Improved Methods for Air Sealing Residences

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ABSTRACT

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In the past decade, a large number of air sealing techniques for residences have been introduced.

Using these techniques, builders have been able to reduce whole house leakage values to below 1.5 air changes per hour at 50 pascals. A disadvantage of the techniques has been increased cost compared to conventional construction.

In this paper a critical look is taken at research data on the location of common air leakage paths in residences, and some improved and simplified techniques for air sealing are suggested.

The two dominant air leakage locations are the ceiling-interior partition joints and the foundation-sill area.

To date, the most popular air sealing technique has been the use of a polyethylene vapour barrier which also serves as the air barrier for the structure. Generally, great care is taken in sealing all the joints in the polyethylene sheets.

It is the author's contention that a substantial amount of the joint sealing with the polyethylene sheets is unnecessary, given that the gypsum board can serve as the air barrier.

Improved details incorporating this approach are included in the paper.

Introduction

Approximately 10 years have passed since techniques to dramatically reduce the space heating energy consumption of residences in North America were introduced. One of the key measures involved is the reduction of air leakage. A number of publications--Energy Efficient Housing: A Prairie Approach(1), Air-vapour Barriers(2), Air Infiltration Control in Residential Housing: A Guide to International Practise(3), and The R-2000 Builders Manual(4)--present these methods for air sealing of residences.

Properly applied, the methods described in these booklets have proven to be successful in reducing air leakage. In houses where the techniques are applied, the air leakage values as measured by a pressure test are routinely reduced below 1.5 air changes per hour at a pressure difference of 50 pascals. This figure represents a reduction from readings of about 4 to 10 air changes per hour at 50 pascals for houses in Canada not incorporating the special sealing measures. In Table 1, air leakage values for various groups of houses in Saskatchewan (5) are presented.

Table 1. Air leakage values for various groups of houses located in Saskatchewan

	Equivalent leakage areas (sq. cm)	AC/h @50Pa	Number of houses
Pre-1945	1078	10.4	19
1946-60	709	4.6	20
1961-80	621	3.6	97
Special low energy houses	330	1.5	40

As can be seen from the Table, the specially sealed low energy houses were able to reduce the air leakage to an average of 1.5 air changes per hour at 50 Pa.

Costs (6) for the improved air tightness have been presented for R-2000 houses built in Canada. For the first 254 houses built under the R-2000 program in 1983, the average incremental cost of providing the air sealing measures amounted to $260. There is room for improvement through better techniques.

In this report, the author will present some material on the relative importance of various air leakage paths in residences, and also present improved details that potentially can reduce the cost of air sealing. The author will concentrate on those walls using polyethylene vapour barrier systems placed just beneath the gypsum boards. Due to space limitations, discussion of wall systems such as strapped walls and double-stud walls using vapour barriers located at an intermediate position through the wall will not be presented. In addition, no discussion will be made of the air-tight drywall approach.

Air Leakage Locations in Residences

A number of reports have presented the approximate distribution of air leakage in residences.

In the 1985 ASHRAE Fundamentals Volume (7), measured data are presented on the air leakage areas associated with various building components.

For typical Canadian houses, the areas most likely to be leakage sites are the following:

a. Joints between interior partitions and ceilings.
b. Joints around the floor joists.
c. Fireplaces.
d. Ductwork in unconditioned spaces.
e. Pipe and duct penetrations.
f. Attic hatches.
g. Window or wall air conditioners.
h. Windows and leakage around window frames.
i. Doors and leakage around door frames.
j. Electrical outlets and switches.
k. Basement floor drain.

An example is presented in Table 2 of a house for which the leakage areas are calculated using the ASHRAE data. The data are also presented graphically in figure 1.

Table 2. Example calculation of the leakage areas of typical holes in an unsealed one storey residence.

	Leakage area (sq cm)	%
Sills (uncaulked) (43.2 m)	173	26.5
Ceiling leakage (due to intersecting partitions.100 m)	150	22.9
Windows & framing (13.1 sq. m)	75	11.5
Fireplace with damper	69	10.5
Exterior doors and framing (5.7 sq.m)	54	8.3
Pipe penetrations (7)	42	6.4
Attic hatch (1)	30	4.6
Air conditioner (1)	24	3.7
Bathroom exhaust fans (2)	22	3.4
Electrical Outlets (20)	10	1.5
Kitchen exhaust fan (1)	5	0.8
Total	654	100.1%

As may be seen from Table 2, the two greatest leakage areas are the foundation sills and the ceiling-partition leakage for this one storey house. Together they amount to almost one-half of the total leakage area for this particular example house. Electrical outlets comprise less than 2 per cent of the leakage. Windows and doors and the adjacent framing leakage amount to about 20%.

Assuming that these numbers are representative of typical houses, the observation can be drawn that the greatest effort should be expended in reducing air leakage in those very leaky locations mentioned above. The two dominant areas appear to be the sill-foundation area and the ceiling-partition wall leakage.

It should be noted that for other types of houses, such as those with two or three storeys, the proportions of leakage area in the house would be different. For instance, a three storey house would likely have a smaller fraction of the air leakage occurring in the ceiling, and a greater fraction in the wall-related components.

Air barriers and vapour barriers

A good explanation of the differences between air barriers and vapour barriers is contained in a paper by Quirouette.[10]

To control air leakage through the envelope of the structure, an air barrier is required. For many applications in residences, gypsum board can serve as the air barrier provided that some means is used to ensure that the gypsum board is continuous, and that joints between the sheets have been properly taped. For example, very little air leakage will occur through a ceiling that has gypsum board installed provided the gypsum board is continuous and the joints have been properly taped. Air leakage can occur at the penetrations of the gypsum board if proper sealing methods are not incorporated.

