RDH BUILDING SCIENCE

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Making Buildings Better™

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10514.001
Amorim Cork Insulation
Testing and WUFI
Cork Insulation Design Report
DATE May 22, 2019

REGARDING **Cork Design Report**

Dear Mr. Rooks,

As requested by Small Planet Supply, RDH Building Science Inc. (RDH) is pleased to provide you with this report for a hygrothermal assessment of wall assemblies featuring Amorim ThermaCork exterior insulation along the Pacific West Coast that fall within ASHRAE Climate Zones 3 to 6.

Objectives

The objective of this report is to identify minimum required exterior ThermaCork insulation in split-insulated wall assemblies to meet common prescriptive building code requirements with minimal interior vapor and airflow control strategies. Those assemblies that do not meet the performance requirements can therefore use more tight vapor and air control measures, or thicker levels of exterior ThermaCork insulation, to provide improved performance. Further, supplemental building science guidance is provided to guide long-term performance of the wall assemblies, such as guidance on air and vapor control.

Scope

This study is limited to light wood-frame wall assemblies with split-insulation configurations using rainscreen/ventilated cladding systems. The assessment of the performance of the wall assemblies in the various climates were completed using transient hygrothermal simulation, WUFI® Pro 6, and acceptable performance metrics, the mould index, are based on ASHRAE 160 (2016) standard.

The exterior insulation in consideration is limited to Amorim ThermaCork Standard Density. The material properties for the ThermaCork insulation were derived from RDH's Material Property Testing Summary Report, dated February 9, 2019. A copy of it is included in the appendix.

The focus of the study is limited to Pacific West Coast jurisdictions, namely the states of California, Oregon, and Washington, and the province of British Columbia. Representative cities in each of the Climate Zones 3 through 6 were selected based on availability within WUFI® Pro 6.

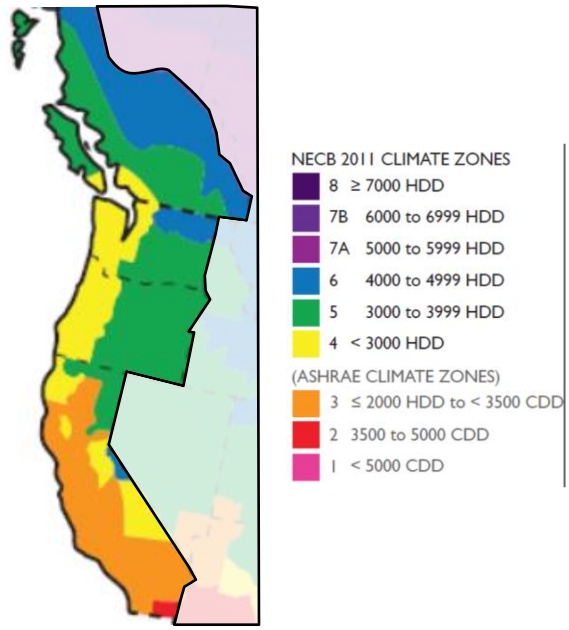


Figure 1 – Extent of Design Geography and Climate

1 Background

ThermaCork is an insulation product made by Isolamentos, SA (Amorim). The insulation consists of granules of cork that are steam-heated and compressed so that its natural resins act as the bonding adhesive. The boards are then cut to dimension.

Figure 2

ThermaCork samples used for material property testing.

A detailed discussion on material properties are included in the *Amorim ThermaCork Material Property Testing Summary Report*, included in the appendix, but the salient thermal and vapor diffusion properties derived therefrom are provided for reference in Table 1 and Table 2.

TABLE 1 – THERMAL CONDUCTIVITY (SI) & RESISTANCE (IP)				
THERMAL CONDUCTIVITY & RESISTANCE	STANDARD DENSITY INSULATION 111 KG/M³			
	25 mm		50 mm	
Mean Temperature	w/m·K	R/in.	w/m·K	R/in.
@-3.9˚C (10˚F)	0.0377	3.82	0.0381	3.78
@4.4˚C (25˚F)	0.0387	3.73	0.0393	3.67
@10˚C (50˚F)	0.0394	3.67	0.0401	3.60
@23.9˚C (75˚F)	0.0410	3.52	0.0425	3.40
@43.3˚C (110˚F)	0.0429	3.36	0.0459	3.14

TABLE 2 – VAPOR PERMEANCE				
VAPOR PERMEANCE	STANDARD DENSITY INSULATION (111 KG/M³)			
	25 mm		50 mm	
Test	ng/Pa·s·m²	US perm	ng/Pa·s·m²	US perm
Dry Cup (RH_{avg} = 25%)	440	7.69	144	2.5
Wet Cup (RH_{avg} = 75%)	473	8.26	171	3.0

To summarize, ThermaCork achieves an R-value of 3.5/inch at 75ºF mean temperature, and at 1” thickness, is a Class III vapor retarder (i.e. greater than 1 US Perm but less than 10 US Perms).

2 Wall Assembly Variations

The Pacific West Coast encompasses multiple jurisdictions with significantly varying climates, construction practices, and building efficiency targets. Despite these differences, a common feature of many of these buildings is the use of wood light stick-frame construction with various insulation strategies. The placement and material properties of the insulation within the wall assembly can have significant effects on its durability. Insulation with unsuitable vapor resistant properties, with either too much or too little vapor control, or positioned such that wall assembly components become susceptible to condensation, can increase durability risks.

A proven solution to reduce these risks is to keep all sensitive materials, such as wood framing and sheathing, sufficiently warm to prevent extended periods of elevated relative humidity. On many high-performance buildings, this is achieved by insulating entirely with exterior insulation. However, an exterior-only insulated approach misses an opportunity to add low-cost insulation within the cavity space for thermal and acoustic benefits. The combination of exterior insulation with cavity insulation is known as a split-insulated wall assembly.

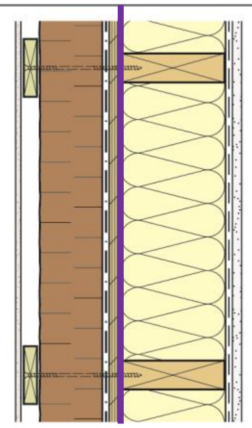


Figure 3

Split insulated wall assemblies use exterior insulation to keep the critical condensation planes above the moisture threshold for deterioration.

In heating conditions, the inclusion of cavity batt insulation keeps the outer portion of the wall (e.g. sheathing) much colder than interior temperatures. Colder surfaces, especially those below the indoor dew-point temperature, are at greater risk of moisture accumulation from warm and humid indoor air. However, these surfaces can be warmed with greater levels of outboard insulation, which minimizes these risks. The balance between outboard insulation to inboard insulation is known as the insulation ratio and is a critical measure of the robustness of a wall assembly.

Cork insulation however is also vapor resistant. Thicker amounts of ThermaCork, while keeping building elements warmer due to its insulation properties, could potentially inhibit outward drying. Consequently, consideration between the thickness of ThermaCork and drying capacity of the wall assembly needs to be considered.

With advancements in building code energy performance requirements, the limits to thermal performance of cavity-only insulation strategies plateaus. In general, the amount of batt insulation is governed by the depth of the stud; 2x4 walls are generally insulated with R-13 batt (i.e. typically R-11 to R-14 depending on manufacturer and mainly density), whereas 2x6 walls may be insulated with R-21 batt (i.e typically R-19 to R-24) insulation. Consequently, the only remaining solutions to achieve higher R-values are to use significantly deeper studs (e.g. 2x8) or double-stud walls or to explore exterior insulation options.

Due to the thermal efficiency of split insulated walls, the focus on this report is investigating the minimum required exterior cork insulation thickness to meet relevant building and energy codes/standards while also meeting ASHRAE 160-2016 durability criteria. The results of this study are also limited to rain-screen assemblies or drained and back-ventilated exterior claddings.

2.1 Code Requirements

Building enclosures must meet minimum energy efficiency requirements, as outlined in the relevant building codes and standards. There are many regional energy codes, but most insulation requirements cluster around a few common values. The following codes and standards were used to inform the required thermal performance:

- IECC-2018 §R402

- ASHRAE 90.1-2016 §5.5 Residential/Wood-Framed and other
- NECB-2015 §3.2.2.2
- BC Step Code: Builder Guide (2018) Minimum Prescriptive Compliance Pathways for Step 3 (Appendix C). Note, additional conditions apply.

The prescriptive enclosure thermal resistance targets were used. The maximum U-factors can be found in Table 3.

