introducing the ADA concept in one demonstration project would unduly complicate framing. All three techniques have been previously proposed in the OVE (Optimum Value Engineering) approaches promoted in the early 1970's by the National Association of Home Builders in the United States. It is unclear why these techniques have not become part of common framing practice in North America.

The first technique needs no further explanation as it is self evident. The second technique relies on the shear strength properties of nails to provide for adequate load bearing properties. The window lintels are typically a single piece of framing material and are either nailed on the surface of the wall framing, necessitating the notching of insulating sheathing around the lintels. Alternatively, the walls studs can be notched to accommodate a single framing member. Both approaches allow for faster framing and less material, yet provide adequate strength. Unfortunately, local building code requirements often require "professional" design if this technique is contemplated. The third technique has been adequately documented elsewhere and will not be discussed here.

11. Space and Domestic Hot Water Heating

Space and domestic hot water heating requirements in all three Edmonton ADA houses were met by utilizing natural gas. However, all of the combustion appliances in the three houses were aerodynamically uncoupled in that their operation was not influenced by the interior house or exterior air pressures. The first two houses both utilized induced draft, medium efficiency forced air gas furnaces which vented through exterior perimeter walls instead of through typical chimneys. Induced draft, gas fired domestic hot water heaters were also used. The third house utilized only one source of combustion to provide both space heat and domestic hot water. This was accomplished by coupling an induced draft, gas fired domestic hot water heater to a fan-coil. A fan-coil is a water-to-air heat exchanger attached to a hot water tank. A water pump is used to circulate hot water through the heat exchanger and back to the domestic hot water tank. A fan or blower then moves house air as part of a forced air heating system over the heat exchanger, thus heating the house air.

12. Ventilation

Ventilation requirements in the first two Edmonton ADA houses were met by coupling a central exhaust system (Figure 19, Pg. 39) to a heat recovery device which acted on the ventilation air, namely an air-to-air heat exchanger or ATAHE (Figure 20, Pg. 40).

Ventilation requirements in the third Edmonton ADA house were met by coupling a central exhaust system to a series of multiple intake inlets and relying on the induced negative pressure in the house as a result of the operation of the central exhaust system to provide for air flow through the intake inlets (Figure 21, Pg. 41).

Recommended operating ventilation rates were determined by the application of ASHRAE Standard 62-1981 which has the following requirement for outdoor air:

- 5 litres per second (10 cfm) per habitable room.

This requirement is independant of house size, and includes bedrooms, living rooms, dining rooms, kitchens and any other rooms in the house. This standard also provides for additional air requirements for bathrooms and for kitchens as follows:

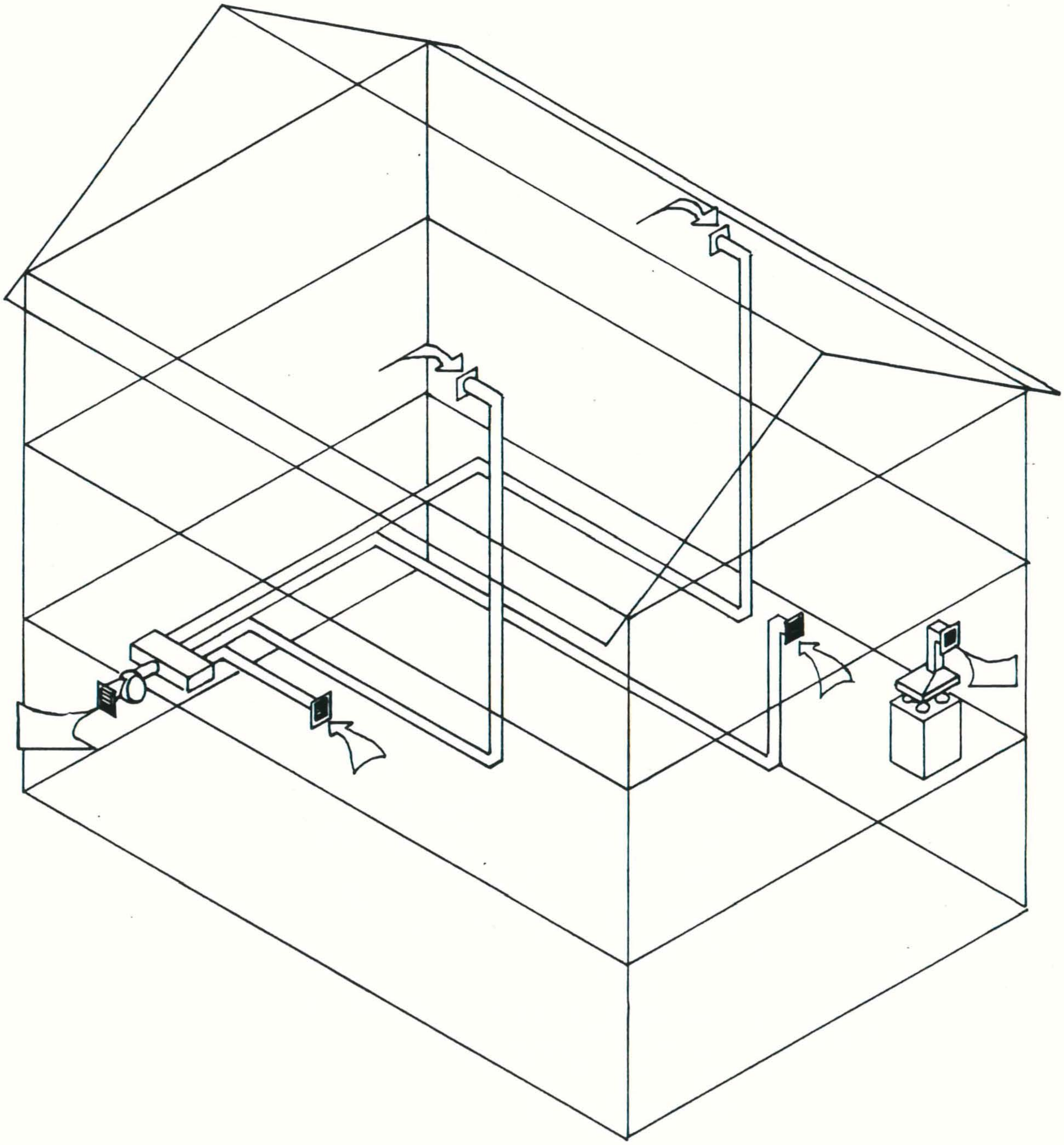


Figure 16: Central Exhaust System

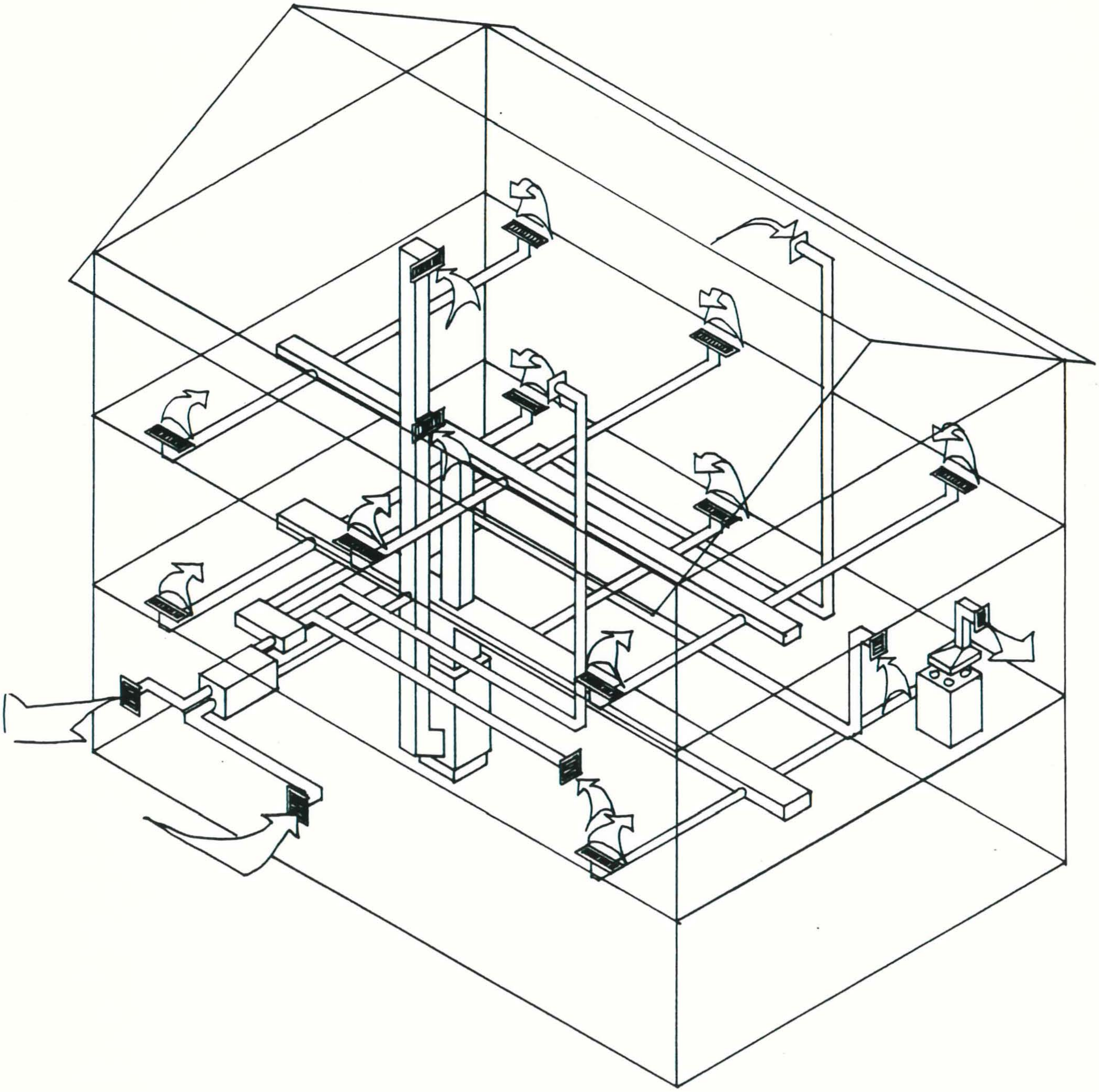


Figure: 17 Central Exhaust System
Single Intake Inlet
Heat Recovery On Ventillation - ATAHE
Forced Air Space Heating

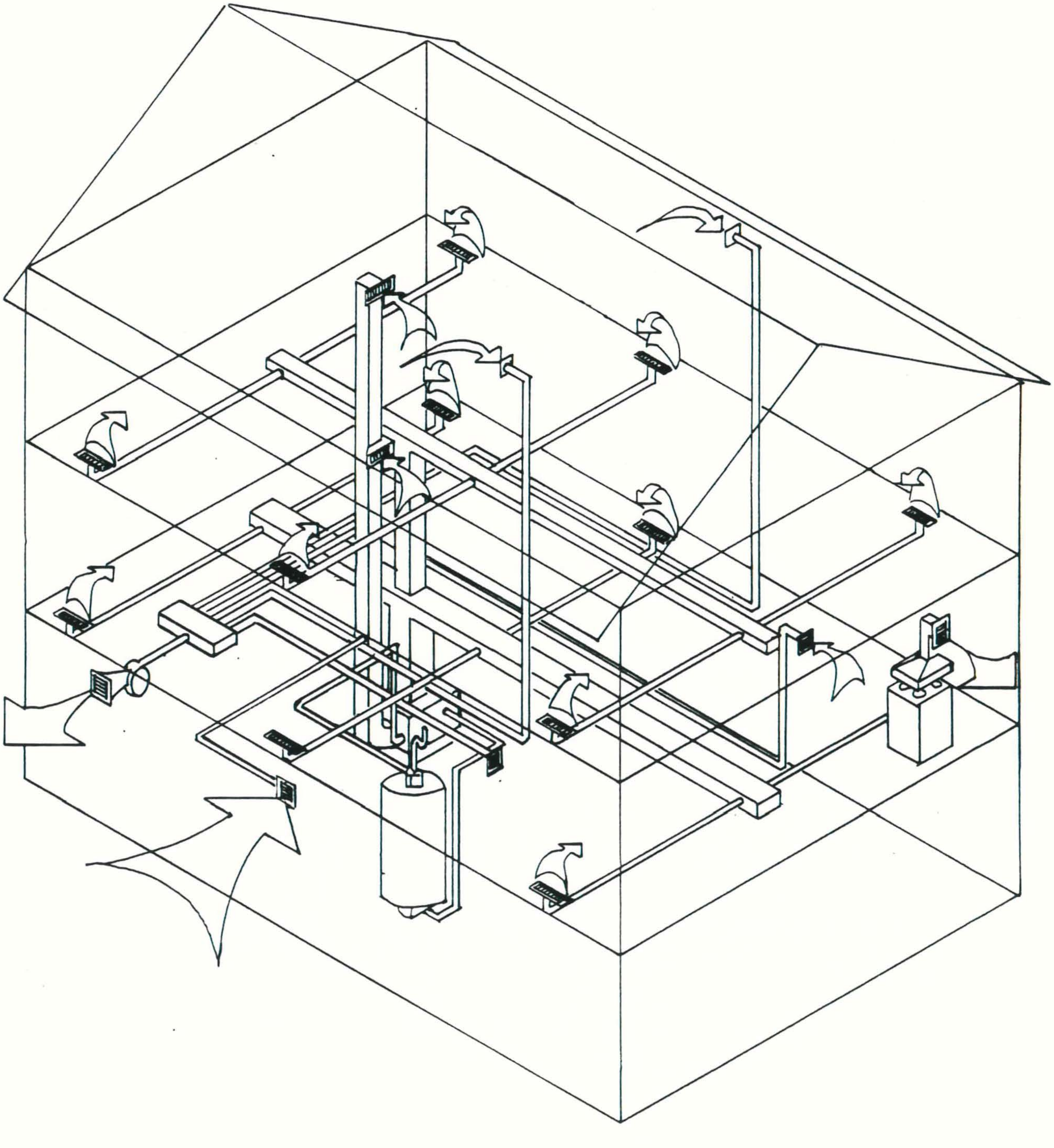


Figure 18: Central Exhaust System
Single Intake Inlet
No Heat Recovery On Ventillation
Forced Air Space Heating -
Fan Coil on DWH

- 25 litres per second (50 cfm) for each bathroom supplied on an intermittent basis when a bathroom is used; and

- 50 litres per second (100 cfm) for kitchen exhausts on an intermittent basis when required.

It should be noted that the ASHRAE standard was used to determine recommended operating ventilation rates, but that the system was sized in a manner that it was capable of delivering 0.5 air changes per hour should that rate ever be required.

13. Airtightness Testing

The three Edmonton ADA houses were tested for airtightness utilizing the Canadian General Standards Board Standard, "Determination of the Equivalent Leakage Area of Buildings By The Fan Depressurization Method" CAN2-149.10-M84 and the following results were obtained:

Bearspaw Show Home	0.5 airchanges at 50 Pascals negative pressure
River Ridge Show Home	0.8 airchanges at 50 Pascals negative pressure
Meadows Show Home	1.1 airchanges at 50 Pascals negative pressure

The three Edmonton ADA houses all achieved significant degrees of airtightness and easily met the R-2000 standard for airtightness which is 1.5 airchanges per hour or less at 50 Pascals negative pressure.

14. Incremental Cost

The incremental costs for the three Edmonton ADA houses are listed below:

INCREMENTAL COSTS ABOVE STANDARD CONSTRUCTION IN EDMONTON, ALBERTA
FOR ADA HOUSES CONSTRUCTED AS DESCRIBED IN SECTION II.

CATEGORY	BEARSPAW	RIVER RIDGE	MEADOWS
Basement Finishing and Below Slab Insulation...............	$1,587.00	$1,435.00	$ 426.00
Insulating Sheathing..............	438.00	539.00	1,327.00
Additional Wall Insulation........	645.00	502.00	380.00
Medium Efficiency Induced Draft Furnace.................	420.00	420.00	420.00
Induced Draft Hot Water Heater....	165.00*	585.00	585.00
Air-to-Air Heat Exchanger Installed.....................	1,250.00	1,250.00	500.00
Electrical.......................	103.00	103.00	104.00
Frame Labour......................	459.00	847.00	400.00
Caulking and Gaskets..............	209.00	394.00	200.00
Windows...........................	324.00	318.00	300.00
TOTAL	$5,497.00	$7,077.00	$4,642.00

* Electric water heater installed

These incremental costs are based on invoiced figures from standard tract trades relating to standard Edmonton, Alberta tract construction practices. For example, it is not standard practice to internally insulate basements, full height, to R.S.I. 3.5 (R-20) and provide finished and painted basement perimeter walls, nor to provide under slab insulation.

No air-to-air heat exchanger was installed in the Meadows Show Home. The $500.00 incremental cost in that category relates to the materials and labour associated with installing a central exhaust system with multiple intake inlets. No medium efficiency induced draft furnace is costed in the Meadows Show Home. The incremental cost in that category relates to the installation of a fan-coil system and the back up electric heater to provide space heat.

D. Rationale and Plan For Long Term Monitoring and Testing

The monitoring program has two components: monitoring the change in airtightness characteristics of the three Edmonton ADA houses, if any, over time, and monitoring the areas of specific interest to low energy house designers, namely energy consumption and performance of specific energy related equipment.

The monitoring of energy consumption will continue until the end of the 1988/1989 heating season. It will be necessary to track airtightness characteristics over a five year period at minimum.

It has been postulated (Timusk; 1982) that the airtightness characteristics of buildings deteriorates over time due to the natural aging process of the materials comprising the building envelope and also varies seasonally due to seasonal changes in the moisture content of the framing materials. As well, there is an initial change in airtightness resulting from the drying of construction moisture.

The three Edmonton ADA houses have been tested to determine their airtightness characteristics at the completion of construction, prior to occupancy. Subsequent airtightness testing will be conducted seasonally in an attempt to track any changes in airtightness. Three standard construction houses have been selected to act as control houses and are also being tested in a similar manner to the three Edmonton ADA houses.

The three Edmonton ADA houses have been instrumented in order to track energy consumption and equipment performance. The areas monitored are:

- space heating energy consumption;
- efficiency of installed heat recovery equipment;
- local climatic conditions;
- interior temperatures;
- hot water energy consumption; and
- total electrical consumption.

The three control houses are also monitored in a similar manner.
Each house monitored has a number of temperature, humidity, and energy measuring sensors. In particular, there are interior temperature sensors at each storey to track interior temperature stratification.

These sensors provide a dry bulb temperature indication. A dry bulb temperature for the exterior temperature of each house is also taken. House interior relative humidity is also sensed. Total electrical energy usage is measured. Gas consumption measurements for space heating and hot water heating are also measured.

E. Conclusions and Recomendations

1. Trade Interviews

Extensive interviews with the tradesmen were scheduled and conducted. Examination of these interviews indicates significant dissatisfaction with the unusual scheduling which was necessary to maintain air barrier continuity across the tops of interior partitions where they intersected insulated ceilings. As was previously described, the gypsum board on exterior walls and insulated ceilings was installed first and taped. Interior partitions were then constructed and finished. This procedure resulted in additional trips to the job site for the carpenter, the electrician, the plumber, the gypsum board installer and gypsum board taper. These additional trips resulted in significant additional costs and scheduling complexity. Techniques are necessary which will allow the use of conventional scheduling practices.

The trade interviews also indicated dissatisfaction with the notching of the gypsum board sheets around the cast-in-place floor joists.

Surprisingly, the notching of the gypsum board sheets themselves was not time consuming, adding only approximately two man-hours of time per 30 metres (100 ft.) of basement perimeter. The major difficulty lay with the caulking of the notched gypsum board to the floor joists. The process was time consuming and labour intensive. An improvement in the detailing in this location is necessary.

The overall impression from the tradesmen regarding the Air Drywall Approach was positive, especially from those tradesmen who had previous experience with continuous, sealed, polyethylene wrapped houses. The gasketing technique proved to be popular with the frame carpenters who typically had an intense distaste for caulking in general, and caulking to polyethylene in particular.

2. Heating and Ventilating Systems

The interaction of the controlled ventilation system with aerodynamically uncoupled combustion appliances needs to be more closely examined especially from the perspective of installed costs. It is generally understood that aerodynamically uncoupled combustion appliances are necessary in sealed houses. However, the installed costs of such systems provide a significant disincentive to the construction of airtight houses with gas combustion appliances. Thus, a significant bias exists towards the use of electric space heating and electric domestic hot water heating in airtight houses. The incremental costs to utilize natural gas to provide space heat and domestic hot water in the three Edmonton ADA houses ranged from $600.00 to $1,000.00. Unfortunately, the use of electricity to provide space heat and domestic hot water is not cost effective in many regions of North America from an operation cost perspective.

Combined systems, which utilize one source of combustion to provide both space heat and domestic hot water, have the potential of reducing the overall cost of installing aerodynamically uncoupled combustion appliances in a house. The use of a fan-coil coupled to an induced-draft gas fired domestic hot water heater is one promising approach and was demonstrated in the Meadows Show Home. Unfortunately, many local building codes do not allow the use of a domestic hot water heater for space heating purposes. This was the case in Edmonton, and as such a supplementary space heating system was required, defeating the purpose of the combined system incorporating the fan-coil. This issue should be made a high priority with authorities having jurisdiction. Current regulations are typically based on high heat loss housing and old equipment characteristics. New equipment, specifically designed for such combined use, is now available for use in low energy houses.

3. Incremental Cost

Incremental costs for the three Edmonton ADA demonstration homes were sufficiently high to prevent the approach, as utilized in the Edmonton houses, from displacing current tract construction practices. However, as a result of subsequent improvements to the ADA techniques, specifically the elimination of basement gypsum board notching and trade scheduling difficulties, the ADA techniques have the potential to displace current continuous, sealed polyethylene air barrier techniques in tract construction situations. These two improvements are estimated to reduce the incremental costs previously presented by \$1,500.00 to \$2,000.00 per building. This cost reduction, coupled with a less expensive and more rational approach to utilizing combustion appliances in airtight houses is expected to make the ADA techniques cost competitive and marketable with respect to current tract construction practices (Note: these incremental costs are not comparable to non-production, non-tract builder incremental costs to achieve R-2000 standards. It is generally understood that tract builder costs cannot be compared to non-tract builder costs).

