Hygrothermal performance assessment of split insulated cork wall assemblies under various moisture load conditions

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Abstract. Every year along with the implementation of energy-saving, energy conservation and other green energy initiatives the demand for effective, but sustainable, renewable insulation materials in the construction industry increases. It is worth mentioning that the selection of insulation materials nowadays is not limited to its cost and technical characteristics only, but health-related aspects and carbon footprint are also taken into consideration. However, there are not many insulation materials that have competitive technical characteristics, are sustainable, renewable and do not pose risk for health. Cork and cork-based materials like insulation cork boards (ICB) are of these types of materials which have unusual combination of material properties, have low to negative carbon footprint and have low to almost zero negative impact on the ecology and human health during the whole life cycle and later on. That is why with the increasing demand for sustainable, renewable and ecological materials the interest toward cork in North America is expected to increase. However, there are not so many researches performed on lightweight wall assemblies common in North America with cork insulation applications. In this paper, the hygrothermal performance of natural cork insulation used in split wall assemblies is compared against similar, commonly used mineral wool and expanded polystyrene (EPS) wall assemblies for three different Canadian climates, using WUFI hygrothermal analysis computer simulation tool. The relative performance of seven wall assemblies, with various combinations of insulation type and vapor control strategies, exposed to different moisture loads including elevated indoor humidity, air leakage and rain penetration are presented. The simulation results suggest that, in general, assemblies with cork have a slight advantage in performance against the EPS assemblies, especially when the amount of moisture affecting the assemblies is high. In most cases, assemblies with mineral wool perform better than that of with cork and EPS insulations.

1. Introduction

Demand for environmentally friendly, renewable, and low carbon materials in the construction industry constantly increases. Thus, more researchers focus on the development of new thermal insulating materials using natural fibers and wastes [1].

At the same time, there are already some environmentally friendly, sustainable insulation materials available in the market, which have a high potential for more wide usage. One example of such materials is an Insulation Cork Board (ICB) made solely from natural cork. For the manufacturing of ICB, only cork granules are used as raw material, without any binding agents or additives [2].
Cork is a natural, renewable, sustainable raw material that has been used for many centuries in a very large number of applications. It is relatively well studied and the production of insulation materials from the cork is utilized in Europe.

Cork is obtained from the outer bark of the “Quercus Suber” Cork Oak tree. It is a “green” material with a very favorable ecological footprint since cork may be extracted from the outer bark of Cork Oak without damaging the tree [3]. The environmental impact of cork products is low to medium, with a low carbon footprint [4].

The low impact of the cork-built environment on human health and nature throughout the entire building lifecycle is making that material one of the top green building products of nowadays [5].

Cork has a unique set of properties such as low density, low permeability to liquids and gases, mechanical elasticity, chemical and biological inertia. It is durable, resistant to wear, does not absorb water, and has low thermal conductivity, therefore it is a good candidate as a material for providing shelter at cold temperatures. In addition, it has energy-absorbing capacity and good acoustical insulation properties, which provide additional application areas in the construction industry. [6].

Because the ICB is made solely from cork, all the above-mentioned cork properties are more or less inherited by the insulation cork boards.

In construction, the ICB can be used for thermal, sound and vibration insulation as well as for decorative purposes. In Europe, ICB is used in many applications including, but not limited to: roofs, external walls, internal partitions, slab and floors, decorative and some other specific applications like formwork insulation, acoustic false ceiling, expansion joints, pipe insulation, equipment vibration control, etc. In North America cork and its products are not widely used, because of the raw material geographical availability limitations, since Cork Oak tree is mainly available in the Mediterranean region [6], which makes the material less attractive from the cost point of view. However, the situation is changing with the increasing demand for new efficient, environmentally friendly, ecological materials and an increase in the ICBs worldwide production. It is expected that ICB’s new applications in envelope systems in North America would grow in the future.

Even though the cork applications in the construction industry are not new, the hygrothermal performance of lightweight wall systems with cork insulation are not well studied. Therefore, it would be beneficial to predict and analyze the hygrothermal behavior of such envelope systems before their wide usage. Taking into consideration that the construction industry is moving toward energy efficiency and highly insulated wall systems are in demand, it seems to be more valuable to select the split-insulated lightweight cork wall assemblies for such analysis and compare their hygrothermal performance with other split-insulated assemblies commonly used in North America. Such assemblies in literature are known as External Thermal Insulation Composite System (ETICS) or Exterior Insulation and Finish Systems (EIFS) and are widely used in Canada and United States.