TABLE 3– WOOD FRAME WALL MAXIMUM U-FACTORS (IP) AND R-VALUE (IP) FOR IECC, ASHRAE 90.1, AND NECB

Climate Zone	IECC– 2018	ASHRAE 90.1– 2016	NECB – 2015	BC Step Code 3*
3	0.060 (16.7)	0.064 (15.6)	-	-
4	0.060 (16.7)	0.064 (15.6)	0.055 (18.1)	0.063 (16)
5	0.060 (16.7)	0.051 (19.6)	0.049 (20.4)	0.055 (18)
6	0.045 (22.2)	0.051 (19.6)	0.043 (23.3)	0.045 (22)

The R-value for 2x4 with R-13 Batt, 2x6 wall with R-21 Batt, and a 2x wall with no cavity insulation were calculated in accordance with ASHRAE Isothermal Planes method and are shown in Table 4. The boundary conditions and cladding assumptions follow those in ASHRAE 90.1 Appendix A section 3.4. These results form the basis for determining acceptable thicknesses of exterior ThermaCork to achieve respective code/standard R-values. Note that these values assume the ThermaCork complies with the definition of 'continuous insulation' in ASHRAE 90.1, and that thermal bridging for cladding support is not included in these values.

TABLE 4 – EFFECTIVE (CI) WALL R-VALUE (IP) CALCULATIONS FOR DIFFERENT THICKNESSES OF EXTERIOR THERMACORK INSULATION

ThermaCork Thickness	1"	2"	3"	4"	5"	6"	7"	8"
2x4 with R-13 Batt	14.9	18.1	21.5	24.9	28.3	31.7	35.1	38.5
2x6 with R-21 Batt	19.7	23.0	26.4	29.8	33.2	36.6	40.0	43.4
2x No Cavity Insulation	6.9	10.2	13.6	17.0	20.4	23.8	27.2	30.6

Wall assemblies with exterior thicknesses of ThermaCork that do not meet the code/standard maximum U-factors were not simulated.

2.2 Water Vapor Control

Consideration of moisture flow across the enclosure is required to ensure adequate performance of the assembly. In some jurisdictions, strict vapor control is required, whereas in others, vapor permeable assemblies are permitted.

Within the British Columbia Building Code, a vapor control layer not exceeding 60 ng/m²·s·Pa (1 U.S. perm) is required. This is equivalent to a Class 2 vapor retarder per US code definitions. Typically, wood-framed wall assemblies in British Columbia will include an interior polyethylene vapor barrier that is also detailed to function as an interior air barrier, with acoustical sealants and tape. However, if sufficient thicknesses of ThermaCork are applied (approximately 6”), the vapor resistance of the assembly meets the vapor control requirements of the code while also providing an insulation ratio which mitigates condensation concerns in the wall assembly.

Within the International Residential Code, alternate solutions are permitted. Clause *1404.3 Vapor Retarders* requires that a Class I or II vapor retarder be used on the interior in climate zones 5, 6, 7, 8, and Marine 4. Class I vapor retarders may not be used on the interior of Climate Zone 3 and 4, other than Marine 4. However, a Class III vapor retarder may be used provided that the requirements within Table 1404.3.2 are followed.

TABLE 1404.3.2
CLASS III VAPOR RETARDERS

ZONE	CLASS III VAPOR RETARDERS PERMITTED FOR:[a]
Marine 4	Vented cladding over wood structural panels Vented cladding over fiberboard Vented cladding over gypsum Continuous insulation with *R*-value ≥ R2.5 over 2 × 4 wall Continuous insulation with *R*-value ≥ R3.75 over 2 × 6 wall
5	Vented cladding over wood structural panels Vented cladding over fiberboard Vented cladding over gypsum Continuous insulation with *R*-value ≥ R5 over 2 × 4 wall Continuous insulation with *R*-value ≥ R7.5 over 2 × 6 wall
6	Vented cladding over fiberboard Vented cladding over gypsum Continuous insulation with *R*-value ≥ R7.5 over 2 × 4 wall Continuous insulation with *R*-value ≥ R11.25 over 2 × 6 wall
7 and 8	Continuous insulation with *R*-value ≥ R10 over 2 × 4 wall Continuous insulation with *R*-value ≥ R15 over 2 × 6 wall

In following the stipulations of Table 1404.3.2 for Class III vapor retarders, the modelled wall assemblies represent worst-case walls from a vapor control perspective. Functionally, if inadequate performance is found with a Class III vapor retarder, a Class I or Class II vapor retarder can mitigate the performance concerns of outward vapor flow, depending on the wall configuration and climate.

3 Hygrothermal Simulations

Hygrothermal simulations were used to assess the performance of the split-insulated wall assemblies with cork insulation. Split assembly walls were modelled in WUFI® Pro version 6 and simulated until a steady-state occurred (typically, 3 years minimum). A list of all the variables investigated are provided in Table 5. Where there is uncertainty of the controllability of a specific variable, a parametric value is also included to assess the relative change.

TABLE 5 – LIST OF PARAMETERS AND VARIABLES	
Parameter	Variable
Locations	Los Angeles, CA (Climate Zone 3) Portland, OR (Climate Zone 4 - Marine) Vancouver, BC (Climate Zone 5 - Marine) Billings, MT (Climate zone 6)
Vapor Control Layer	Class 3 Vapor Retarder: 10 Perm As required: Class 1 Vapor Barrier (modeled as 0.07 Perm)
Exterior Cork Insulation Thickness	1” to 8”
Water Resistive Barrier (WRB) between cork and plywood sheathing	Permeable (>10 Perm)
Cavity Insulation and Framing	2x4: R-13 2x6: R-21
Internal Humidity	EN 15026 – Moisture Load: High, Medium, Medium +5% CZ3: High (Parametric: Medium) CZ4: High (Parametric: Medium) CZ5: High (Parametric: Medium) CZ6: Medium + 5% (Parametric: Medium)
Conditional Building Enclosure Defect	Only wall assemblies with Class I Vapor Barriers: $0.01\ L \cdot s^{-1} \cdot m^{-2}$ @ 4Pa
Sheathing Type	Plywood
Orientation	North (Worst Case for Outward Vapor diffusion)
Cladding	Rainscreen/Back Ventilated Fibre Cement

The generalized configuration of the hygrothermal model wall assembly is provided in Figure 4.

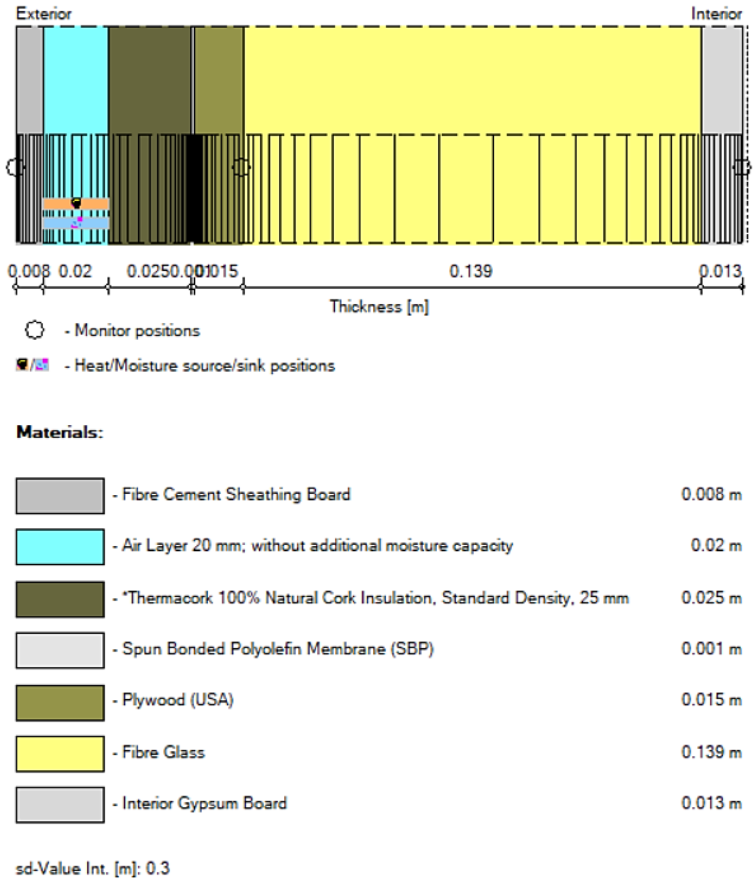


Figure 4 –Generalized Split Insulated Wall Assembly

Wall configurations that include interior vapor control are protected from outward flowing vapor. In the idealised confines of a one-dimension hygrothermal model, these wall assemblies are functionally, hygrically isolated from interior moisture sources. To represent three-dimensional aspects of flanking air flow, an air leak is introduced. This is achieved by first calibrating a 2x6 wall assembly with the introduced air leak; the air leakage value is calibrated to just meet an acceptable durability threshold. The artificial air leak is then created in the ThermaCork WUFI file with interior Class I vapor control and simulated normally.

