A MODELLING APPROACH OF THERMAL INSULATION APPLIED TO A SAHARAN BUILDING

by

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The present work is part of research project titled "Modeling, Simulation, Theoretical and Experimental Thermal Studies of Ghardaia Local Climate. Effect of Thermal Insulation". The main objective of the current work was to determine the temperatures of the building in question with or without thermal insulation. This paper presents experimental and theoretical studies of two rooms thermal behaviour. These rooms are two parts of an apartment building located in semi arid area (Ghardaïa). A mathematical model describing the thermal behaviour of these rooms in question was developed and elaborated. These studies allowed also room internal temperature evolution profile to be determined. Through numerical simulation it has been found that the applied insulation layer reduced the losses of winter and maintained an appropriate temperature. It was found that the theoretically found results were consistent to an acceptable level with those found experimentally.

Key words: *heat insulation, numerical simulation, polystyrene, temperature, air*

Introduction

The heat is spontaneously transmitted from the hotter medium to the colder one. The ecological thermal comfort requires a rigorous control of this heat transfer. Thermal insulation is among of sought harmonies. In winter, it keeps heat losses through walls cavities minimum. The evaluation of apartment thermal loads is a complex process that takes a considerable amount of time and represents the most important steps in bioclimatic design. Therefore, the temperatures calculus and also dynamic aspect perception of heat transfers constitute the major undertaking of the process. This implies necessity to employ a more adequate, accurate, and fast numerical methods and to be equipped with a sophisticated tools in order to compute temperatures values. Conceived to satisfy such need Runge-Kutta fourth order numerical method enables better description of walls thermal behaviour subjected to varying load. Indeed an interactive program enabling better description of heat transfers through wall cavities in dynamic regime was elaborated. The results and recommendations of the present work are based on previous validated models [1-6].

Ghardaïa Saharan oasis is situated at the south of capital (600 km); these areas known by their semi arid climate characterized by the shortage of water fall (160 mm per year).Very high diurnal temperatures in summer and low temperatures in winter (frosts from December to mid-February).

Descriptive of typical house plan

In order to determine room temperature changes, it is appropriate to use the energetic balance while keeping interest essentially into internal temperatures. The latter are compared to those acquired in the case where the walls would be shaded and coated with an insulating air lame and an extra layer of polystyrene. In this context it is judged necessary to use the house plan for dimensioning and characterisation of the room. This maneuver allows form factor to be determined which is a purely geometric factor influencing the heat transfers through radiation between different surfaces.

A typical most commonly used construction in the region had been chosen. The fig. 1 is a schematic outline of real apartment building situated whether at the ground or at the first floor of two storey building. This habitat includes the following elements.

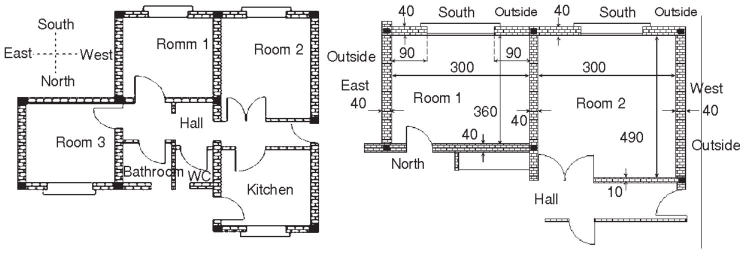


Figure 1. Associated descriptive plan

- Building envelops or outer wall consisting of a heavy structure generally constituted 40 cm of stones jointed and surrounded by two layers having thickness of 1.5 cm of mortar cement. The most inner face is coated with 1 cm thick plaster layer.
- The inner walls (or splitting walls) whose sides are in contact only to the internal ambient are considered to be of heavy structure constructed of stones of 15 cm width jointed and surrounded by two mortar cement layer of 1.5 cm thick and two layer of 1 cm thick of plaster.
- The flooring is placed on plan ground to lodge the ground floor. The concrete of the flooring is directly poured on the ground thus minimizing losses. Floor tiles are inter-imposed, it is an end coating resisting to corrosion and chemical agents.
- The roof is composed of cement slabs and concrete slab made so that it handles the load and be economical. A roof sloping of 5° allowed water evacuation through several openings. Until now the flat roofs are considered as nest infiltration and as architectural solution.
- Windows and doors contribute significantly to the energetic balance. Their contribution however depends of several parameters as: local climate, orientation, frame, relative surface (window--flooring), and concealment performance during night and sun days. In this case focus is made particularly on windows and doors dimensions and all are made of woods [7].