In addition to providing an air barrier, one must also provide a vapour barrier in the envelope. Gypsum board by itself is not a satisfactory vapour barrier. Since about 1960 in Canada, the most popular form of vapour barrier in residential construction has been polyethylene sheeting. Other vapour barriers, such as waxed or asphalt coated paper and vapour barrier paints have been used, although much less frequently.

It is the contention of this author that in residential construction it is possible to use the gypsum board as the air barrier in certain parts of the structure, and to use a polyethylene vapour barrier in other parts of the structure to provide the air barrier. Using this technique, it would be possible to omit sealing the polyethylene sheeting in areas of the structure where the gypsum board was installed in a continuous manner (for instance, on ceilings where the gypsum board is installed before the interior partitions are erected.) In a later part of this paper, this method will be discussed in further detail.

In other parts of the structure, such as in the area around the floor joists, the use of gypsum board for air sealing would be difficult. In this part of the house, a well-sealed vapour barrier can serve as the air barrier.

In summary, the basic method being suggested here is to use the gypsum board as the air barrier where appropriate, and in other locations to use polyethylene sheets that are sealed as the air barrier. The main advantage of this technique is that far less caulking and sealing of the vapour barrier sheets is required.

In figure 2, a cross-section of a house is shown. Areas where the vapour barrier sheets do not require caulking or other types of sealing are marked with circles.

Methods of sealing polyethylene sheets

A number of methods have been used to provide a tight seal between sheets of polyethylene. These methods include:

a. Use of acoustical sealant.
b. Use of tape.
c. Use of a spline.
d. Use of a folded joint.
e. Use of a large overlap (usually a minimum of about 400 mm (16 in)).

These five methods are shown in figure 3. With all these methods, the best performance can be achieved if the joint occurs over solid backing and the joint is held in place between two rigid members, such as between a stud and gypsum board. The technique is shown in figure 4 for the case of joints made using acoustical sealant. The joint performance is greatly enhanced if this approach is used, rather than making the joints in places where solid backing is not present.

Ceiling Air Leakage

Ceilings tend to be leaky for two main reasons:

1. The many joints that occur in the ceiling where the interior partitions intersect the ceiling.

2. The large number of penetrations by services such as plumbing vent stacks, chimneys, electrical wiring, recessed light fixtures, attic hatches, exhaust fans, ductwork, etc.

A sketch of typical ceiling leakage paths is presented in figure 5.

In Canadian houses, standard practise with ceilings is to install the vapour barrier and the gypsum board on the ceiling after the interior partitions are erected. Although strips of vapour barrier are normally placed between the top plates of the interior partitions, the vapour barrier is not continuous, and a considerable amount of air leakage can occur through the interior partition walls into the attic space.

Although it is possible to achieve a good air seal by meticulous attention to sealing all the joints in the vapour barrier at this stage, the amount of labour time involved is considerable and the effort can be negated by the installation of the drywall on the ceiling if care is not taken in installing the drywall.

A much more desirable approach from the standpoint of air sealing is to delay the erection of the interior wall partitions until after the ceiling vapour barrier and the gypsum board are installed. Longer gypsum board sheets and larger vapour barrier sheets can be installed in the ceiling and a continuous air and vapour barrier can be more readily achieved.

The erection of the interior partitions after installation of the ceiling vapour barrier and gypsum board is shown in figure 6. As mentioned earlier, it is possible to omit the use of caulking or taping of the vapour barrier sheets on the ceiling, as the unbroken gypsum board serves as the air barrier in this location. If wide vapour barrier sheets (6 metres width) are used, very few joints will be present in the vapour barrier.

One objection to the above-mentioned method of construction is that the normal framing sequence is interrupted, with the result that additional costs are involved with having the framing crew return to erect the interior partitions after the ceiling vapour barrier and gypsum board are installed. In addition, the gypsum board installers must return after the interior partition framing is completed. In spite of this scheduling problem, some builders are experiencing reduced costs with this method because of savings in material and labour.

A possible solution to this scheduling problem is contained in a document authored by Lstiburek (8). During the framing stage, the exterior walls and the interior partitions are framed in the normal way with two changes. Instead of installing 2 top plates on interior partitions, only 1 top plate is used as shown in figure 7. The roof trusses or rafters are then installed. The top plate of the interior partitions is not nailed at this time to the roof trusses. For interior partition walls that are parallel to the trusses or rafters, there is a need to provide blocking between the trusses and rafters so that there is adequate support for nailing the tops of the interior partitions. A space of about 38 mm should be left at the intersection of the partitions with the exterior walls. This space is used to run the wall vapour barrier and the gypsum board on the exterior walls. Temporary bracing is needed to support the interior partitions. At this stage, the rough electrical wiring, plumbing, ductwork and wall insulation can be installed. The ceiling vapour barrier and the gypsum board are then installed by placing the sheets above the interior partitions. As there is a space of about 38 mm (1 and 1/2 inches) over top of each of the partitions, the vapour barrier and the gypsum board can be installed. After the ceiling vapour barrier and gypsum board are installed, small wooden blocks are inserted over the top plate on each of the interior partitions, and the tops of the interior partitions are nailed to the trusses or the blocking between the trusses. The gypsum board may now be applied to the interior partitions and the exterior walls. This technique has the advantage of traditional scheduling. There are several disadvantages. One is that it is more difficult to install the ceiling vapour barrier and gypsum board than would be the case if the interior partitions were not in place. There exists the possibility of ripping the vapour barrier sheets on the ceiling as the gypsum board is slid over the interior partitions. Another disadvantage is that it is difficult to pass wires between the exterior walls and the interior partitions and maintain a continuous vapour barrier and to use full gypsum board sheets. A revised wiring technique that does not pass wires directly between the exterior walls and the partitions would be desirable so as to ease the installation of the electrical wiring. The wires could be routed down and then up as shown in figure 8. Another alternative would be to provide the wiring from below to the interior partitions, and to run wiring in the exterior walls on separate circuits.