III. SUBSEQUENT EVOLUTIONARY DEVELOPMENT OF THE AIR DRYWALL APPROACH

The three houses built in Edmonton, Alberta as part of the Alberta Air Drywall Demonstration Project, were completed in the summer and early fall of 1984. However, several difficulties with the approach remained, namely trade scheduling, notching of gypsum board sheets around cast-in-place floor joists, concerns regarding gasket durability, cost and long term performance. The latter two concerns became the major focus of a ten house ADA demonstration and research project in Winnipeg, Manitoba jointly funded by the Manitoba Department of Energy and Mines, and Energy, Mines and Resources Canada. The builder of the ten Winnipeg homes was Flair Homes, a major tract home builder in the Winnipeg region well known for their past experience with building double walled airtight polyethylene film homes. Construction of the ten Winnepeg houses began in September, 1984 and was completed by January, 1985.

The remaining concern with the ADA concept, trade scheduling, became the major focus of two American research and demonstration projects, a sixteen house demonstration project in the State of Oregon and a six house demonstration project in the State of Idaho. Both of these two projects were funded by the Bonneville Power Administration as part of their Residential Standards Demonstration Project. The Oregon houses were administered by the Oregon Department of Energy, and the Idaho houses were administered by the Idaho Department of Water Resources. Construction of the Oregon and Idaho houses commenced in August and

September of 1984 and was completed by December, 1984 and January, 1985 respectively.

A. Flair Ten House ADA Demonstration Project

The ten houses constructed in Winnipeg subsequently became known as the "Flair Ten House ADA Demonstration Project". The question of gasket performance, durability and cost was resolved under this project only in the short term. Long term, in service gasket performance remains to be substantiated, however preliminary indications are excellent. Effects of building frame movement over time on gasket performance and overall airtightness is being studied as part of a long term, multi-year monitoring program. During the course of the monitoring program, air leakage tests will be conducted on a seasonal basis. Correlation of these air leakage test results to long term gasket performance and durability will be attempted.

Preliminary results from the Flair Ten House ADA Demonstration Project (Lstiburek; 1985), have indicated that the use of polyethylene foam rope, commonly refered to as sealant backer rod, is not a suitable gasket material. This is because polyethylene deteriorates over time, and the material has an extremely high compression set. In other words, the material, after being compressed under load for an extended period of time and subsequently unloaded, does not return to its original shape. It retains its compressed shape. In polyethylene foam rope this is due to the tiny air pockets within the material becoming ruptured when significant loads are applied. Ethafoam sill seal, another common gasket material also exhibits a high compression set for the same reason and therefore is also unsuitable for use as a gasket material in ADA houses. Favorable performance with respect to compression set has been obtained from closed cell neoprene and vinyl based glazing tapes and weather strips as well as gasket materials based on EPDM, a common gasket used in the automotive industry. Favorable long term durability is expected from these materials by virtue of their already established long service performance histories in the glazing, weather-stripping and automotive industries. The cost of these latter materials varies from \$0.16/metre to \$0.32/metre (\$0.05/ft. to \$0.10/ft.) depending on quantity ordered and availability. This results in costs of \$50.00 to \$150.00 for the gasket material necessary to complete a typical house.

Notching of the gypsum board sheets around the cast-in-place floor joists to achieve air barrier continuity was ultimately eliminated as a result of the experiences arising out of the construction of the ten ADA houses in Winnipeg. This was accomplished by virtue of sealing the continuous rim joist or header to the perimeter concrete foundation wall with a continuous bead of an appropriate sealant and by placing a gasket between the subfloor sheathing and the top of the rim joist and header (Figure 19, Pg. 55 and Figure 20, Pg. 56). Gaskets are also installed in a continuous fashion between the interior surface of perimeter concrete foundation wall and the top plate of interior perimeter basement wall framing and between the same top plate and the perimeter basement wall gypsum board. If the interior of the foundation wall is not finished or if exterior basement insulation is used, it is necessary to use a sealant to seal the basement floor slab to the perimenter foundation wall to provide for air barrier continuity.

B. Bonneville Power Administration ADA Demonstration Project

The proposed solution to the difficulties in trade scheduling in ADA houses arose out of the Alberta Air Drywall Approach Demonstration Project. However, it was not possible to demonstrate this proposed solution there. The proposed solution was subsequently demonstrated in the sixteen ADA houses built in Oregon and the six ADA houses built in Idaho during late 1984 and early 1985 under the Bonneville Power Administration ADA Demonstration Project. The solution involved constructing interior partition walls under insulated ceilings with a single top plate in place of a double top plate, allowing the ceiling gypsum board to be slipped over the top of already constructed interior partitions, much like gypsum board sheets on exterior perimeter walls are run behind intersecting interior partition walls. The single top plate allows room between the top of interior partitions and the underside of roof trusses to allow the drywall to provide a continuous air barrier on an exterior ceiling. Joints between gypsum board sheets are filled as per standard

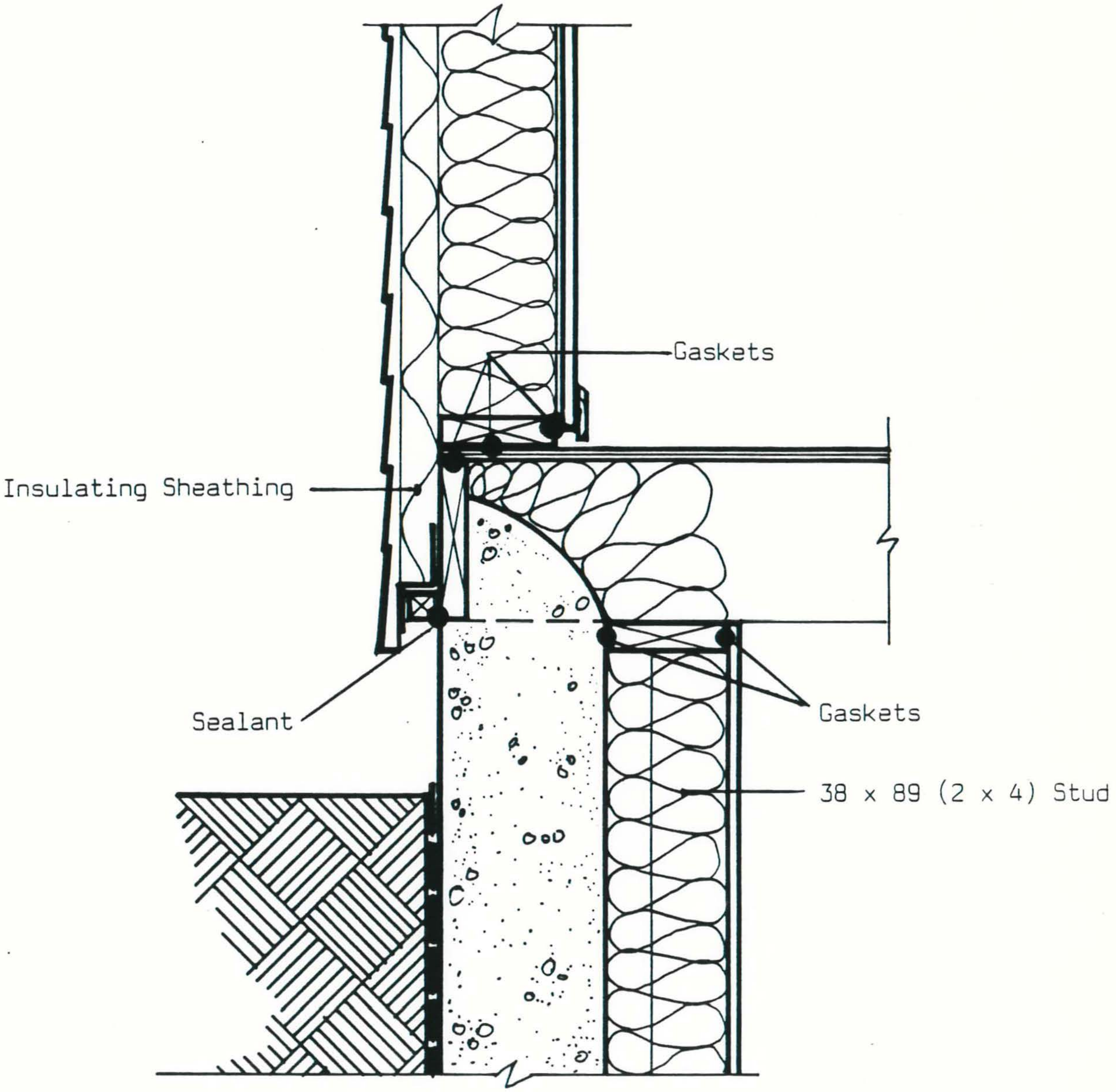


Figure 19: Subfloor at Grade - Western Detail

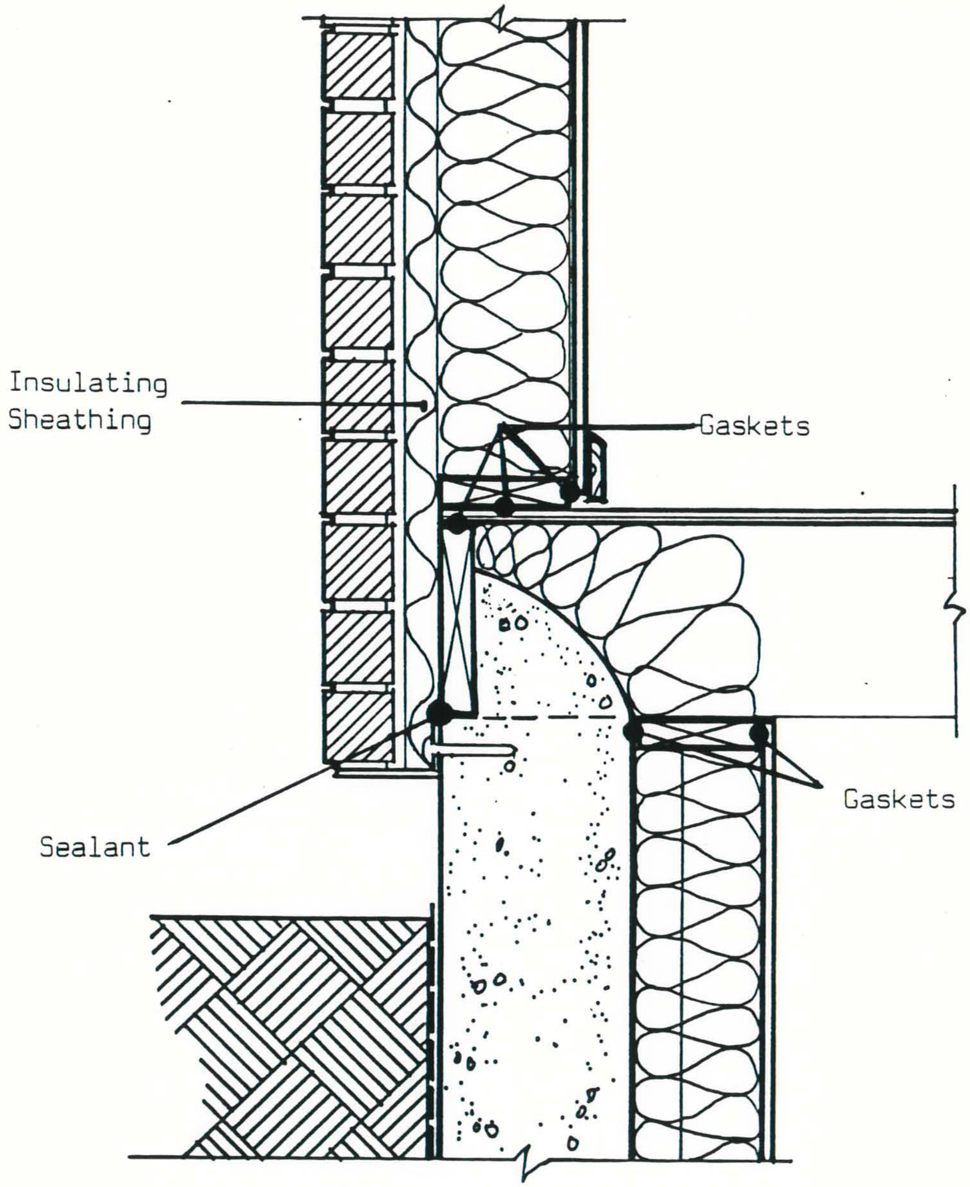


Figure 20: Subfloor at Grade - Western Detail, Brick Veneer

practice, after all the interior gypsum board sheets are installed. The short seams between gypsum board sheets, immediately above interior partition walls not able to be filled by the standard filling and taping operation, are filled by the gypsum board installers with quick setting joint filler immediately prior to the installation of the gypsum board on the interior partition walls. This modification in construction framing allows for all framing to be completed in one trip, all gypsum board installation to be completed in one trip, and all electrical, plumbing and mechanical to be completed as per standard trade scheduling (Figure 21, Pg. 60). Although the gypsum board or drywall installation occurs in one operation, the gypsum board or drywall is installed on exterior ceilings and exterior walls before the interior walls are boarded. Should it be necessary to constuct an interior load bearing wall under an exterior ceiling, then a continuous gasket is installed on both sides of a typical double top plate (Figure 22, Pg. 61). In other words, load bearing walls are constructed with double top plates, while non load bearing walls are constructed with single top plates. The non load bearing interior partition walls under exterior ceilings are not fastened to the underside of ceiling framing until after the ceiling gypsum board is in place. Significant labour saving in gypsum board installation now occurs as large sheets can now be effectively utilized on exterior ceilings. Interior partitions are subsequently fastened to the underside of roof framing by nailing through the gypsum board on the ceiling before gypsum board is installed on the interior partition walls. This nailing is typically done by the gypsum board installers. This requires nails which are at least 110 mm (4

1/2 ") long. This technique proved successful in all the Oregon and Idaho ADA houses. The only concern arising out of the use of this technique is the reliance of the builder on the gypsum board installers to insure that interior partition walls are perpendicular prior to fastening them to the underside of ceiling framing. This concern was shown not to cause difficulties during the course of the construction of the Oregon and Idaho ADA houses.

C. Canada Mortgage and Housing Corporation Non-Poly Experiment

Ten houses, built in Ottawa in late 1983 and early 1984, were chosen by the Canada Mortgage and Housing Corporation as part of a two year moisture research project. Of the ten houses, six houses are being intensively investigated. The moisture contents of preselected structural members in these six houses are being tracked. The final report and analysis of this project is expected in late spring of 1986. The discussion which follows is preliminary and inconclusive.

Three of these homes are of standard construction with the exterior wall consisting of the following components:

- 12.5 mm (1/2") drywall or gypsum board
- 4 mil polyethylene
- 38 x 140 mm (2" x 6") wood studs at 400 mm o/c (16" o/c)
- fibreglass batts between the studs
- 12 mm (1/2") aspenite sheathing
- # 15 building paper
- vinyl siding

The remaining seven houses are constructed using the Air Drywall Approach with the exterior wall construction consisting of the following components:

- 12.5 mm (1/2") drywall or gypsum board
- 38 x 140 mm (2" x 6") wood studs at 400 mm o/c (16" o/c)
- fibreglass batts between the studs
- 25 mm (1") Glasclad insulating sheathing
- vinyl siding

The difference between the standard houses and the ADA houses was the exterior sheathing and the lack of polyethylene in the ADA houses. The Glasclad sheathing which was used on the ADA houses was installed such that the Tyvek surface faced inwards or to the warm side. In normal practice the Tyvek faces outwards or to the cold side. In

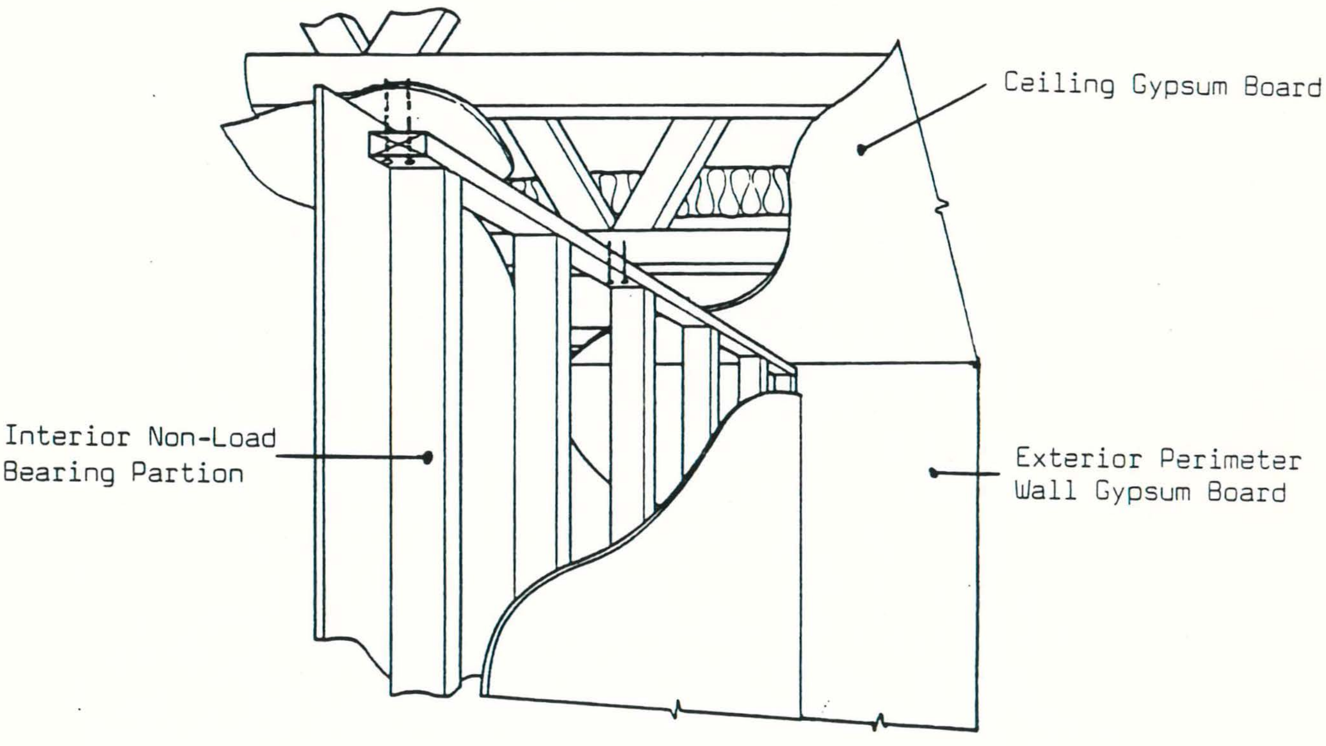


Figure 21 : Interior Wall Intersecting Insulated Ceiling

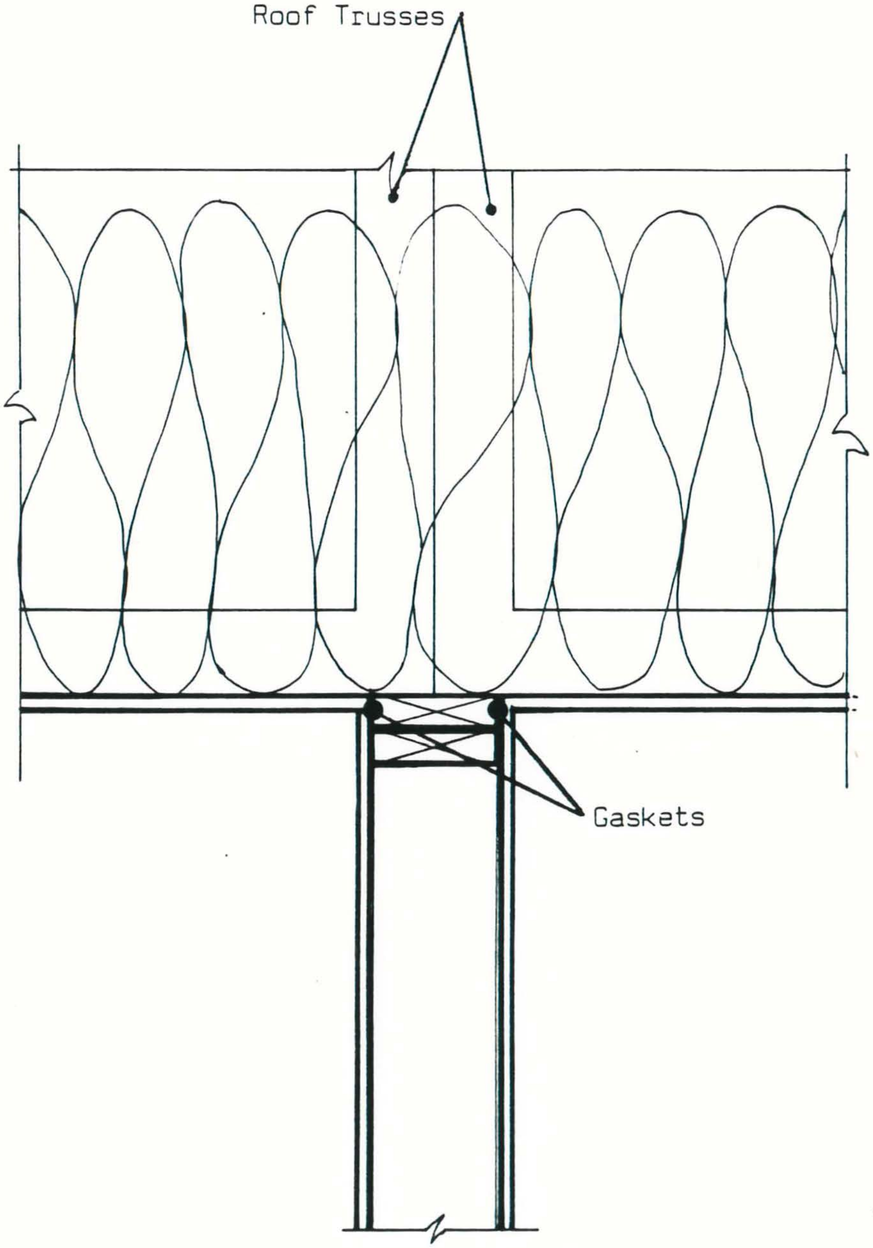


Figure 22: Load Bearing Wall Intersecting Insulated Ceiling

addition one of the ADA houses also contained a # 15 ashphalt-impregnated building paper between the Glasclad sheathing and the vinyl siding.

In each of the houses three studs of known moisture content were placed in one section of the exterior walls. Two of these studs were dry (less than 10 percent moisture content) and one of the studs was saturated (greater than 27 percent moisture content). Moisture pins were located in each one of these studs, near the warm face and near the cold face, at the top, in the middle and at the bottom. Moisture pins were also placed in the bottom plate and header or rim joist assembly. The moisture pins were then read manually once a week using an electronic moisture meter. By these means the moisture content of the studs at the top, middle, bottom and at the cold and warm faces was tracked. In the second week of October, 1984 the walls were opened and two of the studs in each house were removed and the moisture contents determined gravimetrically using ASTM methods.

