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Controlling the Transfer of Heat, Air and Moisture through the Building Envelope

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Bringing small buildings to improved levels of performance and durability through better control of heat, air, moisture and water is not always easy. Failures in envelope function due to inadequate control of these elements can be difficult to diagnose and the causes difficult to isolate. The physics governing these phenomena are quite complex and often interrelated – true systems problems.

This paper addresses seven issues which, if left unresolved, will hamper industry in its efforts to design and construct safe, comfortable and durable buildings. Four of the issues pertain predominantly to the performance of above-grade envelopes:

- wet insulation,
- plastic insulation blown with CFCs,
- radiant barriers,
- air barriers.

Three issues pertain specifically to below grade envelopes:

- adfreezing and ice lensing,
- air and water leakage,
- condensation on concrete walls.

One could easily write a complete dissertation on any one of these topics. This paper, however, provides a short explanation of each issue, why practitioners should be concerned, the causes or mechanisms involved, findings from field and laboratory studies, and solutions or recommendations.

Above-Grade Envelope

The investment in the materials and assembly of the above-grade envelope is considerable. At the stage when the building changes hands from builder to owner, the appearance of the envelope is high on the minds of both. Nevertheless, once that transaction is complete, the proper functioning of the envelope is what justifies the significant investment in the various components and assemblies. The materials selected, assembly techniques, and the environment in which the building envelope operates, determine whether it performs as required.

Wet Insulation

Short-circuiting the thermal resistance

The reduced thermal performance of wet cavity insulation has been investigated and documented for some time[1,2] but until now was not quantified in a way that would help builders, insulation manufacturers and building owners decide on appropriate measures to prevent or minimize its effect. Recent work at IRC[3] has shed some light on what takes place in wet insulation and how its thermal performance is affected.

Very simply, the mechanism consists of the evaporation of moisture on one side of the cavity and condensation on the other. The cold side of the cavity presents a much lower vapour pressure than the warm, saturated side. The water on the warm side responds to the strong vapour pressure gradient through the insulation by diffusing through the insulation (actually through the air in the insulation) from the warm surface to the cold surface. In doing so, the moving vapour transports a considerable amount of heat. This heat is released at the cold side of the cavity as the vapour condenses (Figure 1).

As the temperature cycles between day and night periods, the warm and cold sides of the envelope reverse, and the moisture and heat are transported back across the cavity, resetting the elements to repeat the process. Where the temperature does not cycle but moisture is being continually supplied to the warm side of the cavity, this moisture will continue to diffuse to the cold side, carrying heat with it.

Thus the specific ingredients required to create the short-circuit phenomenon are:

- sufficient water to saturate surfaces or materials enclosing the envelope cavity (e.g.,saturated sheathings, insulations, and/or visible water films on the vapour barrier surface facing the cavity),
- closed or poorly vented cavities,

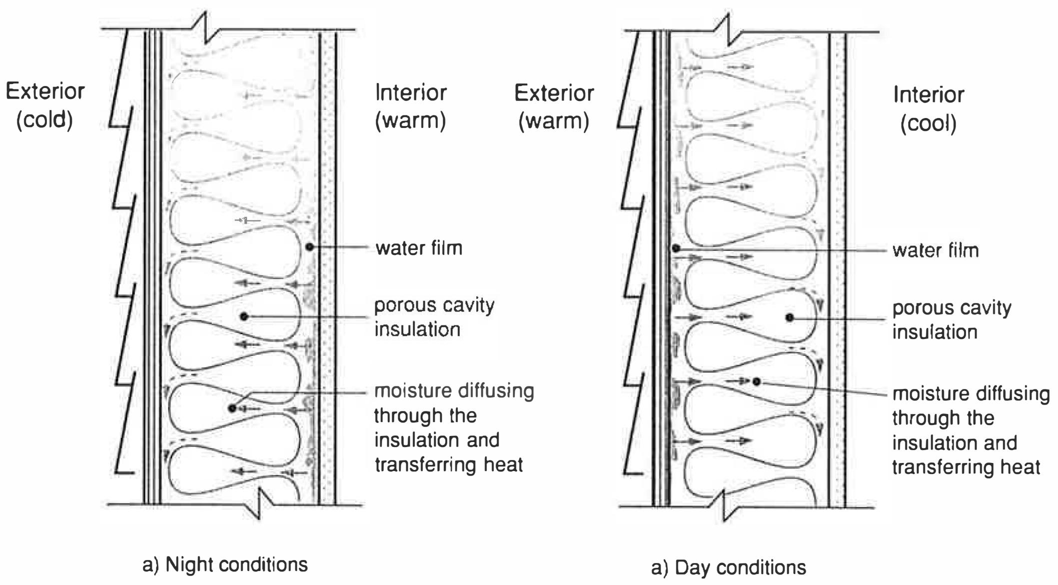


Figure 1 Typical wall cavity showing moisture flow and heat transfer under cyclic conditions brought on by day/night temperature variations

- high permeability insulation in the cavity,
- cycling temperatures or a supply of water.

The problem is not with the insulation itself but rather the moisture in the cavity and the vapour transport mechanism which short-circuits the insulation.

Causes – Sources of moisture

The causes of this phenomenon are not particularly exotic. It is initiated by moisture, which may come from a number of sources. Thus, over the life of a cavity this mechanism can come into play for a short or a prolonged period of time.

- Building with green lumber
  For the first year, green lumber provides a significant source of moisture within the cavity.
- Wet spray insulation
  Again this source of moisture is built right into the cavity and can cause problems. At least for the first few months or year of operation, until that cavity dries out, the material that we are expecting to work as thermal insulation will not, because of the way it is applied and closed in.
- Leaky roofs
  Poorly ventilated leaky roofs are probably the most common and serious cause of this problem. A leaky roof provides an on-going source of the moisture that feeds this mechanism. Furthermore, one of the key ingredients is cycling temperatures and the roof is subjected to the broadest range of temperatures. Air-conditioning loads would be strongly affected by wet cavity insulation in a flat roof.[1]
- Rain penetration
  Faulty rain penetration control systems are another cause of moisture intrusion. Poorly installed flashings or blocked air spaces behind the cladding may create water bridges into the envelope.
- Air leakage
  Ineffective air barrier systems allow moisture from within the building to intrude into the envelope. Effective air barrier systems are especially important in pressurized buildings with high relative humidities. However, if the air leakage through the cavity is cyclic; e.g., leaking in and out, the presence of dry outdoor air passing through the cavity may help eliminate excessive moisture. Therefore, in a leaky cavity the problem is more likely to be air leakage short-circuiting the insulation than the vapour diffusion mechanism.

