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Impact of moisture buffering for improving summer comfort in buildings

Clémence Legros^{1,2,3}, Matthieu Cosnier¹, Amandine Piot², Mickael Pailha³, Monika Woloszyn³

¹CSTB, Saint Martin d'Hères, France

²Univ. Grenoble Alpes CEA LITEN INES, Grenoble, France

³Univ. Savoie Mont Blanc CNRS LOCIE, Chambéry, France

Abstract

Moisture buffering can be defined as the effect on the atmosphere of the exchanges of water vapour between the surface layers of hygroscopic materials and the indoor environment. Since latent heat exchanges take place, the moisture buffering has a direct thermal effect on summer indoor temperatures. We propose here to investigate this thermal effect according to the French thermal regulation conventions. We ran simulations at the whole building scale for residential buildings without any cooling system. Two models are used to simulate moisture buffering effect: a fully coupled hygrothermal model (WUFI Plus) and the Effective Moisture Penetration Depth model. We study the impact of walls assemblies, finishing, climate, ventilation rate and moisture load. Eventually, the main interest is more about relative humidity than temperature.

Introduction

During the last decades, the technical improvements in building envelope regarding winter comfort gave rise to a new problem: summer comfort. Recent years have also seen a surge of interest for bio-based and other unconventional materials. Most of these materials are hygroscopic, which means that they are able to adsorb and desorb moisture and exchange it with the surroundings. This mass exchange goes along with heat exchange. In addition to the thermal effect, there is an attenuation of internal relative humidity variations, as observed by Hameury (2005). This phenomenon can be called either "Moisture Buffering" or "hygroscopic inertia". Moisture buffering is of real interest for summer comfort because it allows to reduce the peaks of indoor humidity and therefore of enthalpy during the day. This means that less energy is needed for cooling, as explained by Zhang et al. (2017). Thus, in presence of a properly regulated HVAC system, Osanyintola and Simonson (2006) have stated that the use of hygroscopic materials makes it possible to reduce cooling consumption by 30%. However, very few studies investigate the thermal effect of moisture

buffering in summer for residential buildings without any air conditioning. Therefore, we propose to do so at the whole building scale in summer according to the French thermal regulation (a whole building transient simulation). As the computational time of the French thermal regulation engine has to be short, we studied the Effective Moisture Penetration Depth (EMPD) model which is known for its fast solution time and reasonable accuracy. The fully coupled mass and heat transfer model implemented in the software WUFI Plus will serve as a reference to carry out a parametric study.

In this article, the fully coupled model and the EMPD model are described. Then, we propose first a study on real buildings following the French thermal regulation. Finally, we undertook a parametric study to assess the moisture buffering efficiency of a wall.

Hygrothermal Phenomena in Buildings

Hygroscopic materials are used in residential buildings for construction materials, furniture, books or carpets for example. For this work, we took only into account the construction materials. A porous medium contains a skeletal portion, called the frame, and some pores filled with one or more fluids (liquid or gas). They are mainly made up of micropores and mesopores. The surface layers of such materials are able to uptake and release moisture to the surrounding atmosphere under cyclic moisture loads.

Usually, in the summer daytime, the outdoor temperature increases and the absolute humidity remains approximately constant, so the relative humidity decreases. Thus the moisture-laden walls desorb. Humidity and latent heat of sorption are extracted from materials (commonly, latent heat of sorption is confused with latent heat of water evaporation, $L_V = 2500 kJ/kg$). The surface temperature of materials decreases during the desorption process and directly impacts the operative temperature and the thermal perception. In the night-time, the opposite phenomenon can take place: walls adsorb moisture, latent heat is released from materials resulting in an

increase of surface temperature. Thus, daily humidity cycles occur. At certain times, operative temperature decreases, at others, it rises. But this operating mode is purely theoretical. It is much more complicated in reality as it depends greatly on weather, materials, occupation schedule or ventilation rates, for instance. Hygroscopic inertia is influenced by two hygric parameters:

- water vapour permeability which represents the material resistance to vapour diffusion,
- moisture sorption isotherm which presents the relationship between water content and equilibrium humidity of a material, at a given constant temperature.

