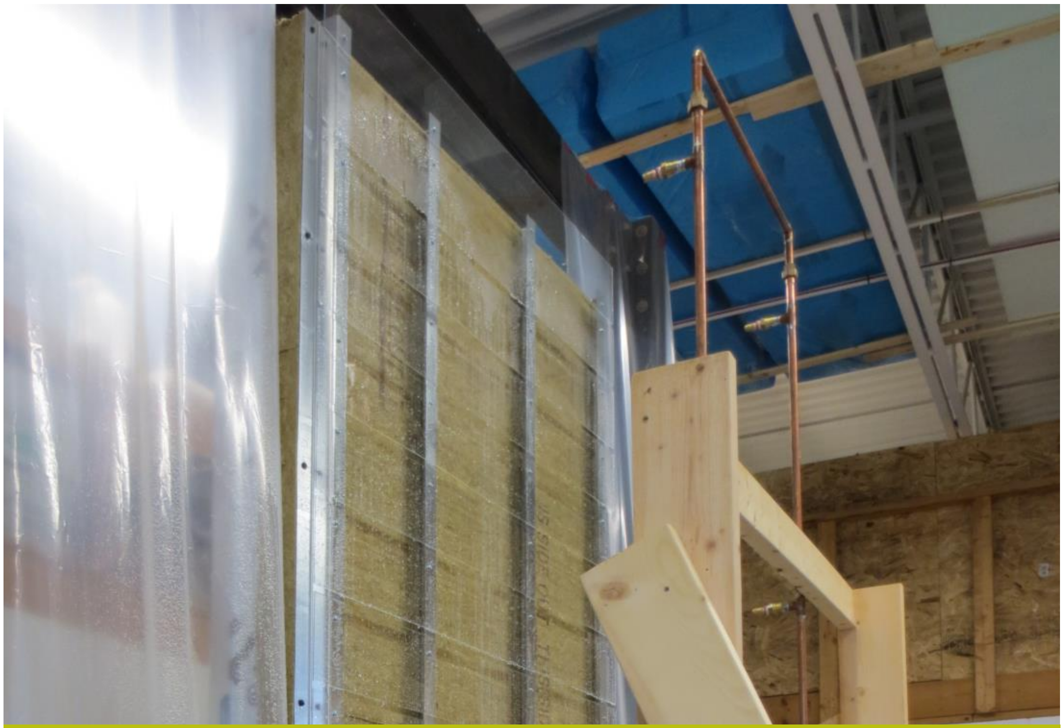
RDH BUILDING SCIENCE LABORATORIES

Moisture Durability of Stone Wool Insulation | Project 21267.000

ROCKWOOL, 8024 Esquesing Line, Milton, ON



To Ms. Alejandra Nieto
ROCKWOOL
8024 Esquesing Line
Milton ON L9T6W3

Submitted September 30, 2020 by
Jonathan Smegal, MASc
Graham Finch, MASc, P.Eng
Aaron Grin, MASc. P.Eng
RDH Building Science Laboratories
167 Lexington Court #6
Waterloo ON N2J 4R9

Introduction

Constructing buildings with continuous exterior insulation reduces thermal bridging and heat loss through the enclosure. It has also been repeatedly shown to reduce moisture durability risks related to cold weather condensation. However, persistent questions from within the construction industry indicate a concern that ROCKWOOL® stone wool insulation will absorb water when installed on the exterior of walls because of its fibrous nature, potentially reducing the thermal performance and moisture durability of the assembly.

This report provides context to address these concerns and summarizes related evidence from field investigations, laboratory studies, and field research. Control functions of the enclosure are reviewed and the performance of exterior stone wool insulation in comparison to other insulation types is analysed. Discussion is limited to wall assembly applications, for both residential and commercial construction.

Control Layers of the Enclosure

The functions of a building enclosure can be broken into three main categories including support functions, control functions, and finish functions (Straube 2005).

The most common control functions related to the long-term durability of the enclosure and the health and comfort of the occupants are rain control, air leakage control, thermal control (i.e., control of heat loss), and water vapor control. The continuity of control layers, especially at penetrations, connections, and interfaces between materials, is critical to a successful enclosure. Poor continuity and the resulting moisture accumulation cause most enclosure durability problems, because moisture gets in through rainwater or air leaks. However, moisture can also accumulate for other reasons. The five most common sources of moisture within buildings (besides plumbing problems) are built-in construction moisture, rain leakage, air leakage condensation, vapor diffusion condensation, and surface condensation from thermal bridging.

Continuous insulation (c.i.), regardless of material type, has one primary function: thermal control. In addition to improving thermal efficiency, c.i. on the exterior of the structure has been repeatedly demonstrated to decrease the risk of enclosure moisture durability problems. Its position in the assembly also allows it to protect the other control layers from heat and cold. There are some exterior insulation products that can be detailed as the air and water control layer, but most c.i. assemblies rely heavily on other specialized materials and products to control rainwater and airflow. For example, Figure 1 shows three different wall assemblies with exterior c.i., and in each case, as is most typical, there is a layer of sheet-applied water resistive barrier (WRB) against the structural sheathing that acts as the drainage plane and in many cases the air control layer. This WRB layer is kept warmer and protected by the exterior c.i. If the ratio of exterior to interior insulation is sufficient, c.i. can also play a role in water vapor control by keeping the structure warm enough to decrease the risk of condensation and accumulation in colder climates. By keeping the sheathing and structure warmer, this insulation also warms the sheathing and backup framing, which increases the rate of possible vapor diffusion drying from these materials in the event of initially wet construction or an in-service leak.

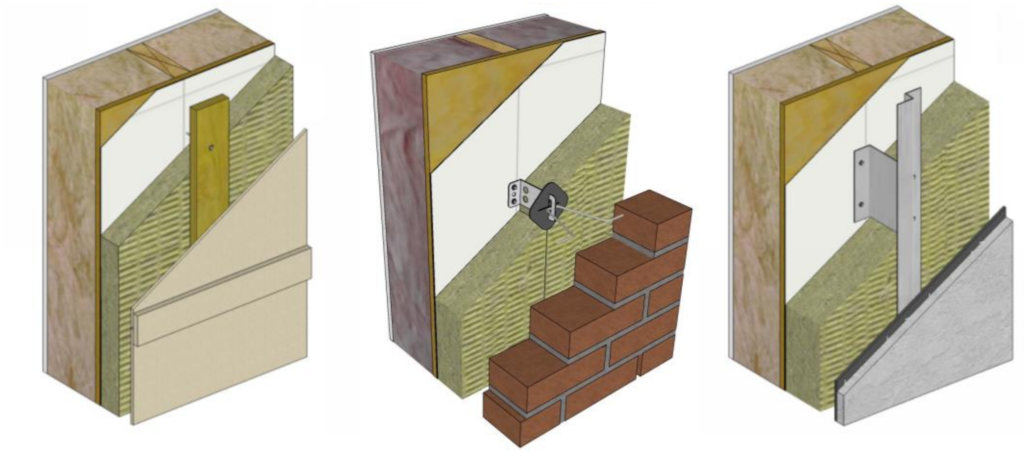


Figure 1 : Three typical wall assemblies with continuous insulation over the air/water barrier (Building Enclosure Design Guide, BC Housing, 2019).

To ensure thermal control continuity, all exterior insulation types need to be installed without substantial gaps to prevent airflow around and behind the insulation. Under certain circumstances, all exterior c.i. insulations may become wet, including XPS, EPS, polyisocyanurate, closed cell and open cell sprayfoam, wood fiber, and mineral wool. However, not all insulation types have the same water shedding and drainage and drying capacity. ROCKWOOL stone wool is manufactured to be hydrophobic and non-hygroscopic; where water is applied, it will bead up on the surface and run off. Stone wool insulation is also vapor and air permeable (i.e. it does not act as a vapor or air control layer); however, it is dense enough that wind washing does not affect its performance (Straube 2018).

Wetting and Drying of Continuous Insulation

To understand the role that wetting has on the exterior c.i., it is important to understand how insulation gets wet, how it dries, and what factors affect the wetting and drying of the insulation.