Why we should be concerned

The implications of wet porous insulation are:

- reduction in the effective RSI value of the insulation while in its wet state;
- potentially heavy moisture loading of the materials in the cavity, which can affect the durability of the insulation and the whole envelope;
- secondary effects, such as potential condensation and dusting on cold inside surfaces due to the loss of effective thermal resistance of the insulation.

Findings

IRC has been able to quantify heat flow through wet insulation.[3] In tests conducted with a 20°C temperature difference across the insulation, moisture in the insulation reduced the effective thermal resistance of 25 mm of insulation from 0.75 (R4.2) to 0.25 (R1.5). In an 89 mm (nominal 2" x 4") stud space, the effective RSI value of a glass

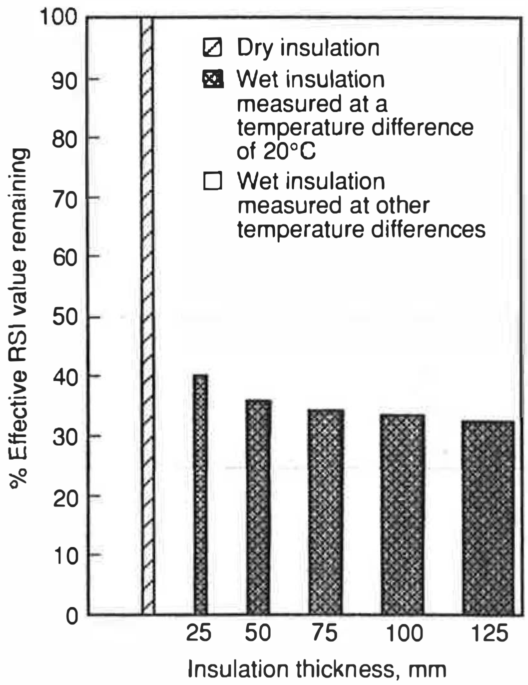


Figure 2 Effective RSI value of wet insulation expressed as a percentage of the RSI of dry insulation

fibre batt falls from RSI 2.11 (R12) to RSI 0.70 (R4), a reduction of 60 to 70% (Figure 2). The thickness of the insulation has only a small effect on the percentage reduction. The reduction is so drastic that it is debatable whether the material can be considered as thermal insulation.

Further work at IRC[3,4] determined that the effective thermal resistance can be reduced by 50 to 75% depending on indoor air temperature and temperature difference across the envelope. This range is shown by the shaded area in Figure 2.

A computer program was used to explore ways of minimizing the short-circuiting mechanism within the wall system by modifying the way the wall is built. The computer model used a wood frame wall with wet insulation in the cavity. The performance of the wall was measured each time, as successive components were added:

- basic wood frame with wet insulation,
- gypsum board on both sides,
- siding,
- 50 mm of extruded polystyrene (XPS) on the cold side,
- 50 mm of extruded polystyrene (XPS) on the warm side.

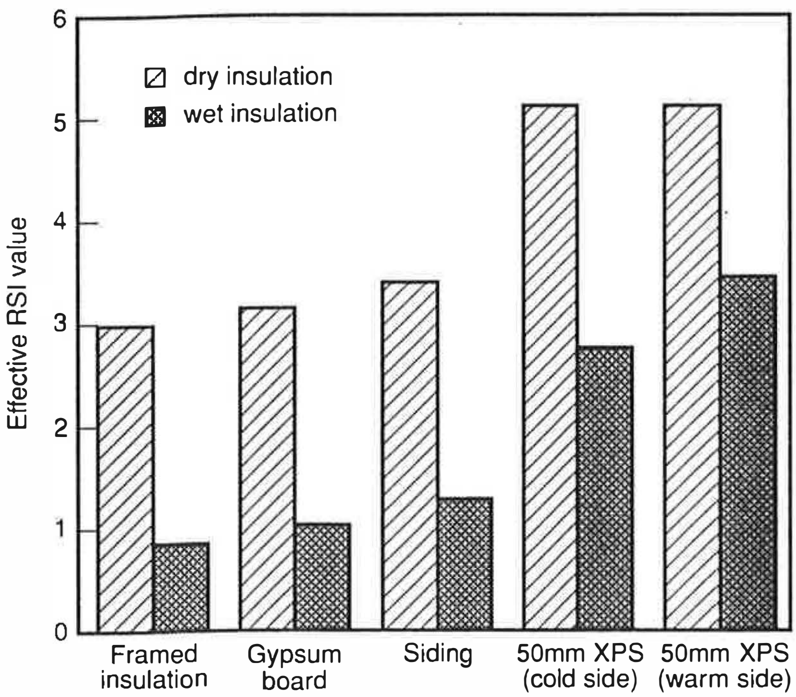


Figure 3 Effective RSI values for the five simulated constructions

Figure 3 shows that increasing the RSI value of the assembly by adding sheathing and finishes to the wet cavity does not defeat the short-circuiting mechanism. For each of these cases, the 140 mm wet cavity is missing RSI 2.1 (R12) due to the short circuit. Adding 50 mm of extruded polystyrene on the cold side of the wall adds close to RSI 1.76 (R 10) as we would expect, but the total resistance is now RSI 2.36 (R13.4) below nominal. Putting additional insulation on the cold side to foil or shield the heat transfer mechanism does not seem to work.

