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# **Impact of thermal inertia coupled to natural night ventilation.**

## **A Case study for a high performance building in continental climate**

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# **Impact of thermal inertia coupled to natural night ventilation.**

## **A Case study for a high performance building in continental climate**

### Abstract

In summer time, thermal inertia appears as a passive solution to improve the thermal comfort in many part of Europe. The objective of this paper is in a first step to generate thermal comfort data from energy efficient houses in summer time with a focus on the impact of thermal inertia and natural night ventilation. In a second step, numerical simulation are run on these configurations to compare their construction systems. This work confirms the positive impact of both thermal inertia and natural night ventilation on the thermal comfort for energy efficient buildings in continental climate. It also allows to quantify the difference of indoor air temperature on this case study and to ensure the reliability of the numerical models. Finally, contrary to what is mentioned in many papers, no significant time lags between the heavy and the light weight envelope have been highlighted.

Keywords: Thermal inertia, Thermal behavior, Measurements, Simulations, Natural ventilation, case study.

## **Introduction**

Today energy issues are becoming increasingly important with a goal for 2050 to reduce by a factor four energy consumption in European countries (Europe, 2011). In Europe, building sector represents about 44% of the total energy consumption and produces around 36% of the CO<sub>2</sub> emissions (Buildings, n.d.). This leads to a changing building sector with more and more energy efficient new buildings with high insulated and air-tightness buildings. This can unfortunately rise to overheating in summer and so discomfort for the inhabitants. At the opposite, cooling systems are also increasingly used worldwide with predictions that energy needs for cooling systems will be higher than for heating in residential buildings before the end of our century (Isaac & van Vuuren, 2009). In this context, passive cooling techniques are becoming more and more important.

Thermal inertia coupled to natural night ventilation appears as an interesting passive solution to improve the thermal comfort in summer time. Indeed, during the day thermal inertia absorbs the heat gains (Gregory, Moghtaderi, Sugo, & Page, 2008). The amplitude of the indoor air temperature of the building is reduced (Ogoli, 2003) and a time lag appears between the peaks of the outdoor and indoor temperatures (Ulgen, 2002). The heat gains absorbed during the day are released at night (Tonelli & Grimaudo, 2014). Geetha et al. (Geetha & Velraj, 2012) said “natural ventilation is the most important passive cooling technique” for release the heat gains of a building. Natural ventilation has to be used with thermal inertia to release at night, when the outdoor air temperature is lower, the heat absorbed in the thermal mass during the day (Pfafferott, Herkel, & Wapler, 2005), (Amos-Abanyie, Akuffo, & Kutin-Sanwu, 2013), (Zhou, Zhang, Lin, & Li, 2008). With the natural ventilation at night, the indoor air temperature is also more comfortable during the day (Balaras, 1996), (Evola, Marletta, Constanzo, & Caruso, 2015).

Many papers exist in the literature dealing with thermal mass, mainly based on simulation. Aste et al. (Aste, Angelotti, & Buzzetti, 2009) showed, by dynamics simulations, a reduction of the cooling energy demand with the use of high thermal inertia walls. Gregory et al. (Gregory, Moghtaderi, Sugo, & Page, 2008) used numerical simulation to assess the impact of the thermal inertia on the thermal behavior for different typical building construction techniques in Australia. They demonstrated that the use of high thermal inertia can minimize the power consumption and can maintain a comfortable indoor temperature. Němeček et al. (Němeček & Kalousek, 2015) examined the influence of the thermal storage mass of a building on the thermal behavior, also by using a numerical simulation methodology. The simulated house is a passive wooden house in the Czech Republic. They showed that, for a single day simulation period, the thermal storage capacity of a wooden house with a reasonable quantity of thermal mass never achieves the same level of thermal storage of a brick house. Di Perna et al. (Di Perna, Stazi, Casalena, & D'orazio, 2011) realized a study in a school building with high internal heat loads in Italy. They showed a better comfort with the wall with high thermal inertia in summer and mid-season.

This study aims to qualify, based on real data and numerical simulation from an experimental case study, the impact of both thermal inertia and natural night ventilation on the summer thermal behavior of high efficient buildings in continental climate. For that some comparison of two different levels of thermal inertia are done thanks to both experimental houses and numerical simulations in summer time. The two experimental houses have different thermal inertia with similar geometries. Two scenarios are studied: with and without natural ventilation. Firstly, the indoor air temperature measurements are analyzed for these two buildings. Secondly, numerical models of these houses are completed with EnergyPlus software and compared to the measurements. Finally two scenarios are studied to evaluate the influence for identical geometry of the natural ventilation on the indoor air temperature of

houses with different thermal mass.

## **Methodology**

The first objective of this work is to compare the thermal behavior at summer time of two different construction system of high performance houses in continental climate. For this, the following methodology illustrated in Figure 1 has been developed.

Firstly, 2 experimental houses with simulated occupation under real weather conditions, described in the following section, has been used. These houses are similar in geometry and insulation performance with a main difference in there construction system (heavy (H-A-M) vs light weight envelop (L-B-M)) Thanks to extensive sensors, and continuous monitoring in August and September 2013, the thermal behavior of each house can be analysed (Step1). Even if, these two houses are similar, they have slight differences in there geometry, especially in the windows properties (geometry A correspond to the experimental high inertia house, and geometry B corresponds to the experimental light weight house). This does not allow to compare directly the experimental results and to conclude on the impact of the construction system on the thermal behavior.