A third approach to sealing houses is one used by an innovative contractor in British Columbia. His approach is to frame the house in a conventional manner, completing all the framing for the house including interior partitions before starting the gypsum board installation. To provide continuity of the vapour barrier over interior partitions, strips of vapour barrier are placed between the two top plates during the framing stage. After framing is completed, rough electrical wiring, plumbing, and heating are done. The next stage is to install the wall insulation. The vapour barrier on the ceiling and walls is then installed. Continuity of the vapour barrier is achieved by using acoustical sealant at the joints.

Although this method appears to involve considerably more caulking and sealing than the two previous methods described, this particular contractor seems to feel that it gets around the scheduling problems mentioned earlier. The techniques also work, in that he is consistently able to meet the air tightness requirements of the R-2000 program.

Joints around floor joists

The joints around the floor joists are a second very major source of air leakage in typical residences. An expanded view of potential air leakage locations around the floor joists is presented in figure 9. To have an effective air seal, continuity of the seal must be maintained. One very effective technique is to wrap the floor joists with polyethylene during the framing stage. The steps are shown in figure 10. Other alternatives have been tried, including using caulking compound to seal between the gypsum board and the framing, and between the gypsum board and the floor, and sealing the spaces between the floor joists with rigid blocking and caulking. The former technique has generally proven to be more successful. It should be noted that the vapour barrier on the outside of the floor joist should always be thermally insulated so as to prevent condensation occurring at this location. In most Canadian climate conditions excluding the far north, about 2 times as much insulation should be placed outside the vapour barrier as is placed inside. In the far north the ratio should be greater.

In figure 10b a detail that can be used to limit air leakage where floor joists rest on a concrete wall is shown. The spun-bonded polyolefin paper acts as an air barrier and yet is permeable to moisture. Hence it can be used on the exterior of the building. Note that the insulation which is placed on the inside of the floor joists has a vapour barrier.

Joints between the wall and the window and door jambs

Another fairly major source of potential air leakage in residences is the gap between the frame of the windows and doors and the adjacent rough opening. In a typical house, a crack length of the order of 50 meters would not be unreasonable. In a typical window or door installation, a rough opening at least 25 mm (1 inch) wider and 12 mm (1/2 inch) higher than the window or door frame size is usually recommended (9). Although a number of different sealing techniques have been recommended, one of the simplest techniques seems to be the one shown in figure 11. The first step is to lightly push strips of batt insulation into the gap between the rough opening and the frame of the window or door. The wall vapour barrier is carried over the window, with some slack allowed in the vapour barrier; at the time that the finish trim is placed on the face of the window frame, the vapour barrier is sealed to the outer face of the window frame using acoustical sealant and staples. To provide a more durable seal, a tape such as electrician's tape is placed over the polyethylene before the staples are placed. One objection to this approach is that if the front of the window frame is not parallel to the gypsum board on the wall, the finish carpenter will tend to damage the vapour barrier when planing the face of the window frame. To reduce the possibility of damage, the vapour barrier should be pulled back from the window frame while the finish carpenter is planing the front edge of the window. A good quality sealing tape can often be used to repair damage to the vapour barrier.

An alternative possibility is to use polyurethane foam to seal the gap between the edge of the gypsum board and the window frame as shown in figure 12. As the foam is a more difficult product to use, however, the former technique is to be preferred. Care must be taken with the foam not to place too great a quantity, as the expanding foam can distort the window frame.

Fireplaces

In addition to the air leakage that occurs through the chimney flue, there is also the air leakage that occurs between the perimeter of the fireplace and the opening in the wall. One technique to reduce this air leakage is to locate fireplaces on interior, not exterior walls. If the fireplace must be located on an exterior wall, the vapour barrier and the gypsum board should be placed behind the fireplace before the unit is installed. With this technique, the only air leakage that can occur will be where the chimney and the outside air ducts penetrate the space. This technique is far superior to trying to provide an airseal between the edge of the fireplace and the gypsum wallboard.

When choosing a fireplace or wood heater, it is also important to choose units that have good chimney dampers and air supply dampers. A noncombustible caulk such as muffler cement should be used to seal the gap between the chimney and the firestop where the chimney passes through the ceiling.

Pipes and ducts

Pipes that penetrate the envelope of the house can be sources of air leakage. As a general rule, one should minimize the number of ducts and pipes that penetrate the air-vapour barrier. For instance, in houses with unheated crawl spaces, ductwork for a warm air furnace should preferably be located in the living space of the house and not in the crawl space, as formidable problems with air sealing of the ducts exist when they are placed in the crawl space. A dropped ceiling in a hallway is a much preferred location for ductwork in such houses. Plumbing vents and pipes should preferably be located in interior and not exterior walls. Where possible, the number of vent stacks penetrating the ceiling air barrier should be minimized by interconnecting the vents below the ceiling. In general, holes cut for ducts or pipes should closely match the diameter of the duct or pipe. A relatively simple technique for sealing between the outside of the duct and the adjacent wallboard is to use polyurethane foam (Figure 13). Another technique uses neoprene sheet rubber with a hole cut in it (Figure 14). The hole is slightly smaller in diameter than the duct or pipe.

A special problem exists with plumbing vent pipes penetrating the ceiling air-vapour barrier. The vent pipes, particularly the plastic variety, can experience large movements due to thermal expansion and contraction. One option is to use the neoprene rubber sheet approach mentioned above, as the flexible rubber would allow the pipe to move. Another product which has been used for this application is a neoprene rubber roof flashing piece.

Attic Hatches

The preferred location for attic hatches is in the gable end of the house, or in the ceiling of an attached garage, if one exists. The attic hatch should not be located in the ceiling of the living space, as it is difficult to provide a good air seal at this location.