In the following, we use common building physics assumptions:

- the relative humidity is lower than 80% so there is no liquid water, only water vapour,
- the air is an ideal gas composed of dry air and water vapour.

For our purpose, we use additional simplifying assumptions:

- the hysteretic behavior of the sorption curve is neglected,
- the vapour diffusion is the only mass transfer phenomenon taken into account.

Numerical models

In a porous medium, heat and moisture transfers interact. They are described by the following partial differential equations, with the relative humidity φ and the temperature T as driving potentials respectively:

MASS CONSERVATION

$$\frac{dw}{d\varphi} \cdot \frac{\partial \varphi}{\partial t} = \nabla \cdot \left(D_w \frac{dw}{d\varphi} \nabla \varphi + \delta \nabla (\varphi P_{sat}) \right) \quad (1)$$

ENERGY CONSERVATION

$$\frac{\partial H}{\partial T} \cdot \frac{\partial T}{\partial t} = \nabla \cdot (\lambda \nabla T) + L_V \nabla \cdot (\delta \nabla (\varphi P_{sat})) \quad (2)$$

On the left-hand side of the two previous equations are the storage terms. The fluxes on the right-hand side are transport terms.

At room scale, the heat balance depends on exchanges through the envelope, internal gains (from sun and occupation), moisture buffering, infiltrations and HVAC gains or losses:

$$\rho c V \frac{dT_{int}}{dt} = \sum_{surf} A_{surf} \alpha_{surf} (T_{surf} - T_{int}) + Q_{int} + nV \rho c (T_{out} - T_{int}) + Q_{HVAC} + Q_{buffer} \quad (3)$$

Likewise, we can define the mass balance of a room which depends on moisture fluxes exchanged with the interior surfaces, infiltrations, internal moisture production and HVAC gains or losses:

$$V \frac{dc_{int}}{dt} = \sum_{surf} A_{surf} g_{buffer} + nV (c_{out} - c_{int}) + W_{int} + W_{HVAC} \quad (4)$$

g_{buffer} is the moisture flux which is exchanged between indoor air and walls. This part is of interest when we study moisture buffering. It can be defined as:

$$g_{buffer} = \sum_{surf} \beta_{surf} (P_{Vint} - P_{Vsurf}) \quad (5)$$

The associated latent flux presented in Equation 3 is:

$$Q_{buffer} = L_V \times g_{buffer} \quad (6)$$

A numerical method is necessary to solve such coupled equations.

Coupled heat and mass transfer model

The equations presented previously are implemented in several existing software, such as WUFI Plus developed by Künzel et al. (2005). It is a heat and moisture simulation tool which has been validated by Antretter et al. (2011) and is widely used.

The software allows two hygrothermal running modes. Heat and moisture fluxes are taken into account and the thermal effect of the moisture buffering can either be considered or not, depending on:

- ▶ latent heat effects switched off: heat of fusion and heat of evaporation are disregarded
- ▶ latent heat effects switched on: heat of fusion and heat of evaporation are regarded

Both options are particularly of interest for our work and will be compared later.

French thermal calculation engine and EMPD model

In the case of the French thermal calculation engine, the heat balance of a room is the same as the one in WUFI Plus (see Equation 3) except that moisture buffering is neglected ($Q_{buffer} = 0$). Likewise, concerning the mass balance presented in Equation 4, the term $\sum_{surf} A_{surf} g_{buffer}$, and thus the Equations 5 and 6, are not taken into account. For the purpose of our work, as the calculation time has to be short, we modified the calculation engine of the French thermal regulation by adding the Effective Moisture Penetration Depth (EMPD) model. It is a simplified approach detailed by Kerestecioglu et al. (1990) to simulate surface moisture adsorption and desorption. It is known for its low computational cost and its reasonable accuracy.

