Enhancing knowledge on energy saving and insulation efficiency in buildings, by analysing thermal behaviour of a realistic small scale house

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Abstract: Within the framework of sustainable development, a small scale genuine materials house (1/20 scale) and surroundings has been designed. The realisation itself has already been described in a previous paper [1]. Due to the modular structure of the design, different types of measurements ate possible, like in a real house for education purposes. In this paper, a study of thermal behaviour of the small scale house is presented. Steady state and transient behaviours with different double wall insulation are compared using temperature sensors and infrared thermal imaging. Results are discussed. As these results are positive, this 1/20 model kit will be used as an educational tool for practical work in the near future.

Key words: thermal measurement, energy saving, infrared measurement, education to Sustainable development,

1. Introduction

1.1 ENSEIRB MATMECA, a graduate engineering school

This “sustainable development” study was initialized at ENSEIRB-MATMECA school: The “Ecole Nationale Supérieure d’Electronique, Informatique et Radiocommunications de Bordeaux”.

1.2 Project short overview

This global project was carried out through national collaboration with “the House of the Nature and the Environment” (MNE) of Bordeaux, national french organism ADEME (Agency of the Environment and the Control of Energy) France, the ENSEIRB-MATMECA (33400 Talence), the colleges Chambéry (33140 Villenave d' Ornon) and Henri Buisson (33400 Talence) (professors and pupils) for the realization of the small scale house.

2. Small scale House project state of art

2.1 Generalities

The project of small scale house model started three years ago [1] from individual initiative of a few researchers and teachers.

A personal sensitivity to sustainable development helped to start the project while respecting obviously the mains scientific fields of our engineering school.

Thus, the « small scale house » project was born. The aim was to build a original fully functional modular model of house with genuine construction materials and its “green” energy generation system. The finished model will be used as:

- demonstrator (exhibition in town halls or local sustainable development events)
- educational support for practical lessons and electronic projects, for sensitizing ENSEIRB MATMECA engineering students.

2.2 Originality and interest of the study

With the climate change, the sustainable development concept introduction and agenda 21 adoption, the Kyoto protocol has defined an ambitious goal for France: to divide French green gasses emission by four. As private houses and buildings represent a significant contribution of the global emission, French government decided to start a renovation program of the French flats and buildings [2].
In order to quantify and to set up priorities, a thermal cartography of the most important French cities has been first decided to determine the main sources of thermal losses and over consumption. Bordeaux was

one of the selected cities for such full thermal assessment [3], [4]. A thermal cartography of the Bordeaux and suburb [5] has been done flying over and scanning the city with an embedded infra red camera. This will and action of our French politic representative show the new importance given to thermal measurements.
Thus, the work (unique in France) presented in this paper shows a possible contribution, among others, to illustrate these new goals within the Sustainable Development concept framework.
This study can be secondly seen as an attempt to experiment a full scale phenomenon in laboratory conditions. Indeed, the small size of the house and small scale materials allows comparative experimental studies who might be difficult to make in true houses.
Thirdly, from a didactical point of view, it is also an innovative approach: Rather than to train our students with the measurement techniques and to apply it to the electronic assembly or circuits, we chose "to move" the field of application towards sustainable development without modifying or lowering the scientific contents.

Finally, it is also a preliminary work to check and to validate the possible uses and performances of the small scale house model. Once validated, it should be transformed in a educational tool and be included in practical lessons in first year of study. Indeed, the small scale house model will offer the possibility to perform "indoor measurements" in the school for a small group of students without the need of heavy infrastructure.
At last, showing thermal losses in a small scale house, discussing and measuring thermal insulation efficiency during practical lessons could have a kind of unconscious impact on the students in their way of minding.

2.3 Scaled house design short overview

The building (with true materials) of small scale house itself is ended. Preliminary design and manufacturing required more than 1500 hours of work, including pupils, students, and teachers work [1].

The external dimensions of the 1/20 scale house model are 50cm x 50cm. It consists of 3 independent parts (cf. figure 1) encasable like a "turned over shoes box". External walls are made of Autoclaved Aerated Concrete (AAC) 2.5cm thickness (part 1) coated and painted. There are one door and 4 windows. Interchangeable interior insulation double wall and ceiling (part 2), is encasable by the top, inside the external walls. At last, a removable pitched roof (part 3) is made of pine tree wood parallel roof truss, covered with terra cotta tiles. Attic may be filled with mineral wool insulation. A roof solar panel is integrated on one side of the roof. The empty "basement" is used for electrical wiring and electronic circuit's installation.

