HYGROTHERMAL PERFORMANCE OF HEMPCRETE FOR ONTARIO (CANADA) BUILDINGS

Hempcrete insulation building :The Camp Kawartha Environment Centre, Trent University, Peterborough, Ontario (Source: The Endeavour Centre, 2015)

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Agendas

1. Introduction to hempcrete
2. Properties
3. Objectives of the study
4. Methodology
5. Materials
6. Test measurements
7. One-dimensional hygrothermal (WUFI) analysis
8. Case studies
9. Findings and Conclusions
10. References

1. Introduction

✓Bio-aggregate-based natural composite material

✓Potential for use as a thermal and acoustic insulation system

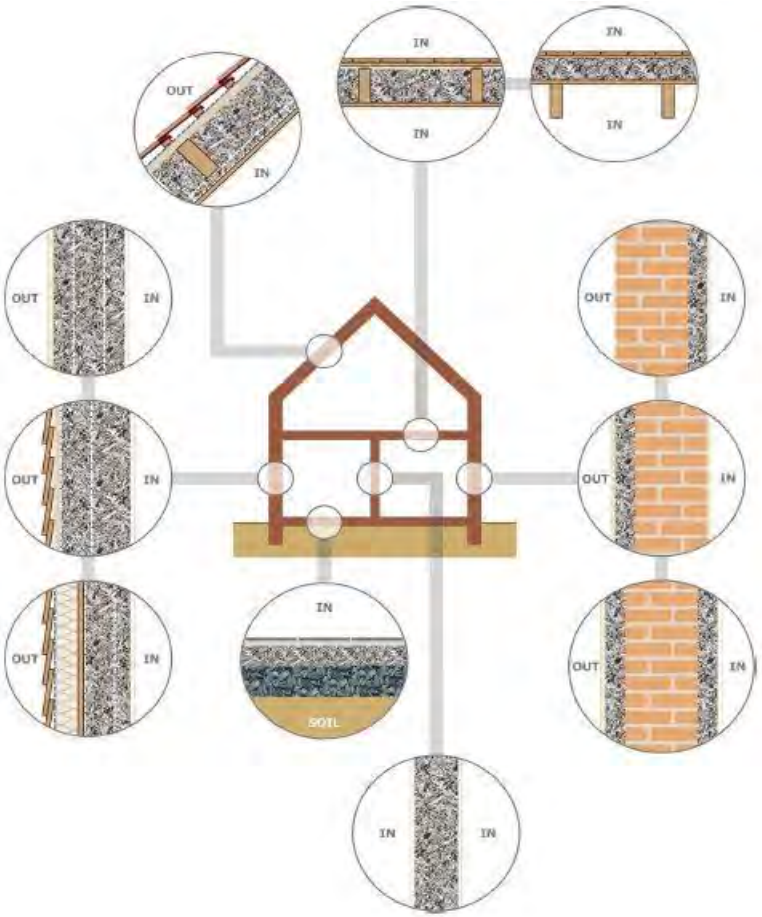
✓Mixture of hemp hurd (woody stem of the hemp plant), lime based binder and water

✓3 forms of production: Cast in situ (moulding), spraying and precast

✓Applicable to roof, wall, floor (low to high density), render, plaster

✓Permissible under Section 9 of the OBC as alternative solutions (for residential projects)

✓Essentially no industry standards



Uses of hempcrete in building
Source: Evrard, 2008

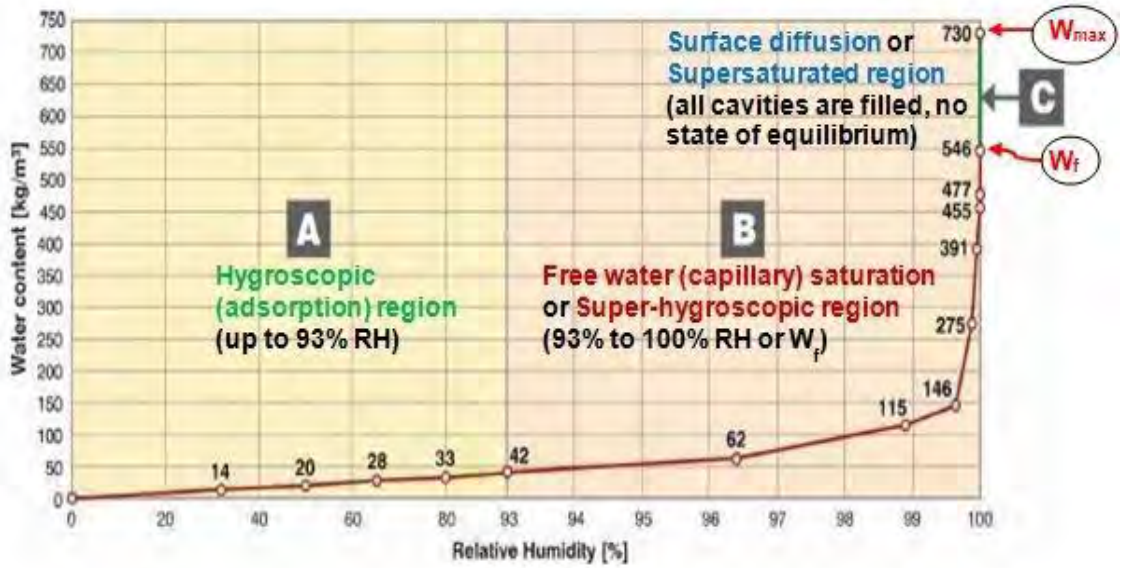
2. Properties

Properties	Normal Range	Unit	Remarks
Dry Density (ρ_0)	200 - 500	kg/m^3	Low
Porosity (Φ)	0.71 - 0.73	m^3/m^3	High
Dry Thermal (Specific Heat) Capacity (c_0)	1500 - 1600	J/kgK	High
Dry Thermal Conductivity (k_0)	0.06 - 0.12	W/mK	Low
Moisture Buffer Value (MBV)	2.11 - 2.14	$g/(m^2\ \%RH)$	Excellent (>2.0)
Thermal Diffusivity (α)	$1.48x10^{-7}$- $1.68x10^{-7}$	m^2/s	Low ("decrement delay "or "time lag)"
Thermal Effusivity (Eff)	286 - 297	$J/m^2Ks^{-1/2}$	Low (feels warm to the touch)
Dampening	98 %, 15	Time Shift	More than mineral wool
Air Tightness	1.2 - 2.0	m^3/hm^2@ 50 Pa	Inherently air tight
Acoustic absorption	0.69	NRC	Excellent
Fire Resistance	1.22 - 1.67	hr	Excellent (apprx. 1 hour / 100mm of th.)
Carbon Sequestration Index	(-)108 - (-)135	$kgCO_2e/m^3$	Lifetime net balance, negative
Compressive Strength	0.80 - 1.00	MPa	1/20th of residential grade concrete (apprx.)
Flexural Strength	0.30 - 0.40	MPa	
R value	2.0 - 2.5 per inch	Imperial	