When additional extruded polystyrene is installed on the warm side, however, the vapour diffusion mechanism is altered. The deficiency in RSI is reduced from RSI 2.36 (R13.4) to RSI 1.67 (R9.5). Although the computer simulation dealt specifically with walls, the findings may have implications for flat roofs of buildings where the cooling load is heavier than the heating load. During the cooling season, when the exterior surface of the roof is warmer than the interior, the effects of the vapour diffusion mechanism may be reduced by adding insulation on top of the roof, thereby creating an upside-down roof and shielding the moist insulation from the sun's driving forces.

Solutions

In summary, the objective is to keep moisture out of the insulation in the building envelope. Otherwise, the effective thermal resistance may be reduced by 50 to 75%. There are several ways of achieving this end:

- keep moisture out of the envelope
  - control rainwater penetration
  - control moisture intrusion due to air leakage and vapour diffusion by installing proper air and vapour barrier systems
  - build dry
- design the envelope so that any moisture that is built in or enters can escape
  - provide proper drainage
  - ensure that the materials that make up the envelope are progressively more vapour permeable from the inside to the outside or are vented toward the outside.

A number of these recommendations are embodied in the National Building Code.

Building dry means avoiding green lumber and wet spray insulation. If these materials are used for reasons of cost, availability, or workability, then designing for moisture escape is vital.

Finally, insulating on the outside may be a viable solution to problems with damp flat roofs.

Plastic Insulation

The issue

Concern for the ozone layer has threatened the availability of high thermal resistivity plastic insulations, which are blown with CFC agents and which derive their high RSI value from the residual CFC gas trapped in their closed-cell structure. These insulations include polyurethane, both foamed-in-place and insulating boards, extruded polystyrenes, the isocyanurates and phenolic foam. Bead boards do not use CFCs for the blowing agent.

CFC is the abbreviation for molecules made up of chlorine, fluorine and carbon atoms. These molecules are very stable and, in gas form, have a low thermal conductivity. The problem is that, when the CFC molecule makes its way to the upper atmosphere, radiation breaks up the molecule, and the chlorine combines with the ozone and depletes the ozone layer.

There is currently a simultaneous push for the preservation of the environment, conservation of energy, and the design and construction of thin building envelopes to maximize space, both inside and outside buildings. These all have an impact on the materials that designers and builders choose. Elimination of CFC-blown insulation from the range of acceptable building materials could have a significant effect on building envelope design and construction.

Findings

The first step toward a solution is to develop an understanding of the performance of CFC-based insulations. These characteristics are established through a short-term test, of about six months, on a thin slice of insulation (10 mm). These results are scaled for time and thickness to obtain the 25-year performance for thicker slices. This technique may become a standard way of expressing the effective RSI value of the materials.[5]

Figure 4 illustrates the thermal resistance curve of a 50 mm sample of CFC-blown polyurethane foam over a 25-year period. This curve lies within a range delineated by the thermal resistance of foams having high concentrations of CFC at the time of manufacture (top of graph) and by the thermal resistance of fully aged foams having high concentrations of air in their cellular structure (lower part of graph). The RSI value of the insulation over a 25-year period depends on some combination of the RSI values of CFCs and air. (Other factors contribute to the RSI value of the insulation but these are beyond the scope of this discussion.) Most CFC-blown insulations show similar behaviour.

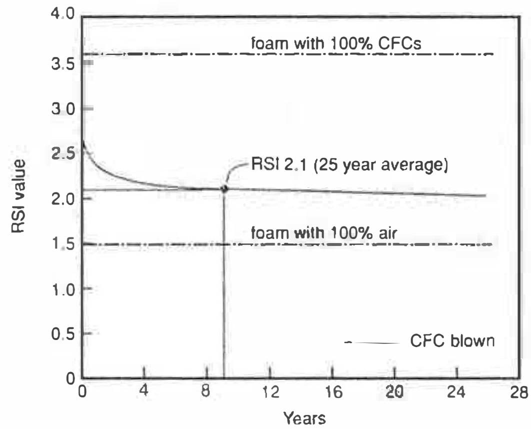


Figure 4 RSI values of CFC-blown insulation over time

The RSI value of the specimen in year nine marks the 25-year average RSI value of CFC-blown insulation. Using the nine-year value of RSI 2.1 per 50 mm (R12 for 2") as a reference, we see that the material provides more than its nominal thermal resistance, starting above RSI 2.8 (R8 for 2") prior to year nine, and moving slowly down toward RSI 1.7 (R10).

The objective of current CFC-replacement research is to find a suitable blowing agent that features the same high level of thermal performance of the CFC-blown foam, while eliminating the threat of ozone depletion. One such candidate is an HCFC blowing agent, which features an extra hydrogen atom that makes the molecule more reactive. The HCFC molecule tends to break down more easily in the atmosphere before reaching the ozone layer.

The RSI values of polyurethane foam blown with this alternative gas have been tested at IRC, with a typical result shown in Figure 5. A near-identical curve overlays the curve produced by the conventional insulation. The important feature to note is that the curve presented for the alternative, more ozone-friendly, HCFC agent displays similar thermal resistance characteristics over the 25-year period. This means that the alternative blowing agent will be able to "duplicate" the 25-year RSI average. There is still more research work to be done. Thermal resistance is not the only property that must be considered. Full compatibility of the alternate blowing agent with the other ingredients in the insulation and toxicology of the replacement blowing agent have to be assessed. Ultimately, the HCFC may have to be replaced as well.

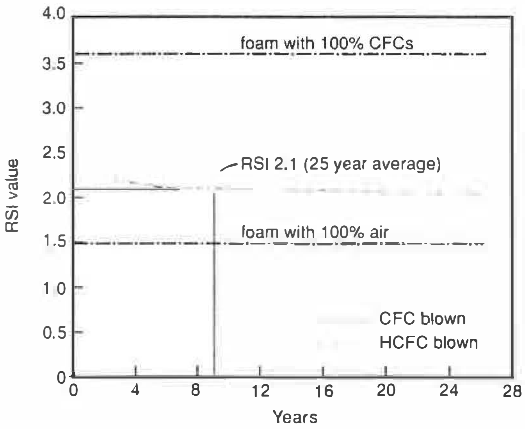


Figure 5 RSI values of CFC-blown and HCFC-blown insulations

Recommendations

The recommendations are straightforward. Don't alter current building practices because of CFCs. The Society of Plastic Industries, in cooperation with IRC and other laboratories, is working on this issue. We will be able to count on high resistivity plastic insulation in the future, despite the environmental problems that concern us today.