In the current work, three similar split wall assemblies are designed with ICB, Mineral Wool and EPS external insulations. The computer simulation analysis had been used to evaluate the assemblies’ hygrothermal performance based on the sheathing MC. The study had been performed for three Canadian cities representing three Climate Zones based on ASHRAE 90.1 classification: Vancouver, BC (Climate Zone 5c); Toronto, ON (Climate Zone 6); and Winnipeg, MB (Climate Zone 7). Walls with three R=5.63 m²K/W, R=6.84 m²K/W and R=8m²K/W thermal resistance values were tested in order to find out how external insulation thickness influences the walls' system performance. However, the results presented in this paper cover mainly the Vancouver climate zone and walls with thermal resistances equivalent to 50mm external ICB walls due to the paper length limitations.

2. Methodology

Hygrothermal simulations help to understand how the building envelope responds to the interior and exterior environment changes over time and to identify the potential moisture-related performance problems. For this study, the commercially available and validated hygrothermal model WUFI Pro 6.4 was used.
2.1. Wall Design Variables Considered for the Study

Two types of 2 x 6” split insulated wall assemblies, with and without rain-screen, were considered for the study. Also, three different insulation materials: ICB, Mineral Wool and EPS were set as external insulation layers. All the walls were designed with the thermal resistances equivalent to 50mm, 100mm and 150mm external ICB split insulated rainscreen walls, where the resistance of walls with different external insulation types was adjusted through the external insulations’ thicknesses. The framing size and internal fiberglass insulation were kept constant. Plywood 19mm thickness was selected for the assembly to accommodate the increasing cladding loads due to external insulation and to make easier the cladding attachment to the sheathing. The hygrothermal properties of the used materials are provided in Table 1.

| Insulation type | Thermal Cond. W/mK | WV Diff. Res. Factor | Bulk Density kg/m³ |
|-----------------|---------------------|----------------------|--------------------|
| Façade ICB      | 0.0417              | 28.3                 | 143                |
| ICB             | 0.0397              | 28.3                 | 107                |
| EPS             | 0.036               | 73.01                | 14.8               |
| MWool           | 0.0336              | 1.76                 | 178                |

Class I vapor retarder. As a Class III vapor retarder 10 perm (SD=0.328m) latex paint on the interior gypsum board was used. The sample design of walls with rainscreen and ICB external insulation is presented in Figure 1. In addition, a special Façade Cork wall assembly presented in Figure 2 was designed to compare with the other wall designs. In such assemblies, the Façade Cork acts as insulation and cladding at the same time.

![Figure 1. Split insulated wall assembly with stucco, rain-screen and external ICB insulation.](image1)

![Figure 2. Split insulated wall assembly with external Façade grade ICB insulation.](image2)

In total seven wall designs were considered for simulations: three stucco walls with external ICB, Mineral Wool and EPS insulations; three stucco walls with rainscreen, and external ICB (Figure 1), Mineral Wool and EPS; and one wall assembly with external Façade grade ICB insulation (Figure 2).

2.2. Simulation Parameters and assumptions

Three-year simulation periods were considered for all cases to present the effect of initial moisture conditions (moisture stored in building materials), and followed assemblies’ long-term behavior trend. Material properties used in the models are from the WUFI Pro® 6.4.1, database 27.0.5.0. The generic weather data files from WUFI were imposed on the walls for each case respectively. Default WUFI Driving Rain coefficients for low-rise building (height up to 10m) was used. Rain-screen cavity ventilation in the WUFI model was implemented as per the recommendation of Karagiōzis and Kuenzel [7]. A 20 mm air cavity was modeled and a modest constant 50ACH air change source was applied in the gap to account for the ventilation effect in the models.
Two orientations were used in simulations. The North orientation was used as an extreme case for colder temperatures and low solar irradiation. Wind-driven rain prevailing direction was used as an extreme case for the rain penetration. The simulations began with the materials at equilibrium moisture content of 80% RH and a temperature of 20°C as recommended in ASHRAE 160. The initial moisture and temperature across each component are assumed to be constant. The indoor climate was set to high and medium moisture loads following EN 15026/DIN 4108/WTA 6-2 indoor humidity model, which are representing residential and office spaces with high (RH 40% - 70%) and normal (RH 30% - 60%) occupancy respectively.

