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SENSITIVITY ANALYSIS OF PARAMETERS INFLUENCING BUILDING HEATING ENERGY CONSUMPTION USING HEMP-LIME MATERIAL

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Abstract

Heating is the dominant energy load in the french construction sector for both residential and commercial buildings. Many researches were made on hemp based insulation products as hemp-lime is a renewable and bio based resource. Moreover, it exhibits interesting ability in inner air moisture control. However, the physical properties of this material show high variability induced by the manufacturing processes and by surrounding environmental condition such as temperature and humidity. In this work we investigate the effect of these variability and uncertainty sources on the heat and mass transfers through a building wall made of hemp-lime material, in order to identify the determinant factors for energy consumption. We apply the coupled heat and mass transfer model by Künzel to calculate the energy consumption of a simplified building model represented by a floating parallelepiped. The parallelepiped faces are made of hemp lime material and are exposed to various environmental conditions. The Morris sensitivity analysis is applied to the energy consumption model in order to identify parameters which can influence the energy consumption when maintaining comfort conditions in the building volume (temperature 20 to 24°C). These parameters are the hemp-lime material physical properties, the parallelepiped dimension parameters, the variability of external and internal conditions. Morris sensitivity analysis provides a classification according to the parameter influences. This ranking can then be used to determine the parameter(s) or group of parameters whose values can be optimized to lower the heating and cooling energy consumption of the simplified building model.

Keywords:

Bio-based material, Morris analysis, Building efficiency, Parameters weight, Hygrothermal transfert

1 INTRODUCTION

The building sector is responsible for 20% of greenhouse gas emissions in France. Building is also one of the most important energy consumers among all industrial sectors. Heating is the main part of energy consumption for both residential and commercial buildings during their use phase, it represents respectively 61% and 66% of the total energy consumption in the building's total consumption in the use phase [ADEME 2013].

Several studies were conducted on the optimization of buildings' energy consumption: studies concerning buildings' materials [Cérézo 2005], buildings' design and characteristics [Peuportier 2001]. The quantification of building energy consumption reduction due to the use of an insulation material can be achieved through numerical simulations. Some of input parameters used in simulation are usually obtained from experimentation and thus uncertain or variable. The sources of this variability or uncertainty can be classified in two categories: inherent variability corresponding to material characteristics that can vary with time or with surrounding environmental conditions, and uncertainties issued from measurements of material characteristics [Corrado 2009].

Two products from hemp stem can be used to produce thermal insulator, the hemp chaff and fiber. This work focuses on the insulator produced using hemp chaff and lime as binder. A hemp sourced material can reduce the energy consumption during the use phase due to its hygroscopic characteristics, but can also be expected to reduce consumption of non-renewable resource.

However, physical characteristics of this material are highly variable and depend on several factors such as the material formulation, manufacturing processes, the surrounding environment during the use phase. Variations of those characteristics can influence global energy consumption by either altering or improving performances of thermal insulation. Indeed, hemp-lime material (HLM) is a hygroscopic material, and its physical characteristics vary with the surrounding relative humidity. It is thus important to identify conditions for which energy consumption is minimized.

The objective of this work is to analyze the influence of the identified sources of variability (and uncertainty) on the building energy consumption using HLM as thermal insulator. In that perspective, a simplified building model was developed, information on variability of input parameters was collected, and a sensitivity analysis (SA) was conducted on the energy consumption in order to identify the most influential parameters.

2 METHODS

2.1 Hemp sourced material

Primary transformation of hemp straw offers three products: chaff, fiber and dust (powder). The two first products can be used to produce building thermal insulation materials. Our study focuses on the use of hemp chaff combined with lime to produce the hemp lime material (HLM). Hemp chaff is a lightweight granulate with an approximately 130 kg.m^{-3} density [Cerezo 2005]. It is a highly porous material with an open porosity of 91.2% and a pore size varying between 10 and 40 µm. Chemical composition of hemp chaff is similar to wood (50% of cellulose, 28% of lignin, 20% of hemicellulose) according to Evrard et al [Evrard 2006].