Insulation Wetting

Insulation installed on the exterior of a wall will be exposed to water in one of three ways:

1. Prior to construction, it is not uncommon for insulation to be stored on site, exposed to the elements. Even when insulation is wrapped in plastic, there are pathways for water to enter the packaging, resulting in sustained physical contact of water with the insulation.
2. Once the insulation is installed on the wall, it can be wetted by driving rain and/or snow/ice prior to installation of the cladding and of flashings, etc.
3. In-service, the insulation can experience wetting as a result of driving rain through an open-jointed cladding or issues with rainwater control details that drain water over insulation products. This may also include outward vapor flow from the building or inward vapor flow from saturated claddings or humid outdoor conditions.

Water can be forced into stone wool insulation by a sustained head pressure such as a spray nozzle, or by submerging it under water for an extended period of time. However, neither scenario is a likely or reasonable exposure for insulation used in an above-grade wall behind a cladding system. Even when stone wool insulation is left in direct contact with water for a short period, only a very small layer at the surface becomes wetted (see next section and Figure 2 below).

Laboratory Testing – Wetting of Stone Wool C.I.

To visually determine the extent of the wetting of ROCKWOOL stone wool insulation, small-scale material testing with the insulation in direct contact with water was conducted in a laboratory condition. Following direct contact with water on one face, for 24 hours, the insulation was cut in half and visually inspected using an infrared (IR) camera. The thermal image (Figure 2) indicates the temperature profile of the sample, where the wetted area is indicated by a lower temperature as a result of evaporation after it is removed from the water. The thermal image clearly indicates that wetting (purple area) occurred only at the edge that was in direct contact with the water in Figure 2. If the material were absorptive or hygroscopic, water would have been drawn up through the thickness of the material even if it was only the edge in contact. To demonstrate the fundamental difference in water uptake in comparison with an absorptive material, the same test was conducted using a brick. As noted, after only 3 hours, the water had risen nearly all the way to the top of the brick (Figure 3).

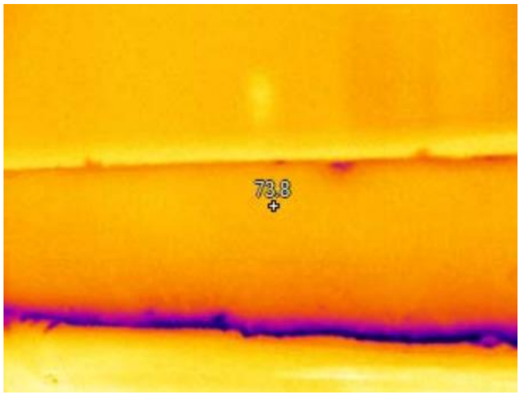


Figure 2 (left): Thermal image showing the extent of the water at the edge of the 2" thick ROCKWOOL® stone wool insulation sample following 24 hours in contact with water.

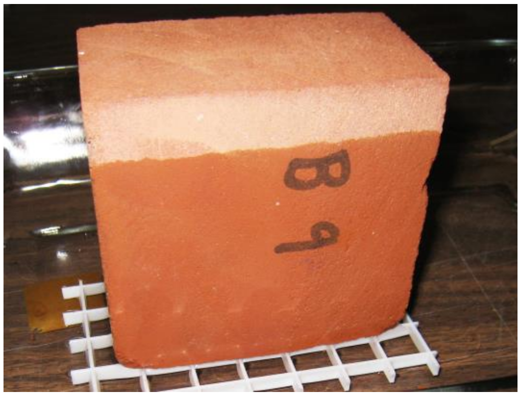


Figure 3 (right): Water wicking up absorptive brick after 3 hours in contact with water

To understand the wetting and water storage behind a cladding, large-scale wall assembly testing was conducted using ROCKWOOL stone wool exterior c.i. compared to XPS exterior c.i. (Smegal 2014b).

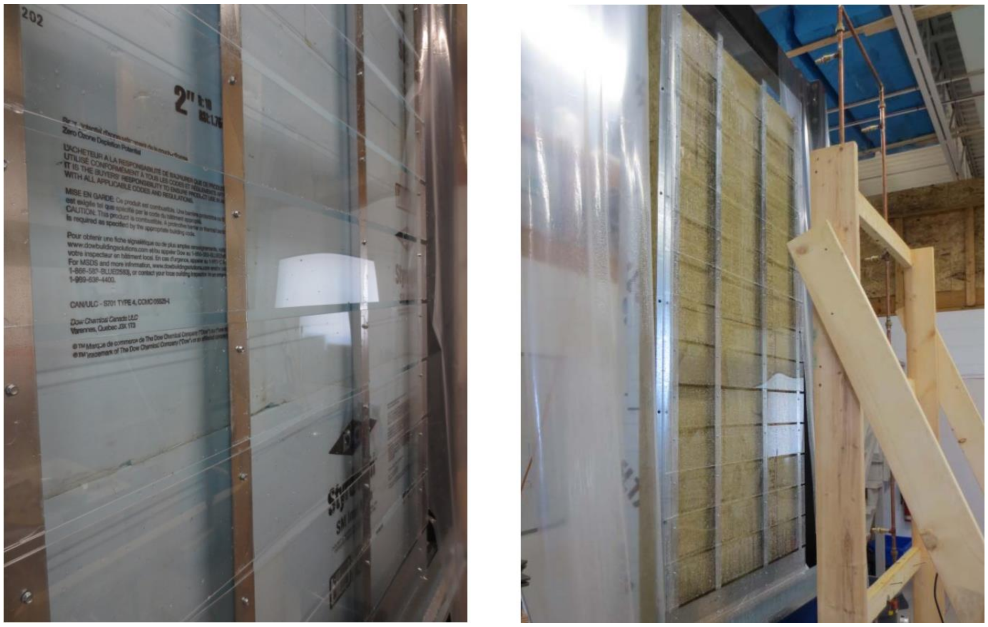


Figure 4 : Open-jointed cladding installed over both an XPS and ROCKWOOL® stone wool wall assembly.

Both walls had an identical open-joint cladding and used a spray rack to apply water to the wall. The water was applied horizontally so both the cladding and the insulation were wetted, at a rate of 2.6 GPM (9.8 L/min) for the test specimen based on ASTM E547*(ASTM 2000).* This water application represents a worst-case scenario since rainwater is typically applied at a driving rain angle, as opposed to horizontally, and the amount of water applied far exceeds a typical driving rain event.

On two comparison test walls that were identical except for the type of continuous exterior insulation, it was found that the ROCKWOOL stone wool wall held an extra 0.26 oz/ft^2 (79 g/m^2 or 0.079L/m^2) of water following a 10 min water application (26 gallons or 98 L of total water applied). A small amount of water was driven into the surface of the ROCKWOOL stone wool by the direct exposure to the water pressure of the horizontal spray nozzles, but the data shows that only a small amount of water was absorbed, with the remainder stored as droplets on the surfaces of the insulation and cladding, similar to the XPS wall assembly.

In a second drainage balance test, water collection troughs were added to the test walls as shown in the schematic in Figure 5 to measure the amount of water that was collected from each of the potential vertical surfaces in the assembly.

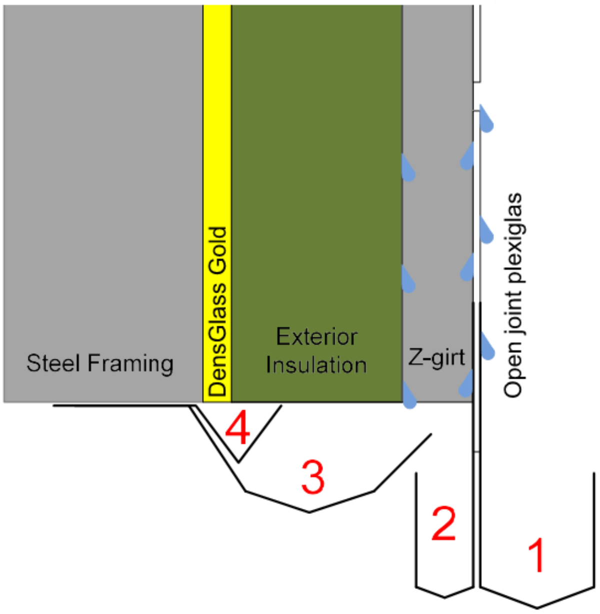


Figure 5: Water collection troughs shown on the wall schematic: 1) exterior surface of the cladding; 2) interior surface of the cladding; 3) exterior surface of the insulation; and 4) interior surface of insulation at the WRB.