When exposed to cyclic relative humidity variations, a thin layer of materials responds dynamically and exchanges moisture with the indoor environment. In order to account for daily and seasonal loads, there are two fictitious layers of materials: a surface layer (indexed b) and a deep layer (indexed d). The EMPD model assumes an unvarying moisture content and temperature for each layer. Their respective thickness is equal to the effective moisture penetration depth. It depends on materials water vapour permeability δ , their hygric capacity (slope of the sorption curve) ε and time periods for humidity fluctuations t_p .

$$d_b = \sqrt{\delta_b \times \frac{P_{sat}(T) \times t_{pb}}{\varepsilon_b \times \pi}} \quad (7)$$

$$d_d = \sqrt{\delta_d \times \frac{P_{sat}(T) \times t_{pd}}{\varepsilon_d \times \pi}} \quad (8)$$

Then, the model calculates the moisture transfer between both layers, and the exchanges between the surface layer and the indoor air. This model is suitable for one-dimensional transfers in homogeneous porous media, with one side loads. In the case of loads on both sides (for partition wall for example), the wall assembly is divided in two parts with no flux in the middle.

Methods

In this work, we want to assess the impact of moisture buffering on summer comfort for unconditioned residential buildings, according to the French thermal regulation. In the French thermal regulation, summer comfort is characterized by an operative temperature, called Conventional Indoor Temperature (T_{ic}). This required indicator is the maximum operative temperature reached on a day during an artificial hot four weeks sequence, as defined by the CSTB (2011). This indicator T_{ic} has to be lower than a reference indicator called T_{icref} . Currently, the calculation engine of the French thermal regulation takes into account some moisture sources like occupants or ventilation, but neglects the moisture buffering. In order to assess the impact of moisture buffering on the heat balance and thus on the indicator T_{ic} , the authors implemented the EMPD model into the calculation engine of the French thermal regulation. The first part of our work focused on real buildings following the French thermal regulation. In the second part of this work, we undertook a parametric study with WUFI Plus on a standard building to compare the orders of magnitude calculated with the EMPD model on T_{ic} to those given by WUFI Plus on the operative temperature T_{op} .

For both parts, the weather file and the occupation schedule used are those defined by the French

thermal regulation rules for residential buildings. No mechanical cooling unit is installed. The mechanical ventilation is a simple extraction system, which means that the incoming air has the same characteristics as the outdoor air. The materials used for the simulations are part of the WUFI database. The weather files are those given by climate zone according to the French thermal regulation. The effect of moisture buffering on heat balance during summer period will be assessed regarding different parameters: climate, wall assembly, coating, ventilation rate and moisture sources.

PART 1: EXISTING BUILDINGS RE-SIMULATED WITH THE EMBEDDED EMPD MODEL

The main goal of this part is to study real buildings. We downloaded a large amount of anonymous files from the French OPE (Energy Performance Observatory) database. This database belongs to the French Government. Each file corresponds to a real building which has been simulated by an engineering office according to the French thermal regulation. Then, we used a database language in order to select and sort the files on the following factors:

- residential buildings
- climate (Nice or Nancy)
- thermal inertia (low, moderate or high)

We collected 1309 files according to our criteria from the OPE database. However, we have been able to get only 296 results, primarily due to encoding errors in the original files.

For each file, we run four simulations with the embedded EMPD model in the calculation engine of the French thermal regulation:

- ① with no hygroscopic material (reference)
- ② by adding lowly hygroscopic materials
- ③ by adding moderately hygroscopic materials
- ④ by adding highly hygroscopic materials

The hygroscopicity of walls depends on the insulation material and internal cladding (see Table 1). Floors and ceilings are made with oriented strand boards. For the while, the walls are uncoated.

Table 1: Construction materials for the first part.