The following preliminary observations resulted (Lischkoff, Lstiburek; 1985):

- No significant moisture content gradient was established in the studs through the length, width or thickness.
- All of the studs placed in the houses reached a moisture content of approximately 10 percent by the end of September, 1984.
- However, the wet studs placed in the ADA houses reached a moisture content level of 10 percent within 4 weeks. While the wet studs

placed in the standard houses did not reach the 10 percent moisture content level for six months.

- About 50 percent of the aspenite sheathing was covered with black mildew when the wall cavities were opened in October in the standard houses.
- The Glasclad sheathing used in the drywall houses was found to be virtually dry in October and no sign of mildew was observed.
- In April when moisture was observed to be present in the Glasclad sheathing it was only present at the cold face of the sheathing, the majority of the sheathing remained dry.

Some of the following points should be considered:

- The wet studs in the standard houses can only effectively dry to the exterior as a result of the polyethylene film. It is possible that wall drying occurs to both the inside and outside in the ADA houses.

- Many existing houses not containing polyethylene are not suffering moisture problems. This may be partially due to the interior cladding acting as an air barrier and vapour diffusion retarder and the ability of the interstitial cavities to dry, at least partially, in both directions.

- Under certain situations polyethylene films may enhance interstitial moisture problems by inhibiting drying especially if the cavity moisture source is initially wet framing lumber (common in Atlantic Canada).

IV CURRENT AIR DRYWALL APPROACH (ADA) TECHNIQUES

The developmental work on the Air Drywall Approach, previously described, as well as hundreds of subsequently built custom homes as a result of the publicity eminating from the initial ADA demonstration projects has lead to the following understanding, conclusions, techniques and approach.

A major component of a good building envelope is the air barrier system. The major function of the air barrier is not the prevention of vapour 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 are responsible for moving moisture in and out of the building envelope has been greatly misunderstood (See APPENDIX A: MOISTURE MOVEMENT). These four moisture transport mechanisms are: bulk water movement, capillarity, air movement and vapour diffusion. This misunderstanding has been partly due to the emphasis on vapour diffusion along with the unfortunate use of the term air/vapour barrier which couples two of the four independent moisture transport mechansims, air movement and vapour diffusion. Recently, builders have tried to use one material in the building envelope to serve both as an air barrier and a vapour diffusion retarder. However, it may be more practical to use one material as the air barrier and a different material to retard vapour diffusion.

Any material or system of materials may be used as an air barrier if the following requirements are met (see also APPENDIX B: CONCERNS ABOUT THE USE OF POLYETHYLENE FILM IN RESIDENTIAL CONSTRUCTION):

1) The material or system must be continuous.

2) The material or system must be impermeable to air allowing not more than 0.1 litres of air to pass through the system per second per square metre 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.

Vapour diffussion retarders, to be effective, do not have to stop diffusion completely. The vapour barrier need only slow down or retard vapour diffusion hence the term "vapour diffusion retarder". The vapour 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 vapour 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 (see APPENDIX A: MOISTURE MOVEMENT) that the movement of water vapour through a 2 cm square hole as a result of a 10 Pascal air pressure differential is 100 times greater than the movement of water vapour as a result of diffusion through that same 2 cm square hole. The amount of vapour which diffuses through a vapour retarder is a function of area. That is, if 90 percent of the building envelope is covered with a vapour retarder, then the vapour diffusion retarder is 90 percent effective. In other words, continuity of the vapour 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, of low permeability, applied only on the interior exposed surface of the building envelope will act as an effective vapour retarder. Correspondingly, a polyethylene film with tears and numerous punctures present will still act as an effective vapour diffusion retarder as the total surface area of the rips, tears and punctures is likely insignificant to the total area of the polyethylene film.

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

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

Building envelope design incorporating the previously defined concepts of air barriers and vapour diffusion retarders is illustrated by the most recent improvements to the Air Drywall Approach (ADA). ADA currently consists of interior cladding and structural elements assembled to act as a continuous air barrier, able to withstand wind and other mechanical loads. Because the air barrier is on the warm side of the building envelope, 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 mouldings and reapplying sealing compounds and or gasket materials. ADA focuses on how to make a 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 vapour diffusion retarder. This requirement, however, is independant 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 vapour 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 vapour diffusion retarder. In this approach, it of course 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 labourers, often install the remaining gaskets and sealants between the drywall and the framing before the drywall is installed. Where gaskets are used they are typically 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 imediately 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. This approach is attractive to mass production builders as training and coordingating with other trades is eliminated.

Where interior partion walls intersect exterior walls, air barrier continuity is maintained by installing a gasket on both sides of the first stud of the intersecting interior partion wall and by sealing this stud to the top and bottom plates with caulking (Figure 23). Where an interior partion wall intersects an insulated ceiling a similar approach is used. A gasket is installed on both sides of the top plate of the interior partion wall (Figure 24).

Between floors, the air barrier is kept continuous by gasketing and/or sealing between plates, rim joist, and subfloor (Figures 26, 27). Vertical joints in the rim joist are sealed as well. In localities where frame carpenters normally glue the subfloor to floor joists, a continuous bead of subfloor adhesive between the rim joist and subfloor sheathing often replaces caulking or a gasket in this location. It is also quite common to replace the gasket under the bottom plates of exterior perimeter walls with a bead of caulking at the inside edge of the bottom plate where it meets the subfloor. This bead of caulking is installed after the framing is complete, usually by a separate trade (labourers or an air-sealing contractor) along with the other gaskets and sealants imediately prior to installing the gypsum board.

It is also possible to eliminate the gasket seal between the gypsum board and the bottom plate as well as the gasket seal between the bottom plate and subfloor with a single operation by sealing the exterior perimeter gypsum board directly to the subfloor with a flexible sealant. This approach, however, relies on a "reasonably" close fit between the sub floor and the bottom edge of the perimeter gypsum board. It also requires and additional trip to the job site as this seal must be applied after the gypsum board has been installed and before the interior trim is in place.

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 as to raise the temperature of the interior surface of the rim joist to limit moisture accumulation. This is recommended for cold climate construction (most of Canada), and not necessary for other climates where standard framing approachs 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 25). 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 a bead of sealant at inside edge of the bottom plate where it meets the floor slab. Alternatively, the perimeter gypsum board may be caulked directly to the floor slab. At the top of the basement perimeter frame wall, the top plate is sealed on both sides with gasket material. On the inside to the perimeter gypsum board, and on the outside to the mud sil. The rim joist is then treated in a similar fashion to upper floor interfaces.

If the basement area is unfinished, then the air barrier in the basement area consists of the concrete foundation wall and the concrete floor slab. The joint between the foundation wall and floor slab is sealed as well as the joint between the top of the concrete wall and the mud sil. Again the rim joist is treated as described previously.

Damp-proofing is installed on the outside surface of the concrete foundation wall as well as between the cast 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 wall to grade level in order to meet local building code requirements.

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 cast concrete foundation wall during the backfilling process. This practice is not recommended in climates which do not have sufficient drying potentials. 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 27, 28).

Where floor trusses are used, air barrier continuity between storeys at subfloors is accomplished as in Figure 32. The major point to note in Figure D-10 is the use of plywood as a rim joist or 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 a waferboard or plywood rim joist or header. Standard floor joist materials, which do shrink as moisture contents decrease, 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 D-10 as opposed to a gasket. A gasket is typically 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 accurately 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 claddings of different thickness, such as brick veneer meeting siding, intersect at subfloor level, details contained in Figures 30 and 31 are used respectively.

Air barrier continuity where exterior perimeter walls meet insulated ceilings is provided for as described in Figure 33. 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 gypsum 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 top plates in order to limit the deleterious effects of wind washing or blow-through in which wind can serve to short-circuit thermal insulation and lead to local chilling of the interior cladding which often results in high interior surface relative humidites and hence mould and mildew growth. It is important to note that a perfect air barrier located on the interior of an exterior wall will not eliminate mould and mildew formation as it does not prevent wind washing. Gable walls are constructed as in Figure 34.

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 moulding (Figure 35). 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 36). These seals are easy to maintain over the service life of the building.

The air barrier is made continuous at exterior corners by taping together the gypsum board or drywall sheets (Figure 37). 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. This reduces the incidence of drywall cracking. 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 mould 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 fibreglass batts.

Cantilevered floor construction, typically encountered at second floor subfloors, is facilitated by the use of the construction details presented in Figure 38 and Figure 39. In Figure D-16, 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 for 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 39, where floor joists are aligned parallel to a lower perimeter exterior 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 38.

Attic hatchs constructed penetrating the air barrier and post supports are decribed in Figure 41 and Figure 42 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. This blocking is caulked between the vertical stud spaces and gaskets are installed in a continuous fashion on both sides of this blocking to provide for the air barrier transition between the drywall on the insulated ceiling and the drywall on the upper exterior wall (Figure 43).

Where plumbing penetrates the air barrier such as in the ceiling, the pipe is clamped to wood 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 44).

Bathtubs, premanufactured shower stalls, etc. installed on exterior walls require special attention. It is recommended that a sheet of plywood or waferboard be installed behind such fixtures prior to their installation. This plywood or waferboard is then sealed or caulked along its bottom edge to the subfloor and its vertical edges to intersecting framing members.

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 under the cover plate of the outlet or switch (Figure 45). 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.

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 space. 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 storey bedrooms with switched wall plugs, with the wall plugs placed 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 46). 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 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 of 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 are not 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 in any manner.