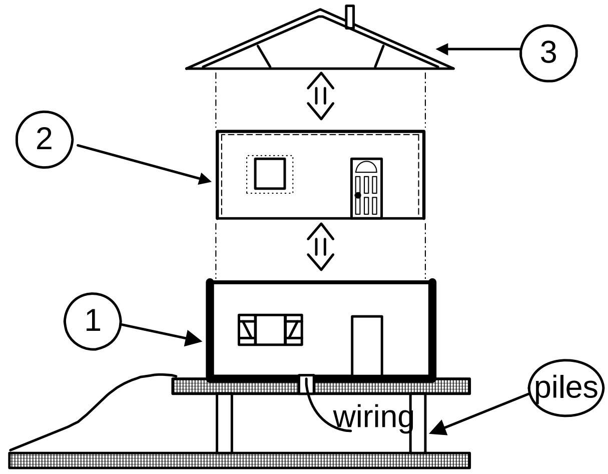

Figure 1: modular house design

Figure 2 shows the AAC walls during the building and assembly phase.

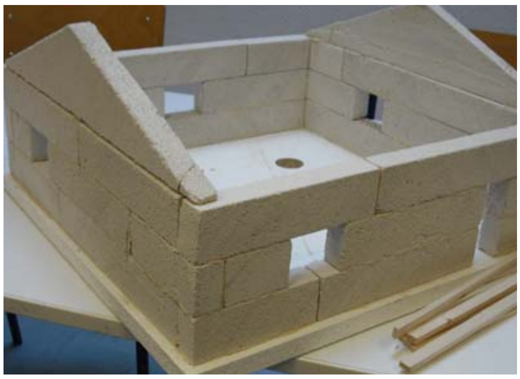
Figure 2: AAC external walls building

The structure of scaled double glazed windows is given in Figure 3. The space between the two glasses is a simple air gap.

All the windows frames have been machined from the same raw material plate (PVC). Small glasses have been cut from a unique wide glass plate. Machining was programmed on a digital milling machine. Thus identical geometrical characteristics (thickness and size) are guaranteed as well as homogeneous thermal characteristics.

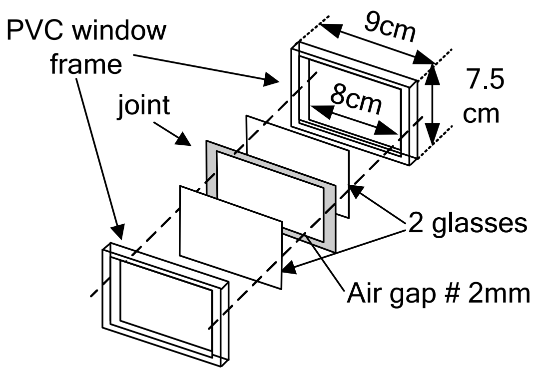

Figure 3: open view of mini double glazed window assembly.

An example of interchangeable insulation internal walls and ceiling, with it s window fram e and main door is given in Figure 4. (The "box" has been turned on one side for an easy capture of picture).
Three "boxes" with three types of insulators have been designed to be able t o make practical thermal performances comparison. Each "insulation bo x" consists of 3 parts:

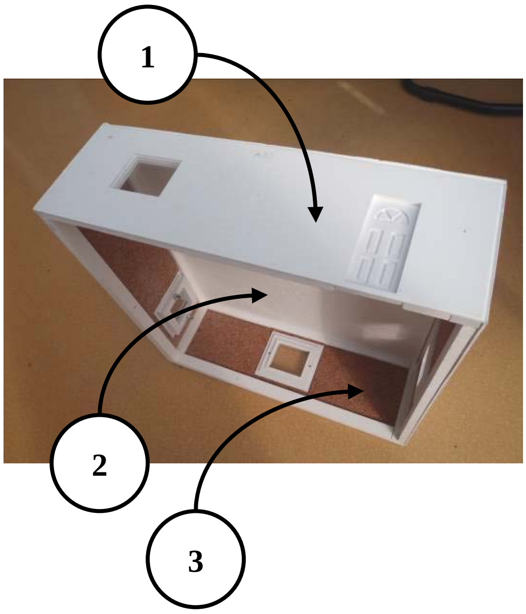

Figure 4: Encasable double wall insulation

Part 1: 3mm thickness Forex frame (walls and ceiling), for mechanical rigidity
Part 2: 5mm polystyrene layer for the ceiling (ceiling internal surface: 41cmx41cm)
Part 3: wall insulation layers. Depending of the "chosen box", walls are insulated as follow:
- Mineral wool (6mm thickness + thin alum inium sheet to press lightly the wool). The thermal conductivity of mineral wool is arou nd 0,038 W/m.K (insulator n° 1).
- Polystyrene insulator 5mm, with a ther mal conductivity # 0,039 W/m.K (insulator n°2).
- Thin cork l ayer 3mm (thermal conductivity # 0 ,05 W/m.K) (insulator n°3).

A photo of the finished scale modular and evolvable small scale house model is shown in Figure 5.

Figure 5: Finished small scale house.

3. Experimental study of the thermal behaviour of the small scale house

3.1 General operating conditions

Our house model is placed in a base ment workroom which remains at a stable temperature during all the experimentations, inside the ENSEIRB-MATMECA School. The workroom temperature is thus considered as the outdoor tem perature for the small m odel. The small house is heated more than the room temperature to produce a te mperature gradient between its insi de and outside. Only comparative measurements will be performed to obtain credible results.

3.2 Experimental platform preparation

The removable roof allows us to install the heating power sources, te mperature sensors…Depending on experimentation; we can r emove the double in ternal insulation or change the insulation materials.

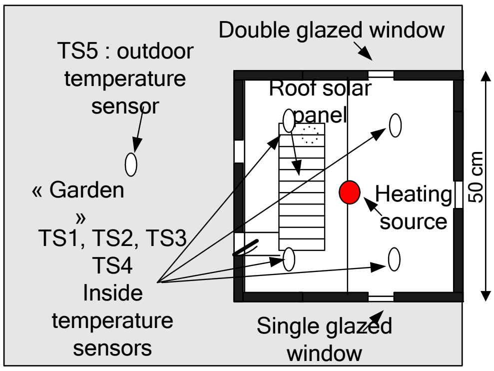

Figure 6: experimental platform

Test bench is prepared as indicated on figure 6.
Heating power source, placed into the house, is a 12V DC 20W halogen small spotlight.
Inside and outside temperature small scale house are permanently displayed and checked during all the practical tests by temperature sensors.
In order to lower the parasitic effects (air turbulence, sun light etc.), the working room and shutters are closed. And measurements are performed early morning before any kind of human activity.

4. Thermal experiments

4.1 General test operating conditions

Absolute errors on temperature measurement are always possible especially with basic thermometers. Thus, to make reliable tests, we worked only by a comparative and differential measurement. Each series of measurements has been performed several times to guarantee reproducibility and representative results. Moreover, we set up strong measurement conditions as follow:

- As indicated in paragraph 4.3, insulation boxes have exactly the same size to guarantee identical physical properties.
- The heating source is located exactly in the middle of the small scale house equally spaced from the walls. The heating power is set up at 20W to increase the temperature difference between indoor and outdoor.
- The two temperature sensors TS1 and TS2 are two K thermocouples associated to two channels thermometer Keithley 871A. They are located in the house at 5cm from the wall and at 3 cm high to measure the indoor temperature. TS3 and TS4 are PT100 temperature sensors.
For each set of measurements, the reported inside temperature is the average between the four values.
- The initial ambient temperature is checked by temperature sensor TS5.
- Initial surface external wall temperature identical on the four walls (checked by contactless IR thermometer MO297).
- An infrared camera FLIR B335 takes pictures at a regular rate during the each experiment.

4.2 Preliminary checking before thermal measurements

The halogen lamp behaviour has been preliminary checked. The shape of the applied electrical power pulse is shown on Figure 7.

The upper trace shows the 12V DC voltage applied to the lamp (Vertical scale 10V/div). The middle trace (curve 2) shows the current across the lamp (Vertical scale 2A/div). The lower trace (red curve 3) show the power pulse shape (Vertical scale 20W/div), obtained by scope internal mathematical functions.