Radiant Barriers and Reflective Insulations

The issue

An air space in a building envelope assembly, can contribute a higher RSI value if there is a reflective material on one side or the other of the space. The question is what the increase in RSI value is and whether it is cost effective.

Reflective materials include radiant barriers and reflective insulations. A radiant barrier is a single sheet of reflective material positioned on one side of a cavity. The radiant barrier itself provides no significant thermal resistance; it must be installed in conjunction with an air space. Reflective insulation is a system of reflective sheets and airspaces designed together to fill a cavity and act as insulation. Thus, reflective insulation would consist of a number of layers of air spaces and reflective sheets.

In the context of increasing need for energy efficiency and minimizing building envelope thickness, radiant barriers present a possible means to increase thermal efficiency without impinging on either interior or exterior space.

The controversy

Controversy has arisen in the wake of conflicting performance ratings. Some of the discrepancies may relate to the application of the product in situations where the mechanisms and directions of heat flow are different. Applications have included radiant barriers and reflective insulation systems in wall cavities, radiant barriers covering attic insulation, and radiant barriers on the underside of roof sheathing.

Some advertisements for radiant barriers show the material acting as a shield against the heat radiating from sun lamps. This introduces the point that if the principal mechanism of heat transfer is radiation, then a reflective system will reduce heat transfer. This has been recognized in window technology; high thermal performance windows are designed to reduce radiation, because two thirds of the heat loss through windows occurs by radiation.

Conversely, if the primary mechanisms of loss through the building envelope are conductive or convective, then addressing radiation alone will not be adequate.

Findings

Figure 6 compares the RSI value of glass fibre insulation in a standard 89 mm wall cavity to the values for the empty air space and for the cavity with one, two and four radiant barriers. It shows the differences between what had been previously accepted[6] and values that have been measured.[7] Measurements were conducted at a number of temperature differences. The numbers reported are for a temperature difference across the wall of approximately 17°C (30°F).

According to previously accepted values, one radiant barrier in the air space increases the thermal resistance from RSI 0.18 to 0.46 (R1.0 to about 2.6). Two radiant barriers would raise the value to about RSI 1.14 (R6.5) and four radiant barriers with four air spaces would provide about RSI 2.8 (R16). This is very enticing, since it would give a thermal resistance greater than that provided by a standard RSI 2.11 (R12) glass fibre batt with an 89 mm cavity.

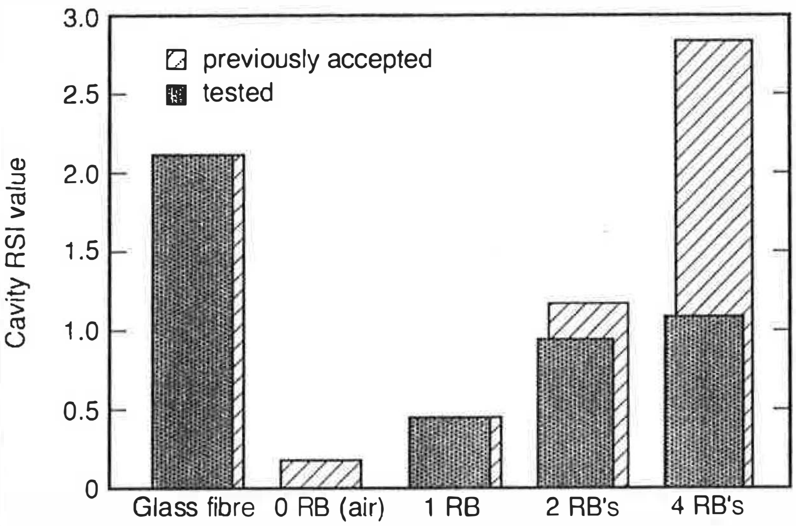


Figure 6 Comparison of previously accepted values and measured RSI values for glass fibre insulation, air and radiant barrier systems[6,7]

In recent tests conducted in the United States,[7] however, the results were rather disappointing for the two-and four-layer radiant barrier system. Values obtained for the glass fibre batt and the one radiant barrier system turned out essentially the same as the values published previously. The two-and four-barrier systems, on the other hand, performed rather poorly, providing thermal resistances of only RSI 0.93 (R5.3) and RSI 1.06 (R 6.0).

In many parts of the U.S., climate conditions, building construction and principle heat transfer mechanisms may be quite different from those encountered in Canada. In southern climes, reflective material may be an appropriate alternative to more insulation. The tests showed, for example, that for heat flow downward under air conditioning loads, the four-ply radiant barrier system could provide the level of performance suggested by the referenced figures. The success of that system is probably due to the stratification of the air in the cavity. This stratification eliminates the convection loops that defeat the radiant barrier in the wall.

Tests done in Alberta,[8] on radiant barriers in attics, indicate some improvement in thermal performance in winter. The reduction in heat loss suggested by the product literature, however, was not achieved.

Additional concerns relate to the long term performance of the material. Dusting will reduce the reflectivity of the material and thus reduce its effectiveness. Since reflective films are foils, they act as vapour barriers and, as such, should not be installed on the cold side of a cavity without precaution, e.g., adequate perforation.

Recommendations

In general, multiple reflective materials do not address conduction and convection losses in building envelope cavities well enough to warrant their use in colder climates. Additional work to improve these products may make them more effective and ensure that they do not adversly affect thermal performance or envelope durability.

In terms of cost, reflective materials are subject to the same principles of diminishing return as conventional insulation. If it is not cost effective to add more conventional insulation, it is probably not cost effective to add a radiant barrier.

Air Barriers

The issue

In *Building Science Insight '86: An Air Barrier for the Building Envelope,*[9] the properties of air barriers were listed as:

- air impermeability,
- continuity,
- structural integrity,
- durability.