In houses that lack gable ends or attached garages, the attic hatch can be located in the ceiling, but special precautions should be taken to ensure a good air seal at the attic hatch. A compression type of clamp will be required to provide such a seal.

Window or through-the-wall air conditioners

Window air conditioners should preferably be removed for the heating season, and through-the-wall air conditioners should have a quality enclosure constructed that has a tight weatherstrip with a compression type seal.

Kitchen and bathroom exhaust fans

Such fans should preferably be located on interior walls, and the air flow directed downward and outward at the lower part of the house as shown in figure 15. It is much easier to seal around a duct than around the fan and its electrical wire.

Electrical Outlets

In a typical house, about 20 such outlets and switches are located in the exterior walls and ceilings. A number of different techniques have been used for sealing such outlets. These techniques include:

a. Locating the switches and outlets on non-exterior walls and ceilings.
b. Using a piece of polyethylene about 450 mm (18 in) square behind the electrical box.
c. Using a pre-formed plastic vapour barrier box.
d. Using wall plate foam gaskets.

As mentioned earlier, electrical outlets and switches make up only a very small fraction of the total leakage in typical residences. Probably the simplest technique is to use the pre-formed plastic vapour barrier boxes and to later use a quality tape to seal the wall vapour barrier to the vapour barrier box. The penetration of the vapour barrier box by the electrical wire should be caulked. As an additional measure, foam gaskets which fit under the cover plates should also be used.

Summary

A number of improved techniques for air sealing houses have been presented. As with any relatively new field, there is a wide scope for innovation. The main point of this paper is that the key leakage areas in most new houses are in the ceilings and at the floor joists. In seeking to reduce air leakage, these two areas have the highest potential for leakage reduction.

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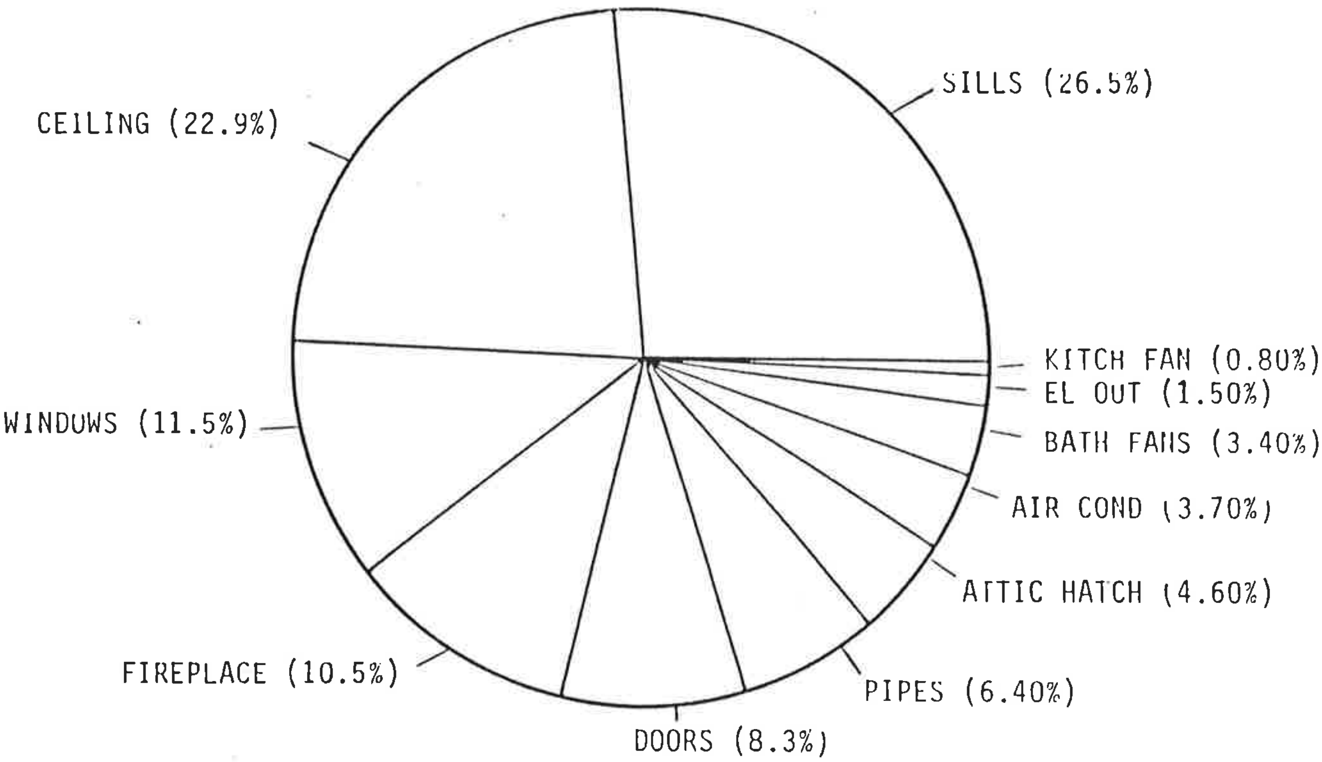