Incident solar irradiation estimation

The Capderou model utilizes the atmospheric trouble factor in order to compute beam and diffuse components of solar irradiation. Absorption and diffusion caused by atmosphere particles are expressed in terms of the turbidity factors. From these factors beam and diffuse irradiation are determined in case of clear sky model [8-13].

Furthermore, instead of implementing Capderou model to simulate the global and diffuse irradiation falling upon an horizontal plan, it was preferred in this work to use directly experimental results provided by a station located in the site where studies are carried out. This has a benefit of having more precise and better estimation of global irradiation on the horizontal.

Figure 2. Sun-Tracker station installed at applied research unit on renewable energies

Sun-Tracker is a station with high precision comport two parts: a fixed part comporting an EKO type pyranometer for measuring of global solar irradiation received by a horizontal surface, a mobile part capable to follow the trajectory of the sun from sunrise to sunset with a robotic system (fig. 2). The figs. 3 and 4 represent instantaneous variations of solar irradiation incidents upon the roof and wall of the apartment for different orientations. These values correspond to the days June 2 and January 5, respectively, under clear sky condition.

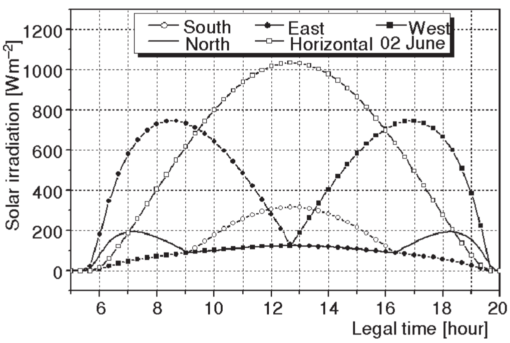


Figure 3. Solar irradiation incident on the walls; June 2

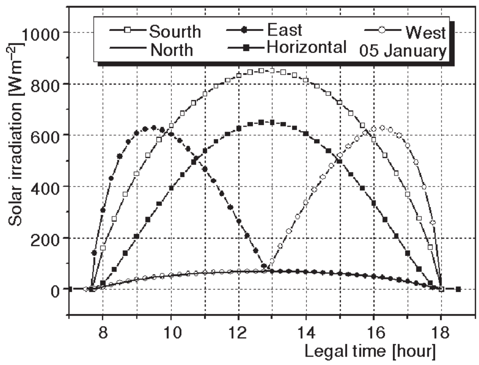


Figure 4. Solar irradiation incident on the walls; January 5

Mathematical model (cold period)

In building energetic field, the predictive numerical model is becoming increasingly used. Also simulating models have been developed during the eighties to essentially respond to dimensioning need of housing. The accomplished task in the current paper has as goal from one side to develop an appropriate model and from another side to contribute to the creation of corresponding simulation tools. These programs have as to be. Subsequently, coupled to a professional interface that can be operable in friendly manner.

However, these models and even more the latter only concern heat exchanges. As consequence of this air stratification studies (wind infiltration influence, and water droplets diffusion in wall cavities …) are not considered in the current study. Variation of humidity factor and states changes are not taken into account either. In the current work it is the envelop which is exclusively studied.

To carry out this study few specific hypotheses are made.

- The flow through different walls layers is assumed to be unidirectional, in perpendicular direction to the wall faces.
- The permanent regime would be established when the flow passes from layer to the next one.
- Temperature distribution (internal and external) on each wall surfaces is considered to be uniform.
- The convection is natural, the flow is laminar.
- Doors and windows are supposed to be closed and made of woods. Their temperatures are measured and considered in the over all energetic balance.