Hygroscopicity	Low	Moderate	High
Insulation material	Mineral wool	Wood fiber	Mineral wool
Internal cladding (13mm thick)	Gypsum board	Spruce	Earth mortar

PART 2: PARAMETRIC STUDY WITH WUFI PLUS

We could not compare directly both software since WUFI Plus cannot fully reproduce the complicated French thermal regulation conventions regarding the ventilation rates and the solar blinds operation. So we implemented a detached standard timber-framed house, as shown in Figure 1, with simpler scenarios in order to carry out a parametric study.



Figure 1: A standard timber building.

The parametric study is based on the following parameters:

- 2 climates: Nice or Nancy
- 2 insulation materials: mineral wool or wood fiber
- 3 internal claddings: gypsum board, spruce or earth mortar
- 3 finishings: oak floor and raw walls, oak floor and acrylic paint on the walls or PVC floor and vinyl wallpaper
- 2 ventilation schedules: with or without night ventilation
- 2 amounts of moisture load: 1.8 or 4 people

All combinations have been tested. Each simulation was run over three years.

Results and discussion

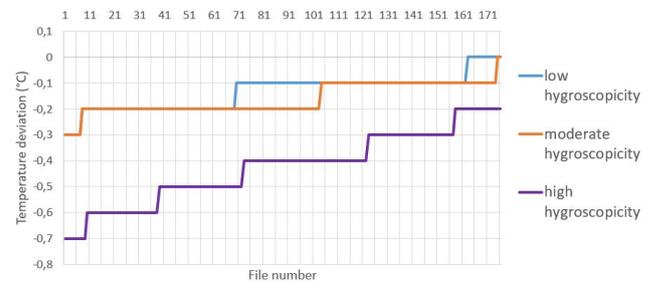
PART 1: EXISTING BUILDINGS RE-SIMULATED WITH THE EMBEDDED EMPD MODEL

The indicator T_{ic} are calculated for each file. The results of the first simulation (①) are references and will be noted T_{ic_0} and T_{icref_0} . The results of the other simulations (②, ③, ④) take into account the effect of moisture buffering. They will be noted $T_{ic_{mb}}$ and $T_{icref_{mb}}$. Then, we assess the reduction of the indicator T_{ic} with the moisture buffering by calculating the difference $\Delta T_{ic} = (T_{ic_{mb}} - T_{ic_0})$ for the three hygroscopicity levels. A negative result means a decrease of T_{ic} by taking into account the moisture buffering effect.

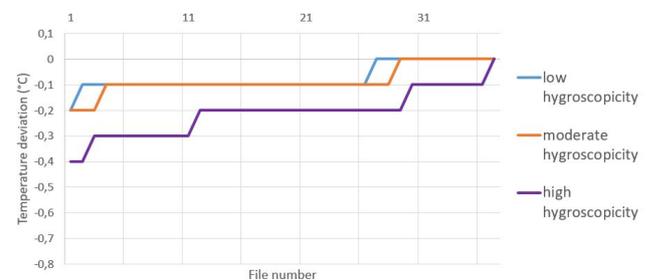
The results are quite similar for T_{ic} and for T_{icref} , consequently only T_{ic} results are represented in this article.

No significant differences were observed between climates of Nice and Nancy. Thus, in this paper, we

present only the results for Nice (Mediterranean climate). Figure 2a presents the results for a moderate thermal inertia (176 files). Figure 2b presents the results for a high thermal inertia (37 files). For sake of clarity, the values ΔT_{ic} have been sorted in ascending order. The blue, the orange and the purple curves represent respectively a low, a moderate and a high hygroscopicity level (see Table 1).



(a) Moderate thermal inertia



(b) High thermal inertia

Figure 2: Temperature deviations ΔT_{ic} in Nice.

The temperature deviation ΔT_{ic} is in the range of $-0,7^{\circ}\text{C}$ to 0°C . It means that moisture buffering has only a slight effect on the thermal balance.