To this list we can add compatibility with the other functions of the envelope, as determined by its location within the envelope.[10]

Although candidate materials can feature strong advantages in one or several of these properties, it is the overall performance of the air barrier system that must be assessed in terms of its main function, the control of air flow, over the life of the building envelope.

Why we should be interested

Many other functions of the envelope system rely on adequate air leakage control. These include:

- control of vapour flow,
- control of water intrusion,
- control of heat loss and gain,
- durability.

Systems other than the building envelope rely on the air barrier to maintain an acceptable indoor environment at reasonable cost. Control of air flow at the building perimeter, for example, is necessary to ensure proper performance of the mechanical system in providing energy efficient thermal comfort and indoor humidity control.

The 1990 National Building Code now refers specifically to the need for a barrier to air leakage. The material or system of materials used to perform the air barrier function must have the "characteristics necessary to provide an effective barrier to air exfiltration under differential air pressure due to stack effect, mechanical systems, or wind."[11]

Findings

Air barriers are generally not materials, but systems of materials. IRC has developed two tests for frame construction to assess:

- the ability of the air barrier system to control air flow under a range of pressures that are likely to occur in buildings,
- the ability of the air barrier system to maintain its integrity under extreme wind load conditions that building envelopes are periodically subjected to during the life of the building.

The rig used for these tests is shown in Figure 7.

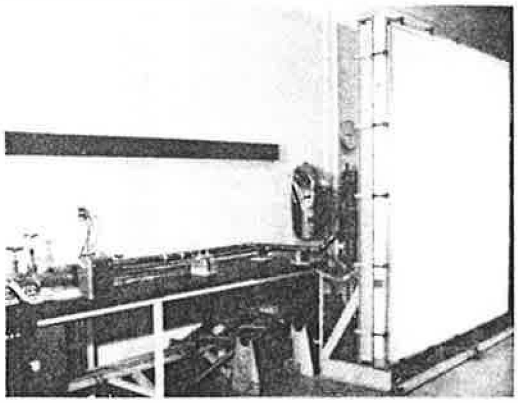


Figure 7 Air barrier test rig

Building Science Insight '86 proposed for discussion a "pass/fail" air leakage rate for air barriers of 0.1 $L/s/m^2$ at 75 Pa for buildings operating at relative humidities between 27 and 55%,[12] a range of relative humidities that should encompass all but exceptionally dry or humid buildings built to today's standards.

The IRC test results[13] show actual performances of various air barriers systems integrated into a standard wood frame wall. The test specimens consisted of 2.44 m x 2.44 m panels as follows :

- polyethylene-based air barriers,
- gypsum board-based air barriers,
- closed cell foam insulations installed to act as the air barrier,
- polyolefin-based systems,
- other assemblies, including double-plywood skins and exterior insulation and finish systems (EIFS).

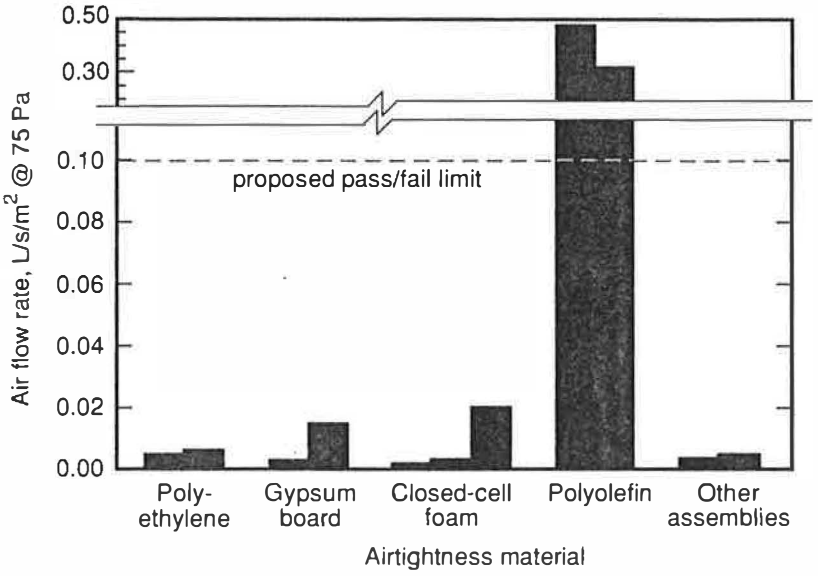


Figure 8 Air leakage measured through wall panels

Two or three systems were tested for each material.

Figure 8 shows that at an air pressure of 75 Pa, most of the systems tested performed as air barriers; that is, they reduced the air flow rate below the pass/fail limit referred to above. Recorded values are close to the measurable accuracy of the test system. The exceptions are the systems that depend on breather type building membranes (polyolefins) to provide air tightness. Based on the IRC tests, these materials cannot be counted on as the basic ingredient of an air barrier system, even though they may play an important role as building membranes.

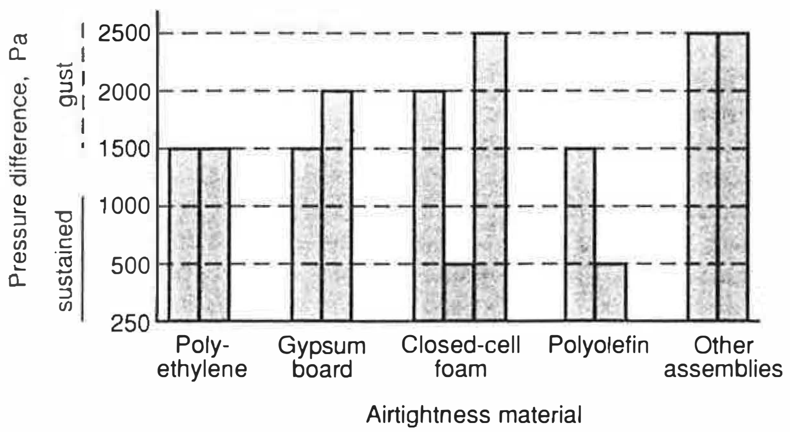


Figure 9 Maximum pressures resisted by the air barrier systems under moderate and severe wind loads

Another test[13] was conducted to determine the ability of these systems to withstand wind loads. In a first round of tests, sustained pressure differences of up to 1000 Pa were applied; the upper limit represents the maximum sustained wind pressure load that a small building is likely to encounter in the windiest areas of Canada. A second round of tests took each sample up to 2500 Pa to investigate maximum gust load resistance. Since most maximum sustained wind loads in Canada are below 500 Pa, this test assessed the capability of these systems to perform under extreme conditions. Most of the standard systems performed well. Some improvement might be made to individual systems, such as improved fasteners for one of the board-based air barrier systems; two systems failed at the lower pressures due to poor fastener design (Figure 9).