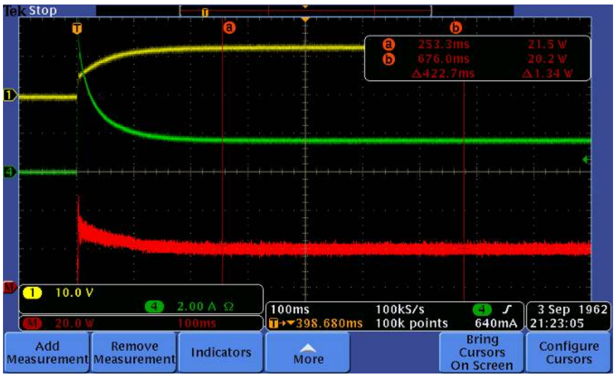

Figure 7: Power pulse settling time (Horizontal scale: 100ms/div)

The transient peak current at the beginning of the pulse is obviously due to the temperature change of the lamp filament bulb. Electrical power pulse reaches a stable value after roughly 200ms. Thus, this settling time is very short compared to thermal time constant of the small scale house; Electrical power pulse can be considered as a “perfect” power pulse.

4.3 Transient measurements strategy

Four successive series of measurements are performed: the first one without insulation and the next three one’s with a different insulation box (numbered 1, 2, 3) described before.
After switching « on » the 20W heating source, temperature measurements are reported each minute, during 22 minutes (long enough to see differences in thermal behaviour). Between each series, a dead time of 30 minutes is required to decrease temperature and to return to exactly to initial conditions.

Figure 8: Interlocking double internal insulation.

A new insulation box (cf. figure 8 and 9) is interlocked and a new set of measurements is performed.

Figure 9: Polystyrene wall and ceiling viewed from inside.

4.4 Infrared measurements [6], [7], [8],

In addition, Infrared camera FLIR B3 35 was taking picture of the house at regular time interval, during each transient test, to che ck external walls and roof temperature evolution. (Cf. figures 11 to 16).

5. Results and analysis

Experimental results are given in §5.1 and discussed in §5.2.

5.1 Experimental results

Figure 10 shows the four transient res ponses of the house inside te mperature, reported according to the conditions given in § 6.1 and 6.3. Vert. scale: average inside temperature (°C), H. scale: time (minutes).

Figure 11 shows the Infr ared image of the house at initial time 0 (before applying the power pulse).
Figure 12, 13 and 14 correspond to the first series of transient test (i.e. without internal insulation)

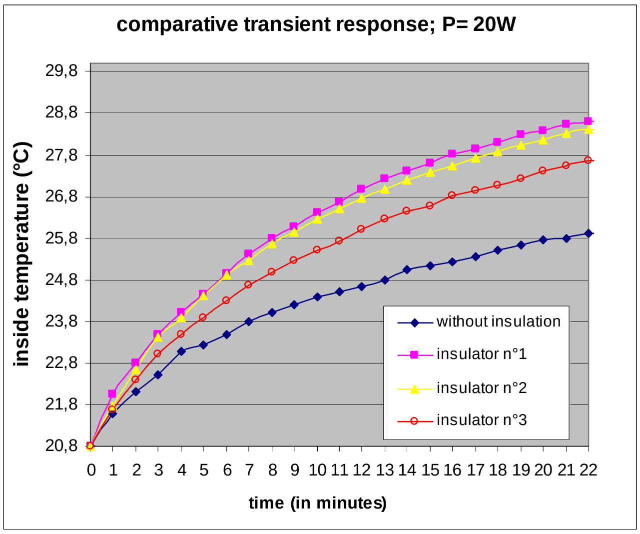

Figure 10: Comparison between the different types of insulators (transient response)

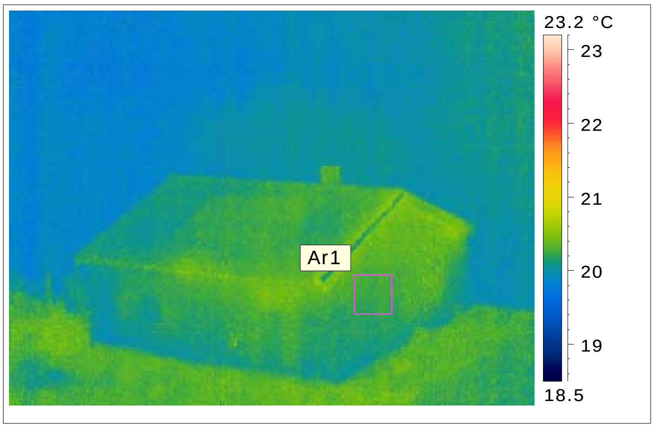

Figure 11: Infrared imaging (initial condition)