If we compare the blue, orange and purple curves, we can state that the more hygroscopic materials, the greater the thermal effect.

Concerning the thermal inertia, since the relative humidity variations (and thus the temperature variations) are the main driving potential of the hygroscopic inertia, the higher the thermal inertia, the lower the moisture buffering.

These results should be interpreted with caution since the weather data used for the T_{ic} calculation are repetitive. Large cycles in temperature and relative humidity occur which enhances moisture buffering.

PART 2: PARAMETRIC STUDY WITH WUFI PLUS

We focused on the operative temperature for the months of June, July and August (months without heating). This period includes 92 days, being 2208 hours. To ensure reliable results, independent of the initial conditions, the following analyses are conducted during the third summer.

The analysis of the collected data is delicate since the moisture buffering leads sometimes to an increase of

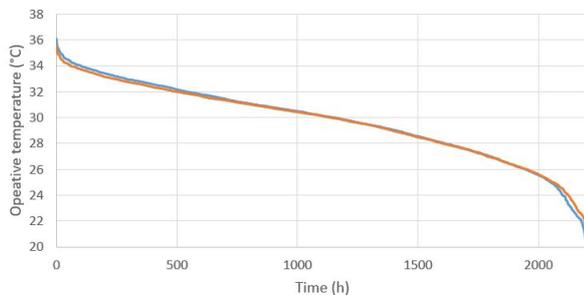
the operative temperature (adsorption period) and sometimes to a decrease of operative temperature (desorption period). We wanted to analyse the results as objectively as possible, therefore we used several methods:

- by plotting and sorting in descending order the operative temperature for the three months in order to see the general trend on the warmest hours of summer,
- by calculating an average with the values obtained during the 12 warmest hours of a day being between 8am and 8pm (we choose a 12 hours calculation because if we consider 24 hours, the average is close to 0 ; we assumed the sorption occurs half of the time on an equal basis with the desorption time),
- by calculating an average taking into account only the values when the walls desorb.

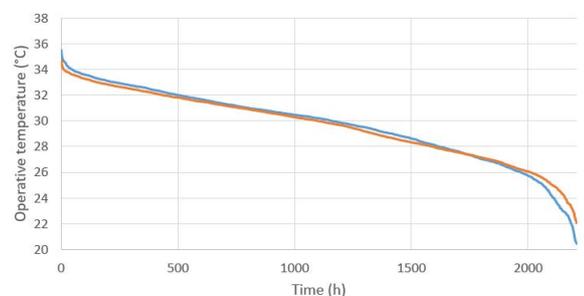
For each method, we compared the operative temperature with moisture buffering ($T_{op_{mb}}$) to the one without moisture buffering (T_{op_0}) as follows: $\Delta T_{op} = T_{op_{mb}} - T_{op_0}$. A negative value of ΔT_{op} means a decrease of the operative temperature by taking into account the moisture buffering effect.

Effect of walls components:

The operative temperature of June, July and August sorted in descending order are presented in Figure 3.



(a) Mineral wool and plaster



(b) Wood fiber and earth mortar

— without latent heat effect — with latent heat effect

Figure 3: Operative temperatures sorted in descending order (Nice).

We aim to compare both options of the hygrothermal mode of WUFI Plus (see "►" in the part Numerical models). The blue curve neglects the latent heat effect whereas the orange one considers it. The Figure 3a presents the results with mineral wool and plaster (low hygroscopicity). The Figure 3b presents the results with wood fiber and earth mortar (high hygroscopicity). The internal claddings are uncoated and the ventilation rate (mechanical and infiltrations) is equal to 0.5vol/h.

Figure 3 points out the general trend. The orange curve is slightly below the blue one on both graphs for the warmest hours. That means the latent heat effect decreases slightly the operative temperature values for the warmest hours. Moreover, the difference seems to be greater for highly hygroscopic materials than lowly hygroscopic materials. As stated before, the more hygroscopic materials, the greater the thermal effect.