Both the ROCKWOOL stone wool assembly and XPS assembly demonstrated nearly identical water collection at all the collection troughs, with over 30% collected on the exterior side of the cladding and over 20% behind the cladding. Approximately 30% of the water drained off the exterior surface of the insulation in both cases. The remaining water deflected off the cladding and onto the floor, missing the troughs altogether. Since no water was collected off the WRB behind the insulation in any of the spray rack tests (Collection Trough 4), it can be said that the ROCKWOOL stone wool did not absorb an excess amount of water.

Insulation Drying

The most durable construction materials have a balance of wetting and drying. As long as the wetting doesn't exceed the ability to dry, overwhelming the safe storage capacity of the material/assembly, then there is little risk of moisture-related issues. The safe storage capacity and drying ability are different for all materials and assemblies.

There are four main mechanisms for drying and moisture redistribution in materials and assemblies:

- Drainage of liquid water in drainage gaps, and from oversaturated materials
- Evaporation from the surface of wet materials via forces such as heating or wind
- Capillary wicking in hygroscopic materials from areas of high concentration to areas of low concentration
- Desorption of adsorbed vapor

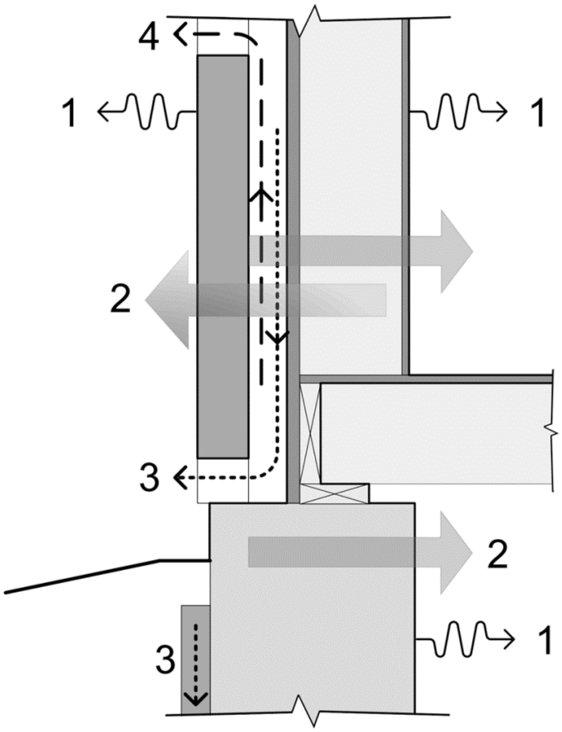


Figure 6: Moisture removal mechanisms from a wall assembly. (Straube and Burnett, Building Science for Building Enclosures).

Because of the air and vapor permeable nature of ROCKWOOL stone wool insulation, it will dry relatively quickly compared to other construction products. For example, if an area of ROCKWOOL stone wool insulation becomes wetted, any excess water will drain to the bottom, and water will also evaporate from the surface of the insulation and from within the insulation. Because it is non-hygroscopic, water will not be held within the ROCKWOOL stone wool insulation unless it is submerged in water. In a plastic foam insulation that becomes wetted, liquid water cannot move easily within the structure to the surfaces to evaporate, and the vapor permeance of the foam plastic insulation is much lower meaning that vapor can not diffuse out of the insulation very quickly.

Laboratory Testing – Drying of ROCKWOOL Stone Wool Exterior C.I.

To visualize the drying potential of ROCKWOOL stone wool insulation, small-scale material testing was conducted by placing the large surface of a 12”x12” (305x305mm) insulation sample in direct contact with water for 48 hours. Following the wetting, and the immediate runoff/drainage off the surface of the sample, the sample was placed vertically as it would be in a wall assembly, and drying was monitored by thermal imaging and periodic weighing of the sample. The initial weighing of the sample indicated that the ROCKWOOL stone wool stored approximately 0.6 oz (17 g), which is the equivalent of 0.6 oz/ft^2 (182g/m^2). Figure 7 and Figure 8 show the change in weight graphically on the left, and the thermal imagery of the wet surface of the ROCKWOOL stone wool insulation on the right. There were no driving forces applied to the insulation such as heat or air movement to aid in drying of the surface. As water evaporates, surfaces cool down, and will look colder on a thermal image relative to the surrounding area.

Approximately 90% of the 0.6 oz (17 g) had dried after 2 hours, and 98% had dried after 3 hours (Figure 8). The thermal imaging showed that there was some drainage and redistribution of the moisture in the insulation to the bottom since the bottom edge was the last place to dry. The redistribution to the bottom means that most of the sample is dry and performing normally, as expected, and only a small portion of the surface area is wet and performing at a slightly reduced R-value until it dries completely.

This test was intended to be conservative, a worst-case scenario, and overestimates the amount of water that ROCKWOOL stone wool insulation will store in a wall system where it is installed vertically. Results suggest that in the event water accumulates from a detail such as a Z-girt through the flashing, ROCKWOOL stone wool insulation will dry quickly.

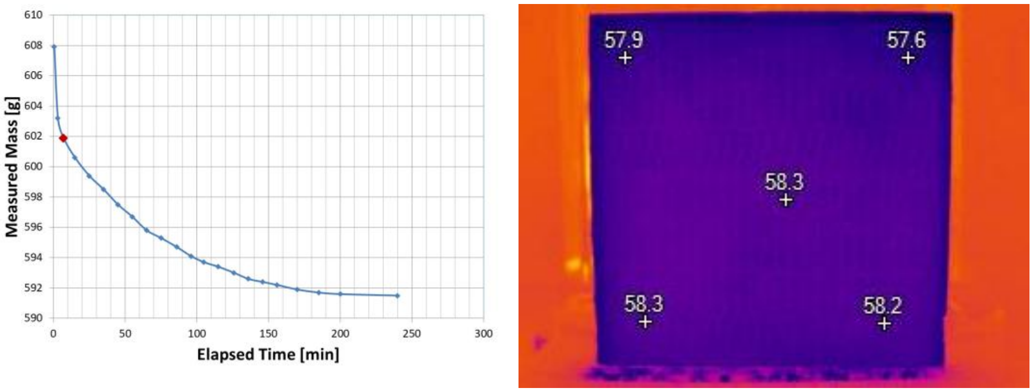


Figure 7: ROCKWOOL® stone wool sample mass and thermal image at 7 minutes of drying, showing surface temperatures in ˚F.

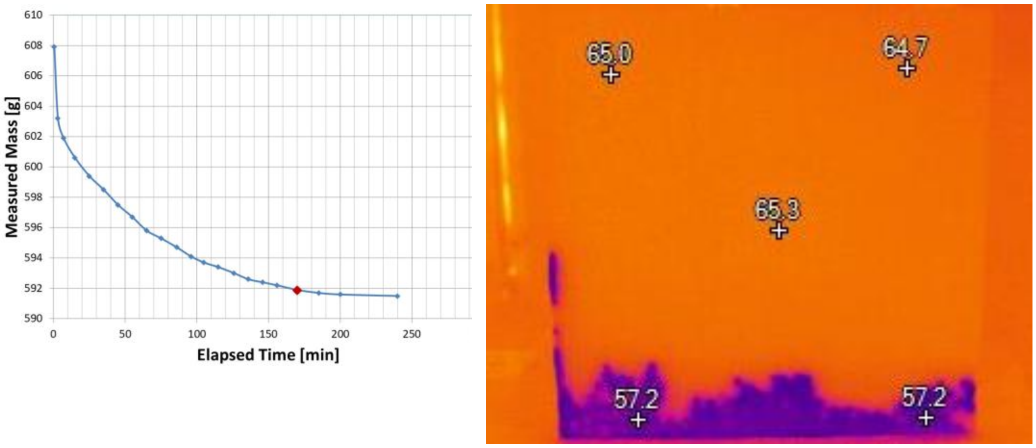


Figure 8: ROCKWOOL® stone wool sample mass and thermal image at 2 hours and 50 minutes of drying, showing surface temperatures in ˚F.

