Wetting pattern of sheathing panels in wood stud walls

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ABSTRACT

Water infiltration in wood frame walls leads to different water transport phenomena: water runoff and spreading of water on the sheathing, water infiltration into the insulation, water flow on the bottom plate and into the bottom plate-sheathing joint, water uptake by sheathing, stud and bottom plate, and leakage of water from the joint sheathing-bottom plate. A laboratory test was designed to quantify the different transport flows. For the water infiltration rates and duration tested, water infiltration into the insulation and leakage are found likely to occur. Water uptake and spreading of water on the sheathing can lower these flows. OSB and fibreboard show no spreading. The spreading of plywood depends on the surface characteristics and fiber direction. Leakage will more likely occur at high infiltration rates. The amounts of water flowing on the bottom plate and taken up by the bottom plate are more limited. Water infiltrating at the stud and flowing down the stud into the stud-bottom plate joint, will be substantially taken up by the stud in longitudinal direction.

INTRODUCTION

Rain is one of the main causes of moisture damage to the building envelope, leading to problems such as frost and salt damage, discoloration by leaching, soiling by differential washing, etc. Rain infiltration past the cladding and into the back wall can result in mould and rot growth, deterioration of wood components, and corrosion of metal components and fasteners. Different water shedding features (cornices, sills, copings) are commonly used to move away the driving rain from the façade in order to restrict direct exposure of the wall to the rain. The potential of deterioration due to rain depends on the façade material, the junction of building envelope components, the overall geometry of the building, but mainly on the occurrence of incorrect detailing, installation errors and defects.

Nowadays, the rain screen approach is commonly used for outside walls. It uses the outside layer only for rain control, behind which an air layer (cavity) allows pressure equalization and water drainage, and a second layer for airtightness. Façade systems can be further subdivided in systems with or without rain buffering capacity of the outside layer. When run-off occurs in such façade systems, rain may penetrate at junctions of components towards the inner layers, leading to damage along its path. Examples of failures due to rainwater infiltration failures have been seen in Vancouver (Barrett 1998), in Seattle (Karagiozis and Desjarlais 2003) and in North Carolina. In these cases, rainwater infiltrated into the second layer (referred to as back wall), and resulted in severe moisture accumulation and deterioration of the back wall.

Little work has been done to quantify water runoff on building facades. Experimental measurements have been done by Couper (1974) and numerical modeling by Blocken and Carmeliet (2004a) and by Blocken et al. (2002b). However, much remains to be done to combine the wetting effects of impinging wind-driven rain and water runoff. So far, models have been developed to predict impinging wind-driven rain, e.g. that of Choi (2000), Straube and Burnett (2000), and Blocken and Carmeliet (2002a). They require the rate of horizontal rainfall, the wind speed and wind direction as input data, and are typically selected from weather databases for a given climate. One model reproduces the wetting and run-off of a glass surface (Carmeliet et al. 2006).

Little field measurements of actual rain infiltration into the back wall have been documented. Some extensive laboratory tests have been done to characterize and quantify wind-driven rain infiltration in wall assemblies (Bomberg et al. 2002; Lacasse et al. 2003). It was shown that wind-driven rain infiltration in wall systems depends on the quantity of water and air pressure difference at the defect location, and geometry and location of the defect. However, envelope defects have not been evaluated stochastically. For the purpose of water infiltration research, it is therefore difficult to reproduce a "typical" defect and quantify the infiltration characteristics. Nevertheless, experimental work has been done by Teasdale-St-Hilaire and Derome (2006) and in the framework of the MEWS project (Lacasse et al. 2003) to determine rate of water infiltration.

Experimental tests on walls with simulated rain infiltration have focused at documenting primarily the drying, and in some cases the wetting, of wall assemblies as summarized in Teasdale-St-Hilaire and Derome (2005). Although some field studies are known, little experimental work was found that attempted to document the distribution of rain water in walls assemblies with different sheathings.

In this paper, the following questions will be addressed: when rain penetration occurs in wood-frame walls, which pathways the water will likely follow, which parts of the wall become wet and what is the influence of infiltration rate, position of infiltration, type of sheathing material, etc. In the first part of the paper, possible pathways of the infiltrating water and possible wetting of materials are discussed. In the second part, the methodology and results of the experimental work performed are presented.