Surface transfer coefficients for exterior surface were set to: heat resistance - 0.0588 [External wall] (m²K/W); short-wave radiation absorptivity – 0.2; ground short-wave reflectivity – 0.2, an adhering fraction of rain - 0.7. For the Interior surface, the 0.125 m²K/W heat resistance and sd=0.328m values were used. The selected sd value was used to represent the class III vapor retarder for the test cases without a vapor barrier. The polyethylene membrane installed behind the gypsum board acts as a vapor/air barrier. It is assumed to be continuous with no air leaks or defects other than specified in the model scenarios. All layers are in good contact with no essential dimensional changes during the simulation period.

2.3. Internal Moisture Sources/Hygrothermal Loads

To compare the drying potential of split insulated Cork wall assemblies with other commonly used split insulated walls the following moisture loads were applied during the simulation analysis:
1. 0.5% incident driving rain passed the Weather Resistive Barrier (WRB) and applied to the 5mm of sheathing outer side.
2. Air leak applied into the inner 5mm part of the sheathing (plywood) through the WUFI built-in IBP air infiltration model for airtightness class B (DIN 4108), which assumes 3 m³/m²h or less air infiltration rate at 50 Pa. The stack effect height was considered 5m and building airtightness Class B.

2.4. Simulation Cases

For each wall type, 16 simulation scenarios were prepared as it is presented in Table 2.

| Scenario # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|
| Orientation| N | N | SE | SE | N | N | SE | SE | N | N | SE | SE | N | N | SE | SE |
| Air and Water Leaks | No | No | No | No | No | No | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Internal Moisture | High | Med. | High | Med. | High | Med. | High | Med. | High | Med. | High | Med. | High | Med. | High |
| Vapor retarder Class | III | III | III | III | I | I | I | III | III | III | III | I | I | I | I |
situation the plywood water content is the major concern during the hygrothermal simulation analysis and the main parameter to be analyzed. Thus, the plywood MC was selected as an output for the WUFI simulations and the various parameters’ influence on the plywood MC was analyzed.

Given the large number of cases available and for ease of presentation, the number of analyzed and presented scenarios was reduced from 16 to 9. These 9 key scenarios were selected in a way to capture the single parameter change effect on the wall assembly hygrothermal performance. The graphical results representing the plywood MC for Climate 5c (Vancouver) and Thermal Resistance I (R=5.63 m²K/W) are presented below in Figures 3-11.

3.1. Vancouver (Climate Zone 5c), Wall Thermal Resistance I, R=5.64 m²K/W.

3.1.1. As was expected, the rainscreen walls for all insulation types are performing better than the respective walls with no rainscreen. The effects from the rainscreen drying potential can be well seen in Scenario 7 (OSE, MH, no leak, VB), where no leaks are present and moisture move from inside is restricted. At the same time, it can be seen that the performance of all rainscreen walls is similar in a long-term perspective when no leaks are present and the vapor retarder class I is restricting the vapor influence from inside.

3.1.2. While observing Scenario 7, it is also notable that plywood MC of Cork and EPS insulated walls without rainscreen have similar drying patterns which are smoother than the drying pattern of Mineral Wool. That indicates on similarities of Cork and EPS permeability and moisture storage properties which are different from the Mineral Wool insulated assembly. In the mentioned scenario the Mineral Wool without rainscreen assembly’s plywood MC has higher variability during the year compared to the other assemblies without rainscreen. Unlike the other scenarios, it has higher levels of MC compared to EPS and Cork rainscreen walls as well.

3.1.3. Even though the plywood moisture contents of Façade Cork cases are slightly higher than rainscreen Cork ones, the performance of façade and rainscreen Cork assemblies is very similar for all scenarios. The variance in performances can be explained by the slightly reduced drying potential of façade Cork assemblies due to minor differences in the densities and thicknesses (Façade Cork is denser and thicker, inducing in slightly lower permeability).

3.1.4. From the comparison of Scenario 7 (OSE, MH, no leak, VB) with vapor barrier in place, and Scenario 3 (OSE, MH, no leak, VR), where the vapor retarder allowing internal moisture to influence the wall performance, it can be concluded, that in all wall types the internal moisture is greatly affecting the plywood moisture content when Class III vapor retarder is used, which can be seen from the comparison of Scenarios 3 (OSE, MH, no leak, VR) and Scenario 4 (OSE, MM, no leak, VR) as well.

3.1.5. It is known that the Mineral Wool has higher permeability than Cork and EPS, and has better drainage ability on liquid water as well, which in our case leads to the smaller MC in the plywood of Mineral Wool assemblies compared to the plywood MC of Cork and EPS assemblies (All Scenarios).