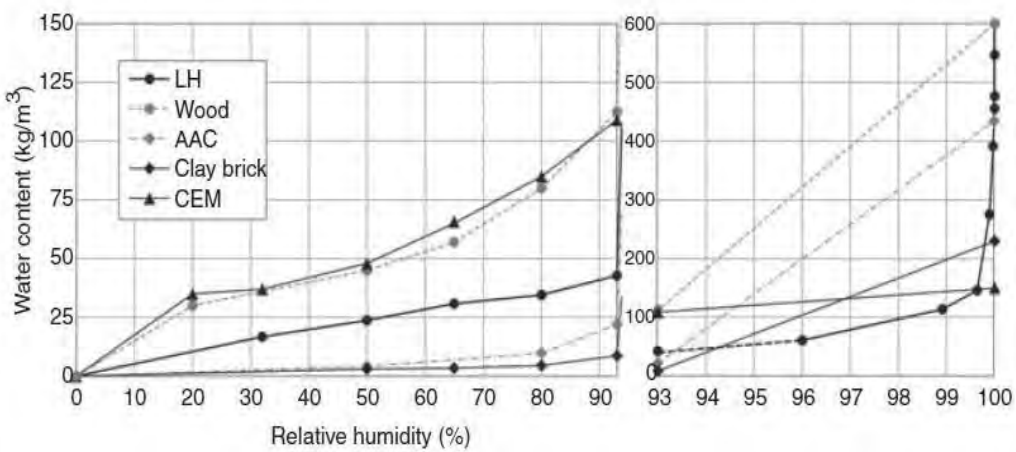
Others:

Biodegradable, fully recyclable	
No risk of "off-gassing" or toxicity	
Pest proof, rot resistant	
No mold growth	Due to lime based binder
Low thermal bridging	Similar to wood, radial
Phase changing between liquid and vapor	Passive regulation of humidity

Moisture retention (Sorption Isotherm)



Complete moisture retention curve of hempcrete
Source: Evrard, 2008



Moisture retention of hempcrete and other materials
Source: Evrard and De Herde, 2010

- ✓Moisture storage regions: 3 (A,B,C)
- ✓In the hygroscopic region sorption isotherm at 23°C is almost linear
- ✓Hempcrete, normally stays in the hygroscopic (adsorption) region i.e. about 90% RH (normal range for other materials 40-70% RH)
- ✓The value acquired for capillary region (above 93% RH) does not come from measurements for other materials

3. Objectives

✓To obtain measured values for three mixes of hempcrete (hemp to binder ratio of 1:1, 1:1.5 and 1:2)
✓To quantify the hygrothermal behavior of hempcrete walls in the context of Canada

4. Methodology

✓Literature review
✓Laboratory testing and analysis
✓One-dimensional hygrothermal (WUFI) analysis
✓Findings and conclusions

5. Materials

Lime Binder

✓Pre-formulated product "BATICHANVRE", a proprietary binder
✓Majority of air (hydrated) lime + a small portion of pozzolanic ingredients + 20-30% of Portland cement
✓Density: 712 kg/m^3

Hemp hurd

✓Plain hemp grown and processed in Manitoba, Canada
✓Particle sizes : L: 5.0mm to 25mm, W: 3mm to 6mm, T: 1.5mm to 2.5mm
✓Density: 125.42 kg/m3

Lime Binder

Hemp Hurd

Hempcrete

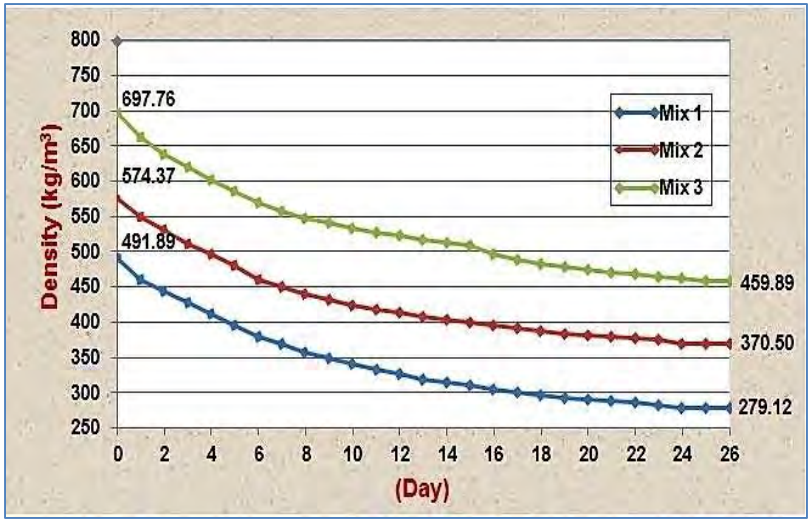
6. Test Measurements

Standards used *(no set standards are available for hempcrete):*

✓ASTM C518-10: Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus
✓ASTM C67-14: Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile
✓ASTM C62-13a: Standard Specification for Building Brick - Solid Masonry Units Made from Clay or Shale

Mix	Samples		Total (nos)
	30.5 x 30.5 x 7.6 cm (1'-0" x 1'-0" x 0'-3") (for conductivity test)	7.6 x 7.6 x 7.6 cm (0'-3" x 0'-3" x 0'-3") (for moisture related tests)	
1	3	12	15
2	3	12	15
3	3	12	15
			45

Test Samples



Natural drying

✓3 Mixes: Mix 1 (1:1), Mix 2 (1:1.5), Mix 3 (1:2)
✓Samples: 2 types, 45 nos
✓Density/mass - stabilized during natural drying at around day 26

Activities

Bell Mixer

Ball and finger test to confirm consistency

Samples in mould and aluminum foil during drying

Oven Drying @ 110^{0}C

5 hours Boiling and Cold Water Submersion

Apparatus with Two Heat Flux Transducers and One Specimen (NETZSCH-HFM 436/3/E)

Plate Temperatures		Set points		Offsets	
Hot	Cold	Mean	Delta (T)	Mean	Delta (T)
25^{0}C	15^{0}C	20^{0}C	10^{0}C	0.45^{0}C	0.86^{0}C