FLOW PHENOMENA DURING WATER INFILTRATION

When liquid water penetrates into the wood frame wall, different phenomena can be distinguished: infiltration, runoff, spreading, uptake, leakage and evaporation.

INFILTRATION

The quantity, rate and location of water infiltration depend on the driving rain load and type of defect. Three infiltration rates, 6, 12 and 18 ml/h were utilized in the experiments. These insertion rates were taken from Teasdale-St-Hilaire and Derome (2006), who determined infiltration rates for defects at windows sills, using sprayed water infiltration tests and wind-driven rain calculated using the method from Blocken and Carmeliet (2002a). Below windows, three main locations of liquid water penetration can be distinguished (Figure 1). Water penetration may occur in the middle of the sheathing or at a stud position. When infiltration occurs at the stud, water can penetrate at the connection of stud and sheathing or more in the centre of the stud.

RUNOFF

Water that has infiltrated into the back wall will run down on the surface of the sheathing or stud. The runoff is driven by gravity and will therefore follow a rather vertical path. Irregularities on the surface or the presence of the insulation in contact with the sheathing or stud may influence the exact path of the water flowing down. Surface tension effects may also play a role leading to spreading of water.

SPREADING

The water running down on the sheathing or wood may spread in the horizontal direction by surface tension effects. Surface tension effects depend among others on the contact angle between water and surface material. Contact angles lower than 90° may favour the spreading of water. Spreading of water on the sheathing depends also on the wood fibre orientation of the surface: spreading will be favored in the wood fibre (longitudinal) direction.

Water reaching the bottom plate may spread on the bottom plate forming puddles or liquid films. Water may also penetrate in the sheathing-bottom plate joint and spread in this gap by capillary forces and surface tension effects.

Water running down the stud or water on the bottom plate can infiltrate into the gap between the wood stud and bottom plate.

UPTAKE OF LIQUID WATER BY MATERIALS

The liquid water present on material surfaces (stud, sheathing, bottom plate) may be taken up by capillary action. The water uptake rate depends on the type of material. Water present on the sheathing is taken up in a direction normal to the sheathing surface. Water in the gap between stud and bottom plate is taken up by the stud in the longitudinal direction. Water on the bottom plate is taken up by wood in the tangential and/or radial direction, which is known to be much slower than uptake in the longitudinal direction. Water may also be taken up by the insulation material by gravity or capillary forces.

LEAKAGE

When liquid water flows out of the gap between bottom plate and sheathing, this phenomenon is addressed as leakage. Leakage is mainly caused by gravity.

EVAPORATION AND DRYING

During infiltration, runoff, spreading and uptake, water will start to evaporate from the liquid water surfaces or from the wet material surfaces. The evaporation rate will depend on local boundary conditions like temperature and relative humidity, but also on the surface mass coefficient, which depends on the local air flow velocity and temperature.

The focus of this paper is to identify the different infiltration, runoff and spreading paths, and to quantify the water uptake of the different materials and the leakage. Common materials for the sheathing will be studied. Parameters are the infiltration rate and infiltration location.

MATERIAL PROPERTIES

Three different sheathing materials were used: plywood (rough finish, general type), oriented strand board (OSB) and asphalt-coated fibreboard. For plywood, two specimens were measured (A and B). The following material properties were determined: dry density, capillary absorption coefficient, dynamic contact angle and wetting width.

DRY DENSITY

The dry density of the different components is obtained by determining the dry weight and volume. The densities are given in Table 1. The values are the average of four specimens.

CAPILLARY ABSORPTION COEFFICIENT

In a water uptake experiment, a dry specimen, waxed at the edges, is brought in contact with a free water surface at the bottom side and the cumulative uptake of water is measured by weighing. The slope of the cumulative uptake curve per square meter versus square root of time is called the capillary absorption coefficient A_{cap} , which is a measure for the rate of water uptake. The measurement results are given in Table 1. The values are the average of more than four specimens.

It is observed that wood has a higher capillary absorption coefficient A_{cap} in longitudinal direction (0.0070– 0.0080) than in tangential direction (0.0019-0.0029).

