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Low-Permeance Materials in Building Envelopes

by M.K. Kumaran and J.C. Haysom

This Update provides guidance on the use of low-permeance materials towards the outside of walls, for the range of climatic conditions found throughout Canada. By following these recommendations, which are reflected in the 1995 National Building Code, one should reduce the potential for the condensation of moisture in walls.

Provisions in the 1995 National Building Code of Canada relaxed restrictions in the 1990 Code on the use of materials with low water-vapour permeance on the outside of insulated exterior walls. These restrictions had been added in order to reduce the potential for condensation of moisture on the interior face of low-permeance materials used as air barriers on the outside of walls. These restrictions, however, went against many years of successful experience with low-permeance insulations used in this way. As a result, a number of manufacturers objected to the overly-restrictive conditions.

The approach to wall design described in the 1995 Code is the result of a series of changes implemented over the years to accommodate changing requirements and expectations in Canadian buildings. In the 1930s, the use of vapour barriers was introduced to control vapour diffusion into walls and attics. When humidification was introduced into houses in the 1950s, moisture accumulation in walls and attics again became a problem in many homes. Researchers determined that most of the moisture was being transported into these locations by air leakage rather than by vapour diffusion. Air leakage can become a significant problem when the various materials in the building envelope, including the vapour barrier, are not installed as seamless components, and the many holes allow air to flow into the walls and roof spaces.

When energy costs rose in the 1970s, the demand for energy-efficiency led to the construction of better-insulated houses. Once the stud cavities of a stud wall are filled with insulation, additional insulation must be placed on the inside or outside to increase the wall's thermal resistance.

Three main mechanisms move air through the building envelope: stack effect, wind action and mechanical ventilation.

Stack effect. The density of air decreases as its temperature increases, making warm air lighter than cold air. As a result, warm air rises and its buoyancy exerts an outward pressure against the ceiling and upper walls. Holes in the vapour barrier allow warm, humid air to flow into the roof or wall structure, where it cools and deposits moisture on the cold interior surfaces of the roof or wall sheathing.

Wind action. Wind blowing against a house produces a positive pressure on the outside of the windward wall and a negative pressure on the other walls. The negative pressure draws air from the interior through holes in the exterior walls, and the moisture that this warm air holds condenses inside the wall structure on the cold sheathing.

Mechanical ventilation. While exhaust fans reduce the pressure inside a house by extracting air, improperly balanced mechanical ventilation systems, including supply fans, can pressurize the interior. Air and moisture can then flow through any openings into the exterior walls and roof space where condensation can accumulate.

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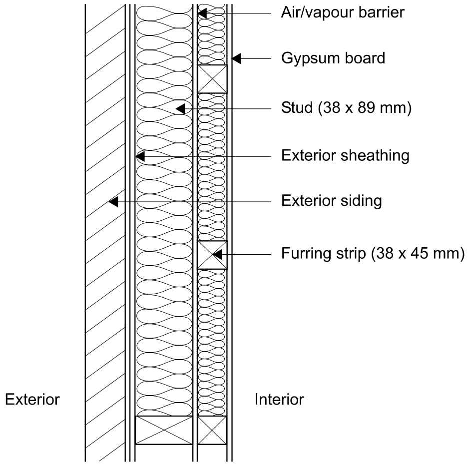


Figure 1. *Vertical wall section showing air/vapour barrier placed between studs and interior furring*

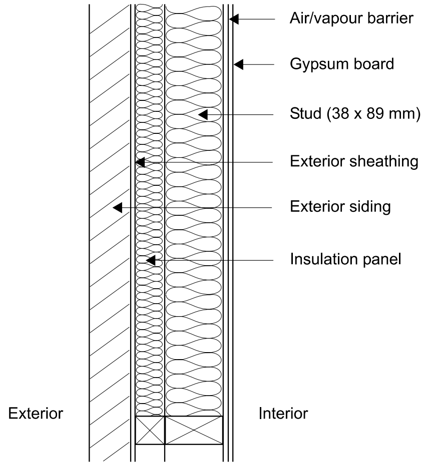


Figure 2. *Vertical wall section showing insulation panel installed on outside of stud wall*

In one technique for adding insulation inside, horizontal furring is placed over the vapour barrier that is attached to the inner faces of the studs; this provides room for a second layer of insulation. As a result, the vapour barrier is sandwiched between the two layers of insulation, with the inside layer being thinner than the outside one (Figure 1). This design, however, raises the possibility that moisture could condense on the vapour barrier if the air temperature at that point were to drop below the dew point temperature for the interior air conditions.

Another system adds insulating sheathing to the outside of the stud wall to increase the thermal resistance of the wall (Figure 2). Because the insulation panel covers the exterior face of the studs, it also reduces the thermal bridging effect of the wood studs, an added benefit. In this case, the vapour barrier is installed on the warm side of the studs as required by the Code. Initially wood- or mineral-fibre panels were used as the exterior sheathing but the use of plastic foam insulations has become popular as well.

