Creating Effective Air Barriers: Materials and Techniques

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ABSTRACT

Studies have confirmed that many moisture problems in houses are caused by penetration into the walls of warm, moist household air. Air leakage can be controlled by installing an air barrier system that meets four requirements: it should be air impermeable, structural or rigid, continuous, and durable or maintainable. Types of air leakage include diffuse flow and orifice flow. The most damaging is channel flow, which leaves moisture in walls. A computer program has been developed that can determine maximum leakage levels for a variety of wall assemblies and climates. This paper provides tables and descriptions of air leakage rates of selected building materials and tests of wind resistance of air barrier systems for wood-frame walls. With airtight materials and developed technology, we can produce airtight buildings.

INTRODUCTION

Two case studies illustrate the importance of air barriers. A 1983 study revealed that many moisture problems in houses are caused by penetration into the walls of warm, moist household air (NRC 1984). This conclusion was confirmed by a later field study in James Bay, Quebec, which was conducted in mid-January when the maximum daytime temperature was −35°C. Since a single design had been used for the majority of the houses in the community, it was easy to determine the effects of relatively minor changes in building materials or construction techniques.

A number of houses showed severe moisture problems due to factors such as the extremely low outdoor temperature and the high relative humidity caused by the large number of people sharing a house. One of the houses in the study was home to 11 people, and the relative humidity in this house was approximately 72%. Relative humidity levels in homes in southern Canada, by contrast, are usually around 40%.

As might be expected, this house experienced a variety of moisture-related problems. The condensation on the windows caused mold and mildew to grow on the frames, and condensation was also leaking through the ceiling. Moisture problems in the attic were even more severe. Condensation had formed around the plumbing stack that ran through the attic. There was so much frost on the underside of the roof that the shanks of the nails used to attach the shingles—which would normally protrude through the roofing sheathing—could not be seen.

A polyethylene film had been installed and sealed in an attempt to provide an effective air/vapor barrier. The builder attempted unsuccessfully to seal the polyethylene film properly to the rubber flashing around the poly stack with caulking.

Some improvements were evident in a newer house of the same model. Another house was home to 13 people, and the relative humidity was approximately 76%. The use of better-insulated windows had reduced the amount of condensation, although some was still evident.

The attic in this house, however, was free of frost or condensation because of the effects of a good air barrier. Plywood had been installed under the trusses and sealed with tape. The electrical wiring was installed under this, followed by drywall. The plywood, in forming a rigid, structural air barrier, made all the difference.

The findings in James Bay show that it is possible to make a home airtight, even under conditions of high relative humidity in very severe climates, using common building materials and techniques.

AIR LEAKAGE

Air leakage can be controlled by installing an air barrier system. Such a system forms a continuous envelope—consisting of the walls, roof, and foundations—that make up the shell of the house.

To be effective, an air barrier must fulfil four requirements. It must be

- air impermeable,
- structural or rigid,
- continuous, and
- durable or maintainable.

Since the prime function of the air barrier system is to prevent airflow, the materials and assemblies must have low airflow properties. The system must be strong enough to resist the effects of wind, which can be a very powerful force, and durable enough to last the life of the building. Finally, it must form a continuous envelope around the building. An air barrier that fails to meet any one of these criteria will be ineffective at preventing air leakage.

Several different types of air leakage are possible. Air leakage through the building materials themselves is referred to as *diffuse flow*. Concrete block, for example, is not airtight because of its porosity.

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Orifice flow is airflow through openings such as those in the window frame or around electrical outlets. Orifice flow is usually not a major source of moisture problems because the air flows directly through and does not cool down and lose its moisture until it is outside the house. This moisture sometimes forms icicles on the outside of the building. While not aesthetically pleasing, this generally does not damage the structure of the building.

By opposition, the most damaging type of air leakage is *channel flow*. In this case, air penetrates the wall and then travels for some distance before escaping. As the air travels, it cools. The moisture that condenses is left behind inside the wall.

Obviously, the less air leakage, the better. Since perfect airtightness would be difficult, if not impossible, to achieve, the question arises of what should be considered the maximum acceptable airflow.