3.1 Durability Evaluation

The output of hygrothermal models is generally a heat and moisture metric, and alone do not adequately describe actual risks for biological growth. Consequently, the output of the hygrothermal model was evaluated using the VTT Finnish Technical Research Institute’s Mould Model, which was adopted by the ASHRAE 160 (2016) Standard.

The output from the VTT Mould Model is the mould index (MI). The mould index is derived from a linear regression on temperature, relative humidity, substrate type, among other parameters. The mould index rating is shown in Table 6. ASHRAE 160-2016 recommends a mould index of 3 for the threshold of acceptable performance, as this is the point at which fungi are just starting to produce spores.

TABLE 6– MOULD GROWTH INDEX AND DESCRIPTION

Index	Description of Growth Rate
0	No growth
1	Initial stages of growth (microscopic)
2	Coverage <10% (microscopic), several local colonies
3	Fungal coverage <10% (visual), or <50% (microscopic): New spores produced
4	Fungal coverage 10-50% (visual), >50% (microscopic)
5	Extensive surface coverage, >50% (visual)
6	Heavy and tight growth, ~100% (visual)

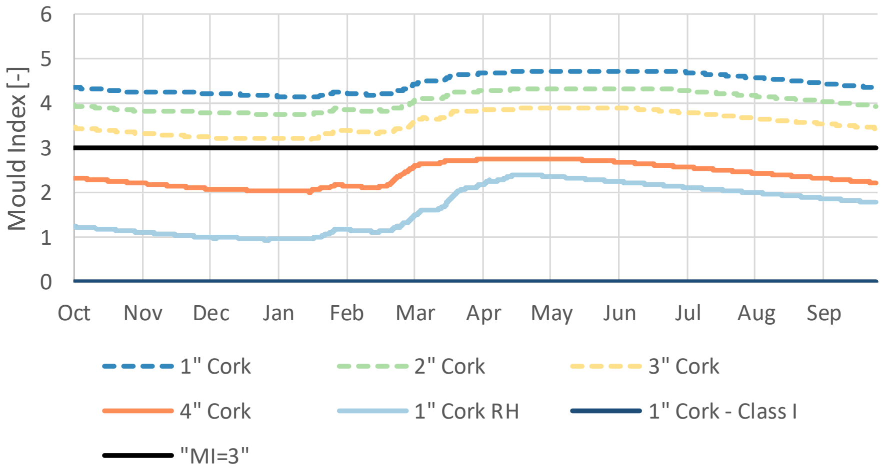
Source: (Viitanen & Ritschkoff 1991; Ojanen et al. 2010)

Due to uncertainty in the type of sheathing, a 'very sensitive' and 'no relevant decline' setting were selected to simulate a 'worst case' sheathing material.

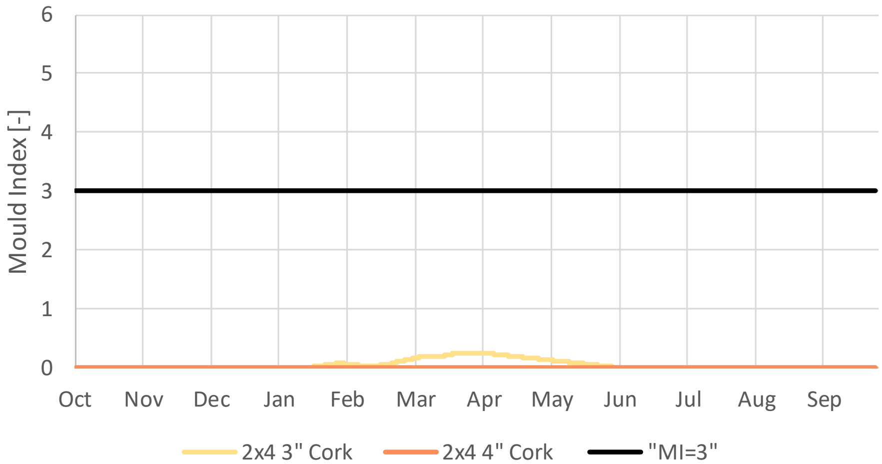
4 Results

The temperature and humidity conditions at the innermost surface of the plywood were extracted from WUFI and processed using the VTT Mould Growth model. Simulations were run until a stabilized annual condition was observed (i.e. after 2 or 3 years of simulations). The "MI=3" line represents the threshold for visual biological growth and is the recommended threshold for acceptable performance according to ASHRAE 160 (2016). Labels with the term "RH" represent the lower indoor moisture generation value of EN 15026 as part of a parametric study (e.g. the building has dedicated mechanical humidity control system). Labels with "Class I" indicate a Class I vapor control. Dashed lines represent wall assemblies that are not compliant with Table 1404.3.2 but are included for information purposes and for jurisdictions where the IBC does not apply.

The annual mould index values for representative cities in Climate Zone 6, 5, 4, and 3 can be found in Figure 5 to Figure 8, respectively.



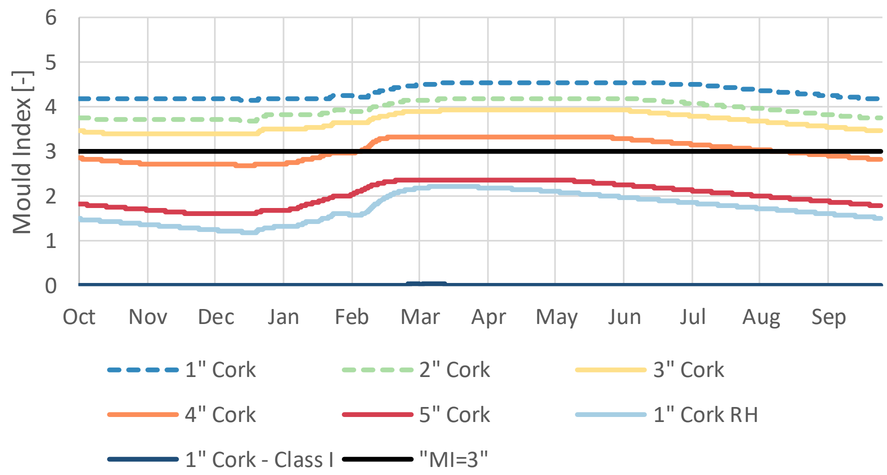
(a) 2x6 walls



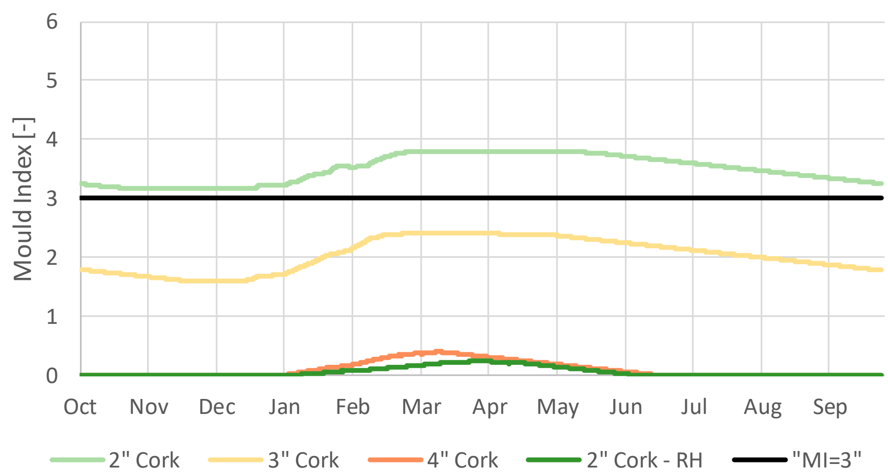
(b) 2x4 walls

Figure 5 – Climate Zone 6 (Billings, MT) – Plywood Sheathing Mould Index for 2x6 (a) and 2x4 (b) Wall Configurations with Varying Levels of Exterior ThermaCork Insulation, Class III Vapor Retarder, with EN 15026 Medium+5% Moisture Production

The primary challenge with Climate Zone 6 wall assemblies is the cold outdoor temperature. With R-21 batt insulation, a large insulation ratio is required to keep the sheathing sufficiently warm to minimize the risk of condensation and biological growth. This necessitates at least 4” of exterior ThermaCork with a Class III interior vapor retarder. To use less than 4” of exterior ThermaCork insulation, a Class I or II vapor retarder, with a continuous interior air barrier, is needed to control outward vapor diffusion. The insulation ratios in the 2x4 wall assembly (i.e. greater than 3” for minimum code R-values) are sufficient to not require any further vapor control.



