ENTUITIVE

HYGROTHERMAL ANALYSIS

MULOCK ESTATE

EN023-00496

JUN 13, 2023

1. INTRODUCTION

The Mulock Estate is a 2-storey residential building located in Newmarket, Ontario. The building was originally constructed in 1870 with an addition in 1880 and has a footprint of approximately 465 square meters (5,000 square feet). The building structure and cladding is comprised of mass brick masonry. The property is located northwest of the intersection of Yonge St. and Mulock Dr. and is encompassed by residential neighbourhoods.

As part of an ongoing revitalization of the entire property, the building will be undergoing an adaptive reuse renovation, including potential retrofits to the building envelope. This will modify the envelope components of the heritage brick masonry, potentially leading to changes to building durability. This report identifies the characteristics, considerations, and freeze thaw risk potential for the proposed wall retrofit design details.

2. SUMMARY

Entuitive assessed the hygrothermal performance of the existing brick masonry components and analyzed freeze-thaw risk at interior insulated retrofits of various walls at the Mulock Estate. The analysis methodology includes laboratory measurements of brick material properties, as well as laboratory measurement of the critical degree of saturation (S_{crit}). The material properties are then used in hygrothermal modelling to determine the expected moisture contents within the brick after the modelling period, while the S_{crit} value is understood to be the threshold where freeze-thaw damage can occur. Expected moisture contents are then compared to the S_{crit} value – if moisture content surpasses S_{crit}, there is a high risk of freeze-thaw deterioration. Please see Appendix A for the laboratory testing data.

The models represent the field of the wall. Although modelling regions of discrete water concentration such as beneath sills may yield high freeze-thaw risk results, these results would not be representative of the overall behaviour. Additionally, durability can be managed through building flashings and geometry to deflect water away.

Our study determined that there is very little risk of freeze thaw deterioration with interior insulation retrofits of up to 150 mm mineral wool, or 100 mm closed cell spray-applied polyurethane foam.

3. DOCUMENT REVIEW

Architectural Drawings:

- "Mulock Estate Adaptive Re-use", sheets 103, 104, 105, 115, by +VG Architects, Jan 31, 2023.

4. METHODOLOGY

The following methodology was employed for the analysis:

- One dimensional hygrothermal analysis (for freeze thaw): WUFI 6 software

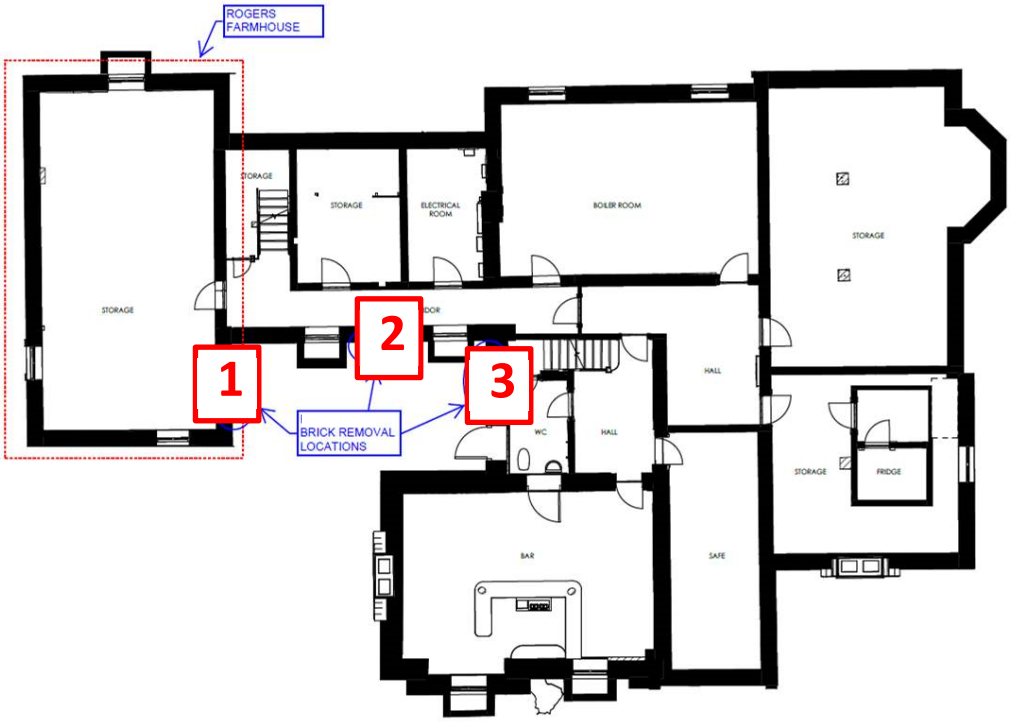
5. ASSUMPTIONS

The material properties used in the study were obtained from the following sources (see Appendix A for the laboratory testing report):

- Measured values from testing laboratory.
- ASHRAE 90.1 (2013).
- ASHRAE Handbook 2013 Fundamentals.
- Material tests to ASTM C177, ASTM C518 or C1363.
- Hutcheon, Neil B. and Gustav O.P. Handegord. *NRC-CNRC Building Science for a Cold Climate*. John Wiley & Sons, 1983.
- WUFI Software material data library.

6. BRICK REMOVALS

Entuitive was present on site on March 16, 2023 to observe, review, document, and transport brick masonry samples. At the time of our visit, the weather was 5 degrees Celsius and cloudy. Bricks were removed from three (3) locations at the ground floor:



From these locations, two (2) wall types were identified. Wall type 1 was found at Location 1 and 2 and comprised (from exterior to interior):

- 3 wythe brick wall (103 mm brick and 20 mm mortar collar joints)
- 25 mm wood strapping/air cavity

- 12 mm wood lathe
- 13 mm gypsum board
- 25 mm horsehair reinforced plaster
- Wallpaper and paint finish

Wall type 2 was found at Location 3 and comprised (from exterior to interior):

- 3 wythe brick wall (103 mm brick and 20 mm mortar collar joints)
- 25 mm wood strapping/air cavity (some variability, up to 50 mm)
- 25 mm gypsum board
- Wallpaper and paint finish

7. PROJECT ENVIRONMENTAL DESIGN CONDITIONS

7.1 WUFI - HYGROTHERMAL ANALYSIS

Hygrothermal analysis in WUFI software includes a time factor, as the simulation is transient and not steady state. The following conditions, as defined in the project specifications, were used in the hygrothermal analysis:

Exterior Temperature:
Typical climate year for Toronto (see next section)

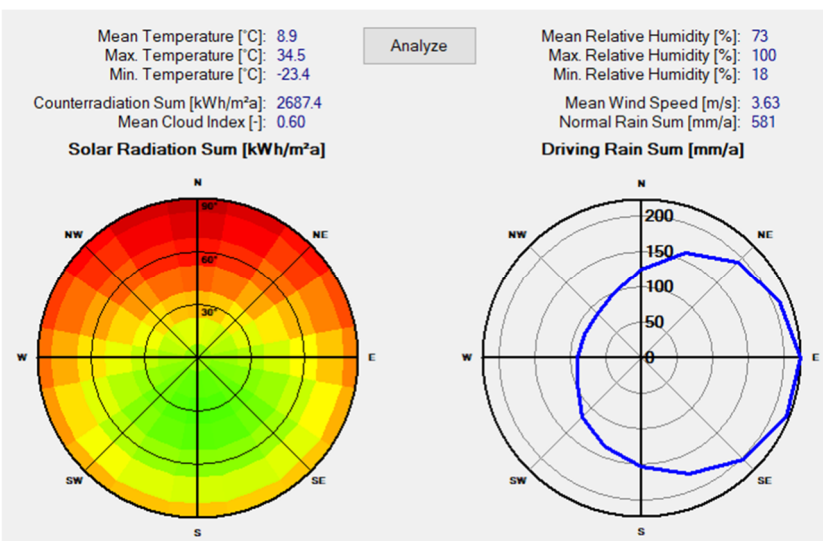
Simulation Time:
5 years

Interior Environment Design Conditions:
20°C +/- 4°C
50% RH +/- 10%

Timestep:
1 hour

7.1.1. Climate

WUFI utilizes a generic historic climate year for the exterior environmental conditions. The climate year is developed from measured historic data in the Toronto region. The climate analysis shows that the elevation with the greatest driving rain is east (Figure 1).



Simulations were set at the east facing elevation to model the worst-case scenario. WUFI also estimates driving rain exposure using an approximation, represented by a simple formula:

Driving rain = rain(R1 + [R2*wind velocity])*

Whereas R1 and R2 are WUFI-specific coefficients that modify the rain based on the climate condition. As the Mulock Estate is 2-3 storeys tall, the following values were chosen for the driving rain exposure:

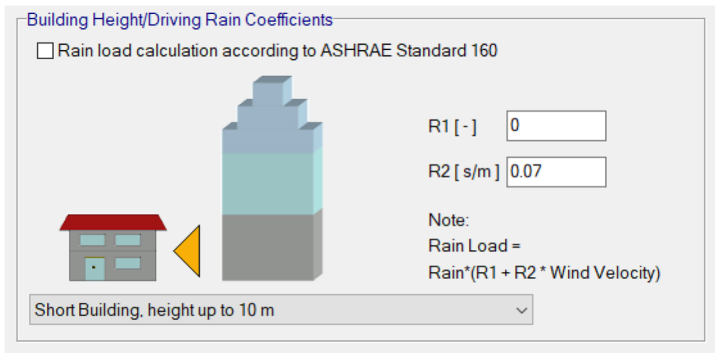


Figure 2: WUFI Driving Rain Calculation

8. WUFI SIMULATION RESULTS

Wall Type 1 and Type 2 were modelled with either mineral wool or closed cell spray-applied polyurethane foam (ccSPF) insulation. Mineral wool interior insulation retrofit cases were modelled with a vapour-permeable air barrier, insulation, smart vapour barrier, interior gypsum board, and paint. The smart vapour barrier is characterized by having a variable vapour permeance of less than 1.0 perms at 60% RH and above, and greater than 10 perms at 60% RH and below. We recommend including the smart vapour barrier to reduce interior moisture from entering the wall. 50 mm and 150 mm insulation thicknesses were modelled. 50 mm is a recommended minimum to bring an uninsulated masonry wall to near modern code compliance. 150 mm is a recommended maximum as there are diminishing returns on energy savings as insulation thickness increases, as well as loss of interior space.

The ccSPF cases were modelled with insulation, interior gypsum board, and paint, as the ccSPF acts as an air and vapour control material. 50 mm and 100 mm insulation thicknesses were modelled; the 100 mm thickness was chosen as it achieves the same R-value as the 150 mm mineral wool.

A list of all the scenarios simulated is shown next.

Model #	Description of Simulation Scenario
1.0	Base case (Wall Type 1)
1.1	50 mm mineral wool insulation, with smart vapour barrier
1.2	150 mm mineral wool insulation, with smart vapour barrier
1.3	50 mm ccSPF insulation
1.4	100 mm ccSPF insulation
2.0	Base case (Wall Type 2)
2.1	50 mm insulation, with smart vapour barrier
2.2	150 mm insulation, with smart vapour barrier
2.3	50 mm ccSPF insulation
2.4	100 mm ccSPF insulation

8.1 WALL TYPE 1:

The bricks have been segmented in WUFI to allow for more granular data. A typical WUFI model geometry for the base case, with the segmented brick portions, is shown in Figure 3. Please see Appendix B for diagrams of all the cases.

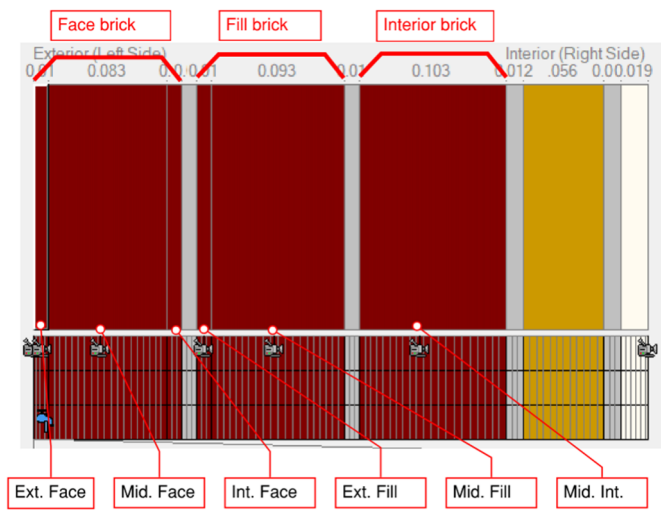


Figure 3: Wall 1 base case WUFI wall diagram.

The mineral wool results are shown in Figure 4.

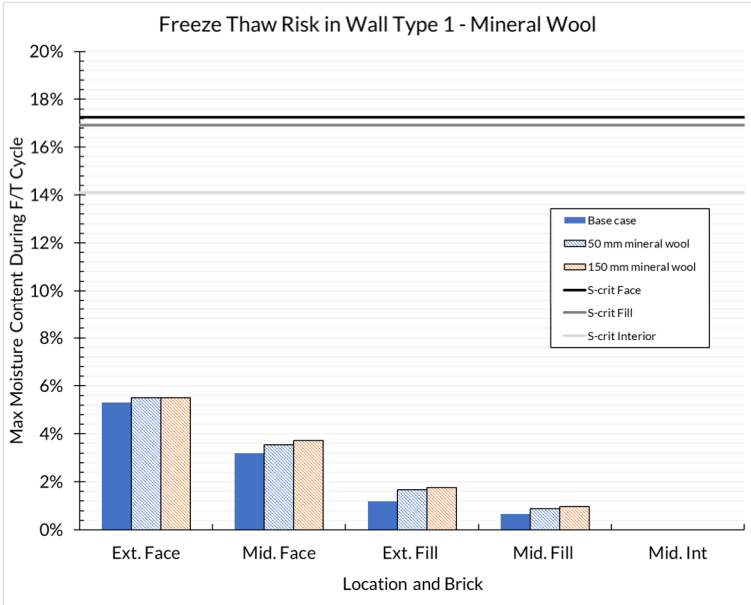


Figure 4: Wall type 1 brick moisture content values with mineral wool

The graph shows that in general, the maximum moisture content values experienced over a typical year do not go beyond 6%. This is well below the S_{crit} threshold of approximately 17% for the face and fill brick, and approximately 14% for the interior bricks. The difference in moisture content values between the 50 mm and 150 mm insulation scenarios is minimal, with a slight increase in moisture content with greater insulation. The ccSPF results are shown in Figure 5.

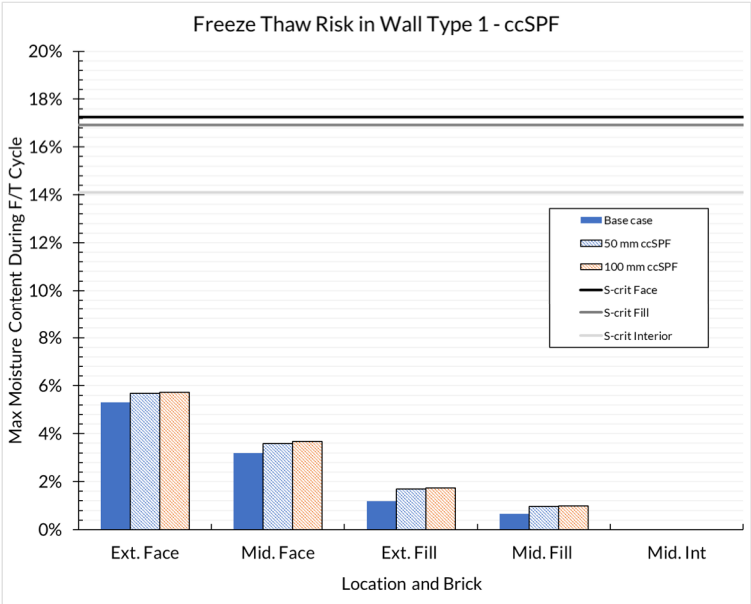


Figure 5: Wall type 1 brick moisture content values with ccSPF

The ccSPF moisture content values are slightly higher than the mineral wool, however, the risk remains the same. **Overall, there is very little risk of freeze thaw deterioration with interior insulation retrofits of up to 150 mm with mineral wool and 100 mm with ccSPF.**

8.2 GROUP 2: 2-WYTHE WALL RESULTS

A typical WUFI model geometry for the base case is shown in Figure 6. Please see Appendix B for diagrams of all the cases.

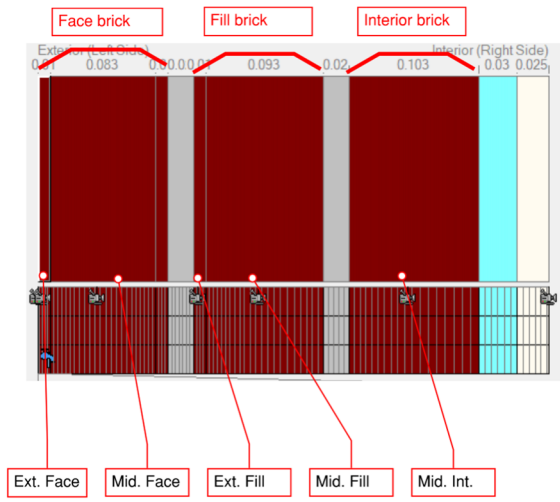


Figure 6: Wall 2 base case WUFI wall diagram.

The results are shown in Figure 7.

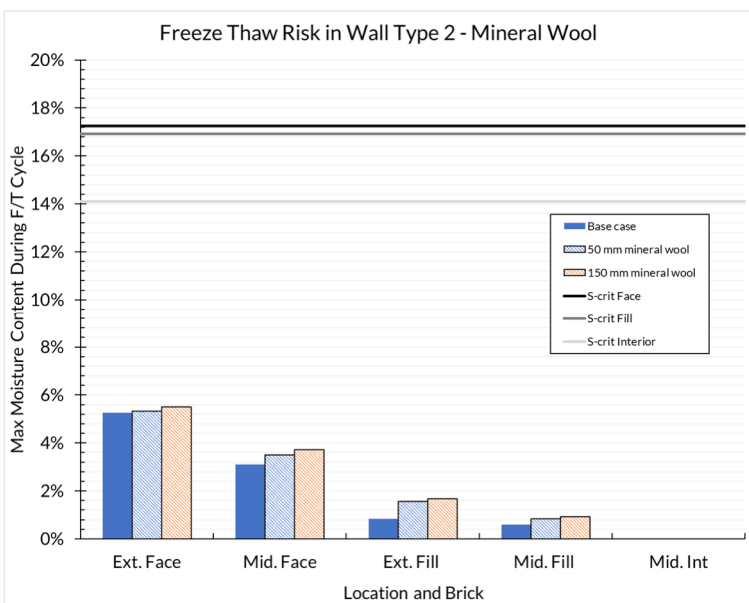


Figure 7: Wall type 2 brick moisture content values with mineral wool

Generally, the maximum moisture content values experienced over a typical year do not go beyond 6%. This is well below the S_{crit} threshold of approximately 17% for the face and fill brick, and approximately 14% for the interior bricks. The difference in moisture content values between the 50 mm and 150 mm insulation scenarios is minimal, with a slight increase in moisture content with greater insulation. The ccSPF results are shown in Figure 8.

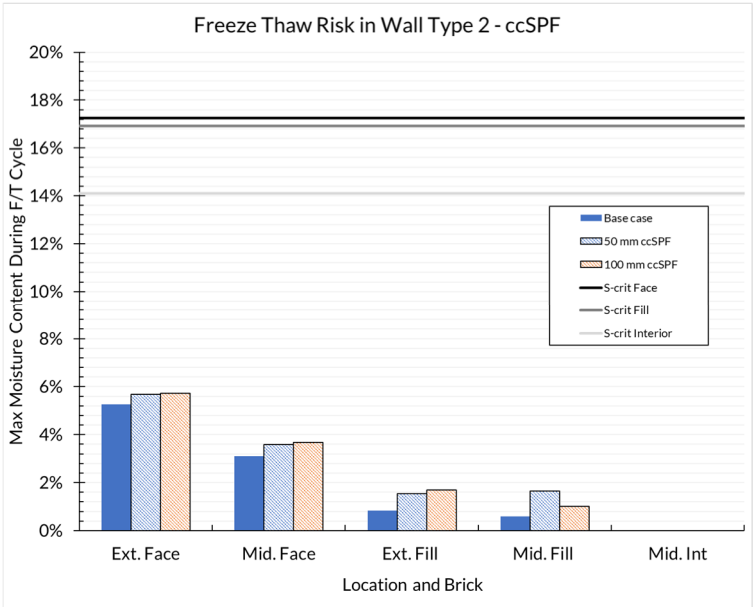


Figure 8: Wall type 2 brick moisture content values with ccSPF

The ccSPF moisture content values are slightly higher than the mineral wool, however, the risk remains the same. We note that the laboratory testing revealed that at 100% saturation, the interior brick from the Wall Type 1 disintegrated after 7 freeze-thaw cycles; however, at 80% and 90%, the samples did not disintegrate. Although our models show a low risk of freeze thaw deterioration because the moisture content in the bricks is low, should this interior brick become saturated due to extreme weather events or proximity to a source of water (such as a poorly detailed window frame or HVAC condensate), there would be significant freeze thaw deterioration. Due to the thickness of this wall, there is a low chance of this occurring. **Overall, there is very little risk of freeze thaw deterioration with interior insulation retrofits of up to 150 mm with mineral wool and 100 mm with ccSPF.**

8.3 LONG TERM MOISTURE ACCUMULATION

Long term moisture content can also affect freeze-thaw damage risk and must be considered. Typically, the moisture contents in a durable wall assembly will increase and decrease with the seasons and long-term moisture accumulation is represented with a gradual upward trend in the seasonal cycles. Graphs for some long-term moisture contents are shown here for 5 years (specifically, for the walls with more insulation). The

innermost wythe of brick is shown in the graphs; as the exterior layers can dry more easily, the inner wythe is the most susceptible to accumulation.

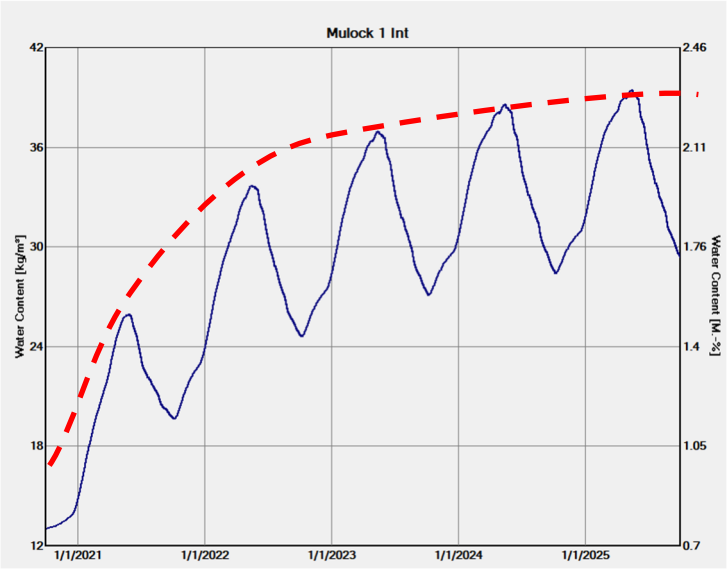


Figure 9: Moisture content over time for the inner wythe, Wall Type 1, 150 mm mineral wool

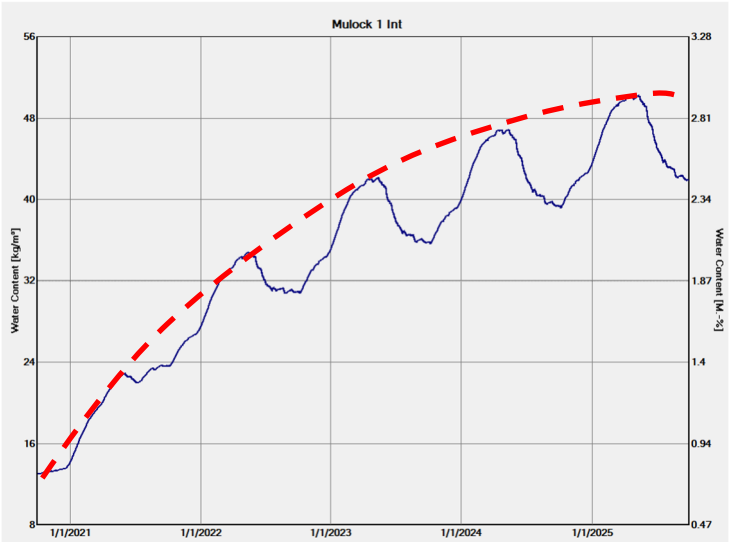


Figure 10: Moisture content over time for the inner wythe, Wall Type 1, 100 mm ccSPF insulation

The moisture accumulation shown in Figure 9 demonstrates a generally balanced seasonal cycle of moisture content increases and decreases with a negligible upward trend in the later years, with peak moisture content increasing by less than a percent per year. The moisture accumulation in Figure 10 is greater than the mineral wool but is still increasing by less than a percent per year, with a smaller amplitude (i.e. moisture content within a season does not change as much). Wall 2 is shown next.