Full-scale ROCKWOOL stone wool drying demonstration was conducted using the spray rack and wall balance test that was discussed previously in the wetting section. Figure 9 shows a drying comparison of 6 walls that were wetted with the spray rack at 2.6 GPM (9.8 L/min) for the entire wall area for ten minutes for a total of 26 gallons (98L). The graph shows that the three walls constructed with extruded polystyrene (XPS) shown by blue, red, and green lines did store slightly less water than the ROCKWOOL stone wool walls (orange, teal, purple lines), as was previously mentioned in the wetting section.

Following the spray rack wetting on the assemblies, drying was monitored in the lab without any forces affecting the drying such as temperature gradients or air pressures. The laboratory space is not tightly controlled but was approximately 20˚C and 45% RH during the drying. At approximately the 3-hour mark following the completion of the wetting event, both walls were very similar in total stored water (Figure 17). These results demonstrate that the drying of both the XPS and ROCKWOOL stone wool walls, when subjected to a simulated driving rain event with an open-joint cladding, dry very similarly and very quickly with non-hygroscopic wall materials.

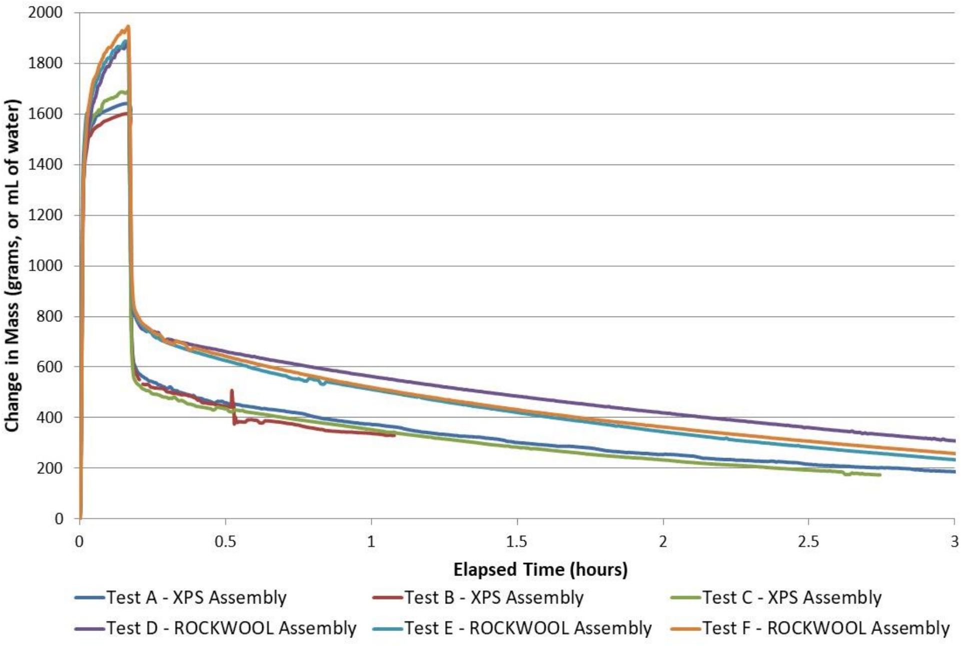


Figure 9: Drying comparison of full-scale test walls.

Field Testing of Full-Scale Test Walls

A number of test hut monitoring studies have been conducted on wall assemblies using ROCKWOOL stone wool exterior c.i., to validate its performance in that application. The studies, conducted in different locations and different climates, demonstrate that ROCKWOOL stone wool c.i. promotes drainage and drying, does not store moisture, and is overall less risky than vapor impermeable c.i. products from a long-term durability standpoint.

A study in Waterloo, Ontario, compared high-R wall assemblies with exterior insulation to thick framed walls such as double stud walls in a side-by-side test wall study, both under normal operating conditions and with imposed moisture loads (either injected water or injected air leakage) (Trainor 2016). Not surprisingly, based on previous research, hygrothermal modeling, and building physics, the measured data showed that the thick high-R walls (with a high level of insulation between the sheathing and drywall) had significantly more risk and higher measured sheathing moisture contents than the exterior insulated wall assemblies with either ROCKWOOL stone wool, XPS, or foil-faced polyisocyanurate insulation. During the application of controlled air leakage into the test walls, all the walls with exterior insulation had similar low moisture content because the sheathing was kept warmer, resulting in less condensation and moisture accumulation. During a simulated rain leak in the test walls at the surface of the sheathing, the wall with vapor permeable ROCKWOOL stone wool insulation had much faster drying compared to the walls with low vapor permeance exterior insulation.

In a study focused on the Pacific Northwest located near Vancouver, British Columbia, a test hut was constructed with side-by-side test walls to measure any performance differences in both wood-framed residential and steel stud commercial wall assemblies, with both high vapor permeance ROCKWOOL exterior insulation and lower vapor permeance XPS and polyisocyanurate (Smegal 2017). The performance of the wall assemblies was compared using measured wood moisture content, relative humidity, and temperature sensors. Since all the walls included similar levels of exterior insulation thermal value, the study demonstrated that condensation was low under normal operating conditions, with the vapor permeable ROCKWOOL stone wool assembly demonstrating consistent levels while the vapor impermeable foam plastics had some high peaks. Similar to the measured test results in the Waterloo study, when water was injected into the assembly on the exterior of the sheathing (simulating a window leak between the exterior insulation and the sheathing), the moisture dried faster in the ROCKWOOL stone wool insulation wall than in the comparison walls with XPS and polyisocyanurate. Figure 10 illustrates the measured relative humidity between the fluid applied air/water barrier and exterior c.i. during an intentional wetting event simulating a window leak. The green line represents the measured RH of the stone wool wall, and it dries much more quickly than the XPS (purple) and Polyiso (blue) lines.

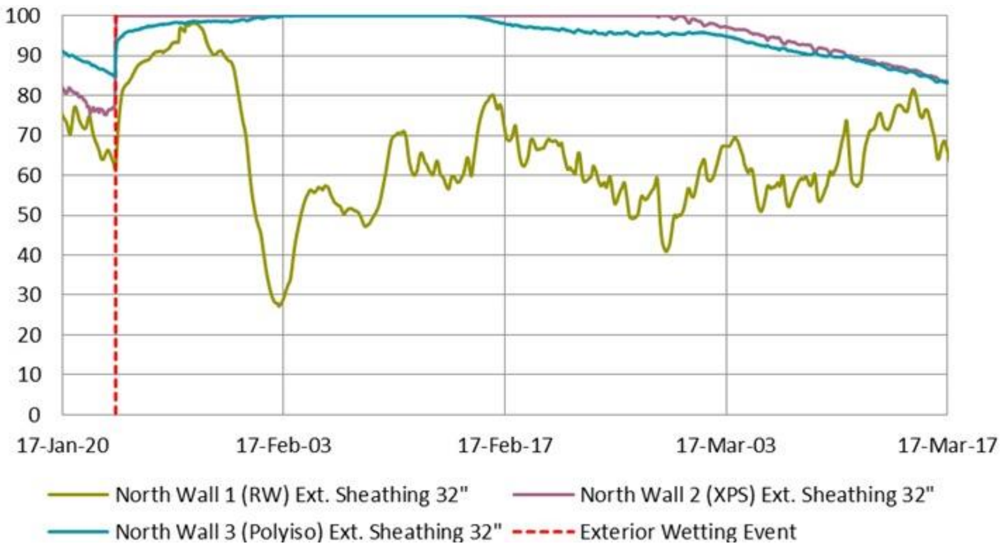


Figure 10 : North orientation comparison of measured relative humidity [%] during winter wetting event, sensor located at exterior side of sheathing between fluid applied awb and insulation (positioned 32" above bottom of wall panels), Vancouver Field Exposure Test Facility in Coquitlam, BC. (Smegal 2016)

In both studies, it was shown that when walls get wet, having a vapor permeable continuous exterior insulation installed behind a cladding may reduce the risk of any moisture-related durability issues.

A third monitoring study that included two walls using ROCKWOOL stone wool c.i. in combination with heavy mass cladding and vinyl siding was conducted in a warm humid climate in Charleston, SC (Boudreaux 2020). The walls are representative of a commercial assembly with a brick veneer and residential assembly with a vinyl siding. Given the hot and humid climate and the use of vapor permeable ROCKWOOL stone wool insulation, inward vapor drive is a concern. However, the study indicated that even when used in combination with a highly absorptive cladding such as brick, the exterior ROCKWOOL stone wool insulation, in combination with a lower permeance WRB and no interior vapor control, did not show signs of water absorption or increased failure risks.