Thus, the averaged temperature evolution of all walls can be determined. In order, to complete the mathematical model the limit and initial conditions of the room must be known. Therefore, on each step the following temperature must be measured:

- the northern wall external face temperature,
- the ground temperature for a given depth (z), and
- the external temperature of the upper storey *i. e.* the temperature of the floor above. It is also necessary to measure the door and window temperatures since they are included in energetic balance.

Prior to establish this energetic balance the temperature profile of each surface of the two rooms has to be determined since it gives glance on directions and sense of heat exchanges with other surfaces. Preliminary remarks on dispositive (without insulation) dictates to decide and judge that:

$$T_{\text{Southern wall}} \quad T_{\text{Eastern wall}} \quad T_{\text{Ground}} \quad T_{\text{Air}} \quad T_{\text{Ceiling}} \quad T_{\text{Western wall}} \quad T_{\text{Northern wall}} \qquad \text{Room 1}$$

$$T_{\text{Western wall}} \quad T_{\text{Southern wall}} \quad T_{\text{Ground}} \quad T_{\text{Air}} \quad {}_{\text{Ceiling}} \quad T_{\text{Eastern wall}} < T_{\text{Northern wall}} \qquad \text{Room 2}$$

These considerations, coupled with the principle of energy conservation provide a no autonomous system having eighteen non-linear ordinary differential equations. The mathematical equations governing the different balances (without insulation) are:

Southern wall (Room 1)

$$\frac{\mathrm{d}T_1}{\mathrm{d}t} \quad \frac{1}{\rho_a v_1 C_a} \quad \frac{(T_1 \quad T_2)S_{ms}}{\frac{2e_a}{\lambda_a} \quad \frac{e_b}{\lambda_b} \quad \frac{e_c}{\lambda_c}} \quad Q_{r31} \quad Q_{r51} \quad Q_{r61} \quad Q_{r81} \quad Q_{r91} \quad Q_{rp1} \quad Q_{cv71} \tag{1}$$

External southern wall face (Room 1)

$$\frac{\mathrm{d}T_2}{\mathrm{d}t} \quad \frac{1}{\rho_c v_2 C_c} \quad \alpha_{platre} S_{ms} G_{sud} \quad \frac{(T_1 \quad T_2)S_{ms}}{\frac{2e_a}{\lambda_a} \quad \frac{e_b}{\lambda_b} \quad \frac{e_c}{\lambda_c}} \quad Q_{rciel2} \quad Q_{rsol2} \quad Q_{cvext2} \tag{2}$$

Eastern wall (Room 1)

$$\frac{\mathrm{d}T_3}{\mathrm{d}t} \quad \frac{1}{\rho_c v_3 C_c} \quad \frac{(T_3 \quad T_4)S_{mc}}{\frac{2e_a}{\lambda_a} \quad \frac{e_b}{\lambda_b} \quad \frac{e_c}{\lambda_c}} \quad Q_{r31} \quad Q_{r93} \quad Q_{r83} \quad Q_{rp3} \quad Q_{cv73} \quad Q_{r3f} \quad Q_{r53} \quad Q_{r63} \tag{3}$$

External eastern wall (Room 1)

$$\frac{\mathrm{d}T_4}{\mathrm{d}t} \quad \frac{1}{\rho_c v_4 C_c} \quad \alpha_{platre} S_{me} G_{est} \quad \frac{(T_3 \quad T_4)S_{me}}{\frac{2e_a}{\lambda_a} \quad \frac{e_b}{\lambda_b} \quad \frac{e_c}{\lambda_c}} \quad Q_{rciel4} \quad Q_{rsol4} \quad Q_{cvext4} \tag{4}$$

Northern wall (Room 1)

$$\frac{\mathrm{d}T_5}{\mathrm{d}t} \quad \frac{1}{\rho_a v_5 C_a} \quad \frac{(T_{5ext} \quad T_5)S_{mn}}{\frac{2e_a}{\lambda_a} \quad \frac{e_b}{\lambda_b}} \quad Q_{r51} \quad Q_{r53} \quad Q_{r5f} \quad Q_{r58} \quad Q_{r59} \quad Q_{r56} \quad Q_{cv57} \tag{5}$$