The National Research Council of Canada addressed this question in a review of existing research on air leakage (NRC 1989). The standards reviewed included one developed by the American Architectural Manufacturers' Association (AAMA) Aluminum Curtain Wall Design Guide Manual. At 75 Pa air pressure, the AAMA standard allows a maximum air leakage of 0.3 $L/s{\cdot}m^2$.

While the AAMA standard is useful as a starting point, it is not directly applicable to the types of air leakage encountered in Canadian houses. The standard applies to curtain walls, the glass walls used in many new office buildings. Curtain walls are constructed primarily from airtight materials such as glass and metal so that channel flow does not occur. The AAMA standard was also developed for the United States, which in general has a milder climate than Canada.

In recognition of the more severe conditions that prevail in Canada, the NRC in its review decided to lower the acceptable level by a factor of two. The NRC also recognized that the level of air leakage that could be considered acceptable would depend on the relative humidity inside a building.

For a building with low humidity, such as a warehouse (0 to 27% RH), the NRC arrived at a maximum acceptable leakage of 0.15 $L/s{\cdot}m^2$. At moderately humid levels of between 25% and 50% RH, similar to those encountered in most houses, air leakage should not exceed 0.10 $L/s{\cdot}m^2$. Under conditions of high indoor humidity (over 50% RH), found in environments such as art galleries, computer rooms, museums, or hospitals, the maximum acceptable leakage would be .05 $L/s{\cdot}m^2$.

Since the completion of the NRC review, Canada Mortgage and Housing Corporation (CMHC) has revisited the question of acceptable levels of air leakage in a more scientific and specific way. CMHC's research was based on the assumption that the acceptable level of air leakage depends on a variety of factors. One of these is climate: a level that is suitable for the more temperate parts of southern Ontario is not suitable for an area such as James Bay. The level would also be affected by the interior relative humidity and by the materials used in construction. Concrete walls are less susceptible to moisture damage than wooden walls, for example.

The result was a computer program designed to take these variables into account. Using this program, it is possible to determine maximum leakage levels for a variety of wall assemblies and climates. Some examples are listed in Table 1.

AIR BARRIER MATERIALS

The air barrier system is composed of materials that must be joined together to form assemblies. These, in turn, are joined to form the air barrier system. Obviously, the failure will be most severe if the materials used are not sufficiently air impermeable. While many common building materials are capable of forming an effective air barrier, many are not, and it is vital to know which is which. A few years ago, a research project was conducted in order to obtain this information (CMHC 1988b).

Forty different building materials were conditioned at a standard temperature and humidity. They were then attached to a testing apparatus, essentially a metal box that could be pressurized or depressurized to force air in either direction through the material being tested. Instruments on the box recorded the amount of air leakage that resulted (see Table 2).

WIND RESISTANCE

The results of the tests provide some guidance to designers in choosing materials to create an effective air barrier. But the selection of air-impermeable materials is not the only criterion that must be considered. The materials chosen must also be joined to make up an assembly, and that can be difficult. Many of these materials do not join efficiently because they are slippery and difficult to work with or because they lack strength when combined into an assembly.

The ability to combine materials into a strong assembly is particularly important. Since the assembly must resist airflow, it must therefore resist wind (movement of air) and further must be able to resist winds that may be extremely strong. Once an assembly with poor wind resistance opens up, its effectiveness as an air barrier is gone forever.

CMHC commissioned the NRC to test a variety of air barrier assemblies to the wind loads specified in the National Building Code of Canada (NRC 1989). The code requires wall assemblies to resist for one hour the type of wind load that is likely to occur once in 30 years. In Ottawa, for example, this worst-case sustained wind load is 400 Pa.

The code requires the materials to resist even higher loads when sustained for only a few seconds, so the tests also simulated the effect of a strong gust of wind. The re-

TABLE 1
Maximum Acceptable Leakage Rates for Selected Wall Assemblies and Climates