3.1.6. At the same time when analyzing the graphs, we can see that in the case of Mineral Wool assembly with rainscreen, the plywood usually starts to dry, up to four months earlier than other assemblies (Scenarios 1, 3, 4, 9, 11, 12, 15, 16). However, it is not so noticeable in Scenario 7 (OSE, MH, no leak, VB), which can be explained by the small amount of moisture entering the system.

Also, the Mineral Wool assembly without rainscreen starts drying later than its rainscreen contra part, which was the expected effect of stucco cladding applied directly over the insulation. That can be explained by the rainscreen effect on the assemblies performance, as well as the stucco cladding water absorption and moisture storage properties which are increasing the water storage of the overall assembly. In addition, the stucco is slowing down the vapor flow from Mineral Wool to out, which also reduces the assemblies’ drying potential.

3.1.7. When comparing the effect of orientation on the wall performance (Scenario 1; ON, MH, no leak, VR vs Scenario 3; OSE, MH, no leak, VR), it becomes clear that north-facing walls have lower drying potential than south-east facing ones.

In addition, when comparing the mentioned above scenarios, it is easy to notice that rainscreen walls drying potential in the southeast orientation are slightly better than in the north, where the amount
Figure 3. Scenario 7 Plywood MC %, R=5.64 m²K/W, Vancouver

Figure 4. Scenario 15 Plywood MC %, R=5.64 m²K/W, Vancouver

Figure 5. Scenario 16 Plywood MC %, R=5.64 m²K/W, Vancouver

Figure 6. Scenario 3 Plywood MC %, R=5.64 m²K/W, Vancouver

Figure 7. Scenario 4 Plywood MC %, R=5.64 m²K/W, Vancouver

Figure 8. Scenario 12 Plywood MC %, R=5.64 m²K/W, Vancouver

Figure 9. Scenario 1 Plywood MC %, R=5.64 m²K/W, Vancouver

Figure 10. Scenario 9 Plywood MC %, R=5.64 m²K/W, Vancouver

Figure 11. Scenario 11 Plywood MC %, R=5.64 m²K/W, Vancouver

Figure 12. Scenario 13 Plywood MC %, R=5.64 m²K/W, Vancouver

Figure 13. Scenario 14 Plywood MC %, R=5.64 m²K/W, Vancouver

Figure 14. Scenario 18 Plywood MC %, R=5.64 m²K/W, Vancouver

Figure 15. Scenario 17 Plywood MC %, R=5.64 m²K/W, Vancouver

Plywood Water Content %, R=5.64 m²K/W split insulated m equal area assemblies, Vancouver
of insolation and wind is lower than in the south-east.

3.1.8. During the analysis of Scenarios 11 (OSE, MH, with leak, VR) and Scenario 15 (OSE, MH, with leak, VB) we can see that the moisture accumulation rate in the plywood is higher for the EPS walls than for Cork assemblies. At the same time, the moisture accumulation difference is more for the rainscreen wall assemblies than for no rainscreen ones and raises from year to year along with the assemblies’ moisture accumulation. For example, in Scenario 15 the difference in plywood MC of EPS and Cork rainscreen assemblies in the second year of simulation is about 2.5%, while in the third year of simulation it reaches 4.5%. This shows that the cork assemblies have a higher drying potential than EPS insulated ones. That phenomenon can be explained by better capillary water transport and vapor permeability properties of the cork insulation, which allows the cork assembly to dry out faster than the EPS assembly. However, both types of assemblies have similar performance when the amount of moisture affecting the walls is not so high (Scenarios 4 and 7).

3.1.9. It is interesting to see the differences between performances of the walls when the leaks are introduced in the system. While comparing Scenario 7 (OSE, MH, no leak, VB) and Scenario 15 (OSE, MH, with leak, VB), we can see, that Mineral Wool easily handling the leak, even without rainscreen, while the EPS is leading to the moisture accumulation in the plywood. It can be noticed that rainscreen Cork can handle the amount of leak selected for simulation, even though the inward drying is restricted by a vapor barrier, while in the case of façade Cork the plywood is slowly gaining moisture, which might be an impact of extra moisture directly absorbed by the façade Cork due to the wind-driven rain.

3.1.10. While analyzing Scenario 11 (OSE, MH, with leak, VR) and Scenario 12 (OSE, MM, with leak, VR) we can see that moisture accumulates in all assemblies of Scenario 11 where the water leak is present, except Mineral Wool assembly with rainscreen. It happens when the internal RH is high and vapor retarder in place, which indicates on the vapor flow into the assembly due to high vapor pressure from inside. However, the situation is changing in Scenario 12 where at the summertime the vapor flow changes the direction due to the lower indoor vapor pressure and class III vapor retarder (medium moisture load) and the excessive moisture from a water leak can dry inside as well. In contrary to Scenario 12 (OSE, MM, with leak, VR), in Scenario 16 (OSE, MM, with leak, VB) the vapor retarder replaced with a vapor barrier, and the moisture drying to inside is restricted, which is causing the moisture accumulation in no rainscreen Cork and EPS insulated assemblies.