Figure 1. Distribution of air leakage locations in a typical bungalow

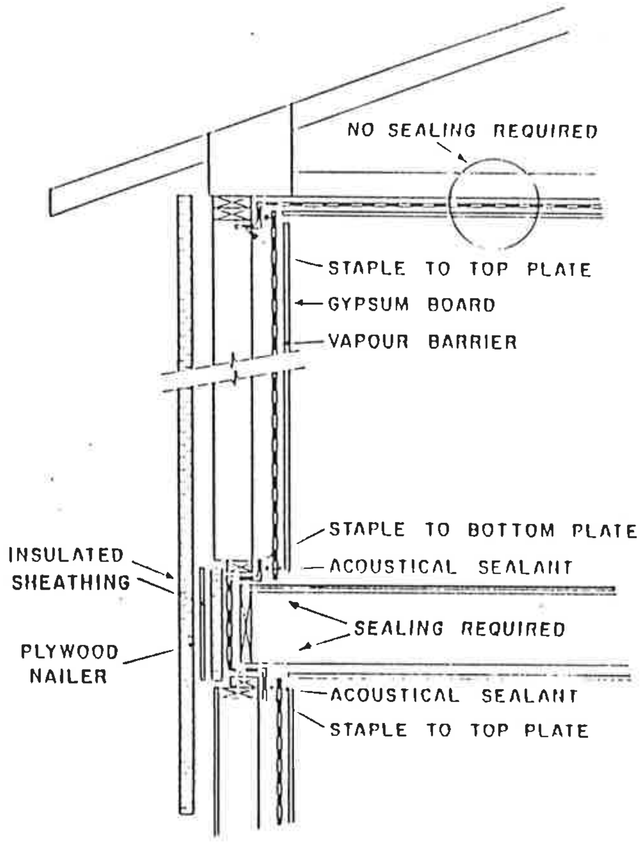

Figure 2. Location where sealing of vapour barrier sheets is not required

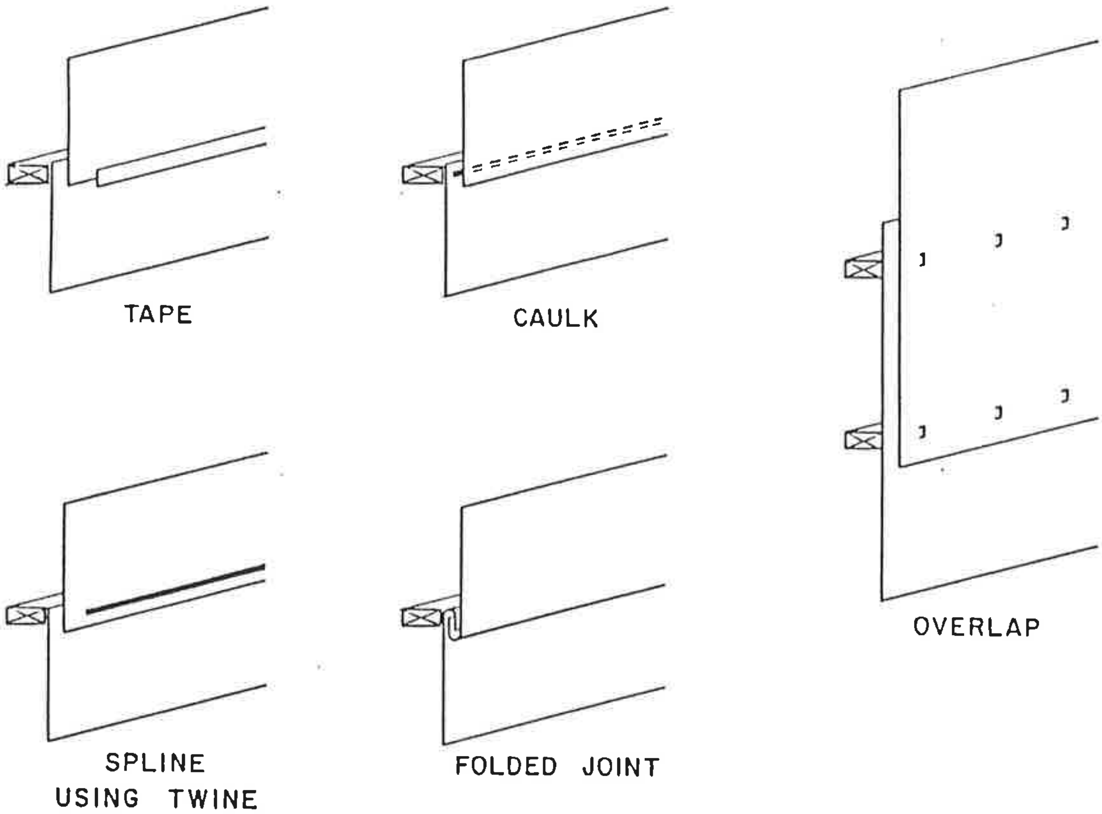

Figure 3. Methods for sealing polyethylene sheets

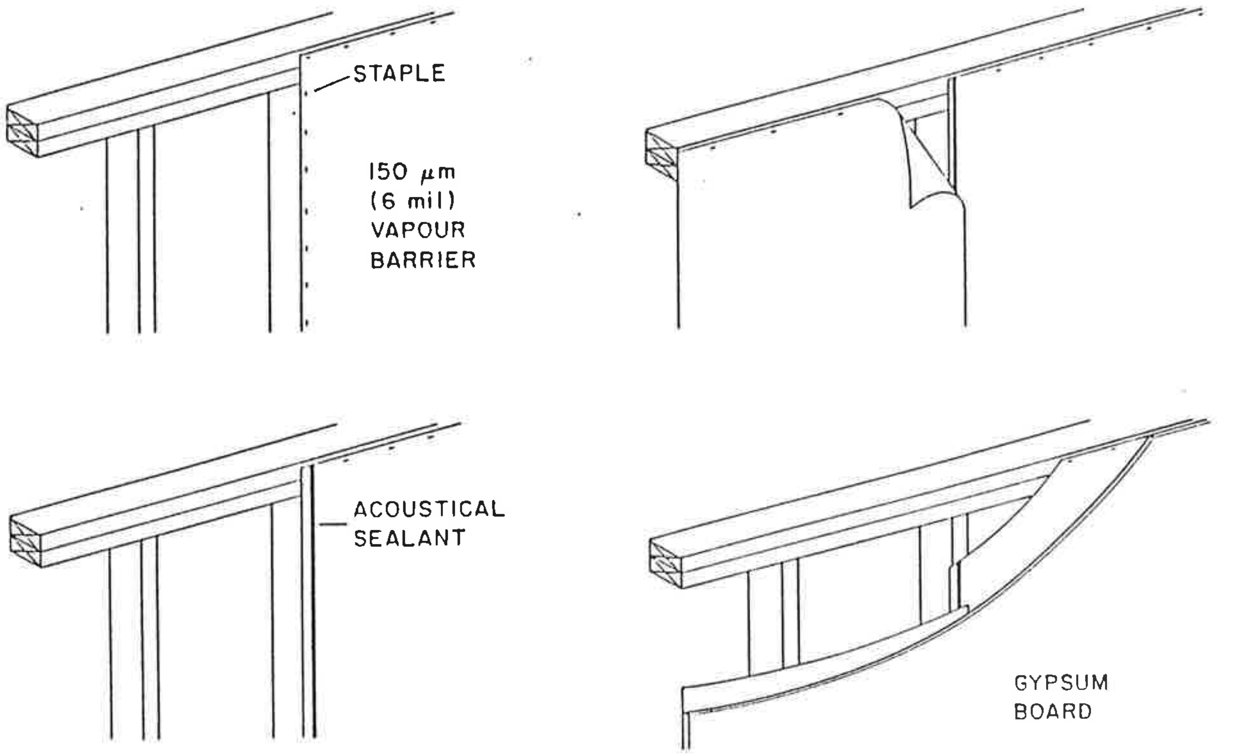