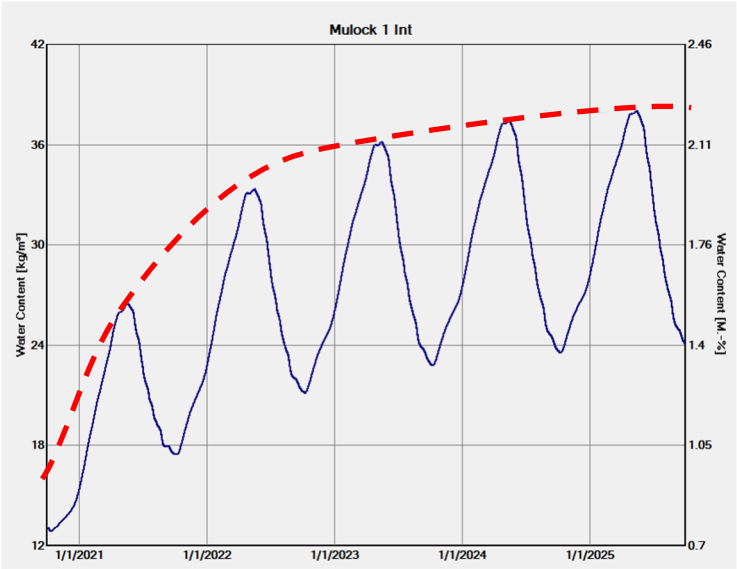


Figure 11: Moisture content over time for the inner wythe, Wall Type 2, 150 mm mineral wool insulation

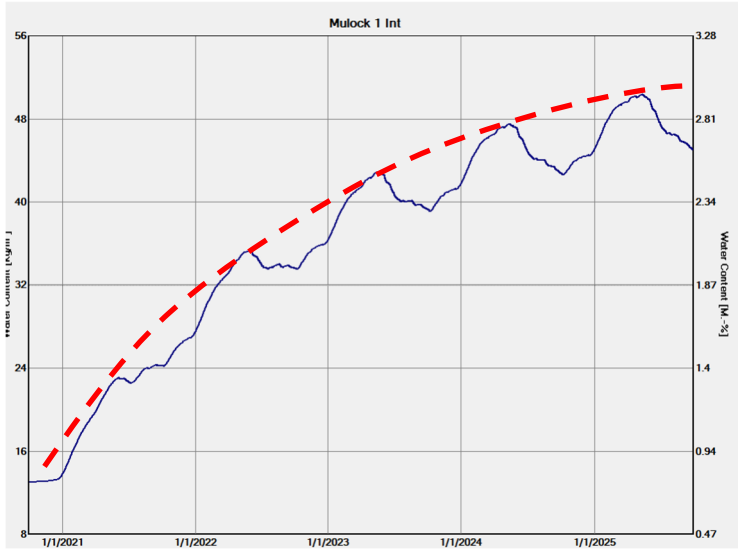


Figure 12: Moisture content over time for the inner wythe, Wall Type 2, 100 mm ccSPF insulation

The moisture accumulation shown in Figure 11 demonstrates a generally balanced seasonal cycle of moisture content increases and decreases with a negligible upward trend in the later years, with peak moisture content increasing by less than a percent per year. The moisture accumulation in Figure 12 is greater than the mineral wool but is still increasing by less than a percent per year, with a smaller amplitude as well.

The risk from long term moisture can be considered low as there is negligible long term moisture accumulation.

9. CONCLUSION

Based on the 1D hygrothermal modelling studies, the risk of freeze thaw deterioration within the brick masonry can be considered low with 150 mm (6 inches) of mineral wool insulation or 100 mm (4 inches) of ccSPF insulation at both wall types.

We recommend the use of mineral wool insulation as the vapour permeance allows for the masonry wall to dry inwards. We would also recommend the use of a vapour-permeable air barrier membrane at the interior side of the masonry, as there is a risk of air movement through the air permeable masonry resulting in condensation within the wall assembly and subsequent moisture damage and/or organic growth. We recommend a smart vapour barrier as it can reduce vapour diffusion in the cold seasons while promoting drying in the warm seasons.

The alternative option of ccSPF insulation results in fewer products required for similar performance (the ccSPF acts as an air and vapour barrier, eliminating the need for the air barrier and smart vapour barrier recommended with the mineral wool). As well, the R-value per unit thickness is greater than mineral wool. To achieve the same R-value as a mineral wool wall, less ccSPF can be used, which allows for more interior space to be retained. ccSPF is challenging to remove once installed, making it difficult to revert any retrofits. Additionally, cured ccSPF is brittle and may crack from building movement, compromising the air and vapour performance.

Beyond any of the modelling from this report, we recommend a robust water management system based on building geometry and physical features that assists in deflecting water and moving it away from the envelope. This includes roof overhangs, rainwater leaders, appropriate window sills and flashings with projecting drip edges, and sub-surface drainage.

Limitations to this analysis include 2D moisture flow and the accuracy of the material properties.

We trust this is the information you require. If you have questions or comments, please do not hesitate to contact the undersigned.

Sincerely,
Entuitive

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APPENDIX B
WUFI REPORT DATA

BELi Building Enclosure Labs Inc.

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Mulock Property
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Masonry Testing
28 April 2023

Mr Zhang,

As requested, Building Enclosure Labs Inc. (BELi) is pleased to provide you with this Masonry Testing Report to support retrofit insulation masonry risk assessment for the Mulock Property in Newmarket, Ontario.

Sample and Preparation Notes

The testing scope included full hygrothermal testing of 10 masonry samples, mortar composition analysis, paint vapour permeance testing, and brick compression testing each of single samples. Samples arrived at our London, Ontario lab on March 17, 2023. Samples were labelled with a number designated the sampling location (opening) 1, 2 or 3 and a letter E, M, or I denoting exterior, middle or interior bricks. Photos of the samples and their labeling are included in Appendix A.

Laboratory Testing Results

Tables 1-3 provide the laboratory testing results. Test methods are listed below Table 3. The testing results indicate that all stone samples had similar material properties.

The critical saturation values (S_{crit}) were derived from a linear curve fit of the 90th percentile of strain measures (determined using small sample student T-test). The individual slice strain values, curve fit, and comparison to free water saturation (W_f) are provided in Appendix B for each sample.

TABLE 1: DENSITY AND WATER SATURATION MEASUREMENT RESULTS (kg/m^3)					
Sample	**Dry Density** [1]	**80% RH Ref.** [2]	**24-Hour Free Water** [3]	**28-Day Free Water*** [3]	**Critical** [4] **Freeze-Thaw**
1E	1648	3	287	332	307
1M	1705	2	238	281	301
1I	1709	13	292	314	241
2E	1691	1.1	260	302	299
2E2	1654	14	264	312	316
2I	1379	21	429	471	417
3E	1694	3	319	345	292
3M	1666	3	287	324	282
3I	1732	13	275	300	272

TABLE 2: HYGRIC AND OTHER MEASUREMENT RESULTS						
Sample	**Absorption Coefficient** [5]	**Wet Cup Perm** [6]	**Wet Cup VDRF** [6]	**Dry Cup Perm** [6]	**Dry Cup VDRF** [6]	**Porosity** [7]
	($kg/m^2\ s^{0.5}$)	**(ng/s m Pa)**		**(ng/s m Pa)**		**(m^3/m^3)**
1E	0.30	18	10	12	16	0.36
1M	0.34	15	12	14	14	0.34
1I	0.21	12	16	10	18	0.35
2E	0.55	19	10	13	14	0.35
2E2	0.37	19	10	14	13	0.36
2I	0.42	12	16	15	13	0.48
3E	0.29	12	16	10	18	0.35
3M	0.16	18	11	12	16	0.37
3I	0.28	12	16	10	18	0.35

TABLE 3: PAINT VAPOUR PERMEANCE RESULTS						
Sample		**US Perms**	**Permeance**	**Permeability @ 1 mm**	**VDRF @ 1 mm**	**Sd (m)**
1E	Dry Cup	18	1009	1.0	187	0.2
	Wet Cup	15	882	0.9	214	0.2
2E	Dry Cup	26	1487	1.5	127	0.1
	Wet Cup	21	1207	1.2	156	0.2
3E	Dry Cup	18	1006	1.0	187	0.2
	Wet Cup	14	802	0.8	235	0.2

TABLE 4: THERMAL PROPERTIES		
Sample	**Thermal Conductivity (W/mK)** [8]	**Specific Heat (kJ/kg*K)** [8]
1E	0.5	0.74
1M	0.7	0.70
1I	0.6	0.66
2E	0.6	0.73
2E2	0.6	0.66
2M	0.4	0.79
2I	0.7	0.71
3E	0.5	0.66
3M	0.6	0.71
3I	0.5	0.74

TABLE 5: COMPRESSIVE STRENGTH AND PRELIMINARY RESULTS				
Sample	**Compressive Strength (MPa)** [9]	**A-Value ($kg/m^2s^{0.5}$)** [5]	**Dry Density (kg/m^3)** [1]	**24-Hour Free Water** [3]
1M2	5.2	0.16	1748	17%
2E3	6.3	0.42	1693	16%

[1] ASTM C20
[2] ASTM C1498
[3] DIN 12087
[4] Fagerlund, G. (1977) "The critical degree of saturation method of assessing the freeze/thaw resistance of concrete." Materials and Structures 10.58 pp. 217-230. Note that the critical saturation has been estimated from linear fit to 95th percentile of the strain measurements.
[5] ASTM C1794
[6] ASTM E96 used and Vapour Diffusion Resistance Factor (VDRF) calculated as equal to 129/(perm(SI)/1.46)
[7] Calculated based on vacuum saturation.
[8] ISO 22007-2.2
[9] ASTM C67 – Compression testing conducted at Western University Civil Structural Lab

Mortar Composition Analysis

Methodology

Mortar from Opening 1 was dried in an oven, broken apart with mortar and pestle, and weighed. The samples were placed in glass containers and 10% acetic acid was added to dissolve the (lime) binder. The samples were stirred regularly and left to digest overnight. After the bubbling (reaction) had slowed the mixture was carefully drained and rinsed with distilled water to remove the dissolved binder. The samples were dried and sieved through 4000µm, 500µm, 250µm, 125µm, and 63 µm sieves to determine particle size distribution. Pictures of the sieved mortar samples are included in Appendix C.

Results

TABLE 6: PARTICLE SIZE DISTRIBUTION		
Sieve Opening Size (µm)	**Collected Mass (g)**	**Composition by Mass (%)**
4000	0.72	1%
2000	0.06	0.1%
500	0.86	2%
250	2.18	4%
125	25.40	46%
63	6.03	11%
Base Pan (fines)	0.90	2%
Percent Binder	19.46	35%

Closure

This report has been prepared by Peter McLachlan and Dr. Randy Van Straaten; please contact us directly if you have any questions about the report

Kindest regards,

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m 519.488.5573

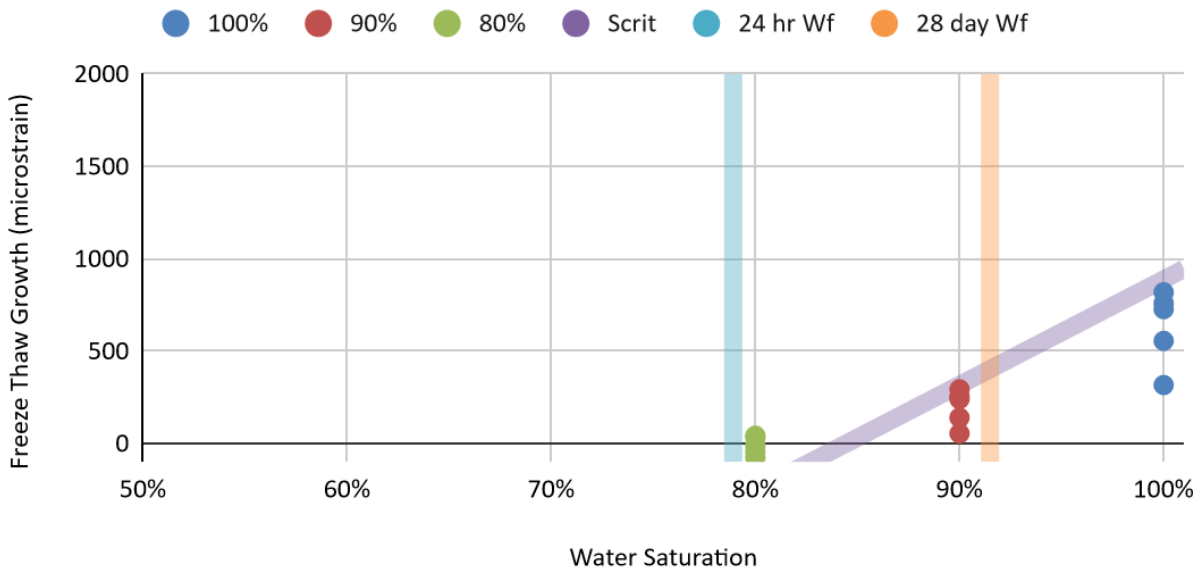
Appendix A - Photos of Tested Samples

2 EXT
2 EXT
2 MID
2 MID
2 INT
MULOCK
LOCATION

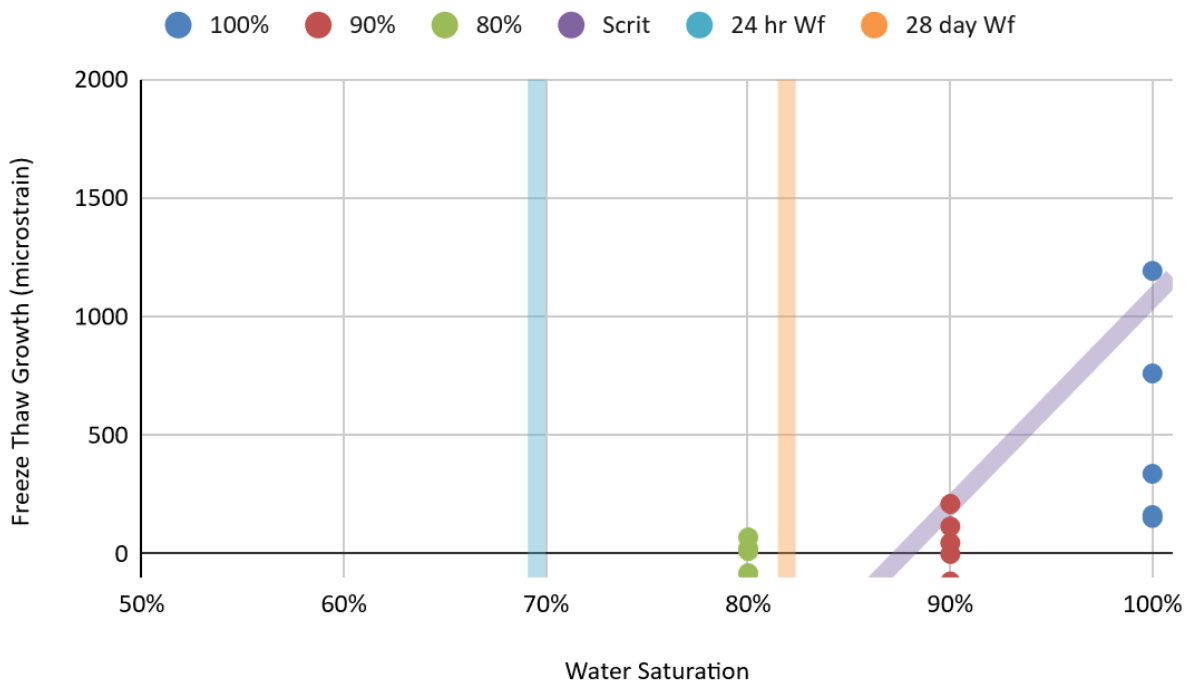
3 EXT
3 EXT
3 MID
3 MID
3 INT

Appendix B – Freeze Thaw Decay Dilation Data

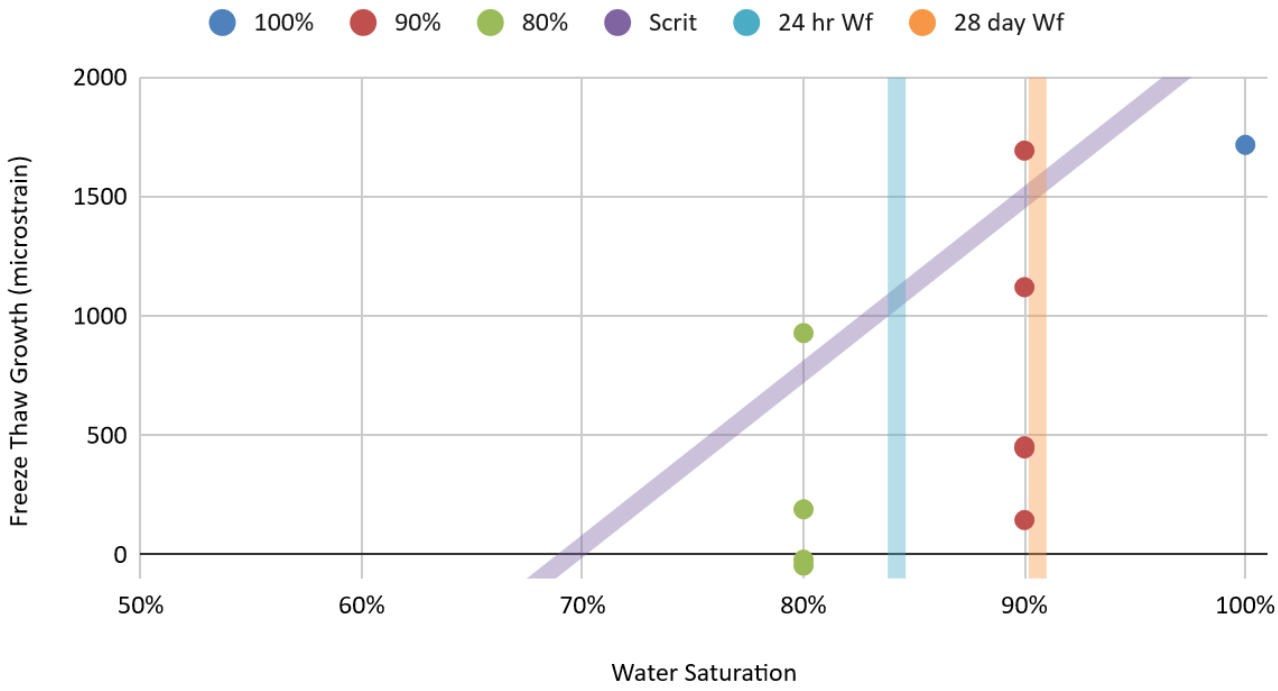
1E



1M

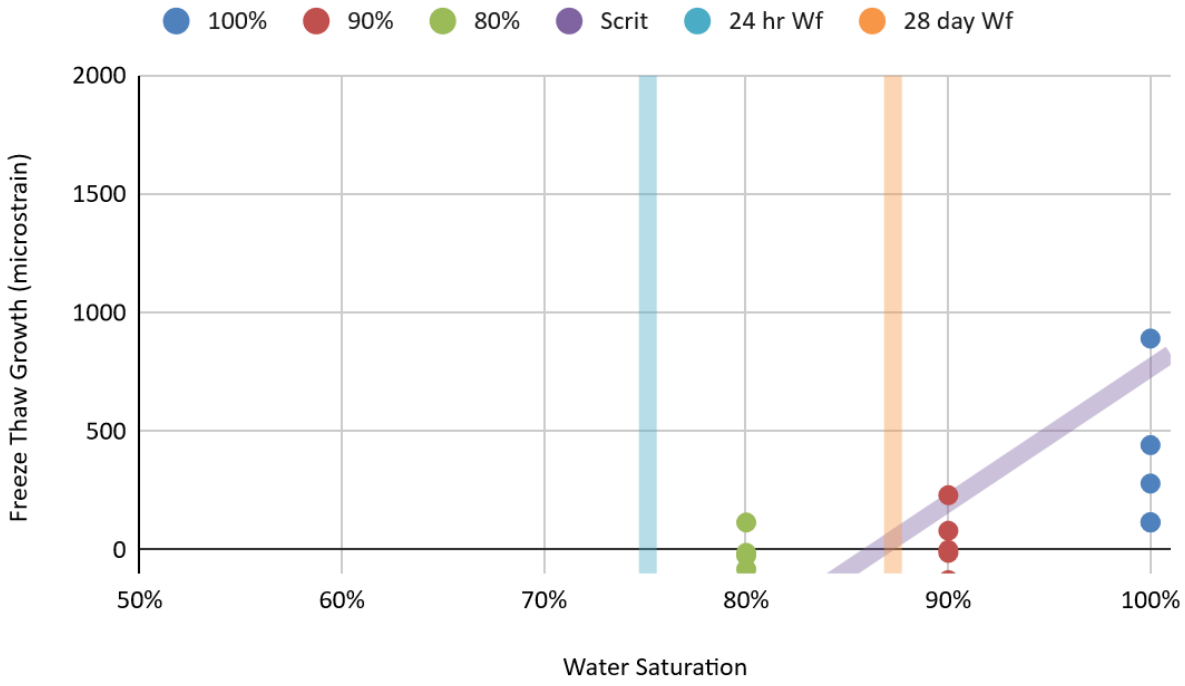


1I

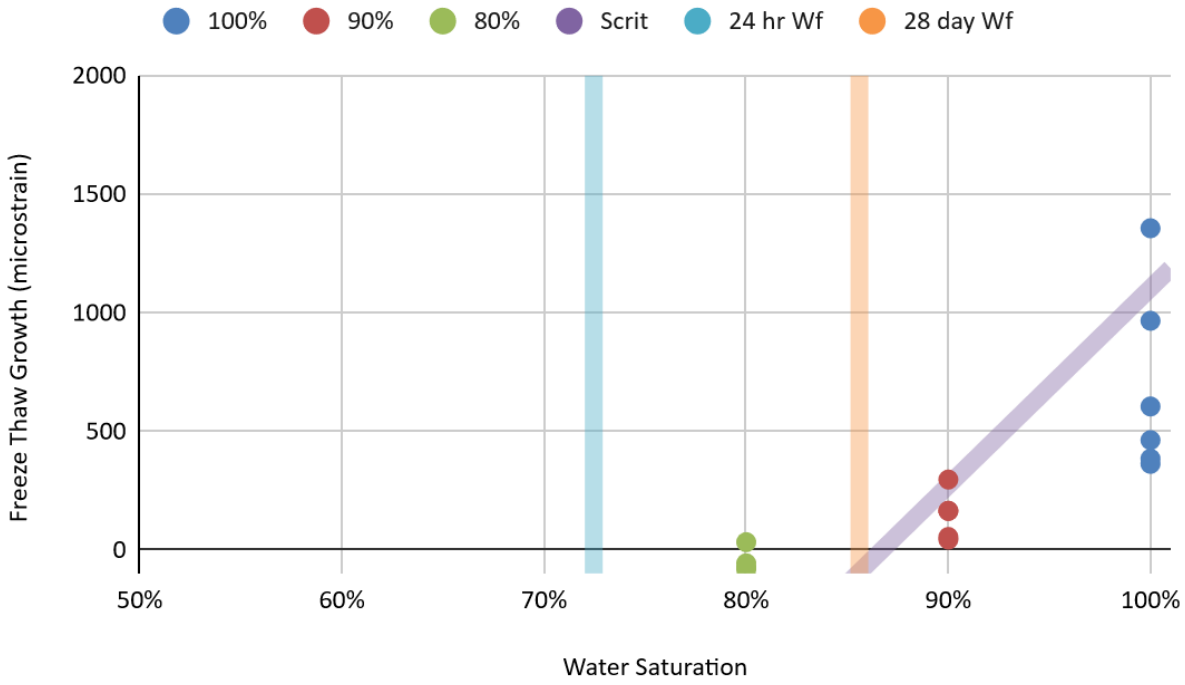


* Most of the 100% saturation samples disintegrated during the 7 freeze-thaw cycles and so the Scrit value was determined based on the 80 and 90% saturation samples.