Western wall (Room 1)

$$\frac{\mathrm{d}T_6}{\mathrm{d}t} \quad \frac{1}{\rho_a v_6 C_a} \quad \frac{(T_{15} \quad T_6)S_{mo}}{\frac{2e_a}{\lambda_a} \quad \frac{e_b}{\lambda_b}} \quad Q_{r61} \quad Q_{r63} \quad Q_{r56} \quad Q_{cv67} \quad Q_{r6f} \quad Q_{r68} \quad Q_{r69} \quad Q_{rp6} \tag{6}$$

Interior air (Room 1)

$$\frac{\mathrm{d}T_7}{\mathrm{d}t} \quad \frac{1}{\rho_{air} v_7 C_{air}} [\; Q_{cv71} \quad Q_{cv73} \quad Q_{cv57} \quad Q_{cv67} \quad Q_{cv7f} \quad Q_{cv87} \quad Q_{cvp7} \quad Q_{cv79} \;] \tag{7}$$

Ceiling (Room 1)

$$\frac{\mathrm{d}T_8}{\mathrm{d}t} \quad \frac{1}{\rho_a v_8 C_a} \quad \frac{(T_{8ext} \quad T_8)S_t}{\frac{e_a}{\lambda_a} \quad \frac{e_h}{\lambda_h} \quad \frac{e_g}{\lambda_g} \quad \frac{e_d}{\lambda_d}} \quad Q_{r81} \quad Q_{r83} \quad Q_{r89} \quad Q_{r58} \quad Q_{r68} \quad Q_{rp8} \quad Q_{cv87} \quad Q_{r8f} \tag{8}$$

Ground (Room 1)

$$\frac{\mathrm{d}T_9}{\mathrm{d}t} \quad \frac{1}{\rho_{\mathrm{d}} v_9 C_{\mathrm{d}}} \quad \frac{(T_9 \quad T_{9\,\mathrm{int}})S_{\mathrm{sol}}}{\frac{e_{\mathrm{a}}}{\lambda_{\mathrm{a}}} \quad \frac{e_{\mathrm{c}}}{\lambda_{\mathrm{c}}} \quad \frac{e_{\mathrm{g}}}{\lambda_{\mathrm{g}}} \quad \frac{e_{\mathrm{d}}}{\lambda_{\mathrm{d}}} \quad \frac{e_{\mathrm{f}}}{\lambda_{\mathrm{f}}}} \quad Q_{\mathrm{r91}} \quad Q_{\mathrm{r93}} \quad Q_{\mathrm{r89}} \quad Q_{\mathrm{r59}} \quad Q_{\mathrm{r69}} \quad Q_{\mathrm{cv79}} \quad Q_{\mathrm{r9f}} \quad Q_{\mathrm{rp9}} \tag{9}$$

Southern wall (Room 2)

$$\frac{\mathrm{d}T_{10}}{\mathrm{d}t} \quad \frac{1}{\rho_{\mathrm{a}} v_{10} C_{\mathrm{a}}} \quad \frac{(T_{10} \quad T_{11})S_{\mathrm{ms}}}{\frac{2e_{\mathrm{a}}}{\lambda_{\mathrm{a}}} \quad \frac{e_{\mathrm{b}}}{\lambda_{\mathrm{b}}} \quad \frac{e_{\mathrm{c}}}{\lambda_{\mathrm{c}}}} \quad Q_{\mathrm{r1012}} \quad Q_{\mathrm{r1410}} \quad Q_{\mathrm{r1510}} \quad Q_{\mathrm{cv1610}} \quad Q_{\mathrm{r1710}} \quad Q_{\mathrm{r1810}} \quad Q_{\mathrm{rp10}} \tag{10}$$

External southern wall face (Room 2)

$$\frac{\mathrm{d}T_{11}}{\mathrm{d}t} \quad \frac{1}{\rho_{\mathrm{c}} v_{10} C_{\mathrm{c}}} \quad \alpha_{\mathrm{platre}} S_{\mathrm{ms}} G_{\mathrm{sud}} \quad \frac{(T_{10} \quad T_{11})S_{\mathrm{ms}}}{\frac{2e_{\mathrm{a}}}{\lambda_{\mathrm{a}}} \quad \frac{e_{\mathrm{b}}}{\lambda_{\mathrm{b}}} \quad \frac{e_{\mathrm{c}}}{\lambda_{\mathrm{c}}}} \quad Q_{\mathrm{rciel11}} \quad Q_{\mathrm{rsol11}} \quad Q_{\mathrm{cvext11}} \tag{11}$$