Figure 4. Joint sealing of polyethylene sheets using acoustical sealant

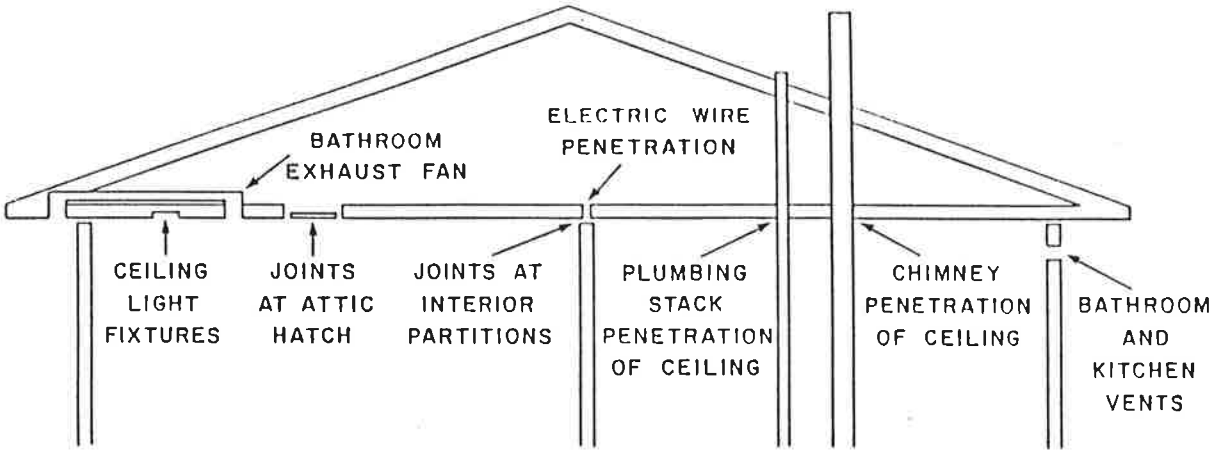

Figure 5. Typical leakage paths in a ceiling

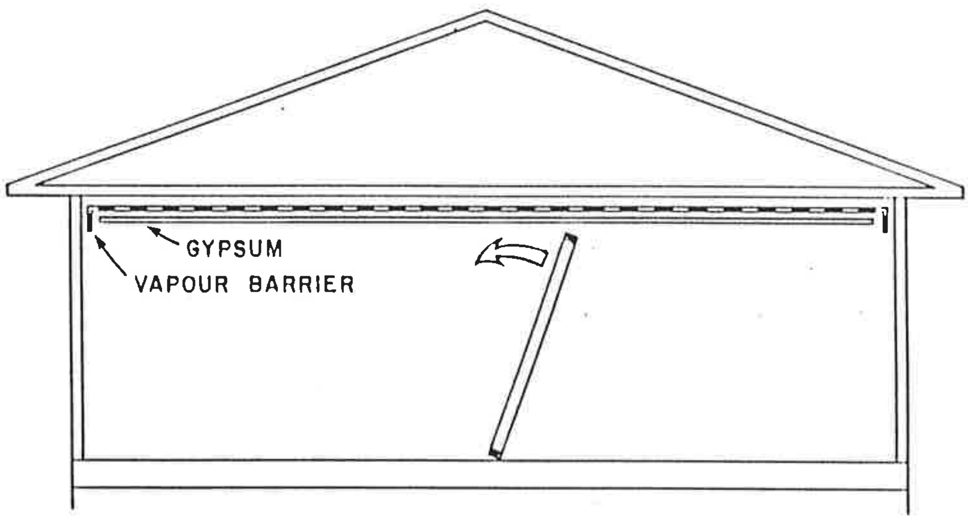

Figure 6. Erection of interior partitions after ceiling vapour barrier and gypsum board are installed