The condensation problems experienced by many homeowners in the 1960s and 1970s prompted the Associate Committee on the National Building Code to incorporate a subsection in Part 9 of the 1980 NBC entitled “Measures to Prevent Condensation.” It contained instructions for the installation of the vapour barrier that, if followed, would make it a more effective air barrier membrane.

Many designers objected to the Code assumption that the vapour barrier would fill the role of both air barrier and vapour barrier. They argued that it would be easier to maintain the continuity of the air barrier if it could be placed in a more appropriate location within the wall, where it would be less likely to be interrupted by ducts, interior partitions, or electrical boxes. As a result, the wording of the 1990 Code acknowledged that the air barrier could be a separate component located anywhere in the wall. This change raised the possibility that someone using a material with low water-vapour permeance as an air barrier might choose to place it close to the outer surface of the wall where condensation could form on its interior face.

To reduce the probability of incorrect placement, the Code included a restriction on the location of air barriers with low water-vapour permeance. These air barriers had to be placed so that the inner surface remained above the dew point of the interior air when the outside temperature was 10°C above the January $2\frac{1}{2}$% temperature. This restriction, however, prohibited the use of certain insulating sheathings that had been used without problems on the outside face of wood-stud walls for a number of years.

Manufacturers of these materials argued that such restriction was unnecessary and asked that it be removed in the 1995 edition of the NBC. Concerns were also raised about the potential for condensation on low-permeance materials placed towards the outside even if they weren’t designated as the air barrier. The researchers at NRC’s Institute for Research in Construction agreed to review the question in detail.

The Study

As a first step, the researchers used computer modelling to establish the relationship between air exfiltration, heat transfer and moisture accumulation in a cavity wall. For this study, the wall consisted of 38 x 89-mm studs, batt insulation in the stud cavity, and a Type II vapour barrier. The interior temperature was 21°C and the interior relative humidity (RH) was 36%. The exterior temperature and RH were -15°C and 60%. The air permeance of the assembly varied between 0.001 L/(s•m^2) and 10 L/(s•m^2) at 75 Pa pressure difference between the interior and exterior.

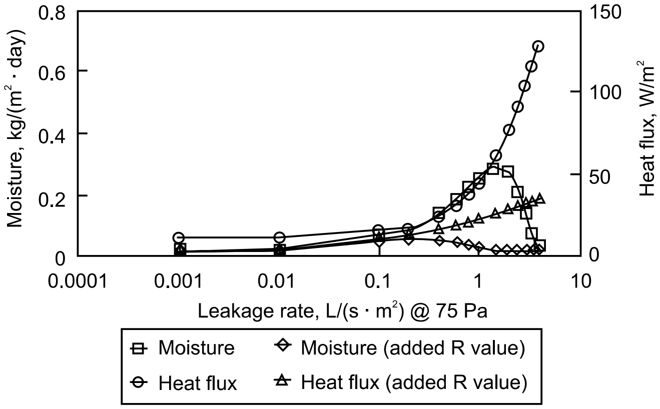


Figure 3. The effect of the additional thermal resistance provided by the exterior sheathing

The results of this modelling showed that the heat flux (the rate of heat flow per unit area through the wall) increased as the air flow rate increased. The moisture accumulation also increased but only up to a certain point. Beyond that point, the moisture accumulation decreased and then became insignificant. The reason for this decrease is that the temperature within the cavity increased as the rate of air flow increased. At a certain point, the cavity became so warm that the conditions required for condensation ceased to exist. This is the reason that many old buildings without air barriers have no moisture problems — the walls are so warm that condensation cannot occur. With today's energy prices and occupant expectations, leaky walls are not a practical solution. Adding insulation on the outside of the wall, however, is another way to keep the wall cavity warm.

The researchers next repeated the computer simulations with an added 25-mm-thick mineral-fibreboard sheathing on the outside of the studs (Figure 3). The simulations confirmed that in this case the cavity was warm enough to prevent condensation on the interior face.

To determine the effect of air leakage and exterior insulation on the performance of a wall, the researchers then carried out a number of other simulations varying such design parameters as air leakage rate, vapour permeance, and interior RH. The studs used were 38 x 140 mm, and the insulation batts were rated at RSI 3.52. One wall also had an external insulating sheathing with RSI 0.75.

The simulations analyzed the hygrothermal behaviour of the cavity for one full year on an hourly basis using weather data for the City of Ottawa. Figure 7 shows the moisture accumulation within the cavity for three of these walls, which are described below.

Wall B0 (Figure 4) – Type II vapour barrier, zero air permeance (no air leakage), interior RH 36%.