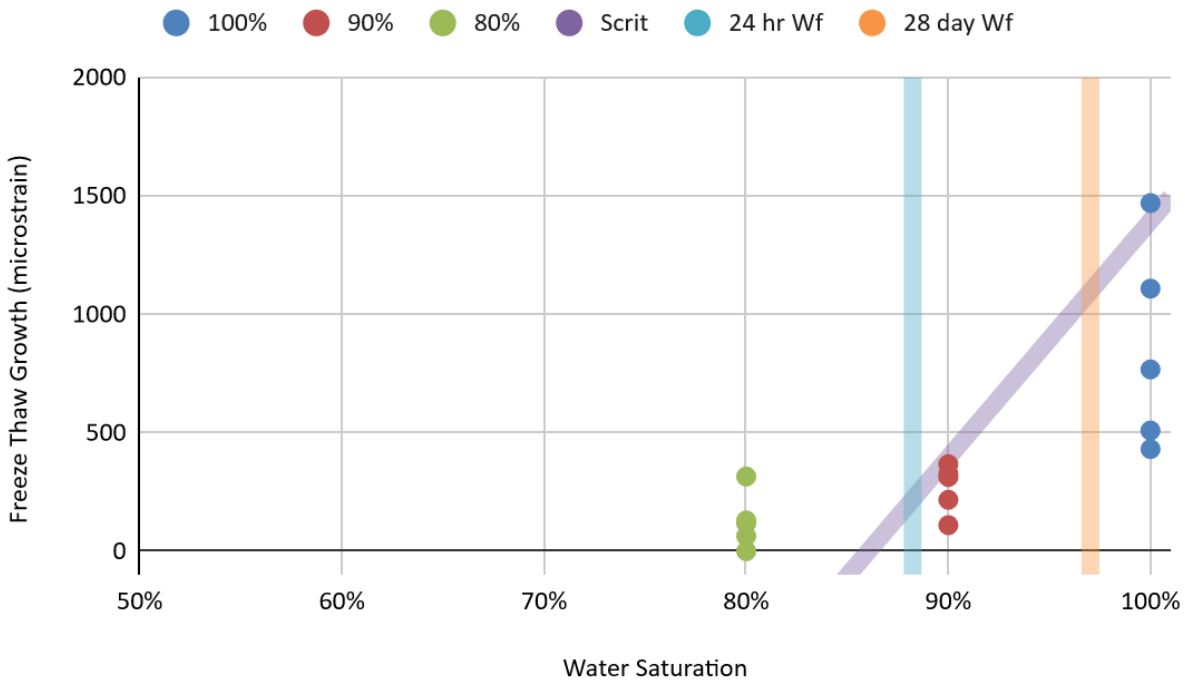
2E



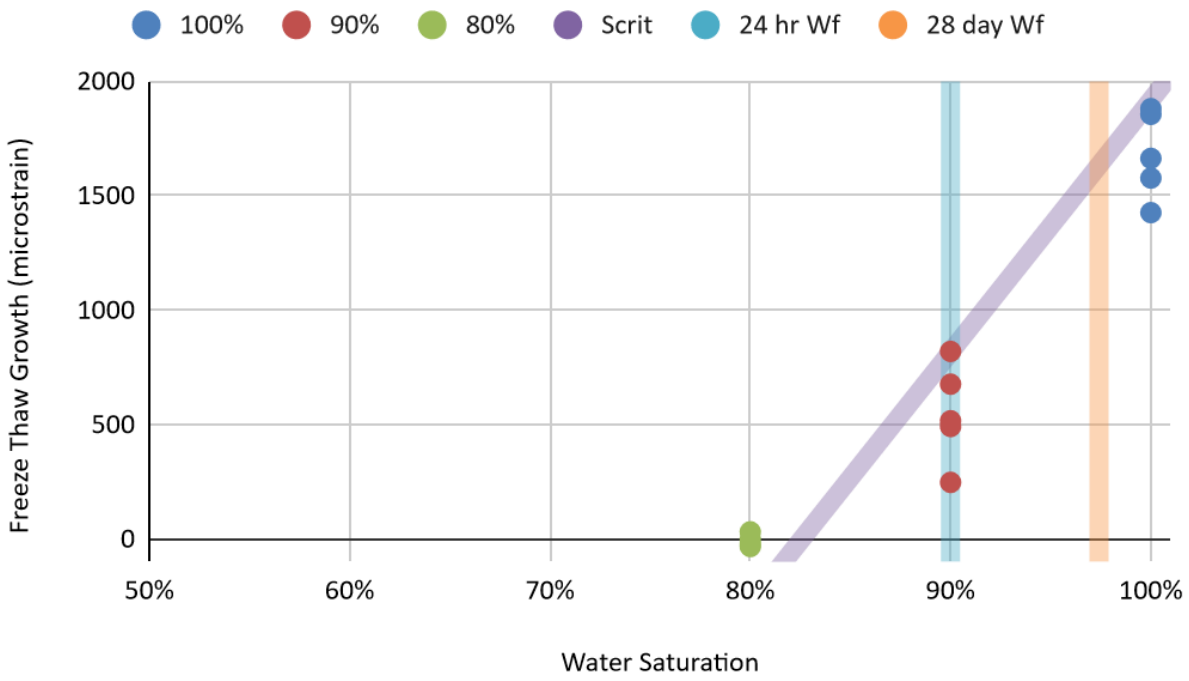
2E2


100%
90%
80%
Scrit
24 hr Wf
28 day Wf
2000
1500
1000
500
0
Freeze Thaw Growth (microstrain)
50%
60%
70%
80%
90%
100%
Water Saturation

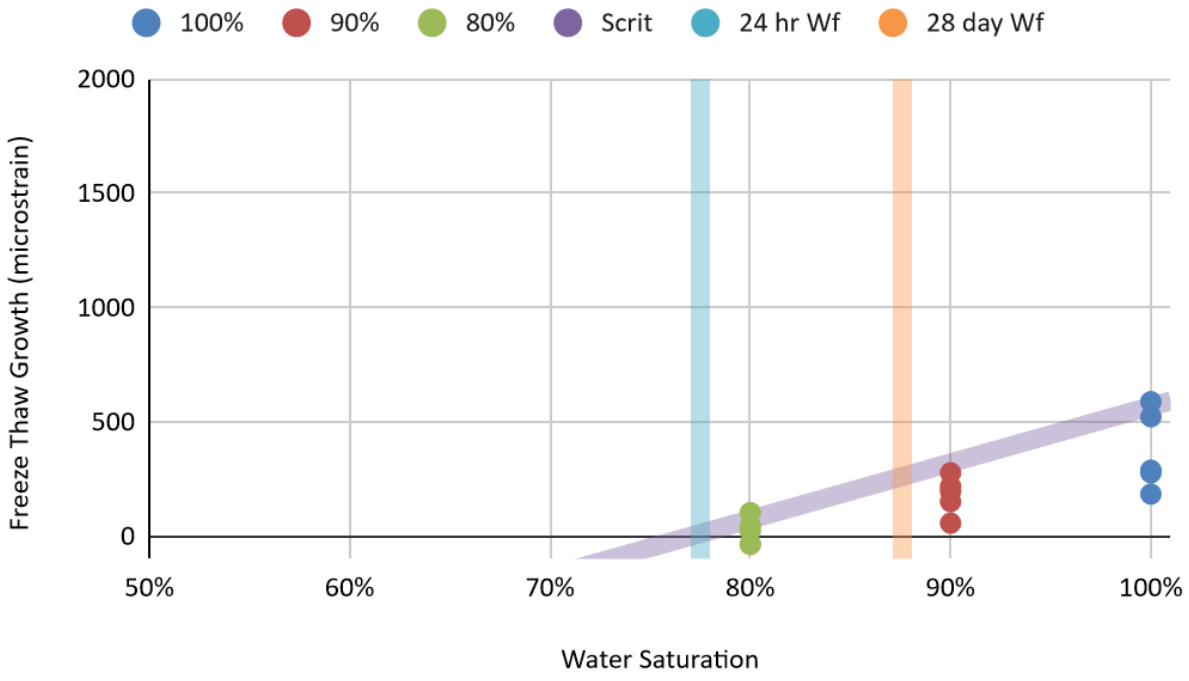
2I


100%
90%
80%
Scrit
24 hr Wf
28 day Wf
2000
1500
1000
500
0
Freeze Thaw Growth (microstrain)
50%
60%
70%
80%
90%
100%
Water Saturation

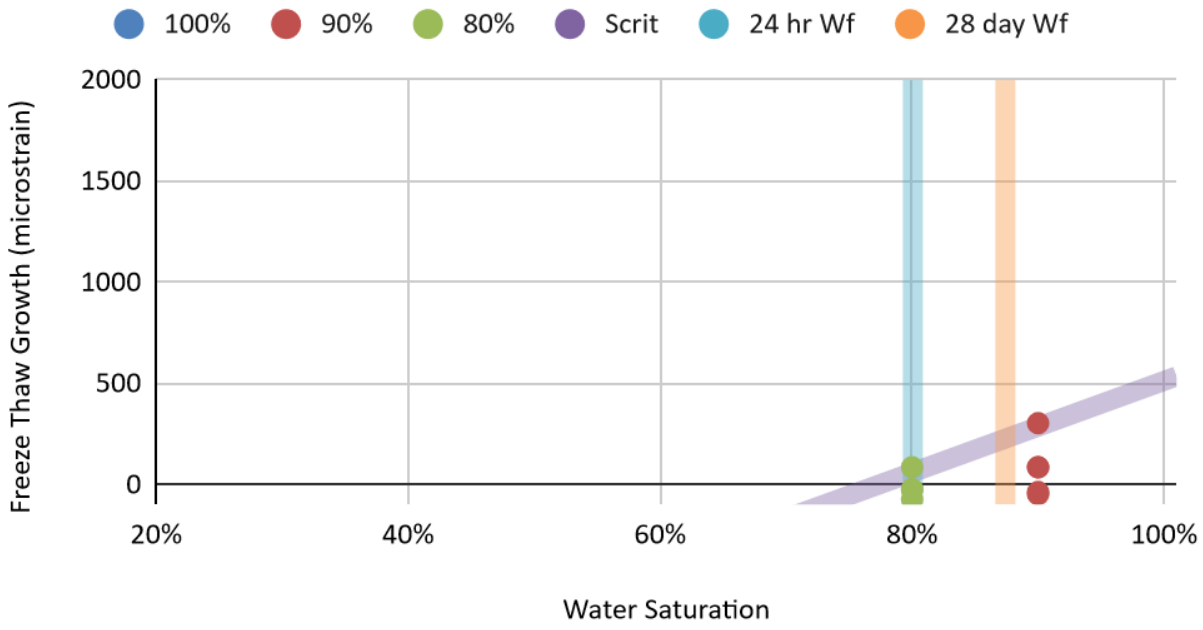
3E


100%
90%
80%
Scrit
24 hr Wf
28 day Wf
2000
1500
1000
500
0
Freeze Thaw Growth (microstrain)
50%
60%
70%
80%
90%
100%
Water Saturation

3M

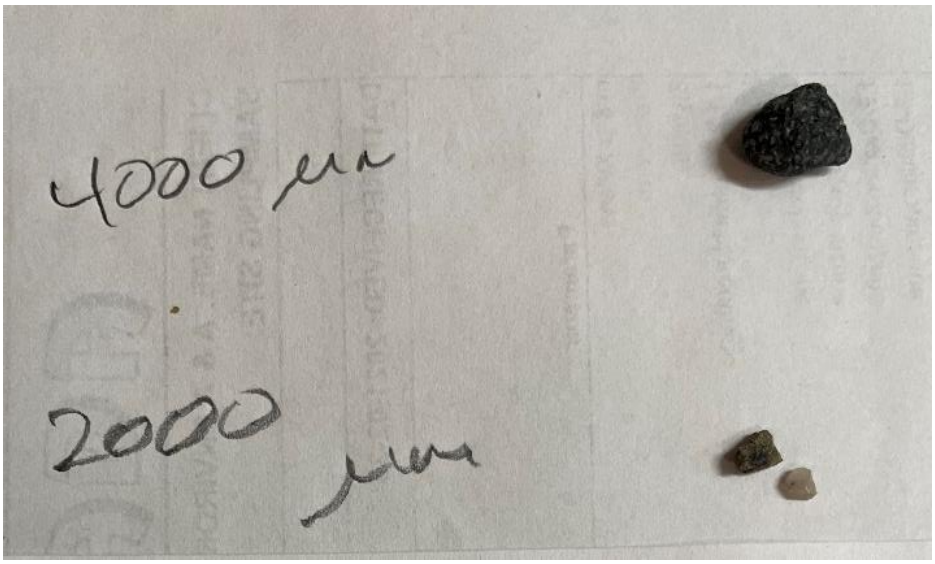

100%
90%
80%
Scrit
24 hr Wf
28 day Wf
2000
1500
1000
500
0
Freeze Thaw Growth (microstrain)
50%
60%
70%
80%
90%
100%
Water Saturation

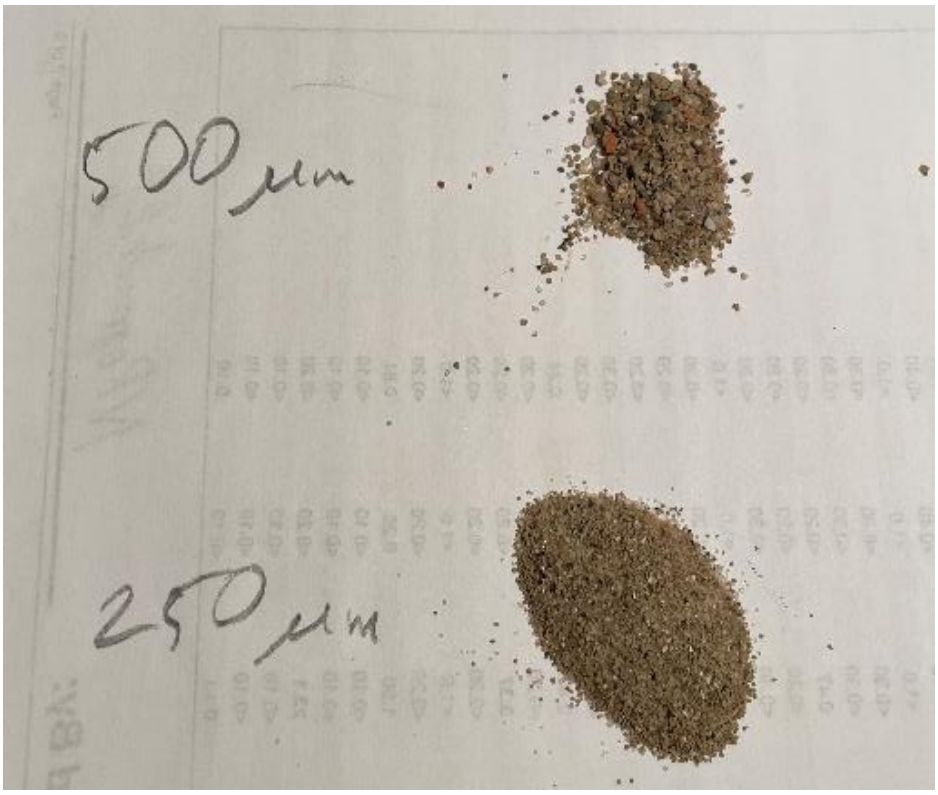
31

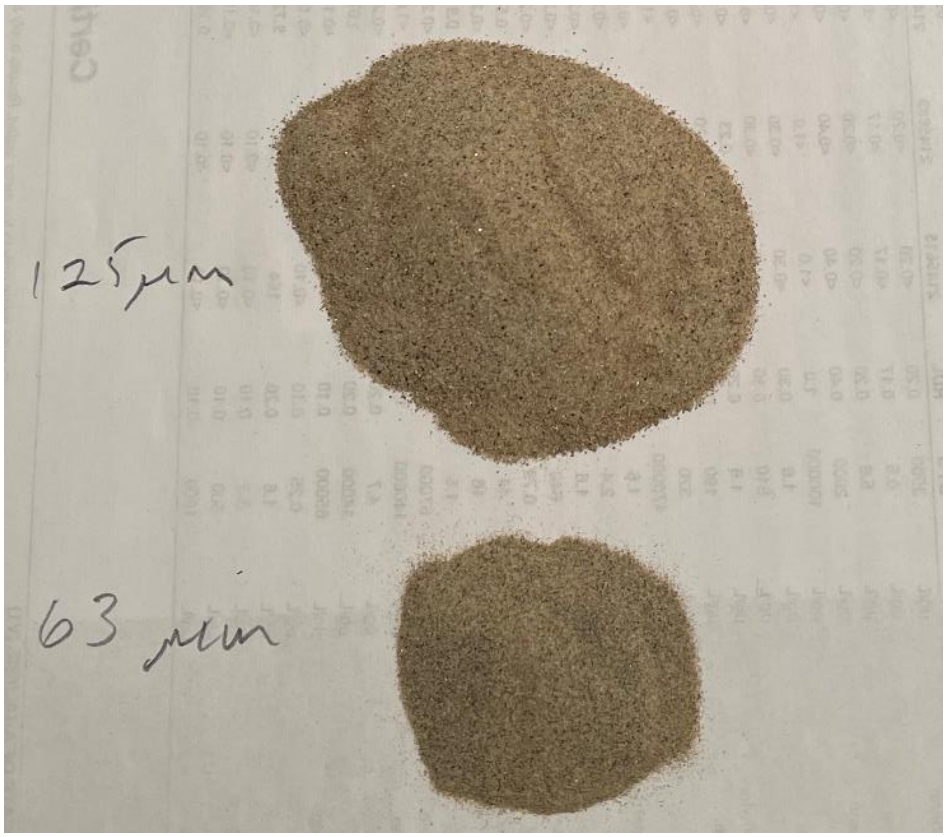


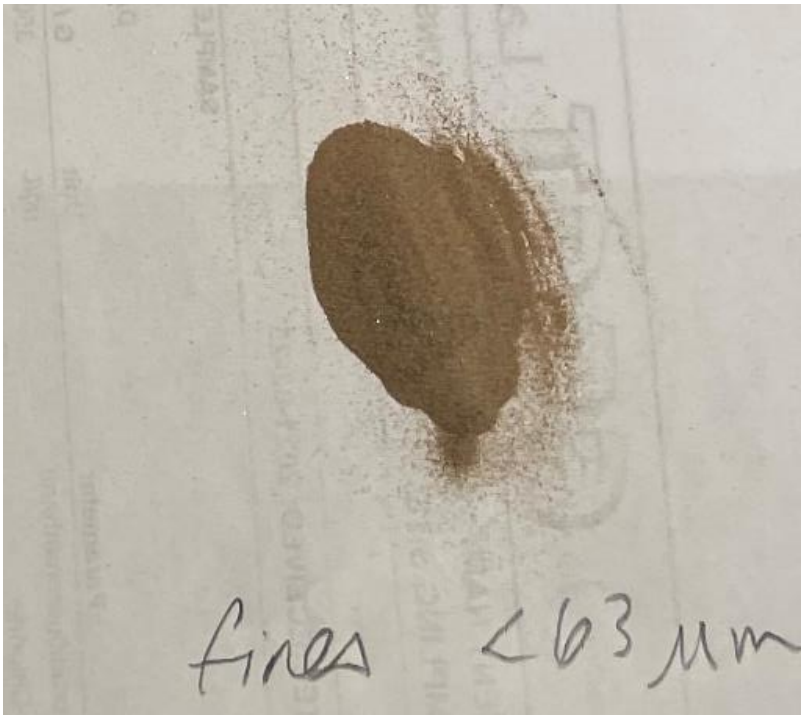
* All of the 100% saturation samples disintegrated during the 7 freeze-thaw cycles and so the Scrit value was determined based on the 80 and 90% saturation samples.

Appendix C – Pictures of Sieved Mortar





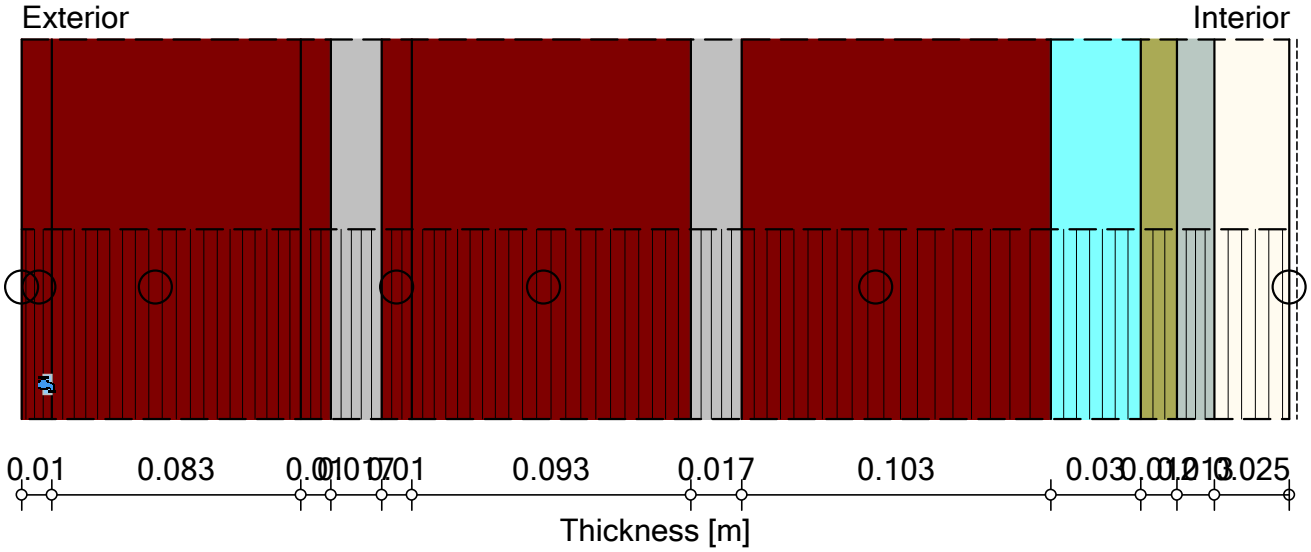

125 µm
63 µm


fines <63 µm

APPENDIX A
LABORATORY TESTING DATA

Component Assembly

Case: W1-Base



- Monitor positions

/ - Heat/Moisture source/sink positions

Materials:

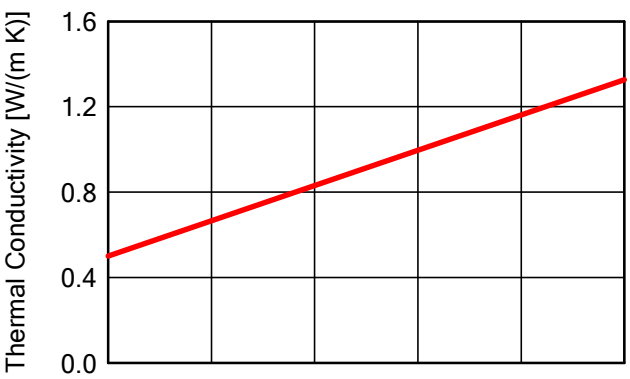
- Mulock 3 Ext	0.01 m
- Mulock 3 Ext	0.083 m
- Mulock 3 Ext	0.01 m
- MOR-EXT-1	0.017 m
- Mulock 3 Mid	0.01 m
- Mulock 3 Mid	0.093 m
- MOR-INT-1	0.017 m
- Mulock 1 Int	0.103 m
- Air Layer 30 mm; without additional moisture capacity	0.03 m
- Southern Yellow Pine	0.012 m
- Gypsum Board (USA)	0.013 m
- Interior Plaster (Gypsum Plaster)	0.025 m

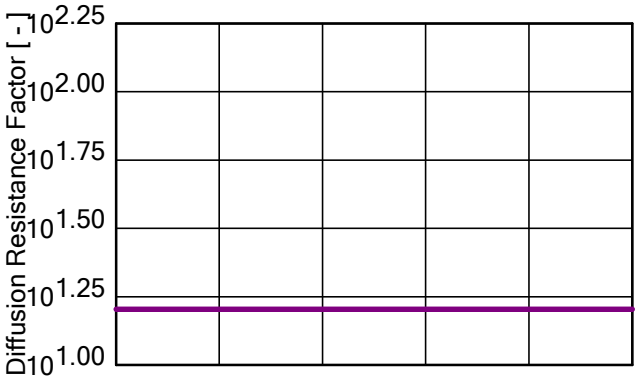
sd-Value Int. [m]: 0.2

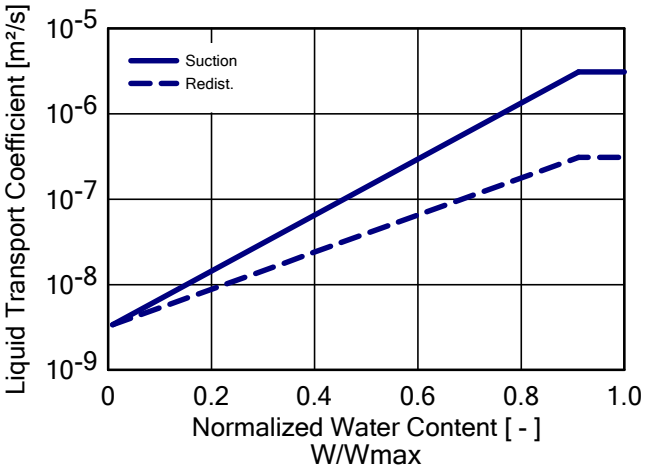
Total Thickness: 0.423 m
R-Value: 1.07 (m² K)/W
U-Value: 0.8 W/(m² K)