Plywood shows a high variation in A_{cap} (0.0017 to 0.0031) when comparing the two different specimens A and B. OSB has an A_{cap} comparable to plywood specimen B. Fibreboard has a lower A_{cap} (0.0010).

For plywood, the penetration depth of water was determined visually after sawing the specimen at different times during the test. It was found that the penetration depth after 210 minutes is limited to the first layer.

DYNAMIC CONTACT ANGLE

The dynamic contact angle for the sheathing is measured by the optical sessile drop method. A micro-droplet of water (1 ←l) is positioned on the material surface and the shape of the water droplet as a function of time is photographed. The shape of the droplet is approximated by an ellipse, and the left and right contact angles between the ellipse and the material surface are determined. The average contact angle at the beginning and end of the test (after approx. 3 min.) are given in Table 1. At the end of the test, the microdroplet is taken up by the sheathing or starts to evaporate significantly. For plywood and OSB, the contact angle is strongly dynamic and decreases with time. For fibreboard, the contact angle remains rather constant. We may conclude from Table 1 that fibreboard remains hydrophobic (> 90°) while OSB and plywood are found to be initially hydrophobic, but become rapidly wet after 20 seconds.

WETTING WIDTH

The wetting width of the sheathing is determined in a water spreading test. Water is deposited on the sheathing surface using a syringe and electrical pomp. The deposition location is at the top of a vertical sheathing at a rate of 12 ml/h. Photos of the wetting pattern are taken every 30 seconds. The width of the wetted sheathing area averaged over the height is determined. It was found that after 30 minutes no further spreading occurred. Table 1 and 2 give the average wetting widths after 30 minutes. Two specimens of plywood A and B were analysed with the wood fibre direction of the finish layer perpendicular to the runoff direction (referred to as horizontal). Plywood specimens 1, 2 and 3 have the wood fibre direction in vertical direction (parallel to runoff direction).

Both OSB and fibreboard show almost no spreading (wetting width limited to 2 mm). For plywood with the wood fibre direction parallel to the runoff direction, the wetting width remains limited to 10 to 15 mm. For the two plywood specimens with the wood fibre direction perpendicular to the runoff direction, the wetting width shows a high variation: from 35 mm for specimen A to 4 mm for specimen B. The difference in wetting width between specimen A and B is remarkable since Table 1 shows that the dynamic contact angle for both specimens is comparable. It is however noted that the contact angle measurement, where a micro-droplet is deposited on the surface, is a microscopic surface property and should be used with care. The spreading test consists of continuously depositing macro-droplets. It was also remarked that plywood A was older and had a much rougher surface. Plywood B was newer and had a glossy surface.

Finally, a correlation between spreading width and capillary absorption coefficient has been noted: a high capillary absorption coefficient means a higher spreading width.

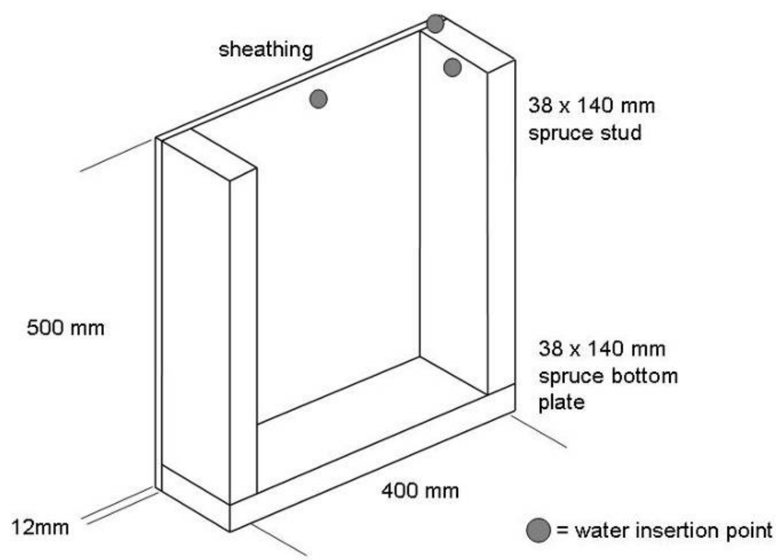

Figure 1 Schematic representation of the test set-up for water infiltration test where the insulation is not included to show all wood components.