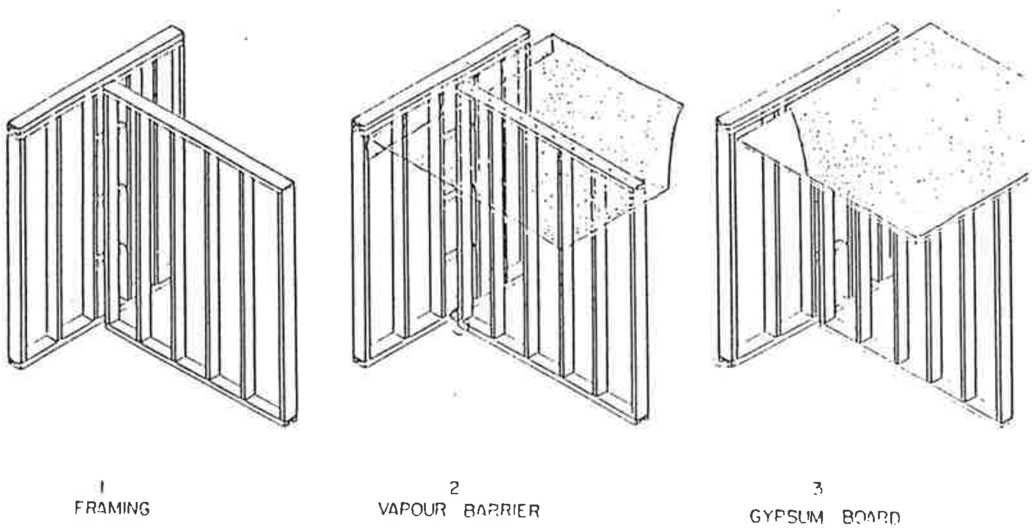

Figure 7. Modified framing technique for interior partitions

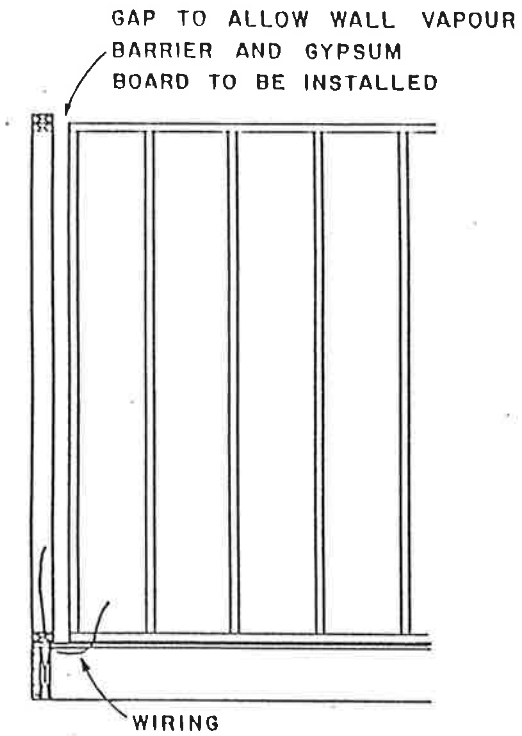

Figure 8. Modified wiring technique at junction of interior partitions with exterior walls

