- IR thermal measurements performed after 1/3 hour waiting to insure steady state conditions,
- Camera mode: “merged”, to superpose normal and IR Image for better understanding
- Distance “camera to target”: one meter
- Autofocus on windows with thermal pointer on the middle of the window.

7.3.2 Infrared measurement

Figure 12 and 13 shows example of comparative measurement between single and double glazed windows with an heating power of 60W. House indoor temperature after 1/3 hour reached 41°C (workroom temperature 23.6°C).

On figures 12 and 13, a cross section along the white horizontal line passing through the middle of windows has been extracted (with FLIR reporter 8.5 software).Temperature profile is given in figure 14.

Looking at these three pictures, it is observed that outside surface of double glazed window is colder than the one of the single glazed. The average difference is around 2.8°C. Thus, efficiency and better insulation of double glazed window is shown in the small scale house like in a true house.

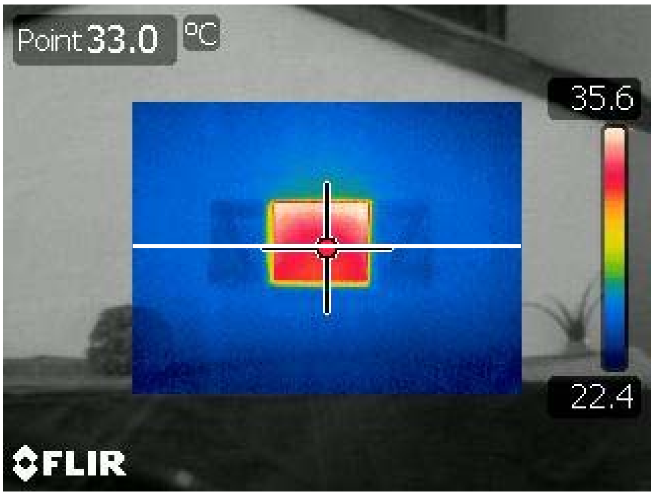

Figure 12: Single glazed window

Several similar measurements have been performed with different heating power and different work room initial temperature to confirm the previous results.

Figure 13: Double glazed window

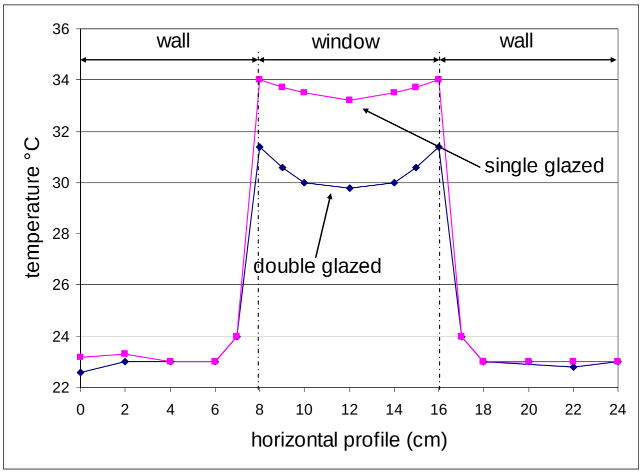

Figure 14: Horizontal temperature profile

Table 1 gives example of measured temperatures for various heating source power values.

Heating power	20W	40W	60W
Outdoor temperature (i.e workroom temp) (in °C)	20.6	20.6	20.6
Indoor scaled house temperature (°C)	26.6	31	39.2
Temp Difference in/out (°C)	6	10.4	18.8
Outside surface temperature single glazed (°C)	24.7	28	35
Outside surface temperature double glazed (°C)	23.6	26	31.7
Delta single/double glazed	1.1	2	3.3

Table 1: Temperature measurements

Figure 15 shows the difference temperature between the outside surface single glazed and double glazed vs. the inside/ outside temperature difference obtained from table 1 and other extended measurements.