Figure 11shows the measured relative humidity levels for the brick veneer wall assembly in the Charleston study. Through the summer months the drywall RH is the highest (purple line) of all the measuring locations as expected but still below 80% for the most part indicating no inward vapor drive moisture problems. Figure 12 shows the measured relative humidity levels in the vinyl siding wall in the Charleston study. The purple line again indicates the relative humidity at the drywall, but because there’s no storage cladding and subsequent inward vapour drive, the relative humidity at the drywall layer is the lowest of all the monitoring locations through the summer months from June to October.

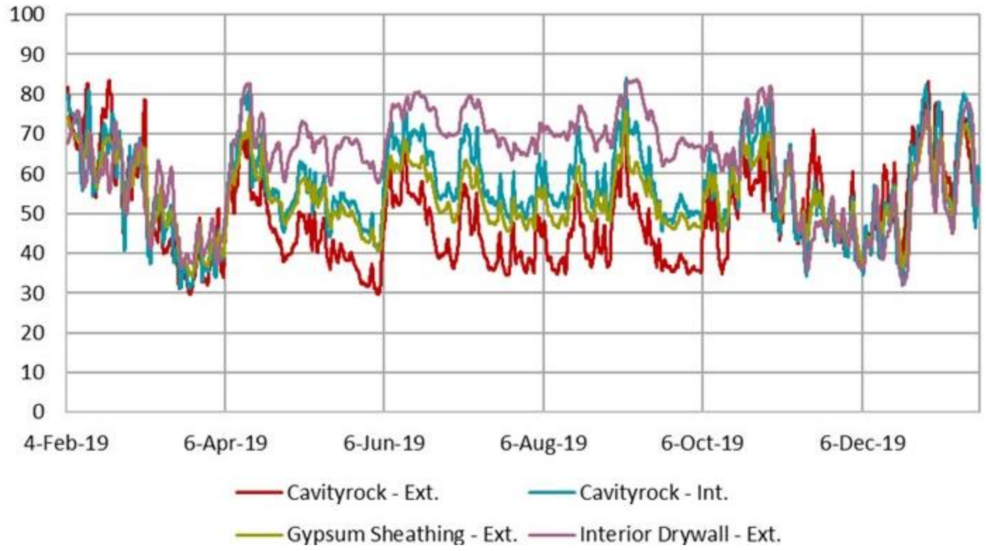


Figure 11 : Steel frame assembly with 2” ROCKWOOL Cavityrock® and brick veneer, relative humidity [%] throughout Wall, 24hr running average, NET Facility, Charleston, NC. (Boudreaux 2020)

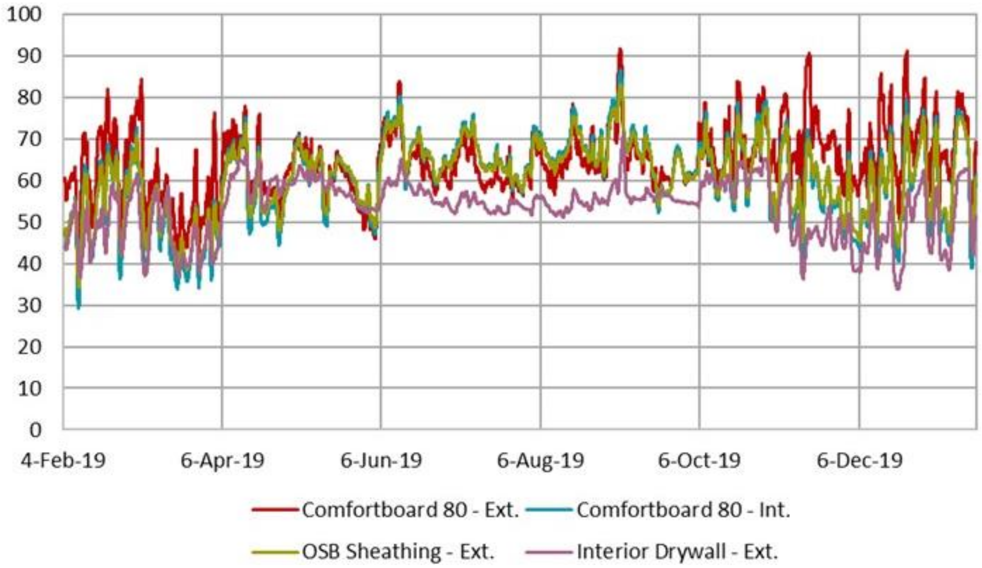


Figure 12 : Wood frame assembly with 1.5" ROCKWOOL Comfortboard™ 80 and vinyl siding, relative humidity [%] throughout Wall, 24hr running average, NET Facility, Charleston, NC (Boudreaux 2020)

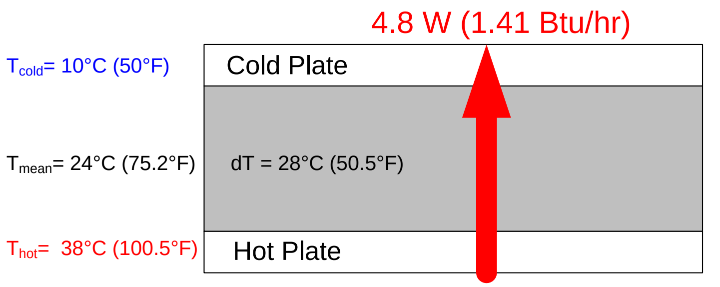
Thermal Resistance of Wet Insulation

Measuring R-value

The R-value of insulation materials can be determined using ASTM C518 *Standard Test Method for Steady-State Thermal Transmission Properties by Means of a Heat Flow Meter Apparatus* (ASTM 2010). A heat flow meter consists of two temperature-controlled plates in contact with the two surfaces of the insulation (Figure 13). By tightly controlling the temperature of the plates at chosen temperatures, the insulation will come to equilibrium with the temperature gradient across the sample. The R-value is calculated knowing the heat flux and the temperature of the plates.

The standard plate temperatures used by insulation manufacturers for measuring the R-value of enclosure insulation are 50˚F (10˚C) and 100˚F (38˚C), which results in a mean or average temperature of 75˚F (24˚C). However, it is important to note that the mean temperature of 75˚F is not representative of the real-world circumstances that would call for insulation to minimize heat flow across the enclosure.

Generally speaking, insulation consists of solid materials that provide structure and air or other gases that provide R-value. If the air/gases within the insulation were to be replaced by something with a higher thermal conductivity such as water, then the thermal conductivity would increase to varying degrees depending on the insulation type and the amount of water within the insulation. The effect on the R-value would depend on how much water was in the specimen and how long the water remained in the sample.



Heat Flux Transducer Dimensions = 10.2 x 10.2 cm (4 x 4 in)

Heat Flux Transducer Area = 0.0103 m^2 (0.111ft^2)

Apparent R-value can be calculated → RSI = 0.86 (m^2·K)/W
R = 4.9 (hr·ft^2·°F/Btu)

Figure 13 : Measuring R-value according to ASTM C-518 in a heat flow meter apparatus

Measuring R-value Of Wet Mineral Fiber Insulation

As noted above, when air (or other gases) in an insulation material are replaced with water, there will be a decrease in R-value until the insulation dries. Some insulation materials such as stone wool are air and vapor permeable and will dry much more quickly than other types of insulation. A small-scale laboratory test described earlier showed how quickly ROCKWOOL stone wool insulation dried in an isothermal condition without any drying forces. For the short period that the ROCKWOOL stone wool is wet, the R-value will be decreased; however, the high rate of moisture movement through the insulation makes R-value measurement difficult as explained in the following sections.

Research has been conducted by different laboratories to investigate the measured R-value of various types of wet mineral fiber and stone wool insulation. In 1987, a research study was conducted by Per Ingvar Sandberg describing the challenges of measuring wet mineral wool insulation (Sandberg 1987). Sandberg references earlier work done in 1952 by Jesperson written in Danish. Jesperson's paper had shown a steep rise in thermal conductivity at only a 1% by volume moisture content. Sandberg thoroughly addresses the underlying physics that complicate these measurements.

