RESEARCH HIGHLIGHT

Technical Series 01-107

Impact of Added Insulation on Air Leakage Patterns

INTRODUCTION

Increased levels of insulation are being promoted to reduce energy consumption. However, before adding insulation to an exterior wall assembly, the expected hygrothermal performance should be evaluated; adding thermal resistance to exterior wall assemblies modifies their temperature gradient and the risk for moisture condensation may increase, particularly due to air leakage. This project involves an experimental procedure to study the moisture content and temperature distribution patterns in walls with different air leakage characteristics when subjected to different insulating strategies.

RESEARCH PROGRAM

A full-scale test hut—4.2 m long by 2.5 m wide by 3 m high—was built inside an environmental chamber. The exterior wall of the test hut consisted of 14 different constructions, as shown in Table 1. Each section was isolated by oriented strand board panels, and two half-cavities acting as thermal "buffers" on either side of the sample section (defined as one complete 0.36 m stud space).

Table 1 Test Wall Sections

Section ID	Stud Space (mm)	Stud Space Insulation	Re-insulation Strategy	Air Leakage Path
1	89	Fibreglass Batt	None	Long
2	89	Fibreglass Batt	None	Direct
3	89	Fibreglass Batt	None	Diffuse
4	89	Fibreglass Batt	Exterior	Long
5	89	Fibreglass Batt	Exterior	Direct
6	89	Fibreglass Batt	Exterior	Diffuse
7	89	Fibreglass Batt	Interior	Long
8	89	Fibreglass Batt	Interior	Direct
9	89	Fibreglass Batt	None	Airtight
10	140	Blown Cellulose	None	?
11	140	Blown Cellulose	None	Direct
12	89	Blown Cellulose	None	Direct
13	89	Blown Cellulose	Interior	Direct
14	89	Blown Cellulose	Exterior	Direct

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The junction between the exterior walls and the roof was built and insulated to simulate a typical ventilated roof. The base-case wall assembly (i.e. prior to an insulation retrofit), included the following (from exterior to interior):

- Spun bonded polyolefin membrane ("Tyvek"),
- 10 mm asphalt-impregnated fibreboard,
- 89 or 140 mm wood studs @ 400 mm centres,
- 89 or 140 mm fibreglass batt insulation or blown cellulose insulation with polyester fibre mesh,
- 6 mil polyethylene,
- 19 mm x 64 mm horizontal wood furring @ 400 mm o/c,
- 13 mm gypsum board,
- standard latex paint (two coats).

In the walls insulated with cellulose, the wood furring was located to the exterior of the polyethylene.

Three different types of air leakage paths were created, as shown in Figure 1. Two distinct re-insulation strategies were employed. In the exterior insulation strategy, rigid extruded polystyrene insulation (38 mm) was added on the exterior of the assembly directly over the fibreboard sheathing—representing a scenario where the exterior veneer would be replaced. In the interior insulation strategy, rigid extruded polystyrene insulation (38 mm) was added to the warm side of the wood studs—representing a scenario where interior renovations (including removal of the existing interior finish) would be undertaken.