Thus, Building Energy Simulation has been used in the following steps. Step 2 consists to develop a numerical model for each house (H-A-S, L-B-S), and to compare numerical results with experimental data, step2a for the heavy weighted houses (H-A-M vs H-A-S), and step 2.b for the light weight house (L-B-M vs L-B-S). In these steps, it is shown that both numerical models reproduce correctly the thermal behavior of the real houses.

The next step consists to develop identical numerical model, except from the construction system. For that, a second light weight model (L-A-S) has been develop for which the construction of the light weighted house (L) has been applied to the heavy weight geometry

(A). Step 3 will compare the numerical results of a light-weight house with its original configuration (L-B-S) with the geometry of the heavy weight house (L-A-S).

Finally, step 4 will compare the construction system light weight (L-A-S) vs heavy (H-A-S) houses everything else identical.

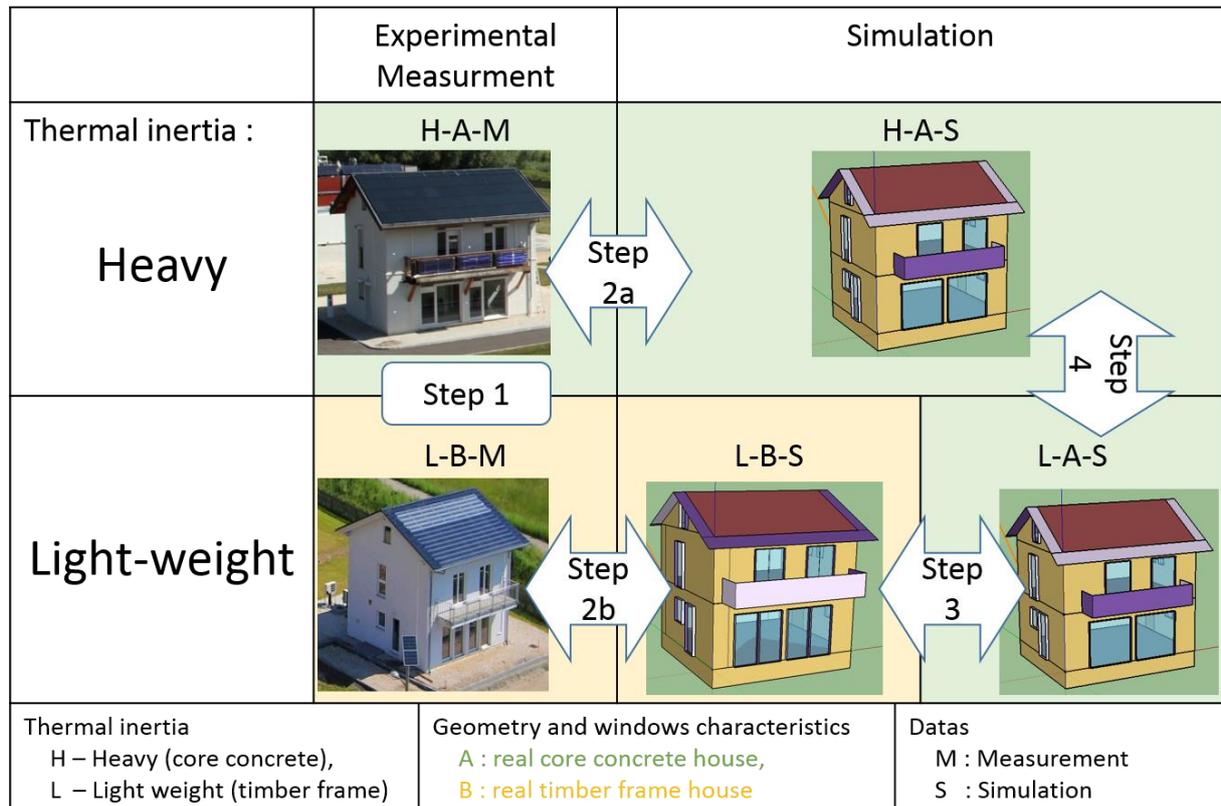


Figure 1: methodology used

### Case study

#### *Experimental houses*

Four experimental houses, named INCAS, are built on the full-scale Building Energy platform (Figure 2 - Top) at the French National Solar Energy Institute (INES). The platform is located in Le Bourget du Lac (N: 45°650, E: 5°867). These buildings are oriented at 15.3° on a North/South axis. Their geometries are simple, compact and similar in shape. They have been designed to have the same heating energy needs.



Figure 2: INCAS houses picture

These houses are low-energy buildings. They have an efficient envelope. On the ground floor of these two houses we have: a kitchen, a living room, an entrance, a storeroom and a WC. As for the first floor: 3 bedrooms, a bathroom and a WC as it can be seen in Figure 2 - Down

In this paper, only two of these buildings are studied: the house with a “pre-cast concrete” construction (that we will name H-A in this paper) and the timber frame house (L-B). H-A house has a high thermal inertia. The building is in pre-cast concrete with an exterior insulation. The building has double glazing on the South, East and West side and triple glazing on the North side. L-B is a timber frame house, which will represent a low thermal inertia building. The glazing is triple to the South and West side and quadruple to the East and North side.

### *Sensors*

Each house contains approximately 100 sensors. The sensors measure air temperature, radiant temperature, wall temperature, humidity, air speed, etc. The acquisition is continuous with a

one minute time step. In this paper only the indoor air temperature is presented. For that PT100 temperature sensors (class A, precision  $\pm 0.35^{\circ}\text{C}$ ) have been used. These sensors are located in the middle of each room at different heights: 0.1m, 1.1m and 1.7m. They are protected from direct solar radiation by white metal cylindrical shields. The experimental platform has a weather station, 50 meters from the houses, with several sensors. These sensors measure outdoor temperature, solar radiation (direct global and diffuse), wind speed and direction, humidity, pressure, etc.