Wall B2 (Figure 5) – Type II vapour barrier, air permeance 0.1 L/(s•m^2) @ 75 Pa, interior RH 36%.

Wall B2R (Figure 6) – Type II vapour barrier, air permeance 0.1 L/(s•m^2) @ 75 Pa, interior RH 36%, low-permeance insulating sheathing with RSI of 0.75.

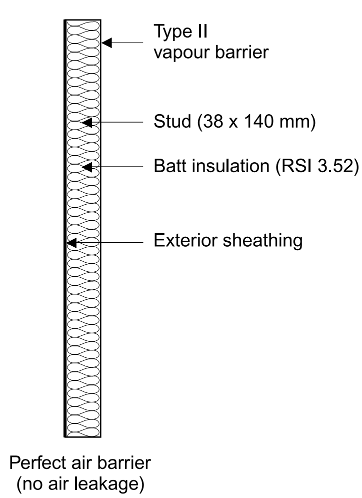


Figure 4. Wall B0

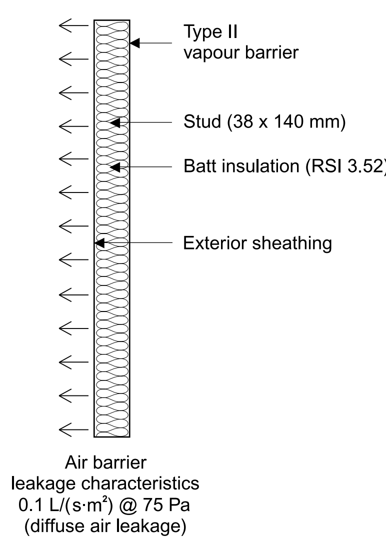


Figure 5. Wall B2

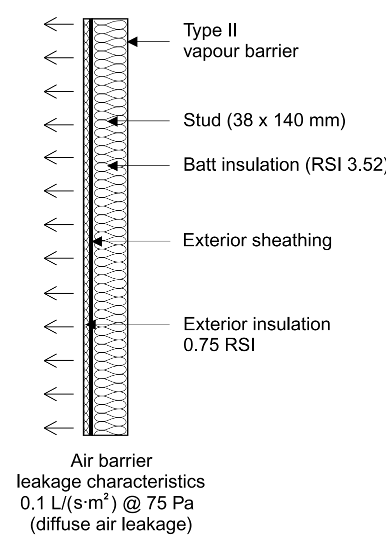


Figure 6. Wall B2R

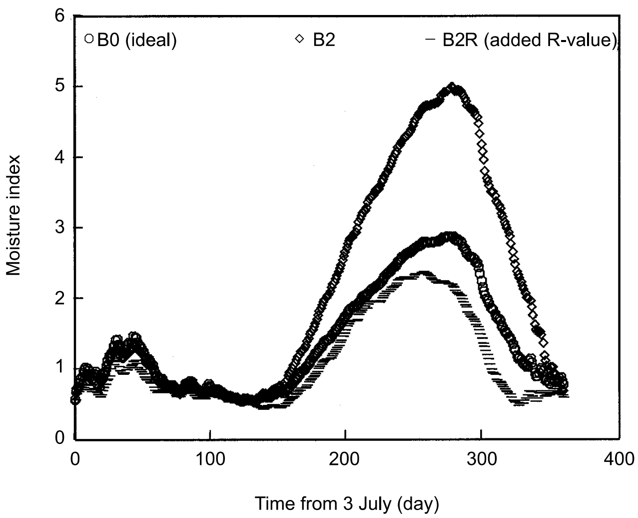


Figure 7. Annual moisture accumulation within the cavity. The moisture index is the daily average on a relative scale.

Curve B0 gives moisture accumulation due to diffusion only.

Curve B2 gives moisture accumulation due to diffusion and air leakage.

Curve B2R shows the beneficial effect of the exterior insulating sheathing on moisture accumulation since moisture diffusion and air leakage were the same as for B2. The moisture accumulation in B2R was less than in B0.

These results show that when sufficient thermal resistance is added along with a low-permeance layer towards the outside of a building assembly, the assembly's ability to accommodate a modest amount of air leakage is enhanced. The simulation determined that the ratio of outboard to inboard insulation used (i.e., 0.75/3.52 = 0.214) was adequate to control moisture accumulation in the wall for an interior relative humidity of 36%, in the Ottawa-area climate. Simulations for other Canadian cities using the appropriate weather data showed that the required ratio of outboard to inboard thermal resistance is proportional to the degree-days. Thus the colder the location, the larger the amount of external insulation required to maintain the necessary temperature in the cavity to control moisture accumulation.