The test results confirm that the plane of planned resistance must incorporate a material that can resist air flow. Though this may seem obvious, materials that do not adequately resist air flow have been promoted as air barriers. Formulations for these materials are being refined where needed. The primary function of others is being rethought and promoted differently.

Recommendations

In general, current practice in residential construction appears to be adequate. Proper materials and construction details are being used. In these cases there is no need to alter or improve on the approach. Quality of construction must be maintained to ensure that the air barrier is adequately supported to withstand wind loads and to maintain joint integrity.

Information on the performance of air barriers in non-residential small buildings is scant. The methods used in wood frame construction can be easily adapted to metal stud walls. Air barrier systems for concrete block infill walls have recently been tested by ORTECH International for CMHC.[14]

Finally, with reference to compatibility with other functions of the envelope, it is easier to make the air barrier compatible with the other requirements of the envelope when it is placed on the warm side than when it is placed on the cold side. For this reason, installation of the air barrier on the warm side of the building envelope is recommended.

Below-Grade Envelope

Many small commercial and industrial buildings are built slab-on-grade and thus avoid below-grade envelope problems. Canadian homeowners, however, have a penchant for basements. Home buyers are demanding more finished basement space in houses, with a concomitant need for energy efficiency and thermal comfort of that space.

Basement problems can be generally attributed to a poor correlation between people's expectations of basements, their design and construction, and the environmental forces with which the basement must contend. Basements are often expected to provide prime living space within a construction that is little better than the traditional cellar. The building envelope below grade is exposed to a completely different environment than that above grade, yet the interior environment is expected to be the same. Unless the loads on the below-grade envelope are recognized and responded to, the capabilities of the envelope will be strained and performance will often prove to be unacceptable.

There are few system approaches to the whole basement issue. Some more exotic systems solutions have been proposed but these tend to be quite expensive. What is currently available are bits and pieces of solutions.

Building statistics reflect the conundrum faced by those who advocate changes to basement design and construction. Today's standard basement, without any special protection or provision for problems, works well most of the time. However, it does not work well all the time. The question is whether current practice is adequate or whether failure occurs often enough to warrant improved design and construction. Whether individual designers or builders address any of the basement problems depends on their individual risk management strategies.

Builders' basement repair budgets are already strained. Costs for each repair case can average $1200 or more. If one in four basements need repair in a given area of the country, repair costs averaged over all basements constructed will amount to $300 per unit. Repairs to fully insulated and finished basements would invariably cost more than those on unfinished ones. Builders in some areas are setting aside hundreds of dollars per house, anticipating repairs that they might have to make.

Myriad issues pertain to the current performance of basements. This paper focuses on concrete block and poured concrete construction, and discusses adfreezing and ice lensing, water and air leakage, and condensation associated with concrete curing.

Adfreezing and Ice Lensing

The issue and reasons for concern

Adfreezing and ice lensing of frost-susceptible soil are mechanisms that can threaten the structural integrity of a foundation and coincidentally the building superstructure. They are regional concerns that do not affect all designers or builders.

The current question is whether the installation of full height interior insulation lowers soil temperatures sufficiently to initiate adfreezing and ice lensing. This is of special concern where basement walls are built of concrete block, since the voids in the block allow convective cooling of the soil around the foundation.

Mechanisms

Adfreezing and ice lensing occur only in fine-grained frost-susceptible soils, such as clays and silts. The creation of an ice lens is initiated when water in the soil migrates from a warmer, wetter area to a colder, drier area and freezes. As the water transfer continues, the lens builds and exerts pressure in the direction of the heat flow. If the soil should freeze and adhere to a basement wall (adfreezing), for example if the basement is unheated, pressures in the soil will be transferred to the wall (Figure 10).

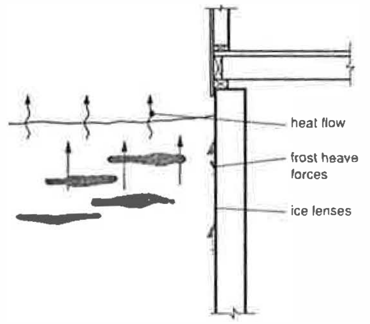
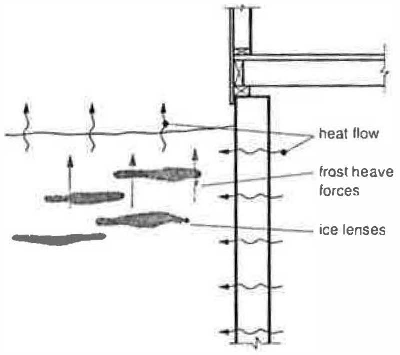


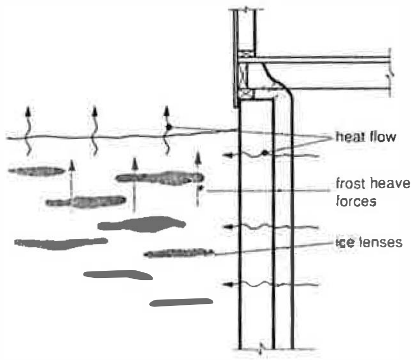
Figure 10 Ice lens and adfreezing forces on a basement wall

Findings

Where concrete block or poured concrete basement walls are uninsulated, there is sufficient heat loss from the basement to prevent adfreezing and ice lens growth toward the wall. IRC test data on adfreezing indicate that this is also the case for insulated poured concrete walls (Figure 11).



a) Uninsulated basement wall



b) Insulated poured concrete wall

Figure 11 Ice lens formation beside an uninsulated wall and an insulated poured concrete wall

Where concrete block walls are insulated to full height on the interior, some caution may be required. The mechanism of convection loops that create a thermal bridge in concrete block walls is well documented. These convection loops may accelerate the growth of the ice lenses towards the wall (Figure 12). Ice lenses growing towards a basement wall will exert lateral and uplifting pressures on that wall, which can cause damage. Some deflections have been recorded in a block wall built in frost-susceptible soil. These deflections appear to result from the forces described above.