### *Scenarios*

Two scenarios have been studied (Table 1):

Table 1: Scenarios definition

	Scenario 1: with natural night ventilation			Scenario 2: without natural night ventilation		
	Mechanical ventilation flow rate	Windows	Shutters	Mechanical ventilation flow rate	Windows	Shutters
7:00 am until 9:00 pm	0.5 vol/h	Closed	Closed except South	0.5 vol/h	Closed	Closed except South
9:00 pm until 7:00 am	OFF	1 opened / floor / orientation	Opened			

Table 2: Scenarios applied

	Week 1: 25/08 → 30/08	Week 2: 30/08 → 05/09
H-A-M	Scenario 1: With natural night ventilation	Scenario 2: Without natural night ventilation
L-B-M	Scenario 1 : With natural night ventilation	

The windows opening consists to some tilt and turn windows as shown in Figure 3 on the window in the middle.



Figure 3: Tilt and turn window of woodframe House (L-B) South face, ground floor.

### ***Simulation***

A numerical model for the heat transfer processes within the INCAS house is developed using the EnergyPlus whole building energy simulation program. The objective is to compare its simulation results contrary to the on-site measurements. Then to use it to carry out all the simulations.

### *Tool*

For the dynamic thermal simulations of the buildings the EnergyPlus 8.1 software was used. This tool was developed by the U.S. Department of Energy Building Technologies Office. It models, among other things, heat transfer through walls and windows, mechanical ventilation, natural ventilation, cooling and heating loads, and systems. The software is very used by the community of researchers (Sptitz, 2012), (Boyano, Hernandez, & Wolf, 2013), (Royuela., 2011), (Mateus, Pinto, & Carrilho Da Graca, 2014). It has been tested and validated by empirical results, analytical solutions and other tools (Henninger, Witte, & Crawley, 2004), (Tronchin & Fabbri, 2010) (Manz, et al., 2006).

### *Numerical model*

The houses are modeled with four thermal zones: the crawl space, the ground floor, the first floor and the attic. The algorithm TARP is used for all zones to calculate the indoor and outside surface heat transfer convection. The door between the ground floor and the first floor was closed but not sealed. Although, it is assumed in the simulation that there is no airflow between the two zones. No air infiltrations are considered between the ground floor and the first floor. Thermal bridges of the ground floor are taken into account with a thermal resistance of 0.0625 m<sup>2</sup>.K/W for H-A and 0.0883 m<sup>2</sup>.K/W for L-B. The infiltrations was measured with a blower door. Infiltrations was defined in the model at 0.0156 vol/h for the H-A house and 0.0324 vol/h for L-B. Data loggers in the houses produced internal heat gains. Regarding the number of data loggers and their position in the houses, the internal heat gains was set to 160W for the ground floor and 40W for the first floor of the H-A house and 70W for the ground floor and 40W for the first floor of the L-B house. The internal heat gains are defined as 70% by convection and 30% by radiation.

Regarding the ventilation, without natural ventilation, the ventilation flow rate is assumed at 0.5 vol/h for the ground floor and first floor. When natural ventilation is “ON”, , the Wind and Stack Open Area model in EnergyPlus is used. In this configuration, the ventilation air flow rate is determined from the wind speed and the thermal stack effect, along with the area of the opening being modeled (EnergyPlus Documentation).

## **Results and Discussion**

### ***Step 1: Measurements***

In this paper, only the indoor air temperature of the ground floor is presented.

#### *Weather conditions*

Measurements of the outdoor daily temperature and global horizontal irradiance are presented in Figure 4 from 25/08 to 05/09. Le Bourget du Lac climate is continental. These figures shows that maximum daytime temperature vary from 23 to 35°C and from 9°C to 21°C for its minimum at night. The daily temperature amplitude vary from 9°C to 21°C.