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

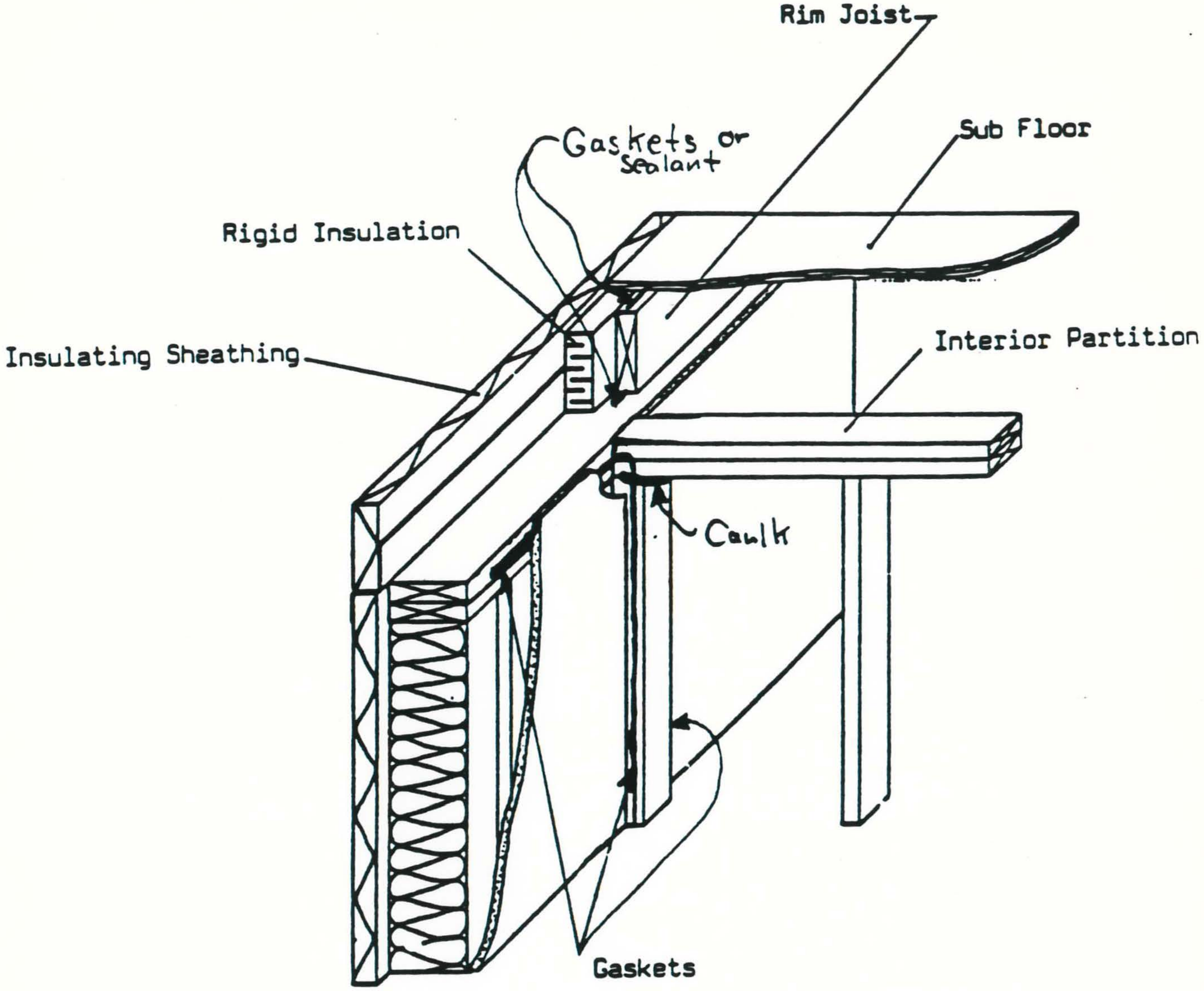


Figure 23 : Intersecting Interior Wall

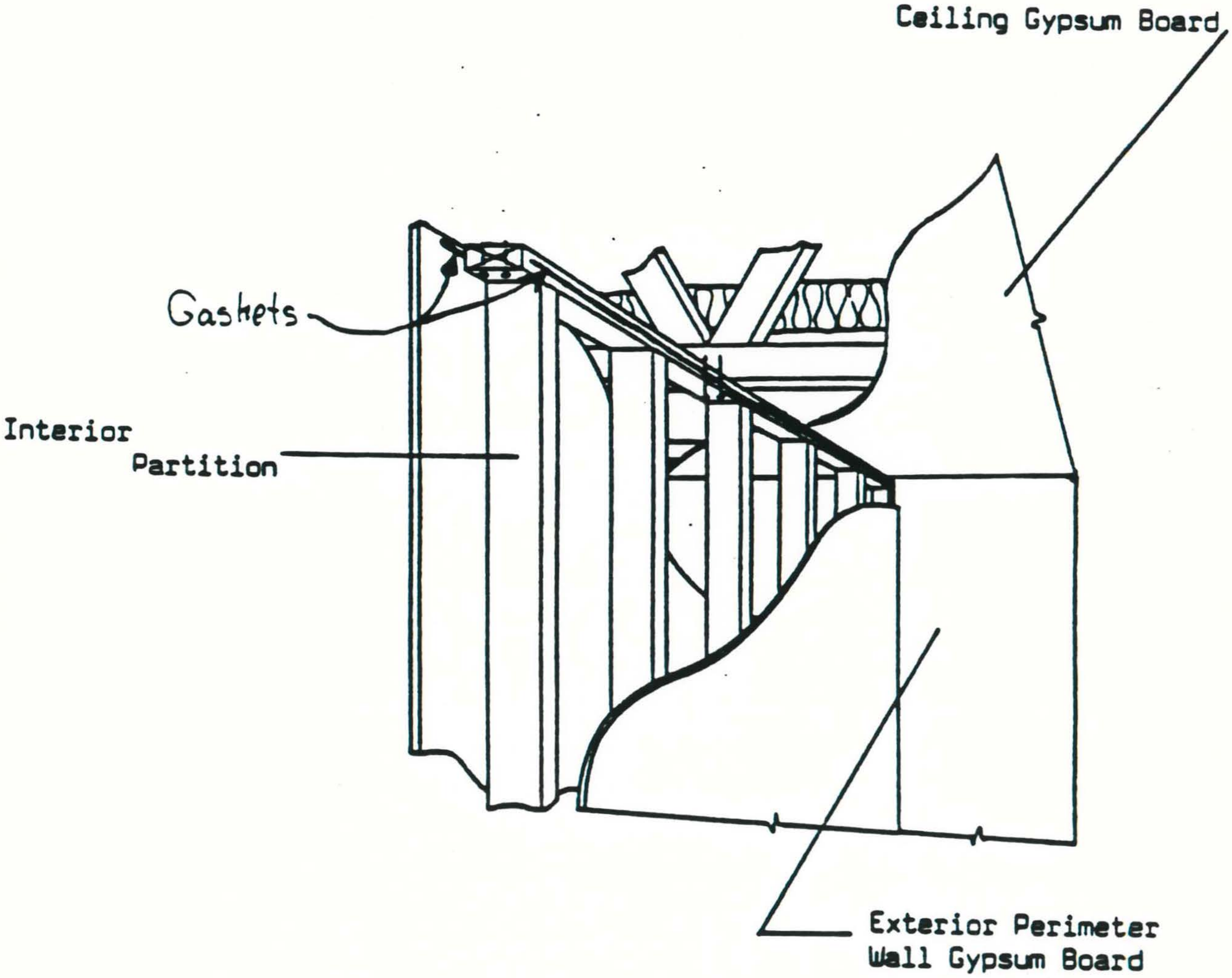


Figure 24 : Interior Wall Intersecting Insulated Ceiling

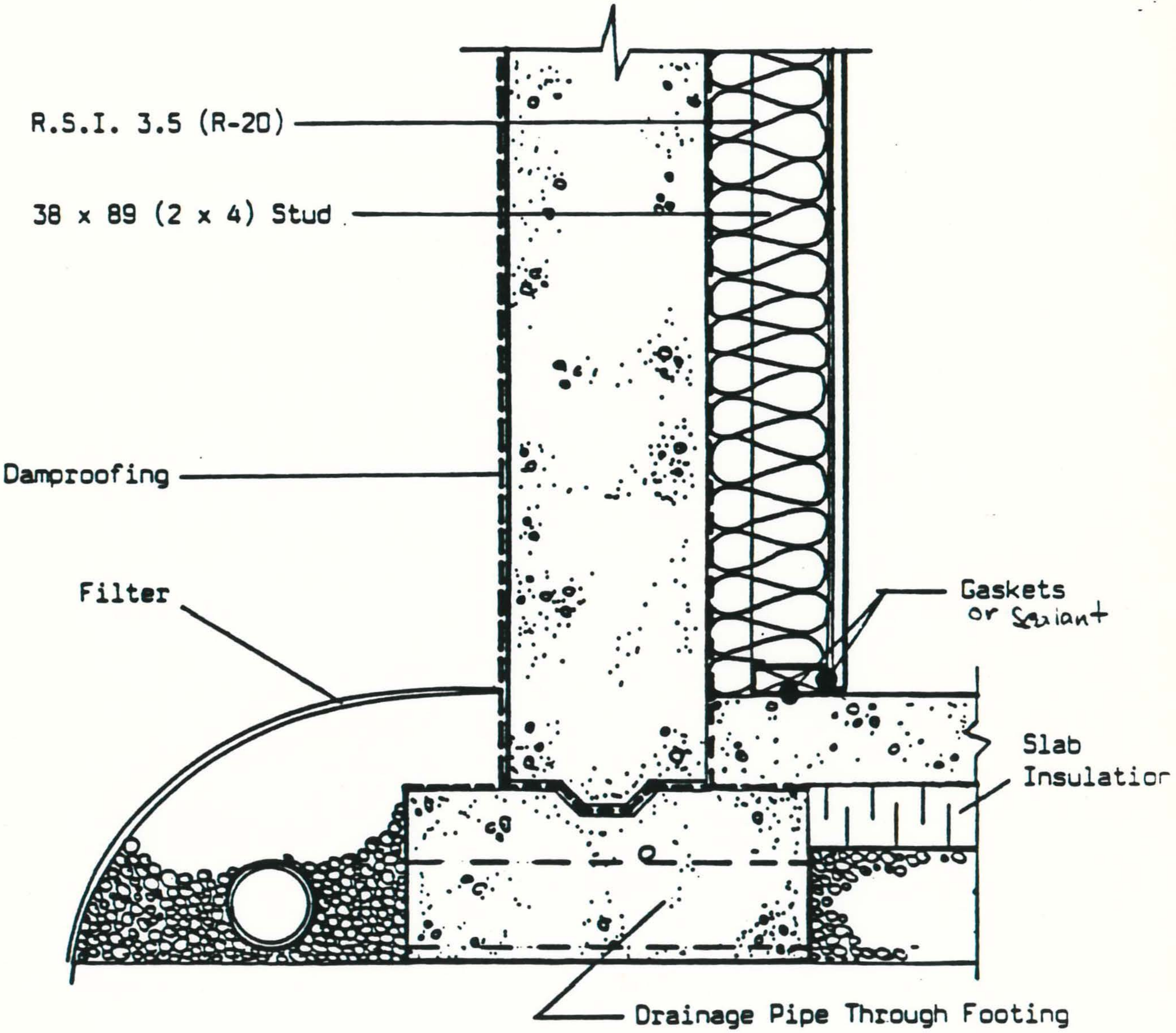


Figure 25 : Footing Detail

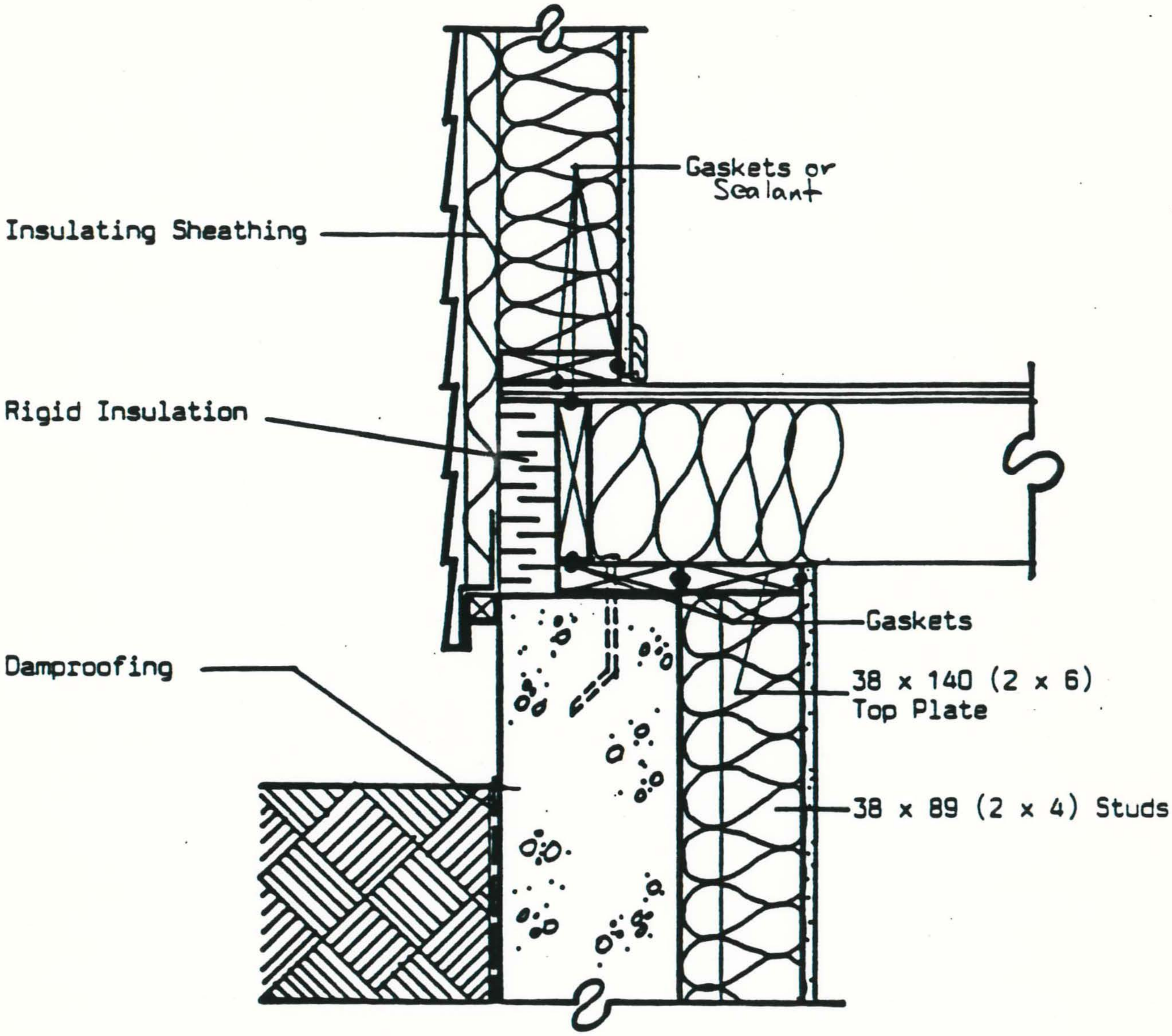


Figure 26 : Subfloor At Grade

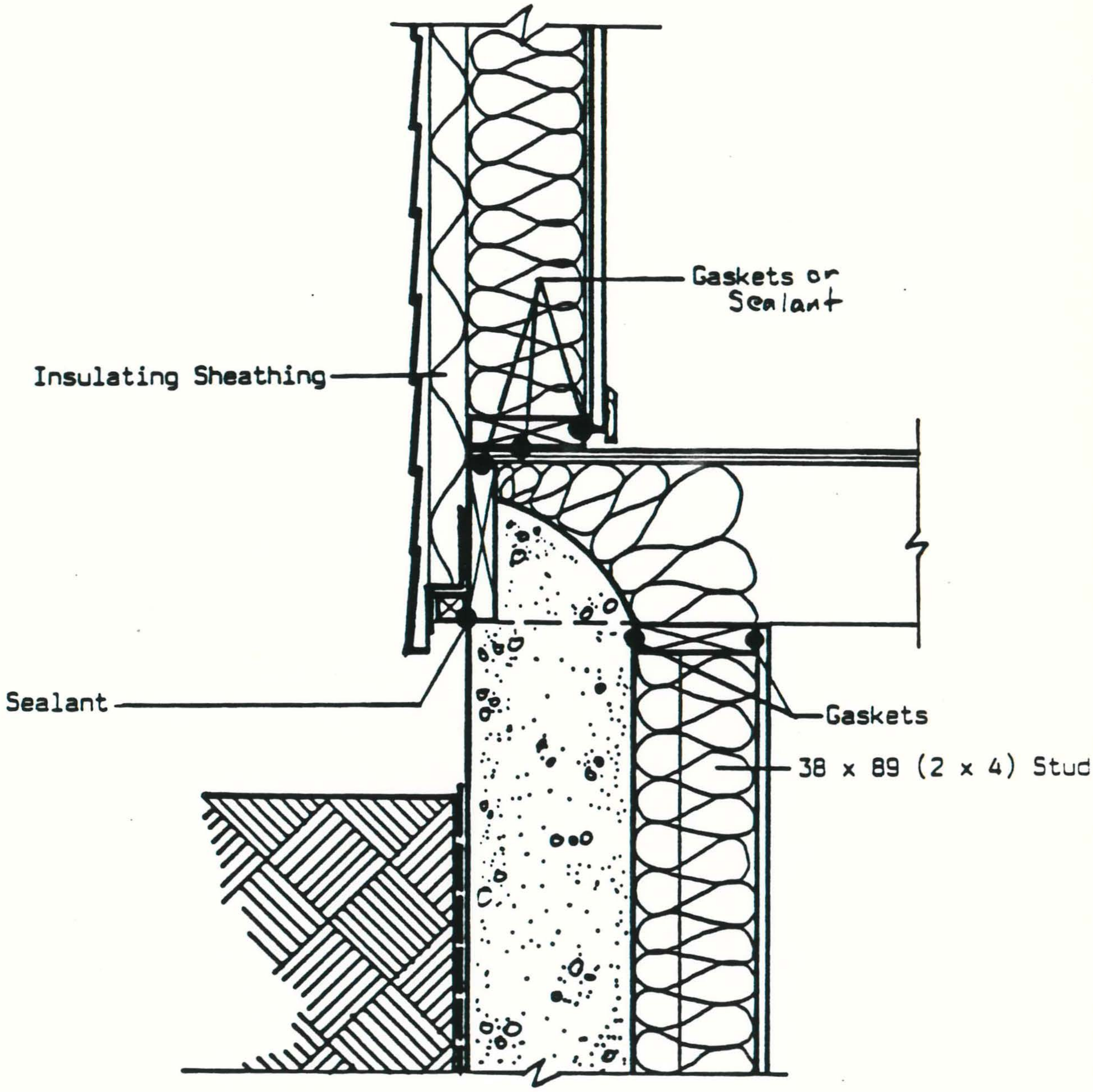


Figure 27 : Subfloor At Grade - Western Detail

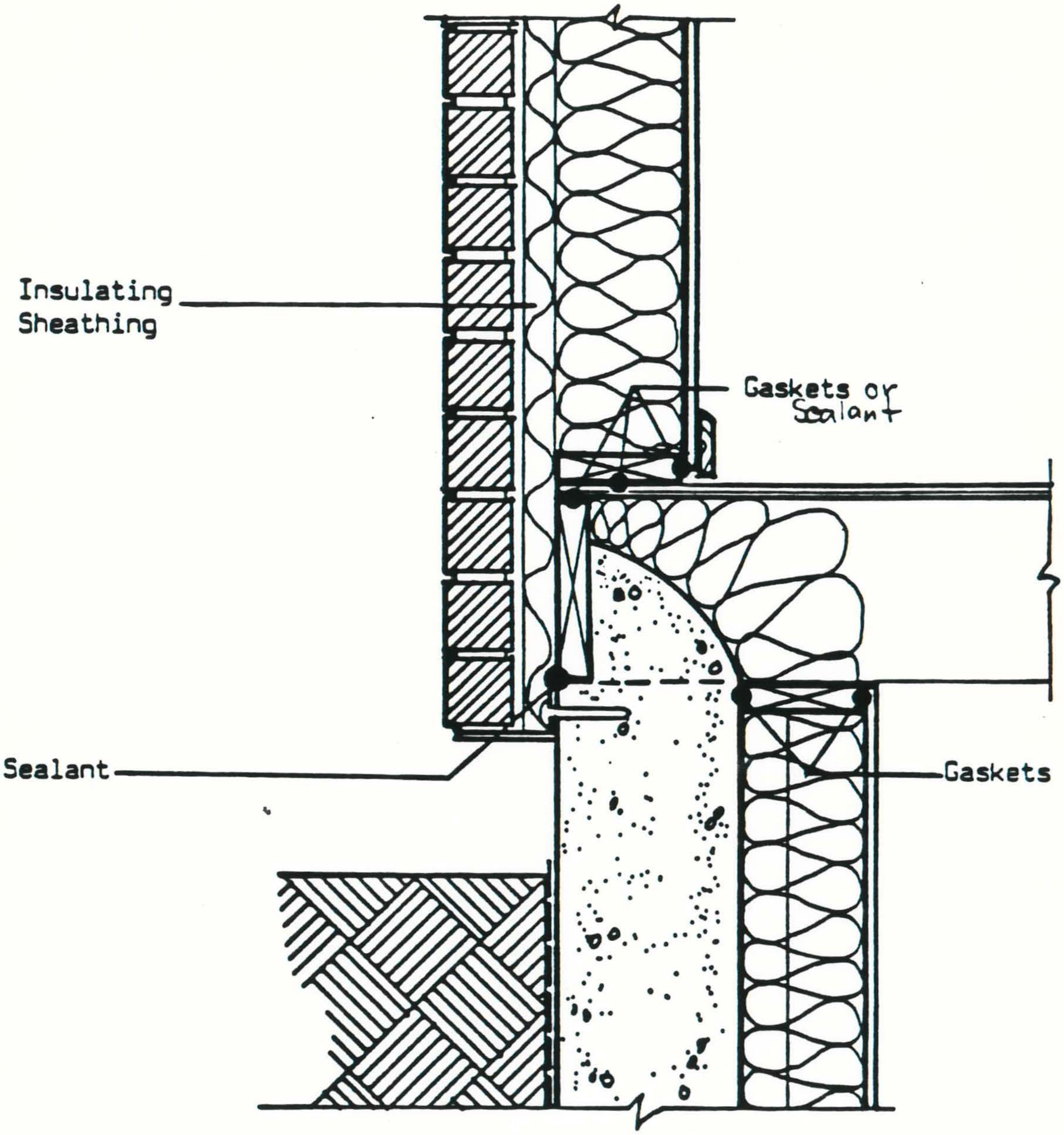
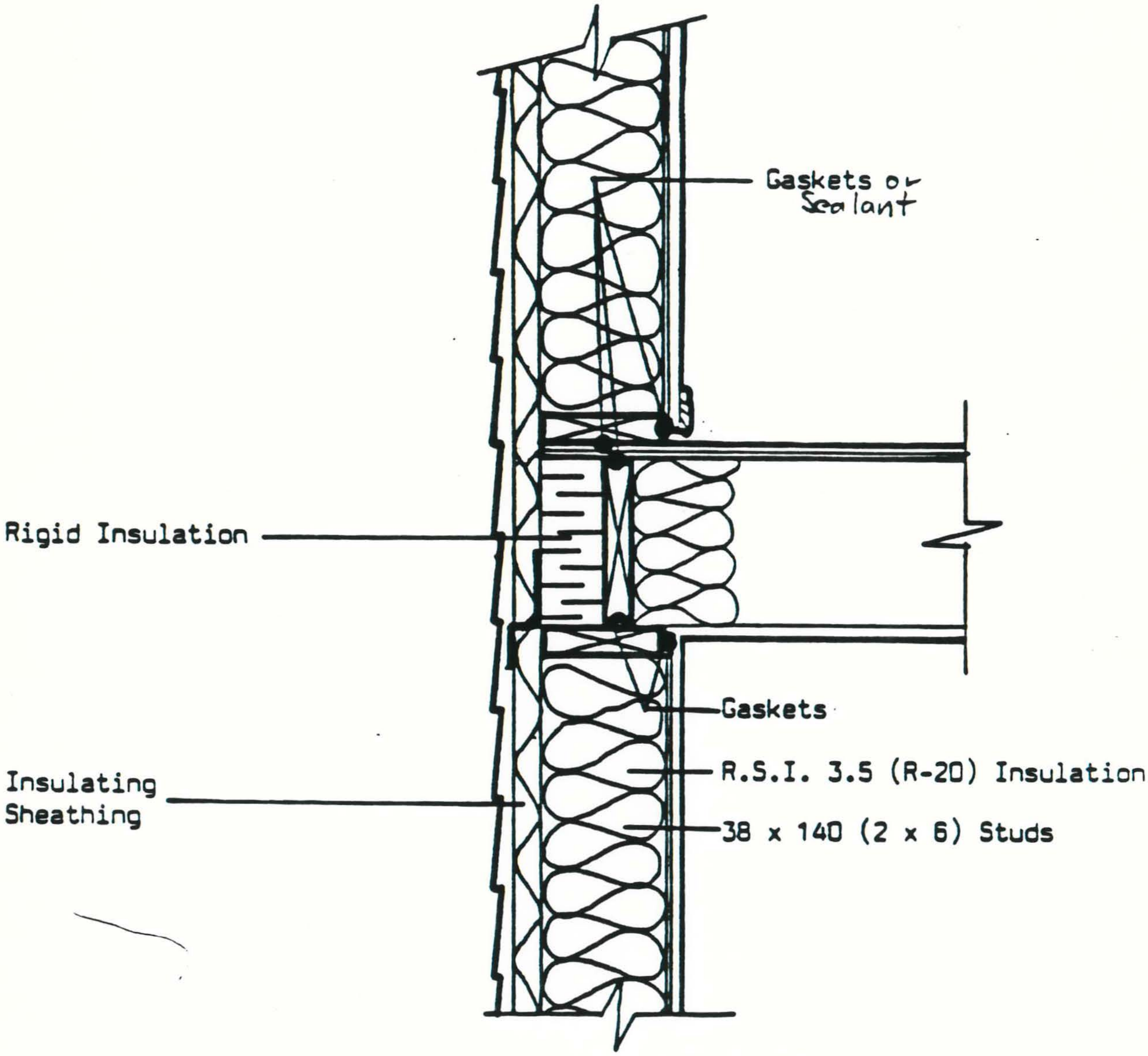