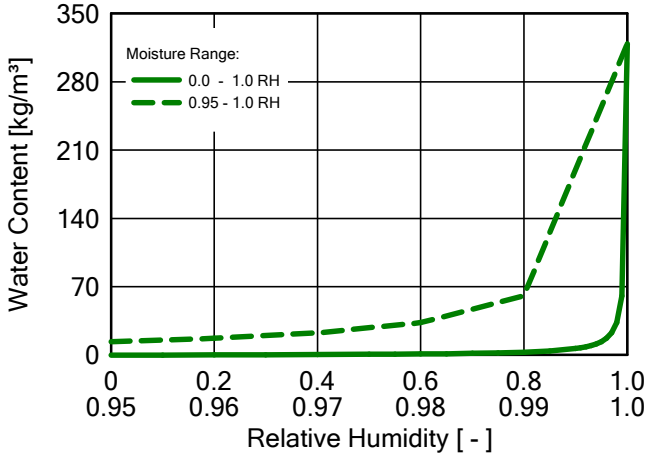
Material: Mulock 3 Ext

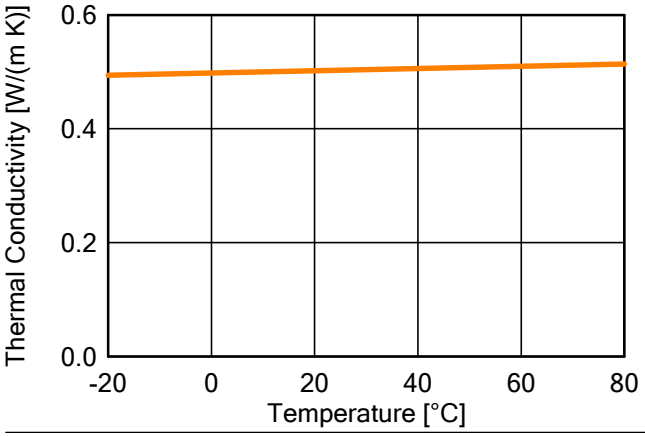
Property	Unit	Value
Bulk density	[kg/m³]	1694
Porosity	[m³/m³]	0.35
Specific Heat Capacity, Dry	[J/(kg K)]	660
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.5
Water Vapour Diffusion Resistance Factor	[-]	16
Reference Water Content	[kg/m³]	3
Free Water Saturation	[kg/m³]	319
Water Absorption Coefficient	[kg/(m² s^0.5)]	0.29
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





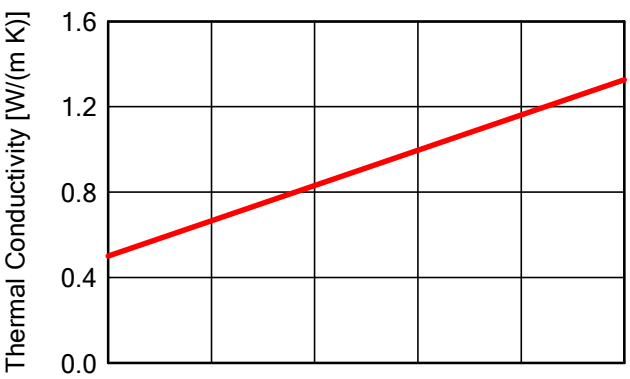


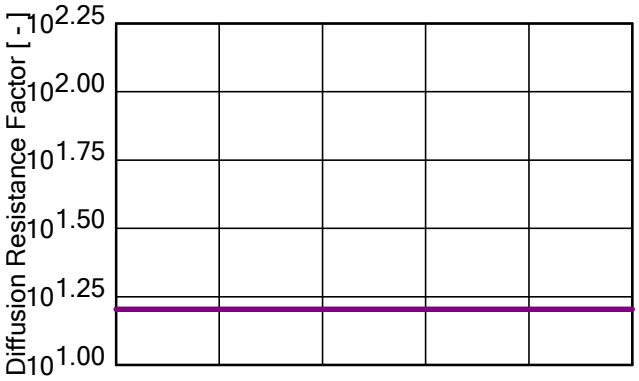


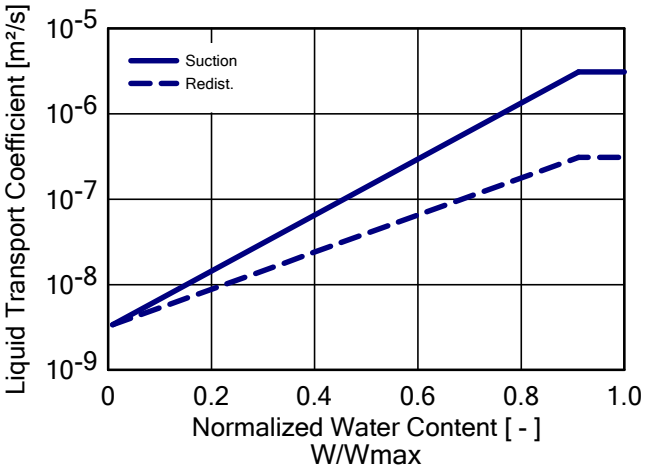


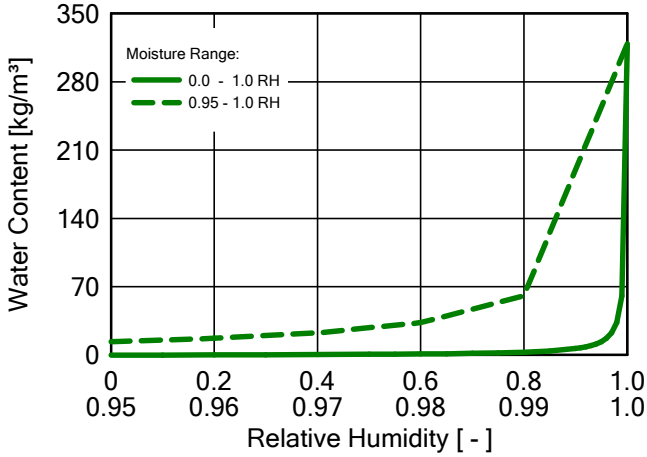
Material: Mulock 3 Ext

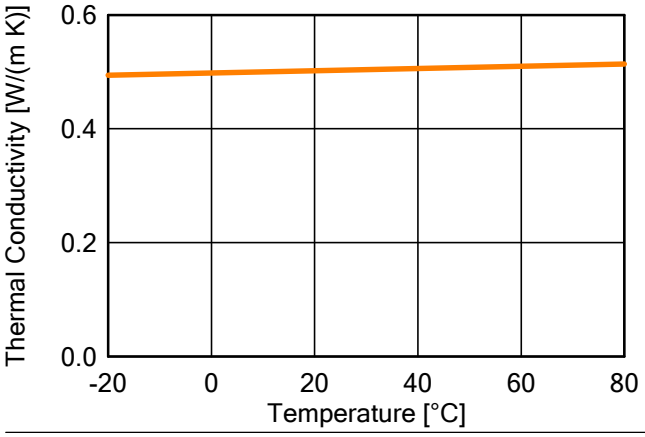
Property	Unit	Value
Bulk density	[kg/m³]	1694
Porosity	[m³/m³]	0.35
Specific Heat Capacity, Dry	[J/(kg K)]	660
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.5
Water Vapour Diffusion Resistance Factor	[-]	16
Reference Water Content	[kg/m³]	3
Free Water Saturation	[kg/m³]	319
Water Absorption Coefficient	[kg/(m² s^0.5)]	0.29
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





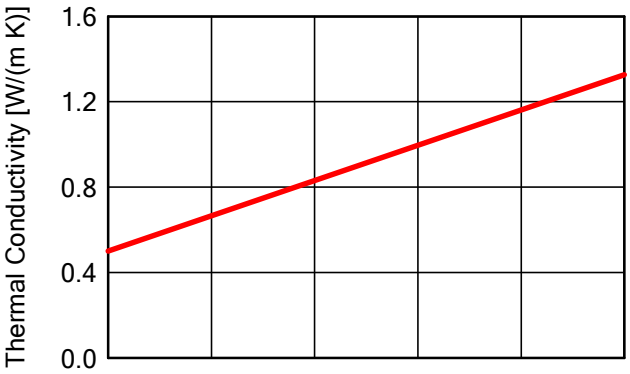


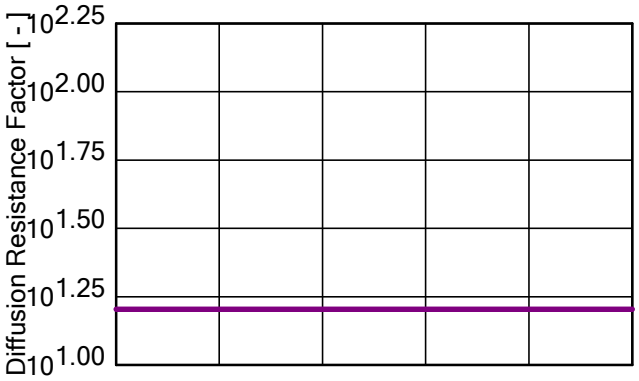


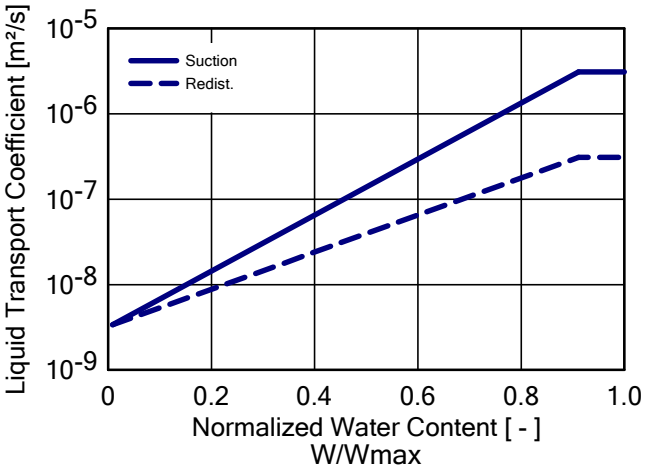


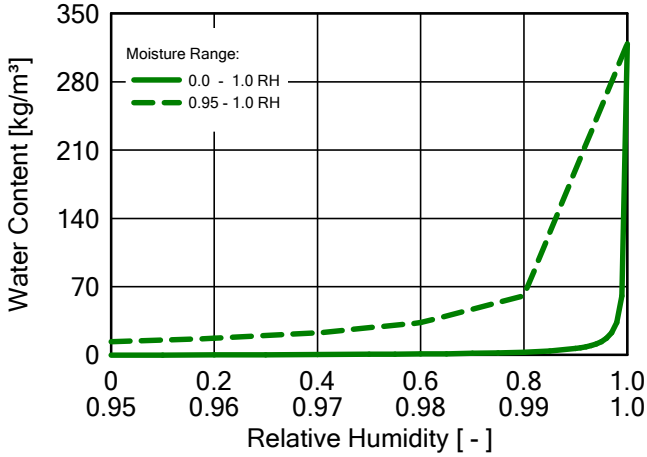
Material: Mulock 3 Ext

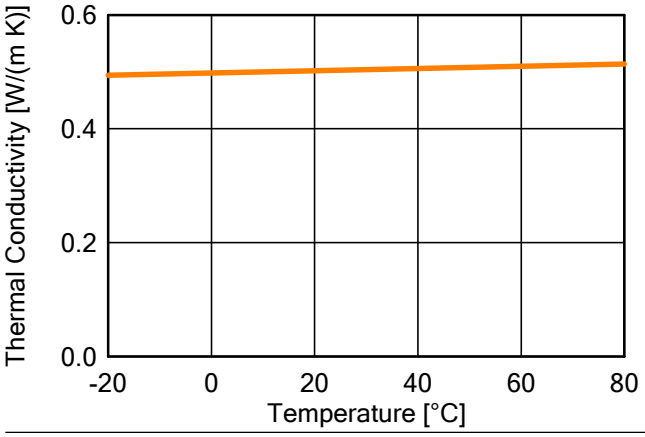
Property	Unit	Value
Bulk density	[kg/m³]	1694
Porosity	[m³/m³]	0.35
Specific Heat Capacity, Dry	[J/(kg K)]	660
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.5
Water Vapour Diffusion Resistance Factor	[-]	16
Reference Water Content	[kg/m³]	3
Free Water Saturation	[kg/m³]	319
Water Absorption Coefficient	[kg/(m² s^0.5)]	0.29
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





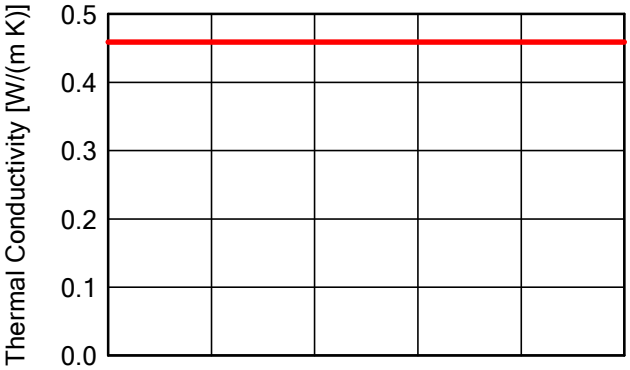


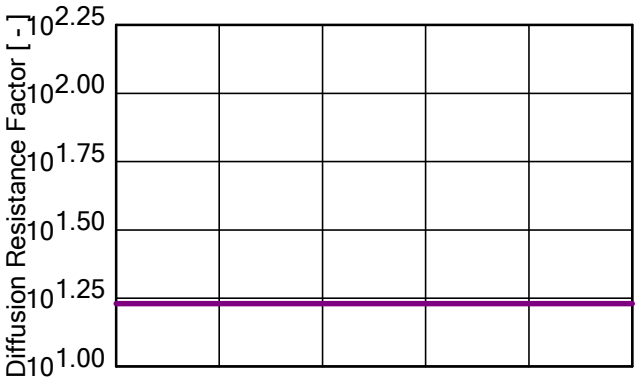


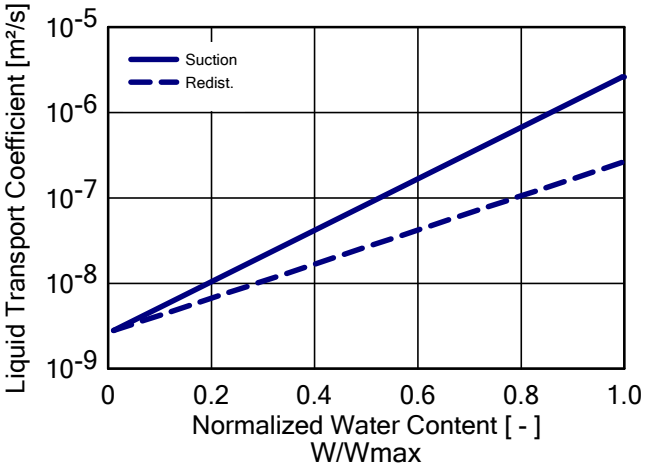


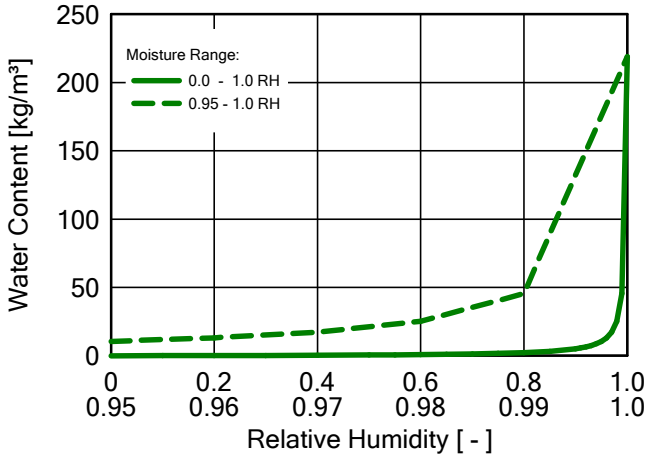
Material: MOR-EXT-1

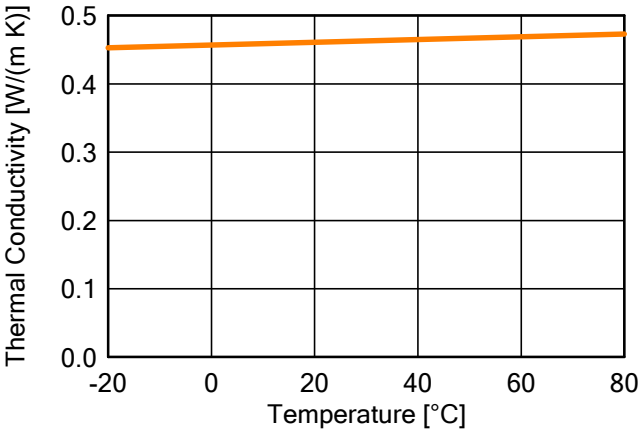
Property	Unit	Value
Bulk density	[kg/m³]	1973
Porosity	[m³/m³]	0.22
Specific Heat Capacity, Dry	[J/(kg K)]	900
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.459
Water Vapour Diffusion Resistance Factor	[-]	17
Reference Water Content	[kg/m³]	2.3
Free Water Saturation	[kg/m³]	219
Water Absorption Coefficient	[kg/(m² s^0.5)]	0.18
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





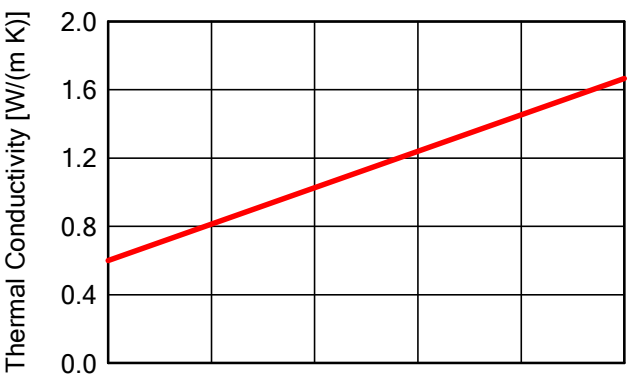


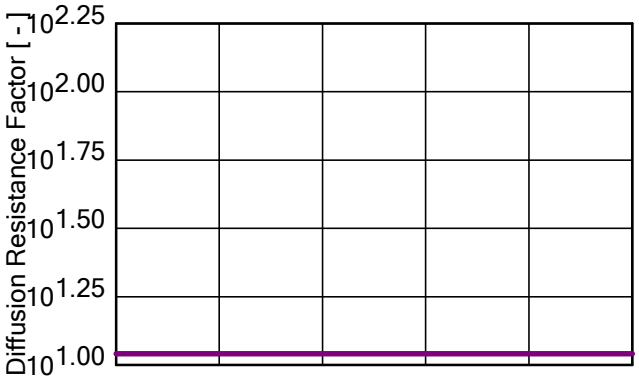


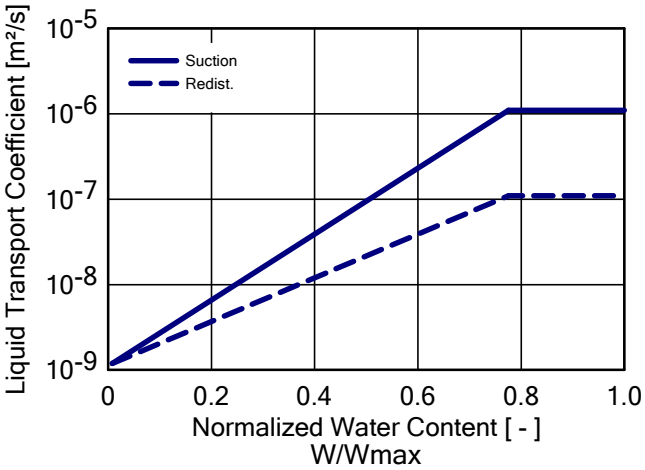


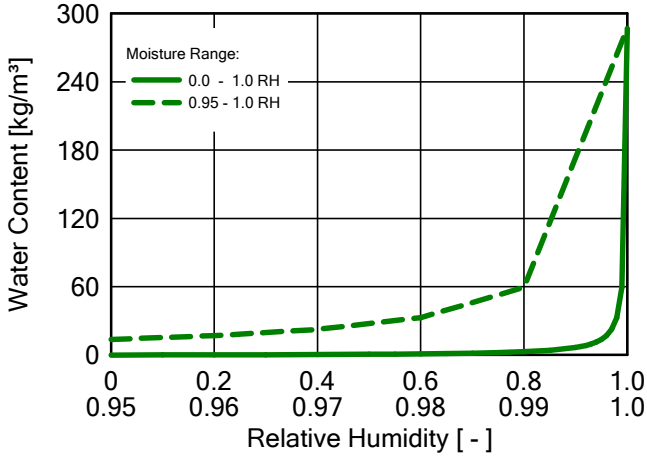
Material: Mulock 3 Mid

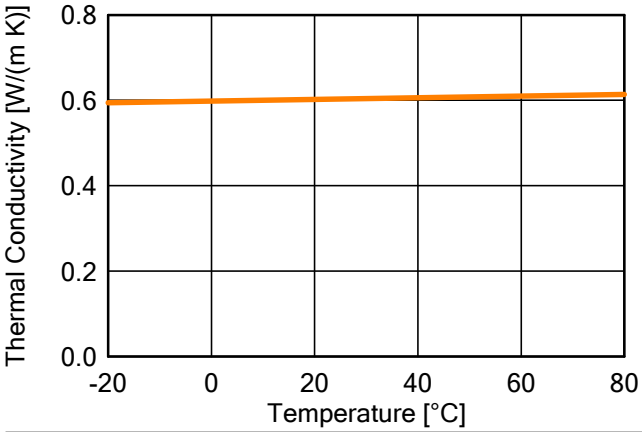
Property	Unit	Value
Bulk density	[kg/m³]	1666
Porosity	[m³/m³]	0.37
Specific Heat Capacity, Dry	[J/(kg K)]	710
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.6
Water Vapour Diffusion Resistance Factor	[-]	11
Reference Water Content	[kg/m³]	3
Free Water Saturation	[kg/m³]	287
Water Absorption Coefficient	[kg/(m² s^0.5)]	0.16
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





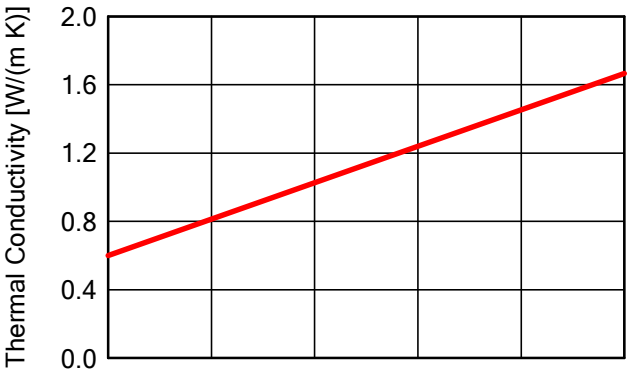


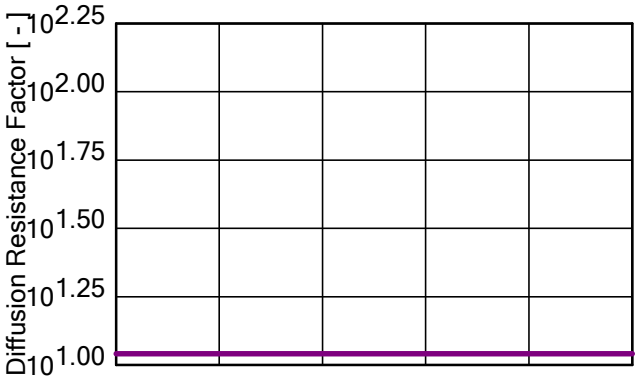


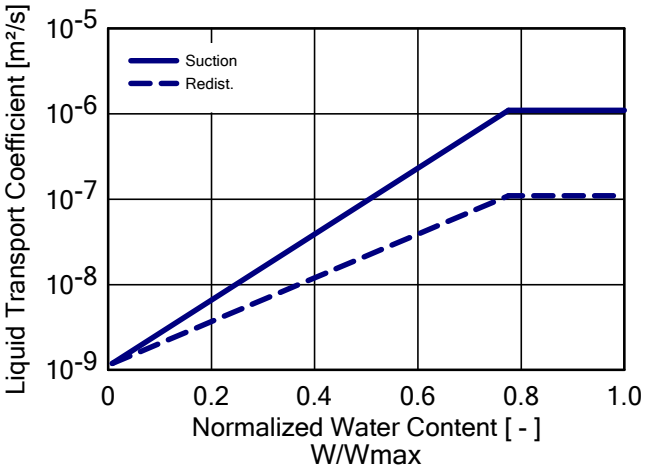


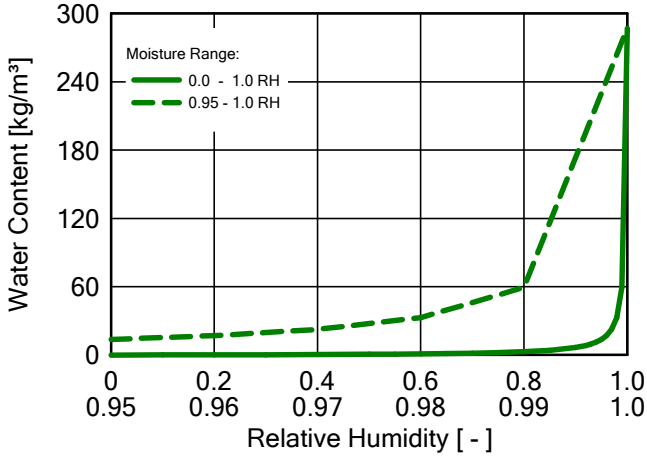
Material: Mulock 3 Mid

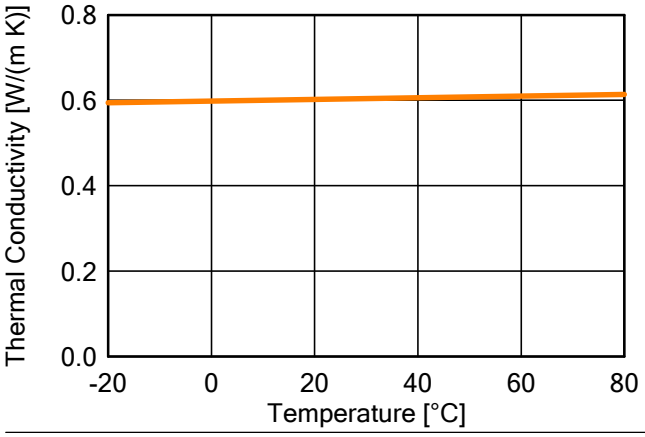
Property	Unit	Value
Bulk density	[kg/m³]	1666
Porosity	[m³/m³]	0.37
Specific Heat Capacity, Dry	[J/(kg K)]	710
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.6
Water Vapour Diffusion Resistance Factor	[-]	11
Reference Water Content	[kg/m³]	3
Free Water Saturation	[kg/m³]	287
Water Absorption Coefficient	[kg/(m² s^0.5)]	0.16
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