3.1.11. The plywood MC difference between Scenarios 11 (OSE, MH, with leak, VR) cases and Scenario 15 (OSE, MH, with leak, VB) cases, indicates the positive effect of inward drying when the leaks are present in the assembly and vapor retarder class III is used.

It is interesting to note that for Scenario 16 where the inside moisture load is medium and air source leak is present the drying capacity of façade and rainscreen Cork assemblies is sufficient for not accumulating the moisture in the plywood, in contrary to the rainscreen EPS insulated wall.

4. Conclusion

The results of the current research project are based on more than five hundred computer simulations done for seven types of split insulated wall assemblies with four types of external insulation materials. The performance of split wall assemblies with Mineral Wool, Façade Cork, Cork and EPS insulation materials are simulated for three Canadian cities representing three different climate zones. Mineral Wool, Cork and EPS assemblies were designed in two ways: with and without rainscreen. All assemblies were designed with three thermal resistance levels. Sixteen simulation scenarios were developed to analyze and compare the hygrothermal performance of mentioned above assemblies in various conditions.

The simulation results show, that when the amount of moisture in the wall assemblies is low, all three wall assemblies have similar hygrothermal performance in all three climates. When the amount of moisture in the assemblies is increased, the situation is changed.

Out of all mentioned insulation the assemblies with the Mineral Wool are handling the leaks the best, even without rainscreen. Even though the Cork and EPS as a material have similar properties, the cork permeability and water drainage abilities are better than EPS, which allows assemblies with cork to have
a slight advantage in performance against the EPS assemblies, especially when the amount of moisture affecting the assemblies are high. The façade Cork performance is very similar to rainscreen Cork assemblies with a slight advantage of rainscreen Cork which is assumed to be due to the lesser exposure to the environmental conditions and slightly lower material density and thickness.

Rainscreen assemblies have better or similar performance with their no rainscreen contra parts in all wall types and climate zones. In addition, it is worth mentioning that in some scenarios in Winnipeg and Toronto Cork assemblies without rainscreen are outperforming the EPS assemblies with rainscreen.

The vapor retarder type is greatly influencing the assemblies’ performance. Class I vapor retarder is reducing the moisture flow from inside to out, but also restricting the assemblies drying toward inside. That reduced inward drying along with reduced permeability due to the increase in external insulation thickness causes all assemblies except Mineral Wool to accumulate the moisture when the leaks are present, and fail in Vancouver climate Thermal Resistance I, II and III cases. It is interesting to note that even though the façade and rainscreen Cork assemblies will fail in most of the scenarios of Vancouver Thermal Resistance I, they have a good drying potential and their performance is close to acceptable.

In overall, the Medium internal moisture is positively affecting the assemblies’ performance and reduces the plywood MC, especially when the vapor retarder class III is in use. The exception is the Thermal Resistance III wall in Vancouver with vapor retarder and leaks. Here the MC of EPS and Mineral Wool assemblies is higher in medium moisture load scenario, than in high moisture scenario.

Due to the higher insolation, the south-east orientation in most cases has an advantage in drying over the North orientation. Also, the rainscreen assemblies drying potential is slightly increased in south-east orientation in Vancouver (wind prevailing direction). However, in Vancouver Thermal Resistance II and III, when no leaks are present and vapor retarder class III is used, the Mineral Wool without rainscreen assembly facing north has lower plywood MC than the same assembly facing south-east. In addition, it was noted that the drying potential of assemblies in the south-east orientation is slightly decreased when the insulation thickness increases. The influence of leaks on the assemblies’ hygrothermal performance is also high.

In conclusion, based on the results of the current study, it can be stated that all types of simulated Mineral Wool assemblies had a good drying potential and low risk of failure in the event of an accidental leak in Climate Zone 5C. In contrast to Mineral Wool, the split insulated walls with EPS external insulation don’t have a good drying potential and pose a high risk of failure in the event of an accidental leak under all tested conditions. Even though the split insulated assemblies with the cork external insulation has a similar performance with their EPS contra parts, they have slightly better drying potential and can be used with a low risk of failure in the wall assemblies with a small amount of external insulation, vapor retarder Class III and Medium internal moisture load conditions.

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