Then, we compare the deviations of operative temperature by calculating both averages defined previously, in Nice (see Table 2) and in Nancy (see Table 3). The internal claddings are still uncoated and the ventilation rate sets to 0.5vol/h.

Table 2: Influence of the walls components on ΔT_{op} in Nice.

NICE	ΔT_{op} (°C)	
	from 8am to 8pm	when walls release moisture
Mineral Wool + Plaster	-0.01	-0.30
Mineral Wool + Spruce	-0.02	-0.37
Mineral Wool + Mortar	-0.08	-0.73
Wood Fiber + Plaster	-0.10	-0.37
Wood Fiber + Spruce	-0.11	-0.36
Wood Fiber + Mortar	-0.17	-0.72

Table 3: Influence of the walls components on ΔT_{op} in Nancy.

NANCY	ΔT_{op} (°C)	
	from 8am to 8pm	when walls release moisture
Mineral Wool + Plaster	0.11	-0.29
Mineral Wool + Spruce	0.14	-0.34
Mineral Wool + Mortar	0.21	-0.61
Wood Fiber + Plaster	0.03	-0.38
Wood Fiber + Spruce	0.05	-0.33
Wood Fiber + Mortar	0.12	-0.54

Focusing on the values from 8am to 8pm, moisture buffering does not seem to have a significant thermal

effect, whatever the climate or walls components. It can be explained by unpronounced cycles in temperature and relative humidity. Sometimes, the materials desorb or adsorb during few days instead of few hours, resulting in an average close to zero on the studied time slot. Nevertheless, focusing on the values when materials desorb, the deviations are in the range of $-0,29\text{ }^{\circ}\text{C}$ to $-0,73\text{ }^{\circ}\text{C}$. Consequently, we will focus on values when walls desorb for the next analyses.

Plaster board has a high vapour permeability and a low moisture capacity (unable to store humidity). Thus, ΔT depends on the insulation materials: the moisture front seems to cross the internal cladding and reach the insulation materials.

Spruce has a low vapour permeability and a high moisture capacity (able to store humidity). The same deviations can be observed whatever mineral wool or wood fiber. The internal cladding slows the moisture front down and the latter does not reach the insulation materials. Moisture is entirely stored by the spruce. Finally, earth mortar has a high vapour permeability and a high moisture capacity. The moisture front enters and is stored in the internal cladding.

These observations agree with Yang et al. (2012). The effective moisture penetration depth of uncoated gypsum board is much higher than for wood paneling. However, the variation of moisture content in the gypsum board is much smaller due to its low moisture capacity. By contrast, moisture buffering in the wood paneling occurs in a thin layer but its high moisture capacity allows a much higher amount of moisture retention in this small volume of material.

Effect of climate:

According to the Table 2 and the Table 3, the summer climate of Nice is slightly more in favor of moisture buffering. Nancy is a wet climate and the relative humidity variations are less regular than in Nice.

Consequently, we will focus on Nice results for the next analyses.

Effect of night ventilation:

Two cases are considered regarding airflow (including ventilation and infiltrations):

- Constant rate (0.5 vol/h)
- Night ventilation: 4 vol/h from 10pm to 6am and 0.5 vol/h otherwise

The Table 4 presents the results.

The night ventilation effect is not clear. We expected an increase in the deviations. Nevertheless, it seems to have the opposite effect. Several reasons

can be given. It is possible that moisture escapes by night ventilation instead of being adsorbed by walls. Moreover, as the indoor temperature is lower when night ventilation occurs, moisture buffering is less pronounced.

Table 4: Influence of the night ventilation on ΔT_{op} .