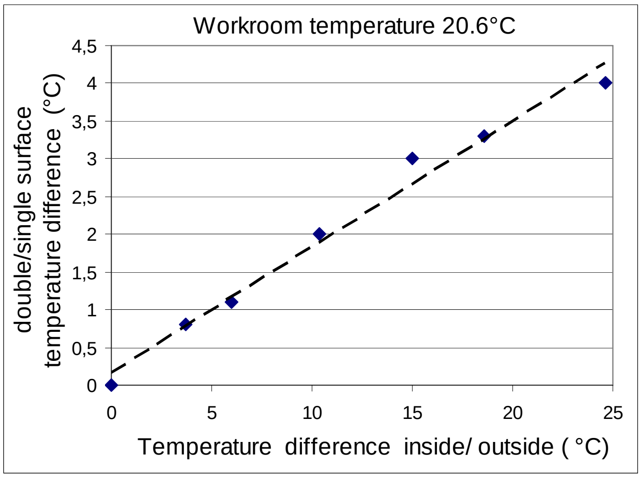

Figure 15: Efficiency of double glazed window

At last, the double glazed window was replaced by a single glazed one's. The same measurements were performed one more time. No significant temperature difference between the two tested windows was detected (less than 0.3°C): improvement in temperature barrier effect comes really from the double glazed window.

7.4 General insulation

Effect of global insulation has been tested by doing the following experiment:
First, the double wall insulation and ceiling insulation was removed. A heating power of 40W was necessary to heat the small scale house at 28.5°C (with a working room temperature of 20.6°C).
Under this condition, figure 16 shows the infrared image of the roof. Rectangular shape on the left slope is the roof solar while the hot point behind the chimney corresponds to a small roof window.

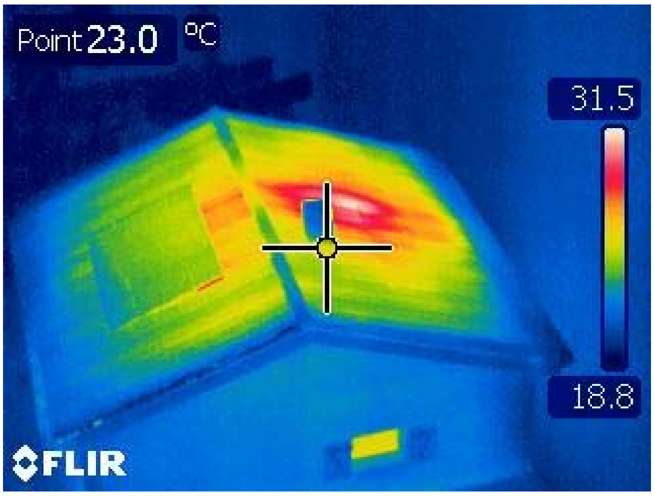

Figure 16: Roof top view without double wall and ceiling insulation

Secondly, we installed the double wall and ceiling insulation. Only a power of 20W was necessary to obtain the same indoor temperature.

Figure 17 shows the infrared image of the roof when insulation is installed. Temperature scale is the same for an easy comparison of the two situations. Heating power was divided by 2 and thermal losses are obviously reduced. The maximum temperature (small roof window) and temperature gradient on the roof are lower.

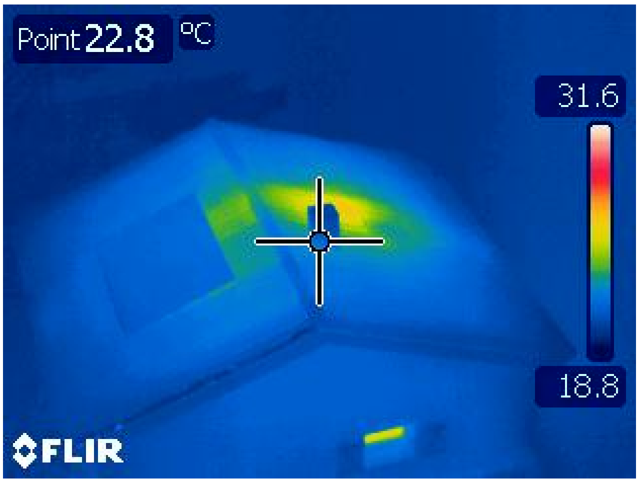

Figure 17: Roof top view with double wall and ceiling insulation

8. Results discussion and credibility checking

Measurement conditions on the house model are obviously different from the reality. It was important to check tendencies and credibility of the work by making a comparison with a real situation. This was done by performing measurements and data collection over 6 years (before and after renovation), in a renovated apartment in Bordeaux. It was located at the 5^{th} floor, just under the flat roof, on east and north side of a building, built in 1984, with poor/medium initial insulation characteristics, heated by natural gas.