Table 1. Material properties

	Capillary absorption coefficient ($kg/m^2s^{½}$)	Dynamic contact angle (°)	Wetting width after 30 min (mm)	Density (kg/m^3)
A Plywood wood fibre horizontal	0.0031	110→20	35	485
Stud tangential	0.0029			468
Stud longitudinal	0.0081			468
Bottom plate tangential	0.0019			461
B Plywood wood fibre horizontal	0.0017	120→10	4	454
Stud tangential	0.0022			432
Stud longitudinal	0.0073			432
Bottom plate tangential	0.0019			450
C Fibreboard	0.0010	138→136	2	249
D OSB	0.0019	100→40	2	539

Table 2. Wetting width for plywood specimens

	Wetting width after 30 min (mm)	Wood fibre direction
Plywood A	35	horizontal
Plywood B	4	horizontal
Plywood 1	10	vertical
Plywood 2	15	vertical
Plywood 3	10	vertical

It can be concluded from the material properties measurements that:

- The spreading of water on the sheathing highly depends on the type of material. A correlation is observed between the capillary absorption coefficient and the spreading width. A correlation with the contact angle, measured using the optical sessile drop method, is less probable.
- OSB and fibreboard show no spreading.
- The spreading of water on the surface of plywood can vary significantly and depends on the wood fibre direction and surface characteristics.
- Wood has a higher capillary absorption coefficient in longitudinal direction and a lower in radial and tangential direction.

WATER INFILTRATION TEST

The test specimens are built out of a wooden (SPF) bottom plate, two SPF studs, sheathing and glass fiber insulation (Figure 1). Four sheathing materials are considered: plywood A with a high water spreading width, plywood B with a low water spreading width, fibreboard and OSB. Liquid water is inserted using a syringe and an electrical pump at the top of the specimen. Three different positions are considered: the middle of the sheathing, at the stud in the centre of the cavity and at the sheathing – stud joint (Figure 1). Each test lasts 210 minutes, which equals the average duration of a driving rain event in August in Montreal, Canada (Teasdale-St-Hilaire and Derome, 2006). Three different water insertion rates are applied: 6, 12 and 18 ml/h.

At regular times during the test, the specimens are disassembled and the following water amounts are measured by weighing:

- the weight increase of the different components (sheathing, stud, insulation and bottom plate) after removing the surface water
- the surface water on the bottom plate (using a blotting paper)
- the amount of water leaking out of the bottom plate-sheathing joint

Photos were taken of the water patterns on the sheathings. Then, the specimens are reassembled and the test resumes.

Figure 2 shows the water pattern on the sheathing after 210 minutes for plywood A and B (infiltration rate of 12 ml/h). For plywood A, surface wetting is observed in the middle of the sheathing over a width comparable with the width measured in the water spreading test (see section on material properties). For plywood B, the spreading of water is not observed. Figure 2a shows a surface wetting at the bottom over the whole width of the sheathing. The surface wetting at the bottom is due to water spreading in the sheathing - bottom plate joint in the horizontal direction. The wetting pattern shows that the whole joint is filled by water. From the joint, water is also taken upwards by the sheathing in vertical direction. Plywood B shows only surface wetting at the bottom of the sheathing. OSB and fibreboard show almost no surface wetting in the middle or at the bottom of the sheathing.

(a) (b)

Figure 2. Wetting pattern of sheathing after 210 minutes of wetting at a rate of 12 ml/h.
(a) plywood A; (b) plywood B.

Figures 3a-c give the mass ratio as a function of time respectively for the sheathing, insulation and bottom plate. The mass ratio is defined as the total amount of water measured in the material, M, at time t divided by the total mass of water infiltrated, M_T. The infiltration rate is 12 ml/h. Table 3 gives the ratio of measured water mass to the total mass of water infiltrated at the end of the test. This balance of the infiltrated water does not account moisture uptake in studs and evaporation.