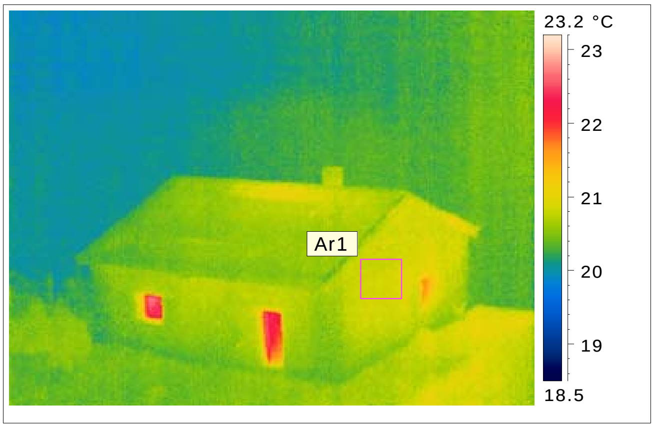

Figure 12: House outside temperature after 20 minutes and without insulation.

Figure 12 shows the outside wall tem perature after 20 minutes of heating. The average initial wal l temperature in cursor Ar1 is 20.4°C.
The final average wall te mperature in the same ar ea increases up to 21°C.

Figure 13 shows the final roof temperature after 20 minutes and Figure 14 the corresponding temperature profile along the roof (cursor line Li1). Temperature variation along the line, is between 20.5°C (ro of border) and 21.5°C (on the top).

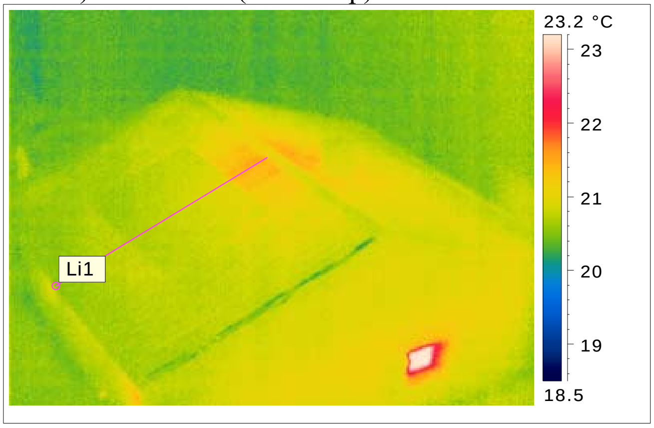

Figure 13: Roof infrared imaging (after 20min without double internal insulation)

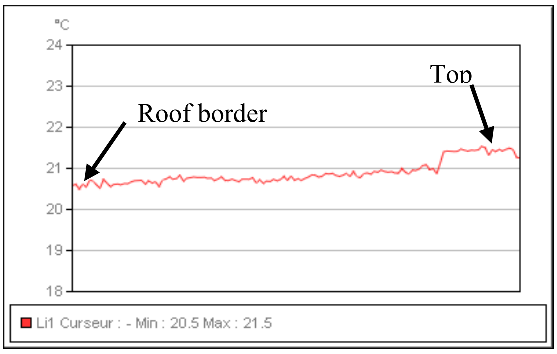

Figure 14: temperature profile along the roof without double internal insulation

Figure 15 and 16 correspond to the second series of measurements (i.e. with insulator n°1). Figure 15 shows the temperature of the roof reached after 20 minutes and Figure 16 the corresponding temperature profile along the roof (cursor line Li1). Temperature variation along the line, is between 20.1°C (ro of border) and 21°C (on the top).

5.2 Results analysis

Results obtained from figure 10 can be analyzed as follows:

a) Without any insulation, inside temperature increases slowly and final temperature is obviously lower than the others.

b) With insulator n°2 (wall and ceiling 5mm polystyrene), the temperature obviously increases more quickly. An improvement of 2.5°C (as compared to the previous situation) is obtained after 22 minutes. Major part of improvement comes from the ceiling insulation.