The Standing Committee on Housing and Small Buildings (responsible for Part 9 of the NBC) adopted the recommendations made by the researchers and incorporated into the 1995 Code Table 1, which gives the minimum ratio of outboard to inboard thermal resistance for low-permeance materials in increments of 1000 degree-days.[1,2] Degree-days for over 600 Canadian cities and towns — from Victoria, BC, at 2900 to Eureka, NWT, at 13800 — are given in Appendix C of the National Building Code (Table 2).

Table 1. Ratio of outboard to inboard thermal resistance (from 1995 NBC, Table 9.25.1.2)

Heating degree days of building location, Celsius degree-days	Minimum ratio, total thermal resistance outboard of material's inner surface to total thermal resistance inboard of material's inner surface
Up to 4999	0.20
5000 to 5999	0.30
6000 to 6999	0.35
7000 to 7999	0.40
8000 to 8999	0.50
9000 to 9999	0.55
10000 to 10999	0.60
11000 to 11999	0.65
12000 or higher	0.75

Table 2. Heating degree days for selected Canadian cities (from 1995 NBC, Appendix C)

City	Heating degree days, Celsius degree-days
Victoria	2900
Edmonton	5400
Regina	5750
Winnipeg	5900
Toronto	3650
Ottawa	4600
Quebec	5200
Fredericton	4650
Halifax	4100
Charlottetown	4600
St John's	4800
Whitehorse	6900
Yellowknife	8500
Iqualuit	10050

Using Low-Permeance Exterior Insulation

Where a material with low water-vapour permeance is used in a wall, the ratio of outboard to inboard thermal resistance must equal or exceed that needed to control condensation.

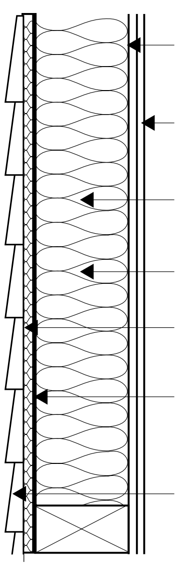
The thermal resistance of a wall is the total of the resistance of all the materials that make up the wall, such as insulation, sheathings, finishes, air spaces and air films. The inboard thermal resistance is the sum of the thermal resistance of all the materials on the warm side of the low-permeance material. To calculate the minimum thermal resistance of the outboard insulation, first the inboard thermal resistance is multiplied by the ratio from Table 1 that applies to the climatic conditions. This result represents the total thermal resistance for all outboard elements including exterior insulation, exterior finish material and air film. Adding up the thermal resistance for all other outboard elements and subtracting this subtotal from the total outboard thermal resistance gives the minimum thermal resistance of the exterior insulation. The example shows a sample calculation for a wall design in Winnipeg.

Conclusion

The study demonstrated that placing a material with low water-vapour permeance on the outside of an exterior wall does not necessarily increase the potential for condensation within the wall structure as long as sufficient thermal resistance is added outboard of the innermost plane of low permeance to keep its temperature high enough to prevent condensation.

Example

Winnipeg has 5900 degree-days which, according to Table 1, requires a minimum RSI ratio of 0.30. The following calculations show how the minimum amount of outboard insulation would be calculated for a 38- x 89-mm stud wall.



38- x 89-mm stud wall

Inboard thermal resistance	RSI	Outboard thermal resistance	RSI
Insulation	2.11	Insulation	to be calculated
Gypsum board	0.08	Metal or vinyl siding	0.12
Air film	0.12	Air film	0.03
Total	2.31	Subtotal	0.15

Minimum outboard insulation = 2.31 x 0.30 =	0.69
Less siding and air film	0.15
Minimum thermal resistance of insulation	0.54
Total wall resistance = 2.31 + 0.69 =	3.00

(without taking into account thermal bridging through studs)

References

1. Note: The provisions in the NBC are based on an assumed indoor humidity of 36%. In cases where the indoor relative humidity is likely to be significantly higher than 36% for long periods in the winter, it would be prudent to use higher ratios than those in Table 1.
2. Note: This NBC requirement applies to materials with an air leakage characteristic less than 0.1 L/(s•m^2) @ 75 Pa. Wood-based sheathing materials are exempt provided that they are installed with gaps at the joints.
3. *National Building Code of Canada 1995*. Canadian Commission on Building and Fire Codes, National Research Council of Canada, Ottawa, 1995.
4. Ojanen, T. and M.K. Kumaran. Air exfiltration and moisture accumulation in residential wall cavities. *Thermal Performance of the Exterior Envelopes of Buildings V: Proceedings of the ASHRAE/DOE/BTECC Conference*, Clearwater Beach, Florida, 1992, pp. 491–500.
5. Ojanen, T. and M.K. Kumaran. Effect of exfiltration on the hygrothermal behaviour of a residential wall assembly. *Journal of Thermal Insulation of Building Envelopes* 19, 1996, pp. 215–227.
6. *ASHRAE Handbook of Fundamentals SI*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, 1997.

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