The lime based binder used is compound of 75% of hydrated lime, 15% of hydraulic lime, 10% of pozzolanic binder and 0.5% of additives, with a 1450 kg.m^{-3} density. The use of lime (hydrated based) as binder with hemp chaff is reported to have many advantages [Evrard 2008]: the high permeability of lime which contributes to the permeability of HLM, the high pH value of lime supposed to protect the material against the mould and bacteria growth and finally, the flexibility of hydrated lime helps to avoid HLM crack in use.

HLM characteristics can vary with several factors, variation occurring in the material manufacturing and in the use phase. During the manufacturing process, HLM properties vary with the chosen formulation. The produced material properties will be near the vegetal granulate or the lime binder or intermediate of both. HLM properties for a fixed formulation can also be altered by the manufacturing process. On the use phases as HLM is a high porous hygroscopic material, its physical properties in use can be altered by the moisture surrounding condition.

In the present study we assume that the material composition is remained unchanged (composed in mass proportion of 17% hemp chaff, 33% of lime based binder and 50% of water). The variability taken into account is then supposed to be inherent to the application process only.

2.2 The building case study

The studied building is a parallelepiped with a variable dimensions (see Tab.1). All the six faces are made of HLM. All the outdoor faces are submitted to the same climatic data sampled randomly. The indoor volume are maintained in a temperature comfort condition (interval range in Tab.1). Two sources (heat and moisture) are considered inside the building.

2.3 Hygrothermal model

To study the hygrothermal behavior of HLM we used the one dimensional formulation of the coupled heat and mass transfer model developed by Künzel [Künzel 1995] described by the following set of partial differential equations.

$$\rho C_P \frac{dT}{dt} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) + h_{lv}\frac{\partial}{\partial x}\left(\delta_P \frac{\partial}{\partial x}(\varphi P_{sat})\right) \quad (1)$$

$$\frac{dv}{d\varphi}\frac{d\varphi}{dt} = \frac{\partial}{\partial x}\left(D_\varphi \frac{\partial \varphi}{\partial x}\right) + \frac{\partial}{\partial x}\left(\delta_P \frac{\partial}{\partial x}(\varphi P_{sat})\right) \quad (2)$$

with ρ the material density (kg/m3), C_P the specific heat (J/kg.K), λ is the thermal conductivity (W/m.K), h_{lv} the enthalpy of water vaporization (J/kg), δ_P the water vapour permeability (kg.s^{-1}.m^{-1}.Pa^{-1}), v the water content (m^3/m^3), D_φ the water diffusivity (m^2/s), φ the relative humidity of air in the material pore space (-),P_{sat} the saturation vapour pressure (Pa), T the temperature (K), x the space direction (m), t the time (s).

The heat transfer equation (1) takes into account the balance between heat storage and heat transfer by conduction and heat absorbed or released by evaporation or condensation phenomenon. The mass transfer equation (2) takes into account the balance between moisture storage and liquid transport by conduction and water vapour diffusion by evaporation or condensation phenomenon. This latter constitutes a coupling term between the heat and mass transfer.

The temperature interacts in the humidity transfer in the calculation of the saturation vapour pressure P_{sat} using the empirical model.

$$P_{sat} = 611.e^{\left(\frac{aT}{T_0+T}\right)}. \quad (3)$$

Values given in [Künzel 1995] were used for P_{sat}. For $T < 0°\ C$, a=22.44 and T_0=272.44°C and for

$T \geq 0°\ C$, a=17.08 and T_0=234.18°C ;

For the sorption storage function of the HLM, we use the model proposed by Künzel which takes into account the three sorption phases (the sorption isotherm, the capillary condensation and the maximum saturation phases). This model doesn't take into account the hysteresis phenomenon (water adsorption/desorption). It takes into account all the relative humidity interval range.

$$v = v_{100\%}\frac{(b-1)\varphi}{b-\varphi} \quad (4)$$

where the value of the coefficient b is given by the measured water content at φ = 80% ($v_{80\%}$) and at the maximum saturation ($v_{100\%}$).