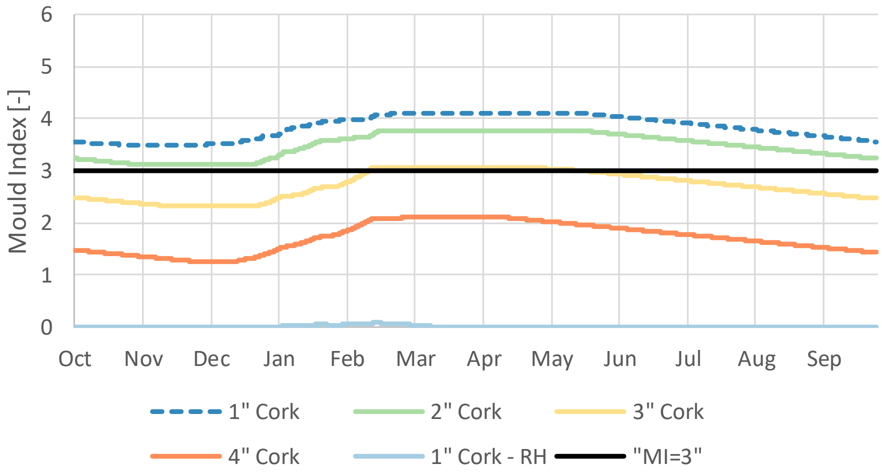
(a) 2x6 walls



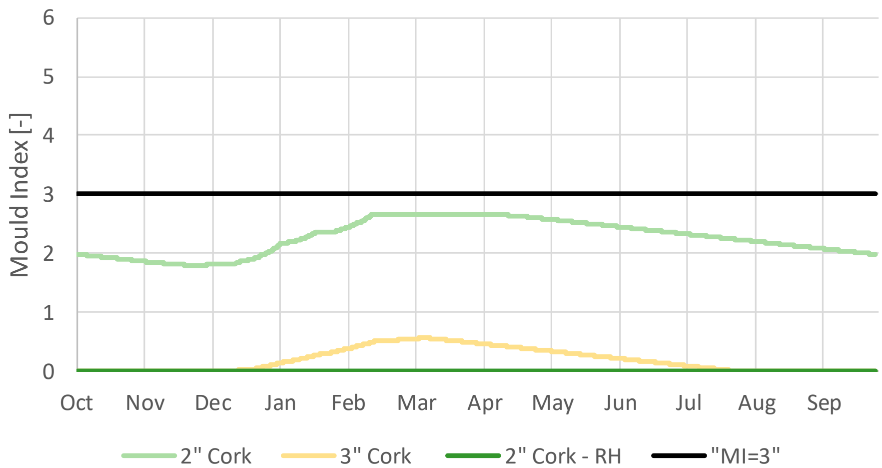
(b) 2x4 walls

Figure 6 – Climate Zone 5C (Vancouver, BC) – Plywood Sheathing Mould Index for 2x6 (a) and 2x4 (b) Wall Configurations with Varying Levels of Exterior ThermaCork Insulation, Class III Vapor Retarder, with EN 15026 High Moisture Production.

In contrast to Climate Zone 6 wall assemblies, Climate Zone 5 Marine conditions have both cool outdoor temperature and high interior relative humidity. With only a Class III interior vapor retarder, a 2x6 wall requires a minimum of 5" of exterior ThermaCork to have a mold index less than 3; alternatively, a Class I or II vapor barrier with a continuous interior air barrier could be used with any thickness of ThermaCork. Alternatively, maintaining an interior RH below 50% throughout the winter, by means of mechanical dehumidification, can also ensure adequate performance of the assembly. The insulation ratios in the 2x4 wall assembly (i.e. greater than 3" for minimum code R-values) are sufficient to not require any further vapor control.



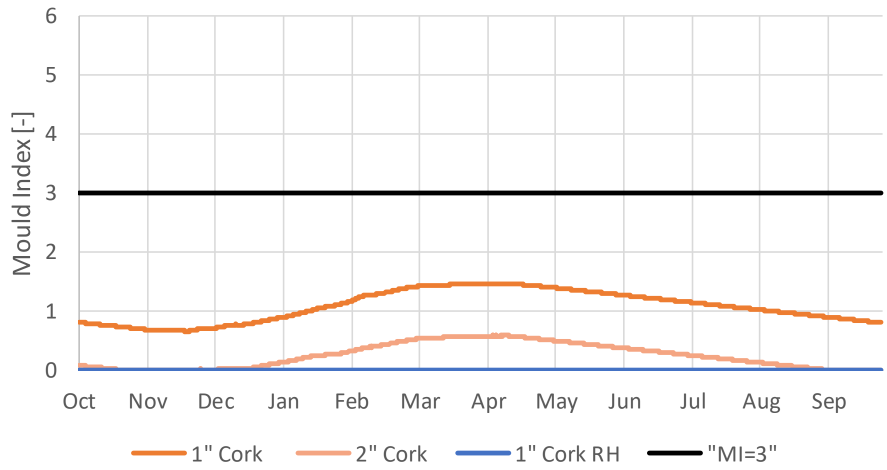
(a) 2x6 Wall



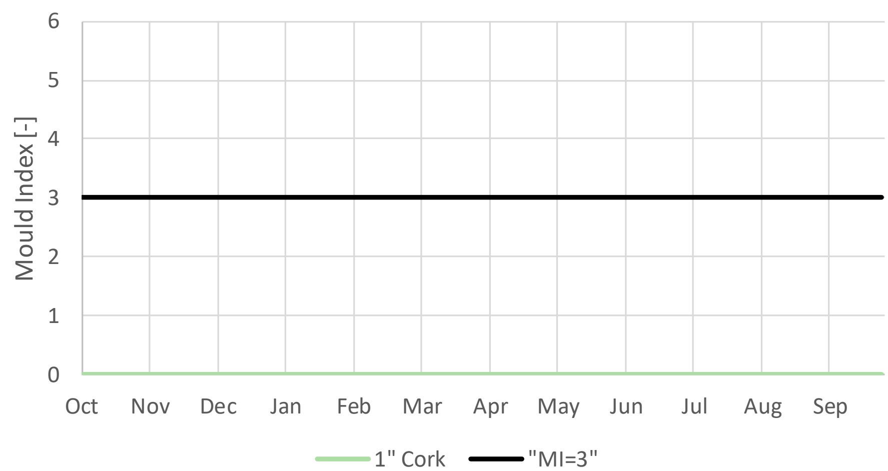
(b) 2x4 Wall

Figure 7 – Climate Zone Marine 4C (Portland, OR) – Plywood Sheathing Mould Index for 2x6 (a) and 2x4 (b) Wall Configurations with Varying Levels of Exterior ThermaCork Insulation, Class III Vapor Retarder, with EN 15026 High Moisture Production.

For Climate Zone Marine 4, higher outdoor vapor pressure result in higher interior relative humidities if there is no mechanical dehumidification. As a result, the 2x6 assemblies require at least 3” of ThermaCork to avoid a mould index of 3, or the use of a Class I vapor barrier with a continuous interior air barrier. However, the milder outdoor temperatures permit the 2x4 wall assemblies to perform adequately with a Class III vapor retarder and only 2” of ThermaCork.



(a) 2x6 Wall



(b) 2x4 Wall

Figure 8 – Climate Zone 3 (Los Angeles, CA) – Plywood Sheathing Mould Index for 2x6 (a) and 2x4 (b) Wall Configurations with Varying Levels of Exterior ThermaCork Insulation, Class III Vapor Retarder, with EN 15026 High Moisture Production.

The mild outdoor climate results in sheathing temperatures sufficiently warm as to avoid any appreciable risk of biological growth with any amount of exterior ThermaCork, using only Class III vapor retarders.