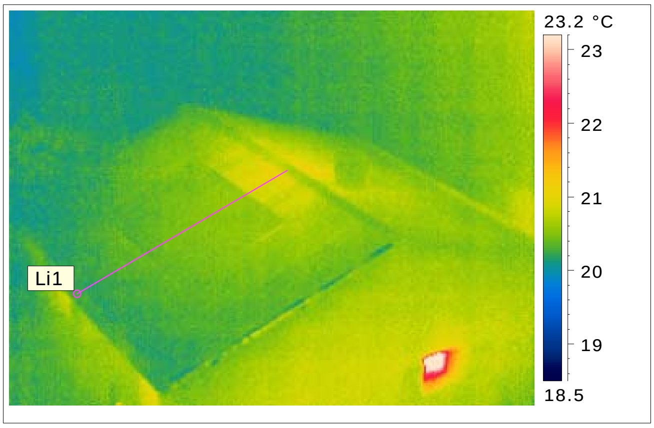

Figure 15: Roof infrared imaging (after 20min with insulator 1)

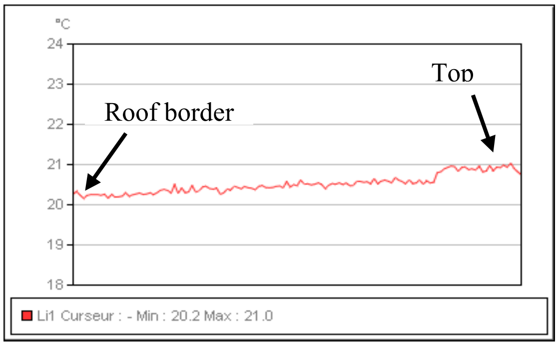

Figure 16: temperature profile along the roof (with insulator n°1)

c) Insulator n°1 (6mm mineral wool) gives almost the same result than insulator n°2 (thermal conductivity are quite identical).

d) Insulator n°3 (thin 3mm cork layer on the wall) is not so good than the others: gain compared to a) is around 1.76°C. From b), contribution of polystyrene ceiling represent around 1.31°C, contribution of cork layer wall insulation is thus around ΔT_{cork}= 0.35°C. Relative efficiency of cork and polystyrene can be checked approximately:
Since thickness of cork layer is 3mm (against 6mm for mineral wool) and its thermal conductivity is around 0.05 W/m.K (against 0.03 W/m.K for mineral wool) insulation, we retrieve correct proportions between the two materials.

From infrared imaging outside surface temperature, we can make some checking and cross validation:

a) From figure 12, 13, 14, ("without insulation" test) final surface wall temperature (21°C) and roof temperature (20.5°C to 21.5°C) after 22 minutes of heating.

b) From figure 15 and 16, (insulator n°1 test), the final outside surface temperature are a little bit lower : 20.8°C for the wall and 20.2°C to 21°C for the roof.

Thermal effect of insulation is thus confirmed. Main tendencies, relative measurements and order of magnitude are enough coherent and significant to use the small scale house as didactical tool and/or demonstrator.

6. Future work

6.1 Theoretical aspects

From experiments, an equivalent SPICE thermal modelling is going to be extracted. It will allow prediction of thermal behaviour under various conditions (changing insulator materials, replacing single by double window or moving the heating source), and quantification of energy saving. A comparison with suitable finite element 2D or 3D Thermal CAD tools modelling should be done [8], [9], [10], in order to check the quality and performance of our SPICE modelling

6.2 Thermal behaviour and house energy consumption link

In order to make our small scale house as realistic as possible, an electronic circuit to heat the house and regulate the inside temperature is going to be designed. Some ceramic resistors and heating floor will act as electrical heaters driven by an "on/off" PWM signal. By a real time monitoring of the consumption, it will be possible to know the average energy consumption of the house under various conditions ; in particular, impact of heater's position in the house will be investigated. Comparison between heaters fixed below the window, a common situation in true houses, or elsewhere), will be easily done and thermal measurement correlated to energy consumption monitoring.

7. Conclusion

Three years were necessary to design and to build a functional realistic small scale house, with genuine materials. It was completed successfully within the framework of an innovative sustainable development project and awarded by the town hall of TALENCE during the sustainable development week event. Thermal behaviour of the house model was investigated. Insulation materials efficiency was checked. And relative tendencies are demonstrated by a comparative approach like in a true house.

Reliability of our model being proved, it can now be used transferred for didactical applications.

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