NICE	ΔT_{op} ($^{\circ}\text{C}$) when walls desorb	
	no night ventilation	with night ventilation
Mineral Wool + Plaster	-0.30	-0.33
Mineral Wool + Spruce	-0.37	-0.35
Mineral Wool + Mortar	-0.73	-0.72
Wood Fiber + Plaster	-0.37	-0.38
Wood Fiber + Spruce	-0.36	-0.33
Wood Fiber + Mortar	-0.72	-0.65

Effect of coating:

The ventilation rate is equal to 0.5vol/h. There is no night ventilation. The Table 5 compares the results with a oak floor and raw walls (high vapour permeability) to those with a PVC floor and vinyl wallpaper (low vapour permeability).

Table 5: Influence of the coating on ΔT_{op} .

NICE	ΔT_{op} ($^{\circ}\text{C}$) when walls desorb	
	raw materials	PVC floor +wallpaper
Mineral Wool + Plaster	-0.30	-0.15
Mineral Wool + Spruce	-0.37	-0.18
Mineral Wool + Mortar	-0.73	-0.35
Wood Fiber + Plaster	-0.37	-0.21
Wood Fiber + Spruce	-0.36	-0.21
Wood Fiber + Mortar	-0.72	-0.35

The deviations are divided by approximately two. The PVC floor and vinyl wallpaper reduce the superficial moisture exchanges. This effect has already been noticed by Ramos et al. (2010).

Effect of moisture load:

According to the French thermal regulation conventions, an active person produces 55g/h of water vapour and an asleep person produces 38.5g/h of water vapour. Still according to the French thermal regulation, a 70m^2 detached house is occupied by 1.8 people. Then, following the occupancy schedule given by the French thermal regulation (CSTB, 2011) the average moisture production equals 1.8kg/day of water vapour. This is a very low value so we also ran additional simulations with 4 inhabitants. The

claddings are still uncoated and the ventilation rates fixed to 0.5vol/h. The Table 6 presents the results.

Table 6: Influence of the moisture load on ΔT_{top} .

NICE	ΔT_{top} (°C) when walls desorb	
	1.8 inhab.	4 inhab.
Mineral Wool + Plaster	-0.30	-0.30
Mineral Wool + Spruce	-0.37	-0.38
Mineral Wool + Mortar	-0.73	-0.71
Wood Fiber + Plaster	-0.37	-0.38
Wood Fiber + Spruce	-0.36	-0.37
Wood Fiber + Mortar	-0.72	-0.71

There is no effect, even for 4 inhabitants. Nevertheless, the assigned values are low and do not take into account other transient moisture sources as cooking or showers for instance. Further works could be able to state if it has a greater impact or not.

Eventually, the main interest is more about the reduction of indoor relative humidity variations than the thermal effect. The Figure 4 presents indoor relative humidity and air temperature variations over 20 days (from June 18th to July 8th) for four cases in Nice:

- in light blue: thermal mode, without any exchange of moisture between walls and environment,
- in orange: hygrothermal mode, with moisture exchanges for walls made of mineral wool and gypsum board (low hygroscopicity),
- in green: hygrothermal mode, with moisture exchanges for walls made of wood fiber and spruce (moderate hygroscopicity),

- in dark blue: hygrothermal mode, with moisture exchanges for walls made of wood fiber and earth mortar (high hygroscopicity)

The high values of air temperature can be explained by the good insulation and the airtightness of the building, the steady ventilation rate equals to 0.5vol/h and the absence of night ventilation.

Hygroscopic materials are able to damp the daily fluctuations in relative humidity. The more hygroscopic materials, the higher the attenuation. The temperature variations are similar for all cases. It means the difference in relative humidity variations between the three cases studied is mainly due to moisture buffering ability of materials and thus their properties.

Conclusion

In this article, we investigated the impact of moisture buffering on thermal indicator for summer comfort. In a first part, we focused on real buildings using the EMPD model. Then, we undertook a parametric study with WUFI Plus.

For both cases, the order of magnitude observed are quite similar. The results show a slight decrease in T_{ic} and T_{op} (up to 0.7°C).

In this work, we did not see a significant difference between the two climates studied.