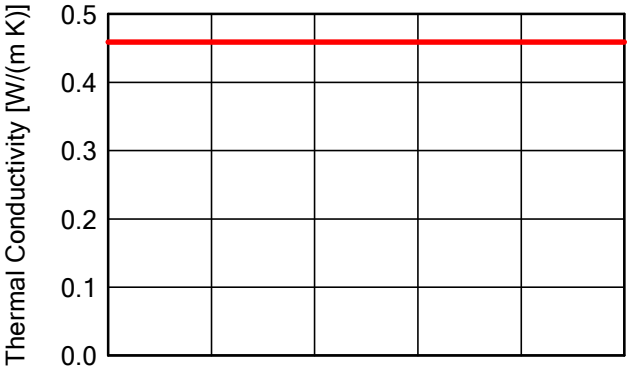


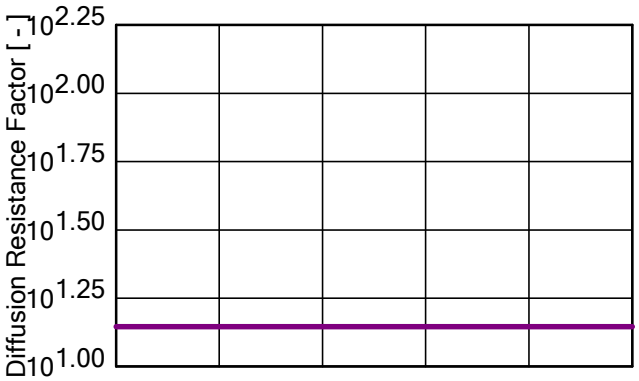


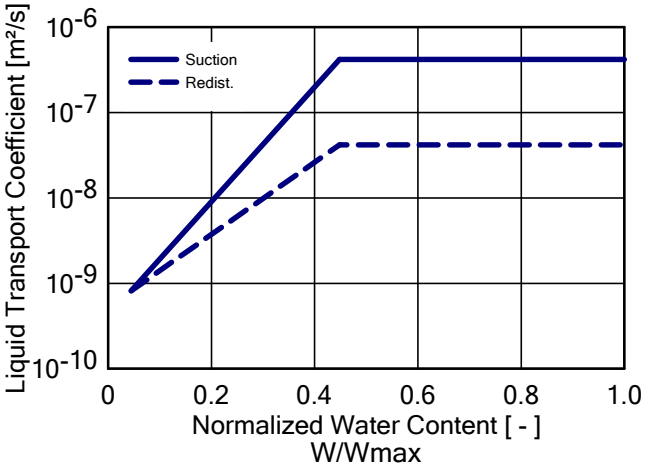


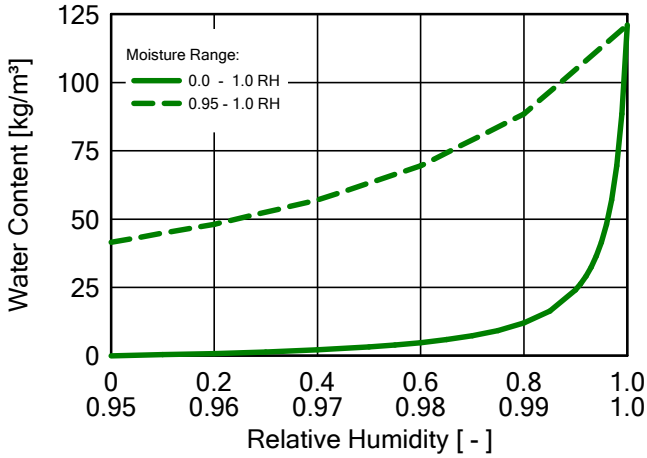
Material: MOR-INT-1

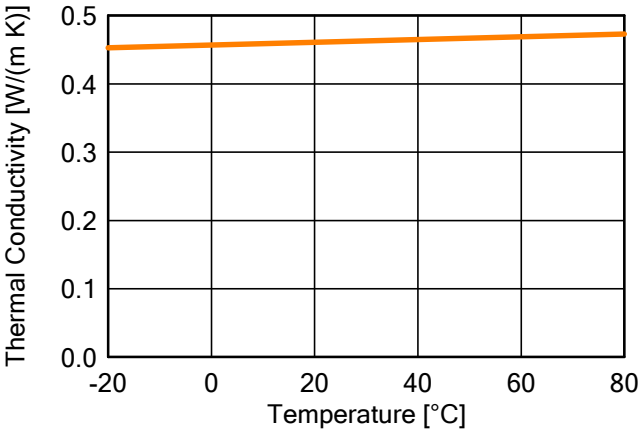
Property	Unit	Value
Bulk density	[kg/m³]	1894
Porosity	[m³/m³]	0.27
Specific Heat Capacity, Dry	[J/(kg K)]	900
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.459
Water Vapour Diffusion Resistance Factor	[-]	14
Reference Water Content	[kg/m³]	12
Free Water Saturation	[kg/m³]	121
Water Absorption Coefficient	[kg/(m² s^0.5)]	0.04
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





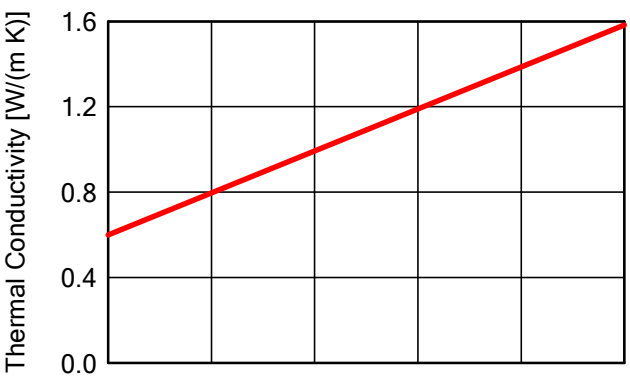


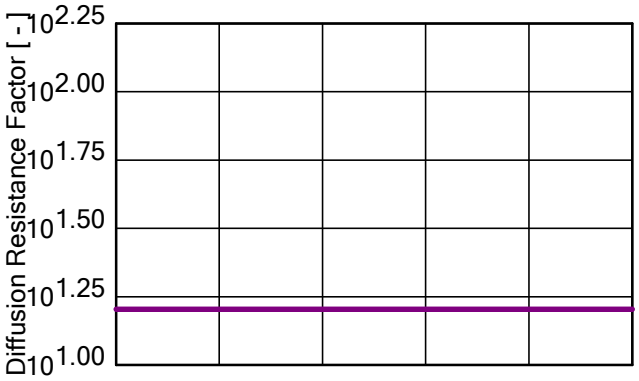


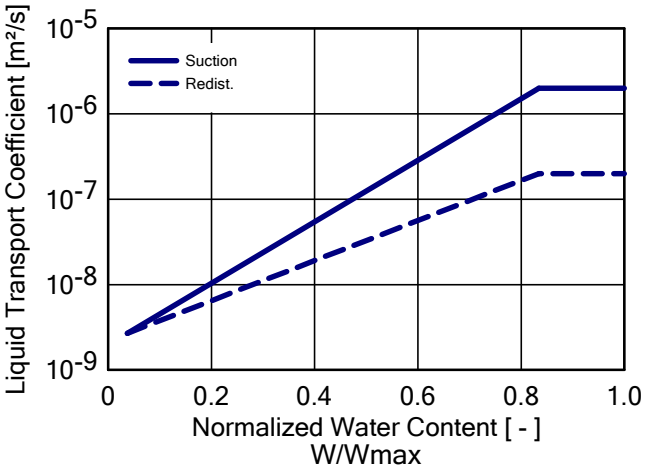


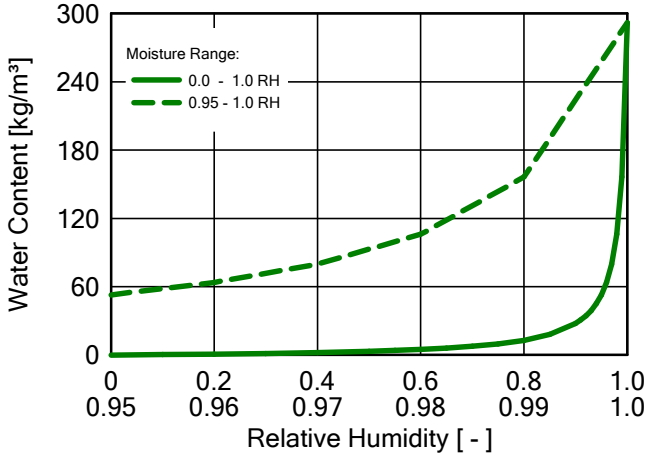
Material: Mulock 1 Int

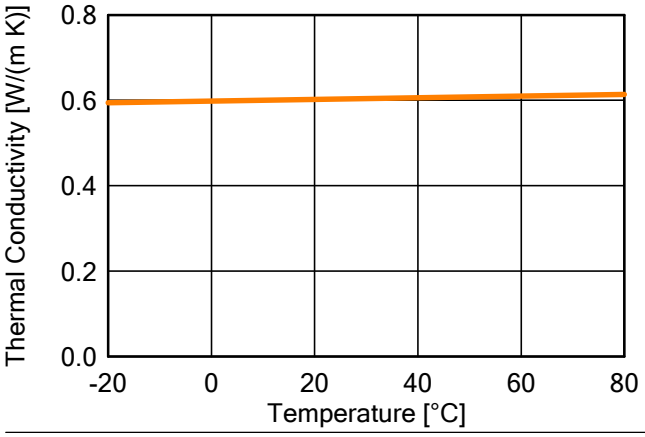
Property	Unit	Value
Bulk density	[kg/m³]	1709
Porosity	[m³/m³]	0.35
Specific Heat Capacity, Dry	[J/(kg K)]	660
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.6
Water Vapour Diffusion Resistance Factor	[-]	16
Reference Water Content	[kg/m³]	13
Free Water Saturation	[kg/m³]	292
Water Absorption Coefficient	[kg/(m² s^0.5)]	.21
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





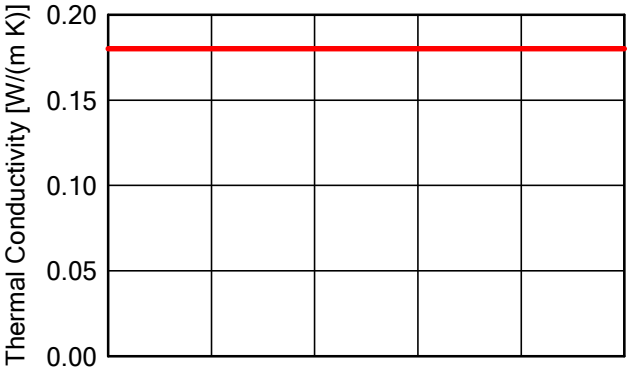


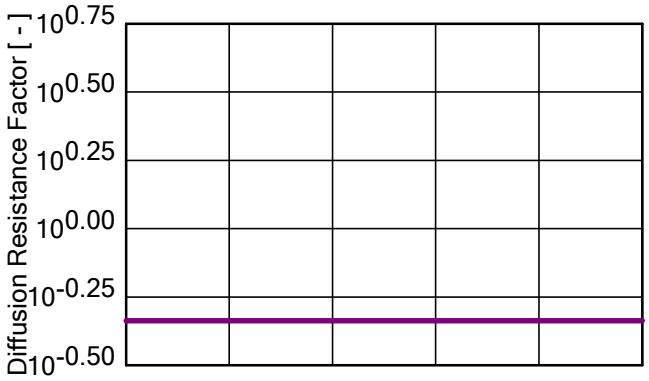


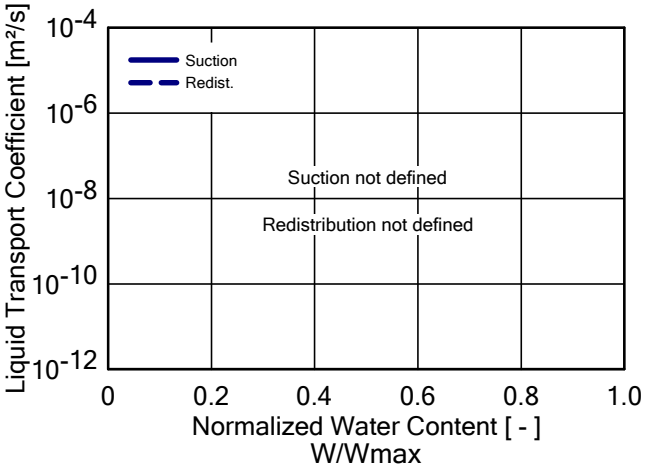


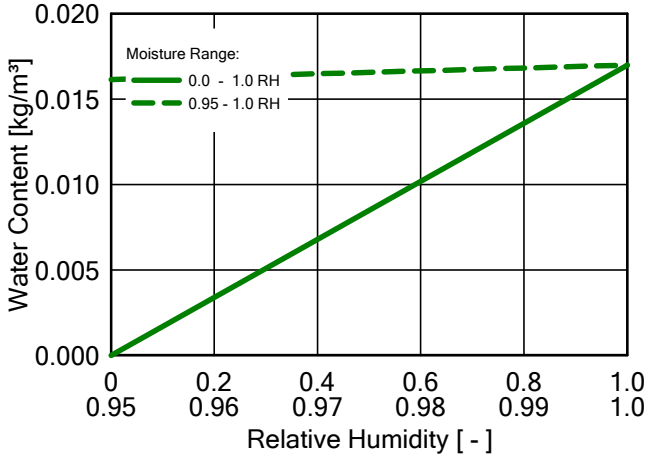
Material: Air Layer 30 mm; without additional moisture capacity

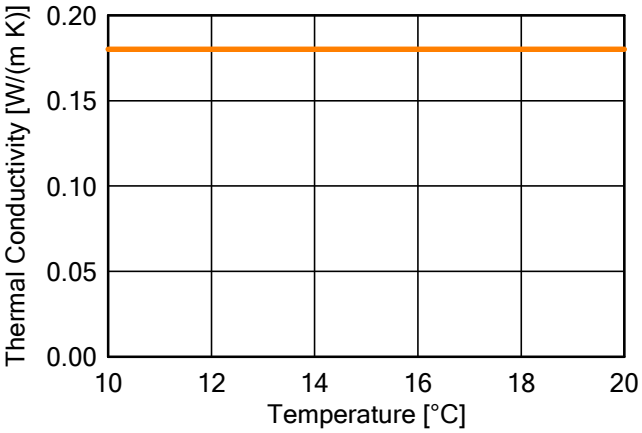
Property	Unit	Value
Bulk density	[kg/m³]	1.3
Porosity	[m³/m³]	0.999
Specific Heat Capacity, Dry	[J/(kg K)]	1000
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.18
Water Vapour Diffusion Resistance Factor	[-]	0.46





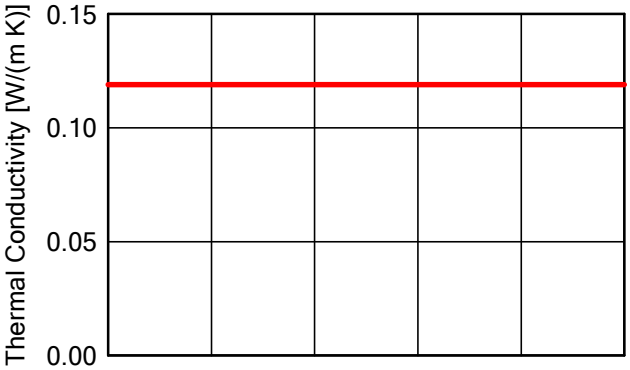


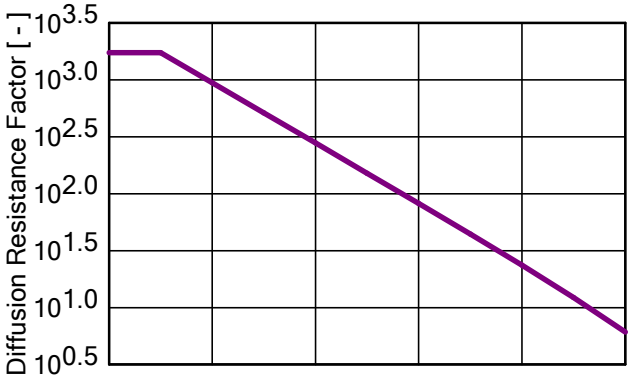


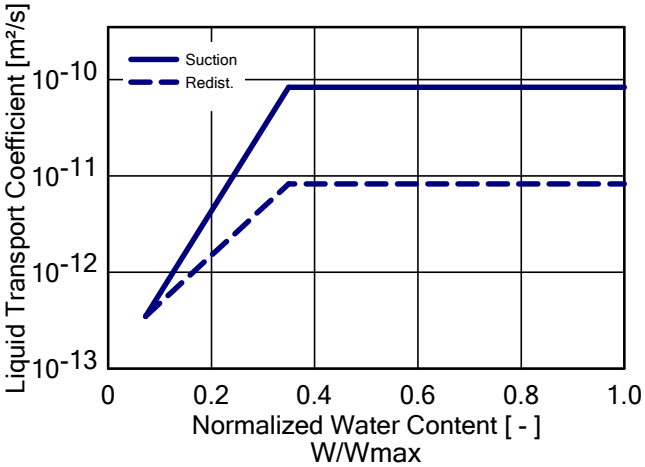


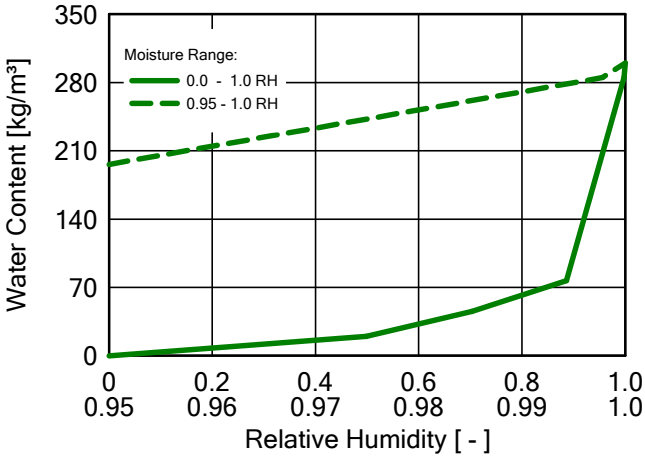
Material: Southern Yellow Pine

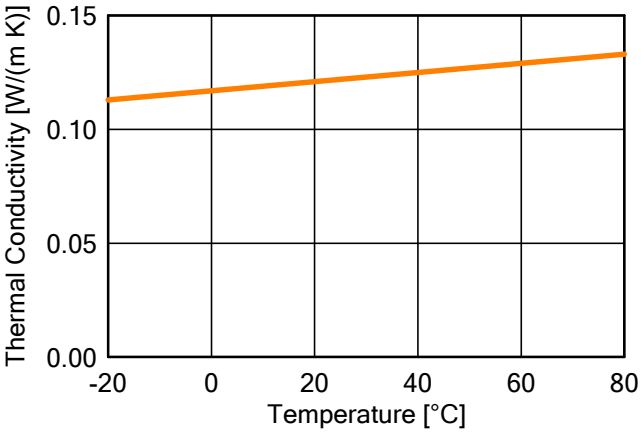
Property	Unit	Value
Bulk density	[kg/m³]	500
Porosity	[m³/m³]	0.858
Specific Heat Capacity, Dry	[J/(kg K)]	1880
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.119
Water Vapour Diffusion Resistance Factor	[-]	1734.1
Reference Water Content	[kg/m³]	62.2
Free Water Saturation	[kg/m³]	300
Water Absorption Coefficient	[kg/(m² s^0.5)]	0.0014
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





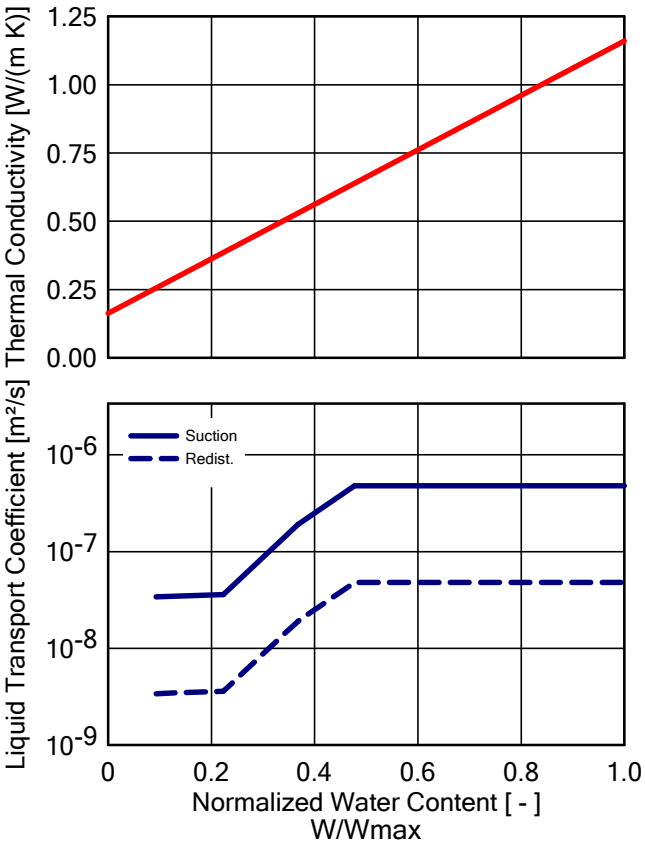


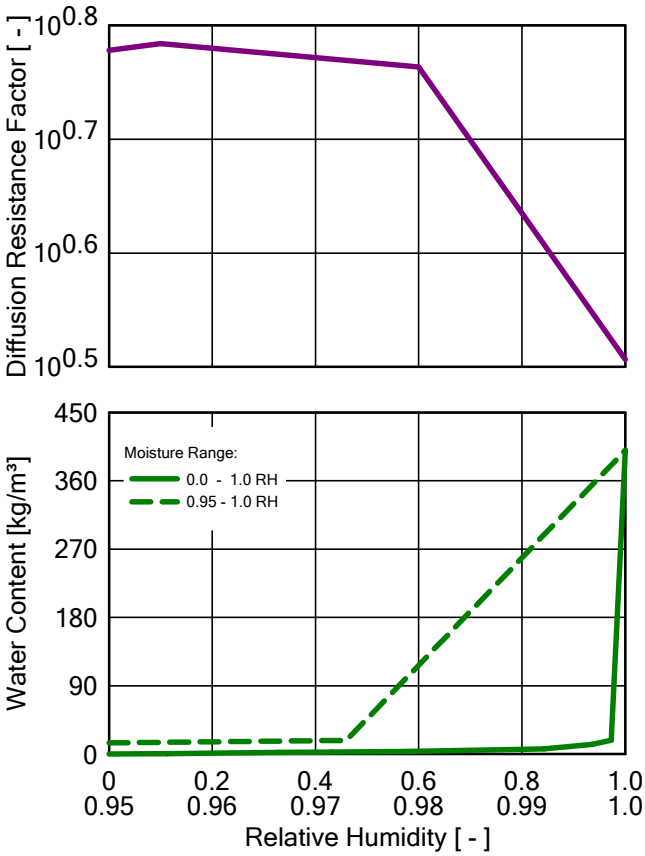


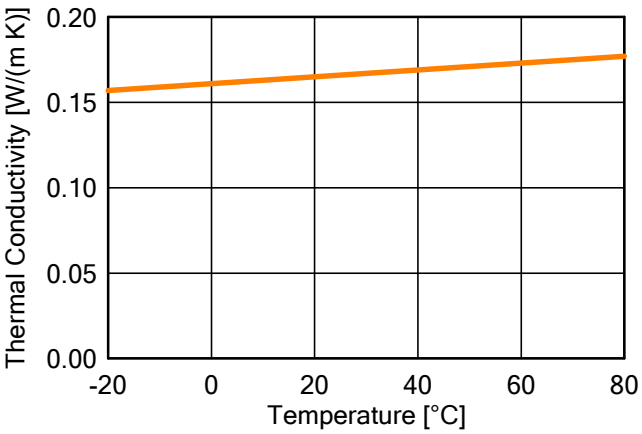


Material: Gypsum Board (USA)