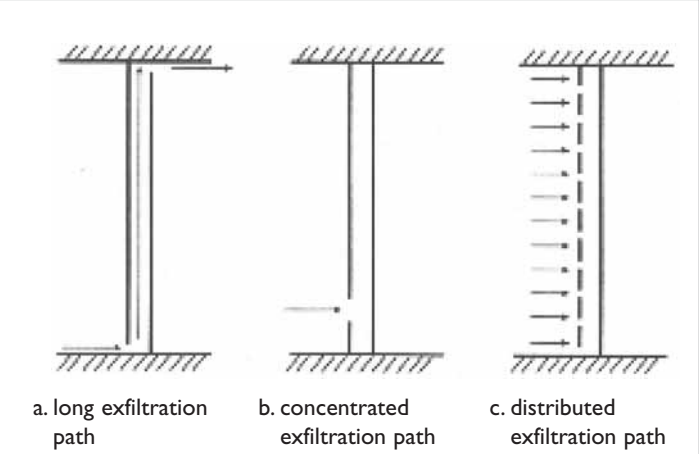

Figure 1 Section view of air leakage paths– Sample sections with fibreglass wool

To study moisture accumulation and drying potential, the experiment was divided into two distinct climatic periods: a wetting period and a drying period. The conditions inside the environmental chamber were based on actual weather data for Montréal over a 12-year period. For the wetting period, the conditions were based on the average temperature for the 75 days from mid-December to the end of February. This temperature (-8.5°C) was maintained for 66 days, at which point the rate of moisture accumulation appeared constant. The drying conditions (17°C) were based on the 45-day period from mid-May to the end of June. This part of the experiment lasted 47 days. The conditions inside the test hut were kept at 22°C, 50% r.h. and +4 Pa for the wetting period and at 23°C, 45% r.h. and +1 Pa for the drying period.

For the sections insulated with fibreglass, temperatures were measured using 10 to 12 type "T" thermocouples on the interior surface of the fibreboard (cold plane) and on the interior surface of the stud insulation (warm plane) at five or six different heights, depending on the air leakage configuration of the sample section. For the sections insulated with cellulose, the thermocouples were installed on the warm and cold sides of the wood studs at the bottom, mid-height and at the top. Temperatures were monitored at 267 locations. Readings were taken automatically every 10 minutes.

In addition to temperature monitoring, moisture content monitoring was used to assess where moisture-related problems were likely to occur. Six electronic moisture content sensors were installed in each sample section (three in the cellulose-insulated sections) to monitor the moisture content of the fibreboard sheathing every 10 minutes. Gravimetry (weighing of samples) was also used to determine moisture content of the studs and fibreboard sheathing. Gravimetry samples were taken from the exterior of the test hut and weighed weekly for the first 30 days of each climatic period and then every two weeks for the remainder. The stud samples—12.5 mm deep by 12.5 mm high by 38 mm wide—were cut out of the exterior side of the studs. Fibreboard samples were 38 mm in diameter (except those required to access the wood samples, which were 50 mm in diameter). Where exterior insulation was present, a removable piece was cut out to allow access to the gravimetry samples. Air leakage around the gravimetry samples was minimized to avoid impact of the samples on the behaviour of the assembly. Fifty-nine electronic moisture sensors and 237 gravimetry samples were used to evaluate moisture content.

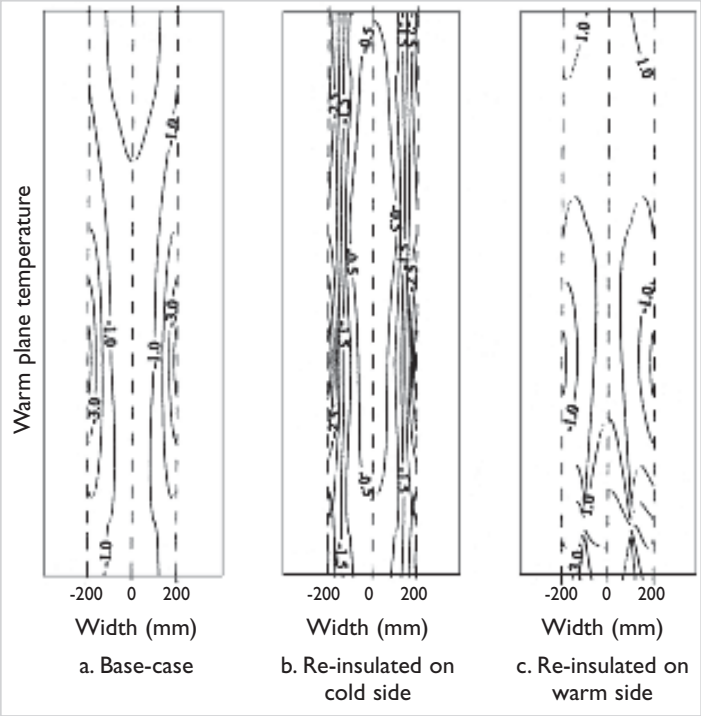

Figure 2 Differential isotherms for sections with the long exfiltration path (°C)

RESULTS

Numerical characterization of moisture accumulation was impossible due to the small number of monitoring points in the cellulose cavities. However, cellulose fibre tends to agglomerate where it has been wetted. Therefore, the cellulose itself was a moisture accumulation marker; the shape and location of the altered texture indicating where moist indoor air had flowed.