Figure 3a and Table 3 show that plywood A takes up a large part of the infiltrated water compared to plywood B, OSB and fibreboard. The large uptake of water by plywood A can be explained by the high capillary water absorption coefficient and the large surface wetted by spreading water. The mass ratio of water taken up decreases with time, since water uptake and spreading are proportional to the

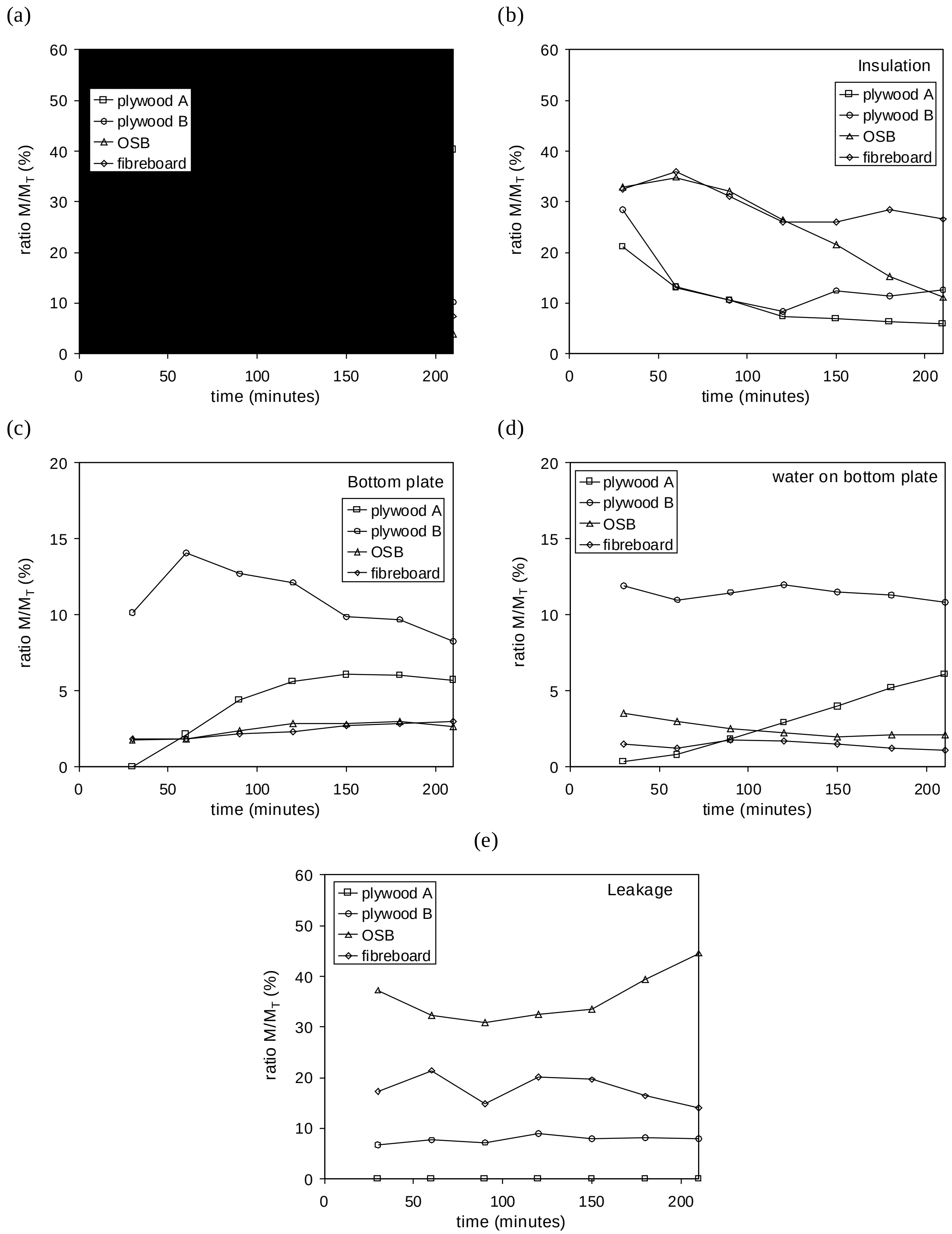

Figure 3. Mass ratio as a function of time for plywood A, plywood B, OSB and fibreboard, infiltration position in the middle of the sheathing: (a) sheathing; (b) insulation; (c) bottom plate; (d) water on bottom plate; (e) leakage.

square root of time. Drying may also play a role in the mass decrease; the higher wetted surface area also increases the drying capacity. The smaller mass gain by water uptake for plywood B, OSB and fibreboard can be explained by the limited surface wetting and smaller capillary absorption coefficient.