Property	Unit	Value
Bulk density	[kg/m³]	850
Porosity	[m³/m³]	0.65
Specific Heat Capacity, Dry	[J/(kg K)]	870
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.163
Water Vapour Diffusion Resistance Factor	[-]	6
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4

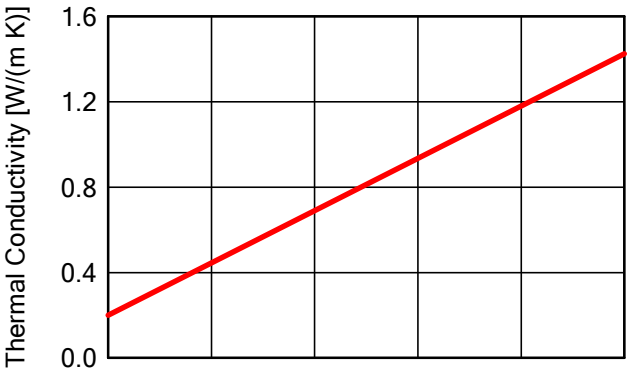


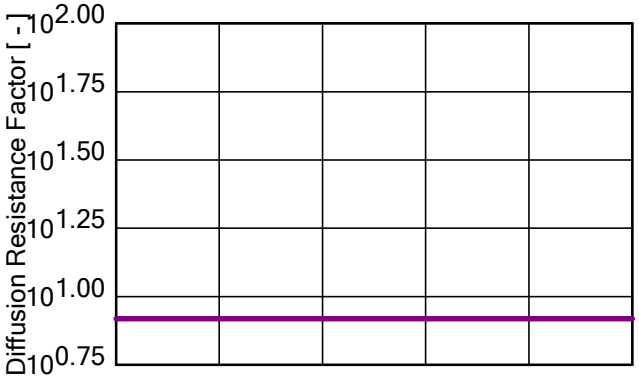


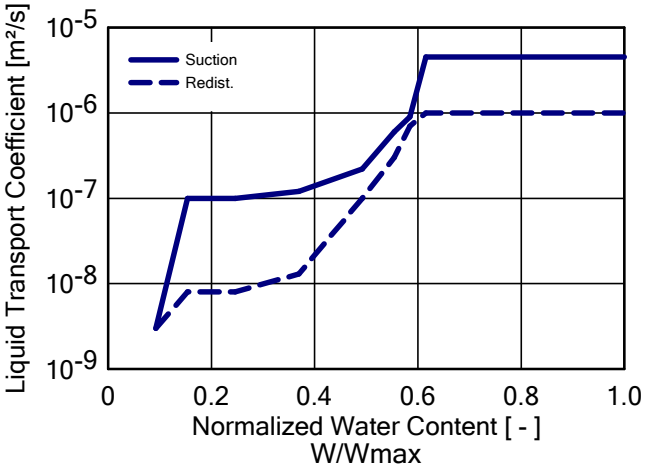


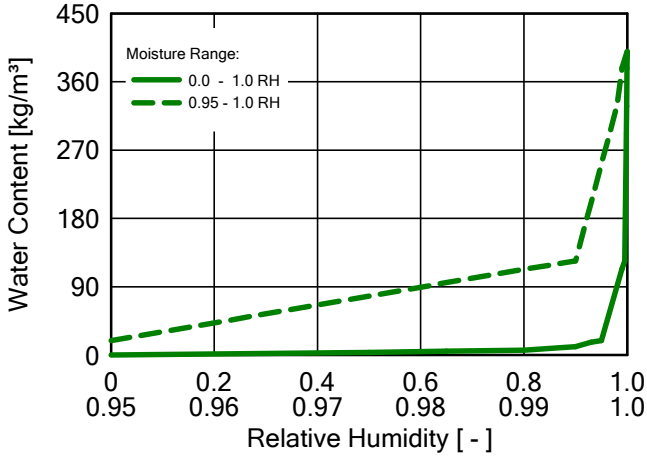
Material: Interior Plaster (Gypsum Plaster)

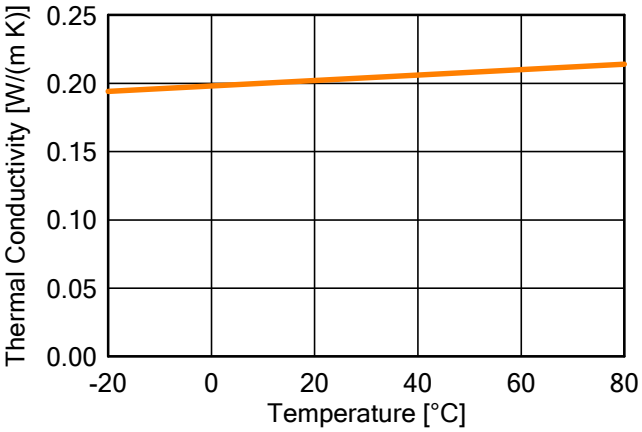
Property	Unit	Value
Bulk density	[kg/m³]	850
Porosity	[m³/m³]	0.65
Specific Heat Capacity, Dry	[J/(kg K)]	850
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.2
Water Vapour Diffusion Resistance Factor	[-]	8.3
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4











Boundary Conditions

Exterior (Left Side)

Location: Toronto; warm year
Temperature Shift: 0.0 °C
Orientation / Inclination: East / 90 °

Interior (Right Side)

Indoor Climate: WTA Guideline 6-2-01/E
User-Defined Sine Curve Parameters

Surface Transfer Coefficients

Exterior (Left Side)

Name	Description	Unit	Value
Heat Resistance - includes long-wave radiation	External Wall	[(m² K)/W]	0.0588 yes
sd-Value	No coating	[m]	----
Short-Wave Radiation Absorptivity	Brick, white, glazed	[-]	0.26
Long-Wave Radiation Emissivity	Brick, white, glazed	[-]	----
Adhering Fraction of Rain	Depending on inclination o	[-]	0.7
Explicit Radiation Balance			no

Interior (Right Side)

Name	Description	Unit	Value
Heat Resistance	External Wall	[(m² K)/W]	0.125
sd-Value	Latex paint 1	[m]	0.2

Sources, Sinks

Mulock 3 Ext

Name	Type		
Driving Rain	*Moisture Source; Fraction of Rain Load*		
	Depth in Layer	[m]	0.009
	Cut-Off at Free Water Saturation	[kg/m³]	319
	ANSI/ASHRAE standard 160	[%]	1

Results from Last Calculation

Status of Calculation

Calculation: Time and Date	5/29/2023 4:39:32 PM
Computing Time	2 min,7 sec.
Begin / End of calculation	10/1/2020 / 10/1/2025
No. of Convergence Failures	0

Check for numerical quality

Integral of fluxes, left side (kl,dl)	[kg/m²]	87.36 -77.75
Integral of fluxes, right side (kr,dr)	[kg/m²]	0.0 10.48
Balance 1	[kg/m²]	3.04
Balance 2	[kg/m²]	3.04

Water Content [kg/m²]

	Start	End	Min.	Max.
Total Water Content	3.18	6.22	2.82	10.33

Water Content [kg/m³]

Layer/Material	Start	End	Min.	Max.
Mulock 3 Ext	3.00	10.07	0.23	173.78
Mulock 3 Ext	3.00	30.62	1.18	69.49
Mulock 3 Ext	3.00	25.04	2.39	36.23
MOR-EXT-1	2.30	15.52	2.14	23.45
Mulock 3 Mid	3.00	14.64	2.99	25.12
Mulock 3 Mid	3.00	5.47	2.99	12.09
MOR-INT-1	12.00	13.37	11.84	20.30
Mulock 1 Int	13.00	13.49	12.48	20.31
Air Layer 30 mm; without additional m	0.01	0.01	0.01	0.01
Southern Yellow Pine	62.20	50.38	35.63	62.26
Gypsum Board (USA)	6.19	4.66	3.24	6.19
Interior Plaster (Gypsum Plaster)	6.30	5.12	3.60	6.30

Time Integral of fluxes

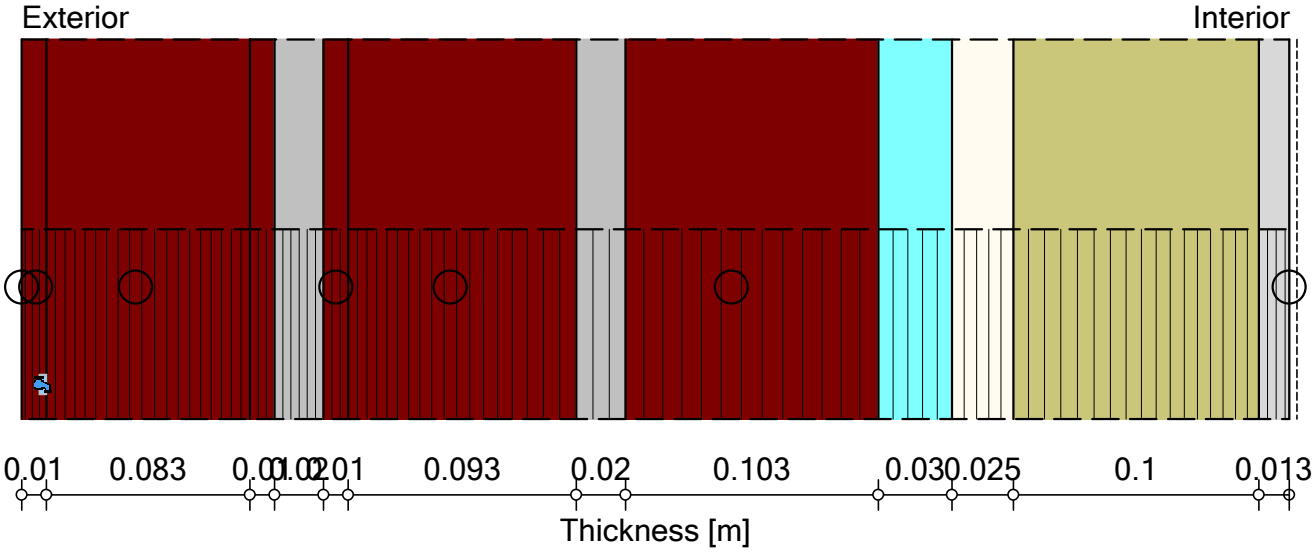
Heat Flux, left side	[MJ/m²]	-4928.48
Heat Flux, right side	[MJ/m²]	-1259.48
Moisture Fluxes, left side	[kg/m²]	9.61
Moisture Fluxes, right side	[kg/m²]	10.48

Hygrothermal Sources

Heat Sources	[MJ/m²]	0.0
Moisture Sources	[kg/m²]	3.905
Unreleased Moisture Sources (due to cut-off)	[kg/m²]	0.0
Driving Rain (Moisture Source)	[kg/m²]	3.905

Component Assembly

Case: W2-100 mm insulation



- Monitor positions

/ - Heat/Moisture source/sink positions

Materials:

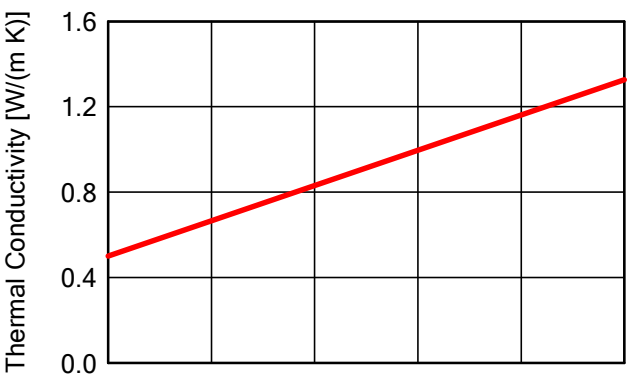
- Mulock 3 Ext	0.01 m
- Mulock 3 Ext	0.083 m
- Mulock 3 Ext	0.01 m
- MOR-EXT-1	0.02 m
- Mulock 3 Mid	0.01 m
- Mulock 3 Mid	0.093 m
- MOR-INT-1	0.02 m
- Mulock 1 Int	0.103 m
- Air Layer 30 mm; without additional moisture capacity	0.03 m
- Interior Plaster (Gypsum Plaster)	0.025 m
- Sprayed Polyurethane Foam; closed cell	0.1 m
- Interior Gypsum Board	0.013 m

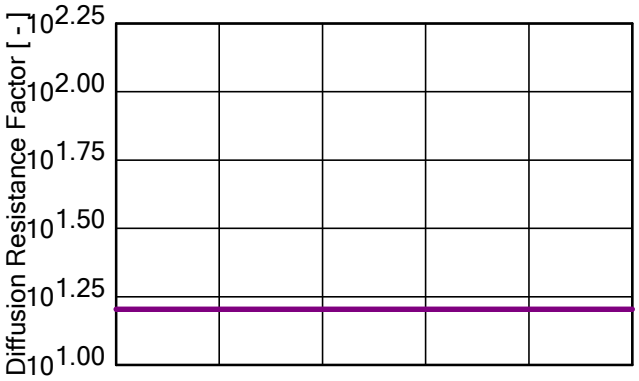
sd-Value Int. [m]: 0.2

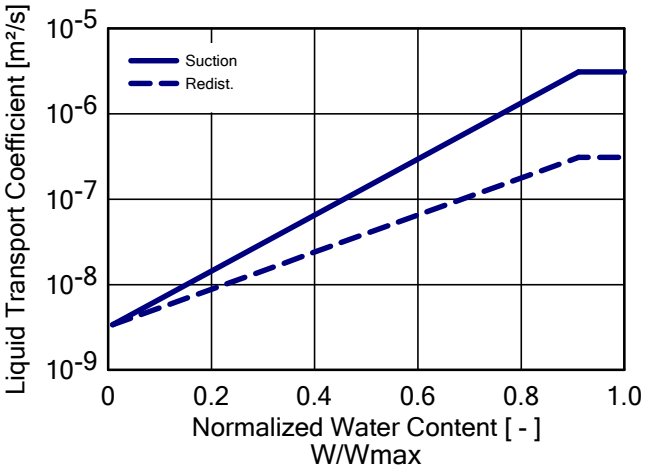
Total Thickness: 0.516 m
R-Value: 4.98 (m² K)/W
U-Value: 0.194 W/(m² K)

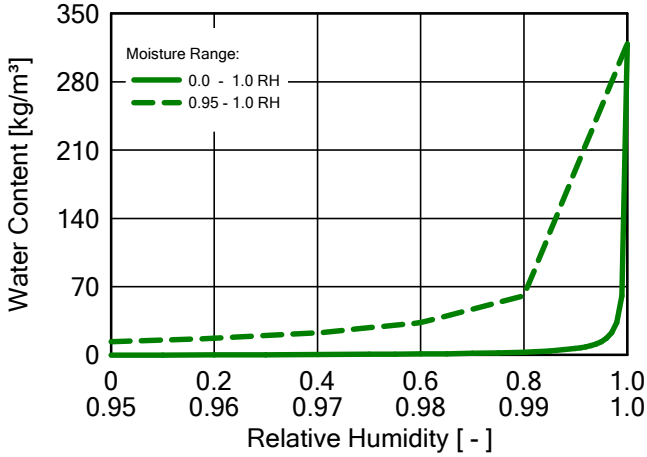
Material: Mulock 3 Ext

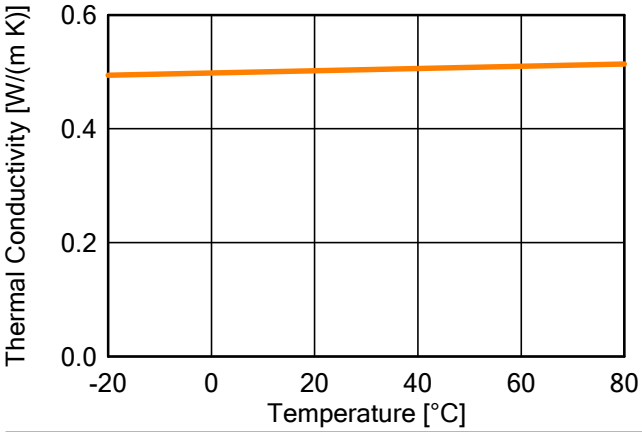
Property	Unit	Value
Bulk density	[kg/m³]	1694
Porosity	[m³/m³]	0.35
Specific Heat Capacity, Dry	[J/(kg K)]	660
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.5
Water Vapour Diffusion Resistance Factor	[-]	16
Reference Water Content	[kg/m³]	3
Free Water Saturation	[kg/m³]	319
Water Absorption Coefficient	[kg/(m² s^0.5)]	0.29
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





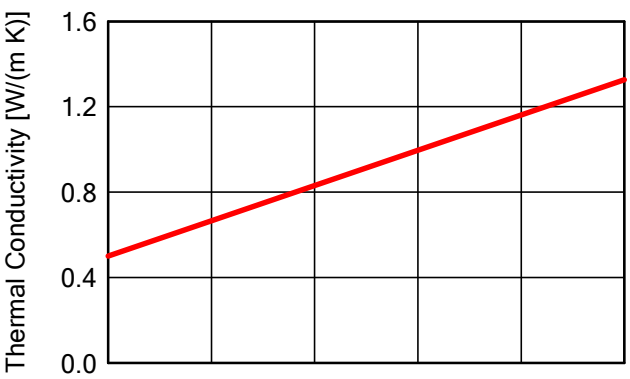


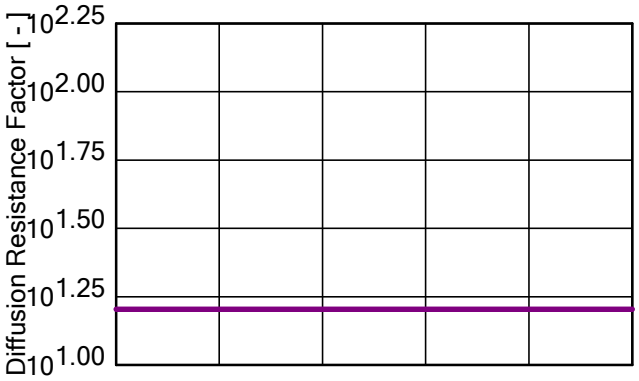


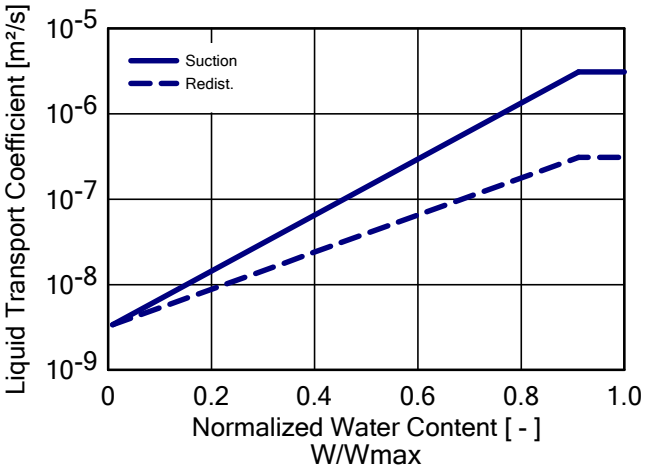


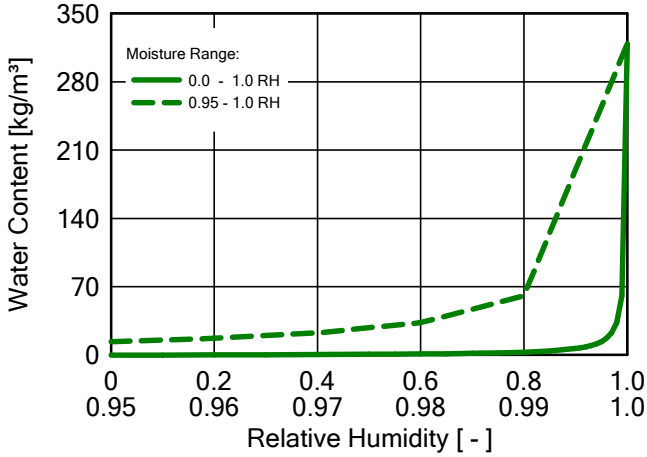
Material: Mulock 3 Ext

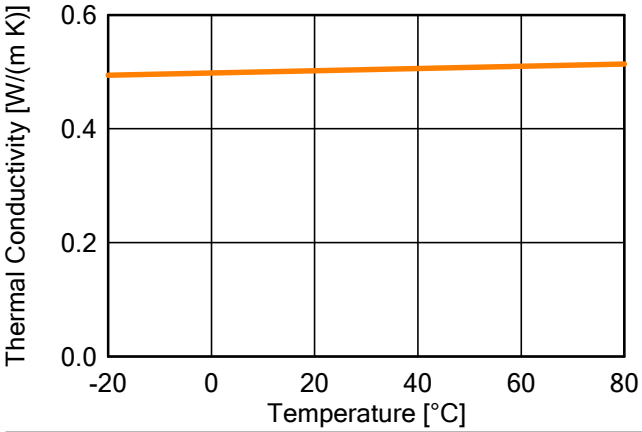
Property	Unit	Value
Bulk density	[kg/m³]	1694
Porosity	[m³/m³]	0.35
Specific Heat Capacity, Dry	[J/(kg K)]	660
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.5
Water Vapour Diffusion Resistance Factor	[-]	16
Reference Water Content	[kg/m³]	3
Free Water Saturation	[kg/m³]	319
Water Absorption Coefficient	[kg/(m² s^0.5)]	0.29
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





