Supplementary data

1. Materials hygrothermal properties

In Table S1 and Table S2, it can be seen the set of parameters, and respective results, that were used to characterise the constructive solutions that were evaluated in terms of their hygrothermal behaviour through simulation.

Table S1. Thermal insulation materials' properties

Property	**TR reference**	**TR aramid**	**TR sisal**	**TR biomass**	**Ind thermal render** [1,2]	**EPS** [3,4]	**XPS** [4,5]
ρ_{hard} [kg m^{-3}]	158.7	164.5	160.3	161.6	208.7	15	40
P_0 [%]	86.3	85.1	86.9	87.0	34.7	95.0	95.0
c_p [J kg^{-1} K^{-1}]	930.1	800.0	894.5	957.3	1000	1500	1500
$\lambda_{10ºC,dry}$ [W m^{-1} K^{-1}]	0.0293	0.0315	0.0298	0.0306	0.049	0.036	0.030
μ [-]	13.7	13.3	12.7	12.4	11.7	30	100
w_{80} [kg m^{-3}]	7.8	7.1	7.2	7.5	1.3	-	-
w_f [kg m^{-3}]	281.0	246.0	260.2	274.8	346.5	-	-
A_w [kg m^{-2} s$^{-1/2}$]	0.1090	0.0286	0.0325	0.0310	0.0296	-	-
λ_w [W m^{-1} K^{-1}]	see Figure 4 of the paper				see [1]	Generated WUFI	Generated WUFI
D_{ws} [m^2 s^{-1}]	see Figure 6 of the paper						

Note: ρ_{hard} – bulk density hardened state [kg m-3]; P_0 – open porosity by MIP [%]; c_p – specific heat capacity [J kg^{-1} K^{-1}]; $\lambda_{10ºC,dry}$ – thermal conductivity at 10 ºC and in dry-state [W m^{-1} K^{-1}]; μ – water vapour resistance factor [-]; w_{80} – moisture content at 80%RH [kg m^{-3}]; w_f – free water saturation [kg m^{-3}]; A_w – capillary water absorption coefficient [kg m^{-2} s$^{-1/2}$]; λ_w – thermal conductivity as a function of different moisture contents [W m^{-1} K^{-1}]; D_{ws} – moisture diffusivity for suction [m^2 s^{-1}].

Table S2. Properties of other materials used in the simulations

Property	**Finishing coat** [2,6,7]	**Basecoat** [2,6,8]	**Lwt concrete block** [9–11]	**Fired clay hollow brick** [9–11]	**Cement/sand mortar** [9–12]	**Gypsum board** [5]	**Interior plaster** [5]
ρ_{hard} [kg m^{-3}]	1750^a	1250^a	700^a	654	1800	730	850
P_0 [%]	20	25	70	40	32	72	65
c_p [J kg^{-1} K^{-1}]	1000	1000	850	1000	890	1384	850
$\lambda_{10ºC,dry}$ [W m^{-1} K^{-1}]	0.8200^a	0.4500^a	0.2115^a	0.3800^a	1.0000	0.1925	0.2000
μ [-]	300	12	16	17.5	20	6.8	8.3
w_{80} [kg m^{-3}]	^{b}	-	15	15	50	8.3	6.3
w_f [kg m^{-3}]	^{b}	-	500	80	283	353	400
A_w [kg m^{-2} s$^{-1/2}$]	^{b}	< 0.026^a	-	0.142	0.300	0.130	-
λ_w [W m^{-1} K^{-1}]	^{b}	-	Generated WUFI				
D_{ws} [m^2 s^{-1}]	^{b}	-					

Note: ^{a} – manufacturer data; ^{b} – assumed that the exterior coating had no hygroscopic behaviour [13,14]; ρ_{hard} – bulk density hardened state [kg m-3]; P_0 – open porosity by MIP [%]; c_p – specific heat capacity [J kg^{-1} K^{-1}]; $\lambda_{10ºC,dry}$ – thermal conductivity at 10 ºC and in dry-state [W m^{-1} K^{-1}]; μ – water vapour resistance factor [-]; w_{80} – moisture content at 80%RH [kg m^{-3}]; w_f – free water saturation [kg m^{-3}]; A_w – capillary water absorption coefficient [kg m^{-2} s$^{-1/2}$]; λ_w – thermal conductivity as a function of different moisture contents [W m^{-1} K^{-1}]; D_{ws} – moisture diffusivity for suction [m^2 s^{-1}].

2. Wall assemblies

The constitution of the wall assemblies for new construction located in Lisbon (NW) can be seen in Table S3. As for the new construction located in Zurich (ZNW), their constitution can be seen in Table S4.

Table S3. New wall solutions for Lisbon (NW)

Case	Layer 1 – exterior	Layer 2	Layer 3	Layer 4	Layer 5	U-value [W m^{-2} ºC^{-1}]
NW1	Finishing coat + Basecoat (0.0055 m)	TR reference (0.025 m)	Lwt concrete block (0.25 m)	Interior plaster (0.02 m)	-	0.473
NW2		TR aramid (0.025 m)				0.475
NW3		TR sisal (0.025 m)				0.468
NW4		TR biomass (0.025 m)				0.476
NW5		Ind thermal render (0.040 m)				0.484
NW6		EPS (0.030 m)	Basecoat (0.003 m)	Lwt concrete block (0.25 m)	Interior plaster (0.02 m)	0.477
NW7		XPS (0.025 m)				0.451

Table S4. New wall solutions for Zurich (ZNW)