5 Conclusions

The hygrothermal simulation results are limited to the assumptions contained within the simulation methodology and the limitations of the software. However, it nonetheless provides guidance on acceptable solutions which should meet minimum standards for performance. The results are summarized in the Figure 9 through Figure 12.

The x-axis for the figures represents the thickness of exterior ThermaCork insulation. The colored bars represent the range of acceptable thicknesses that meet the respective energy efficiency standard. Bars that include a black line down their middle indicate that these assemblies surpass the Mould Index 3 threshold with only Class III interior vapor control. Consequently, assembly configurations with a black line require increased interior vapor control beyond Class III and the inclusion of interior air control layer. Note that jurisdictional requirements may mandate other vapor and air control measures and should be followed.

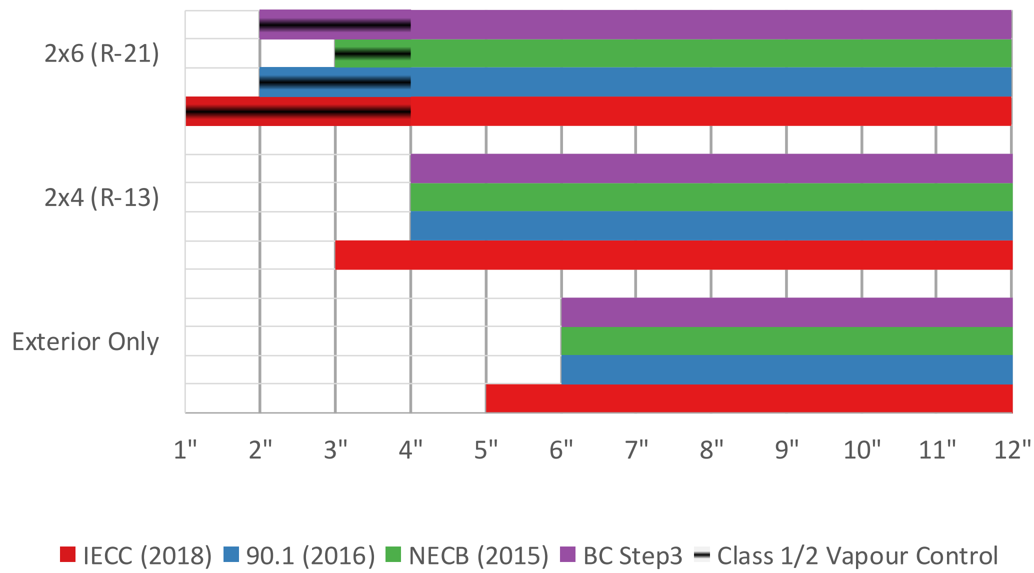


Figure 9 – Climate Zone 6, minimum exterior ThermaCork Insulation for 2x6 (R-21), 2x4 (R-13), and 2x exterior only wood framed walls, colored by energy efficiency standard. All assemblies were simulated with class III vapor control – a black bar indicates class 1 or 2 interior vapor control is required.

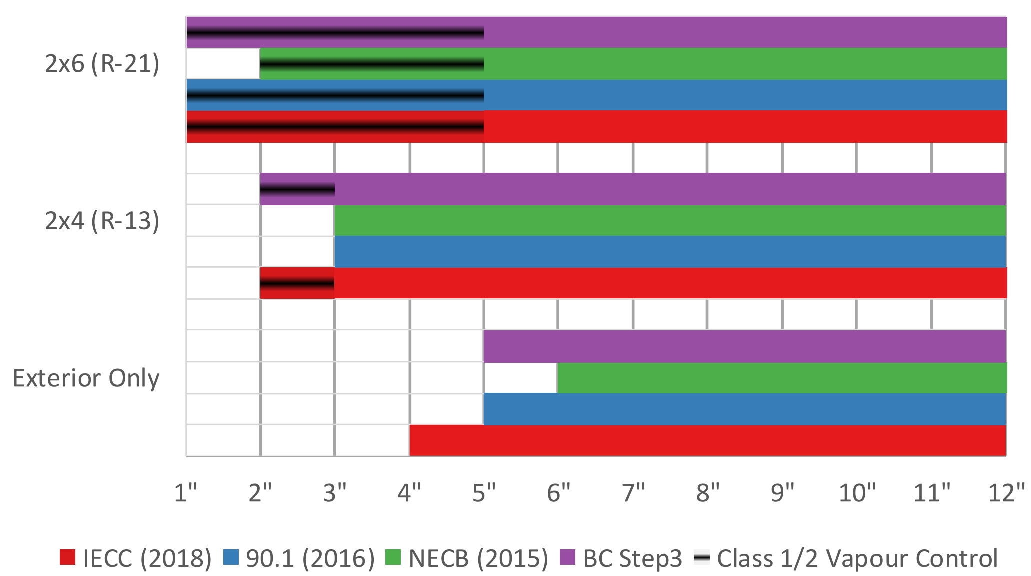


Figure 10 – Climate Zone 5C, minimum exterior ThermaCork Insulation for 2x6 (R-21), 2x4 (R-13), and 2x exterior only wood framed walls, colored by energy efficiency standard. All assemblies were simulated with class III vapor control – a black bar indicates class 1 or 2 interior vapor control is required.

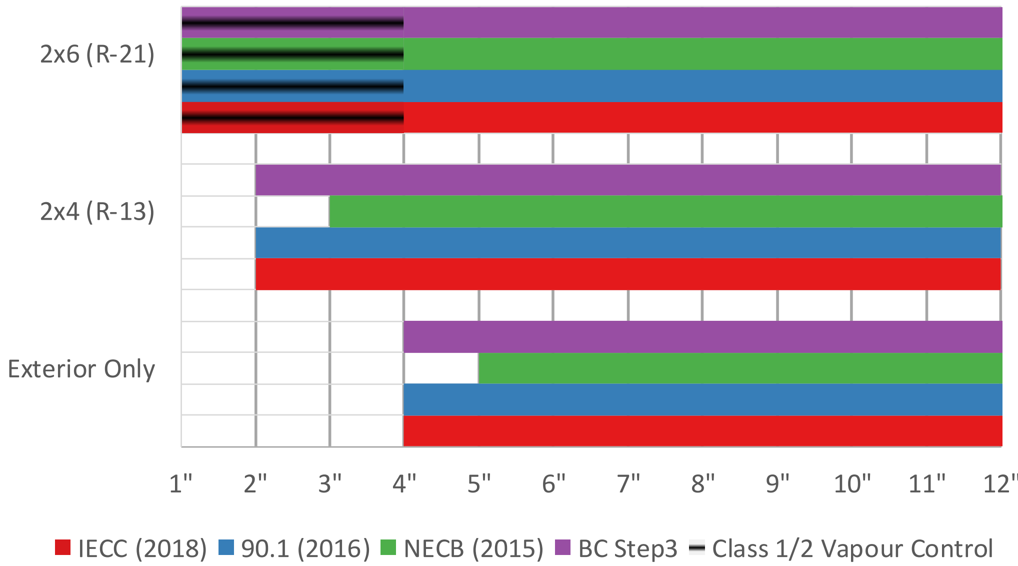


Figure 11 – Climate Zone 4C, minimum exterior ThermaCork Insulation for 2x6 (R-21), 2x4 (R-13), and 2x exterior only wood framed walls, colored by energy efficiency standard. All assemblies were simulated with class III vapor control – a black bar indicates class 1 or 2 interior vapor control is required.