Conductivity Test Conditions

Test measurement values

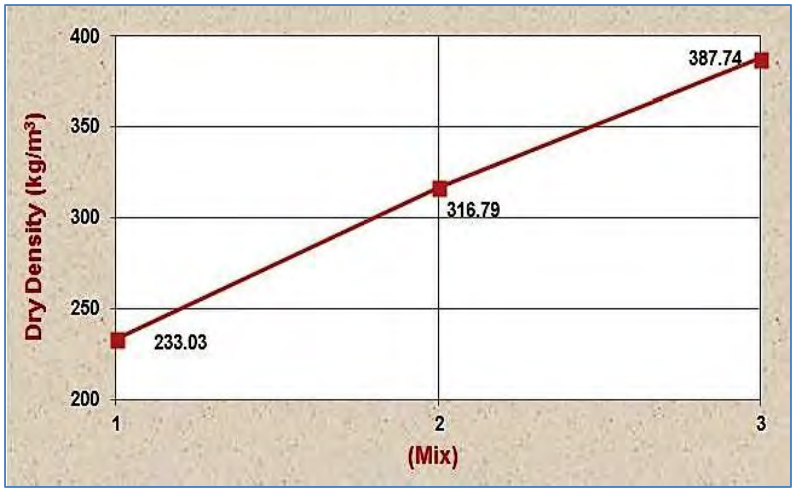
Mix	Dry Density (ρ_0) (kg/m^3)	Dry Thermal Conductivity (k_0) (W/mK)	Porosity (Φ) (m^3/m^3)	Free Water Saturation (W_f) (kg/m^3)	Maximum Water Content (W_{max}) (kg/m^3)	WC at 80% RH ($MC_{80\%\ Equiv}$) (kg/m^3)	Saturation Coefficient (-)	Typical built-in (Initial) MC (kg/m^3)
	(ASTM C67)	(ASTM C518)	(ASTM C67)	(ASTM C67)	(ASTM C67)	(ASTM C67)	(ASTM C62)	(ASTM C67)
1	233.03	0.074	0.53	376.29	532.66	17.47	0.71	259
2	316.79	0.088	0.53	374.96	525.66	23.17	0.71	257
3	387.74	0.103	0.66	423.55	655.31	29.08	0.65	286
*σ	77.44	0.015	0.075	27.68	72.92	5.81	0.035	16.2

σ = Standard Deviation

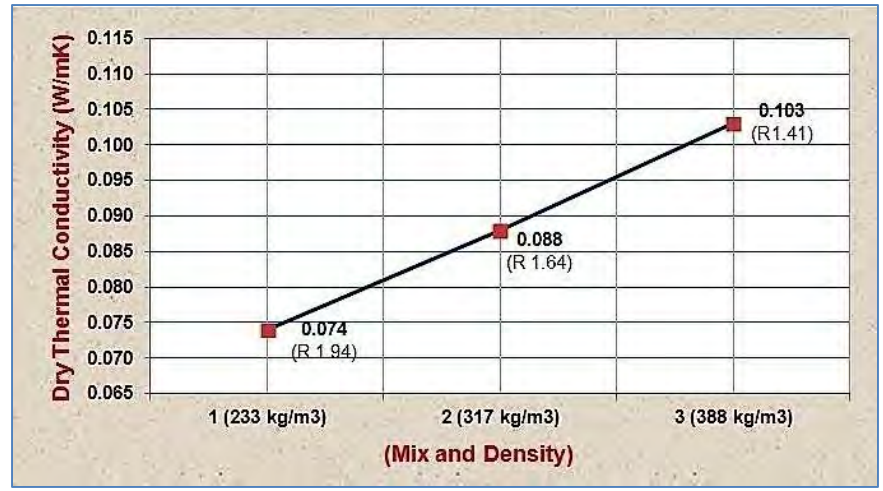
✓Dry densities and thermal conductivities were within the published reference values

✓Moisture related prosperities [W_f, W_{max}, $WC_{80\%\ Equiv}$, porosity (Φ) and saturation coefficient] were slightly less than reference values (however, the mass differences in % were essentially the same to references)

Analysis



Dry Density



Dry Thermal Conductivity

✓Dry density was linearly related to the proportion of binder (when binder was increased by 50% and 100%, densities increased by 36% and 67%)

✓Similarly, dry thermal conductivity maintained a near linear relationship with density (when densities increased by 36% and 67%, thermal conductivities increased by 18% and 38%)

Visual image of samples in dry state

7. One - dimensional hygrothermal (WUFI) analysis

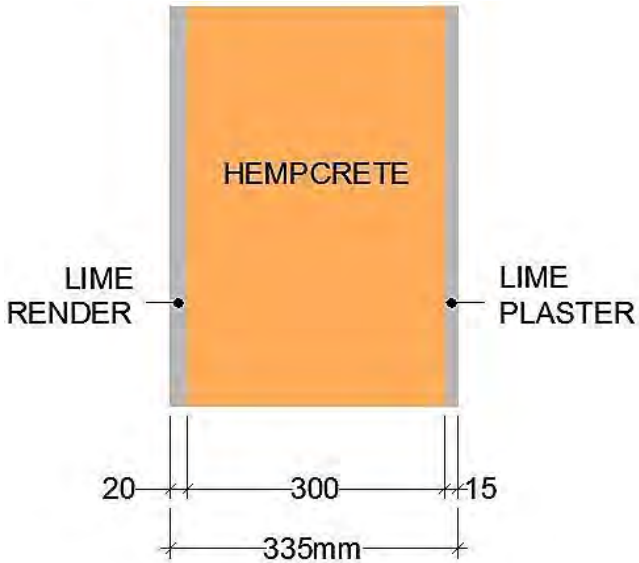
Material Inputs

✓Measured from the laboratory tests supplemented with reliable published (reference) values

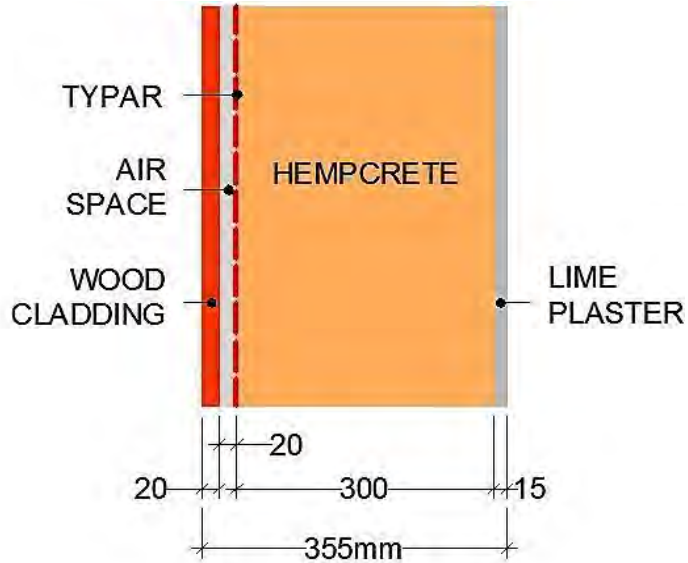
✓Hempcrete was inserted into the WUFI material database as a user-defined material

States	Hygrothermal Parameters (Mix 3)	Values	Source(s)	Standards
Dry	Dry Density (ρ_0)	388 kg/m^3	Test	ASTM C67
	Porosity (Φ)	0.66 m^3/m^3	Test	ASTM C67
	Dry Thermal Capacity (c_0)	1560 J/kgK	Reference	-
	Dry Thermal Conductivity (k_0)	0.1 W/mK	Test	ASTM C518
	Dry Vapor Diffusion Resistance Factor (μ_0)	4.85	Reference	-
Moist	Thermal Conductivity Supplement (b)	3.34 %/%mass	Reference	-
	Maximum WC (W_{max})	655 kg/m^3	Test	ASTM C67
	Free Water Saturation (W_f)	424 kg/m^3	Test	ASTM C67
	WC at 80% RH ($MC_{80\%\ Equiv}$)	29 kg/m^3 (7.5% mass)	Test/reference	ASTM C67
	Liquid Absorption Coefficient(A Value)	0.074 kg/m^2/s$^{1/2}$	Reference	-
	Typical Built-In (Initial) MC	286 kg/m^3	Test	ASTM C67