$$b = 0.80\frac{(v_{80\%}-v_{100\%})}{(v_{80\%}-v_{100\%}*0.80)} \quad (5)$$

Equations (1) and (2) describe the heat and mass transfer at the wall scale. At the building scale, we applied a similar approach as described by Qin et al [Qin 2009]. From energy balance principle, the heat storage inside the volume (the simplified building) is set proportional to the heat exchange from the six building faces, the heat exchange from ventilation and the heat produced by indoor sources (occupants and electrical equipment) $Q_{H\,sources}$ and heat from the heating or cooling system $Q_{heat;\,cooling}$.

$$\rho_{air}.C_{Pair}.V\frac{dT_{int}}{dt} = -\sum_j S_j.\alpha_j(T_{int} - T_s) + n.V.\rho_{air}.C_{Pair}.(T_{ext} - T_{int}) + Q_{H\,sources} + Q_{heat;\,cooling} \quad (6)$$

with V is the room volume (m^3), S_j the area of surface j (m^2), α_j the heat transfer coefficient between the air and surface j (W/m^2.K), T_s the wall inner surface temperature (K), n the air change rate (h^{-1}), $Q_{H\,sources}$ the thermal power supply by internal sources (W), $Q_{heat/cooling}$ the thermal power supply by the heating or cooling system (W).

The heating and cooling power is regulated using a proportional integral regulation system.

$$Q_{heat;\,cooling} = K\int(T_{comfort} - T_{int}).dt \quad (7)$$

In the same manner, the mass balance inside the room volume (using the water content as the leading parameter) yields the following equation.

$$V\frac{dv_{int}}{dt} = -\sum_j S_j.\beta_j.(v_{int} - v_s) - n.V.(v_{int} - v_{ext}) + Q_{m\,sources} \quad (8)$$

with β_j the mass transfer coefficient between the air and surface j (m.s^{-1}), v_{int} the internal water content (kg.m^{-3}), v_s the water content of the inner surfaces (kg.m^{-3}), v_{ext} the outdoor water content (kg.m^{-3})

The moisture storage inside the volume is set proportional to the moisture exchange throughout the six building faces and the moisture exchange from ventilation and the moisture from humidity sources $Q_{m\,sources}$. The finite difference method was used for the computation.

2.4 Sensitivity analysis method

Sensitivity analysis (SA) approach can be used to quantify (or qualify) the influences of model input parameters on the computed output(s) according to Campolongo et al [Campolongo 2011]. Numerous SA methods exist, they can be classified according to (i) the inputs consideration. According to the inputs variation (range interval) considered, we have “local” and “global” method, (ii) according to the calculation strategy (the input consideration) we have “one at a time” or “simultaneous” methods. Another classification can be made against the type of results that the SA method offers, there are “quantitative” and “qualitative” methods. Qualitative here refers to method for which indices give only rank of input parameters studied without quantitative proportion of the influences. Details and review of numerous SA methods can be found in [Hamby 1994, Christopher Frey 2002, Iooss 2011]. In this study we used the screening SA method of Morris [Morris 1991] a semi-local, semi-qualitative, and ameliorated “one at a time” method. We choose this method as it can help identify the most influential parameters on the energy consumption with a low number of calculations compared to SA method requiring intensive sampling. Morris method can classify the influences of all input parameters as low, moderate and high. The method provides also information on the relationship between input and output parameters: quasi-linear, highly non-linear or input parameters with high interaction with other. The monotonicity and the mean trend (increasing or decreasing for the considered interval range) of each input parameters are also obtained with Morris method.

Tab. 1: Parameters variability considered.

Parameters	Units	Type	Probability Distribution	Interval range	Default value
Specific heat C_p	J.kg^{-1}.K^{-1}	Qt	U	[1000-1590]	1295
Thermal conductivity λ	W.m^{-1}.K^{-1}	Qt	U	[0.06-0.19]	0.12
Density ρ	Kg.m^{-3}	Qt	U	[391-470]	430.5
Building width	m	Qt	U	[3-6]	4
Building length	m	Qt	U	[3-8]	4
Building height	m	Qt	U	[2.2-2.8]	2.5
Building location	-	Ql	Ud	[1:H1b, 2:H2a,3:H3]	1
Water vapor permeability δ_p	m.s^{-1}	Qt	U	[1.10^{-11}-9.10^{-11}]	5.10^{-11}
Air change rate n	Vol.h^{-1}	Qt	U	[0.5-1]	0.5
Wall thickness	m	Qt	U	[0.2-0.3]	0.25
Internal heat sources $Q_{H\,sources}$	W	Qt	U	[500-1000]	500
Internal humidity sources $Q_{m\,sources}$	g.h^{-1}	Qt	U	[500-1000]	500
Comfort temperature $T_{comfort}$	°C	Qt	Ud	[20-24]	24