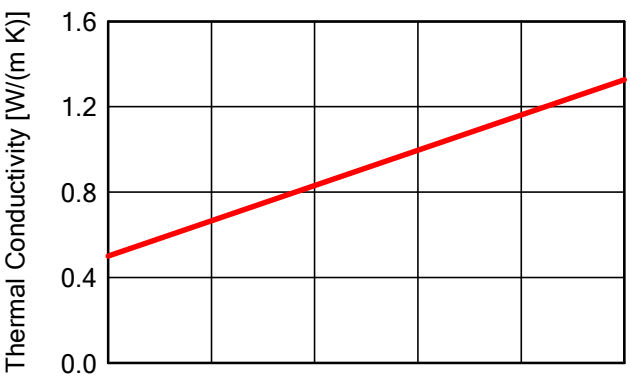


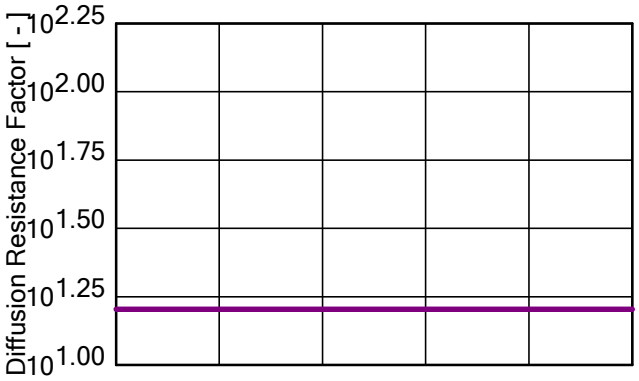


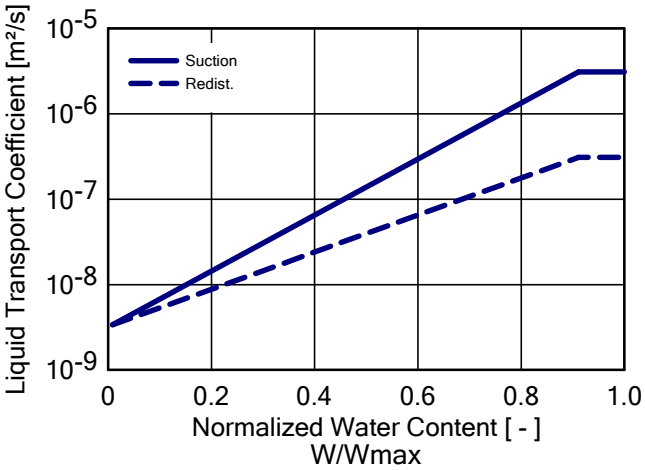


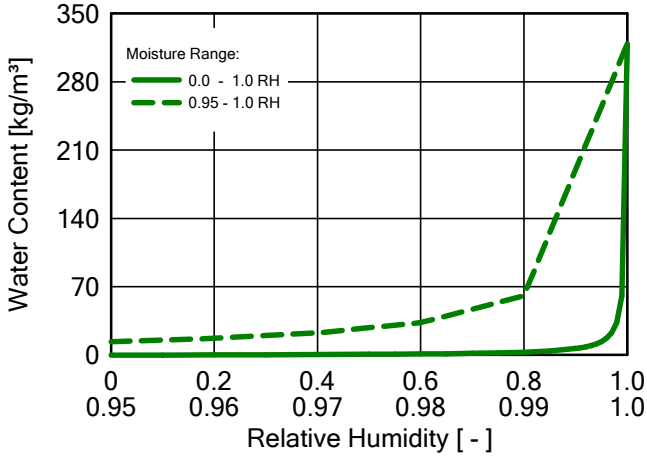
Material: Mulock 3 Ext

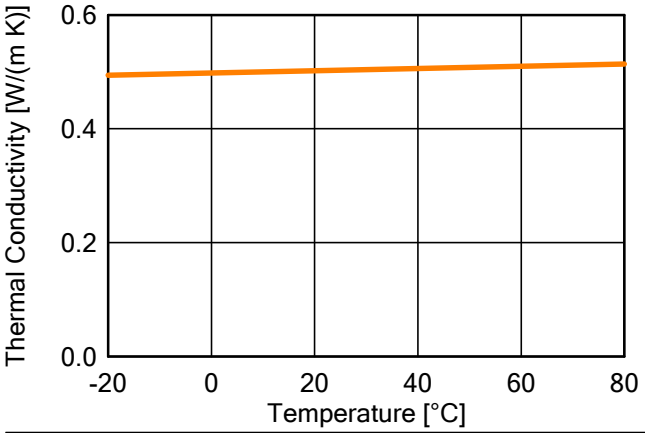
Property	Unit	Value
Bulk density	[kg/m³]	1694
Porosity	[m³/m³]	0.35
Specific Heat Capacity, Dry	[J/(kg K)]	660
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.5
Water Vapour Diffusion Resistance Factor	[-]	16
Reference Water Content	[kg/m³]	3
Free Water Saturation	[kg/m³]	319
Water Absorption Coefficient	[kg/(m² s^0.5)]	0.29
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





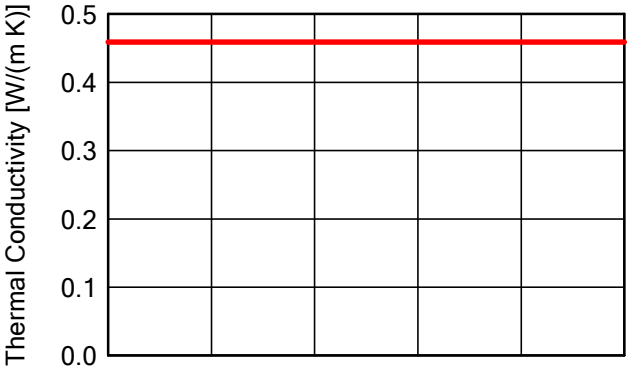


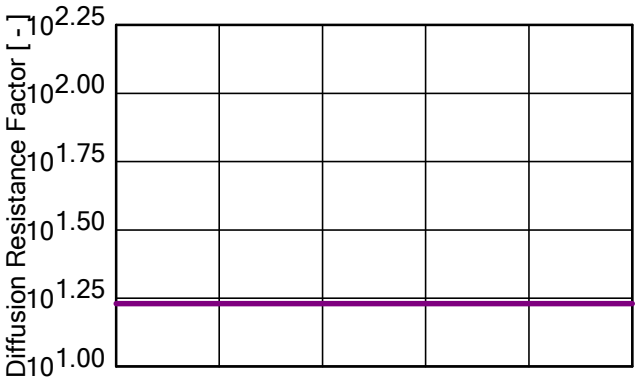


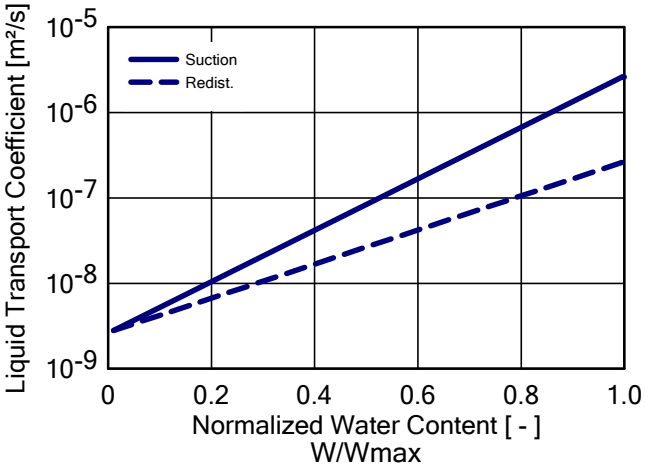


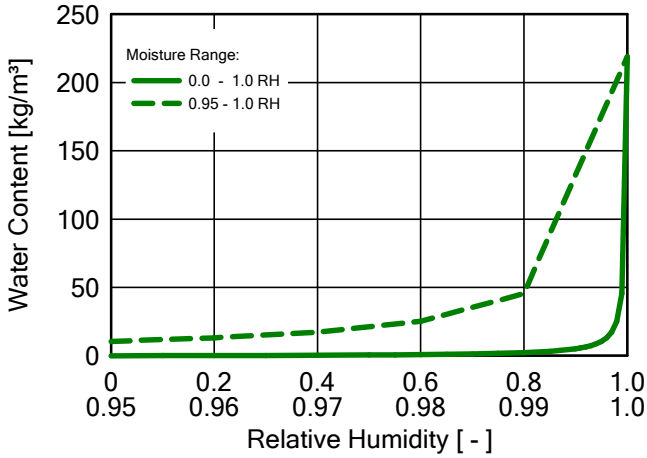
Material: MOR-EXT-1

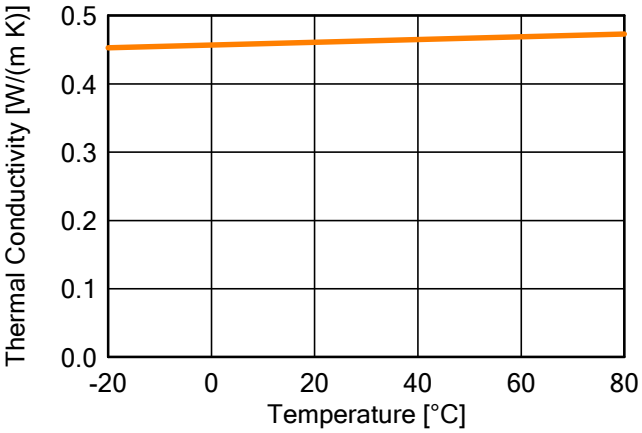
Property	Unit	Value
Bulk density	[kg/m³]	1973
Porosity	[m³/m³]	0.22
Specific Heat Capacity, Dry	[J/(kg K)]	900
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.459
Water Vapour Diffusion Resistance Factor	[-]	17
Reference Water Content	[kg/m³]	2.3
Free Water Saturation	[kg/m³]	219
Water Absorption Coefficient	[kg/(m² s^0.5)]	0.18
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





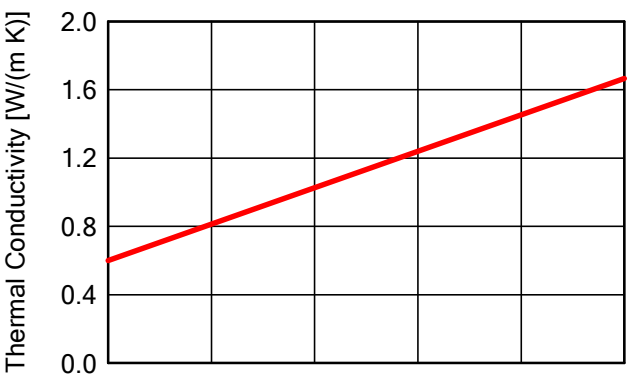


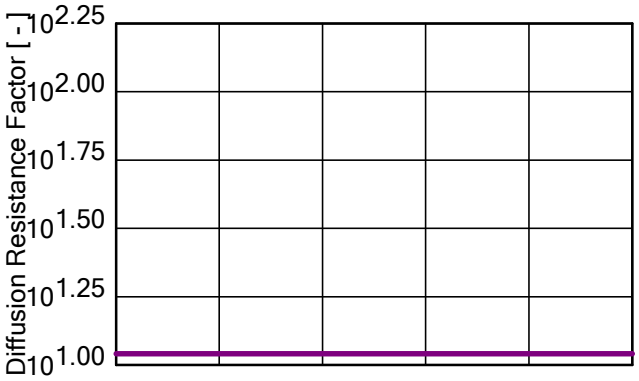


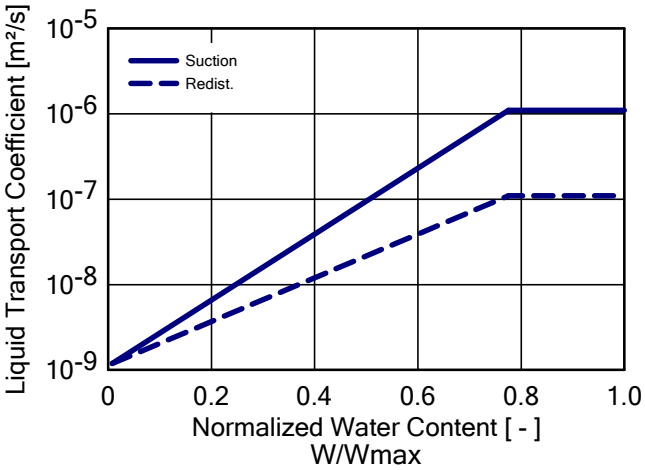


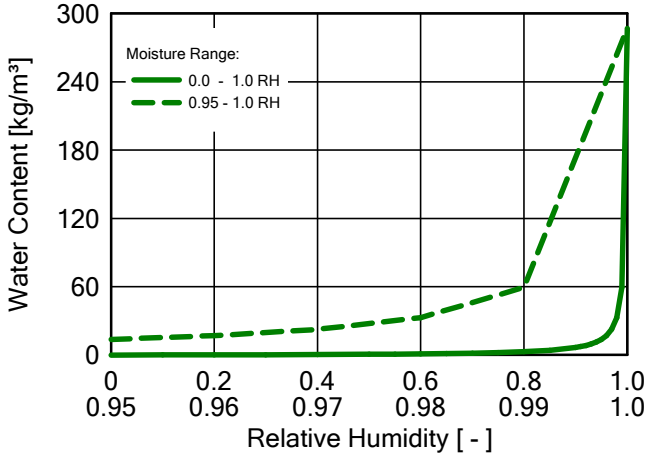
Material: Mulock 3 Mid

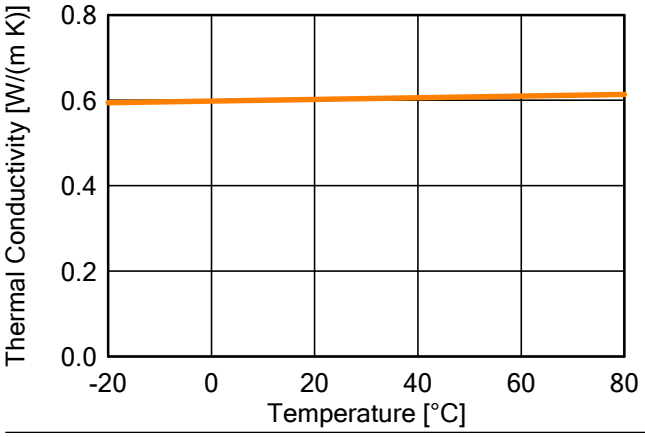
Property	Unit	Value
Bulk density	[kg/m³]	1666
Porosity	[m³/m³]	0.37
Specific Heat Capacity, Dry	[J/(kg K)]	710
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.6
Water Vapour Diffusion Resistance Factor	[-]	11
Reference Water Content	[kg/m³]	3
Free Water Saturation	[kg/m³]	287
Water Absorption Coefficient	[kg/(m² s^0.5)]	0.16
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





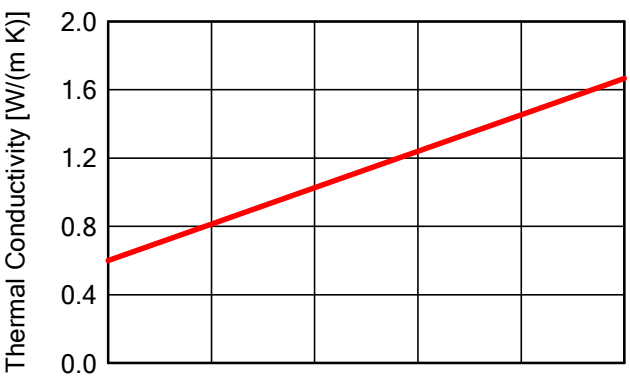


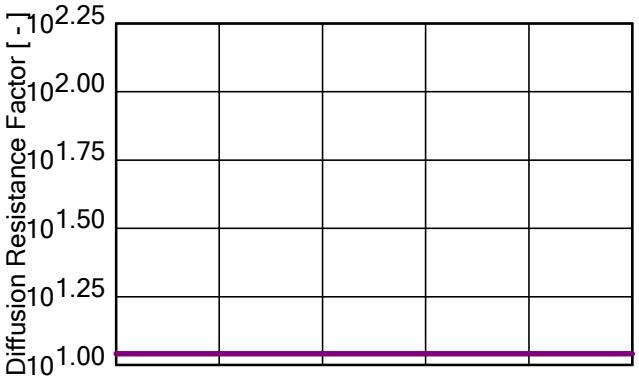


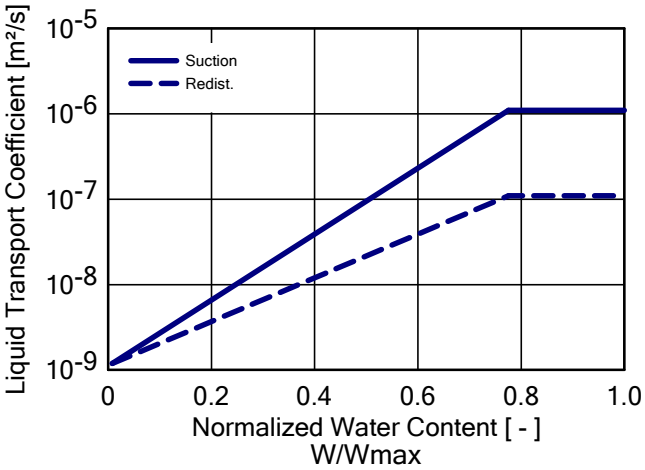


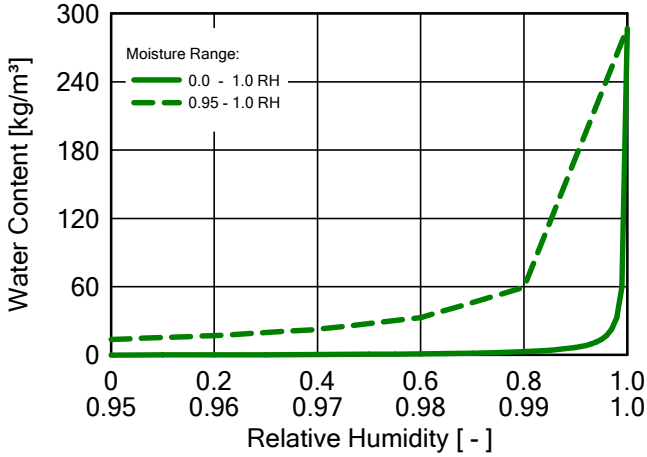
Material: Mulock 3 Mid

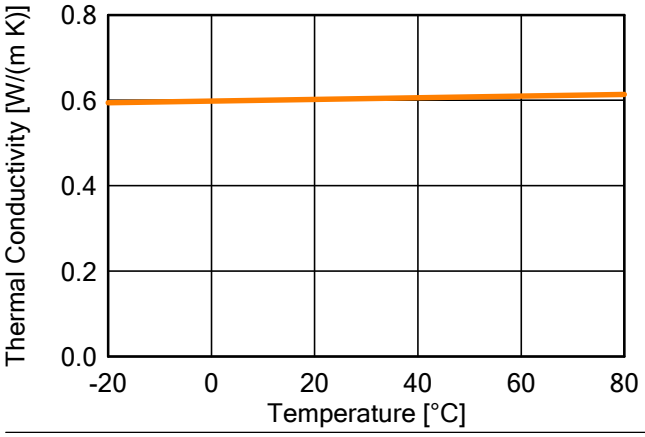
Property	Unit	Value
Bulk density	[kg/m³]	1666
Porosity	[m³/m³]	0.37
Specific Heat Capacity, Dry	[J/(kg K)]	710
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.6
Water Vapour Diffusion Resistance Factor	[-]	11
Reference Water Content	[kg/m³]	3
Free Water Saturation	[kg/m³]	287
Water Absorption Coefficient	[kg/(m² s^0.5)]	0.16
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





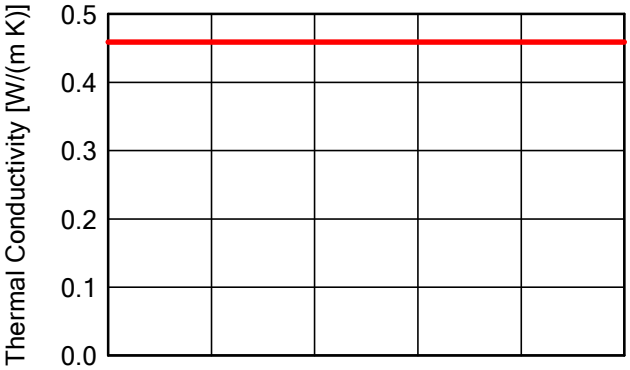


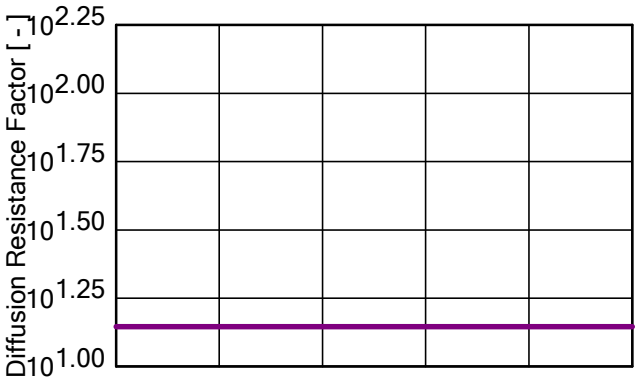


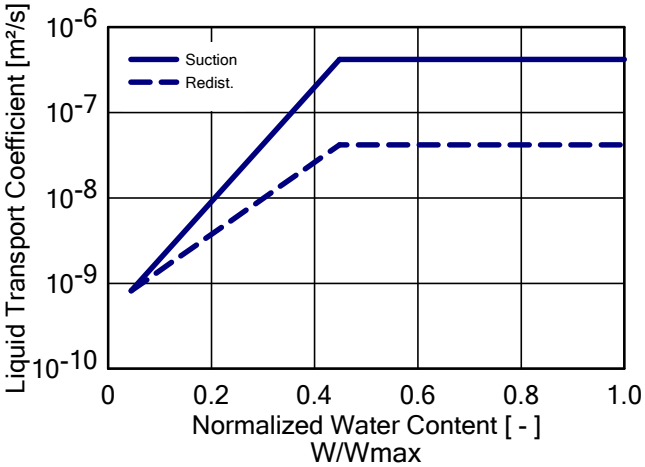


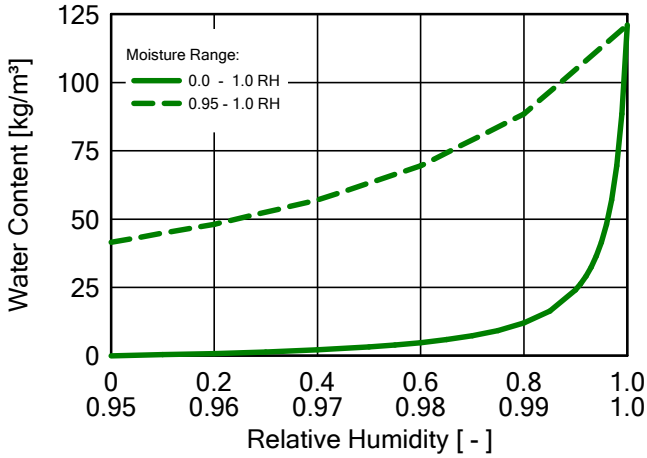
Material: MOR-INT-1

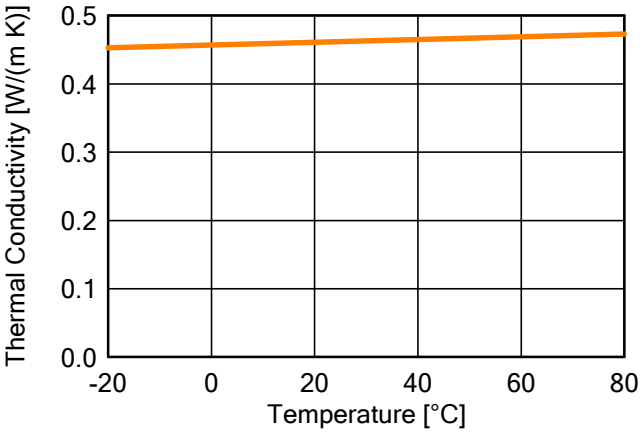
Property	Unit	Value
Bulk density	[kg/m³]	1894
Porosity	[m³/m³]	0.27
Specific Heat Capacity, Dry	[J/(kg K)]	900
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.459
Water Vapour Diffusion Resistance Factor	[-]	14
Reference Water Content	[kg/m³]	12
Free Water Saturation	[kg/m³]	121
Water Absorption Coefficient	[kg/(m² s^0.5)]	0.04
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