Figure 28: Subfloor At Grade Western Detail Brick Veneer



Firgure 29 : Second Floor Sub Floor

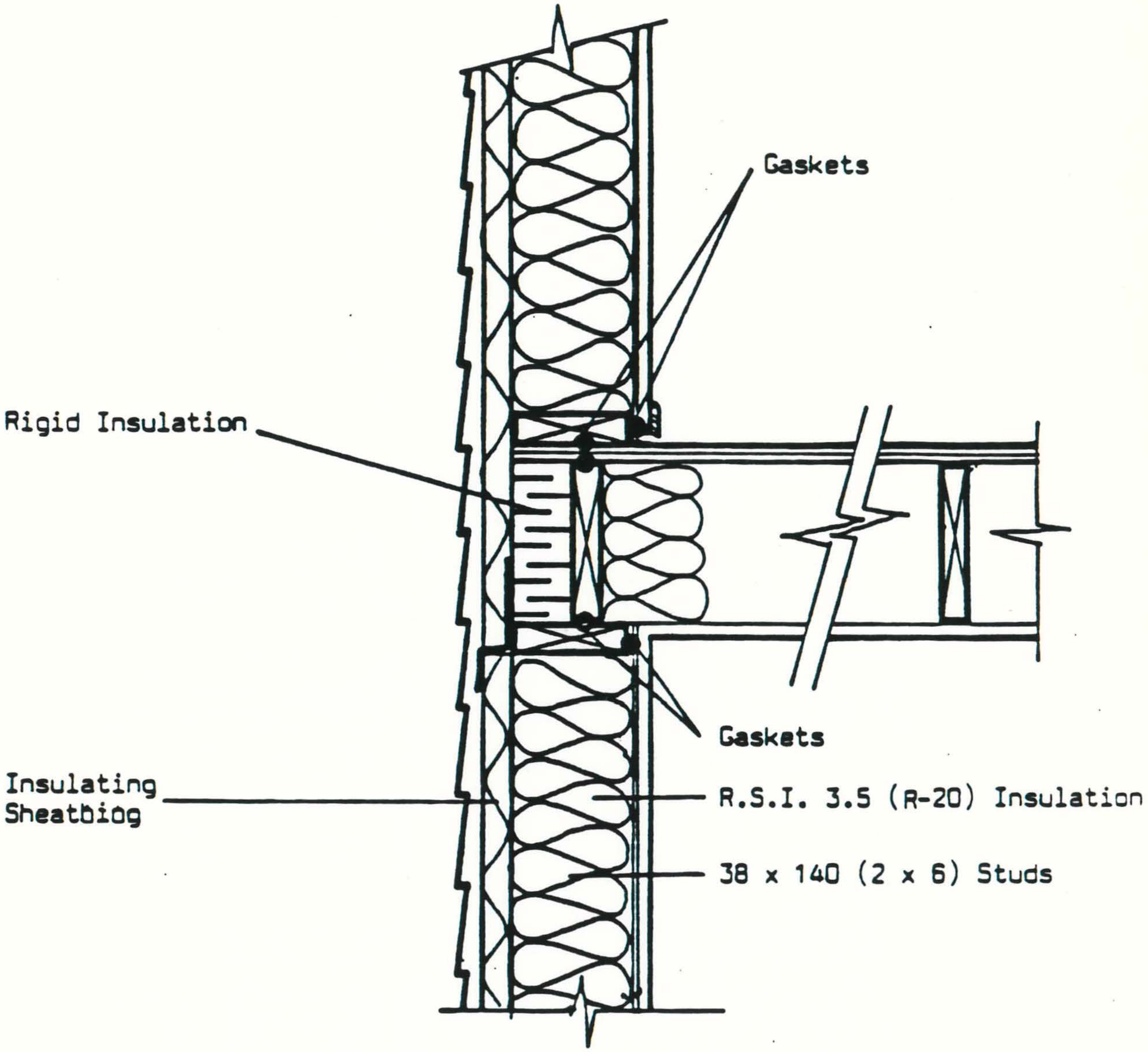


Figure 30 : Second Sub Floor
Parallel Joists

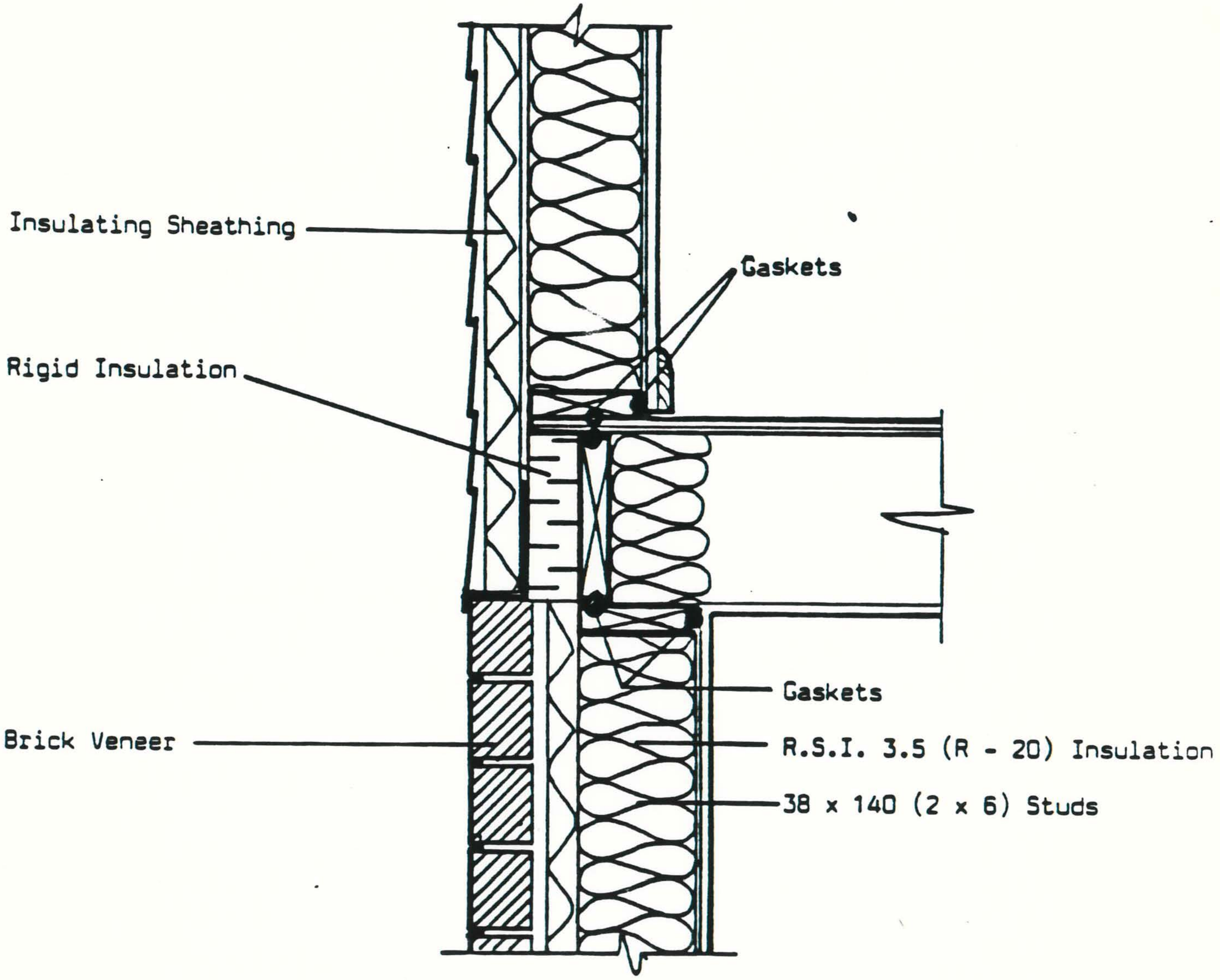


Figure 31 : Second Sub Floor
Brick Veneer/Siding Transition

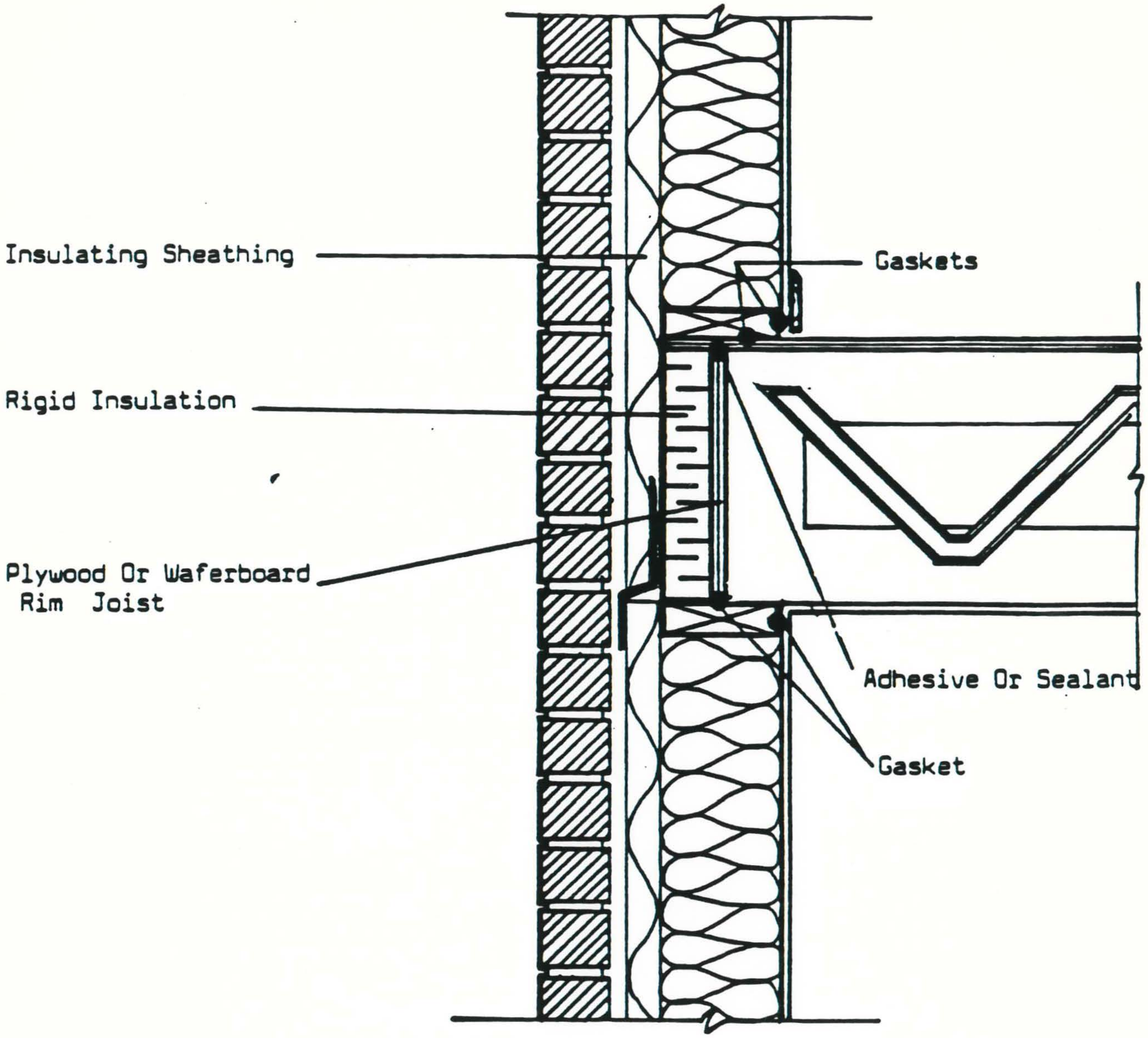


Figure 32 : Second Floor Subfloor - Floor Trusses

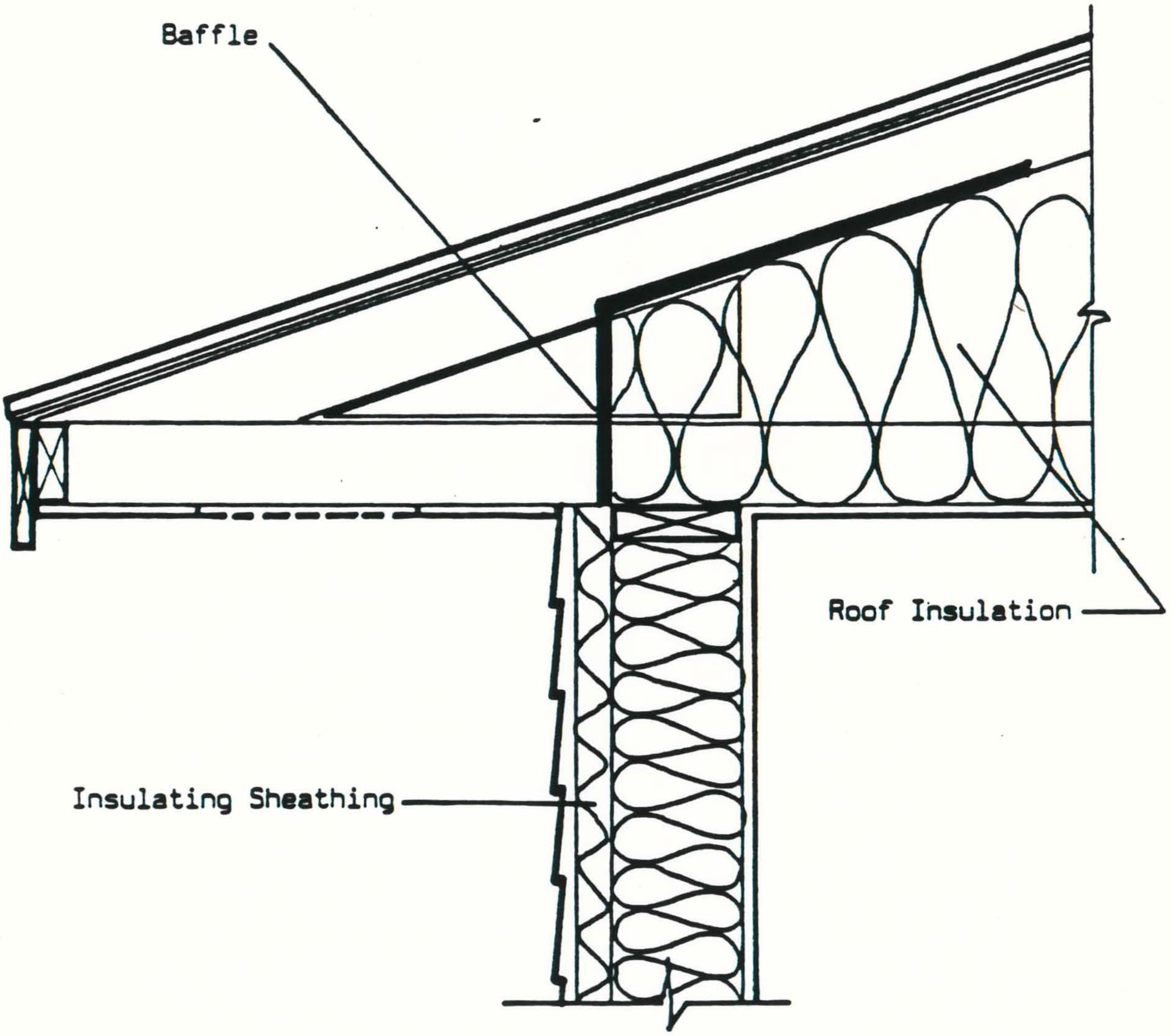


Figure 33 : Roof/Ceiling Interface

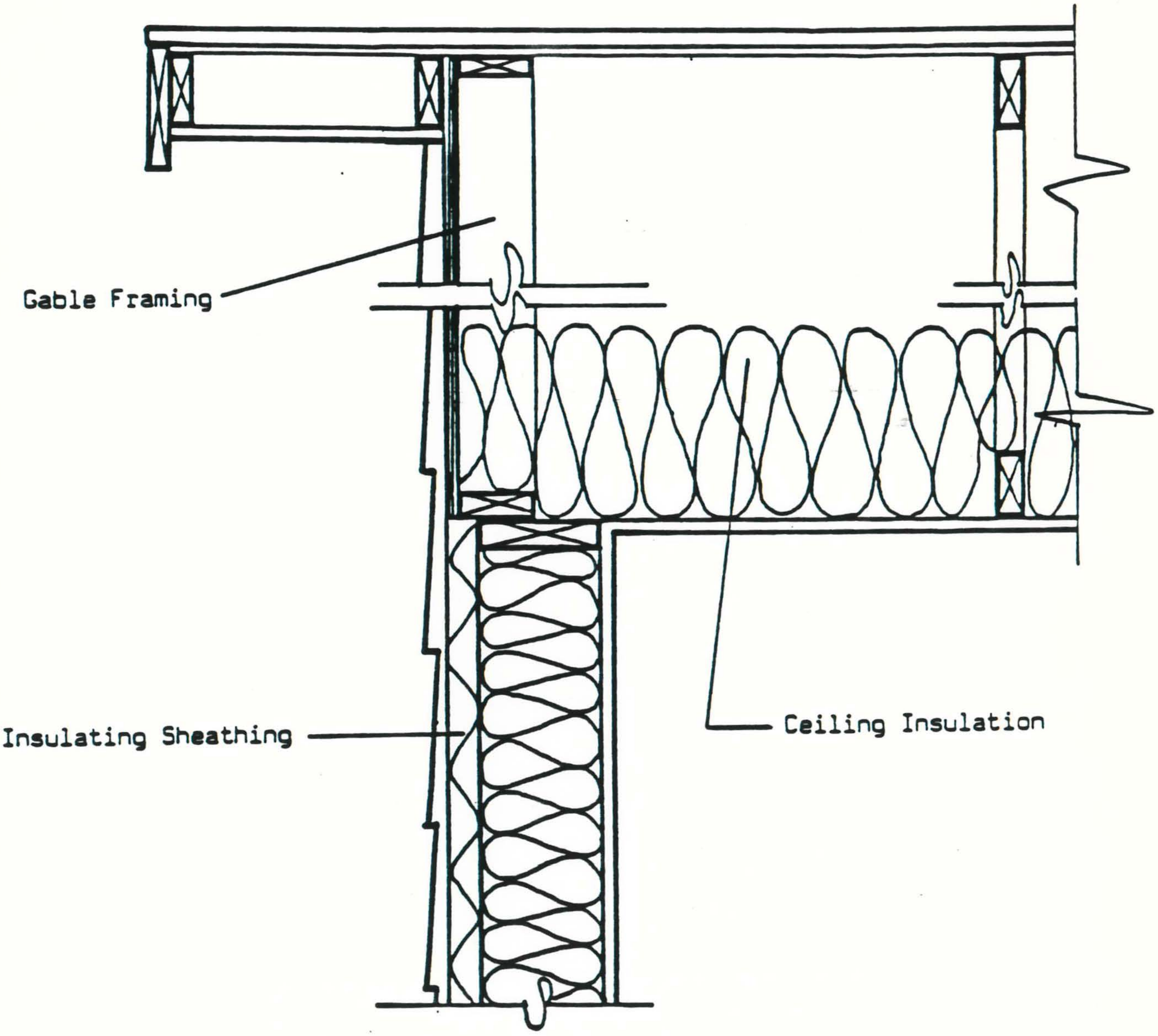


Figure 31 : Gable Construction

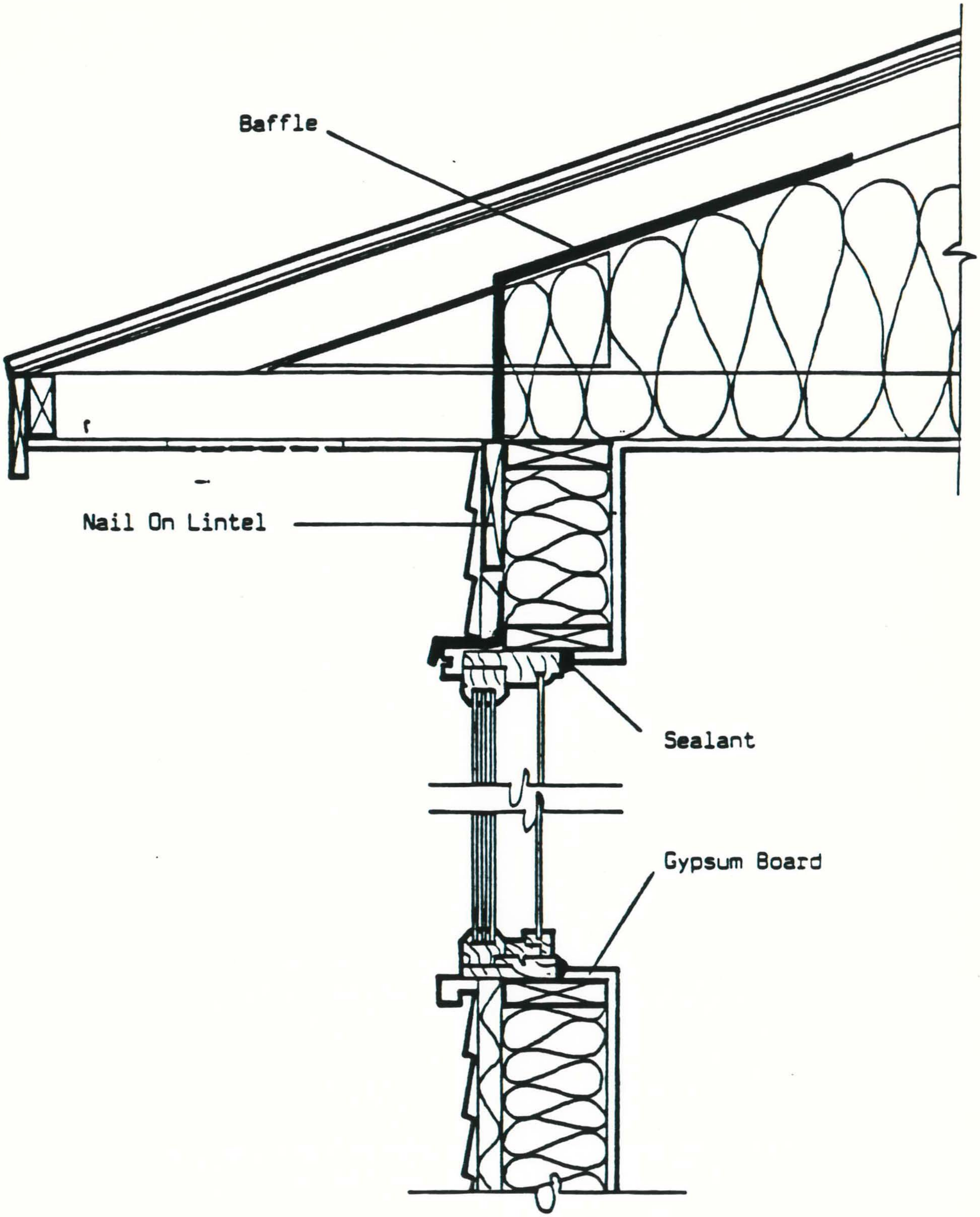


Figure 35 : Window Detail Drywall Return

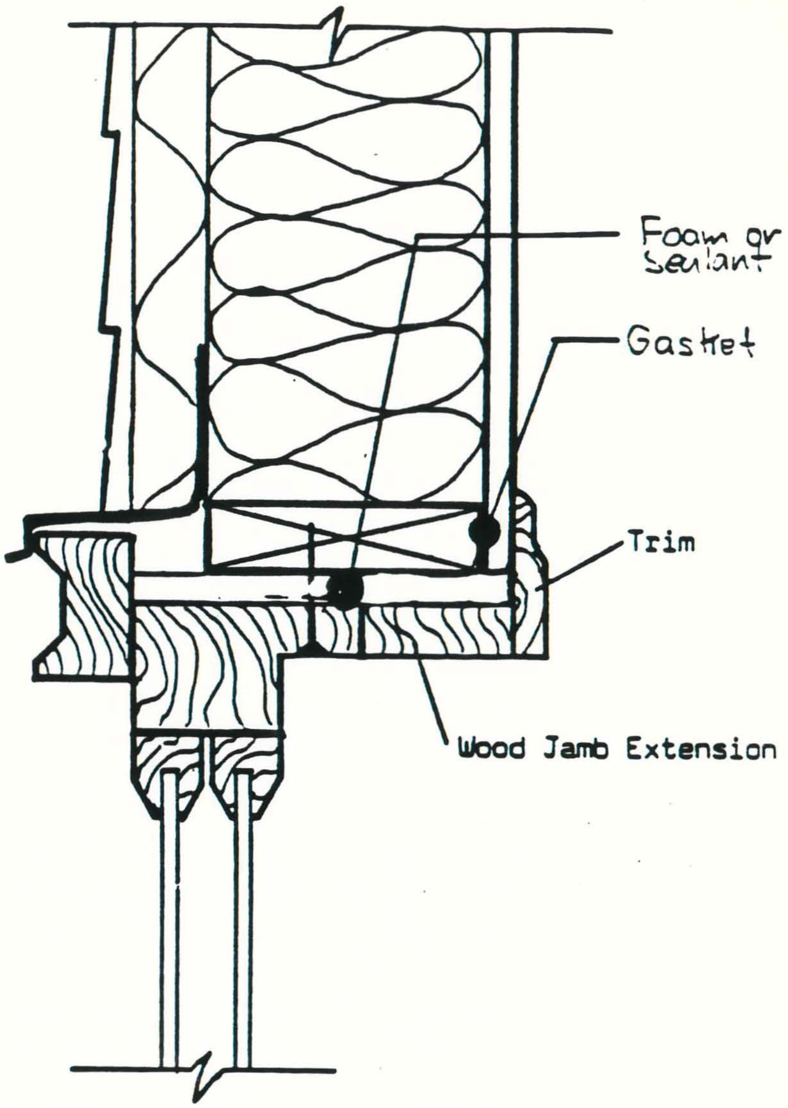


Figure 36 : Window Detail - Wood Jamb Extension

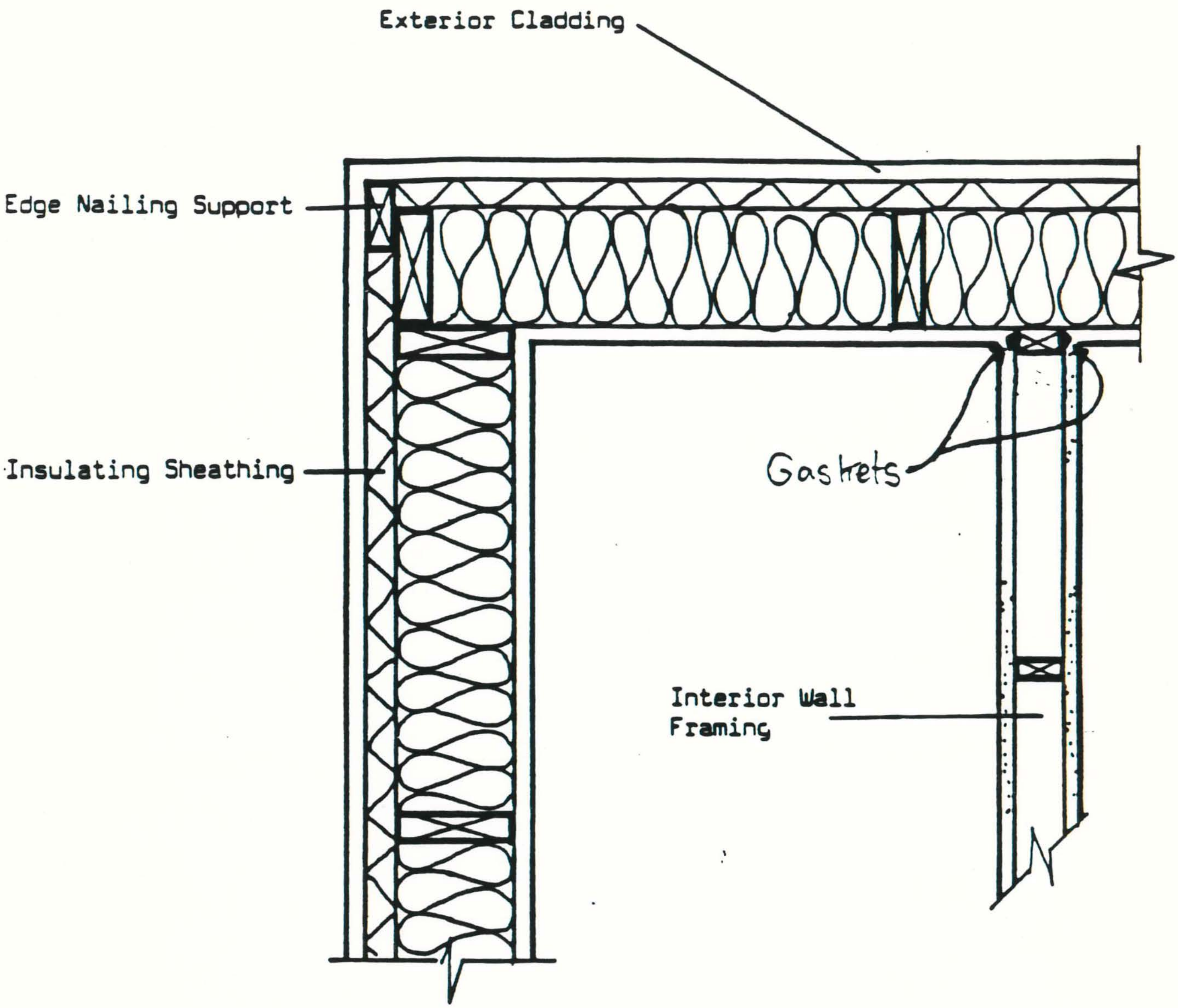


Figure 37 : Exterior Corner

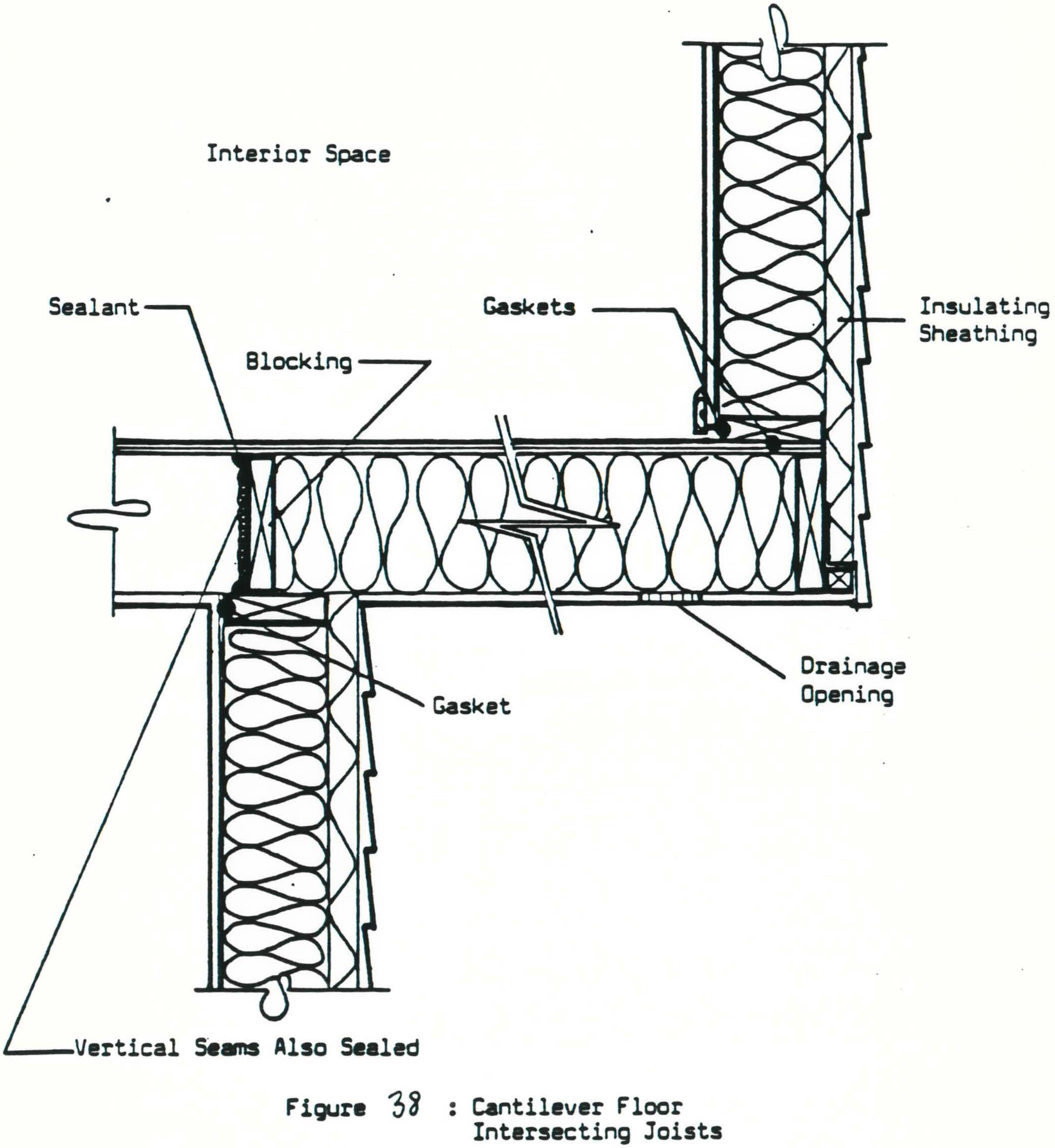


Figure 38 : Cantilever Floor Intersecting Joists

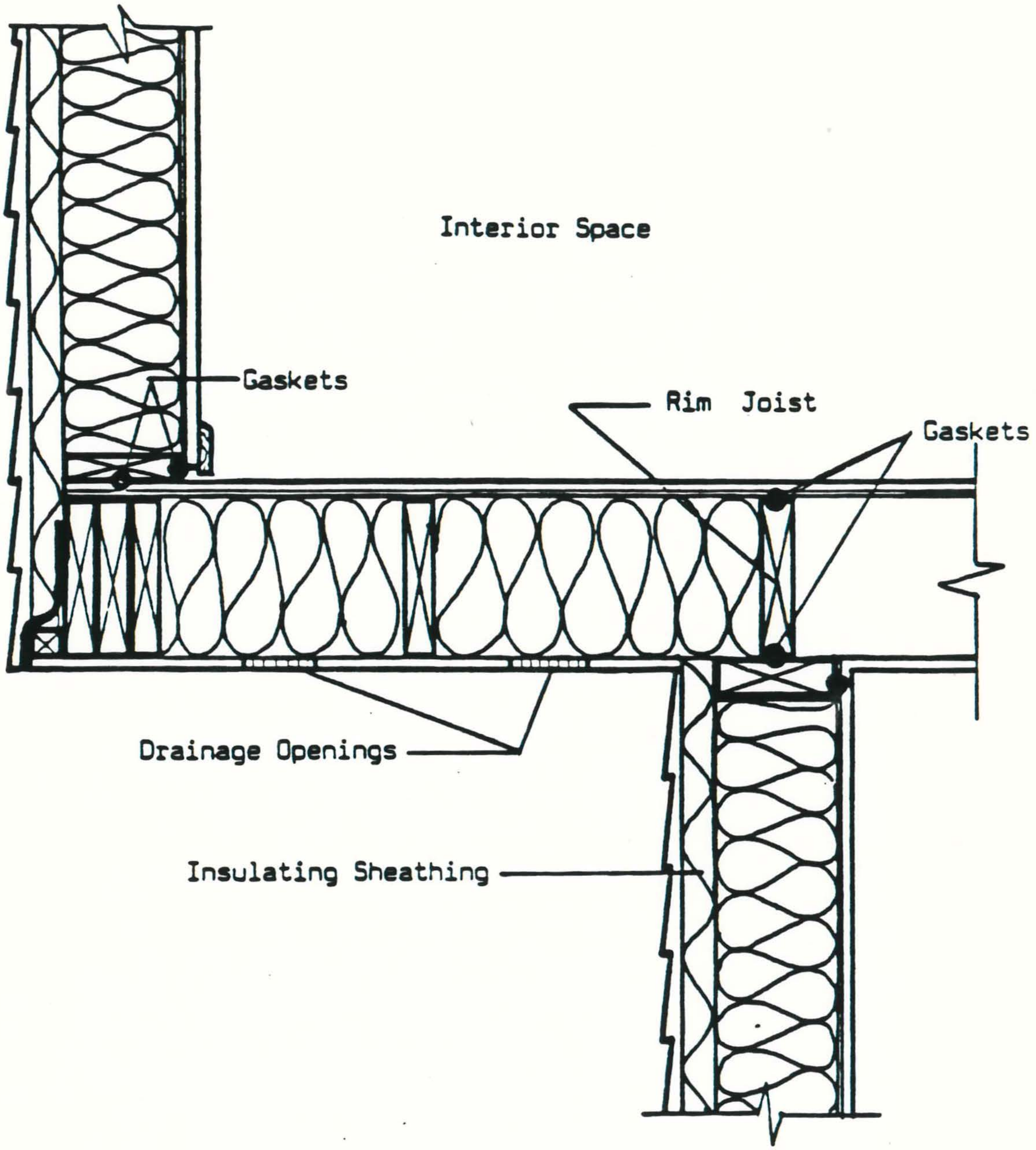


Figure 39 : Cantilever Floor
Parallel Joists

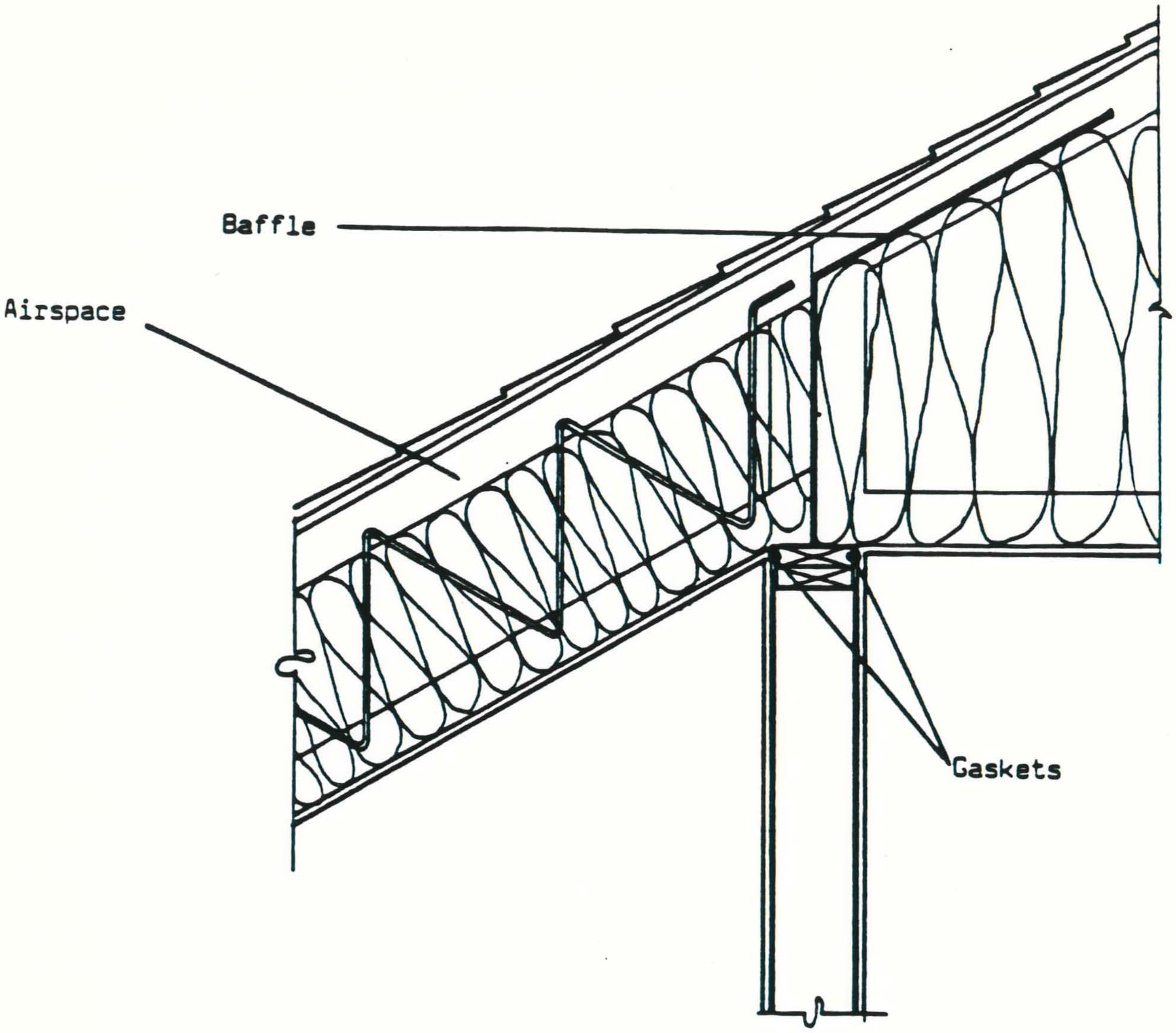


Figure 40 Load Bearing Wall-Sloped Ceiling

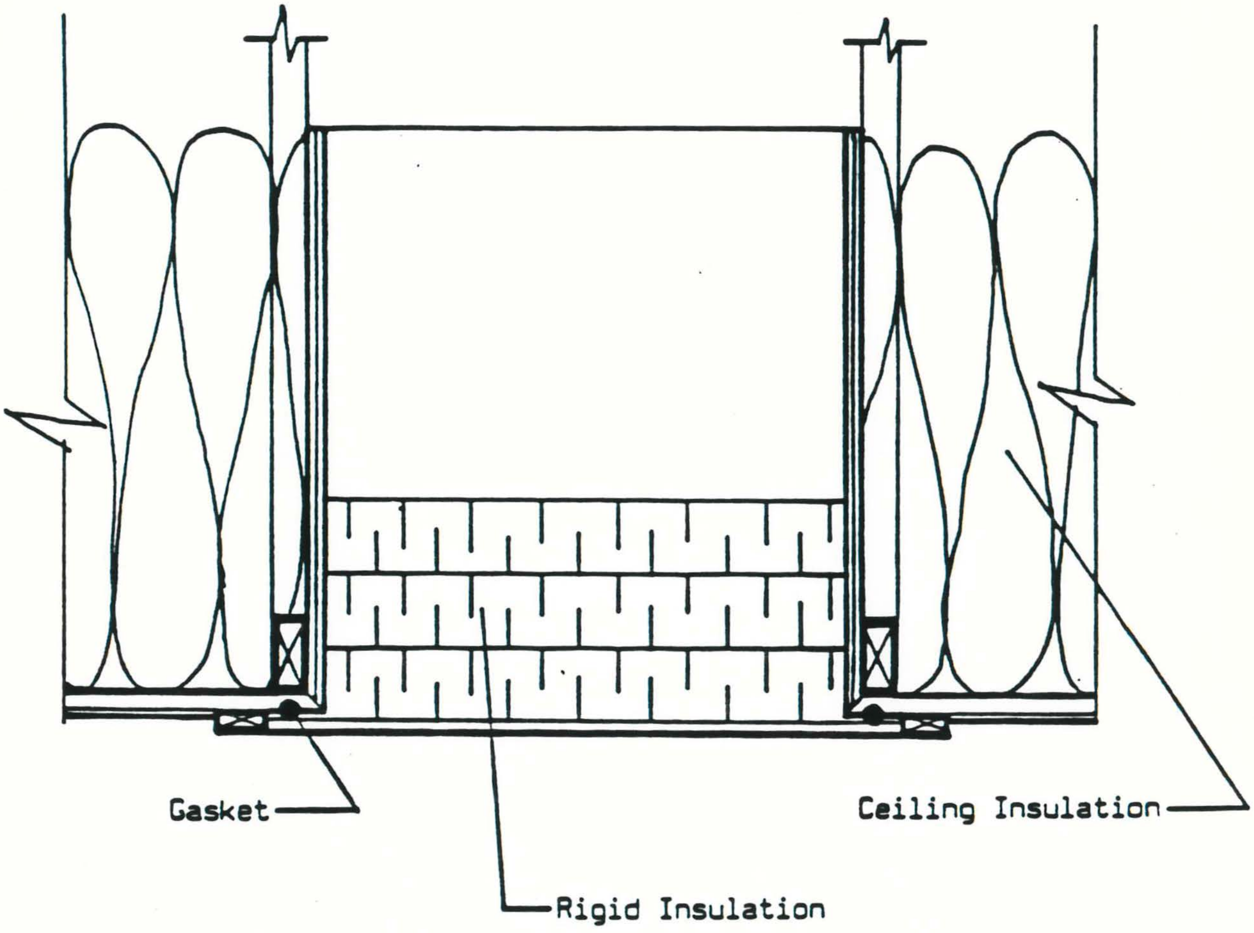


Figure 41 : Attic Hatch

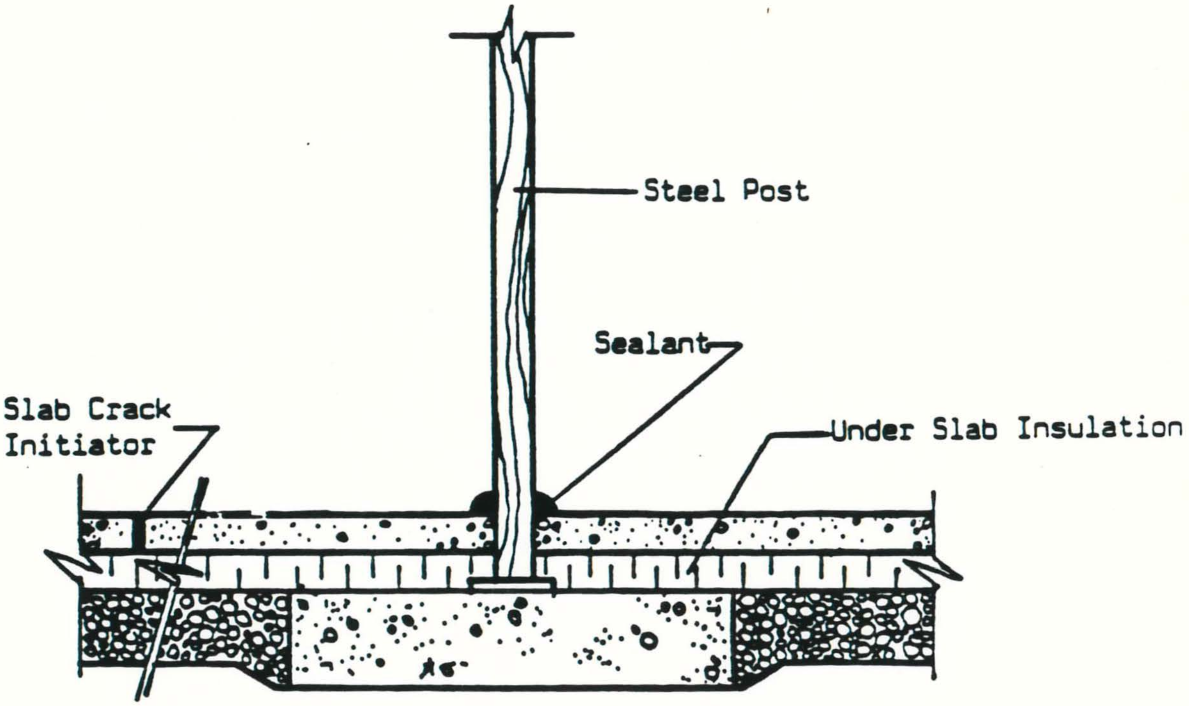


Figure 42 : Post Detail In Basement

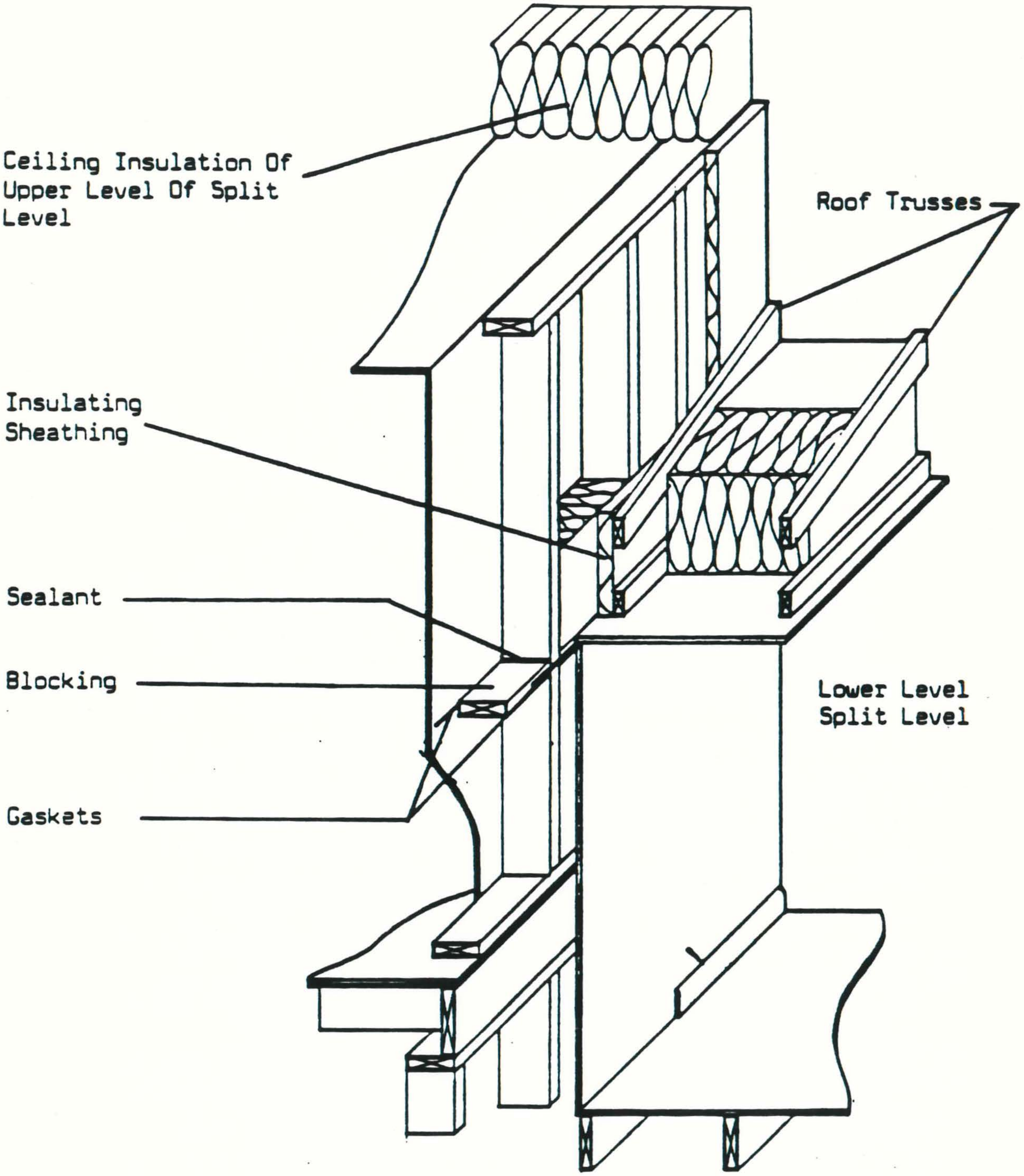


Figure 43 Split Level Detail

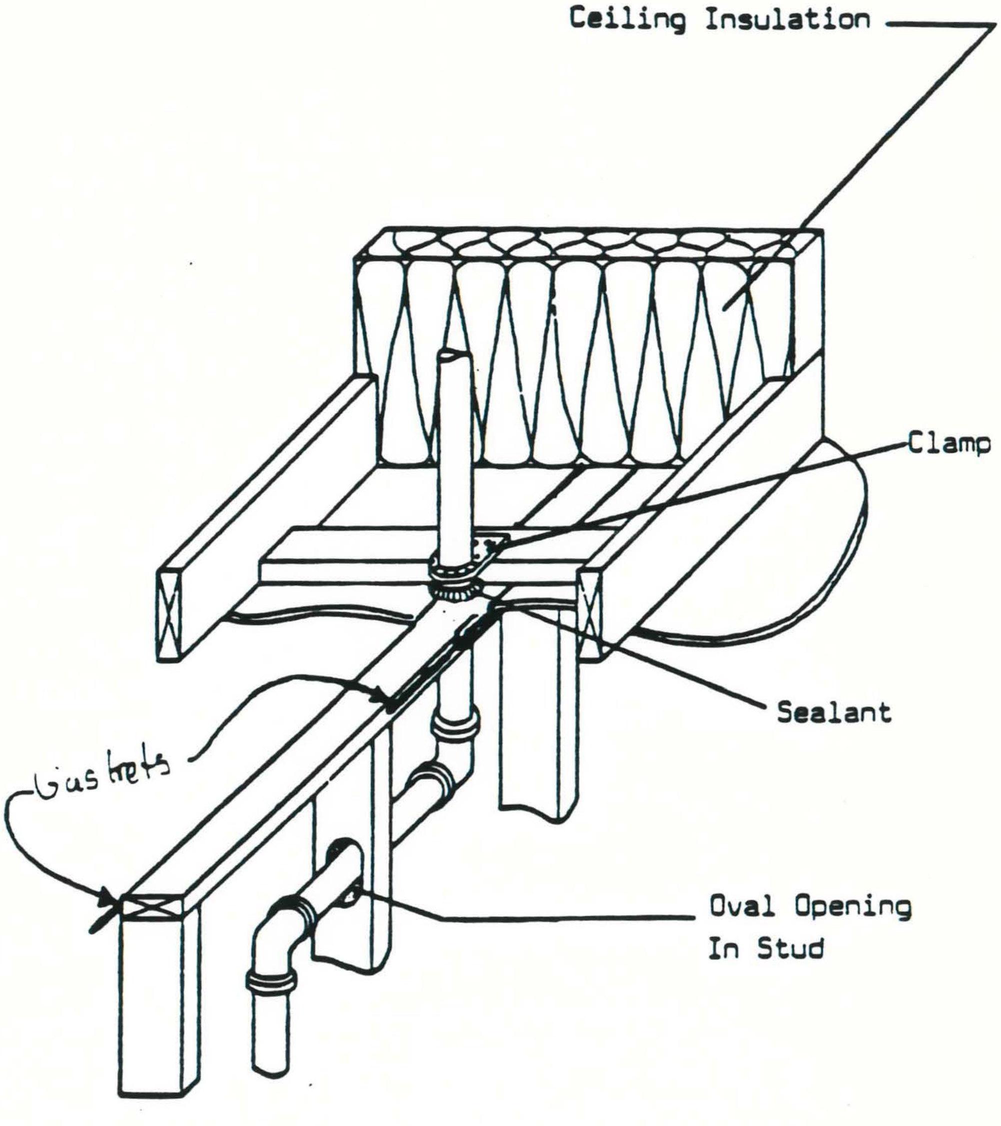


Figure 44 : Plumbing Vent Pipe

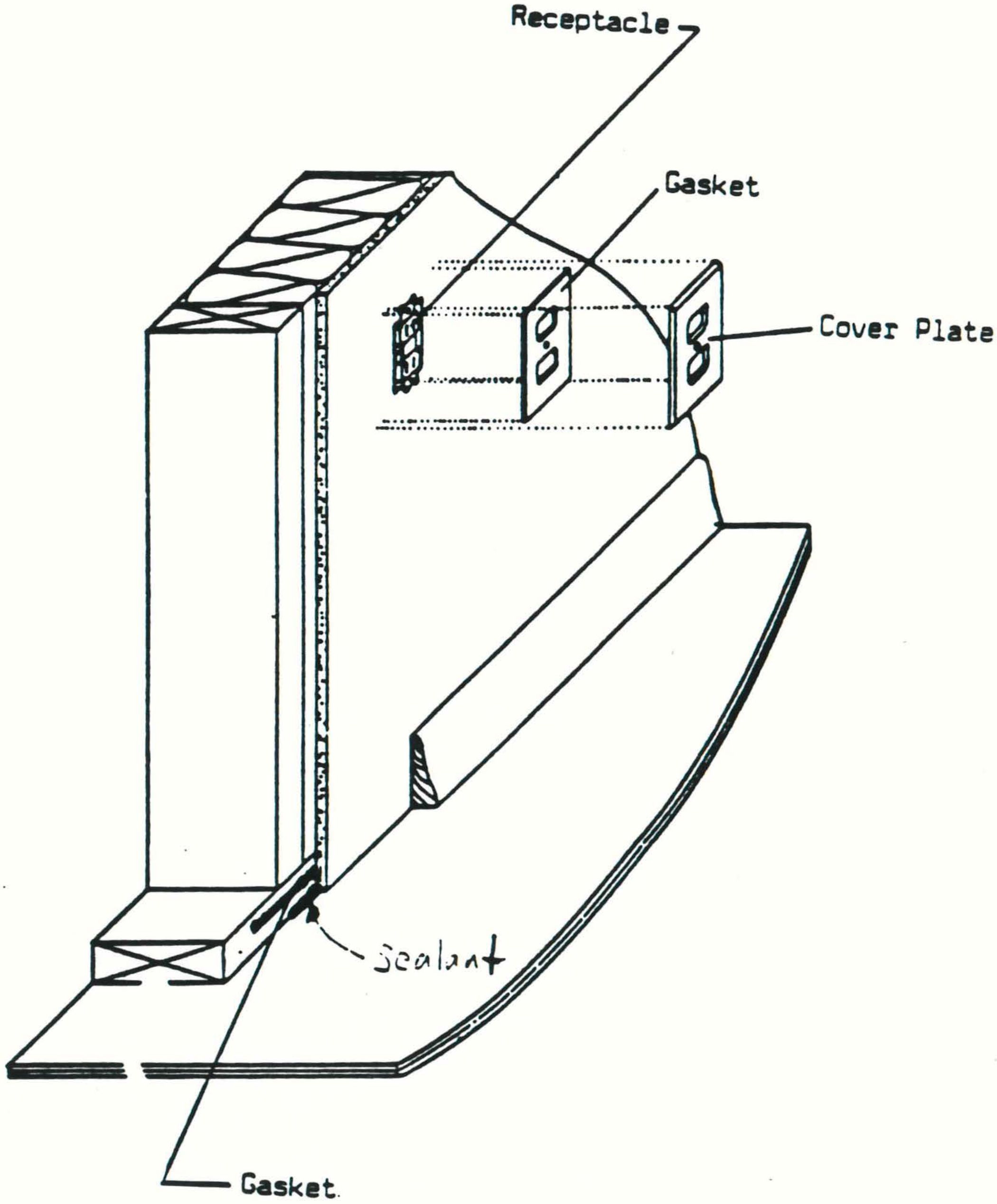


Figure 45 : Electrical Outlet

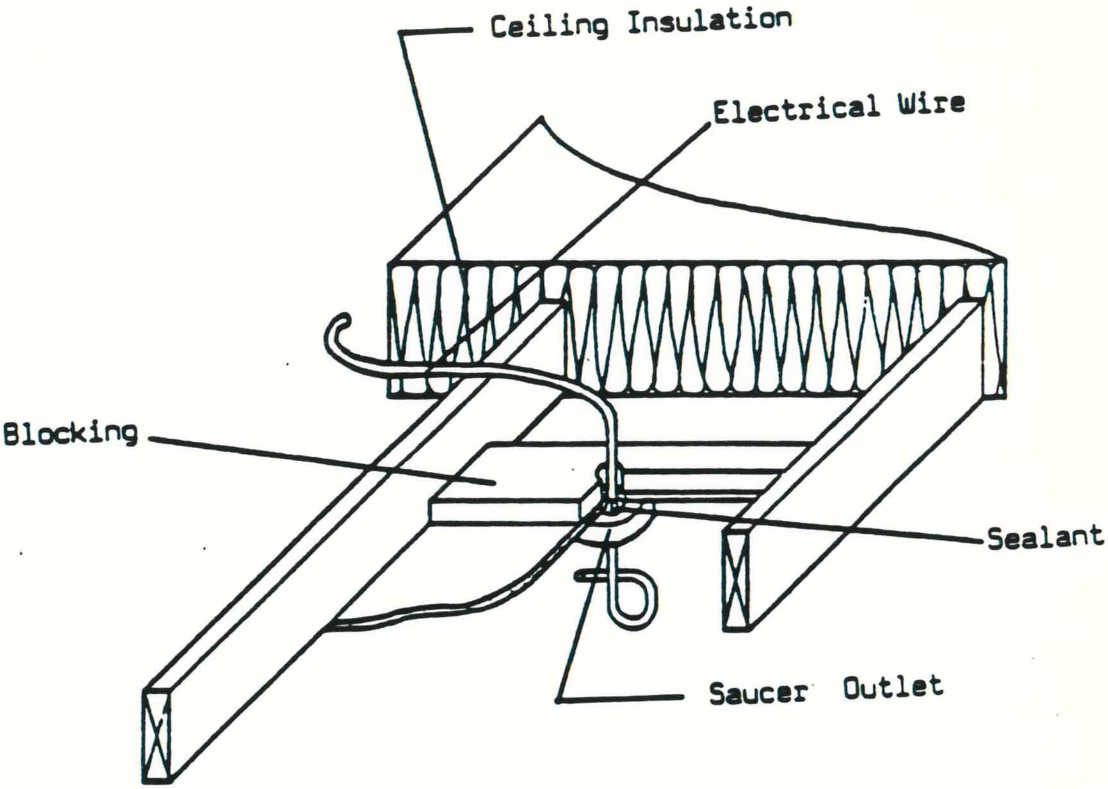


Figure 46 : Ceiling Fixture

I. EXECUTIVE SUMMARY

The following conclusions can be drawn from the Alberta Airtight Drywall Approach Demonstration Project and the previous and subsequent research work related to that project documented in this report:

1. Providing high degrees of airtightness in new residential construction is within the project management and supervision skills of major tract homebuilders with the use of the Airtight Drywall Approach.

2. When using the Airtight Drywall Approach, the incremental costs of providing high degrees of airtightness in new residential construction to major tract homebuilders are low when trade scheduling is similar to current practice and when the notching of gypsum board sheets around cast-in-place floor joists is not necessary, however, the related costs of providing a controlled ventilation system and aerodynamically uncoupled combustion appliances necessary in "airtight" houses currently provide a significant financial disincentive to the construction of "airtight" houses.

3. The related costs of providing controlled ventilation systems and aerodynamically uncoupled combustion appliances have fallen significantly over the past two years and are likely to continue to fall as new products are introduced and competition increases.

4. Combined combustion appliances, that is, where an induced draft, gas fired domestic hot water heater is coupled with a "fan-coil", hold further potential for reducing costs associated with aerodynamically uncoupling gas combustion appliances, as they eliminate a combustion source.

5. Concerns regarding a lack of moisture protection when using the Airtight Drywall Approach vis-a-vis the continuous polyethylene wrap do not appear to be valid in light of past and current research and current demonstrations. In fact, there may be legitimate concerns regarding the reduction of envelope drying due to the use of polyethylene. Building envelope durability may possibly be enhanced by the removal of sheet polyethylene in certain climates.

6. Long term durability of gasket and sealing materials used in the Airtight Drywall Approach remains to be evaluted conclusively. Current indications are positive, however, more study is recomended.

7. The effect of building frame movement, settlement and materials shrinkage on the long term airtighness of the Airtight Drywall Approach remains to be evaluated conclusively. Current experience suggests that differential movements between materials are "taken-up" by the gasket sealing approach and long term indications are positive, however, more study is recomended.

APPENDIX A: MOISTURE MOVEMENT

In order to control moisture levels and moisture movement in buildings, the mechanisms governing such movement must be understood, along with the relative magnitude of each mechanism. Appreciating the magnitudes of each moisture transport mechanism are key in developing an effective design and construction strategy to deal with moisture levels and moisture movement. When working with limited resources, it is unwise to concentrate a disproportionate share of those resources and effort on relatively minor factors, while allowing major factors to be ignored. Unfortunately, such has been the case over the past five decades, with respect to moisture movement in buildings.

Ever since F.B.Rowely conducted his excellent pioneering work in Minnesota in the 1940's, we in North America have been mesmorised by vapour diffusion. As we shall see below, of the four moisture transport mechanisms typically operating in building envelopes, vapour diffusion is a relatively minor one. It is not that we should ignore vapour diffusion as a moisture transport mechanism, it is that there are other important moisture transport mechanisms which may need to be addressed first.

The four moisture transport mechanisms predominant in building envelopes are:

1) Bulk moisture, in solid or liquid form, moving as a result of gravity, air pressure and/or hydrostatic pressure;

2) Moisture movement due to capillarity;

3) Air transported moisture movement; and

4) Vapour diffusion.

Each of these mechanisms can act independantly of one another and must be dealt with during design and construction. The first two, bulk moisture movement and capillarity are primarily responsible for moving moisture into the building envelope from the exterior. The latter two, air transported moisture movement and vapour diffusion, can move moisture into the building envelope from both the exterior as well as from within the building enclosure into the building envelope depending on exterior and interior conditions. For example, when a building is in a "cold" climate and is being heated, air transported moisture movement and vapour diffusion typically move moisture from within the building enclosure into the building envelope. When a building is in a "warm" climate and is being cooled, air transported moisture movement and vapour diffusion typically move moisture from the exterior into the building envelope.

This "duality" of moisture transport function that air transported moisture movement and vapour diffusion possess with respect to their ability to move moisture from both the interior and exterior of a building enclosure into the building envelope dependant on both climatic and interior conditions is often overlooked by designers and builders. It is not unusual to find "cold" climate building envelope designs employed in "warm" climate regions. Even more confusing to the builder and designer are conditions where both heating and cooling occur for extended periods of time. The region of North America where this occurs has been affectionately dubbed the "rot belt" and is testimony to the failure of builders and designers to recognize this "duality" that air movement and vapour diffusion possess.