Figure 3b shows that water infiltration in the insulation occurs for all sheathing materials. With time, the ratio of water taken up reduces or levels off. At the end of the test, in plywood A, which takes up itself a lot of water, the water amount in the insulation is smaller (6 %). For fibreboard, which takes up itself only 7 % of water, the insulation is wetted up to 27 %. It can be concluded that water buffering by the sheathing can limit significantly the amount of water infiltrating in the insulation. It is also observed that the water in the insulation may be taken up from the water remaining on the bottom plate.

Figure 3c shows that the amount of water taken up by the bottom plate is limited (less than 15 % of the infiltrated water) due to the low capillary absorption coefficient of wood in the radial and transverse directions. Comparing Figures 3c and 3d, it is found that specimens having a significant amount of water on the bottom plate surfaces also show the highest water uptake by the bottom plate.

Figure 3e shows that plywood A has no leakage since most of the water is buffered by the sheathing material. In contrast, in the case of OSB where water uptake by the sheathing and insulation was limited, leakage is above 30 % and goes up to 45 % at the end of the test. Finally, for fibreboard, showing less buffering but where more water is taken up by the insulation, the leakage is lower (between 14 and 20%).

Table 3. Mass ratio of measured water mass to the total mass of water infiltrated at the end of the test. The infiltration rate is 12 ml/h and is located at the center of the cavity..

Mass ratio (%)	Plywood A	Plywood B	OSB	fibreboard
Sheathing	40	10	4	7
Insulation	6	13	11	27
Bottom plate	6	8	3	3
Leakage	0	8	45	14
Water on bottom plate	6	11	2	1

Figure 4 gives the mass ratio of water taken up by the stud for the cases of water infiltration at the stud in the middle of the cavity and at the stud–sheathing joint. The amount of water taken up by the stud at the end of the test ranges between 24 to 34 % of the infiltrated water. The water is primarily taken up by the stud in longitudinal direction from the bottom plate-stud joint, which is filled by water running down the stud surface. At the beginning of the test, the mass ratios may vary a lot.

Figure 5 gives the mass ratio of water taken up at the end of the test by the sheathing and the bottom plate and the leakage as a function of the infiltration rate. A constant mass ratio for leakage means that the leakage increases linearly with the infiltration rate. An increase of the mass ratio for leakage means that pathways for water to leak become more likely. It should be noted that for these tests, the specimen did not contain an insulation layer.

Plywood A shows no leakage for infiltration rates lower than12 ml/h. Leakage becomes more likely at high infiltration rates, which can be explained by the fact that additional buffering of infiltrated water by the sheathing becomes less probable. The likelihood for water flowing down to be taken up by the bottom plate increases also slightly with the infiltration rate. For Plywood B, which shows less buffering by the sheathing, the probability for leakage increases dramatically with the infiltration rate. Therefore, the risk of leakage increases with infiltration rate. Sheathing materials showing buffering capacity may lower this risk.

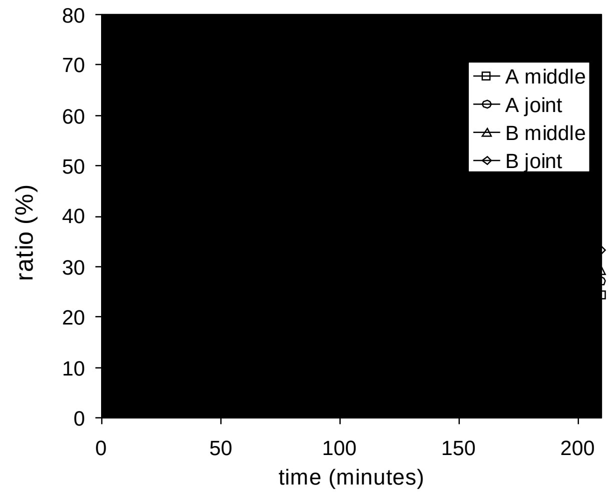

Figure 4. Mass ratio as a function of time for two different infiltration positions at the stud for plywood A and plywood B