Western wall (Room 2)

$$\frac{\mathrm{d}T_{12}}{\mathrm{d}t} \quad \frac{1}{\rho_{\mathrm{a}} v_{12} C_{\mathrm{a}}} \quad \frac{(T_{12} \quad T_{13})S_{\mathrm{me}}}{\frac{2e_{\mathrm{a}}}{\lambda_{\mathrm{a}}} \quad \frac{e_{\mathrm{b}}}{\lambda_{\mathrm{b}}} \quad \frac{e_{\mathrm{c}}}{\lambda_{\mathrm{c}}}} \quad Q_{\mathrm{r1012}} \quad Q_{\mathrm{r1412}} \quad Q_{\mathrm{r1512}} \quad Q_{\mathrm{cv1612}} \quad Q_{\mathrm{r1712}} \quad Q_{\mathrm{r1812}} \quad Q_{\mathrm{rp12}} \quad Q_{\mathrm{rf12}} \tag{12}$$

External western wall (Room 2)

$$\frac{\mathrm{d}T_{13}}{\mathrm{d}t} \quad \frac{1}{\rho_{\mathrm{c}} v_{12} C_{\mathrm{c}}} \quad \alpha_{\mathrm{platre}} S_{\mathrm{me}} G_{\mathrm{est}} \quad \frac{(T_{12} \quad T_{13})S_{\mathrm{me}}}{\frac{2e_{\mathrm{a}}}{\lambda_{\mathrm{a}}} \quad \frac{e_{\mathrm{b}}}{\lambda_{\mathrm{b}}} \quad \frac{e_{\mathrm{c}}}{\lambda_{\mathrm{c}}}} \quad Q_{\mathrm{rciel13}} \quad Q_{\mathrm{rsol13}} \quad Q_{\mathrm{cvext13}} \tag{13}$$

Northern wall (Room 2)

$$\frac{\mathrm{d}T_{14}}{\mathrm{d}t} \quad \frac{1}{\rho_{\mathrm{a}} v_{14} C_{\mathrm{a}}} \quad \frac{(T_{14\mathrm{ext}} \quad T_{14})S_{\mathrm{mn}}}{\frac{2e_{\mathrm{a}}}{\lambda_{\mathrm{a}}} \quad \frac{e_{\mathrm{b}}}{\lambda_{\mathrm{b}}}} \quad Q_{\mathrm{r1410}} \quad Q_{\mathrm{r1412}} \quad Q_{\mathrm{cv1416}} \quad Q_{\mathrm{r1417}} \quad Q_{\mathrm{r1418}} \quad Q_{\mathrm{r14f}} \tag{14}$$

Eastern wall (Room 2)

$$\frac{\mathrm{d}T_{15}}{\mathrm{d}t} \quad \frac{1}{\rho_{\mathrm{a}} v_{15} C_{\mathrm{a}}} \quad \frac{(T_{15} \quad T_6)S_{\mathrm{mo}}}{\frac{2e_{\mathrm{a}}}{\lambda_{\mathrm{a}}} \quad \frac{e_{\mathrm{b}}}{\lambda_{\mathrm{b}}}} \quad Q_{\mathrm{r1510}} \quad Q_{\mathrm{r1512}} \quad Q_{\mathrm{r1415}} \quad Q_{\mathrm{cv1516}} \quad Q_{\mathrm{r1517}} \tag{15}$$

Interior air (Room 2)

$$\frac{\mathrm{d}T_{16}}{\mathrm{d}t} \quad \frac{1}{\rho_{\mathrm{air}} v_{16} C_{\mathrm{air}}} [\, Q_{\mathrm{cv1610}} \quad Q_{\mathrm{cv1612}} \quad Q_{\mathrm{cv1416}} \quad Q_{\mathrm{cv1516}} \quad Q_{\mathrm{cv1716}} \quad Q_{\mathrm{cv1618}} \quad Q_{\mathrm{cv16f}} \quad Q_{\mathrm{cvp16}} \,] \tag{16}$$