Case	Layer 1 – exterior	Layer 2	Layer 3	Layer 4	Layer 5	U-value [W m^{-2} ºC^{-1}]
ZNW1	Finishing coat + Basecoat (0.0055 m)	TR reference (0.06 m)	Lwt concrete block (0.38 m)	Interior plaster (0.02 m)	-	0.239
ZNW2		TR aramid (0.06 m)				0.240
ZNW3		TR sisal (0.06 m)				0.236
ZNW4		TR biomass (0.06 m)				0.240
ZNW5		Ind thermal render (0.08 m)				0.263
ZNW6		EPS (0.07 m)	Basecoat (0.003 m)	Lwt concrete block (0.38 m)	Interior plaster (0.02 m)	0.244
ZNW7		XPS (0.05 m)				0.244

For the retrofit scenarios, both located in Lisbon, their constitution is presented in Table S5 – when the thermal insulating material is placed on the external surface of an exterior wall – and in Table S6 – when the thermal insulating material is placed on the interior surface of an exterior wall.

Table S5. Retrofit solutions applied on the wall's external surface (RE)

Case	Layer 1 – exterior	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	U-value [W m^{-2} ºC^{-1}]
RE1	Painted mortar (0.02 m)	Fired clay hollow brick (0.11 m)	Air layer (0.03 m)	Fired clay hollow brick (0.11 m)	Interior plaster (0.02 m)	-	-	1.076
RE2	Finishing coat + Basecoat (0.0055 m)	TR reference (0.04 m)	Mortar (0.02 m)		Air layer (0.03 m)	Fired clay hollow brick (0.11 m)	Interior plaster (0.02 m)	0.474
RE3		TR aramid (0.04 m)						0.477
RE4		TR sisal (0.04 m)						0.465
RE5		TR biomass (0.04 m)						0.478
RE6		Ind thermal render (0.065 m)						0.488
RE7		EPS (0.045 m)	Basecoat + Mortar (0.003 + 0.02 m)					0.498
RE8		XPS (0.04 m)						0.441

Table S6. Retrofit solutions applied on the wall's internal surface (RI)

Case	Layer 1 – exterior	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	U-value [W m^{-2} ºC^{-1}]
RI1	Painted mortar (0.02 m)	Fired clay hollow brick (0.11 m)	Air layer (0.03 m)	Fired clay hollow brick (0.11 m)	Interior plaster (0.02 m)	-	-	1.076
RI2						TR reference (0.035 m)	Gypsum board (0.0125 m)	0.496
RI3						TR aramid (0.035 m)		0.499
RI4						TR sisal (0.035 m)		0.488
RI5						TR biomass (0.035 m)		0.500
RI6						Ind thermal render (0.060 m)		0.496
RI7						EPS (0.040 m)		0.500
RI8						XPS (0.035 m)		0.431

3. Graphical results of the hygrothermal simulations

The next Figures graphically show the hygrothermal simulation results that were presented in the paper. This presentation is expected to help the reader to better understand the differences that were identified between the different adopted constructive solutions, as well as the impact that different climates have on the hygrothermal performance of the materials.

To further help to identify the different simulation scenarios, it is shown in Figure S1 how they were organized.

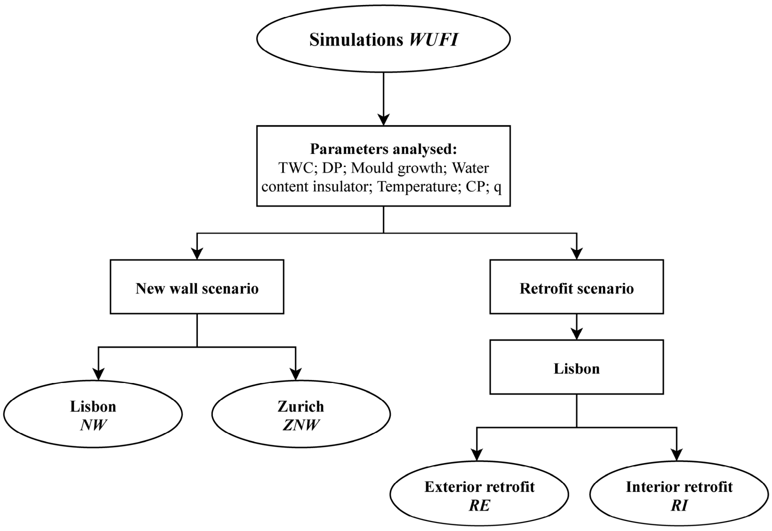


Figure S1. Flowchart of the conducted hygrothermal simulations

3.1 New wall scenario (NW and ZNW)

The following Figures (Figure S2 to Figure S8) represent the most significant results that were obtained for the new wall scenario, for both Lisbon (NW) and Zurich (ZNW) and how they compare.