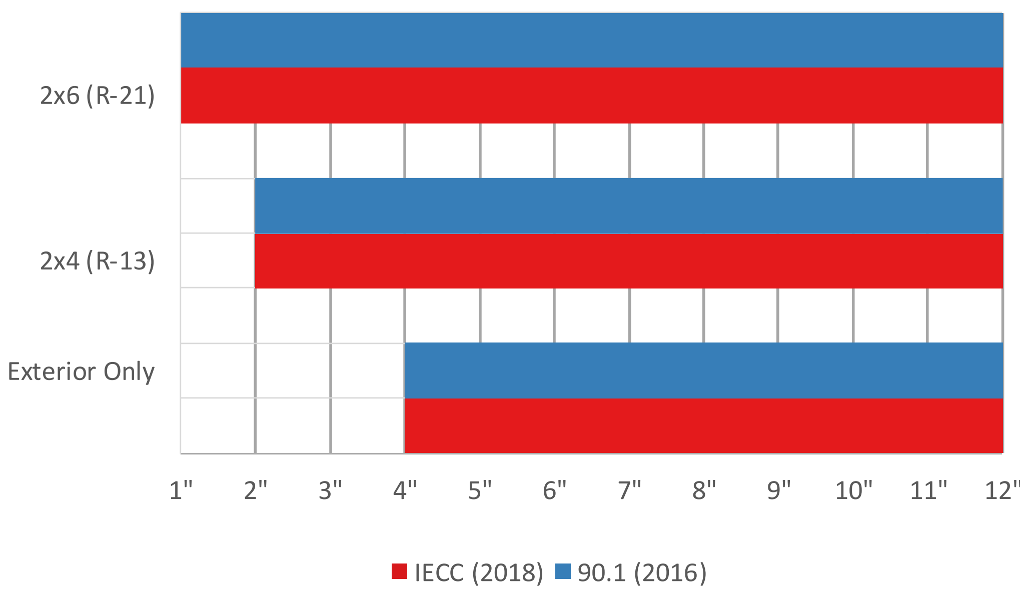


Figure 12 – Climate Zone 3, minimum exterior ThermaCork Insulation for 2x6 (R-21), 2x4 (R-13), and 2x exterior only wood framed walls, colored by energy efficiency standard. All assemblies were simulated with class III vapor control.

6 Summary

A series of hygrothermal simulations were conducted on permutations of different split insulated wall assemblies that use ThermaCork exterior insulation in multiple climate zones and jurisdictions that span the length of the Pacific West Coast. The assemblies were simulated to identify the minimum amount of exterior insulation needed for a 2x6 or 2x4 wall with minimal vapor control (Class III) assembly such that it just meets the thermal performance requirements of the IECC (2018), ASHRAE 90.1 (2016), NECB (2015), or minimum wall assemblies to meet BC Step Code to Step 3 (note that additional condition, such as mechanical systems, apply). These hygrothermal outputs were then processed in a mould growth model to evaluate the risk of biological growth, in general conformance to ASHRAE 160 (2016).

The output of acceptable solutions for rainscreen or drained and back-ventilated cladding wall assemblies are provided in figure format for each climate zone. The colored bars represent the range of acceptable thicknesses of Thermacork for the respective energy efficiency standard given a different wall framing thicknesses. Assemblies that exceeded the biological growth threshold are identified with a black bar, which indicates that a Class I or II vapor control layer and an interior air barrier layer is required to achieve acceptable performance.

These figures are intended to provide guidance on acceptable solutions and have not been cross-validated with all possible regional by-laws or building codes. Designers should ensure wall assemblies conform to local codes.

Yours truly,

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Reviewed by

Appendix A

Supporting Material

Material Property Testing Summary Report | Project 10514.000

Amorim Cork Insulation Testing and WUFI Material Files, 167 Lexington Court, Unit 6, Waterloo, ON

RDH CELEBRATING 20 YEARS EST. 1997

MAKING BUILDINGS BETTER™

To Mr. Lino Rocha
Amorim Isolamentos, SA
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Mozelos-VFR Aveir 4535-186

Submitted February 9, 2018 by
RDH Building Science Laboratories
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Waterloo ON N2J 4R9

Contents

1 Introduction

This report provides a summary of material property testing on two of cork insulation products manufactured by Amorim Isolamentos, SA (Amorim):

1. Standard Grade Cork Insulation
2. Medium Density Cork Façade

In North America these products are distributed by Small Planet Supply (Small Planet) and marketed as THERMACORK cork insulation.

1.1 Background

Amorim and Small Planet commissioned RDH Building Science Laboratories (RDH-BSL) to conduct hygrothermal material property testing to check, support, and supplement previous third-party test reports and documents with the goal of creating material property data for use in hygrothermal simulation programs such as WUFI.

Specifically, RDH-BSL was asked to:

1. Conduct testing on samples of THERMACORK Standard Grade Insulation (SGI) and Medium Density Façade (MFI) products
2. Summarize past third-party test reports provided by Amorim
3. Organize the creation of WUFI material property files for the SGI and MFI products

1.2 RDH Building Science Laboratory Testing

Amorim and Small Planet provided RDH-BSL with a dozen THERMACORK Standard Grade Insulation samples in thicknesses of 25 and 50 mm (1 and 2 in.), and Medium Density Façade samples in a thickness of 50 mm (2 in.). RDH-BSL conducted the following property testing at our research and testing facility in Waterloo ON, Canada.

- **Density (ρ)**, using methods from ASTM D2395 "Standard Test Methods for Density and Specific Gravity (Relative Density) of Wood and Wood-Based Materials"
- **Thermal Conductivity (k)** at mean temperatures of -3.9, 4.4, 10, 23.9, and 43.3˚C (10, 25, 50, 75, and 110˚F), using methods from ASTM C518 "Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus", and ASTM C1038 "Standard Practice for Selecting Temperatures for Evaluating and Reporting Thermal Properties of Thermal Insulation"
- **Vapor Permeance (M)**, using dry- and wet-cup methods described in ASTM E96 "Standard Test Methods for Water Vapor Transmission of Materials"
- **Water Absorption Coefficient (A-value)** using methods based ASTM C1794 "Standard Test Methods for Determination of the Water Absorption Coefficient by Partial Immersion", and on ISO 15148 "Hygrothermal Performance of Building Materials and Products - Determination of Water Absorption Coefficient by Partial Immersion"

- **Moisture Storage Function,** described using Equilibrium Moisture Content (EMC) at 50, 80, 90, 95% RH, and at capillary saturation, and based on methods from ASTM C1498 "Standard Test Method for Hygroscopic Sorption Isotherms of Building Materials" and ASTM C1699 "Standard Test Method for Moisture Retention Curves of Porous Building Materials Using Pressure Plates"

1.3 Third-Party Test Reports Provided by Amorim

Numerous third-party tests have been commissioned to document the Standard Grade Insulation and Medium Density Façade products. Amorim provided RDH-BSL with over 750 test documents from past testing and certification efforts. Almost all were prepared by laboratory, testing, and certification agencies from the EU, and the clear majority of them are written in Portuguese. The topics include thermal and moisture material property testing, as well as acoustic performance, structural properties, fire testing, VOC testing, performance testing of assemblies, etc.

RDH-BSL conducted a brief review of the available documentation with the goal of identifying past third-party test reports that might inform our current efforts: the development of material properties for hygrothermal simulations. Thirty-four documents were identified; copies of these are included in Appendix B of this report. RDH-BSL did not undertake a detailed review to confirm (and are not responsible for) the validity of any information in third-party test reports and documentation.

1.4 Structure of this Report

RDH-BSL material property test methods and results are summarized in Section 2 of this report. Section 3 provides a comparison between RDH-BSL test results and those collected from the thirty-four third-party test reports that were selected from the documentation provided by Amorim. The generated WUFI material property files are discussed in Section 4 of this report and presented in Appendix A. Finally, Appendices B includes third-party test documentation we reviewed.

2 RDH-BSL Testing and Results

The goal of this research work was the production of material property data for use in hygrothermal simulation programs such as WUFI. The RDH-BSL test program was established to check, support, and supplement data from previous third-party test reports and other documentation provided by Amorim and Small Planet. The specific properties considered include density, thermal conductivity, vapor permeance, absorption coefficient, and the moisture storage function. The test program considered focused on quantifying these five material properties for THERMACORK Standard Grade Insulation samples in thicknesses of 25 and 50 mm (1 and 2 in.), and Medium Density Façade samples in a thickness of 50 mm (2 in.). A summary of the test methods and results follows. All RDH-BSL testing was conducted at the RDH-BSL research facility in Waterloo ON, Canada.

2.1 Dry Density

Dry density is a fundamental material property that is used as a basic input for all hygrothermal simulation programs. It is used to predict how much heat and moisture are stored in a material over a given time period.

2.1.1 Methodology

For this project RDH-BSL determined dry density using methods from ASTM D2395 "Standard Test Methods for Density and Specific Gravity (Relative Density) of Wood and Wood-Based Materials". Density was determined using samples cut for the other material property tests (size varied according to needs of those tests).

"Lab Density" was determined using the mass of the samples after they were allowed to rest for two weeks at, and reach equilibrium with lab conditions of 20-24˚C (68-75˚F) and 40-60% RH. Dry Density was determined using mass of samples that were dried in a ventilated oven at 40˚C (104˚F) until no change in mass was observed over a 24 hr period.