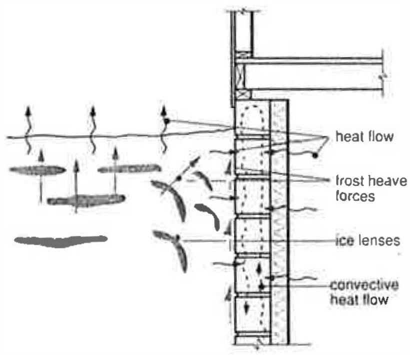


Figure 12 Ice lens and adfreezing forces acting on a concrete block wall insulated to full height on the interior

Recommendations

When building with concrete block in soils that are susceptible to frost heave, capping the basement wall at grade will break the convective heat loss loop and reduce the risk of frost damage (Figure 13). Filling the cavities of the blocks below grade would provide additional protection against convective heat loss but this can be expensive.

Installing the insulation on the exterior will disconnect the wall from any potential adfreezing and eliminate the convective cooling of the soil.

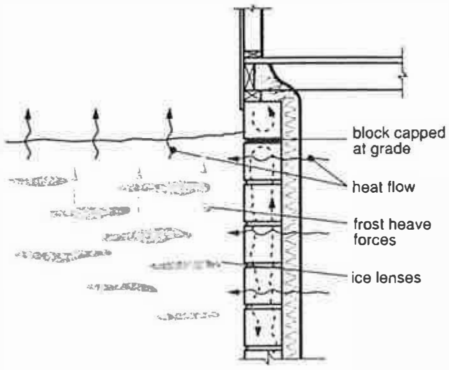


Figure 13 Concrete block wall with full height interior insulation, cavity capped at grade

Water and Air Leakage

The issues and reasons for concern

Water leaks and air leaks in basements are ongoing problems. Water leakage confounds attempts to control indoor humidity levels and encourages the growth of fungi. These problems in turn can lead to damage of interior finishes and health problems. Air leakage in the context of basements is primarily the infiltration of soil gases, such as radon and methane, which can present serious health and safety hazards.

Causes of the problems

A principal factor related to water and air leaks is cracking of basement walls and floors. Some builders estimate that 50% of all basements crack. A percentage of these are subjected to high water loads due to poor drainage or high water tables and develop leaks. Soil gas infiltration is aggravated in the winter by the depressurization of below grade space, due to stack effect.

Findings

Present practice is uneven and depends on the risk management strategies invoked by individual designers and builders. Concrete block walls as currently designed cannot be relied upon to act as soil gas and water barriers. Poured concrete may or may not provide adequate protection, depending on the loads, the quality of the material and the installation. The 1990 National Building Code requires a polyethylene sheet below the slab[15] to reduce air infiltration.

Recommendations

The appropriate response depends on site conditions. Since call-backs cost a lot of money, it may be prudent to invest more in preventive measures, upgrading the quality of construction and attempting to avoid the problems altogether. In general, rather than relying on the concrete structure, separate provisions should be made for effective and durable water and air barriers. In areas plagued by cracking basements and water leaks or soil gas problems, special precautions are recommended (Figure 14). Many of these are not new.

Provision should be made for disposing of rain water. The grade should be sloped away from the basement walls. In higher risk areas, a drainage layer, consisting of granular backfill, draining exterior insulations or geotextiles, should be installed around the walls to assist the flow of water to the weeping tile. Beyond the standard bituminous dampproof coatings required by the National Building Code, bituminous, polymeric and composite membranes should also be considered. The use of

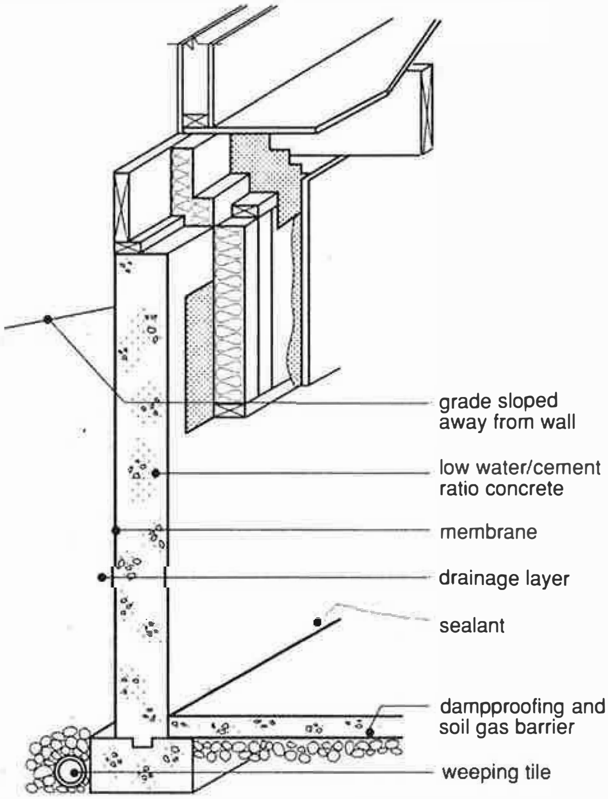


Figure 14 Measures to prevent water and soil gas leakage

higher quality, low water/cement ratio concrete will significantly reduce cracking. Installation of the material is as important as the quality of the material itself.