Qt : quantitative; Ql : qualitative; U: Uniform continuous; Ud: Uniform discrete

The Morris indices is based on the estimation of the partial derivate of the function f against each parameter x_i, the elementary effect (EE_i).

$$EE_i = \frac{f(x_i+\Delta x_i)-f(x_i)}{\Delta x_i} \qquad (9)$$

The calculation of the EE_i is repeated r times (10 to 50 depending on the chosen step discretization) in order to cover the range interval of the studied parameters and to avoid the weakness of fully local SA methods (give only the effect of a small variation). Then the mean μ_i and the standard deviation σ_i of all computed EE_i are used as sensitivity indices.

The mean μ_i represents the individual effect of the parameter and σ_i the interaction or the non-linearity effect. A third indices was introduced by Campolongo et al [Campolongo 2007] in order to overcome the non-identification of influential non monotonic parameters, the absolute value of the mean of EE_i.

$$\mu_i^* = \frac{1}{r}\sum_{k=1}^{r}\left|EE_i^{(k)}\right| \qquad (10)$$

In addition, we propose to use a normalized Morris indices.

$$\mu_{norm}^* = \frac{\mu^*}{\sum_{j=1}^{p}\mu_j^*} \qquad (11)$$

This normalized value of μ_i^* provides quantification of parameters influences if parameters have a low interaction influences. Other improvements and extensions of the Morris method can be found in the literature: concerning the sampling phases, the use of radial sampling by Campolongo et al [Campolongo 2011], constellation sampling by Santiago et al [Santiago 2012] and the calculation of second (or more) order indices by Campolongo and Bradock [Campolongo 1999].

2.5 The sensitivity analysis experiment plan

Variability of parameters considered in this study are presented in Tab.1. These parameters belong to the different scales of the building: material, wall, building indoor and outdoor environment. We assumed that materials' physical properties are not correlated to each other. For building location we considered three building locations taken as representative of the French winter climate disparity: Nancy (H1b), Brest (H2a) and Nice (H3).

Hourly climatic data (temperature and relative humidity) from Energy Plus website corresponding to these three locations were used. We did not consider uncertainty for each climatic data. Comfort conditions are chosen to be exclusively based on temperature. Two indoor internal sources (heat and moisture) were considered inside the building.

The following parameters were set at their default values according to a previous study as their variation are not relevant at the wall scale. For the HLM properties, we set the water content at φ=80% to 30 kg.m^{-3}, the water content at maximum saturation to 620 kg.m^{-3}. For parameters related to the model we fixed also the number of space intervals for the wall discretization Nx and the number of time intervals Nt.

Initial value of temperature and relative humidity were set at 20°C and 40% respectively. For heat and moisture transfer between the wall surface and the inside/outside environment we used a boundary condition of the third kind. The heat and mass fluxes at the surfaces is set proportional to the temperature (and mass vapour pressure) gradient. Convection coefficients were set for inside and outside surfaces, at α_j= 8 W.m^2.K^{-1} for thermal and β_j= 3.10^{-7} m.s^{-1} for moisture transfer.

We also set the value of the HLM liquid diffusivity δ_P = 2.10^{-18} m^2.s^{-1} for this study because of instability occasioned. The mass transfer in (2) take into account only the liquid vapor diffusion (no rain, no capillary raise).

3 RESULTS

The results concerning the influence of group of parameters according to the different scales (material, wall, building) are presented in (Tab 2) by calculating the μ_{norm}^* for all the parameters involved in each groups. The Morris indices ($\mu, \mu^*, \mu_{norm}^*, \sigma, \sigma/\mu^*$) of each individual parameter are presented in (Tab 3).