> *"the thermal conductivity reported by Jesperson is not a material property but an 'apparent thermal conductivity,' which is dependent not only on the moisture content, but also on the moisture flow and the boundary conditions.*
>
> *Apparently, many of those who have used Jesperson's results have made the mistake of basing heat flow calculations in mineral wool on measurements carried out with a very special moisture situation that is seldom encountered in practice. This situation requires a permanent supply of moisture at the warm side. In reality, the amount of moisture is limited, and in such permeable materials as mineral wool, the moisture under the influence of a temperature gradient is rapidly concentrated to a thin layer on the cold side."*

This demonstrates the knowledge existed since at least 1987 that measuring the thermal conductivity of wet mineral fiber insulation only provides an apparent thermal conductivity and is not representative of a true wet insulation R-value. Langlais also conducted a series of experiments looking at the thermal conductivity of wet fibrous insulating materials and analyzed previous work done by Jesperson and others (Langlais

1983). They found similar results that the initial conductivity measurements were elevated as a result of moving moisture, but the conductivity decreased as the moisture moved through the insulation and the insulation dried due to the test conditions.

RDH Building Science Laboratories (RDH) performed similar thermal conductivity testing in 2017 in response to industry concerns that wet stone wool insulation had a reduced R-value. The same conclusions were reached by RDH that had been reached previously by Sandberg. As soon as a temperature gradient is applied to the wet insulation, water immediately begins to move across the insulation following the vapor pressure gradient. Therefore, the thermal conductivity of wet stone wool insulation cannot be determined in the typical way of using a heat flow meter for a standard ASTM C518 test, because the results of the test are only an indication of the heat flux required to move water very easily through the sample, not an indication of the equilibrium thermal conductivity.

One of the main assumptions to measure the thermal conductivity correctly with the heat flow meter is that the material must be at equilibrium. If improper equilibrium criteria are used for the analysis, it means that the heat flow meter may calculate the thermal conductivity of a sample before the sample has reached equilibrium with the heat flow meter.

To determine the moisture distribution within a 2” (50mm) thick sample of ROCKWOOL stone wool, R-7.6 (RSI 1.3), five thin layers that act as one solid piece were placed in the heat flow meter as shown in Figure 14. Thin pieces were used so that the moisture distribution within the 2” (50mm) total thickness could be determined.

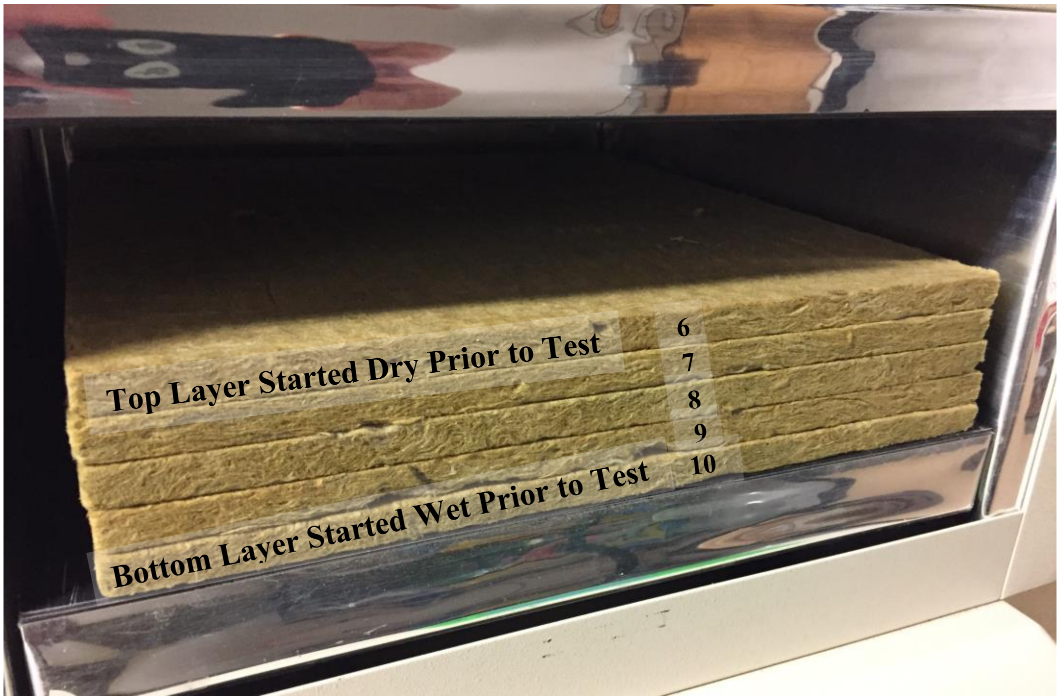


Figure 14: Five samples of ROCKWOOL® stone wool insulation about to be tested in C518 apparatus. Moisture concentrated in the bottom layer at start of test.

The bottom layer was wetted by submerging the material under water for several hours and gained approximately 2.1oz (60g) of water, which equates to a moisture content of approximately 30% by weight. All other layers were at equilibrium with the laboratory conditions prior to testing. The samples were placed in the heat flow meter, and the door was closed to seal the meter during thermal conductivity measurement. This demonstration shows how moisture can move in the sample, but the test apparatus traps all the water inside the sample, which does not happen in an exterior c.i. application in typical construction, where water can dry from the insulation.

Figure 15 illustrates the effect of measuring the thermal conductivity or thermal resistance of wet ROCKWOOL stone wool insulation using a default equilibrium criteria for the measurement. The thermal conductivity was measured and R-value calculated seven times in a row without disturbing the sample in the heat flow meter so all of the moisture remained in the heat flow meter during the test. The first time the heat flow meter reached “equilibrium”, the R-value was approximately R3.8 (RSI 0.67), but as the heat flow meter progressed through the sequence of identical heat flow measurements and water moved within the ROCKWOOL stone wool sample, the R-value increased, eventually to approximately R6.7 (RSI 1.2), which is an R-value improvement of 43%. We would expect the R-value to be closer to R7.6 (RSI 1.3) for 2” (50mm) of ROCKWOOL stone wool insulation (rigid, roofing product), but unlike the small-scale lab tests, and in-service exterior insulation, the water has become trapped in the system by the sealed heat flow meter and is not able to dry out as it would if it was installed on the exterior of a wall assembly. If water were to become trapped within an insulation material, there would be a decrease in temperature for the length of time that the insulation was wet.

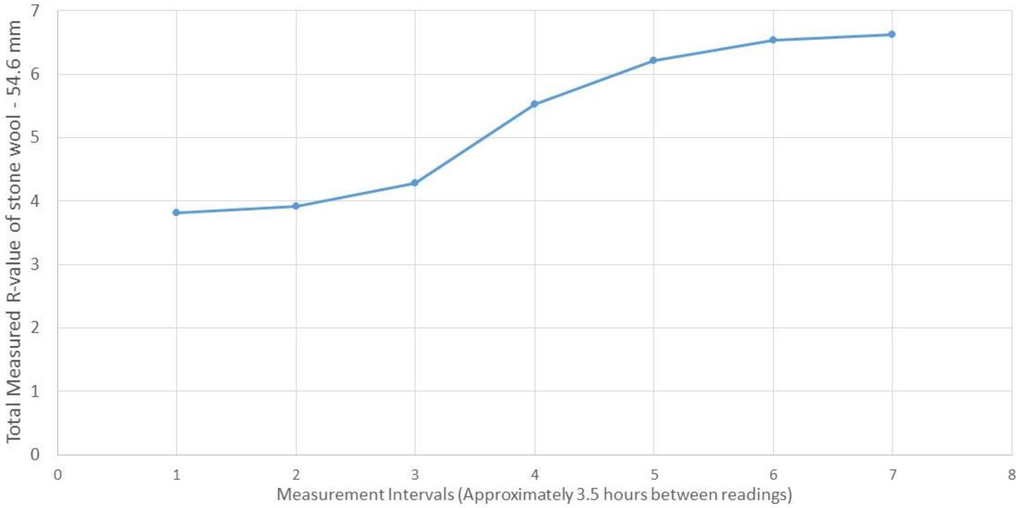


Figure 15: A series of sequentially measured R-values for a sample of wet ROCKWOOL® stone wool.