Ceiling (Room 2)

$$\frac{\mathrm{d}T_{17}}{\mathrm{d}t} \quad \frac{1}{\rho_\mathrm{a} v_{17} C_\mathrm{a}} \quad \frac{(T_{8\mathrm{ext}} \quad T_8)S_\mathrm{t}}{\frac{e_\mathrm{a}}{\lambda_\mathrm{a}} \quad \frac{e_\mathrm{h}}{\lambda_\mathrm{h}} \quad \frac{e_\mathrm{g}}{\lambda_\mathrm{g}} \quad \frac{e_\mathrm{d}}{\lambda_\mathrm{d}}} \quad Q_{\mathrm{r}1710} \quad Q_{\mathrm{r}1712} \quad Q_{\mathrm{r}1417} \quad Q_{\mathrm{r}1517} \quad Q_{\mathrm{cv}1716} \quad Q_{\mathrm{r}1718} \quad Q_{\mathrm{r}17\mathrm{f}} \quad Q_{\mathrm{rp}17} \tag{17}$$

Ground (Room 2)

$$\frac{\mathrm{d}T_{18}}{\mathrm{d}t} \quad \frac{1}{\rho_\mathrm{d} v_{18} C_\mathrm{d}} \quad \frac{(T_9 \quad T_{9\,\mathrm{int}})S_\mathrm{sol}}{\frac{e_\mathrm{a}}{\lambda_\mathrm{a}} \quad \frac{e_\mathrm{c}}{\lambda_\mathrm{c}} \quad \frac{e_\mathrm{g}}{\lambda_\mathrm{g}} \quad \frac{e_\mathrm{d}}{\lambda_\mathrm{d}} \quad \frac{e_\mathrm{f}}{\lambda_\mathrm{f}}} \quad Q_{\mathrm{r}1810} \quad Q_{\mathrm{r}1812} \quad Q_{\mathrm{r}1418} \quad Q_{\mathrm{r}1518} \quad Q_{\mathrm{cv}1618} \quad Q_{\mathrm{r}1718} \quad Q_{\mathrm{r}18\mathrm{f}} \quad Q_{\mathrm{rp}18} \tag{18}$$

These rooms in question have two exposed walls. Then, if a wall needs to be insulated (adding one or more insulating layer), the modifications that could be introduced in the energetic balance would be those concerned by conduction equations and the used material specific heat parameter. For example the insulation of the western wall (room 1) by a lame of air and a polystyrene layer lead to another equation of the overall balance. These models describe the system thermal behaviour in both cases at the same climatic conditions.

$$\frac{\mathrm{d}T_6}{\mathrm{d}t} \quad \frac{1}{\rho_\mathrm{poly} v_6 C_\mathrm{poly}} \quad \frac{(T_{15} \quad T_6)S_\mathrm{mo}}{\frac{2e_\mathrm{a}}{\lambda_\mathrm{a}} \quad \frac{e_\mathrm{b}}{\lambda_\mathrm{b}} \quad \frac{e_\mathrm{poly}}{\lambda_\mathrm{poly}} \quad \frac{e_\mathrm{air}}{\lambda_\mathrm{air}}} \quad Q_{\mathrm{r}61} \quad Q_{\mathrm{r}63} \quad Q_{\mathrm{r}56} \quad Q_{\mathrm{cv}67} \quad Q_{\mathrm{r}6\mathrm{f}} \quad Q_{\mathrm{r}68} \quad Q_{\mathrm{r}69} \quad Q_{\mathrm{rp}6} \tag{19}$$

The most important step in this current study consists in using a semi-empirical model allowing estimation of energy received by different walls to be made. In this sense, Capderou model has been chosen because it is the most adequate to the site where studies are carried out (according to the previous studies). However, instead of implementing Capderou model to simulate the global and diffuse irradiation falling upon an horizontal plan, it was preferred in this work to use experimental results provided by a station located in the site where studies are carried out. This has a benefit of having more precise and better estimation of global irradiation on the vertical walls. For room 1, the two walls exposed to the Sun are insulated by a lame of air of 4 cm and another layer of 6 cm of polystyrene. The western wall is insulated by 8 cm polystyrene layer. The roof is also insulated by 4 cm of polystyrene layer. Then in order to complete the insulation process, the northern wall was also insulated by 4 cm of polystyrene [14-16].