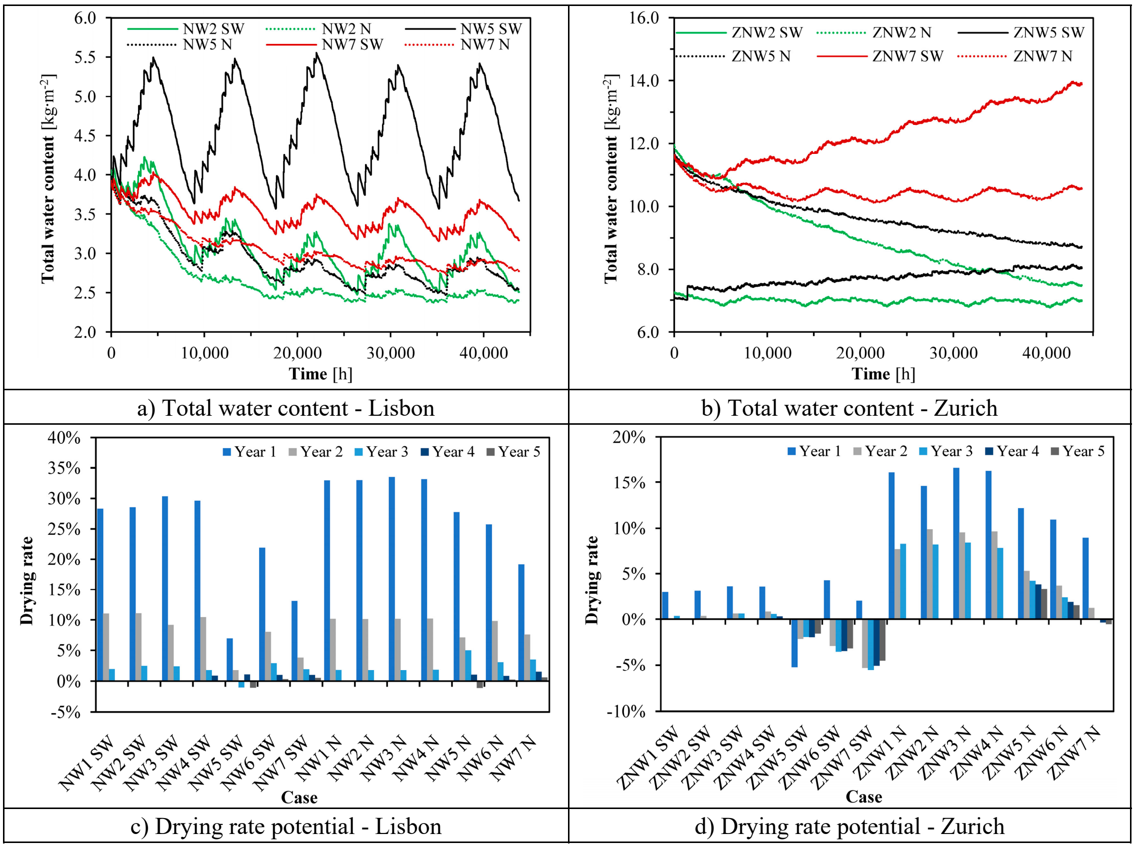


Figure S2. Total water content and drying rates for Lisbon (NW) and Zurich (ZNW)

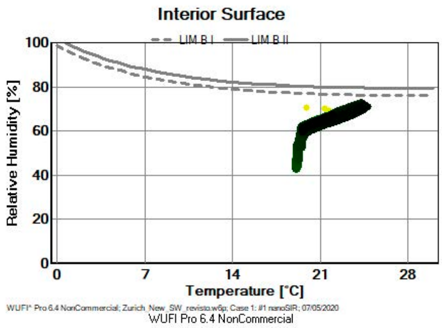
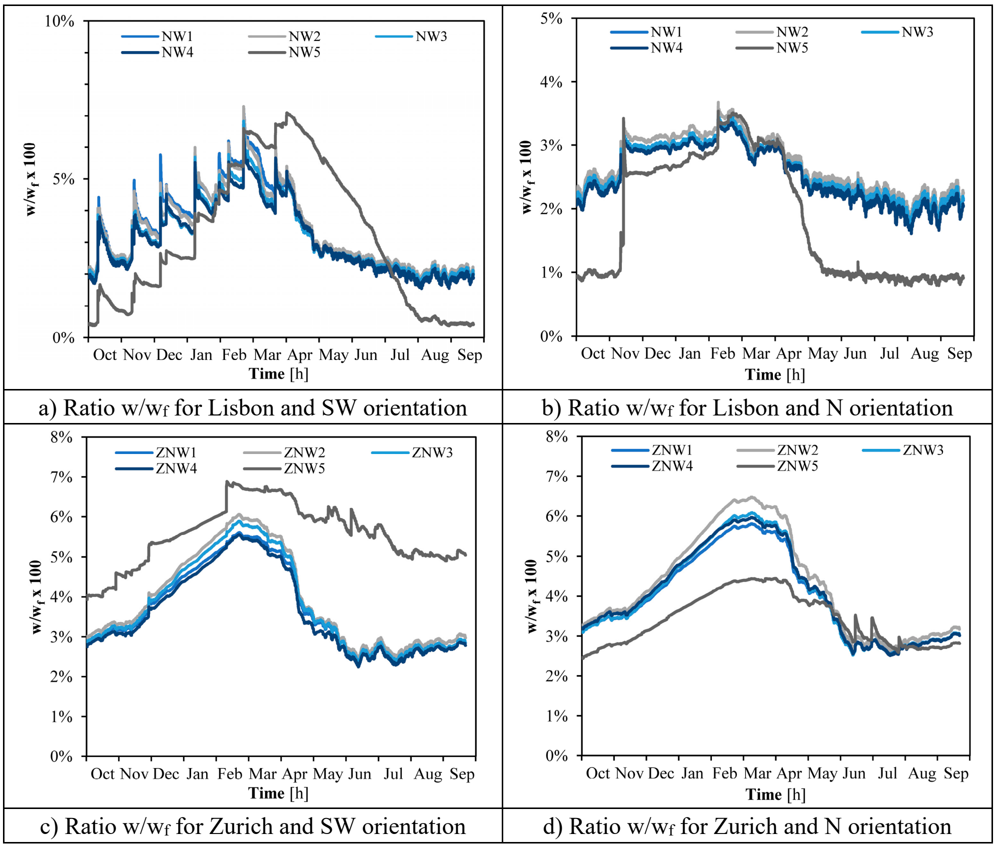