✓Two types of wall assemblies with and without exposure of rain, wind and sun (i.e. mass wall and vented rain screen wall) for mix 3 were simulated



Wall Assembly 1

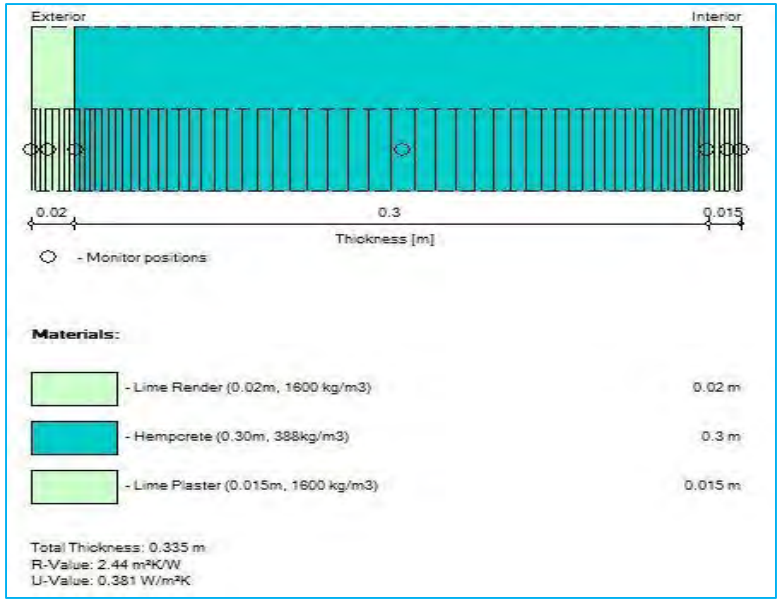


Wall Assembly 2

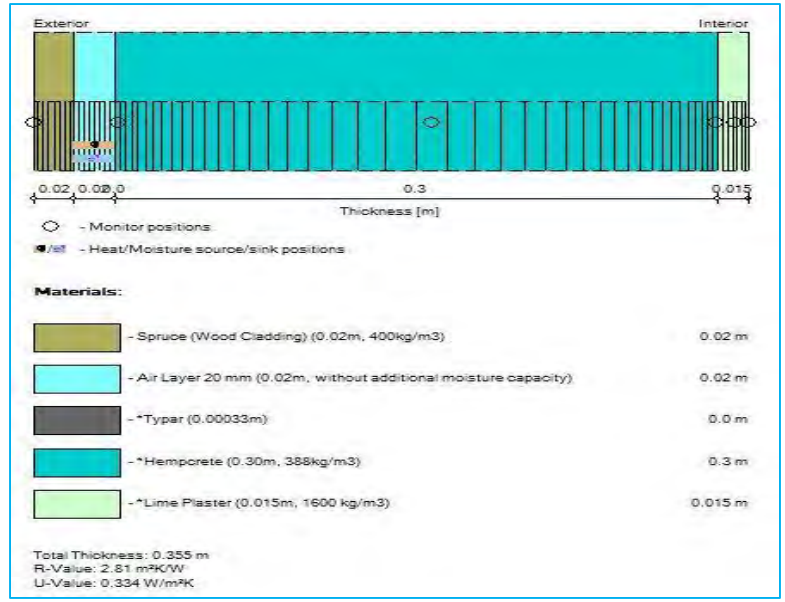
Simulation Variables

✓Default exterior WUFI climate file for Toronto, cold year
✓User defined sine curve to define the inside temperature and RH (21±1^{0}C,50±10%)
✓Southeast orientation to maximize the combination of sun exposure and rain wetting
✓ACH- 8 (constant)for 20mm air layer (vented) as air change source (Assembly 2)
✓Simulation period: 3 years (10-1-2015 to 10-1-2018)

✓*A series of (four) sensitivity analyses were also conducted by using referenced material properties (moisture sorption and thermal conductivity) for wall assembly 1 (Base Case)*



Wall Assembly 1 (Mass Wall)



Wall Assembly 2 (Rain Screen System)

Assumptions made to simplify the model :

✓Samples - isotropic, homogenous and without volumetric variations (swelling and shrinkage neglected)

✓No any chemical reactions between water, in all the 3 phases

✓No energy dissipation during flows

✓No parameter has time dependency

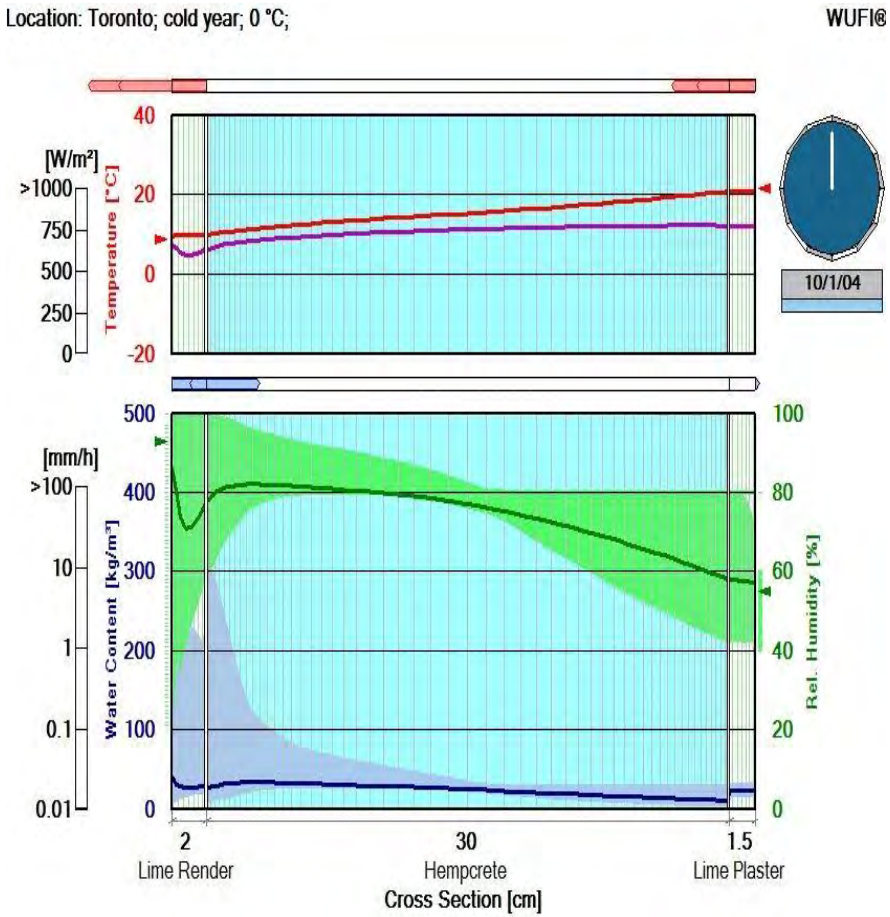
✓No hysteresis (univalent relationship between water content and relative humidity)