BULK MOISTURE MOVEMENT

The first moisture transport mechanism a designer and builder must deal with is bulk moisture, in solid or liquid form, moving under the influence of a driving force, typically gravity, air pressure and/or hydrostatic pressure. This mechanism of bulk moisture movement is responsible for moving moisture from the exterior into the building envelope. It can be appreciated that a great deal of moisture in the bulk state, usually water, can get into a building envelope in the form of rain, especially wind driven rain. In addition, a great deal of moisture in the bulk state can get into a building envelope as ground water moving under the influence of gravity and hydrostatic pressure.

This first moisture transport mechanism requires three components to operate:

1) bulk moisture in the solid or liquid;

2) an opening or hole in the building envelope; and

3) a driving force be it an air pressure difference, a hydrostatic pressure or gravity.

Understanding the role of these components gives the designer and builder flexibility in developing various strategies to control this first moisture transport mechanism.

A designer or builder can seldom control whether ground water is present or not and the designer or builder certainly can not control whether or not there is rain, snow, wind or gravity. However, a designer or builder can control the number of openings or holes and two of the driving forces, air pressure differences and hydrostatic pressure.

The control of these two driving forces, air pressure differences and hydrostatic pressure, has been shown by experience to be the most effective and practical approach to controlling bulk moisture movement as it is typically next to impossible to build an enclosure without holes or openings in it. In the portions of the building envelope above grade, air pressure differences across exterior cladding can be controlled by the use of the "rain screen" principal or pressure equalization. Below grade it has also been more effective to prevent or control the build-up of hydrostatic pressure than to rely on a barrier without any openings or flaws in it to resist the hydrostatic pressure.

CAPILLARITY

The second moisture transport mechanism a designer or builder must deal with is capillarity. This mechanism of capillary draw acts primarily to move moisture from the exterior into the building envelope. Capillarity is the movement of moisture in porous materials under the influence of capillary action. For example, blotter paper, with one end in contact with water, draws water into itself against the force of gravity as a result of capillary action. Capillarity is a function of, among other things, pore size and available moisture. If pore size in a material is large, such a clear gravel and course sand, then capillarity will not exist. If pore size in a material is small, such as in concrete, silty clay and blotter paper, then capillarity is possible.

Capillarity can be a major moisture transport mechanism in the portions of building envelopes where they are below grade or where they come in contact with the ground. Capillary draw, however, can also be a factor in building envelopes above grade such as where a film of water is deposited on the exterior of a building envelope as a result of rain action. This water film may be drawn into the building envelope under the action of capillary draw. This is illustrated by the water found trapped between the laps in horizontal wood siding.

The water is held between the laps in spite of the influence of gravitational forces.

A designer or builder can control capillarity by controlling the pore size of the building material or building assembly selected. Materials can be selected which do not support capillarity as a result of their large pore size such as gravel, or materials may be selected which do not have any pores such as glass, or capillary pores in susceptible materials can be filled to "break" the capillary draw such as is done when concrete basements are "damp-proofed". Capillarity is also controlled by sealing conections between materials or by making the conections wide enough not to support capillarity. In the siding example to control capillarity, the seams at the laps could be sealed or alternatively the overlapping material spaced apart sufficiently so that water is not drawn up between the overlapping material as a result of capillarity. Joints between materials, above and below grade, must also be designed with capillarity in mind.

AIR TRANSPORTED MOISTURE MOVEMENT

The third moisture transport mechanism a designer or builder must deal with is air transported moisture movement. This mechanism can act in such a manner as to move moisture from, both, within the building enclosure and exterior of the building enclosure, into the building envelope. Air, depending on temperature, can hold varying amounts of moisture in the vapour state. When air moves as a result of an air pressure difference it will carry the moisture held within it. If air containing moisture comes in contact with a surface below the air's dew point temperature, the air may deposit some of its moisture on that surface in the form of condensation. For moisture to be moved as a result of air movement the three following conditions must be satisfied:

1) Air containing moisture must be present;
2) An opening or hole must exist; and
3) An air pressure difference acting across the opening or hole must exist.

An opening and moisture laden air are not sufficient. Moisture laden air will not be carried across an opening if an air pressure difference does not exist as well. In the same vein, moisture movement will not occur as a result of air movement if no moisture is present in the air or if there is no opening. Therefore, to control moisture movement as a result of the movement of air, three factors can be controlled, either individually or in combination, namely the moisture content in available air, the number, location and size of openings in the building envelope and the air pressure differential acting across the building envelope. It is typically more practical to control the moisture content in available air and the pressure differential acting across the building envelope than it is to control openings in the building envelope.

In "heating" climates, moisture content in interior air is often controled by utilizing air change to dilute interior moisture levels and in "cooling" climates with a high ambient vapour pressure, dehumidification is used to accomplish the same effect.

Slight depressurization in "heating" climates is used to induce infiltration across the building envelope to limit moisture problems in the recognition of the fact that cold infiltrating air does not carry much moisture along with it. In "cooling" climates, slight pressurization of a dehumidified enclosure, can also be used to accomplish the same result as the oposite is often true with respect to moisture content of exterior air being greater than the moisture content of interior air interior air. Of course, there are exceptions to the interior/exterior air moisture content generalization with heating/cooling climates, such as where in heating climates exterior air infilatrates below grade into basement spaces after being drawn through moisture laden earth. This infiltrating air can be at a saturated moisture content and can be responsible for moving significant amounts of moisture into a building enclosure.