Figure S3. Isopleth example for the ZNW1 solution



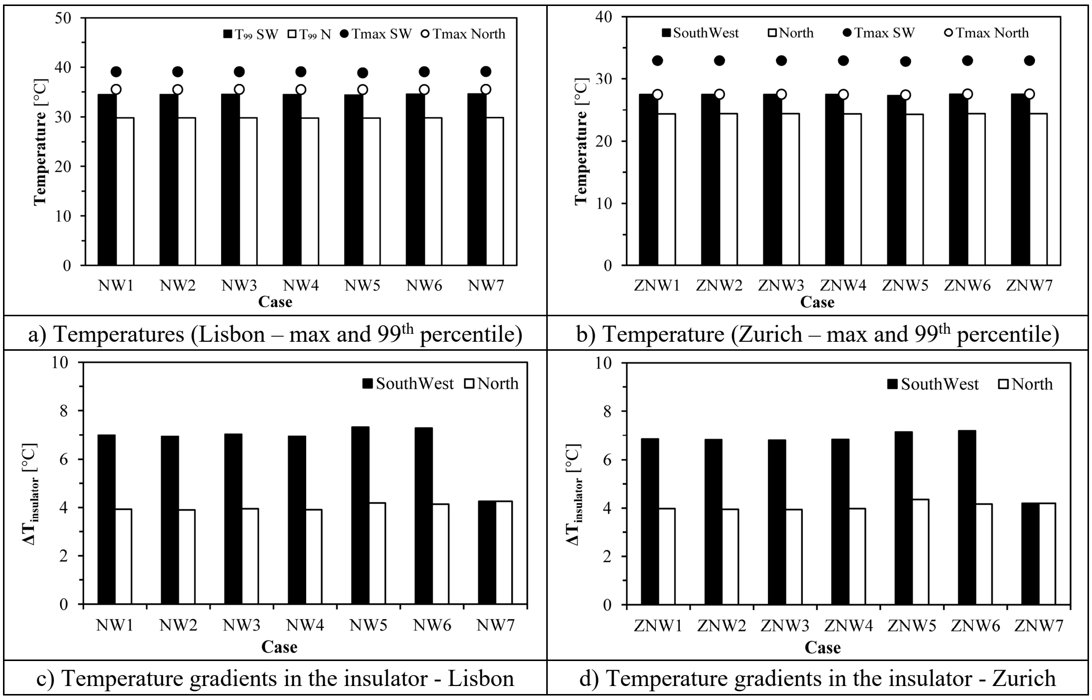
a) Ratio w/w_f for Lisbon and SW orientation

b) Ratio w/w_f for Lisbon and N orientation

c) Ratio w/w_f for Zurich and SW orientation

d) Ratio w/w_f for Zurich and N orientation

Figure S4. Ratio of water content to w_f for the renders



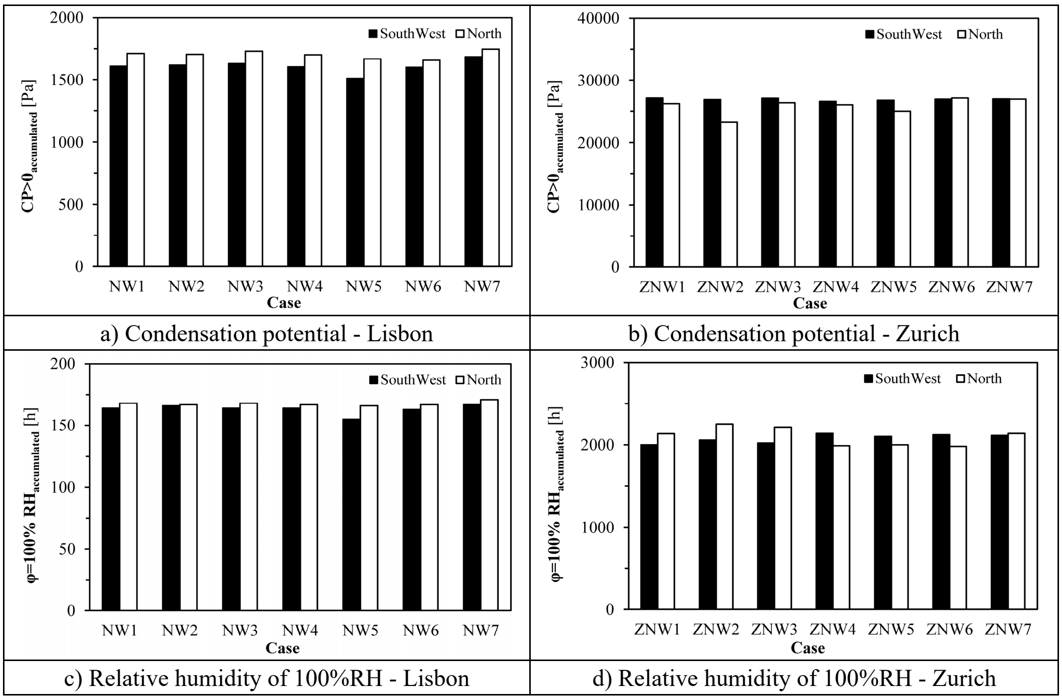
a) Temperatures (Lisbon – max and 99th percentile)

b) Temperature (Zurich – max and 99th percentile)