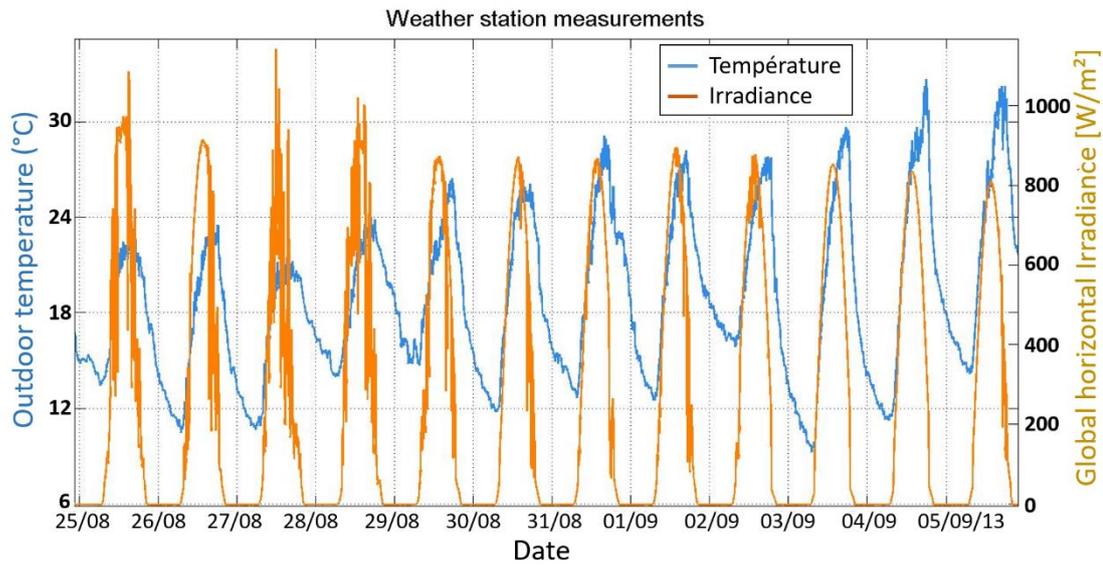


Figure 4: Weather station measurements – Zoom from 25/08 to 05/09

#### *Discrepancy of indoor air temperature in one floor*

As mentioned previously, many sensors are set in each house, especially for the air-temperature. Figure 5 shows the air temperature in different points of H-A ground floor. Most of sensors are located at 1.1m height except two in the living room: one at 0.1m and the other one at 1.7m height. It illustrates that the air temperature is not uniform throughout the same level. Higher temperatures are recorded at positions near the south windows (living room, eating area) at daytime. Relatively lower temperatures are recorded at positions away from the windows (WC, entrance). This is predictable due to the effect of the solar gains passing through the large south windows and heating mainly the floor part that is near these windows. The discrepancy between all the sensors can reach around 1°C. L-B house ground floor air temperature is not presented in this study but results are similar on the discrepancy of the measurements.

For the following parts, when only one measurement is displayed, the sensor in the living room at 1.1m height is chosen. This sensor is chosen because it's located in the middle of the ground floor.

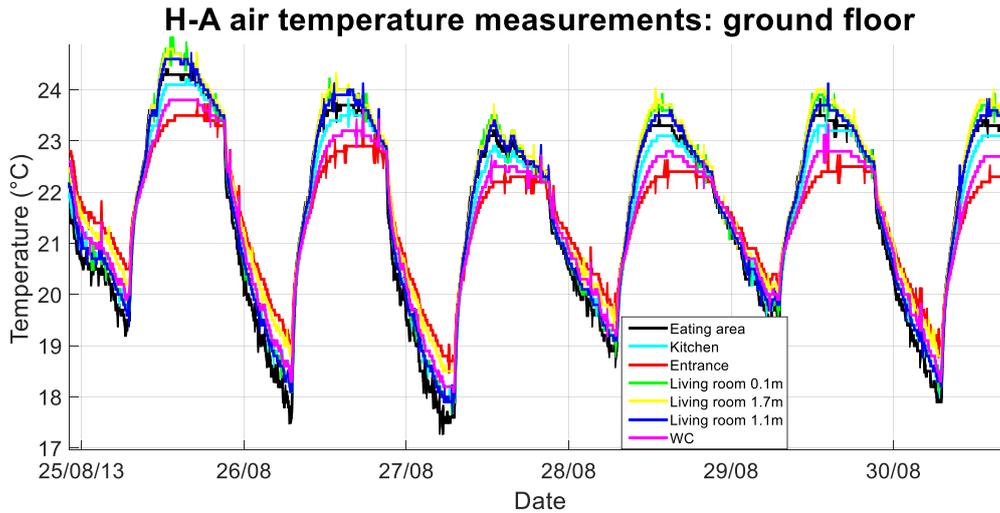


Figure 5: H-A air temperature measurements in ground floor

#### *Air temperature in each houses*

Measurements of the indoor air temperature in the living room at 1.1m height for H-A and L-B are presented in Figure 6.

From 25/08 to the 30/08, the same scenario, number 1 with natural night ventilation (see Figure 6), is applied in both houses. At 7 AM shutters (except South) and windows are closed, there is a direct increase of the air temperature because of the windows closed. The increase of the air temperature in the morning is faster in the H-A than in the L-B which is mainly due to the windows differences. Indeed, solar heat gains are around 40% lower in L-B than in H-A. At 9 PM, a significant decrease of the air temperature appear, when windows are opened, due to the natural ventilation. For this scenario and external condition, these houses have a similar behavior.

From 30/08 noon, the two houses do not follow the same scenario. H-A house follows the scenario 2 (without natural night ventilation) while L-B continues to follow scenario 1 (with natural night ventilation).

Figure 6 highlights the large impact of the natural night ventilation on the thermal behavior for both construction typologies. Indeed, L-B keep the same thermal behavior contrary to H-A. Without natural ventilation the H-A air temperature average increases day after day and the daily amplitude is reduced at around 2°C (compared to an amplitude from 5 to 6°C for the scenario 1). In the morning, H-A temperature without natural night ventilation, starts to

increase a bit later (around 30 minutes) than with natural night ventilation (as L-B), which follow the solar radiation and external temperature increase.