Controlling building envelope openings is often the most recommended approach to dealing with this moisture transport mechanism, however, it is typically ineffective as significant degrees of "airtightness" are seldom achieved due to materials and workmanship problems. Furthermore, as building envelope airtightness increases, particularly in "heating" climates, the dilution of moisture in interior air by natural airchange decreases, leading to increased moisture concentrations in interior air and subsequently to increased incidents of moisture induced envelope problems if the other two factors, besides "airtightness", are also not controlled.

VAPOUR DIFFUSION

The fourth, and final, moisture transport mechanism is vapour diffusion. It can act to move moisture into the building envelope both from within the building enclosure as well as from the exterior. Vapour diffusion is the movement of moisture in the vapour state through a material. All materials are vapour permeable to one extent or another. Even sheet steel is permeable to vapour. Where steel is concerned, the process may take millions of years before any appreaceable amounts of water diffuses. Materials are not able to stop vapour diffusion from occuring as a result of their resistance to vapour diffusion, they are only able to slow the process down, or retard it. Hence, the term "vapour diffusion retarder" is appropriate, not "vapour barrier".

Vapour diffusion is a function of the vapour permeability of a material, the driving force or vapour pressure differential, the length of time the mechanism acts and the surface area involved. In a typical building enclosure, the surface area and time are not often able to be influenced. Only the vapour permeability and the driving force can usually be influenced. The driving force or vapour pressure differential refers to the difference in amount of moisture or difference in moisture concentration across a material. If no vapour pressure difference exists across a material, then no moisture will move as a result of vapour diffusion.

It is often practical only in "heating" climates to reduce the driving force where diffusion is concerned by reducing interior moisture levels, and this approach is typically limited by human comfort constraints. Hence, it is often only practical to manipulate the vapour permeabilities of materials to control moisture movement by diffusion. In a "cold" climate where a building is being heated, it is typical to have vapour diffusion act to move moisture from within the building enclosure into the building envelope.

In a "warm" climate with high ambient vapour pressures where cooling is occuring, the opposite is often true. However, exceptions are common and often overlooked, such as a south facing, highly insulated wall with wood cladding which has absorbed moisture in the wood cladding during the evening due to high ambient relative humidities (note: wood absorbs moisture according to ambient relative humidity not vapour pressure). This moisture is driven out of the cladding during the day and into the wall by a high surface temperature caused by incident solar radiation. The vapour pressure gradient, under these circumstances, can act from the outside of the wall towards the interior of the building enclosure.

Since vapour diffusion is a function of surface area, if, for instance, 90 per cent of a building envelope surface area is covered with a specific "vapour diffusion retarder", then, all other things being equal, that apour diffusion retarder is 90 percent effective. Continuity of a vapour diffusion retarder is not an over-riding factor where vapour diffusion is concerned. For instance, a paint film, of appropriate permeance, applied only on the interior exposed surface of a building envelope will typically act as an effective vapour diffusion retarder.

CONCLUSIONS

In addition to understanding the mechanisims governing the movement of moisture into and out of the building envelope, understanding the relative magnitudes of these mechanisms is also important. Of the four mechanisms, the first, bulk moisture movement is the most significant. This mechanism can move the most amount of moisture, most quickly into a building envelope as the building industry's historical preoccupation with rain and ground water can attest to.

The second moisture transport mechanism, capillarity, can also be significant, but it is an order of magnitude removed from bulk water movement. It has also been a historical preoccupation of the building industry.

It is the last two moisture transport mechanisms, air transported moisture movement and vapour diffusion, whose significance and magnitude has been most misunderstood. Air movement, as a moisture transport mechanism, can be as significant as capillarity. Vapour diffusion, however, is typically an order of magnitude less in effect than both air movement and capillarity and is typically insignificant when considering the total moisture movement in a building envelope.

Building envelopes rarely fail as a result of moisture movement by vapour diffusion, however, they are commonly misdiagnosed as having done so. Dr. N.B.Hutcheon, formerly of the Division of Building Research, National Research Council of Canada, sums up the current state of affairs:

> "It was nearly 30 years from the time of F.B.Rowley's paper (on the use of vapour barriers to prevent condensation in insulated building constructions) before it was clearly established and widely accepted that the leakage of air from inside a building through constructions and not vapour diffusion alone was often the principal means by which water vapour moved to cold surfaces. The concept of vapour diffusion was not wrong but it was not the only way. It is incredible, in retrospect that it should have taken so long to reach this conclusion..."(Hutcheon; 1979).

It has been calculated that the movement of water vapour through a 2 cm (3/4") square hole as a result of a 10 Pascal air pressure differential is 100 times greater than the movement of water vapour as a result of vapour diffusion through a 1 square metre (10 sq.ft.) sheet of interior gypsum board.

In "Canadian Building Digest", No. 175, J.K.Latta states: "Air leakage is now considered the prime cause of most condensation problems in walls and roof spaces. If, therefore, a building can be made tight against air leakage it may not need a vapour barrier, as defined. On the other hand, if there are openings that permit air to leak from the warm side to the cold side of the insulation, adding a vapour barrier (even of zero permeance) that does not seal off openings will be useless." (Latta; 1976). Latta was on the right track; he also might have noted that controlling leakage area was not the only factor involved in moisture movement by air transport, that air pressure differences and actual moisture contents in air were also significant an typically can be manipulated more readily.