Based on the graphical results and the changing R-value, it is clear that the ROCKWOOL stone wool sample is not at equilibrium for the initial measurements, so the measured heat flux is the heat flow associated with moving water through the sample. However, some testing agencies and methods may not account for water movement and as a result may misreport the R-value of the material. As the water moves through the sample and collects at the colder surface of the material against the cold temperature plate, the actual R-value of the ROCKWOOL stone wool sample is approached. The movement of water between the five layers is shown graphically in Figure 16 with five bars overlaid on the graph simulating the five layers of ROCKWOOL stone wool during testing. Sample 10, which was wetted and installed on the bottom of the stack, becomes drier during the test. As the moisture is driven upwards during the test by the vapor pressure gradient and vapor diffusion, Sample 6 gains moisture, demonstrating how moisture can be transported through the ROCKWOOL stone wool insulation with a temperature-induced vapor pressure gradient.

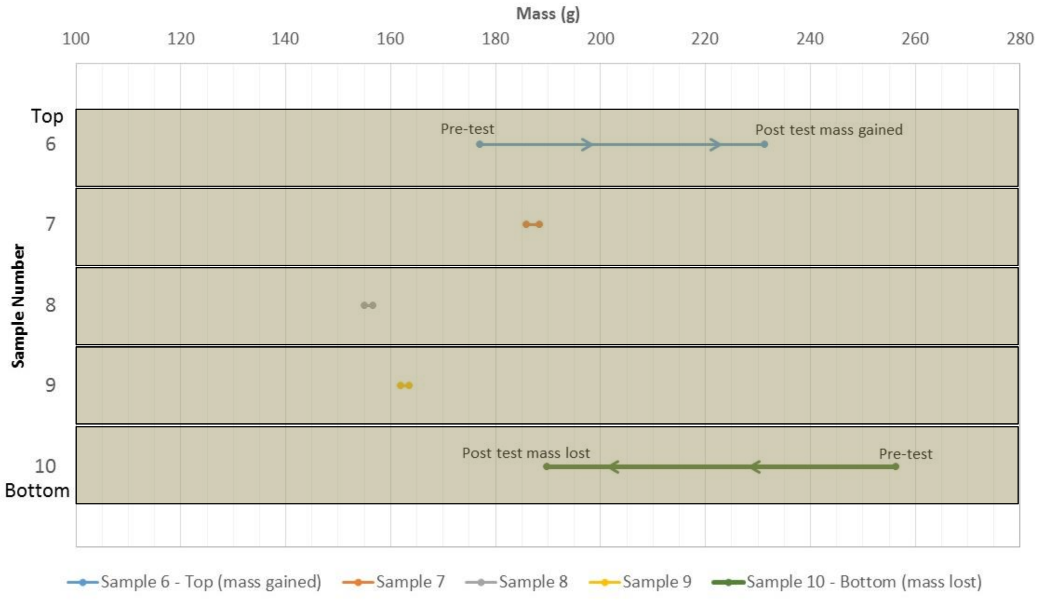


Figure 16: Measured mass of ROCKWOOL® stone wool samples before and after testing

The reality of the situation is that if exterior ROCKWOOL stone wool insulation becomes wetted in an above-grade wall assembly on the surface of the insulation, the moisture in the wall assembly will be redistributed based on the temperature gradient, and it will dry quite quickly unless the poor design of the enclosure traps the water into the insulation. The thin layer of wetted ROCKWOOL stone wool insulation may have a reduced R-value for the short time that it is wet, but laboratory and R-value testing has shown it will typically dry very quickly in most enclosure designs.

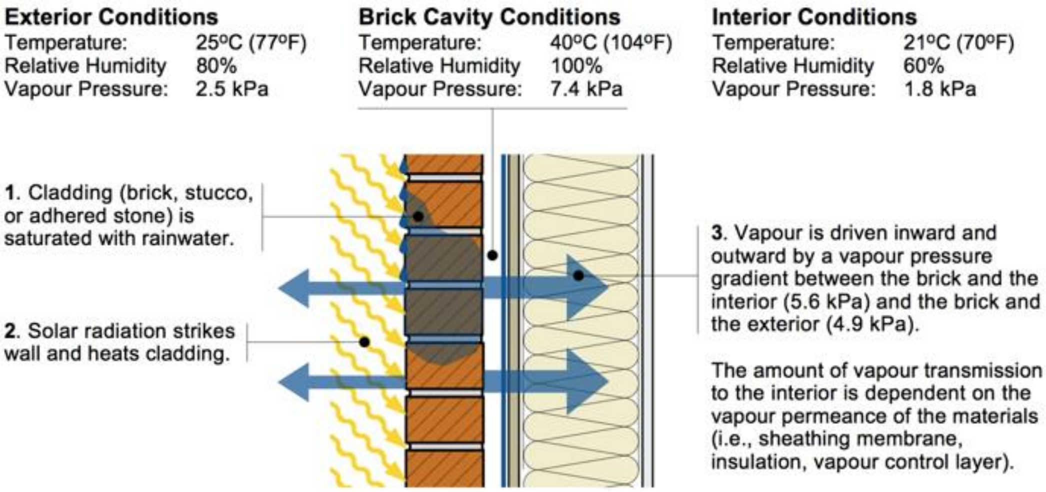
Inward Vapor Drives

In certain situations, the use of highly vapor permeable c.i. such as stone wool can allow the movement of water vapor and potentially undesirable condensation wetting. Since stone wool insulation is highly vapor permeable, it will allow water vapor to pass through to the interior or exterior of the enclosure depending on the vapor pressure gradient across the enclosure. This has been advantageous in some wall assemblies to allow water vapor to easily flow outward from the interior in the colder winter months and has been quantitatively compared to other types of exterior c.i. (Trainor 2014, Smegal 2011).

A potential risk occurs with all vapor permeable enclosure assemblies if there is a high inward-acting vapor pressure gradient from the cladding as a result of solar heated moisture from a saturated storage cladding (e.g., adhered stone veneer, poorly ventilated brick or stucco not installed over a drained/ventilated cavity). If a vapor impermeable layer is installed on or near a cooled interior layer such as a polyethylene vapor barrier, vinyl wall paper, or large vapor impermeable wall covering such as a mirror, cabinetry, etc., moisture accumulation may occur at the surface of the low vapor permeance layer.

As a result, inward vapor drives can be a durability concern if the enclosure is not correctly designed based on the climate and enclosure materials. If inward vapor drives are anticipated, then a lower permeance layer should be installed at a location in the enclosure where water accumulation and collection will not be a concern, such as the sheathing membrane (Smegal 2014).

Figure 17 shows a schematic of an inward vapor drive scenario where driving rain has saturated the masonry veneer cladding. The exterior air conditions are 77˚F (25˚C) and 80% RH, but the conditions within the brick and the brick cavity as a result of solar heating are 104˚F (40˚C) and 100% RH, resulting in a large inward vapor pressure gradient. Some of this hot and humid air may be ventilated away from the brick space, but without significant ventilation there is a significant vapor pressure gradient of 5.6 kPa across the sheathing membrane and cavity insulation; this will drive water vapor towards the interior. Depending on the vapor permeance and temperatures of the layers inside of the brick cavity, it is possible that condensation and moisture accumulation may occur and could result in mould and rot.



Exterior Conditions
Temperature: 25°C (77°F)
Relative Humidity 80%
Vapour Pressure: 2.5 kPa

Brick Cavity Conditions
Temperature: 40°C (104°F)
Relative Humidity 100%
Vapour Pressure: 7.4 kPa

Interior Conditions
Temperature: 21°C (70°F)
Relative Humidity 60%
Vapour Pressure: 1.8 kPa

1. Cladding (brick, stucco, or adhered stone) is saturated with rainwater.

2. Solar radiation strikes wall and heats cladding.

3. Vapour is driven inward and outward by a vapour pressure gradient between the brick and the interior (5.6 kPa) and the brick and the exterior (4.9 kPa).

The amount of vapour transmission to the interior is dependent on the vapour permeance of the materials (i.e., sheathing membrane, insulation, vapour control layer).

Figure 17 : Inward vapor drive schematic from a saturated brick cladding.