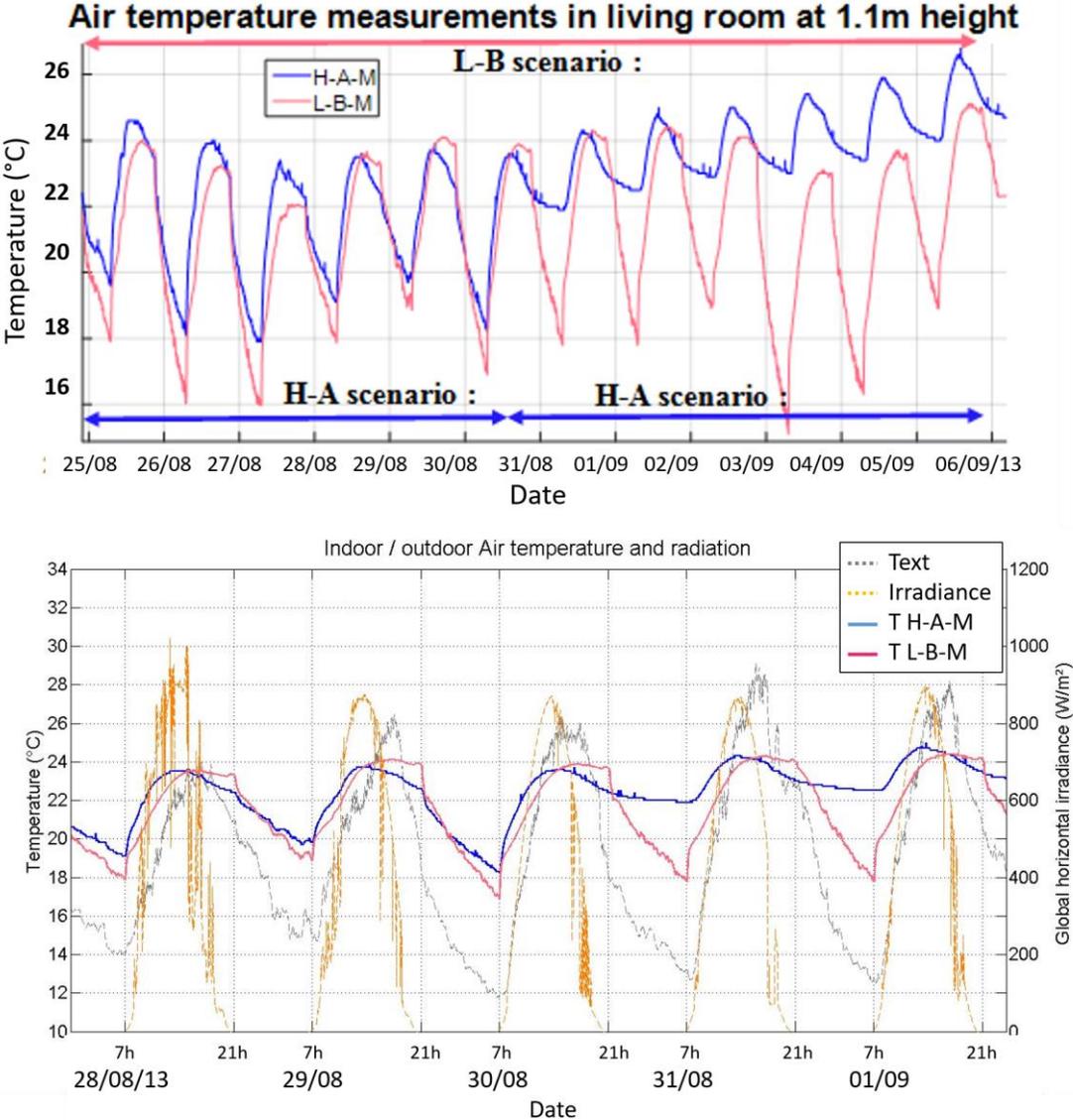


Figure 6: Air temperature measurements in living room from 25/08 to 06/09 (Top) - Zoom on Air temperature in Living Room with Weather conditions (Down)

**Step 2: Comparison measurements / simulations**

In this part, the comparison of the air temperature between the measurements and the simulations is done separately for each house (steps 2a and 2b respectively for the heavy and lightweight house). Simulations are carry out with a one minute time step as described in 0. In this study, only the ground floor is presented, the results on first floor are similar.

*Step 2a: Heavy weight House*

Scenario 1: With natural night ventilation

First the measurements and the simulation of the H-A house for the scenario 1 is compared.

As illustrated in Figure 7, and taking into account the uncertainty range of the sensors measurements, an acceptable agreement is obtained between the measured and the simulated temperatures. The maximum discrepancy between a measure and the simulation is around 1°C and appears at daytime. The day peaks are more pronounced for the numerical model. The reason may be that the model is overestimating the amount of solar radiation entering the house and/or underestimating the thermal inertia of the house. We also observe that the peaks are in phase between the measurements and the simulation.

Scenario 2: without natural night ventilation

Then, the air temperature measured and simulated for the scenario 2 are compared. Figure 7 shows a satisfactory agreement between the measurements and the numerical model. The maximum discrepancy is about 1°C between a measurement and the simulation and around 2°C just between the measurements due to sensors positions.

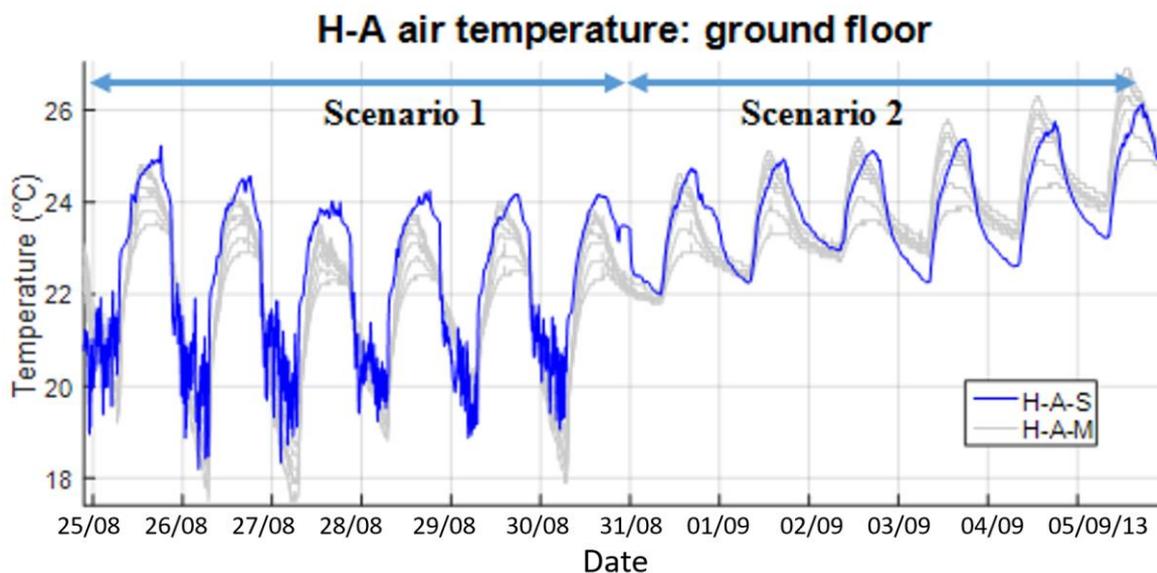


Figure 7: H-A air temperature: ground floor

In this part we can conclude that the numerical model of the H-A house represents correctly the thermal behavior in agreement with the measurements.