(a) (b)

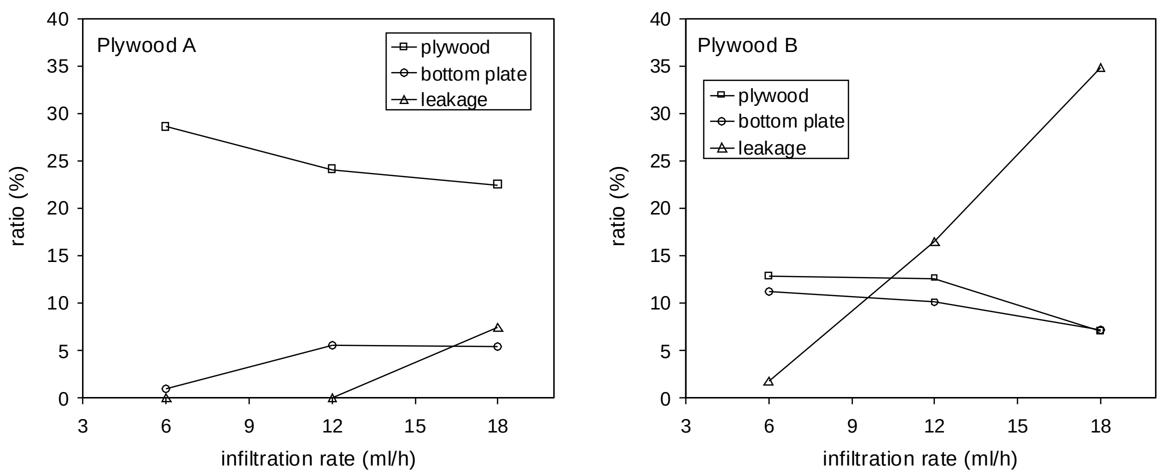

Figure 5 Mass ratio as a function of the infiltration rate for infiltration position in the middle of the sheathing: (a) plywood A; (b) plywood B.

CONCLUSIONS

In this paper, water infiltration in wood frame walls was studied, and different paths for water runoff and spreading, water uptake and leakage were identified. A laboratory test was designed, where water was inserted with constant infiltration rate at different positions. It was found that, depending on the material, water not only runs down the sheathing, but can also spread laterally. This spreading can increase substantially the water uptake by the sheathing. OSB and fibreboard show no spreading. The spreading of plywood depends on the surface characteristics, such as the wood fibre direction. Water uptake by the sheathing also depends on the capillary absorption coefficient. Experimental results show that sheathing materials with a high capillary water absorption coefficient show also a larger spreading of water in horizontal direction.

Apart from wetting the sheathing, water may also infiltrate into the insulation. Infiltration was found in all cases, with values ranging between 10 and 30 % of the total amount of water inserted in the wall. Water uptake by the sheathing can lower the infiltration quantity.

When water reaches the bottom plate, it will partly flow onto the horizontal surface of the bottom plate, where it can be taken up by the bottom plate, or it will flow into the sheathing-bottom plate joint. Depending on the characteristics of the sheathing, water will spread horizontally and may fill the joint over a certain width. Plywood was found to promote spreading of water in the joint in contrast to OSB and fibreboard.

Water may leak out of this joint. High leakage amounts up to 40 % of the infiltrated water were found for sheathing materials with no buffering capacity and where the infiltration of water in the insulation is limited. When water infiltration into the insulation is more pronounced, the leakage lowers to 20 % of the infiltrated water. For sheathing materials with more buffering capacity or which promote water spreading, the leakage percentage lowers to less than 10 % and is even nil for sheathing materials with high buffering capacity. The risk for leakage depends on the infiltration rate, with high infiltration rates increasing the potential for leakage. For buffering sheathing materials, the risk for leakage remains substantially lower.

Results indicate that the amount of water flowing on the bottom plate is limited: less than 15 % of the infiltrated water. The water on the bottom plate is partly taken up by the bottom plate. The amount of water taken up by the bottom plate correlates with the water flowing on the bottom plate. When water infiltrates at the stud, it will flow down the stud into the stud-bottom plate joint, where it is taken up by the stud in longitudinal direction. Values of 30 to 40 % of the infiltrated water may be expected.