c) Temperature gradients in the insulator - Lisbon

d) Temperature gradients in the insulator - Zurich

Figure S5. Temperatures verified for the different solutions



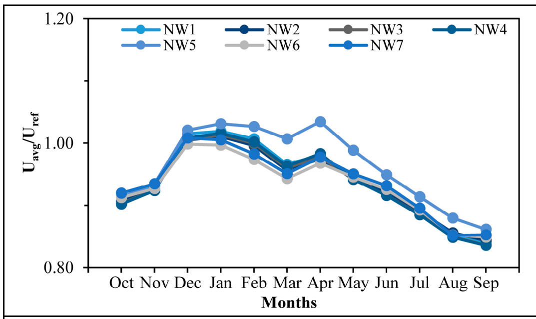
a) Condensation potential - Lisbon

b) Condensation potential - Zurich

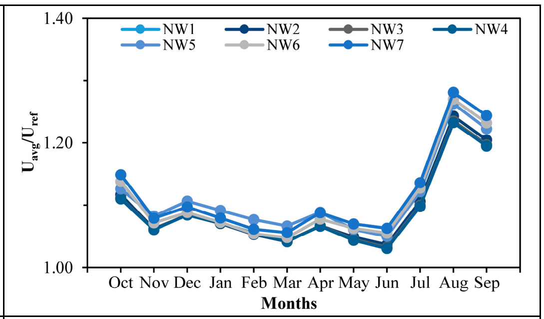
c) Relative humidity of 100%RH - Lisbon

d) Relative humidity of 100%RH - Zurich

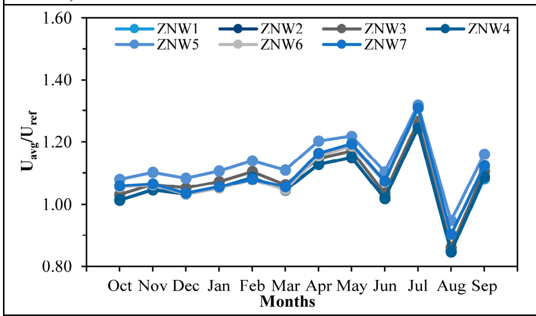
Figure S6. Superficial condensation potential



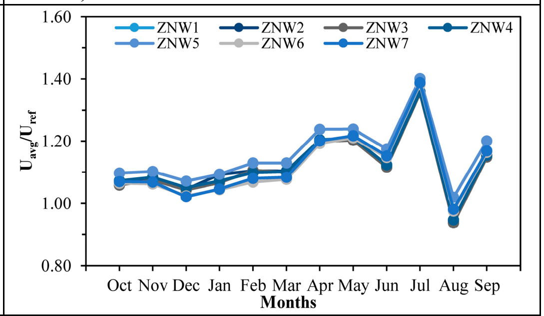
a) Thermal transmittance ratio – Lisbon SW



b) Thermal transmittance ratio – Lisbon N

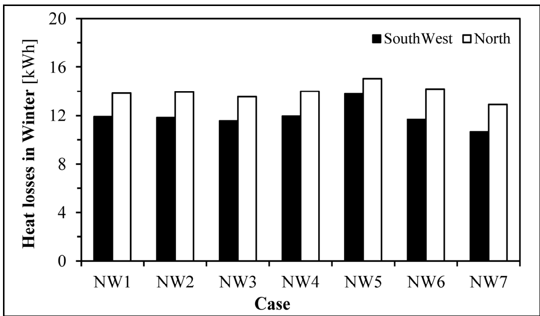


c) Thermal transmittance ratio – Zurich SW

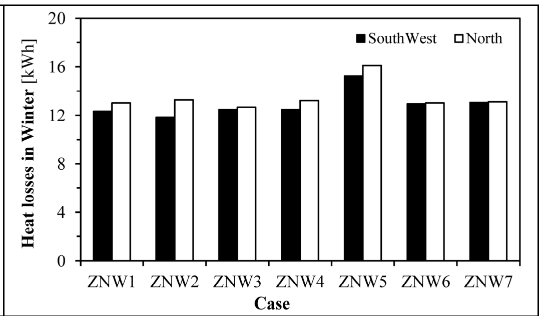


d) Thermal transmittance ratio – Zurich N

Figure S7. Thermal insulation losses over the reference performance during the year



a) Walls' heat loss during Winter - Lisbon

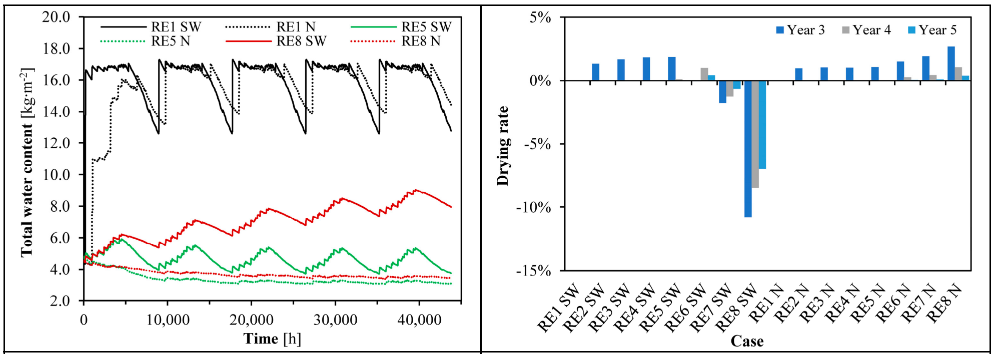


b) Walls' heat loss during Winter - Zurich

Figure S8. Heat loss during Winter per square meter of wall

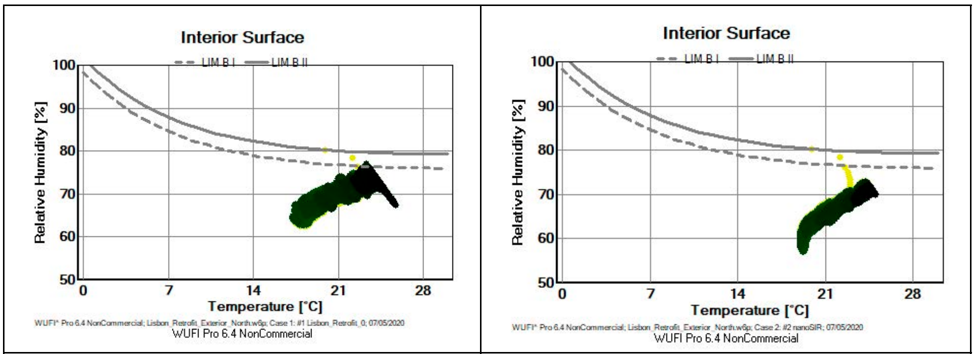
3.2 Exterior retrofit of the thermal insulation (RE)