The Ontario Home Builders' Association is coordinating a demonstration project of a number of homes where various methods will be tried, costed and documented. The costs of the various solutions must be compared and assessed in the context of repair costs.

Specific provisions should be made to control soil gas intrusion. Some of the possible solutions are the same as for water leakage. These include the use of higher quality concrete and the installation of sealed barrier membranes. The drainage layer around the basement envelope may be depressurized to remove gases from the vicinity. The below grade space may be subjected to a positive pressure or the basement envelope may be depressurized. The last is the subject of a patent.

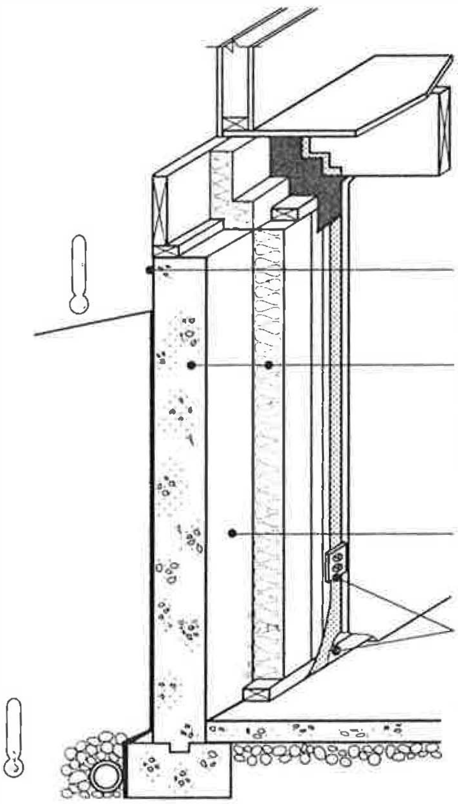


Figure 15 Postulated mechanisms involved in condensation on poured concrete basement walls

Condensation during Concrete Curing

The issue

Condensation of water on basement walls during the concrete curing process seems to be related to the trend toward full height interior insulation. There are no comprehensive data to indicate the incidence of this problem but cases have been reported in Quebec, Manitoba, and Alberta. As with water leakage, dripping water can cause moisture damage and support the growth of moulds.

Causes of the Problem

Condensation during curing is related to the fact that, at the time of installation, concrete is loaded with water. Several thousand litres of water are involved in the mix at pouring. It can take up to a year for that water to either combine with the concrete or evaporate from the surfaces of the concrete. Installing full height interior insulation may induce the condensation problem through a number of mechanisms which are not yet fully understood (Figure 15).

First, installation of a full height interior wall restricts the evaporation of the excess water in the concrete. As the surfaces behind the insulation are cool, moisture trapped behind the insulation is likely to condense and flow down the wall.

Where a concrete wall has cured and is exposed on the interior, a certain amount of moisture from the basement space can be absorbed by the concrete, causing no problems. Where the concrete has not yet lost its excess moisture or where it is covered by a moisture barrier, however, any additional moisture that comes in contact with the wall or moisture barrier will not be absorbed and will flow down the surface of the wall just as condensation flows down a cold window.

Another possible mechanism is the redistribution of excess moisture within the concrete as induced by temperature gradients from the top to the bottom of the wall in spring and summer. This mechanism may act within the concrete or through the insulation. That is, the mechanism would be exacerbated where interior dampproofing is omitted and moisture from the concrete can diffuse into the air within the assembly. Saturation of the air at the bottom of the wall could lead to condensation on the cooler surfaces.

Recommendations

What is required is a water management strategy. Investigators working for CMHC[16] suggested that making sure that moisture in the indoor air does not come in contact with the concrete surface or interior damp-proofing behind the inner wall structure will reduce the problem. This would be a first step.

If vapour diffusion from the concrete into the insulation were found to be the predominant mechanism, traditional interior damp-proofing techniques should reduce the transfer of moisture to the air within the assembly and thus reduce the likelihood of condensation on the concrete at the bottom of the wall.

Another potential solution depends on the control of the temperature gradient in the wall. This concept may lead to a means of managing the excess water, since it addresses all of the suspected mechanisms. Overheating the basement over the first spring after it is built will theoretically increase the vapour pressure at the lower portion of the wall, where the problems occur, and either drive the moisture to the outside or at least block its migration towards the bottom of the wall. This is untried and could be an expensive solution, but may be worth examining further.

Insulating the exterior of the concrete wall is a proven alternative that keeps the inside surface of the concrete generally above the room air dew point temperature, while keeping the temperatures in the concrete walls more uniform. As well, this option does not interfere with evaporation from the interior concrete surfaces.

Summary

Above-Grade Envelope

Wet insulation

Between 50 and 75 % of the effective thermal resistance of porous insulation is lost if the system allows vapour transfer from one side of the cavity to the other. Take steps to avoid moisture intrusion or design for its rapid removal.

Plastic insulation

The current research will ensure that the CFC-based foams will be replaced by more environment-friendly materials that maintain similar long term thermal performance.

Radiant barriers

These are subject to the same diminishing returns as other energy conservation measures. Tests from the U.S. show that multi-layer radiant materials do not perform as expected and are probably not appropriate for most applications in colder climates.

Air barriers

Home builders appear to be on the right track. Continued attention to details and choice of materials is recommended.

Below-Grade Envelope

Adfreezing and ice lensing

When building concrete block basement walls in frost-susceptible soil, capping the cavity in the block at grade will break convective heat loss loops and reduce the risk of damage. Filling the cavities in the blocks will provide a further margin of safety.

Water and air leakage

When building in areas that have a history of basement leakage or soil gas hazards, look at some of the alternatives for tightening basement walls and floors and adjust your risk management strategy accordingly.

Condensation during concrete curing

Take care in detailing the wall construction to ensure that indoor air will not come in contact with the concrete. Installing a moisture barrier on the interior of the concrete wall should reduce the diffusion of construction water into the insulated assembly. The home owner can take control of the moisture management strategy by overheating the basement in the first spring of operation, thereby reversing temperature gradients in the walls. Remember, however, that this last strategy has not yet been proven.

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