For all the results presented, the test was performed on initially dry assemblies. The measurement of the distribution of water in assemblies previously wetted and subjected to a second water infiltration test was not performed. Finally, when studying damages and remedial measures for water infiltration into wood frame constructions, not only phenomena like water uptake by the sheathing or bottom plate, but also water infiltration in the insulation and leakage through the bottom plate-sheathing joint should be addressed. In addition, when infiltration occurs at the stud, water uptake by the stud at the stud-bottom plate joint has also to be addressed.

REFERENCES

Barrett, D. 1998. The renewal of trust in residential construction. Commission of enquiry into the quality of condominium construction in British Columbia. Report submitted to the Lieutenant Governor in Council of the Government of British Columbia. June. http://www.qp.gov.bc.ca/condo/ Website accessed December 20, 2003.

Bomberg, M.T.; Rousseau, M.Z.; Desmarais, G.; Nicholls, M.; Lacasse, M.A. 2002. Report from Task 2 of MEWS Project - Description of 17 Large Scale Wall Specimens Built for Water Entry Investigation in IRC Dynamic Wall Testing Facility. Ottawa: National Research Council, Institute in Construction, Oct., RR-111, 142 pp. http://irc.nrc-cnrc.gc.ca/fulltext/rr111/

Blocken, B., and Carmeliet, J. 2002a. Spatial and temporal distribution of driving rain on a low-rise building. Wind & Structures: An International Journal. Taejon, Korea: Techno-Press, vol. 5, no. 5, pp. 441-462.

Blocken B, Janssen H, Carmeliet J. 2002b. On the modelling of runoff of driving rain on a capillary active surface. Proceedings 11th Symposium for Building Physics, Dresden, Germany, 26-30 September, 2002, pp. 400-408.

Blocken B, Carmeliet J. 2004a. On the accuracy of wind-driven-rain measurements on buildings. Submitted to Building and Environment.

Carmeliet J, Rychtarikova M. and B. Blocken. 2006. Numerical modelling of impact, runoff and drying of wind-driven rain on a window glass surface, Research in Building Physics and Building Engineering – Fazio, Ge, Rao and Desmarais (eds), London, pp. 905-912.

Choi, E.C.C. 2000. Variation of wind-driven rain intensity with building orientation. Journal of Architectural Engineering, New York: American Society of Civil Engineers, vol. 6 no. 4, Dec., pp. 122-128.

Couper, R.R. 1974. Factors affecting the production of surface runoff from wind-driven rain. 2nd International CIB/RILEM Symposium on Moisture Problems in Buildings. Rotterdam, The Netherlands, September 10-12, paper 1.1.1.

Karagiozis, A. and Desjarlais, A. 2003. What influences the hygrothermal performance of stucco walls in Seattle. 9th Conference on Building Science and Technology, Vancouver, B.C. February 27-28, pp. 32-44.

Lacasse, M.A., O'Connor, T.J., Nunes, S. Beaulieu. P. 2003. Report from Task 6 of MEWS Project: Experimental Assessment of Water Penetration and Entry into Wood-Frame Wall Specimens – Final Report. Ottawa, Ont.: National Research Council, Institute for Research in Construction, RR-133, Feb., 308 p. http://irc.nrc-cnrc.gc.ca/fulltext/rr133/

Straube, J. F. and Burnett, E. F. P. 2000. Simplified prediction of driving rain on buildings. Proceedings of the International Building Physics Conference, Eindhoven, the Netherlands: Eindhoven University of Technology, pp. 375-382.

Teasdale-St-Hilaire, A., Derome, D. 2005. State-of-the-Art Review of Simulated Rain Infiltration and Environmental Loading for Large-Scale Building Envelope Testing, ASHRAE Transactions, American Society of Heating, Refrigerating and Air-Conditioning Engineers, vol. 111, pt 2, June, 13 p.

Teasdale-St-Hilaire, A., Derome, D. 2006. Methodology and Application of Simulated Wind-Driven Rain Infiltration in Building Envelope Experimental Testing, ASHRAE Transactions, American Society of Heating, Refrigerating and Air-Conditioning Engineers, vol. 112, pt 2, June, 13 p.