Volume was calculated as the product of dimensions measured using a 1/32" (0.8mm) or with a digital caliper with resolution to 0.01 mm wherever possible. Mass was measured using digital scales of capacity 3000 g and resolution 0.01 g or capacity 300 g and resolution 0.001 g. Density was calculated as measured mass divided by calculated volume.

2.1.2 Results

TABLE 2.1 DENSITY (OVEN DRY AND EQUILIBRIUM W/ LAB CONDITIONS)

DENSITY	STANDARD DENSITY INSULATION (SDI)				MEDIUM DENSITY FAÇADE (MDF)	
	25 mm		50 mm		50 mm	
Condition	kg/m^3	pcf	kg/m^3	pcf	kg/m^3	Pcf
Oven Dry (@40˚C)	111	6.92	103	6.43	143	8.93
Equilibrium with Lab (40-60% RH)	115	7.18	107	6.78	148	9.24

2.2 Thermal Conductivity

Thermal Conductivity (k) is a key property for all materials. It is particularly important for materials that serve an insulating function.

2.2.1 Methodology

For this work thermal conductivity was determined using equipment and methods from ASTM C518 “Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus”. Thermal conductivity of the cork insulation samples was determined at five mean temperatures -3.9, 4.4, 10, 23.9, and 43.3°C (10, 25, 50, 75, and 110°F). The two lowest and highest setpoints are recommended by ASTM C1038 “Standard Practice for Selecting Temperatures for Evaluating and Reporting Thermal Properties of Thermal Insulation”; the middle setpoint (10°C or 50°F) represents the standard mean temperature employed in European testing.

Two test specimens were cut from each of three sheets of 25 mm (1 in.) thick and 50 mm (2 in.) thick, for a total of six SDI test specimens. A total of six MDF test specimens were cut from five sheets of 50 mm (2 in.) thick Medium Density Façade Grade Insulation. All test specimens were cut to 300 x 300 mm (nominal 12 x 12 in.) and seasoned in the laboratory at approximately 40-60% RH for two weeks.

2.2.2 Results

TABLE 2.2 THERMAL CONDUCTIVITY (SI) & RESISTANCE (IP)

THERMAL CONDUCTIVITY & RESISTANCE	STANDARD DENSITY INSULATION 111 KG/M^3				MEDIUM DENSITY FAÇADE 143 KG/M^3	
	25 mm		50 mm		50 mm	
Mean Temperature	w/m·K	R/in.	w/m·K	R/in.	w/m·K	R/in.
@-3.9°C (10°F)	0.0377	3.82	0.0381	3.78	0.0401	3.60
@4.4°C (25°F)	0.0387	3.73	0.0393	3.67	0.0411	3.51
@10°C (50°F)	0.0394	3.67	0.0401	3.60	0.0417	3.46
@23.9°C (75°F)	0.0410	3.52	0.0425	3.40	0.0434	3.33
@43.3°C (110°F)	0.0429	3.36	0.0459	3.14	0.0452	3.19

2.4 Vapor Permeance

Vapor Permeance (M) is a measure of the rate at which water vapor diffuses through a given thickness of the material or system. For many materials, vapor permeance changes as the relative humidity (and associated equilibrium moisture content) of the material change. This effect can be identified, characterized, and quantified by measuring vapor transport under a range of different humidity conditions; for example, 50 to 0% RH (dry cup, RH_{avg} = 25%), 100 to 50% RH (wet cup, RH_{avg} = 75%), 100 to 80% RH (RH_{avg} = 90%), 100 to90% RH (RH_{avg} = 95%), etc.

2.4.1 Methodology

For this work dry- and wet-cup vapor permeance were measured using methods based on ASTM E96, "Standard Test Methods for Water Vapor Transmission of Materials".

Three test specimens were cut from 25 mm (1 in.) thick sheets of Standard Density Insulation and three from 50 mm (2 in.) thick sheets, for a total of six SDI test specimens. An additional six MDF test specimens were cut from 50 mm (2 in.) thick sheets of Medium Density Façade Grade Insulation. All test specimens were cut to 150 x 150 mm (nominal 6 x 6 in.). The perimeter edges of each specimen were sealed using wax and foil tape to prevent vapor flanking through the thick test specimens, and to facilitate sealing of the specimens to the vapor permeance test containers ("cups").

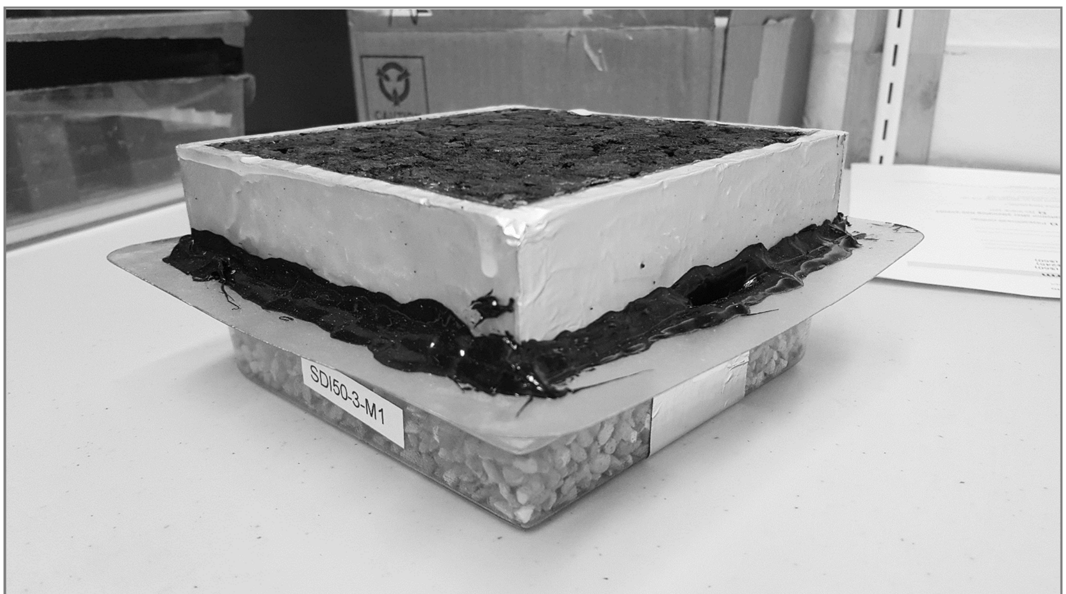


Figure 2.1- Standard Density Cork Insulation, 50 mm thick, ready for dry-cup test

2.4.2 Results

The results are tabulated below, in both US (IP) units and Canadian metric units.

TABLE 2.3 VAPOR PERMEANCE						
VAPOR PERMEANCE	STANDARD DENSITY INSULATION (111 KG/M³)				MEDIUM DENSITY FAÇADE (143 KG/M³)	
	25 mm		50 mm		50 mm	
Test	ng/Pa·s·m²	US perm	ng/Pa·s·m²	US perm	ng/Pa·s·m²	US perm
Dry Cup (RH_{avg} = 25%)	440	7.69	144	2.5	69	1.2
Wet Cup (RH_{avg} = 75%)	473	8.26	171	3.0	80	1.4

2.5 Liquid Water Uptake (by Absorption Coefficient)

The Liquid Water Uptake test and Water Absorption Coefficient (A-value) are used to characterize moisture transport in the capillary regime. This is a critical transport mechanism for hygroscopic materials that are exposed to liquid water. Some hygrothermal simulation programs (e.g. WUFI) use A-value to estimate liquid transport coefficients for uptake and redistribution.

2.5.1 Methodology

For this work RDH determined the water absorption coefficient using methods based on ASTM C1794 "Standard Test Methods for Determination of the Water Absorption Coefficient by Partial Immersion", and on ISO 15148 "Hygrothermal Performance of Building Materials and Products - Determination of Water Absorption Coefficient by Partial Immersion"

Three test specimens were cut from 25 mm (1 in.) thick sheets of Standard Density Insulation and three from 50 mm (2 in.) thick sheets, for a total of six SDI test specimens. An additional six MDF test specimens were cut from 50 mm (2 in.) thick sheets of Medium Density Façade Grade Insulation. All test specimens were cut to 150 x 150 mm (nominal 6 x 6 in.). The perimeter edges of each specimen were sealed using wax to prevent flanking absorption. Specimens were seasoned in the laboratory at approximately 40-60% RH for two weeks prior to undertaking the liquid water uptake tests.