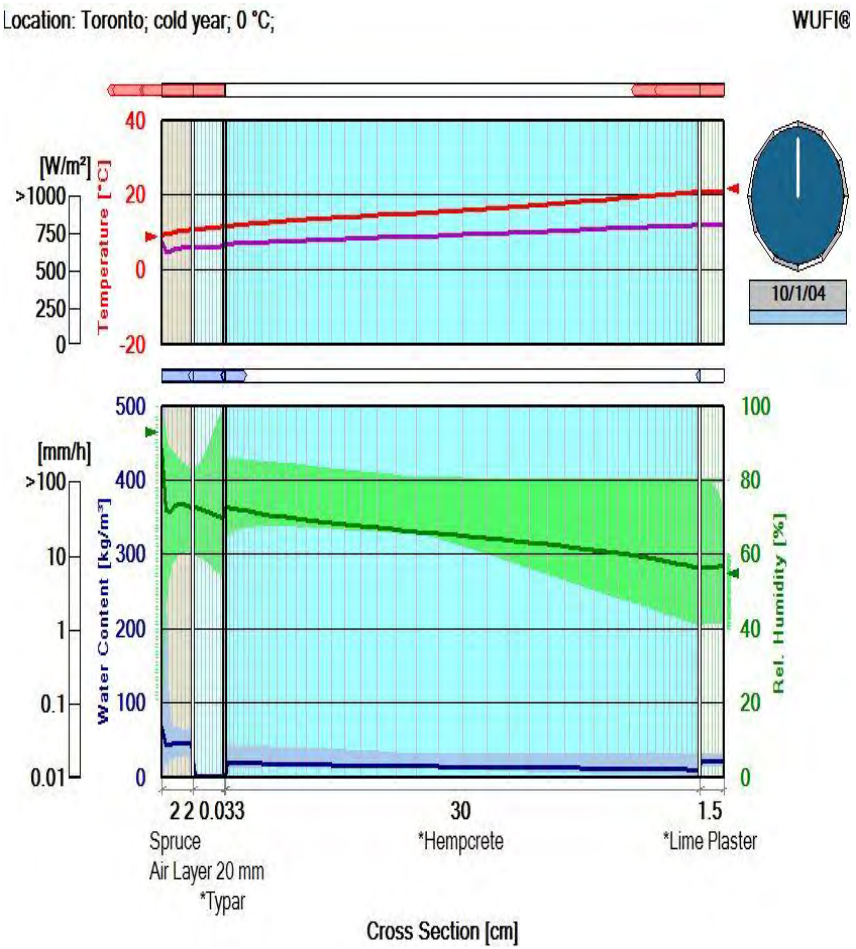
✓No air infiltration (user defined air-related moisture)

✓No relevancy of temperature in moisture sorption

✓No natural or forced convection and no stack effect

Films



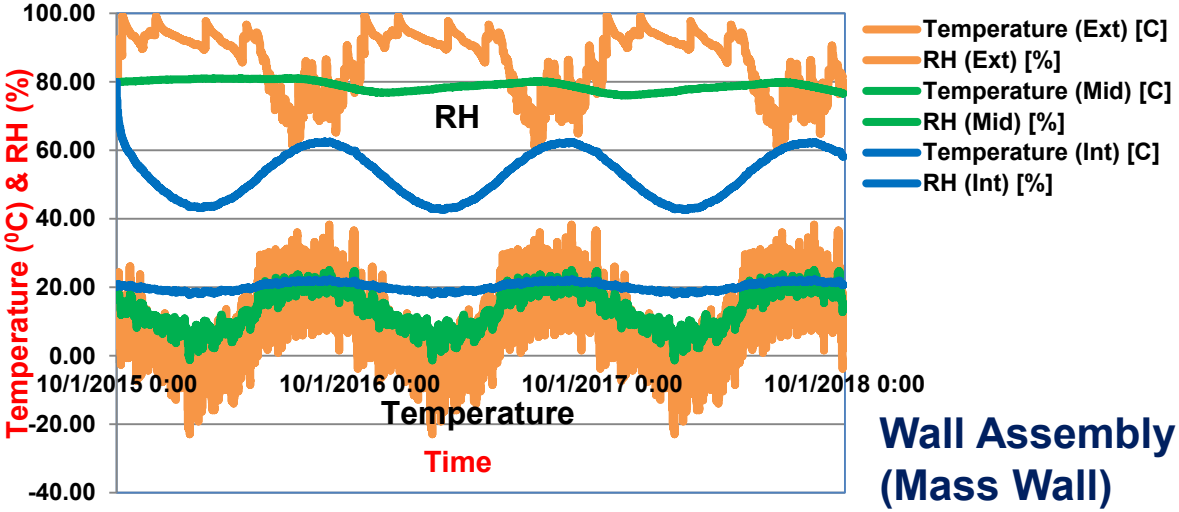


Wall Assembly 1 (Mass Wall)

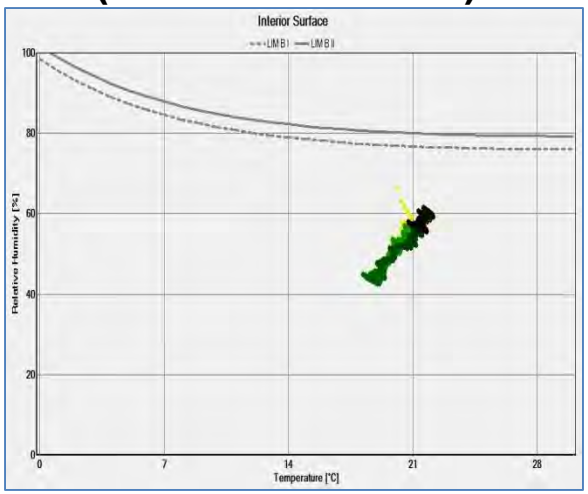
Wall Assembly 2 (Rain Screen System)