Tab. 2: Parameters group variability influences on the building energy consumption per unit area per year.

Parameters group	$\sum \mu_{norm}^*$ [%]
Material properties	40.6
Building outdoor parameters	19.1
Building indoor parameters	18.7
Wall characteristics	17.8
Building dimensions	3.8

3.1 Influence of parameters group

Variability associated to all parameters related to HLM properties is the most important one (Tab 2). Influence of material properties group variability represents almost the half of the building energy consumption. Parameters group related to the indoor environment (controlled by or due to occupants) and those related to the outdoor environment (climatic data) represent around one fifth each of the building energy consumption. Parameters associated to the wall characteristics have an influence in the same order of magnitude as these two previous parameters group.

Parameters related to building dimensions are found to be the least influential ones with a quite negligible influences, when using as an output the energy need per surface unit.

3.2 Influence of parameters taken individually

Considering each parameters individually, the first five influential parameters (with a normalized Morris indices up to 5%) are related to the three scales considered (material, wall and building) (Tab 3).

The HLM thermal conductivity is found to be the most influential parameter. It is the major contributor to the normalized Morris indices of the parameters group related to material properties.

The building location and the wall thickness are respectively found to be the second and third influential parameters.

Tab. 3: Morris indices of input parameters on the building heating and cooling energy consumption.

Rank of influence	Parameters	μ^* [kWh.m^{-2} ans^{-1}]	μ [kWh.m^{-2} ans^{-1}]	μ^*_{norm} [%]	σ [kWh.m^{-2} ans^{-1}]	σ/μ^* [%]
1	Thermal conductivity	485	485	38.3	21.3	4
2	Building location	242	-242	19.1	32.3	13
3	Wall thickness	225	-225	17.8	16.2	7
4	Comfort temperature	100	100	7.9	9.7	10
5	Internal heat sources	83	-83	6.6	7.8	9
6	Air change rate	31	31	2.4	1.5	5
7	Water vapour permeability	27	27	2.1	2.2	8
8	Internal humidity sources	23	23	1.8	1.6	7
9	Building width	18	-10	1.4	3.5	20
10	Building length	16	-5	1.3	3.8	24
11	Building height	14	14	1.1	1.0	7
12	Specific heat	1	-1	0.1	0.1	29
13	Density	1	-1	0.1	0.0	17

Parameters related to building indoor conditions are identified as the fourth and the fifth influential parameters with a similar influence. That are the comfort temperature and the internal heat sources variability. The combined influence of these two parameters represents the major part of the influence of the building indoor parameters.

3.3 Trend of influence

The following parameters were identified with increasing trend: the thermal conductivity, the temperature comfort condition, the ventilation rate, the water vapour permeability, the humidity sources and the building height.

These identified trends are rational as some of these parameters increase directly the need for heating like the building height which increases the heated volume, the comfort temperature which increases the need for heating to reach the imposed comfort condition. The humidity sources was also identified as having an increasing trend, because of an increasing effect on building indoor humidity as well as an effect on the material thermo-physical properties. In the other hand the increase of the remaining parameters increase the heat loss, the thermal conductivity, the ventilation rate (depending on the temperature difference between indoor and outdoor). We identify the following parameters having decreasing trends: the wall thickness, the material specific heat and the density. An increase in the wall thickness provokes an increase of the thermal resistance and thus a decrease of heat loss. For the material specific heat and density both parameters have an increasing effect on the heat storage. The building location is logically found to decrease heating energy needs in warmer winter climate zones.

Monotonic effect

All studied parameters are found to have a monotonic effects except the building width and length, probably due to their interaction in the calculation of the building area. However these parameters were identified having non relevant influences (Tab. 3).

Interaction influence and non-linear effect

A considerable influence in interaction and/or a non-linear effect are characterized by a high value of σ/μ*. We identified considerable influence/non-linear effects (σ/μ^*) of the following parameters: material specific heat (29%), building width (20%) length (24%), and HLM density (17%). A moderate interaction influence/non-linear effects were identified for building location (13%) and comfort temperature (10%).