The following Figures (Figure S9 to Figure S15) represent the most significant results that were obtained for the exterior retrofit scenario, located in Lisbon (RE).



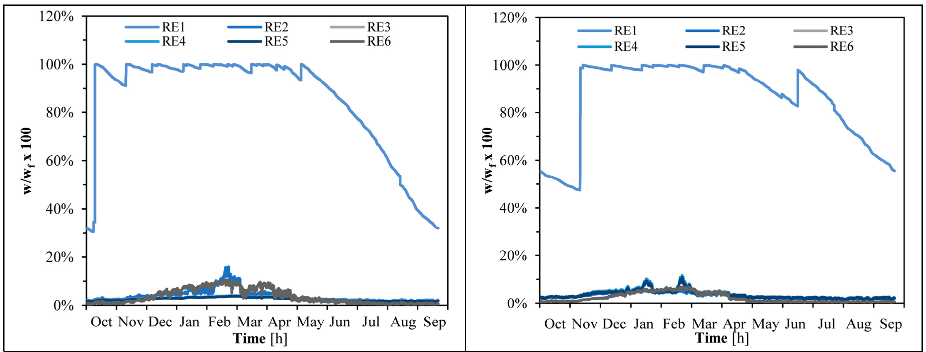
a) Total water content over time | b) Drying rate potential

Figure S9. Total water content and drying rates of the solutions (RE scenario)



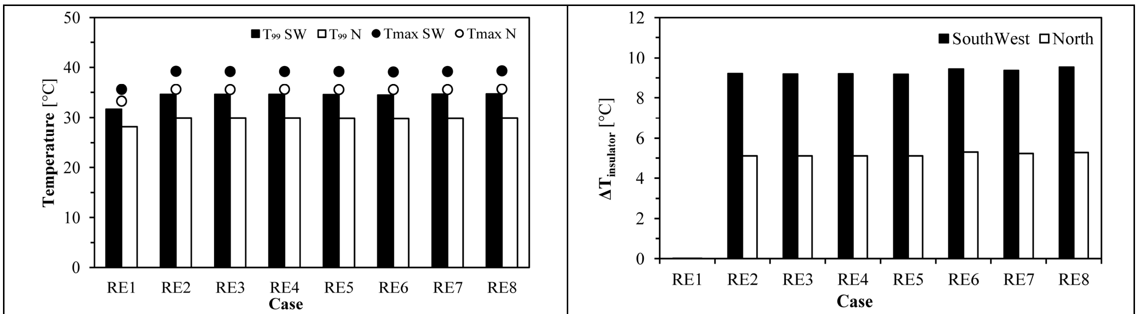
a) Isopleths for the RE1 solution | b) Isopleths for the RE3 solution

Figure S10. Mould growth potential



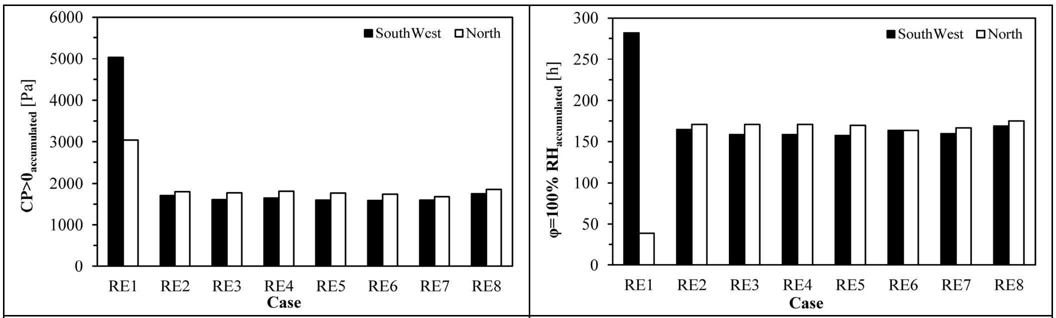
a) Ratio w/wf for the SW orientation | b) Ratio w/wf for the N orientation

Figure S11. Ratio of water content to wf for the renders



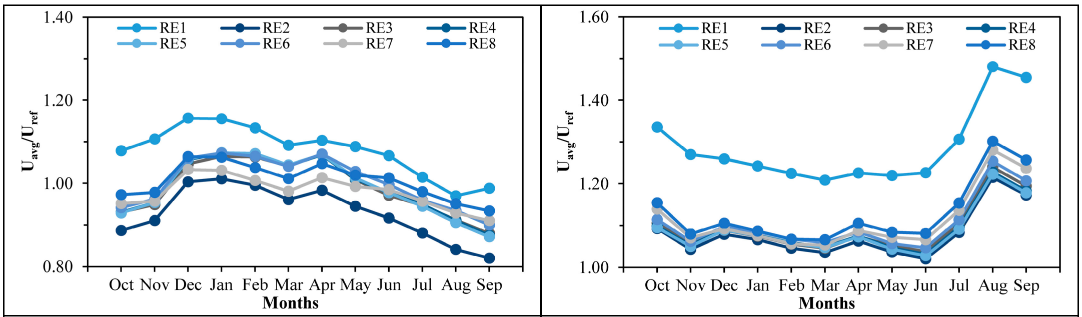
a) Temperatures exterior and superficial, 99th percentile | b) Temperature gradient on the insulator, 99th percentile