### *Step 2b: Light weight House*

Figure 8 shows the L-B ground floor air temperature measured and simulated for the August period. There is a good agreement between the numerical model and the measurements.

During the day and the night the simulated air temperatures are very close to the measurements (difference lower than  $0.5^{\circ}\text{C}$ ). Furthermore, peaks are in phase between the measurements and the simulation.

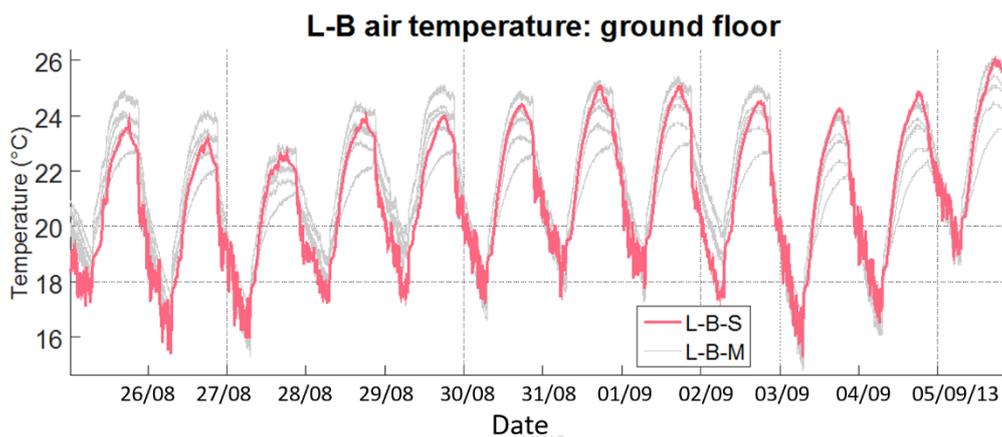


Figure 8: L-B air temperature: ground floor

In this part we have compared the indoor air temperatures between the measurements and the simulations for these two houses. The results showed an acceptable agreement between the numerical model and the measurements.

In the next part the objective is to estimate the impact of the type of construction on the thermal performance based on these numerical models. But as we have seen before differences exist between them: the geometry, the windows, the internal heat gains, and the infiltrations air flow rate.

### ***Step 3: Impact of the geometrical differences of the experimental houses – Numerical comparison based on light weight models***

A new numerical model of the light weight house has been defined. The model has the type of construction of the L-B house. But geometry, windows, thermal bridges and infiltrations air flow rate are the same as the H-A house. The new model is named L-A. Figure 9 shows the simulated air temperature for the L-B house and the L-A house. During the day time the L-A indoor air temperature is higher than L-B (around 2°C for the day peaks) due to larger solar heat gains as explained before. Indeed, the geometry A has double glazing windows and the surface of glazing is more important (+2.2m<sup>2</sup> for the ground floor) and the balcony is smaller for the geometry A, so the solar irradiance in this house is more important. At night the indoor air temperature is close between the buildings (differences is lower than 0.5°C).

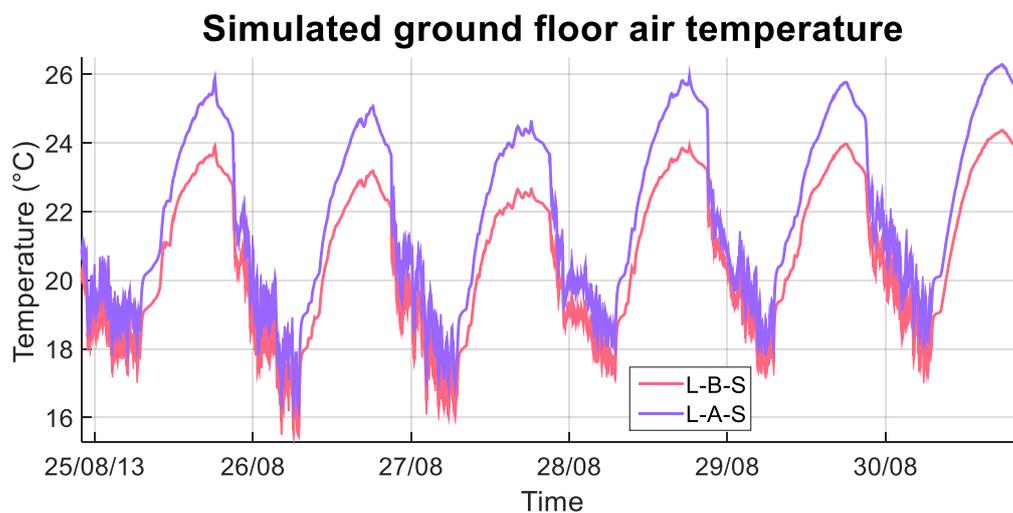


Figure 9: Simulated ground floor air temperature

### ***Step 4: Impact of thermal inertia and natural night ventilation on the thermal behavior***

The objective of this final step is to compare the type of construction of the two experimental houses. For this, H-A and L-A numerical models are used. Figure 10 represents the H-A and L-A air temperature simulated in August. As mentioned above, the numerical model used for L-