4 DISCUSSIONS

4.1 Parameters influences

Material properties variability is identified as the most influential parameters group on the energy consumption of the simplified building model considered here.

As introduced before, variation of material properties considered here are supposed to be due to the manufacturing process of HLM. The HLM manufacturing process is thus one of the main keys to decrease building heating energy needs using this material. Two HLM manufacturing processes are reported in the literature: the projection process [Elfordy 2008] and the mixing process with manual application [Cerezo 2005, Evrard 2008]. The HLM thermal properties were shown to depend then on the compression constraint occurring during these processes. It alters the material density (the air proportion), and components arrangement. For the sprayed material, Elfordy et al [Elfordy 2008] established a correlation between the projection distance and the HLM properties (density, thermal conductivity). A similar observation was made by [Cérézo 2005] for the manually applied HLM, she founds that the HLM density (thermal conductivity) is proportional to the compaction constraint applied. Our study does not consider the relationship between manufacturing modes and thermal conductivity. The wall thickness was also identified as an influential parameter. The relevant influences of both parameters variability can be interpreted as the relevant influence of the wall thermal resistance which confirm the finding of [Peuportier 2001] who identified the wall composition as one of the main keys for building comfort energy consumption optimization.

4.2 Comparison with literature

We compared our study to two similar SA studies of building heating and cooling energy consumption using the SA of Morris. Corrado and Mechri [Corrado 2009] investigated the influence of 129 data (grouped in the following groups: climatic data, building envelope data and building use data) on the building's heating and cooling energy consumption [kWh.m^2.year^{-1}]. They used the monthly heating and cooling energy demand calculation method presented in ISO 13790:2008. They chose as a case study, a two-storey single family house located in Torino, Italy.

Garcia Sanchez et al [Garcia 2014] investigated the influences of 24 parameters on the energy heating and cooling consumption [kWh.year^{-1}] of a seven-storey residential building containing 32 dwellings. The ESP-R building energy calculation software was used for their study. In order to harmonize the input parameters the following changes were made. Wall thermal resistance was used instead of materials' thermal conductivity and thickness. All parameters altering heat indoor source were grouped in one parameter. Variability of relevant parameters on the building's energy consumption and their influences are reported in Tab. 4.

The materials characteristics

Corrado and Mechri [Corrado 2009] considered in their study a wall composed of four elements with a similar total thermal resistance as ours. They considered a half relative variation of the entire wall thermal resistance as compared to ours, nonetheless they obtained a three order less normalized Morris indices as compared to ours. That can be due to the fact that our building model overestimates the effect of this parameter as the model considers that the six faces are composed by the same material. For the study of Garcia Sanchez et al [Garcia Sanchez 2014] even though they considered a high relative variation of the insulation thickness (1900%), the computed effect was low. They found that variability of building's energy consumption variability is mainly dominated by the building's dimension [Garcia Sanchez 2014] and the thermal comfort parameters [Corrado 2009].

The building dimension

The influences of parameters related to building dimensions mainly depend on the choice of the model output. If the heating energy need per surface or volume unit (our case and [Corrado 2009]) is chosen as a model output, building' dimension parameters are not found relevant. If the energy consumption per year is chosen as output, a considered relative variation of 200% of these dimension parameters occasioned a normalized Morris indices around 67% [Garcia Sanchez 2014].

The indoor parameters

Parameters related to indoor environment, can be classified as parameters related to comfort temperature, or to the internal heat sources. For variations of comfort temperature, we chose a relative variation of 20% from 20°C. This parameter is identified as the fourth influential parameter, with a normalized Morris indices around 8%. A relative variation twice as high as ours was considered by [Garcia Sanchez 2014], from a minimal temperature of 17°C. It was identified as the fourth influential parameter with a normalized Morris indices of 15% considering as output the annual energy consumption for heating. A larger variation was considered by [Corrado 2009] around 92% (with a difference using normal distribution in the sampling). The Morris normalized indices of this parameter was found around 16%. The effect of the temperature comfort condition is quite proportional to the relative variation considered regarding our study and this of [Garcia Sanchez 2014]. For the study of [Corrado 2009] even if the considered variation is higher than ours, they obtained a normalized indices in the order of 16%.