Figure S12. Temperatures verified in the simulation



a) Condensation potential on the exterior surface | b) Surf. air relative humidity equal to 100%RH

Figure S13. Conditions for formation of superficial condensation



a) Thermal transmittance ratio – SW | b) Thermal transmittance ratio – N

Figure S14. Thermal insulation loss over the year

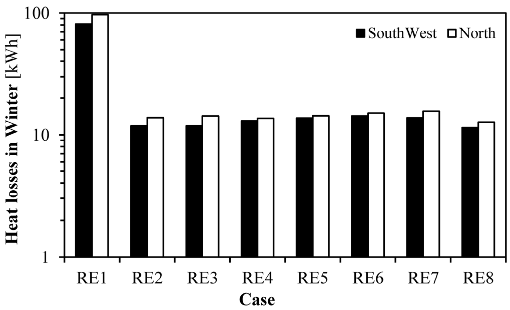
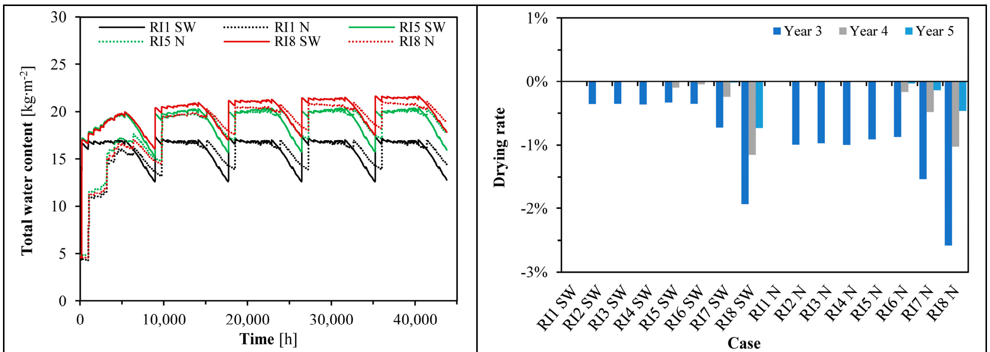


Figure S15. Heat loss during Winter, per square meter of wall

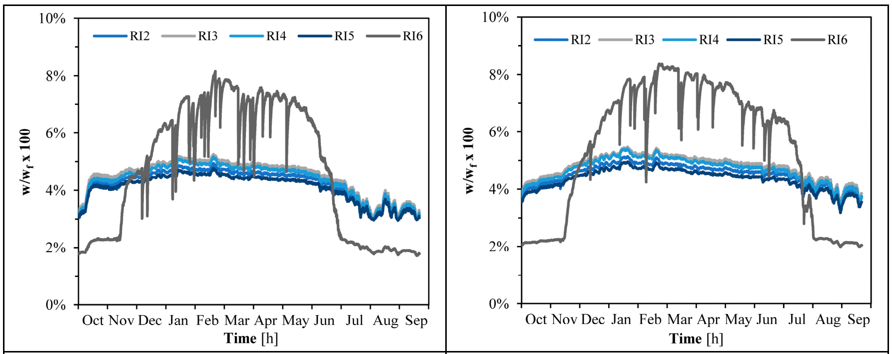
3.3 Interior retrofit of the thermal insulation (RI)

The following Figures (Figure S16 to Figure S21) represent the most significant results that were obtained for the interior retrofit scenario, located in Lisbon (RI).



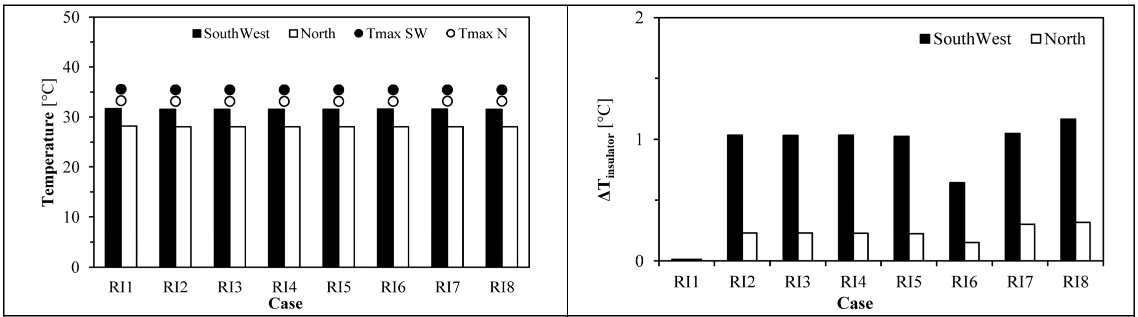
a) Total water content over time | b) Drying potential rate