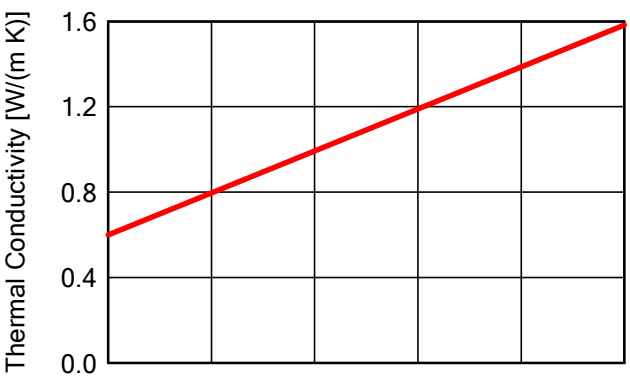


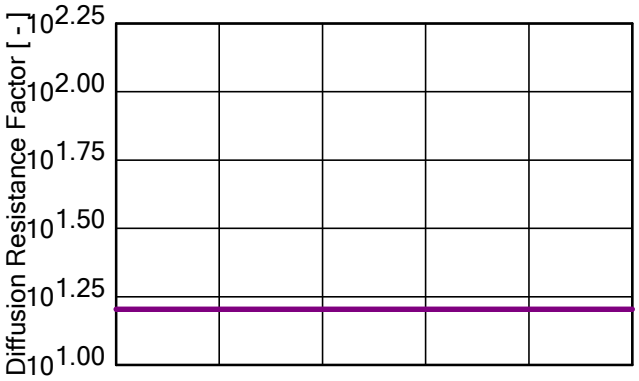


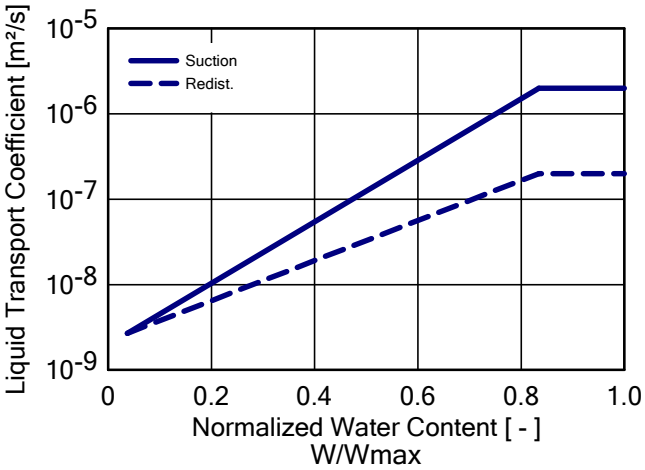


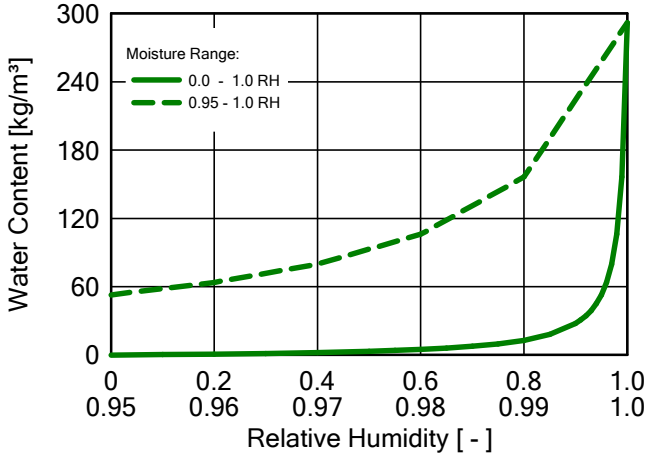
Material: Mulock 1 Int

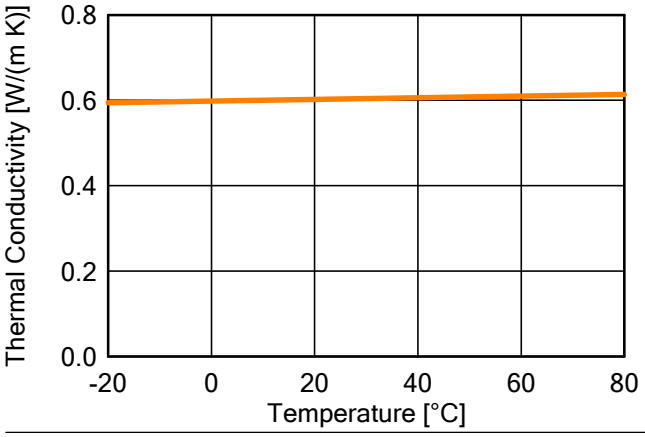
Property	Unit	Value
Bulk density	[kg/m³]	1709
Porosity	[m³/m³]	0.35
Specific Heat Capacity, Dry	[J/(kg K)]	660
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.6
Water Vapour Diffusion Resistance Factor	[-]	16
Reference Water Content	[kg/m³]	13
Free Water Saturation	[kg/m³]	292
Water Absorption Coefficient	[kg/(m² s^0.5)]	.21
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





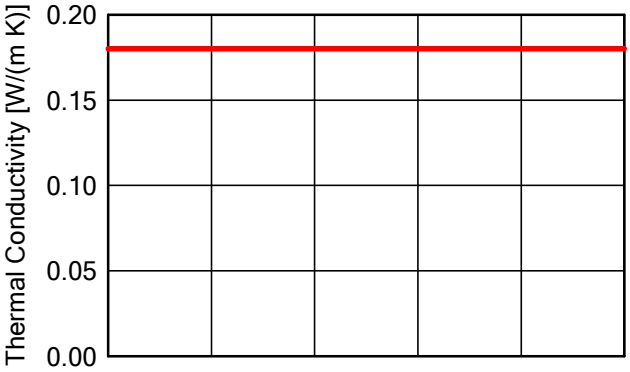


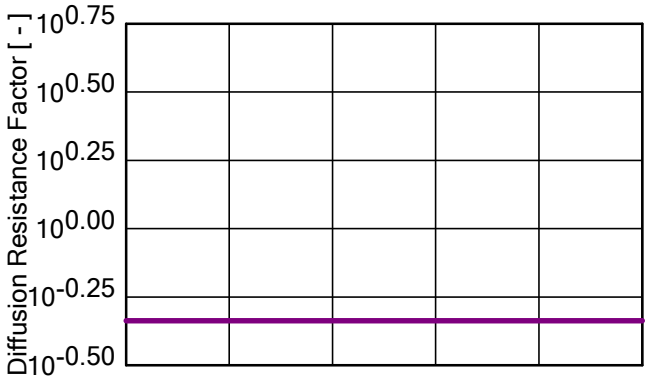


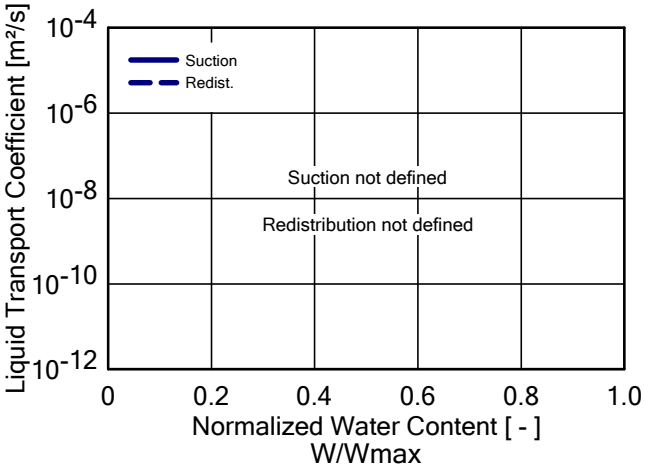


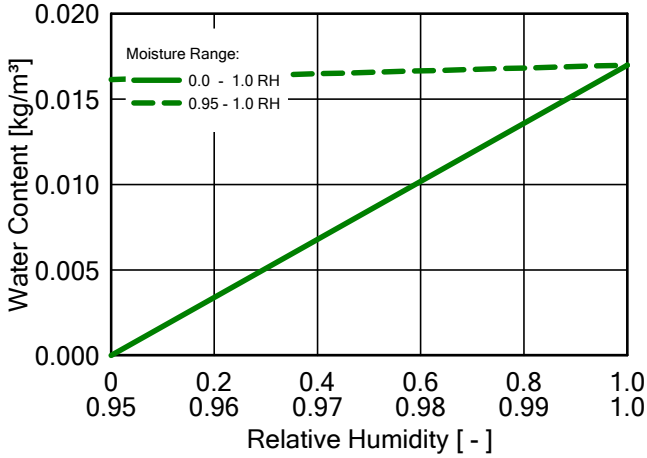
Material: Air Layer 30 mm; without additional moisture capacity

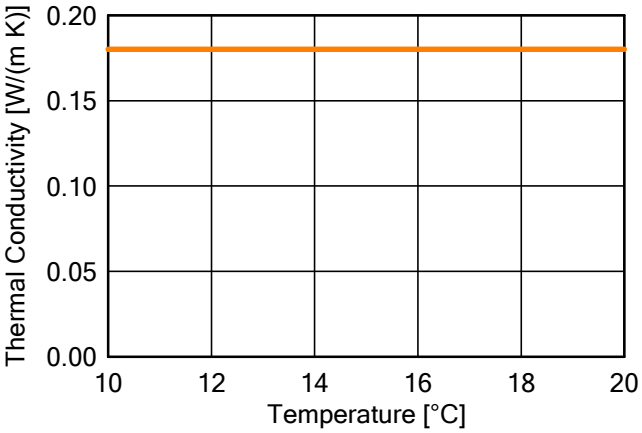
Property	Unit	Value
Bulk density	[kg/m³]	1.3
Porosity	[m³/m³]	0.999
Specific Heat Capacity, Dry	[J/(kg K)]	1000
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.18
Water Vapour Diffusion Resistance Factor	[-]	0.46





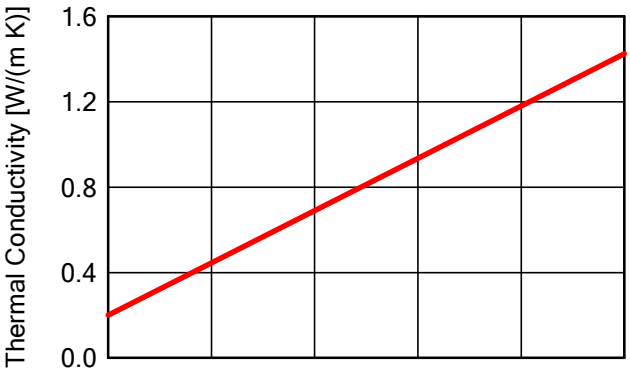


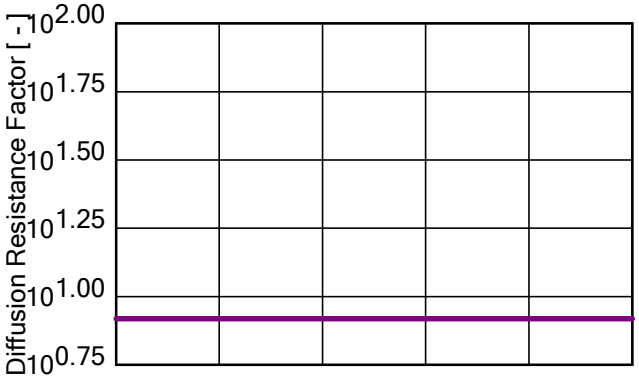


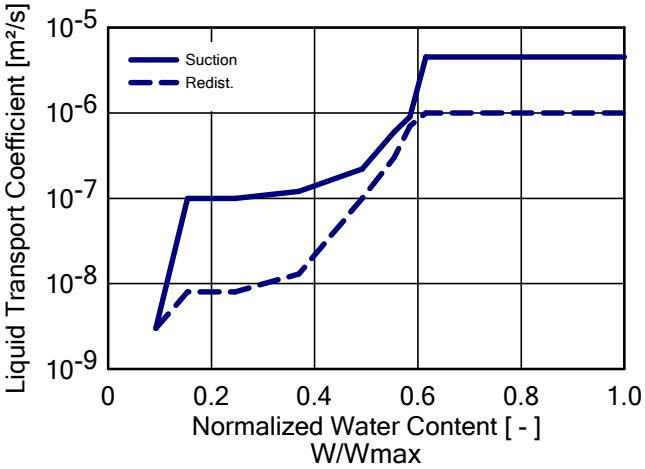


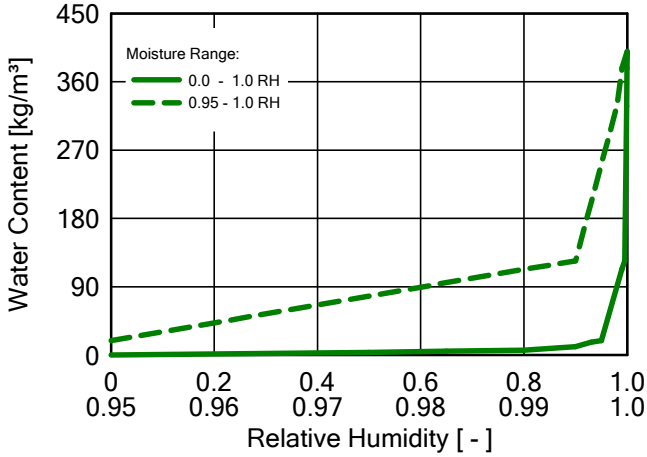
Material: Interior Plaster (Gypsum Plaster)

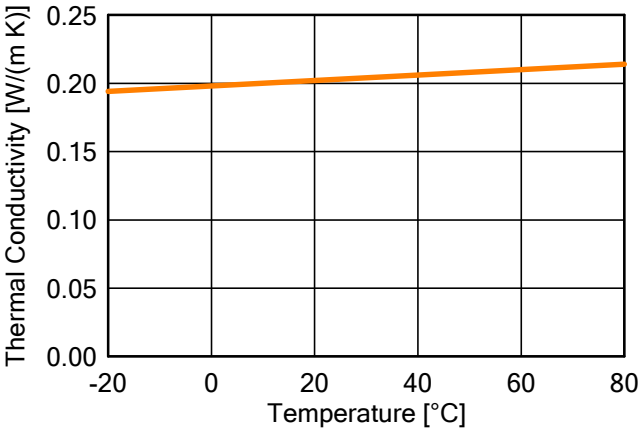
Property	Unit	Value
Bulk density	[kg/m³]	850
Porosity	[m³/m³]	0.65
Specific Heat Capacity, Dry	[J/(kg K)]	850
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.2
Water Vapour Diffusion Resistance Factor	[-]	8.3
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





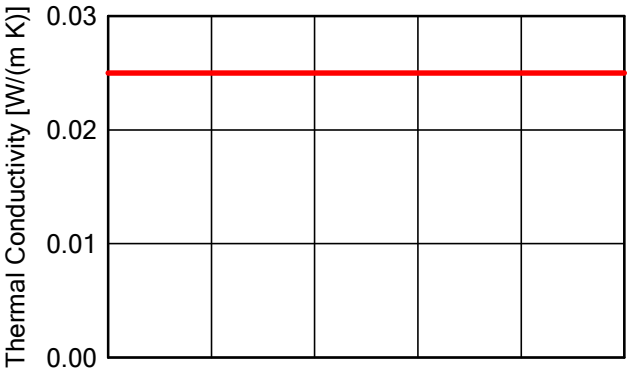


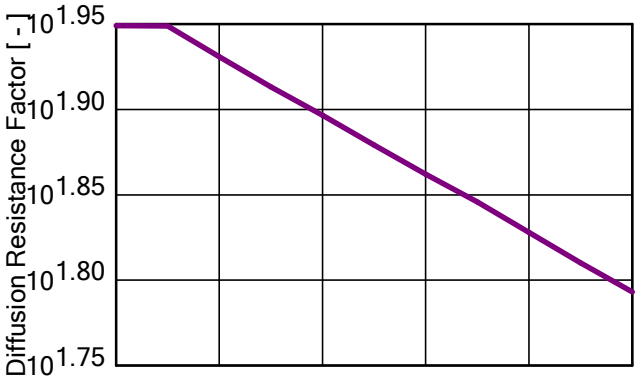


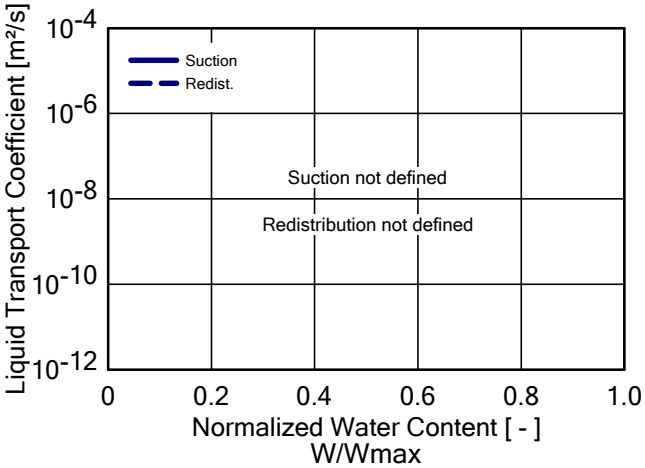


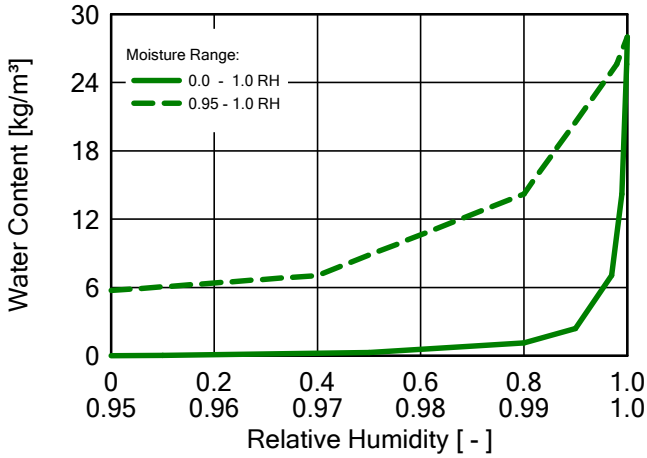
Material: Sprayed Polyurethane Foam; closed cell

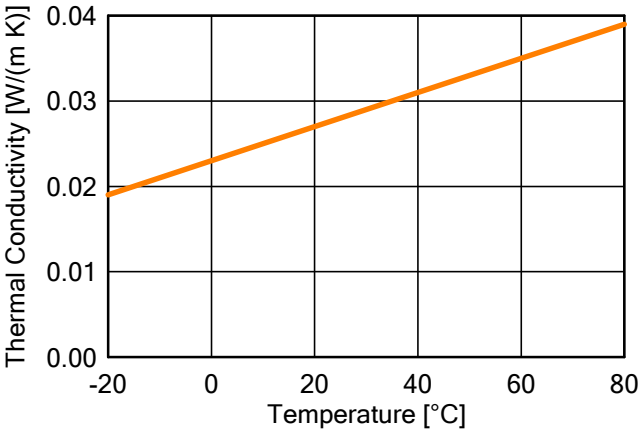
Property	Unit	Value
Bulk density	[kg/m³]	39
Porosity	[m³/m³]	0.99
Specific Heat Capacity, Dry	[J/(kg K)]	1470
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.025
Water Vapour Diffusion Resistance Factor	[-]	88.93
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





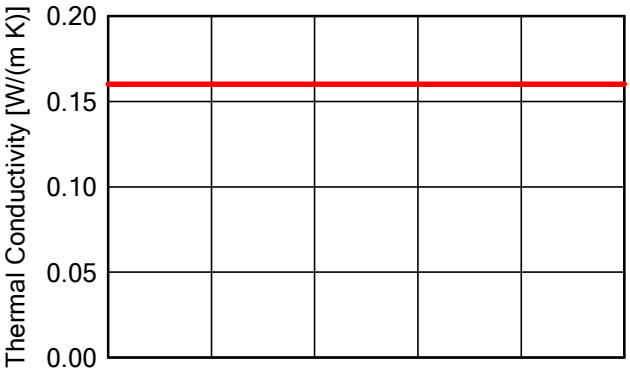


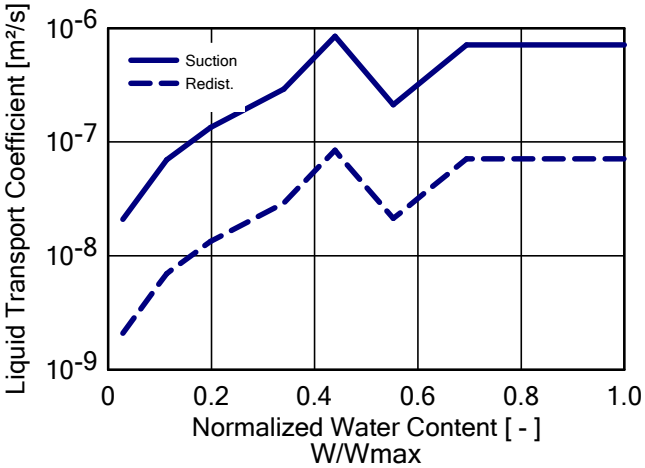


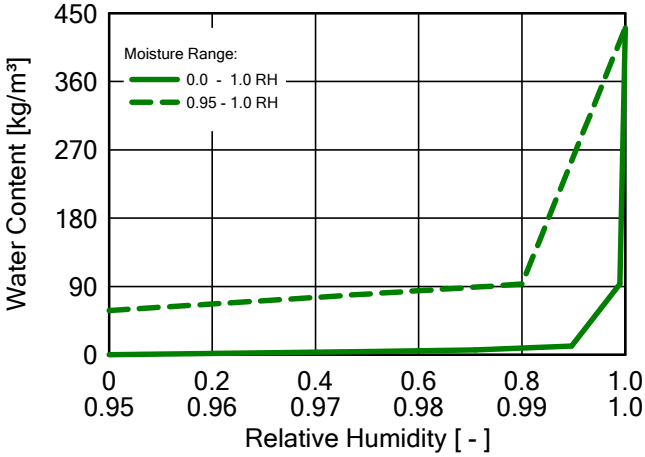


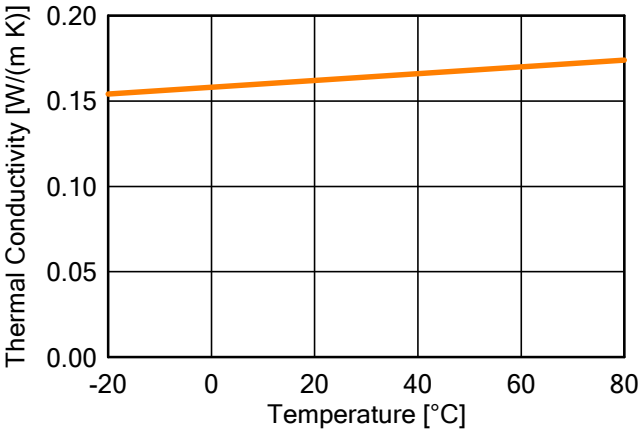
Material: Interior Gypsum Board

Property	Unit	Value
Bulk density	[kg/m³]	625
Porosity	[m³/m³]	0.706
Specific Heat Capacity, Dry	[J/(kg K)]	870
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.16
Water Vapour Diffusion Resistance Factor	[-]	7.03
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4









Boundary Conditions

Exterior (Left Side)

Location: Toronto; warm year
Temperature Shift: 0.0 °C
Orientation / Inclination: East / 90 °

Interior (Right Side)

Indoor Climate: WTA Guideline 6-2-01/E
User-Defined Sine Curve Parameters

Surface Transfer Coefficients

Exterior (Left Side)

Name	Description	Unit	Value
Heat Resistance - includes long-wave radiation	External Wall	[(m² K)/W]	0.0588 yes
sd-Value	No coating	[m]	----
Short-Wave Radiation Absorptivity	Brick, white, glazed	[-]	0.26
Long-Wave Radiation Emissivity	Brick, white, glazed	[-]	----
Adhering Fraction of Rain	Depending on inclination o	[-]	0.7
Explicit Radiation Balance			no

Interior (Right Side)

Name	Description	Unit	Value
Heat Resistance	External Wall	[(m² K)/W]	0.125
sd-Value	Latex paint 1	[m]	0.2

Sources, Sinks

Mulock 3 Ext

Name	Type		
Driving Rain	*Moisture Source; Fraction of Rain Load*		
	Depth in Layer	[m]	0.009
	Cut-Off at Free Water Saturation	[kg/m³]	319
	ANSI/ASHRAE standard 160	[%]	1

Results from Last Calculation

Status of Calculation

Calculation: Time and Date	6/13/2023 2:59:24 PM
Computing Time	1 min,57 sec.
Begin / End of calculation	10/1/2020 / 10/1/2025
No. of Convergence Failures	0

Check for numerical quality

Integral of fluxes, left side (kl,dl)	[kg/m²]	84.99 -79.73
Integral of fluxes, right side (kr,dr)	[kg/m²]	0.0 1.16
Balance 1	[kg/m²]	8.01
Balance 2	[kg/m²]	8.0

Water Content [kg/m²]

	Start	End	Min.	Max.
Total Water Content	2.62	10.62	2.49	14.77

Water Content [kg/m³]

Layer/Material	Start	End	Min.	Max.
Mulock 3 Ext	3.00	10.77	0.23	176.77
Mulock 3 Ext	3.00	32.79	1.50	75.90
Mulock 3 Ext	3.00	27.72	2.95	42.10
MOR-EXT-1	2.30	17.36	2.28	27.29
Mulock 3 Mid	3.00	17.22	2.99	29.85
Mulock 3 Mid	3.00	10.90	2.99	18.34
MOR-INT-1	12.00	36.00	11.95	40.39
Mulock 1 Int	13.00	44.98	12.99	50.36
Air Layer 30 mm; without additional m	0.01	0.02	0.01	0.02
Interior Plaster (Gypsum Plaster)	6.30	17.18	6.06	18.37
Sprayed Polyurethane Foam; closed c	1.12	1.36	0.52	1.56
Interior Gypsum Board	8.65	5.04	3.54	8.65

Time Integral of fluxes

Heat Flux, left side	[MJ/m²]	-3988.8
Heat Flux, right side	[MJ/m²]	-303.05
Moisture Fluxes, left side	[kg/m²]	5.27
Moisture Fluxes, right side	[kg/m²]	1.17

Hygrothermal Sources

Heat Sources	[MJ/m²]	0.0
Moisture Sources	[kg/m²]	3.905
Unreleased Moisture Sources (due to cut-off)	[kg/m²]	0.0
Driving Rain (Moisture Source)	[kg/m²]	3.905