Habitat thermal behaviour (hot period)

In this section it has been proved that the simulated temperature values are comparable to those measured experimentally which implies that the proposed model fit satisfactory to describe physical state of the studied phenomena. This fact allowed the integration of this model in a general program in order to apprehend the problem related to thermal comfort and to study the feasibility of internal and external thermal insulation. The sought of identified solutions dictates the implementation of rigorous methodology whether in terms of defining the input and output or in terms of the conduction of the experimentation. To design a mathematical model during a hot period, we will follow the same steps as those explained in a cold period.

The thermal insulation of walls exposed to the Sun radiation is fulfilled by using 6 cm thick layer of polystyrene and 1 cm thick air layer whereas the roof inner side of the apartment was insulated by 4 cm thick polyester layer. The results that will be soon presented are all subjected to uncertainty margin as is always the case of any comparative study. This uncertainty is due in one hand to the inaccuracies in the implemented model and on the other hand to the inaccuracies of the measuring instrument being in use.

In order to accomplish the measurement phase, a data acquisition unit of type Fluke Hydra Series II. Which in spite of its high accuracy it accumulates some errors at levels even if they are not really considerable? Another inherited difficulty of this confrontation resides in presence of noise phenomenon that may arise whether from the measurement process or the studied system itself. Type K thermocouples were used to measure temperatures. Their measuring principle is based on Seebeck effect. In order to monitor the temperatures of south and north walls, five thermocouples were placed in different locations of the walls. Also the temperatures of the internal ambient air were monitored by placing five thermocouples in different points. The plotted temperatures experimental values are those corresponding to the average of the monitored ones.

The fig. 5 describes temperature evolution of external ambient temperature during days June 2 and 3, 2008 in Ghardaïa. The used program allowed simulation from the beginning of the project. It allowed also making comparison between the temperatures of the apartment.

To do so the example given in fig. 6 representing temperature curves of each medium is considered. It can be observed that the room 3 temperature is generally the highest. The results can be justified without doubt by the number of walls exposed to highest solar irradiations. Following this principle, we can predict (what is actually confirmed) that temperatures of bathroom and toilet are the lowest without conducting study. It can also be observed that living room (room 2) temperature became higher during the evening time and lower during over morning in terms of comparison to that of room 1. Whereas the opposite of that can be observed, the reason is that in case of the room 1 that is the south and east walls which are exposed to solar irradiations, in the other hand, in case of the living room that is south and west walls which are exposed to solar irradiations. Thus reasonably the amount of energy absorbed during morning time by room 1 walls is higher than that absorbed by living room walls and vice-versa.

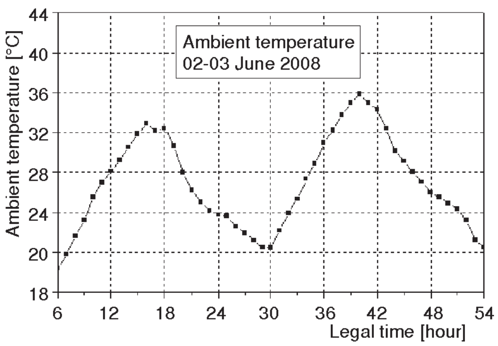


Figure 5. Ambient temperature; June 2 and 3, 2008

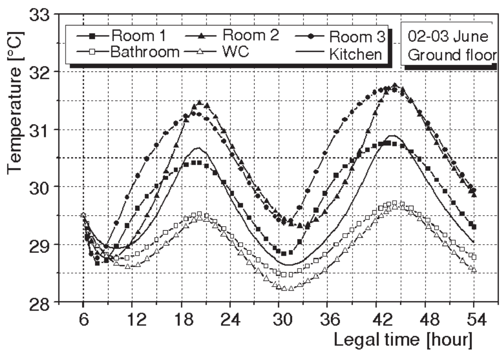


Figure 6. Internal group floor temperatures; June 2 and 3, 2008

Remaining again in this context, it is common to find the temperatures of the first floor to be higher than those of the ground floor because their South, East, west walls and roofs are directly exposed to solar irradiations. Figure 7 for example, may explain the immerging behavior.