Conclusions

All exterior insulation types (stone wool, EPS, polyiso, XPS, SPF) can become wet if subjected to rain wetting or vapor-driven condensation, although the rates of water absorption and degree of saturation vary significantly. In many cases these moisture problems are a result of poor construction details that collect and trap water within the enclosure against the insulation layer. The most common source of water is wind driven rain, although laboratory testing showed that even with an open-joint cladding, most water sheds off the cladding and exterior face of the insulation, with little water storage, and quick drainage and drying. Other potential sources of moisture discussed include vapor drives (both inward vapor drives from wet storage claddings and outward vapor drives in cold climates). Condensation wetting of the surfaces within the enclosure is possible with these sources of moisture, so good design principles should be followed.

The rates of drying for different wet insulations vary significantly between different insulation types. The rates of drying are the highest in insulation types with greater air and vapor permeability. As with wetting, drying capacity should be considered during design.

ROCKWOOL stone wool fibers have a hydrophobic coating throughout the insulation board. In typical above-grade walls, the insulation is installed vertically, so water would contact the vertical surface and drain to the bottom, but small amounts of water can still be held by the surface of the board if kept in contact with water. Small-scale lab tests showed that when ROCKWOOL stone wool insulation was in direct contact with water for 48 hours, water did not absorb or wick through the insulation material but was only present at the very surface that had been wetted. It was also demonstrated that this water was able to dry out of the insulation sample quickly under natural evaporation conditions in the laboratory. Measured data from two full-scale wall assemblies in the laboratory comparing XPS and ROCKWOOL stone wool exterior insulation products demonstrated only a very small increase in water storage for the ROCKWOOL stone wool wall assembly under very conservative worst-case water application, and both walls dried to similar levels within 3 hours of wetting, resulting in no notable performance difference between XPS and ROCKWOOL stone wool insulation in this demonstration.

Field studies of full-scale test walls in the Pacific Northwest showed that water accumulation in the enclosure as a result of detailing issues or outward air leakage was able to dry faster with a vapor permeable ROCKWOOL stone wool exterior c.i. Field testing of wall systems in Waterloo, Ontario showed similar results to the Pacific Northwest study, and simulated rain leaks at the surface of the sheathing were able to dry more quickly with a vapor permeable c.i. compared to the test walls with low vapor permeance c.i. Full-scale wall testing in Charleston, NC showed no moisture problems as a result of inward vapor drives from normal operating conditions and natural rain conditions when using vapor permeable ROCKWOOL stone wool exterior c.i.

There have been attempts to measure the R-value of wet stone wool insulation in the laboratory using a heat flow meter but it is clear based on the literature review as well as testing conducted by RDH that moisture moves much too quickly and easily within the ROCKWOOL stone wool insulation to measure the R-value when the insulation is wet. The heat flow meter measures the water vapor moving inside the sample and provides an "apparent thermal conductivity" instead of a true thermal conductivity of the insulation. For the short period of time that the insulation on the exterior of the wall assembly is wetted, there will be a reduction in R-value because water is displacing the more thermally efficient air voids, but the moisture moves through and/or out of the insulation very quickly so any effects on R-value are short-lived. Having such a substantial amount of water within the enclosure that wet insulation becomes a concern is typically a design or construction deficiency and the durability of the enclosure may be at risk regardless of the insulation used.

Based on this review of laboratory testing, field monitoring, and moisture physics, the concerns of the industry related to water absorption and reduced R-values of wet ROCKWOOL stone wool insulation appear to be largely unfounded. There are short term reductions in R-value if the insulation becomes wetted, but laboratory and field testing has shown that stone wool c.i. is not easily wetted and dries very quickly unless there are design or construction deficiencies that promote wetting and trapping of water within the enclosure. Field studies show repeatedly that exterior continuous ROCKWOOL stone wool insulation will allow outward drying of moisture in cold climates. Attention to enclosure design and construction is required when installing stone wool exterior insulation behind a moisture storage cladding (e.g. brick, adhered stone and stucco installed an undrained/unventilated application over the insulation) because of the high level of vapor permeance and risk for inward vapor drive. As with any wall assemblies constructed with any materials, good design decisions and good construction practices should be used to minimize the risk of moisture problems.

References

ASTM Standard E547-2000. 2000. “Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Cyclic Static Air Pressure Difference.” West Conshohocken, PA: ASTM International.

ASTM Standard C518-2010. 2010. “Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus.” West Conshohocken, PA: ASTM International.

BC Housing. 2019. *Building Enclosure Design Guide Wood-Frame Multi-Unit Residential Buildings, 2nd Edition.* Vancouver, BC: BC Housing.

Boudreaux, P. et al. 2020. *The Effect of Heat and Moisture on Exterior Walls Field Tested in the Hot and Humid Climate of Charleston, SC- Part 2.* Oak Ridge, TN: Oak Ridge National Laboratory. ORNL/SPR-2020/1524.

Langlais, C., Hyrien, M., and Klarsfeld, S. 1983. “Influence of Moisture on Heat Transfer Through Fibrous-Insulating Materials.” In *Thermal Insulation, Materials, and Systems for Energy Conservation in the ‘80s, ASTM STP 789,* ed. F.A. Govan, D.M. Greason, and J.D. McAlleister, pp 563-581. West Conshohocken, PA: ASTM International.

Sandberg, P.I. 1987. “Thermal Resistance of a Wet Mineral Fiber Insulation.” In *Thermal Insulation: Materials and Systems, ASTM STP 922*, ed. F.J. Powell and S.L. Matthews, pp 394-404. West Conshohocken, PA: ASTM International.

Smegal, J., et al. 2016. “Moisture-Related Durability of In-Service High-R Wall Assemblies in Pacific Northwest Climates.” In *Proceedings of Thermal Performance of the Exterior Envelopes of Buildings XIII, Clearwater, FL, 2016*, pp 617-627. Oak Ridge, TN: Oak Ridge National Laboratory.

Smegal,J. and Straube.J. 2011. *Hygrothermal Analysis of Exterior Rockwool Insulation, Research Report 1104*. Waterloo, ON: Building Science Consulting Inc. Retrieved from https://www.buildingscience.com/sites/default/files/migrate/pdf/RR-1104_Hygrothermal_Analysis_of_Exterior_Rockwool_Insulation_rev.pdf.

Smegal, Jonathan. 2014. *Hygrothermal Simulations and Analysis of Solar-Driven Inward Water Vapor*. Waterloo, ON: RDH Building Science. Retrieved from https://www.rdh.com/resource/hygrothermal-simulations-and-analysis-of-solar-driven-inward-water-vapor.

Smegal, J., and Straube, J. 2014. Drainage Balance Testing and Wall Comparison. Waterloo, ON: RDH Building Science Laboratories. Retrieved from https://www.rdh.com/wp-content/uploads/2017/10/RDH-BSL-Drainage-Balance-Spray-Rack-Report.pdf.

Smegal,J., et al. 2017. “Comparing the Enclosure Wall Performance of Low-Permeance Exterior Insulation to High-Permeance Exterior Insulation in the Pacific Northwest.”. 2017. In *Advances in Hygrothermal Performance of Building Envelopes: Materials, Systems and Simulations*, ASTM C16 STP 1599, ed. P. Mukhopadhyaya and D. Fisler, pp 95-121. West Conshohocken, PA: ASTM International.

Straube, J.F., and Burnett, E.F.P., 2005. *Building Science for Building Enclosure Design*. Westford, MA: Building Science Press.

Straube, J., and Smegal, J. 2018. “Literature Review and Research Summary on Wind Washing of Air Permeable Insulation.” Waterloo, ON: RDH Building Science. Retrieved from https://www.rdh.com/wp-content/uploads/2018/06/Wind-Washing-Summary-Report-RDH-Tech-Library.pdf.

Trainor, T. “The Hygrothermal Performance of Exterior Insulated Wall Systems.” Master’s thesis, University of Waterloo, 2014.

Trainor, T., et al. 2016. “Measured and Predicted Moisture Performance of High-R Wall Assemblies in Cold Climates.” In *Proceedings of Thermal Performance of the Exterior Envelopes of Buildings XIII, Clearwater, FL, 2016*, pp 504-514. Oak Ridge, TN: Oak Ridge National Laboratory.