Analysis

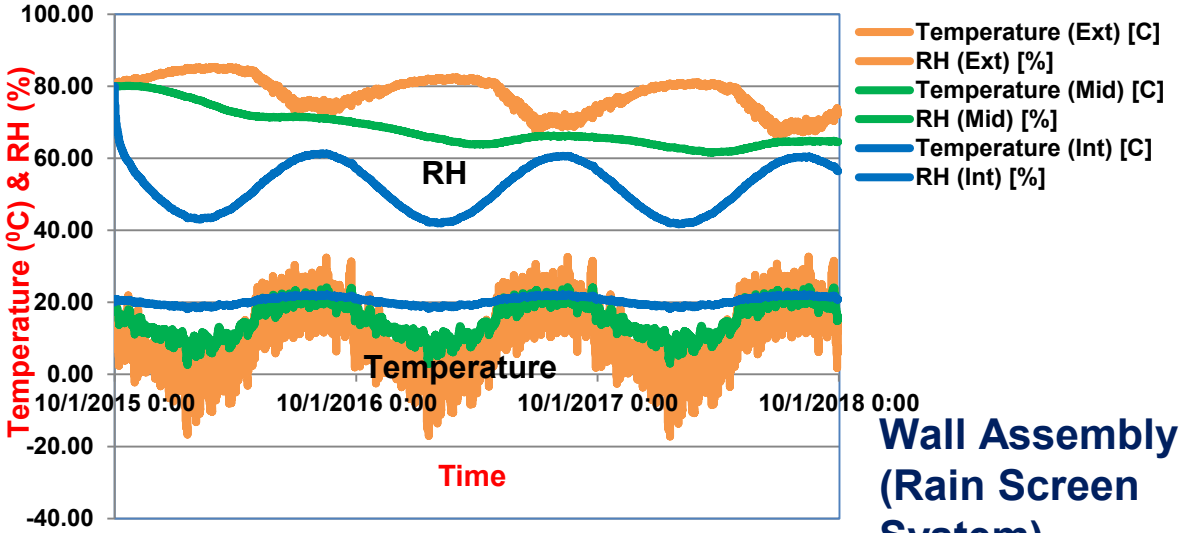
Temperature & RH: Hempcrete Section

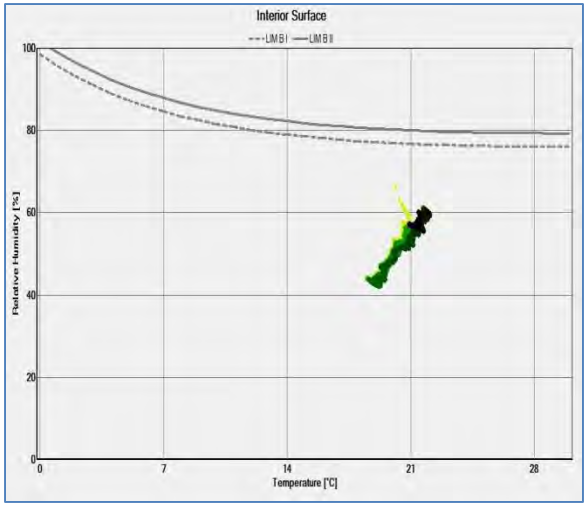


Mold Isopleths Distribution (Interior Surface)



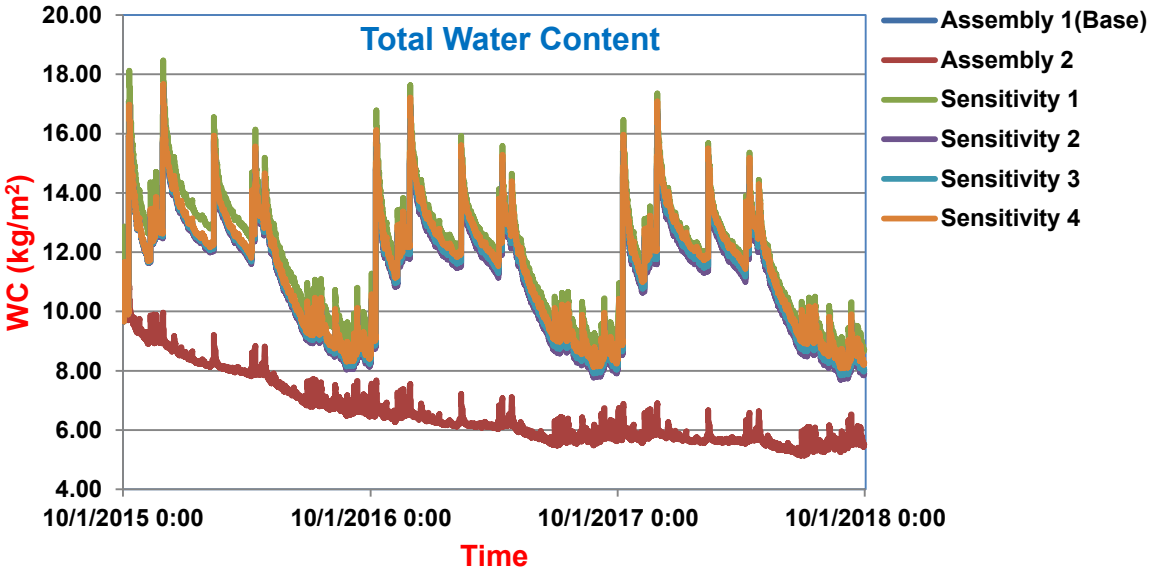
Wall Assembly 1 (Mass Wall)



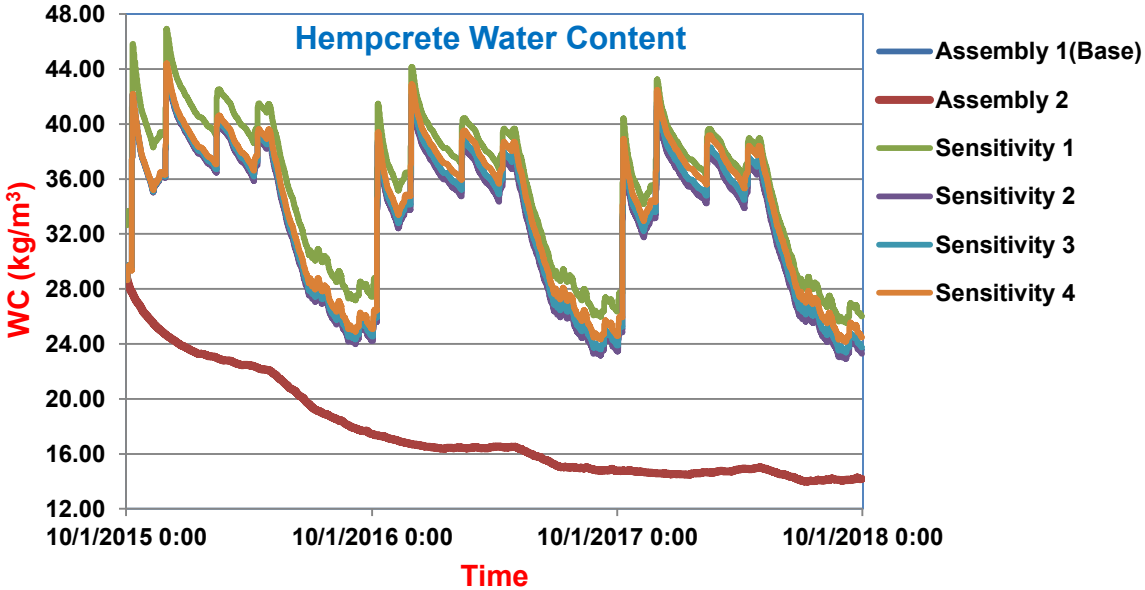


Wall Assembly 2 (Rain Screen System)

Water Content (WC)



✓Both the wall assemblies (face-sealed mass wall and vented rain screen system) are performing well without any hygrothermal risks (no evidence of water accumulation, no dew points, no high T & RH at same time, and isopleths distribution below dotted graph)



✓Vented rain screen system (Assembly 2) is performing significantly better from a hygrothermal perspective