Wall composition	City	Maximum leakage rate
- gypsum board - insulation - waferboard - hardboard	Toronto	0.30 $l/s\text{-}m^2$
	Winnipeg	0.20 $l/s\text{-}m^2$
	Edmonton	0.22 $l/s\text{-}m^2$
	Vancouver	0.38 $l/s\text{-}m^2$
- gypsum board - insulation - gypsum sheathing - brick	Toronto	0.67 $l/s\text{-}m^2$
	Winnipeg	0.44 $l/s\text{-}m^2$
	Edmonton	0.57 $l/s\text{-}m^2$
	Vancouver	0.94 $l/s\text{-}m^2$
- gypsum board - insulation - glass fibre - hardboard	Toronto	0.08 $l/s\text{-}m^2$
	Winnipeg	0.06 $l/s\text{-}m^2$
	Edmonton	0.07 $l/s\text{-}m^2$
	Vancouver	0.08 $l/s\text{-}m^2$
- gypsum board - insulation - polystyrene - hardboard	Toronto	0.08 $l/s\text{-}m^2$
	Winnipeg	0.06 $l/s\text{-}m^2$
	Edmonton	0.07 $l/s\text{-}m^2$
	Vancouver	0.08 $l/s\text{-}m^2$

TABLE 2
Air Leakage Rates of Selected Building Materials

(l/s per m^2)

2mm	smooth-surface roofing membrane	no measurable leakage
2.7mm	modified bituminous torch on grade membrane (glass fibre mat) aluminum-foil vapour barrier	no measurable leakage
l.3mm	modified bituminous self-adhesive membrane	no measurable leakage
2.7mm	modified bituminous torch on grade membrane (polyester reinforced mat)	no measurable leakage
9.5mm	plywood sheathing	no measurable leakage
38mm	extruded polystyrene	no measurable leakage
25.4mm	foil-back urethane insulation	no measurable leakage
24mm	phenolic insulation board	no measurable leakage
42mm	phenolic insulation board	no measurable leakage
12.7mm	cement board	no measurable leakage
12.7mm	foil-back gypsum board	no measurable leakage
8mm	plywood sheathing	0.0067
16mm	waferboard	0.0069
12.7mm	gypsum board (MIR)	0.0091
11mm	waferboard	0.0108
11mm	spunbonded olefin film	0.130
12.7mm	particle board	0.0155
	reinforced non-perforated polyolefin	0.0195
12.7mm	gypsum board	0.0196
15.9mm	particle board	0.0260
3.2mm	tempered hardboard	0.0274
	expanded polystyrene type 2	0.1187
30lb	roofing felt	0.1873
15lb	non-perforated asphalt felt	0.2706
15lb	perforated asphalt felt	0.3962
	Glass fibre rigid insulation board with a spunbonded olefin film on one face	0.4880
11mm	plain fibre board	0.8223
11mm	asphalt-impregnated fibre board	0.8285
	perforated polyethylene #1	4.0320
	perforated polyethylene #2	3.2307
	expanded polystyrene (type 1)	12.2372
	tongue-and-groove planks	19.1165
	fibreglass insulation	36.7327
	vermiculite insulation	70.4926
	cellulose insulation	86.9457

quired gust load is two-and-a-half times the sustained load; in Ottawa, the level required would be about 1,000 Pa.

The apparatus used in these tests is a large pressure box, about two-and-a-half meters square, in which a positive or negative pressure could be applied to the assemblies being tested, simulating either a wind pushing on the building or a partial vacuum that pulls against the wall.

In these tests, the material being tested was installed, complete with studs, as if it were being used in a house. The initial air leakage at 75 Pa was measured. Then the material was subjected to a sustained load of 250 Pa. At the end of one hour, the pressure was reduced to 75 Pa and the leakage rate measured again. Any changes in the leakage rate indicated damage to the material. Materials that survived a 250-Pa load unscathed were tested again at 500 Pa, 750 Pa, and 1,000 Pa.

Similar tests were conducted to measure the material's resistance to gust loads. Test samples were subjected to a load of 1,500 Pa for a few seconds, then tested for leakage at 75 Pa. The tests were then repeated at 2,000 Pa and 2,500 Pa. The same series of tests were repeated, using negative pressure (see Table 3).

CMHC performed similar tests on concrete-block walls similar to those commonly used in high-rise buildings (CMHC 1989b). The first round of tests involved walls without any special airtightening systems. An example of this is a plain block wall.

We built another wall that was four by four and had brick ties in it. Then we built a gap wall that had a hole in it, not going right through the blocks, but just on the surface. We wanted to see if the material could span a crack in the blocks. When concrete block needs steel beams, steel columns, or slabs, there is always a crack because you can't get the block 100% tight—nor do you want it 100% tight because you want to allow for some expansion.