A steady-state, three-dimensional finite-difference approach was used to generate expected isotherms for the warm and cold planes for each test section (see Figure 2). The calculated isotherms compared to those obtained from the monitoring of the assemblies allowed visualization of the effect of air leakage on temperature within the assemblies. Similarly, moisture content data was used to produce contour lines of equal moisture content, called isohygrons.

It was determined that a correlation existed between the moisture distribution patterns in the fibreboard sheathing and the air leakage patterns. Problem areas were generally linked to the entry point of warm indoor air into the cavity.

Air Leakage Paths

- Long air leakage path—fibreboard moisture content was higher at the bottom. When rigid insulation was added on the cold side, moisture content ranged from 60% at the bottom to about 5% at the top. For the base-case and for the case with rigid insulation added on the interior, the moisture content ranged from 20% to 25% at the bottom and 10% at the top.
- Concentrated air leakage path—circular pattern of moisture accumulation was evident in the fibreboard for the base-case and with the warm-side insulation. This pattern was less obvious with the cold-side rigid insulation. Moisture was concentrated just above the air entry point in all cases.
- Distributed air leakage path—moisture content of the fibreboard was higher towards the centre of the cavity and slightly towards the top.

The moisture content in the fibreboard sheathing and the wood studs were plotted over time. The airtight section was the one with least moisture accumulation (less than 20%) and least moist content variation. In this section, the moisture content varied rapidly in the fibreboard and more slowly in wood. Further, moisture content in the fibreboard at the studs increased slightly more than in the fibreboard between the studs. At the end of the drying period, the moisture contents of the sample was close to its original value, on average only 2% higher.

Location of Insulation

For the base-case assemblies, where no insulation was added, the moisture contents were generally less than 25%. Except for the assembly with the long air leakage path, after initial accumulation, the moisture contents were relatively stable, and after the start of the drying period, moisture contents dropped very rapidly to just above the initial level. (A problem with a gap in the insulation at the top of the cavity of the section with the long leakage path affected its results.)

Similar trends were observed when rigid insulation was added to the warm side, with moisture contents generally less than 25%.

The sections with rigid insulation on the cold side had much higher moisture contents. Further, for the long and concentrated air leakage paths, the moisture contents did not seem to reach a plateau, but continued to climb until the drying period was started. For all exterior insulated sections, the moisture contents after the drying period remained approximately 5% to 7% higher than before testing, suggesting their drying potential is slightly lower.

IMPLICATIONS FOR THE HOUSING INDUSTRY

The experimental results demonstrated that thermal performance, air and moisture transfer cannot be looked at independently. For example, while the R-value of the assemblies is the same whether rigid insulation is added to the warm or the cold side, the performance of these two assemblies in terms of moisture accumulation is very different.

When insulation was added on the warm side, moisture contents generally did not rise above 25% and reached a plateau during the testing. This is likely due to the fact that studs and fibreboard sheathing remained at temperatures below freezing, and that moisture from the warm interior air formed as frost, rather than as liquid water. As a result, less water was absorbed into the assembly. Further, the rigid insulation seemed to help decrease the flow of air, and therefore the amount of moisture, getting inside the wall. At the initiation of the drying period, the moisture content of the assembly increased sharply, but drying proceeded quickly.

On the other hand, when insulation was added to the cold side, moisture accumulation was up to 70% and no plateau was reached during the wetting period. In this case, the studs and fibreboard sheathing were at temperatures above freezing, but below air dew-point. Therefore, moisture was deposited as liquid, which could be absorbed into the materials. The rigid polystyrene insulation is relatively air and vapour impermeable, so that the drying period was hampered.

The airtight section with no added insulation showed the lowest moisture accumulation, suggesting that, for best hygrothermal performance, increasing the airtightness of a wall should be considered before increasing the thermal resistance.

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