A has the characteristics of H-A, in order to only compare the type of construction of these two houses. The day peaks for the L-A temperature are higher than H-A (up to 2°C for August 28) because the H-A house has more inertia so the heat gains are absorbed by the thermal mass and the air temperature increases less. At night, the L-A temperature decreases more than H-A (around 2°C). Indeed the natural ventilation releases the heat gains and the H-A house stores more heat gains than L-A during the day so at night the H-A temperature is higher. The amplitude day/night is smaller (around 3°C) for the H-A house because of the inertia, but allow to keep the H-A in a smaller range of temperature between 19 and 25°C most of the time for these weather conditions.

This confirms the impact of thermal inertia in a continental climate on the decrement factor with the reduction of the temperature daily amplitude and the maximum temperature to improve the thermal comfort. However, contrary to what is mentioned in many papers, no significant time lags between the two types of construction have been highlighted.

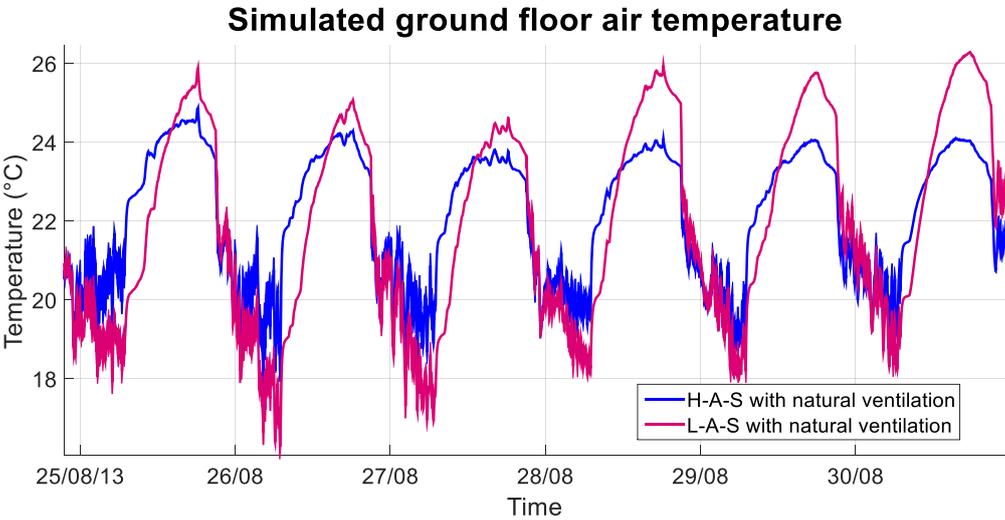


Figure 10: Simulated L-A and H-A ground floor air temperature

In this configuration, the air exchange rate vary from one night to another and is really dependent of the wind speed as shown in Figure 11. This figure shows the measured wind speed at night (From 9PM to 7AM), and the airflow rate in the simulated case of the Heavy house

which is strongly linked to the wind speed at night. The air flow vary from 2 to 3 vol/h for low wind speed (between 0.5 and 1 m/s) and rise up to 12 vol/h for higher wind speed velocity (up to 3 m/s).

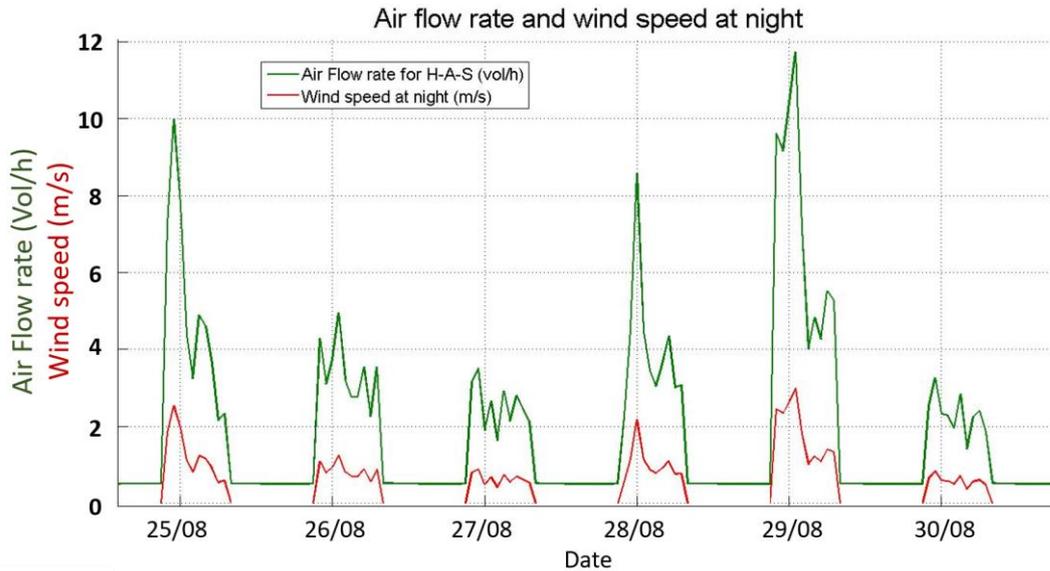


Figure 11: Simulated Air flow rate in ground floor of H-A-S, and wind speed at night

In order to qualify the impact of both natural night ventilation and thermal inertia, 4 simulations have been run and are presented here, 2 with H-A model, 2 with L-A. For each thermal inertia level, 2 different scenarios have been applied from 31/08, one with natural night ventilation (scenario 1), one without (scenario 2). Each simulation has the same scenario applied until the 30/08, with natural night ventilation (scenario1), as described in Table 3.