2.5.2 Results

TABLE 2.4 ABSORPTION COEFFICIENT (A-VALUE)			
ABSORPTION COEFFICIENT	STANDARD DENSITY INSULATION (SDI)		MEDIUM DENSITY FAÇADE (MDF)
	25 mm	50 mm	50 mm
	kg/m²·√s	kg/m²·√s	kg/m²·√s
A-Value	0.00058	0.00082	0.00050

2.6 Moisture Storage Function

The Moisture Storage Function quantifies the moisture content as a function of relative humidity; that is the amount of moisture stored (by adsorption and absorption) in the pores of the material for any given RH.

2.6.1 Methodology

For this project RDH-BSL characterized the moisture storage function by measuring the Equilibrium Moisture Content (EMC) at 50, 80, 90, 95% RH, based on methods from ASTM C1498 "Standard Test Method for Hygroscopic Sorption Isotherms of Building Materials". The moisture content at capillary saturation was determined using methods described in ASTM C1699 "Standard Test Method for Moisture Retention Curves of Porous Building Materials Using Pressure Plates"

Twenty-seven 50 x 50 mm (nominal 2 x 2 in.) test specimens were cut from each of the 25 and 50 mm (1 and 2 in.) thick sheets of Standard Density (SDI) Insulation, and from the 50 mm (2 in.) thick sheets of Medium Density Façade (MDF) Grade Insulation.

The twenty-seven test specimens were allocated as follows: six replicates were used for each of the EMC tests (50, 80, 90, and 95% RH each, for a total of 24 test specimens); the remaining three specimens were employed as replicates for the capillary saturation test.

2.6.2 Results

TABLE 2.5 MOISTURE STORAGE FUNCTION

CONDITION	STANDARD DENSITY INSULATION (SDI)		MEDIUM DENSITY FAÇADE (MDF)
	25 mm	50 mm	50 mm
	%wt	%wt	%wt
EMC50 Eq. with 50% RH	3.0	2.6	2.3
EMC80 (measured 82% RH)	4.5	4.0	3.6
EMC90 (measured 91% RH)	4.9	4.5	4.0
EMC95 (measured 93% RH)	5.4	4.9	4.7
Saturation	113	NA	70.9

3 Summary of Data from Select Third-Party Test Reports

Thermal conductivity, vapor permeance, and water immersion test reports were reviewed.

The thermal conductivity of a material such as expanded cork is expected to vary with density, moisture content, and the mean temperature of the sample. A number of thermal testing reports from ITeCons at the University of Coimbra were provided by the client for a range of sample densities and thicknesses and mean temperatures. It is also worth noting that some of the testing was conducted at oven dry moisture content (i.e, near 0%MC) and some at equilibrium with laboratory conditions (higher moisture contents). Unsurprisingly, the dry specimens returned slightly lower conductivity (higher R-values) than the samples with some moisture content. The testing at colder mean temperature showed a slightly lower conductivity (higher R-values) than the samples at warmer temperatures.

As thermal conductivity is routinely reported at the US Federal Trade Commission (FTC) required mean temperature of 23.9 °C, this value is likely to be the best comparison to other products in North America. Intertek / ATI tested a 109 kg/m^3 sample (file:g4535.01-116-25-r0) and reported a conductivity of 0.041 W/mK at a mean of 23.9°C. For the more common European mean temperature of 10°C, the RDH results for the SDI (111 kg/m^3) were between 0.039 and 0.040 W/mK. Many of the ITeCons results (file:OMH068_015, OMH067_015) were for a lower density product (of 82-89 kg/m^3) and therefore expected to have slightly lower conductivity, were reported to be between 0.037 to 0.038 W/mK. The thermal conductivity testing conducted by LNEC of samples with an average density of 105 kg/m^3 at a mean temperature of 10 °C, reported a conductivity of 0.039 W/mK.

For higher density samples of 128 kg/m^3 ITeCons reported around 0.044 W/mK (file: HIG485 10_MDF) and for 132 kg/m^3 was 0.043 W/mK (file:HIG484 10_MDF). A sample of 151 kg/m^3 exhibited a conductivity at 10°C mean temperature of 0.043 W/mK (file:HIG086 10). Many test reports were reviewed with much higher densities (i.e., in the 170-190 kg/m^3) range, for which the conductivity was also higher (i.e., 0.043 to 0.045) as expected.

Thus it can be concluded that the extensive thermal conductivity testing by ITeCons and the testing by Intertek/ATI and RDH Building Science Labs demonstrate excellent agreement and provide support that very good repeatability between labs can be achieved.

The vapor permeance of a product such as cork is expected to vary with the sample MC (directly related to the mean equilibrium RH in standard tests) and density. Testing of vapor permeance by other labs was provided by the client. Note that in Europe, the vapor diffusion properties of a material or product are commonly described as a resistance with the help of the equivalent (to still air) vapour diffusion thickness, the s_d-value [m].

In North America, the water vapour permeance, M is often given in SI units of [ng/(Pa s m^2)] or in US perms (inch-pound units). One perm is defined as a grain/(h ft^2 in Hg) and the conversion between IP units and SI is approximately:

1 US Perm = 57.2 ng/(Pa s m^2)

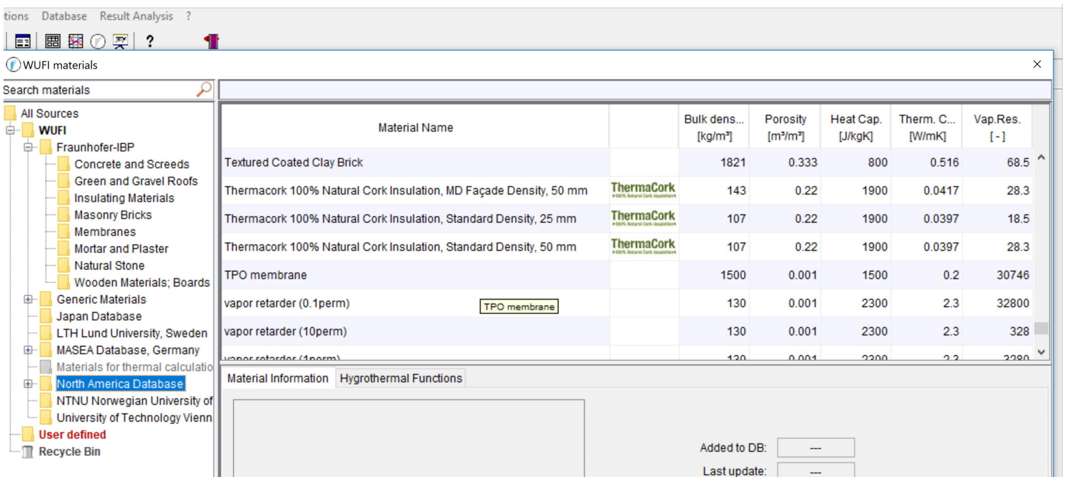
The conversion from s_d-value [m] to metric perms is approximately 182 ng/(Pa s m^2) / s_d.

ITeCons measured samples of unknown density and 40 to 100 mm thickness under ASTM E96 dry-cup (mean 25%RH) conditions. The permeance reported for the 50 mm sample was about 107 metric perms (HIG766/12) and 67 metric perms for a 100 mm thick sample (HIG014/13). RDH results for the dry cup samples were higher, at 144 metric perms for a 50 mm thickness. Vapor permeance exhibits a larger natural variation than thermal conductivity, and given the small number of samples tested and the unknown sample density, it is likely the deviations between the two sources are just normal variability. If the value of the permeance is important more samples should be tested to understand the statistical variability to be expected.

The water immersion testing (file: HIG 220-09) did not appear to follow any known testing standard and appeared to merely compare the water absorption of a sample of cork to extruded polystyrene. The cork product absorbed almost five times as much water as compared to extruded polystyrene.

4 WUFI Material Property

The hygrothermal properties measured were sufficient to develop a WUFI material database file. This data resulted in Amorim ThermaCork product appearing in the WUFI material database update on Dec 15, 2017. The images of the material properties are provided in Appendix A.



5 Closing

The most important hygrothermal properties of two cork insulation products manufactured by Amorim Isolamentos, SA have been measured. Comparison with previous measurements shows excellent agreement between thermal conductivity measurements by different labs.

The density, thermal conductivity, vapor permeance, water absorption, and moisture storage function have been measured for several samples. These values have been used to generate a material database file and implement it for worldwide users of the WUFI hygrothermal modelling program.

Yours truly,

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