Figure S16. Total water content and drying potential rate



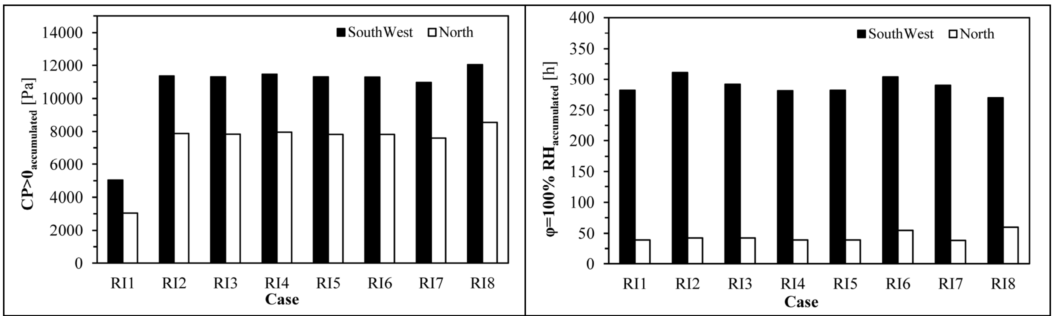
a) Ratio w/wf for the SW orientation | b) Ratio w/wf for the N orientation

Figure S17. Ratio of water content to wf for the renders



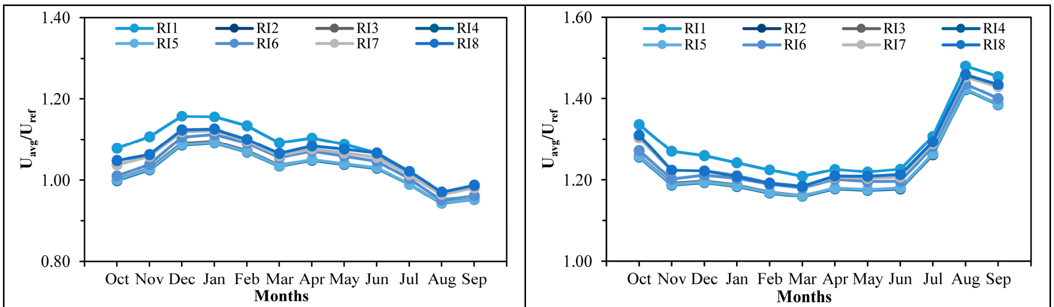
a) Temperatures exterior and superficial, 99th percentile | b) Temperature gradient on the insulator, 99th percentile

Figure S18. Temperatures verified in the simulation



a) Condensation potential on the exterior surface | b) Surf. air relative humidity equal to 100%RH

Figure S19. Verification of the conditions for the formation of superficial condensation



a) Thermal transmittance ratio – SW | b) Thermal transmittance ratio – N

Figure S20. Thermal insulation loss over the year

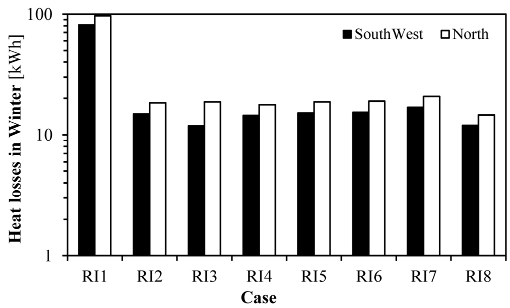


Figure S21. Heat loss during Winter, per square meter of wall

References

[1] J. Maia, N.M.M. Ramos, R. Veiga, Evaluation of the hygrothermal properties of thermal rendering systems, Build. Environ. 144 (2018) 437–449. doi:10.1016/j.buildenv.2018.08.055.

[2] J.F. Maia, Durability of Thermal Rendering and Plastering Systems, University of Porto, 2019.

[3] L. Ducoulombier, Z. Lafhaj, Comparative study of hygrothermal properties of five thermal insulation materials, Case Stud. Therm. Eng. 10 (2017) 628–640. doi:10.1016/j.csite.2017.11.005.

[4] S. Schiavoni, F. D'Alessandro, F. Bianchi, F. Asdrubali, Insulation materials for the building sector: A review and comparative analysis, Renew. Sustain. Energy Rev. 62 (2016) 988–1011. doi:10.1016/j.rser.2016.05.045.

[5] Fraunhofer - IBP, WUFI Pro 5.0, Holzhirchen, Germany, 2009.

[6] M. Pedroso, I. Flores-Colen, J.D. Silvestre, M.G. Gomes, L. Silva, P. Sequeira, J. de Brito, Characterisation of a multilayer external wall thermal insulation system. Application in a Mediterranean climate, J. Build. Eng. 30 (2020) 101265. doi:10.1016/j.jobe.2020.101265.

[7] Saint-Gobain Weber, Technical datasheet: Weberplast decor plus (in Portuguese), 2019.

[8] Saint-Gobain Weber, Technical datasheet: Webertherm pro (in Portuguese), 2019.

[9] CEN, EN 12524 - Building materials and products - Hygrothermal properties - Tabulated design values, Comité Européen de Normalisation, Belgium, 2000.

[10] CEN, EN 1745: Masonry and masonry products — Methods for determining thermal properties, Comité Européen de Normalisation, Belgium, 2012.

[11] M.K. Kumaran, Heat, Air, and Moisture Transfer in Insulated Envelope Parts. Final report. Task 3: Material properties, Canada, 1996.

[12] ISO/TC 163/SC 2, ISO 10456: 2007 - Building materials and products - Hygrothermal properties - Tabulated design values and procedures for determining declared and design thermal values, ISO, Switzerland, 2007.

[13] E. Barreira, V.P. de Freitas, External Thermal Insulation Composite Systems: Critical Parameters for Surface Hygrothermal Behaviour, Adv. Mater. Sci. Eng. 2014 (2014) 1–16. doi:10.1155/2014/650752.

[14] J.M.P.Q. Delgado, E. Barreira, N.M.M. Ramos, V.P. de Freitas, Hygrothermal Numerical Simulation Tools Applied to Building Physics, Springer Berlin Heidelberg, Berlin, Heidelberg, 2013. doi:10.1007/978-3-642-35003-0.