In 2008/2009, this apartment was renovated: global insulation of the flat roof (12 cm of polyurethane foam + bituminous watertightness), north wall insulation (12 cm thickness polystyrene tiles) and replacement of old windows by double glazed windows (4cm/16cm/4cm) has drastically decreased the annual heating power consumption (divided by more than 2) for the same comfort temperature as shown on figure 17.

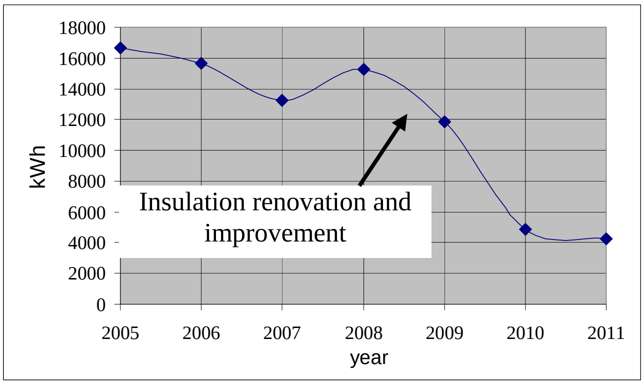

Figure 17: Annual heating energy real consumption (KWh) of the tested apartment

Since only north wall was double insulated, while the east wall was not, it was easy to compare the thermal efficiency of the two. Outside surface temperatures of the two walls were compared using the same infrared camera. Measurements were done late evening in autumn season, when the outside air temperature goes down. Room temperature was 18.5C. Outside air temperature varies from 6°C to 12°C. Temperature difference between the two wall surface was roughly 0.5°C and 1°C when temperature difference between inside and outside varies from 6°C to 12°C. Same measurements have been done on the same apartment (but without renovated insulation) on the 4th floor, just under. North wall and east wall outside temperatures were identical.

Thus, effects of insulation are similar for the small scale house model and for a true apartment. Compared to a true situation, order of magnitude of the heating power saving given in paragraph 7.4 seems to be realistic. And results given in §7.3.2, are definitively reasonable and validated: In particular, effect of the scaled double glazed windows is demonstrated.

9. General assessment

9.1 Technical benefits

This work was first the opportunity to carry out an infrared camera, in an original application.
As we obtained concrete and positive experimental results, this work will be valorised by transferring and including it first in a measurement techniques practical lesson cycle in fist year of study. Later, a more general and transversal "sustainable development" practical lesson should be implemented.
This full practical lesson dedicated to sustainable development will be described in a future publication.

9.2 Pedagogical assessment

Since the beginning of project (house building), 15 students worked on this multi thematic house model thermal equipment:
- 8 pupils from secondary school participated to the house design and some of them attended the first thermal measurements.
- 1 student from Bordeaux IUT GEII (training period 2 months for mechanical integration)
- 2 students from Craiova University (preliminary design)
- 1 training student worked on thermal characterisation.

Moreover, 6 students will work very soon next year on electronic heating system design in second years study.

10. Future work

10.1 Possible theoretical study

We are looking for collaboration with thermal specialists to study a CAD thermal model of the house and to run thermal simulation by finite element with ANSYS or SILVACO software for example.

10.2 Thermal losses measurement 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 like often in true house, or elsewhere), will be easily done and thermal measurement correlated to energy consumption monitoring.

10.3 House model project global continuation

Despite the lack of sponsors, the project will go on: some accessories such as parabolic solar dish and scaled solar tower generator (from Didacsol retailer) [20], [21] are going to be added on the house surrounding. As thermal losses localisation and evaluation is not enough in consumption reduction process, house energy consumption will be monitored and registered on computer to make the house more "intelligent": A "home automation" mini system will be included very soon.

11. Conclusion

Three years were necessary for ENSEIRB-MATMECA school and its academic partners, to design a functional realistic small scale house, built in genuine materials. It was completed successfully within the framework of an innovative sustainable development project. Thermal behaviour of the house model was investigated by infrared imaging. Thermal losses have been identified like in a true house. Insulation materials efficiency has been checked and demonstrated by a comparative approach.

This work should be now adapted and converted for creating a practical lesson on Infrared measurement techniques. It will be included in the "measurement techniques" module in first year of study at ENSEIRB-MATMECA.

Lastly, we hope that the presented work will help to stir the conscience of students and teachers to the need for sustainable development. We also wish that we will cause some vocations among the students for their future job.

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