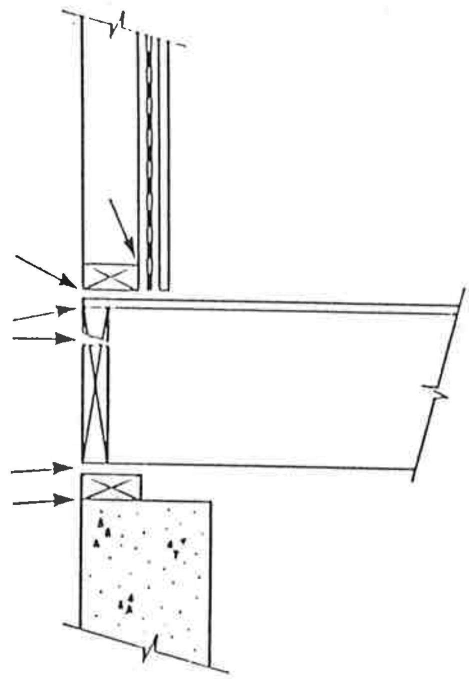

Figure 9. Air leakage locations around floor joists

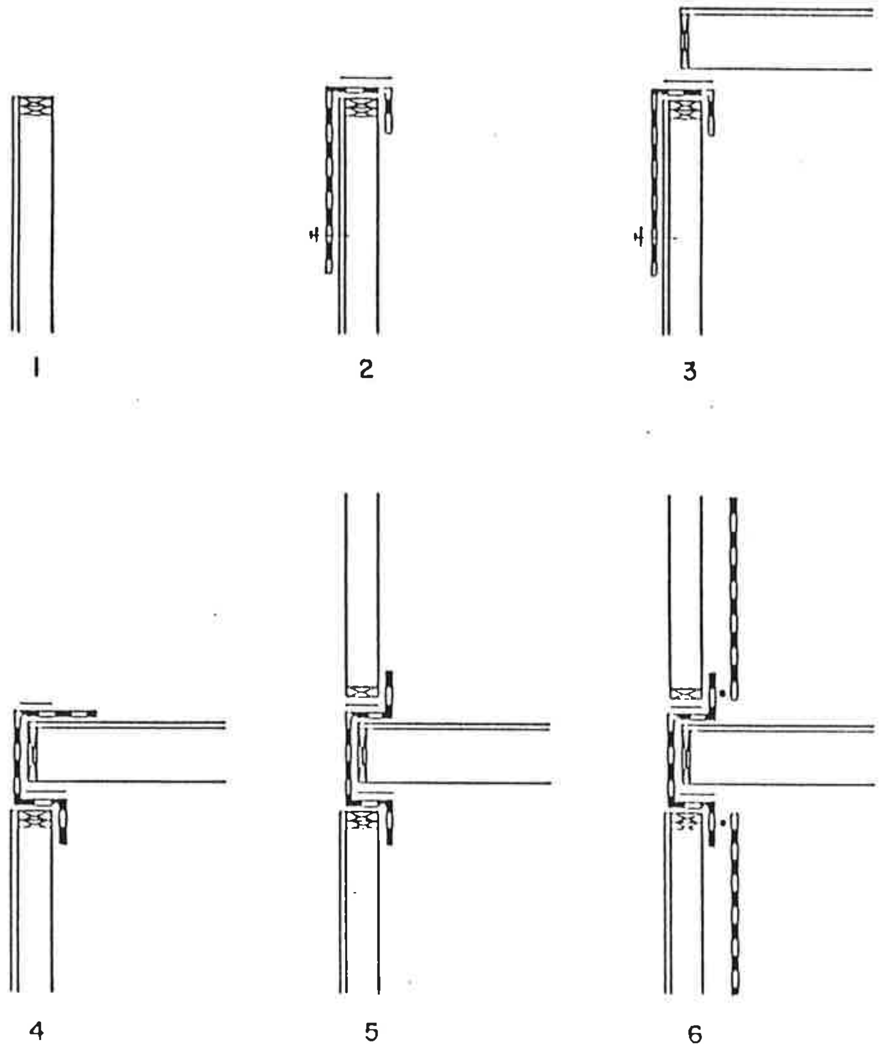

Figure 10a. Technique for wrapping floor joists to reduce air leakage

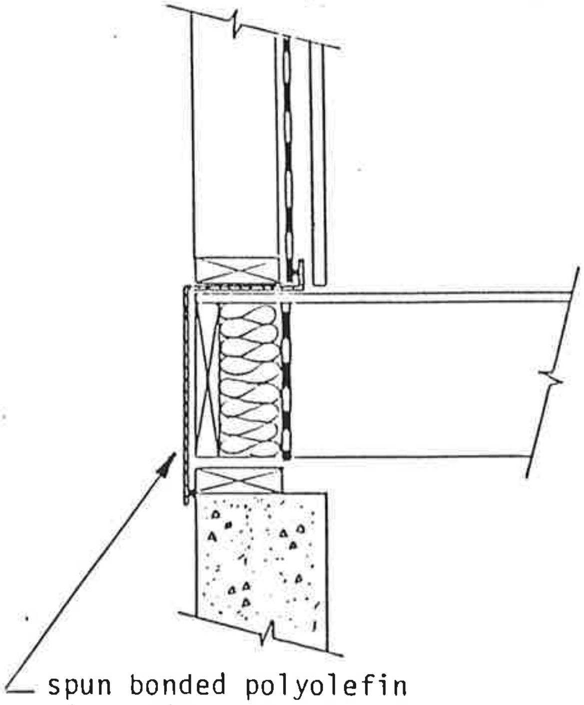

Figure 10b: Technique for air sealing at floor joists using spun-bonded polyolefin air infiltration barrier paper

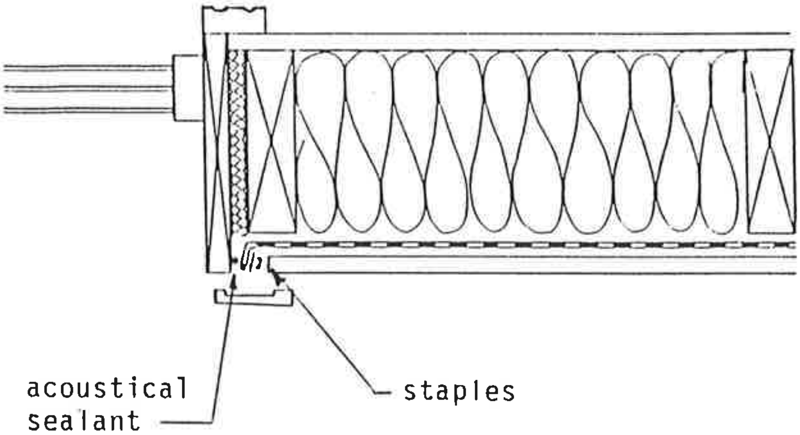

Figure 11 Technique for air sealing around window and door frames

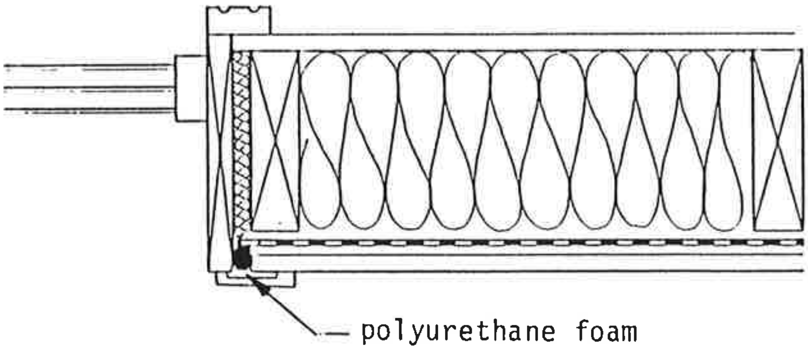

Figure 12. Alternative technique for air sealing around window and door frames using polyurethane foam

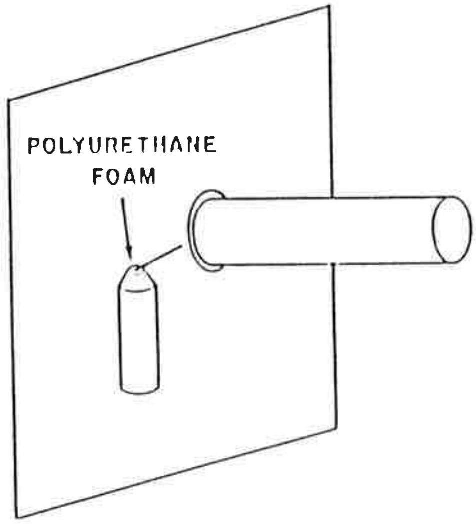

Figure 13. Technique for sealing around duct or pipe penetrating the exterior walls or ceilings