Concerning the heat internal source a relative variation of the heat power around 100% from a minimal value of 500W, conducts to identify this parameter as the fifth influential one with a normalized Morris indices around 7%. A variation of the number of inhabitants from 1-8 per dwelling was considered by [Garcia Sanchez 2014], assuming that the variation of the heat released by occupants is proportional to the occupants number. With such variation no considerable effect was identified. Corrado et al [Corrado 2009] considered three parameters related to internal heat sources: the number of occupants, the metabolism, and the heat released by electronic equipment. Using these three parameters a total heat relative variation of 112% was observed. The normalized Morris indices of these three parameters combined is found around 36%. Here we can see the differences of the heat internal source effect for studies considered here due to its considerations.

The outdoor parameters

For parameters related to the building outdoor environment, we considered a variation of the temperature and the relative humidity encompassed directly in the variation of the climatic data (localization). Thus, we considered here variability instead of uncertainty. In our study, the Morris normalized value of this parameter is around 19%. It is identified as the second most influential parameter. Surprisingly, [Garcia Sanchez 2014] did not identify a relevant influence of the climatic outdoor parameters although considering a correction coefficient varying in the range [0.2-1] (relative variation around 800%) for climatic data (temperature, solar radiation, direct normal solar intensity and wind speed). [Corrado 2009] did not observe also a relevant influence of these parameters considering a monthly variation as reported in their work.

As we can see here, the magnitude and the order of parameter influence can be affected by numerous factors: the considered interval range, the probability distribution of the considered parameter and the other parameters. The model used and the case study are also relevant factors which can influence the parameters effect.

Tab. 4: Comparison of building heating and cooling influential parameters

. Parameters	References	Min value	Relative variation [%]	$\sum\mu^*_{norm}$ [%]	Rank of individual parameter
Wall thermal resistance [$m^2.K.W^{-1}$] (Thermal conductivity and thickness of wall components)	This study	1.05	375	**38.3**	**1 ; 2**
	[Corrado 2009]	0.85	170	12	4
	[Garcia Sanchez 2014]	-	1900 *	9	5
Building width ; length ; height [m] (Building dimension)	This study	3 ; 3 ; 2.2	100 ; 166 ; 27	3.8	9 ; 10 ;11
	[Corrado 2009]	-	-	-	-
	[Garcia Sanchez 2014]	-	200 ; 200 ; 200	**67**	**1 ; 2 ; 3**
Thermal comfort condition [°C] (Indoor parameter)	This study	20	20	7.9	4
	[Corrado 2009]	13	92	**16**	**1**
	[Garcia Sanchez 2014]	17	41	15	4
Indoor heat sources [W] (Indoor parameter)	This study	500	100	6.6	5
	[Corrado 2009]	397	112	36	3 ; 5 ; 6
	[Garcia Sanchez 2014]	100	700	-	-
Ventilation rate [$vol.h^{-1}$] (Indoor parameter)	This study	0.5	100	2.4	6
	[Corrado 2009]	0.12	2400	14	2
	[Garcia Sanchez 2014]	-	150	9	6

(*) Relative variation considered is for insulation thickness not for thermal resistance [Garcia Sanchez 2014]
(-) Value were not found

5 CONCLUSION

In this work the Morris SA method was used to identify main keys for the building heating and cooling energy consumption with a simplified building model made by hemp lime material. The approach helped us to identify the material properties as the most influential parameters on the building's heating and cooling energy consumptions, which is responsible for almost a half of the heating and cooling energy consumption variability.

This result is however specific to our case study (material and model used). From literature comparison, we can see that some parameter's influence can be overestimated and that we will need to integrate effects of combined multilayers insulators.

Such a model should allow us to calculating life cycle environmental impacts associated to choices of material, indoor comfort conditions, and provide action levers to improve the environmental performances of a building during the design phase.

Perspectives of this work can be the consideration of material properties dependency on factors like upstream process or the material properties evolution.

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