Table 3: Scenarios applied

	Configurations	01/08→ 30/08	31/08→08/09
Heavy	H-A with nnv	Scenario 1	Scenario 1
	H-A without nnv		Scenario 2 - without
Light	L-A with nnv	With natural night ventilation	Scenario 1
	L-A without nnv		Scenario 2 - without

Figure 12 shows the simulated ground floor air temperature for these 4 configurations. This confirms the combined positive effect of natural night ventilation and thermal inertia.

Natural night ventilation has a positive effect for both construction systems. For the light weight building, it allows to decrease the maximum of temperature up to 2°C and the minimum of temperature at night time up to 6°C. For the high thermal inertia house, there is a slight drift of the maximum temperature higher without natural night ventilation in this configuration which rises to 1°C after 5 days. The major difference appears at night where the minimum of temperature is higher of 4°C without natural night ventilation. As shown previously, the high thermal inertia is more comfortable than the light weight house with or without natural night ventilation. The difference between the light and the high thermal inertia house rises if the buildings don't have a strategy of natural ventilation during the night for this weather conditions. In this case, the high thermal inertia house is more robust to guarantee the thermal comfort for a few days of hot wave without a control strategy to benefit from the cool nights.

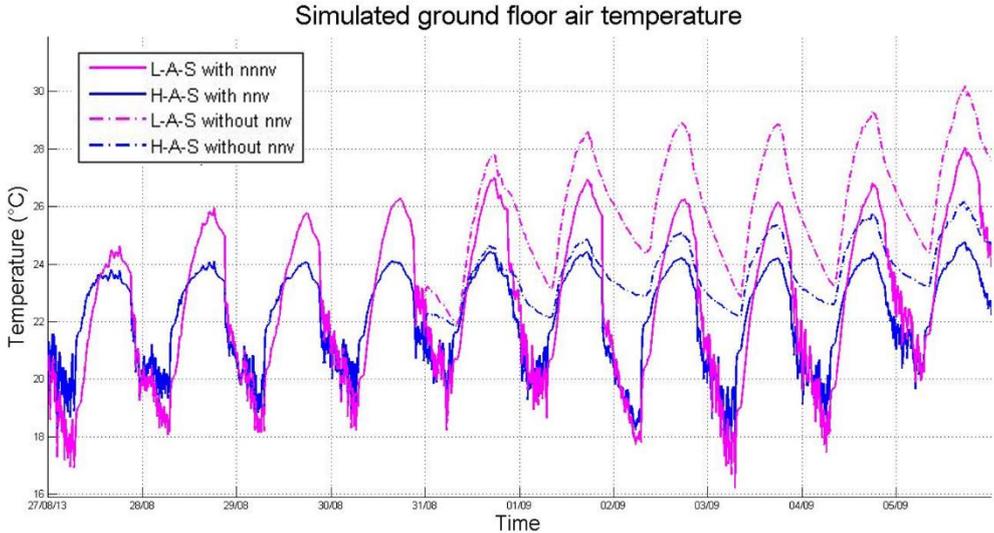


Figure 12: Impact of thermal inertia and natural night ventilation on thermal comfort

## Conclusion

The objective of this paper is in a first step to generate thermal comfort data from energy efficient houses in summer time with a focus on the impact of thermal inertia and natural night ventilation. In a second step, numerical simulation are run on these configurations to compare their construction systems. For this, the thermal behavior of two energy efficient houses with different thermal mass is studied in summer time. These two experimental houses are located on the Building Energy platform at INES in the French Alps. The heavyweight building is built with a “pre-cast concrete” construction and the lightweight house has a timber frame construction. They are unoccupied and are equipped with many sensors (around 100). Two scenarios are studied during one month: one with natural ventilation at night and the other one without. Firstly, the indoor air temperature measurements of these two houses on the ground floor are presented. The impact of natural night ventilation is quantify for this configuration. Indeed the daily amplitude in this configuration is reduced from a value of around 6°C with natural night ventilation to only 2°C without, and the daily maximum of indoor air temperature is kept globally constant with natural night ventilation while it is increasing day after day without. However, differences between the two houses exist and so it is not possible to compare directly their thermal behavior. This is why numerical models have been developed with the EnergyPlus 8.1 software. First step, ensures that these models represents correctly the thermal behavior of each house, and so numerical results are compared to the measures. Finally, an additional model has been built to compare the two construction systems on the same geometry and characteristics (except from the wall materials).

This work confirms the positive impact of both thermal inertia and natural night ventilation on the thermal comfort for energy efficient buildings in continental climate. Thermal inertia reduces the peaks of temperature during the day and the amplitude day/night of the temperature.

The difference between the case ‘light weight and without natural night ventilation’ and ‘heavy weight and with natural night ventilation’ is up to 5 to 6°C on the indoor air temperature during a whole day. It also highlights that internal mass permits to have a building less dependent of the natural ventilation scenario for energy efficient buildings. However, contrary to what is mentioned in many papers, no significant time lags between the heavy and the light weight envelope have been seen.

As a perspective, a new experimental house has been built in a Mediterranean climate in which, specific sensors has been implemented to follow the impact of the thermal inertia on the building thermal behaviours. Indeed, temperature and heat flux sensors have been implemented in the concrete slabs and in a massive concrete wall at different depths. This will allow first to better know the heat flux between the massive elements of the house and the air, to have another type of climate, and to continue in the comparison with numerical models and improve them.

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