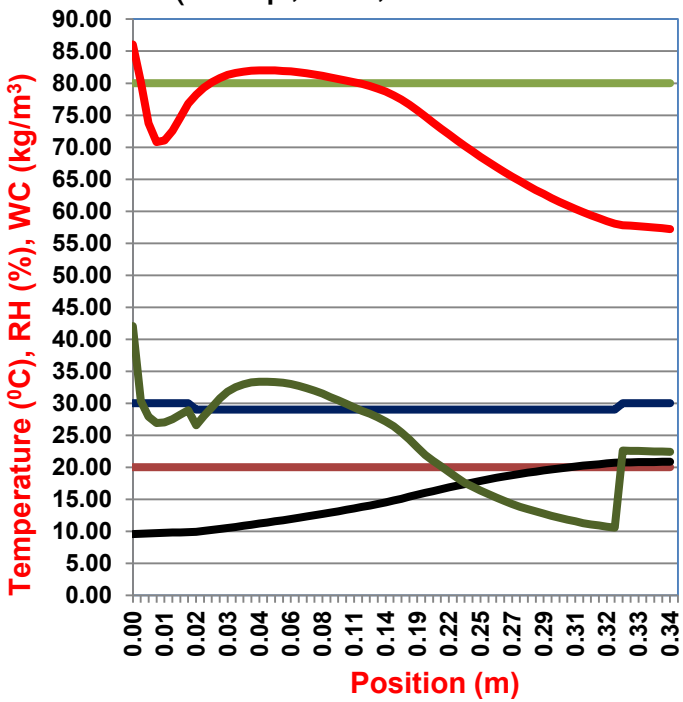
✓No significant changes in hygrothermal characteristics were also detected through the sensitivity analysis

Water content of hempcrete

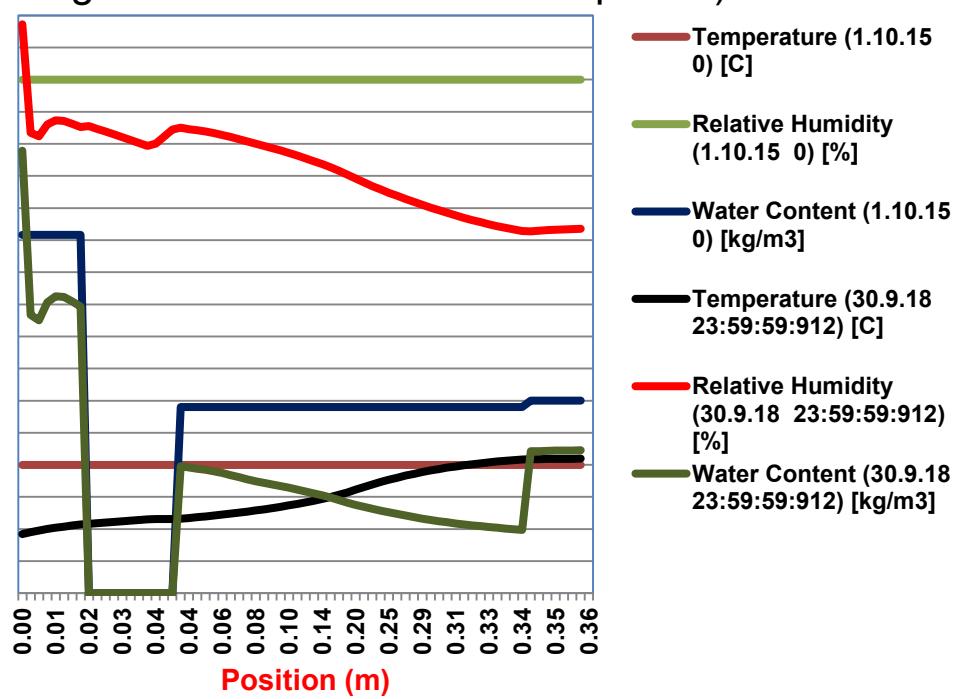
Descript-ions	WC	Assemblies (Base)		Sensitivity Analysis (Assembly 1)			
		Assembly 1	Assembly 2	Sensitivity 1	Sensitivity 2	Sensitivity 3	Sensitivity 4
Hempcrete	kg/m³	23.18- 44.07	13.98-29.00	25.54- 46.93	22.90-43.95	23.38-44.15	24.16-44.41
	% M	5.97-11.36	3.60-7.47	6.58-12.09	5.90-11.33	6.02-11.38	6.23-11.45

✓MC < 12%, Mass (< 20% dry basis, threshold for decay)

Profiles (Temp, RH, and WC: Status at starting and end of the simulation period)



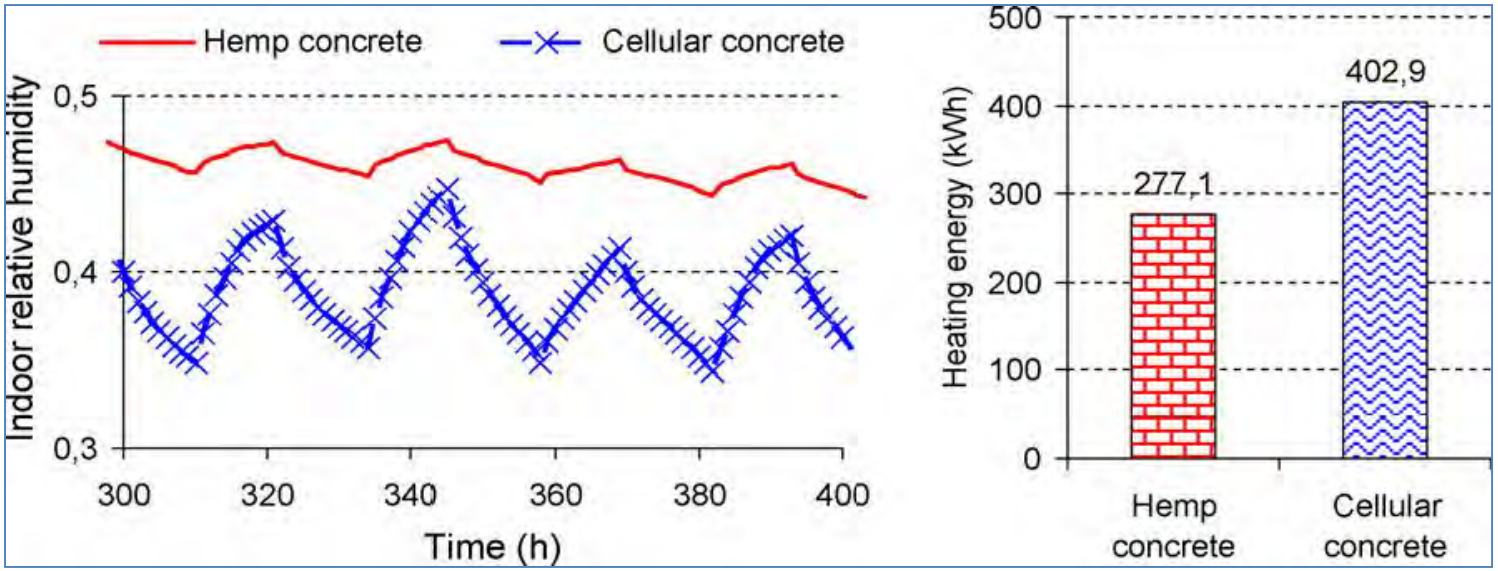
Wall Assembly 1 (Mass Wall)