The more hygroscopic and vapour open materials, the greater the moisture buffering, provided an uncoated internal cladding. Given the minor thermal effect of moisture buffering, hygroscopic materials cannot be a solution to ensure summer comfort. It is not a substitute for shadings or thermal inertia for instance. Moreover, we may wonder if human body is able to feel such a small difference.

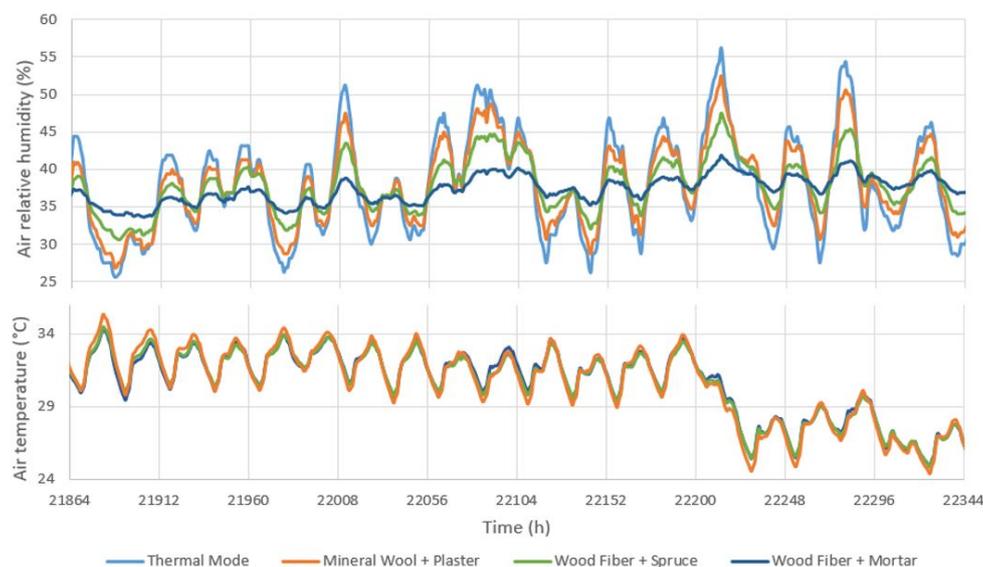


Figure 4: Indoor relative humidity and air temperature variations.

Eventually, the main interest is more about relative humidity than temperature. Indeed, the wide variations in relative humidity which cause discomfort, are damped by hygroscopic materials. It is of real interest as it could reduce ventilation rates or cooling loads for instance. Further works could review these issues.

Acknowledgments

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Nomenclature

A	Surface area [m^2]
c	Specific heat [J/kgK]
c_{int}	Absolute moisture ratio of the indoor air [kg/m^3]
c_{out}	Absolute moisture ratio of the outdoor air [kg/m^3]
d	Effective moisture penetration depth [m]
D_w	Liquid diffusivity [m^2/s]
g_{buffer}	Moisture flux from the interior surface into the room [kg/m^2s]
H	Total enthalpy [J/m^3]
L_V	Latent heat of phase change [J/kg]
n	Air change per hour [h^{-1}]
P_V	Vapour pressure [Pa]
Q	Heat flux [W]
RH	Relative Humidity [%]
t	Time [s]
t_p	Cycle time for humidity fluctuations [s]
T	Temperature [K]
T_{ic}	Conventional Indoor Temperature [$^{\circ}C$]
T_{icref}	Reference Conventional Indoor Temperature [$^{\circ}C$]
T_{op}	Operative temperature [K]
V	Volume [m^3]
w	Moisture content [kg/m^3]
W	Moisture flux [kg/h]
α	Heat transfer coefficient [W/m^2K]
β_{surf}	Convective moisture transfer coefficient [s/m]
δ	Water vapour permeability [$kg/msPa$]
ϵ	Hygic capacity [kg/m^3]
λ	Thermal conductivity [W/mK]
φ	Relative humidity [-]
ρ	Density of the air [kg/m^3]

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