When testing a concrete-block wall without any membranes, there was quite a bit of leakage through it. The result was 1.2 $L/s \cdot m^2$, which, since we are looking for a number of .1 $L/s \cdot m^2$, is 12 times too much. Results of the testing are listed in Table 4.

Having tested materials and assemblies, the ultimate test is how airtight the finished building will be. Together with the NRC, we developed means of testing the whole building for airtightness (CMHC 1989a). We have conducted these tests across Canada on buildings to see if the buildings are airtight; unfortunately, the old buildings, especially high-rises, are not airtight at all. They range from 2 $L/s \cdot m^2$ to 7 $L/s \cdot m^2$.

CONCLUSION

Because we have airtight materials and because we have the technology, it is practicable to produce buildings

TABLE 3
Results of Wind Resistance Testing

ASSEMBLY	INITIAL AIR LEAKAGE AP=75 Pa (l/s-m2)	SUSTAINED LOAD TEST (Pa)	GUST LOAD TEST (Pa)
SPRAY APPLIED POLYURATHANE	0.02	1000 (POS/NEG)	2500 (POS/NEG)
POLYETHYLENE FILM SANDWICH BETWEEN FIBREBOARD/DRYWALL	0.005	1000 (POS/NEG)	2500 (NEG) 1500 (POS)
EXTERIOR INSULATING FINISH SYSTEMS	0,002	1000 (POS/NEG)	2500 (POS/NEG)
GYPSUM BOARD	0,002	1000 (POS/NEG)	2500 (NEG) 1800 (POS)
PLYWOOD	0,004	1000 (POS/NEG)	2500 (POS/NEG)
EXTERIOR DRYWALL PEEL & STICK MEMBRANE ON JOINTS	0,0157	1000 (POS/NEG)	2500 (NEG) 2300 (POS)
EXTENDED POLYSTYRENE	0	1000 (POS/NEG)	2500 (NEG) 2000 (POS)
PHENOLIC INSULATION	0,0003	1000 (NEG) 500 (POS)	25000 (NEG)
POLYOLIFILM BETWEEN FURRING STRIPS & FIBREBOARD	0,5	1000 (NEG/POS)	1500 (POS/NEG)
POLYOLIFILM ON FIBROUS INSULATION	0,3	1000 (NEG)	2500 (NEG)