Wall Assembly 2 (Rain Screen)

8. Case Studies

1. Hempcrete building compared with Cellular Concrete building (Model)



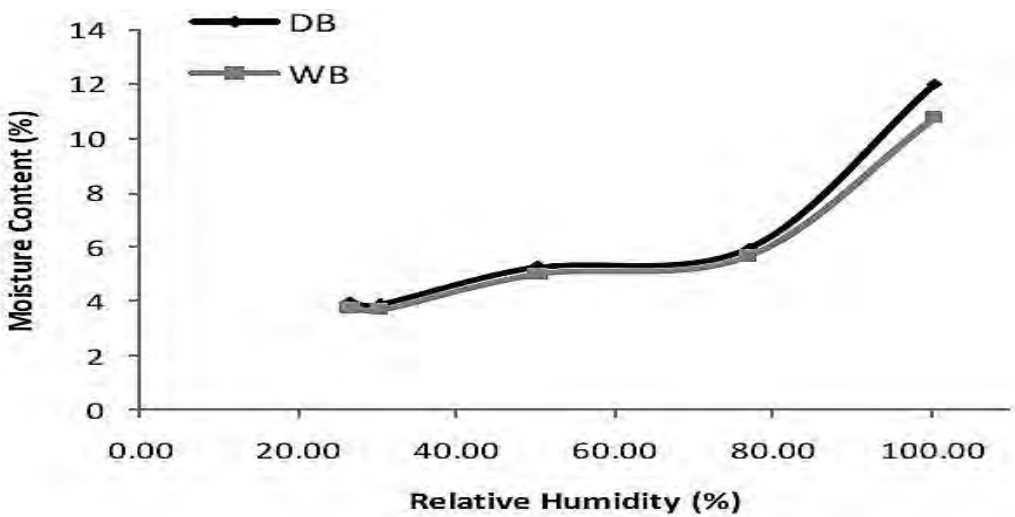
Variation of indoor relative humidity and heating energy

Source: Tran Le et al, 2010

✓Hempcrete wall building could regulate better indoor RH (42%) than cellular concrete building (35%) because of high hygroscopic capacity

✓Similarly, in energy consumption, hempcrete building leads to a reduction of 45% (125.8KWh) than cellular concrete (k=0.14W/mK) building because of low thermal conductivity (k=0.10W/mK).

2. Hempcrete building at Alternative Village, Manitoba University (Test Building)

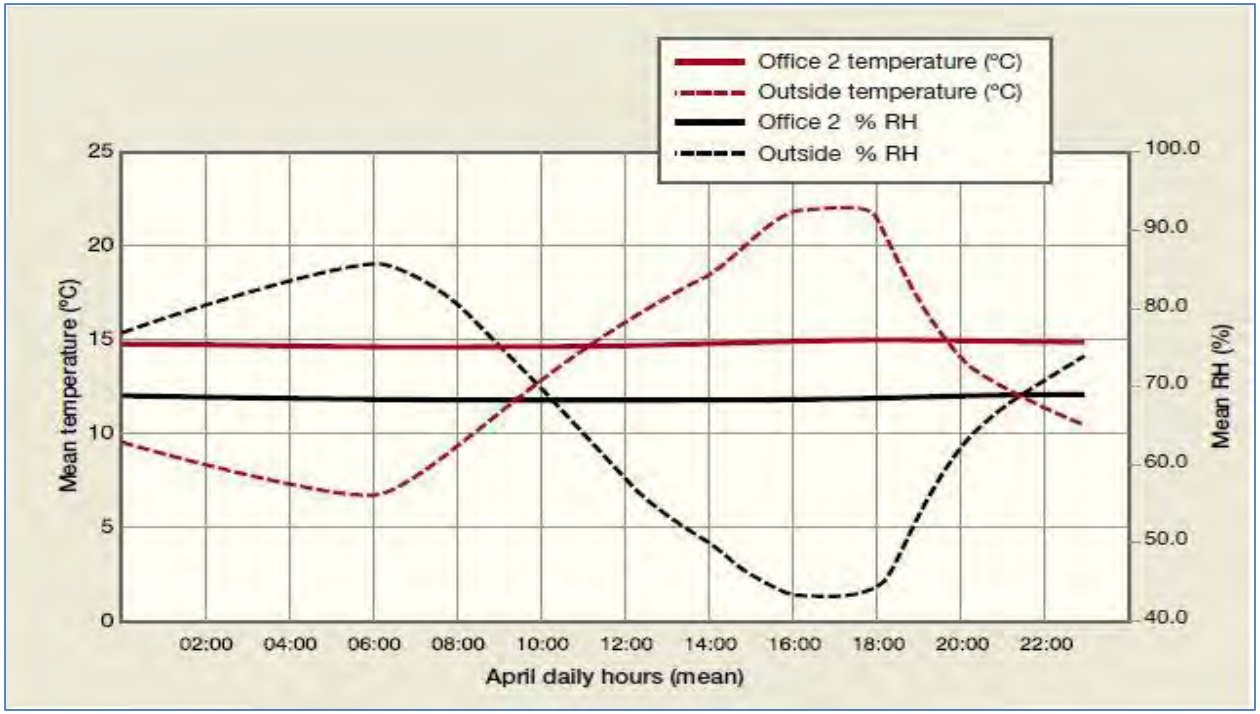


Sorption Curve, wet and dry basis

Source: Pinkos et al, 2011

- ✓MC 12% at RH 98% (MC < 20% dry basis, threshold for decay)
- ✓300mm thick wall covered with a building wrap (Typar), rain-screen gap and wood sheathing; interior was left unfinished
- ✓Power consumption 153.9 kWh, less but > R2000 building (118.8kWh)
- ✓Provided a stable temperature throughout the wall
- ✓Similarly, RH through the wall showed that the internal portion of the wall managed moisture in a consistent manner

3. Lime Technology office building, UK (Real Building)



Monitoring of the Lime Technology Ltd head office (UK) during April 2007

Source: Bevan and Woolley, 2008

- ✓500mm thick Hemcrete® walls
- ✓Exterior: Temp.,7^{0}C to 22^{0}C; RH, 42% to 88%
- ✓Interior: A very stable internal environment (15^{0}C, 68%RH)

9. Findings and Conclusions

✓The higher the binder content, the higher the density, leading to a higher thermal conductivity. This relationship follows a near linear pattern.

✓Measurements of dry density and thermal conductivity were ranged from 233 kg/m^3 to 388kg/m^3 and 0.074 W/mK to 0.103 W/mK, respectively

✓Drying period of hempcrete was noted as approximately 26 days, where minimum density was stabilized

✓In all cases, no mold growth/decay risk, no condensation risk, no heat loss risk, and no risk of damage from freeze thaw and salt effect were evidenced

✓However, from hygrothermal perspectives, the vented rain screen system could be considered as a better option for a hempcrete wall assembly in an Ontario (Canada) climate

✓Finally, no significant impacts on hygrothermal characteristic of hempcrete wall were also noticed during the sensitivity analysis due to some variations in moisture sorption and thermal conductivity, based on published reference values.

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