It should not be concluded that vapour diffusion should be ignored by builders and designers as a moisture transport mechanism. Rather, it should not be the major or only moisture transport mechanism considered. In the past few decades it has been "the tail wagging the dog" with respect to moisture considerations in bulding envelopes.

APPENDIX B: CONCERNS ABOUT THE USE OF POLYETHYLENE FILM IN RESIDENTIAL CONSTRUCTION

BACKGROUND

Polyethylene film was introduced into the residential construction industry in the early 1950's on a limited basis. It was initially used only to replace the asphalt-kraft paper vapour barriers which were used beneath loose fill attic insulations. These vapour barriers were originally designed to retard vapour movement by diffusion alone and not to stop the movement of air which may carry moisture with it. In essence the early use of the term vapour barrier actually referred to a vapour diffusion retarder.

Polyethylene was brought into wide use as a ground cover material in the crawl spaces of homes in the late 1950's and early 1960's. It was also promoted as a vapour barrier in the campaign to promote electric heating in houses in the 1960's, although in these houses it was also used primarily in the ceiling. The walls of these electrically heated houses were still insulated with insulation batts backed with asphalt-kraft paper which acted as the vapour barrier.

In the early 1970's polyethylene began to be widely used as an additional vapour barrier in the walls of houses and was installed over the traditional asphalt-kraft paper vapour barrier still found on insulation wall batts. Subsequently, in many cases it became one of the few code recognized vapour barriers in wall construction as the insulation manufacturing industry began to phase out the manufacture of asphalt-kraft paper backed batts.

In the mid 1970's it was recognized by the regulatory agencies involved in residential construction that air movement was a significant factor in moisture movement, although this information had been available from the research community since the early 1960's. Subsequently the use of the term air-vapour barrier was adopted. The air-vapour barrier was meant not only to retard vapour diffusion but also to prevent mass air movement. Polyethylene was thought to be able to serve this function of an air-vapour barrier and became predominantly promoted as such in the late 1970's. It was not however, installed in a continuous manner, nor were seams sealed. Joints were commonly only overlapped, and rim joists or header joists typically ignored.

The energy crisis of the mid 1970's served to focus attention on infiltration/exfiltration as a major source of energy loss and airtightness as a method of overcoming this energy loss. The design and construction of extremely low infiltration houses was encouraged and significant degrees of building envelope airtightness were in fact achieved in experimental and demonstration houses in the late 1970's and early 1980's. Building envelope airtightness in these latter houses was most commonly achieved through adapting installation practices of the typical polyethylene film air-vapour barrier and installing it in a sealed, integral fashion.

Today, building codes, government policy and regulatory agencies promote, encourage and in a few limited cases require sealed, integral polyethylene air-vapour barriers. However, the residential building industry is currently far from adopting this approach as standard practice. It is the author's opinion that it may be incapable of doing so regardless of the incentives or penalties offered due to the significantly increased levels of workmanship required to successfully utilize it. In addition, significant problems exist with sheet polyethylene from a materials standpoint as well as broader problems from a building science or systems perspective. These materials problems and building science and systems problems may lead to a significant reduction of the use of polyethylene film as the principal method of achieving an air-vapour barrier in the residential construction industry in the near future.

CHEMICAL COMPOSITION OF POLYETHYLEME

When small organic molecules, or compounds of carbon, are caused to be linked together to form long chains, or complex two and three dimensional networks, the process is called polymerization. This process is usually dependant upon temperature, pressure, and an appropriate catalyst. When the gas ethylene, $H_2C=CH_2$, is heated under pressure it polymerizes to form polyethylene. Ethylene is said to be the monomer of polyethlene. The polyethylene is usually in the form of a solid transparent mass consisting of CH_2 units linked together in endless chains. The chains have as their backbone carbon atoms linked together with each carbon atom additionally linked to two hydrogen atoms.

The solidified polymeric mass may assume three types of geometric form: amorphous, crystalline, and oriented. The molecules in the amorphous state are arranged in a completely random manner, while if they exhibit a degree of regularity they may assume an ordered arrangement or a crystalline state. Polyethylene is a crystalline polymer but it typically has different parts of the same molecule in a number of ordered arrangements and other parts in amorphous regions. When a tensile stress is applied to a crystalline polymeric mass the molecular chains become aligned or oriented parallel to the direction of applied stress. Such materials are said to be oriented (Blaga; 1973).

Orientation causes a closer packing of molecular chains increasing the forces holding the chains together. For example, tensile strength can increase significantly by the unidirectional orientation of a polymer over that of an amorphous polymer. In oriented materials, hovever, material properties vary with molecular alignment. Hence, in sheet polyethylene, or polyethylene film, the material is stronger in the direction of orientation than the strength of the material at right angles to the direction of orientation. In the manufacture of polyethylene film these directions are referred to as machine direction and transverse direction respectively.

The polyethylene polymer is typically mixed with numerous additives to reduce deterioration during production and use as well as to facilitate processing. The end products physical, chemical or electrical properties are usually altered in this manner. This physical mixture of a polymer and an additive is called a compound.

Recent surveys (Rode; 1983) indicate that common additives to polyethylene include:

- pigments (carbon black)
- flame retarders (antimony trioxide, halogenated metals)
- slip agents/antiblocking agents (oleamide)
- blowing agents (pp'-oxy-bis-benzene sulphany hydrazide, azocarbonamide)
- plasticizers (polyisobutylene, butyl rubber)
- cross-linking agents (dicenyl peroxide)
- antioxidants (amines, phenols, DLTP)
- processing stabilizers (2-6-5-butyl-4-methyl phenol, Topanol CA, Nonox WSP)
- weathering agents (carbon black)
- antistatic additives (polyethylene glycol alkyl ester).

These common additives are typically grouped into classes. The three classes of additives of interest to this paper are: lubricants, stabilizers and plasticizers.

Lubricants provide external and internal lubrication in plastic compounds. Of specific importance to polyethylene film manufacture are additives which reduce friction between the polymer and metal surfaces of the dies and other processing equipment. Without the addition of lubricants, degradation can begin to occur during processing and as such impair long term durability.

Protection against polyethylene degradation caused by heat, oxidation, and solar radiation can be provided by the addition of stabilizers. The three groups of stabilizers used in polyethylene manufacture are: thermal (heat) stabilizers, antioxidants and ultraviolet light stabilizers (UV stabilizers).

Plasticizers are additives which improve processing and serve to reduce the brittleness of the end product. Material properties can change dramatically from hard, brittle, and glass-like to soft, flexible and tough (Blaga; 1973).

MATERIALS DEGRADATION PROBLEMS

Polyethylene films are susceptible to degradation due to chemical attack, radiation degradation, bacterial degradation, thermal degradation and thermal oxidation (Rode; 1984). These mechanisms will now be discussed as well as the influence of various manufacturing processes on these degradation mechanisms.

RADIATION DEGRADATION

The long-chained molecules comprising sheet polyethylene are attracted to each other by secondary forces (Ashton; 1969). In order to break these bonds energy is required. This energy can be supplied by radiation. One of the properties of radiation is that as the wavelength of radiation decreases, its energy increases. The energy required to break the carbon bonds in polyethylene occurs at a wavelength of 350 nm, a wavelength in the ultraviolet band. When polyethylene is exposed to ultraviolet light embrittlement of the polymer occurs. However, biologically active UV is only about one percent of the total radiant energy from the sun at the earth's surface due to the absorption of most of the solar emitted UV radiation by the earth's atmosphere. This atmospheric absorption allows organic materials some degree of exterior durability. The magnitude of the atmospheric absorption of UV radiation is dependant on both seasonal climate and location so that significant variation in the outdoor weathering of polyethylene occurs (Rode; 1984).

High energy irradition of polyethylene can initate the reverse of the polymerization reaction that resulted in the original production of the polyethylene. This process is sometimes referred to as the unzipping of the polymer (Ashton; 1969) and leads to catastrophic failure as it is a chain reaction. Additives which are classed as UV stabilizers are typically pigments which reflect the UV or absorb it preferentially to the polymer and convert it to heat energy. Carbon black is commonly used as an effective UV stabilizer due to its property of UV absorbtion. Other compounds, such as titanium dioxide and zinc oxide, are also effective UV stabilizers as a result of their ability to reflect UV rather than mearly absorb it.

The conversion of UV radiation to heat by the stabilizers can lead to elevated temperatures in the polyethylene leading to an increase in the rate of chemical reactions, such as oxidation, which may be occuring due to other reasons.

Concerns that the degradation of polyethylene film due to UV exposure, once started, could continue even after the UV source is removed, due to chain reaction properties of the process, have recently been expressed (Gridley; 1984) and serve to underscore the desirablity of access to the polyethylene for inspection purposes once installed.

High energy irradition also can result in the production of smaller molecules such as hydrogen gas forming as a result of chain scission. These smaller molecules react across the chains in a process called cross-linking. Continued cross-link formation interferes with crystallization eventually resulting in an amorphous polymer. As such the material becomes harder and brittle and the induced brittleness causes cracking.

If during the cross-linking process sufficient oxygen is present, oxidation may occur. This polymer degradation process is thought to offset the effects of cross-linking (Rode; 1984) but does not stop the degradation process in general as it now is a combined process.

The UV degradation process is thought to be partially responsible for a recently documented (Eyre; 1984) incident of catastrophic failure of polyethylene film in a low energy house in Saskatchewan. It is likely that the polyethylene film utilized was insufficiently stabilized from UV degradation although it is possible to obtain highly UV stabilized film such as polyethylene films having a high component of carbon black. Unfortunately the vast majority of polyethylene film in use in residential construction in North America is insufficiently stabilized against UV degradation to provide adequate service life if current methods for accelerated UV degradation testing and UV degradation protection (Howard, Gilroy; 1969) are applied.

THERMAL OXIDATION

Oxidative degradation effects most polymers, however, hydrocarbon polymers such as polyethylene are specially susceptible (Ashton; 1970). Polyethylene films utilized in residential construction are typically manufactured and installed in environments which allow continued contact with oxygen contained in a gaseous state in the atmosphere. When the effect of temperature is superimposed, the rate of reactions increase. Oxidation, a slow reaction at room temperature in polyethylene, increases dramatically at elevated temperatures (Ashton; 1969). According to recent research "during thermal oxidation, the hydrocarbon groups of the polyethylene react with oxygen to form a hydroperoxide which results in cleavage at high temperatures to form an alkoxy and hydroxyl radical that abstracts hydrogen from the polyethylene" (Rode, Kilp; 1984).

Rapid oxidation of polyethylene film can also occur in the presence of ozone. Ozone is an extremely reactive gas that is an unstable derivative of oxygen gas and is an oxygen molecule containing three atoms instead of two. Materials which oxidize, such as polyethylene, will react with ozone. Concerns have been expressed that where electronic air cleaners are used in residential construction, the production of ozone as a result of their use, could lead to significant deterioration of polyethylene films used as air-vapour barriers.

Processing, which occurs at elevated temperatures, typically leads to some form of oxidative degradation, however, slow aging still occurs at service temperature. Particularly significant to thermal oxidation occuring in polyethylene films is frequent processing and subsequent exposure to oxygen as can occur when reprocessed or reclaimed material is used (Platts, Benson; 1984).

Specific additives, antioxidants such as amines and phenols, can retard the oxidation process by preventing the formation of hydroperoxide by the reaction of a hydrocarbon with oxygen.

Unfortunately the use of polyethylene films in residential construction which are appropriately stabilized against oxidation is next to nonexistent. In fact appropriate material is typically not available nor even manufactured. Recent testing conducted for Energy, Mines and Resouces Canada (Rode, Kilp; 1984) revealed that only one of the polyethylene films manufactured in Canada for use in residential construction came close to meeting the standard developed by the Swedish National Authority for Testing and Inspection based on an accelerated test method to simulate lifetime residential service. Furthermore, the testing revealed that great disparities existed between the actual performance of films from various manufacturers within the sample. Although all the samples tested met the CGSB Standard for polyethlene films in residential construction, CAN2-51.33-M80, performance measuring oxidation resistance of the samples varied two orders of magnitude within the sample, with even the best sample performing poorly. Three methods of monitoring thermal oxidative degradation were used:

- polyethylene film samples were aged at elevated temperatures (95 degrees Celcius) for 10 days and 30 days, with mechanical properties such as tensile strength and percent elongation in both the machine direction and transverse direction measured after aging.

- infrared (IR) spectra of the samples were measured as a function of heating time at 99.6 degrees Celcius under an air atmosphere.

- differential scanning calorimetry (DSC) of the samples was carried out by heating the samples from room temperature to 180 degrees Celcius under a nitrogen atmosphere and determining the intersection of trace lines.

The test methods utilized correlated well with one another and there is some optimism that the test methods reflect long term behaviour under actual service conditions. Unfortunately, although it is possible to manufacture polyethylene film which will resist thermal oxidation over the useful service life of a house, and although it seems possible to provide for a standard for the manufacture of polyethylene film which deals with resistance to thermal oxidation and to test for compliance, such films are not currently available or manufactured for the residential housing industry and no current standard dealing with the thermal oxidation of polyethylene film exists or is contemplated. With respect to the development of an appropriate standard, it seems that political ramifications are the major hurdle, in that if such a standard is implemented it would imply (perhaps correctly) that current polyethylene films are completely inadequate to resist thermal oxidation. That would fly in the face of current multi-million dollar government sponsored promotion campaigns for the use of polyethylene films as air-vapour barriers in low energy housing.

THERMAL DEGRADATION

Temperature also effects polyethylene in a physical manner. A temperature increase softens materials that do not contain much cross-linking between molecules. Rate of change of temperature is also important as organic materials typically can accommodate slow rates of strain more readily than fast rates of strain. Furthermore, "thermal shock can cause cracking or exudation of plasticizer from plastics" (Ashton; 1969). Migration of the plasticizer out of the polyethylene can cause embrittleness and subsequent catastrophic failure to occur when external loads are applied on the polyethylene film such as wind pressure effects. Migration of the plasticizer may be rapid enough in typically installed polyethylene film in residential applications that brittleness can occur, depending on the composition of the polyethylene, within five years (Bowerman; 1983).

DEGRADATION DUE TO BIOLOGICAL ATTACK

Synthetic polymers are susceptible to attack by micro-organisms even though in general such synthetic polymers are not normally sources of food. It is not so much the pure polymer which is attacked, but the additives such as plasticizers and stabilizers which become the compounds of nutritional value for the micro-organisms. In the production of low cost polyethylene film it is not uncommon to utilize plasticizers containing fatty acid components. In such cases the probability of attack increases directly in proportion to plasticizer content unless inert plasticizers are used (Ashton; 1970).

It is now felt that conditions present in wall cavities and beneath concrete slabs are conducive to the biological attack of polyethylene films (Rode; 1983). Wall cavities are susceptible due to their high humidities and temperature and concrete slabs due to their contact with the soil and the micro-organisms contained within the soil. In fact, recent evidence (Maloney; 1984) may indicate that polyethylene degradation beneath concrete slabs could be quite common.

CHEMICAL ATTACK

Polyethylene film has excellent resistance to chemical degradation by a wide range of chemical reagents, non-oxidizing acids, alkalis and aqueous solutions (Rode; 1983). It is unlikely that the polyethylene films installed in typical service locations in residential construction come in contact with the limited number of chemical reagents which deleteriously affect it. Problems and concerns existed with the compatibility of polyethylene films and the numerous sealants and caulking compounds that the films came in contact with in the attempts to provide sealed polyethylene air-vapour barriers. These concerns and problems have been overcome with intensive testing and investigation of materials compatibility in this area by governments and regulatory agencies promoting energy conservation through airtightening and manufacturers wishing to promote their products.

Concerns have been recently raised (Riley; 1983) about the potential degradation of polyethylene in contact with concrete. Specific concerns centered around the numerous chemicals which may be added in low concentrations to concrete to modify its properties. These chemicals e typically accelerators, water reducers, retarders, super-plasticizers, air-entraining agents, fungicides, and corrosion inhibitors. However, a study commissioned to investigate this area of concern found no direct evidence of deleterious chemical attack on polyethle films (Rode; 1983).

One of the few concerns in this area remains the reaction of polyethylene films to certain wood preservatives. It is felt that copper napthanate could induce degradation (Platts, Benson; 1984).

INFLUENCE OF FILM MANUFACTURING PROCESSES ON MATERIALS DEGRADATION

To the chemical industry, the production of polyethylene vapour barrier film has always been a very low margin product, and as such it typically attracts sufficient quantities of reclaim resin to significantly impact service performance. The use of reclaim material is further encouraged by the polyethylene film industry being a process industry with first pass efficiencies on the order of 90 percent, allowing 10 percent to be available for recyling (Platts, Benson; 1984). This reprocessing of material, depending on the mix of the chemical soup, can significantly reduce the resistance of the polyethylene film to thermal oxidation, as components of the raw materials may be subjected to the elevated temperatures of processing several times.

The actual process equipment used in the manufacture of film seems to be one of the single greatest sources of polyethylene film failure according to a recently conducted field survey of Canadian houses by the Canada Mortgage and Housing Corporation (Platts, Benson; 1984). A large percentage of the degraded films found in the field, contained brittle bands. Degraded material and durable material would coexist on the same sheet inches apart. These bands were found to be parallel to the machine direction of the film. This occured as a result of the polymer emerging from the process equipment die in a hetrogeneous and not homogenous condition. It has been postulated (Platts, Benson; 1984) that certain die designs can "hang up clumps or streams of polymer which cook for extended periods and then create hetrogeneity at the die lips".

In the same study it was also speculated that homogeneous instability is introduced by certain extrusion processes recently adopted, as numerous older samples of polyethylene film performed in a more durable fashion than relatively young samples. It was felt that the recent trend to higher pressure and higher temperature dies promote early degradation.

It has become obvious that in addition to standards specifying additives and chemical composition of polyethylene films being necessary, standards relating to process equipment will also be necessary.

SUMMARY OF MATERIALS DEGRADATION PROBLEMS

Significant material durability problems exist with currently utilized polyethylene films in the residential construction industry. These problems include UV degradation, thermal oxidation, thermal degradation, chemical attack, biological attack and built-in manufacturing process pre-aging. It is possible, in spite of these numerous and seemingly insurmountable problems, to manufacture polyethylene film for use in residential construction which will stand the test of time. Unfortunately such materials are either not being utilized or not available nor is there likelihood in the near future for significant changes to this state of affairs. However, even if durable polyethylene film in the materials sense was readily available, it is the author's contention that it would make little difference to the typical performance of polyethylene air-vapour barriers currently installed as durable polyethylene film would still not be able to adequately meet the other building science or systems concerns relating to air barriers and buildability. These building science or systems concerns will now be discussed.

BUILDING SCIENCE SYSTEMS PROBLEMS

Government regulatory agencies, while promoting the use of a sealed, integral polyethylene film air-vapour barrier, and ignoring the substantial materials problems discussed earlier, are stymied in their attempts to achieve widespread adoption to the technique. This has been due to one significant overiding fact: the sealed, integral polyethylene film air-vapour barrier technique is far too lur intensive, and hence too expensive to be adopted readily by the building industry. In fact, it is the author's opinion that large tract builders would not likely successfully adopt the technique even if cost were no object due to the significant amounts of supervision and training required. Furthermore, the material is typically too fragile to withstand the tract construction process. The development of super-polys with multiple cross-laminated plys and reinforcements has been an outgrowth of this concern. However, this trend may lead to impractical extremes with costs multiplying by orders of magnitude.

The difference between air barriers and vapour diffusion retarders seems to be lost on the industry in general and the government and regulatory agencies in specific. Agreement by the various proponents can be found with the concept of airtightness. Unfortunately, it is felt by many that airtightness can be practically achieved with polyethylene films and that the use of films to achieve airtightness in fact obey basic building science principles. Even if practicality were removed as a consideration, the use of polyethylene films to achieve airtighness would not be acceptable as the technique does not meet the basic requirements of an air barrier system. It is ironic that outside of a few researchers in the building science community, the industry has not defined the principles and characteristics of air barriers or more specifically air barrier systems.

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

- The material, or system, must be continuous.
- The material, or system, must be impermeable to air (allowing not more than .1 litres of air to pass through the system per second per square metre at 75 Pascals).
- The material, or system, must be able to withstand the air pressure loads which act on it. That is, in addition to the influence of mechanical systems and stack action, the local peak wind loads must be taken into account.
- 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.
- The material, or system, must be durable and easy to maintain over the service life of the building.

When examining the sealed, integral polyethylene film system under these five requirements we find significant problems. The first requirement of continuity can be met by the poly-film approach as well as the second, that of impermeability of the system or material to air. The last three requirements, however, cannot be met with the poly-film approach.

The polyethylene film as it is currently being installed in practice is unable to withstand the air pressure loads which act on it. To be effective, the polyethylene film must be supported to resist wind and stack air pressures. Recent work carried out at the Division of Building Research of the National Research Council of Canada by R.L. Quirouette indicates that simply suspending polyethylene between wall studs, caulking the seams and fastening battens over the joints is not sufficient to allow the polyethylene to resist wind and stack air pressures. Under peak wind loading, the polyethylene will be sucked into the wall cavity, rupture its seal and compress the insulation. In addition, under fluctuating wind load conditions, the polyethylene film will billow in and out causing a pumping action resulting in rain deposited water on the surface of the exterior cladding being sucked inward. The polyethylene film must therefore be rigid in addition to being able to withstand necessary wind loads. Techniques which provide the necessary support for the polyethylene are prohibitively expensive. It may be more practical to use other materials, such as the interior cladding, as the air barrier rather than the polyethylene film.

The last requirement of an air barrier, or air barrier system, is also not being met by the current polyethylene film system. The materials durability problems have been previously discussed. While materials durability probles can be overcome, however, the problems of system maintainability may not be practical to overcome. In current approaches, the polyethylene is hidden wn the exterior walls of a building envelope. When flaws in the air barrier occur, repairs, or maintenance is not easy. In fact it is unlikely that problems will be noticed at all.

CONCLUSIONS

Significant materials problems and building science systems problems exist with the use of polyethylene film in residential construction. The basic materials problems can be resolved, however their resolution is not likely in the immediate future due to institutional inertia. The building science systems problems may possibly not be overcome in a practical and cost effective manner which will allow continued, widespread use of polyethylene film in residential construction as an air barrier system. It is likely that the use of polyethylene film in residential construction will be significantly reduced in the foreseeable future.

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