TABLE 4
Results of Concrete Block Air Barrier Membrane Testing

SAMPLE MEMBRANE NO.	DESCRIPTION & NO.	BLOCK WALL POST SUSTAINED APPLICATION	P=75 PASCALS L/s-m2	MEMBRANE AIR BARRIER LEAKAGE P=75PASCALS L/s-m2 Measured	INITIAL AIR LEAKAGE DELAMINATION P=3000Pa (%) Measured	AIR LEAKAGE P=75 Pa (L/s-m2) Measured	POST GUST AIR DELAMINATION SUST/(TOTAL) (%) Measured
0	Brick Tie Wall	No Membrane	11956.3E-04				
1	Plain Wall	Thermofused	3.82E-04	2.50E-04	6.57	3.50E-04	7.42/(13.99)
	Brick Tie Wall	Thermofused	196.0E-04	200.2E-04	7.43	202.0E-04	0.00/(7.43)
	Gap Wall	Thermofused	Non-Detect.	Non-Detect.	2.11	Non-Detect.	0.00/(2.11)
2	Plain Wall	Thermofused	l.16E-04	Non-Detect.	0.00	08E-04	0.00/(0.00)
	Brick Tie Wall	Thermofused	8.65E-04	12.3E-04	0.00	8.4E-04	8.32/(8.32)
	Gap Wall	Thermofused	Non-Detect.	Non-Detect.	0.00	Non-Detect.	0.00/(0.00)
3	Plain Wall	Thermofused	Non-Detect.	Non-Detect.	0.00	Non-Detect.	3.74/(3.74)
	Brick Tie Wall	Thermofused	121.4E-04	125.1E-04	0.00	126.1E-04	0.00/(0.00)
	Gap Wall	Thermofused	Non-Detect.	Non-Detect.	0.00	Non-Detect.	2.00/(2.00)
4	Plain Wall	Thermofused	Non-Detect.	Non-Detect.	5.90	Non-Detect.	35.86/(41.76)
	Brick Tie Wall	Thermofused	214.6E-04	254.0E-04	0.00	230.0E-04	3.80/(3.80)
	Gap Wall	Thermofused	Non-Detect.	Non-Detect.	3.06	Non-Detect.	29.67/(32.73)
5	Plain Wall	Adhesive	25.5E-04	50.8E-04	-40.00	266.0E-04	-60.00/(100)
	Brick Tie Wall	Adhesive	Pretest Failure	Pretest Fail	100.00	Pretest Fail	100.00
	Gap Wall	Adhesive	Pretest Failure	Pretest Fail	100.00	Pretest Fail	100.00
6	Plain Wall	Adhesive	4.33E-04	5.80E-04	-0.5	2.70E-04	-05/(1)
	Brick Tie Wall	Adhesive	489.5E-04	507.2E-04	0.00	541.1E-04	0.00/(0.00)
	Gap Wall	Adhesive	3.87E-04	4.40E-04	0.00	5.40E-04	0.00/(0.00)
7	Plain Wall	Adhesive	2.92E-04	Non-Detect.	0.00	Non-Detect.	0.00/(0.00)
	Brick Tie Wall	Adhesive	225.6E-04	237.0E-04	0.00	237.0E-04	0.00/(0.00)
	Gap Wall	Adhesive	3.72E-04	3.40E-04	0.00	71.0-138E-04	0.00/(0.00)
8	Plain Wall	Adhesive	N.D.	Non-Detect.	2.15	Non-Detect.	19.50/(21.65)
	Brick Tie Wall	Adhesive	270.6E-04	285.2E-04	17.14	2488.3E-04	40.99/(58.13)
	Gap Wall	Adhesive	Non-Detect.	4.8E-04	9.10	5.1E-04	27.36/(36.46)
9	Plain Wall	Trowel	85.2E-04	26.3E-04	0.00	Non-Detect.	0.00/(0.00)
	Brick Tie Wall	Trowel	28.1E-04	19.9E-04	0.00	11.8E-04	0.00/(0.00)
10	Plain Wall	Trowel	11.6E-04	7.70E-04	0.00	9.1E-04	0.00/(0.00)
	Brick Tie Wall	Trowel	451.6E-04	329.7E-04	0.00	267.6E-04	0.00/(0.00)
11	Plain Wall	Trowel	431.3E-04	438.0E-04	0.00	448.0E-04	0.00/(0.00)
	Brick Tie Wall	Trowel	16.3E-04	23.7E-04	0.00	22.8E-04	1.0/ 1.0)
	Gap Wall	Trwl/Sht	13.3E-04	23.2E-04	16.00	5151.7E-04	29.70/(45.70)
12	Plain Wall	Trowel	169.7E-04	211.3E-04	0.00	258.2E-04	0.57/(0.57)
	Brick Tie Wall	Trowel	1934.7E-04	1823.0E-04	0.5	1908.0E-04	0.5/(0.5)
13	Plain Wall	Mechanical	24.4E-04	20.0E-04	0.00	19.0E-04	0.00/(0.00)
	Brick Tie Wall	Mechanical	69.8E-04	77.0E-04	0.00	77.0E-04	0.00/(0.00)
	Gap Wall	Mechanical	4.38E-04	10.1E-04	0.00	96.0E-04	0.00/(0.00)
14	Plain Wall	Mechanical	70.2E-04	71.0E-04	0.00	70.3E-04	0.00/(0.00)
	Gap Wall	Mechanical	58.0E-04	50.9E-04	0.00	50.1E-04	0.00/(0.00)
15	Plain Wall	Spry Applied	Non-Detect.	Non-Detect.	0.00	Non-Detect.	0.00/(0.00)
16	Plain Wall	Spry Applied	3.46E-04	5.8E-04	0.00	3.5E-04	0.00/(0.00)
17	Plain Wall	Spry Applied	Non-Detect.	Non-Detect.	0.00	Non-Detect.	0.00/(0.00)

that are airtight. CMHC wants to get this information to designers and practitioners in the interests of better quality housing.

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