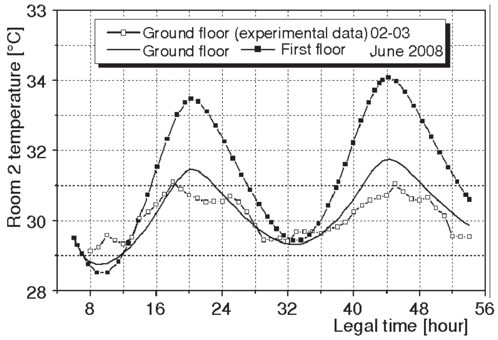


Figure 7. Room 2 temperatures; June 2 and 3, 2008

Figures 8 and 9 represent, respectively, temperatures curves of internal air and of room 1 and the

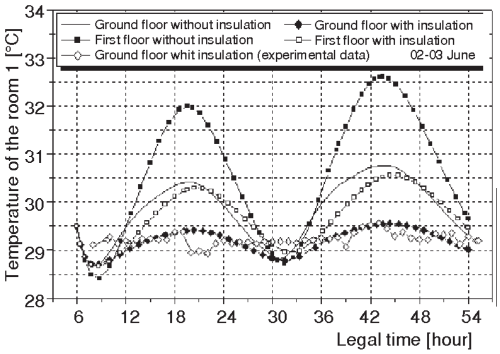


Figure 8. Room 1 temperatures; June 2 and 3, 2008

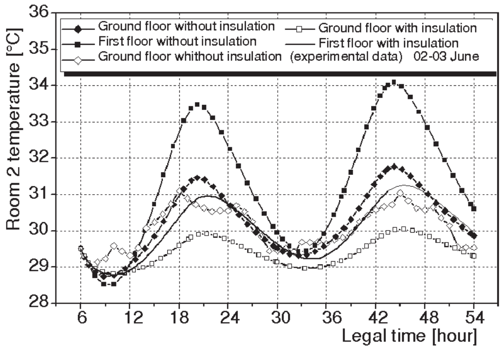


Figure 9. Room 2 temperatures; June 2 and 3, 2008

living room in different cases. The found results show that the temperatures in case of absence of thermal insulation were found to be between 28.6 °C and 30.8 °C in case of room 1 of the ground floor, and between 28.3 °C and 32.7 °C in case of the first floor. Which are a relatively higher temperatures compared to the desired one *i. e.* (27 °C). The thermal insulation technique allows only maintaining these temperatures not to lower them. It is for this reason that the temperatures of room 1 will be comprised between 28.7 °C and 29.5 °C in case of the ground floor and between 28.8 °C and 31.85 °C in case of the first floor. Living room temperatures are found to be between 28.8 °C and 29.5 °C for the ground floor. Whereas in case of the first floor, the recorded temperatures are between 28.5 °C and 34 °C. It follows that the delivered temperatures by the insulation means under these conditions will have to be comprised between 28.9 °C and 30 °C in case of the ground floor and between 28.85 °C and 31.3 °C in case of the first floor.

Theoretical and experimental results, remakrs, and discussions (cold period)

The experimental measurements are carried out in the first week of December 2007 and the first week of January 2008. The following step of the study consists in viewing and determining the impact and influence of thermal insulation on interior air and walls which had already stocked an important amount of cold (see figs. 13, 14, and 15). The interior temperature of air and various temperature of southern and northern wall will be confronted with experimental values in absence of insulation. The comparison proves as a whole acceptable. These forecasts and appreciations will be proven by figs. 10, 11, and 12. It must be noted in this case that the results obtained through numerical simulation differ from those obtained in the case where the walls had not yet stored cold. This noticeable decrease in the ambient temperature during the month of January, provide a diminution of the temperature inside the rooms.

The other most important part of the current study deals with determining a theoretical model which gives a best method adequate to improve the performances of insulation task. Mathematical

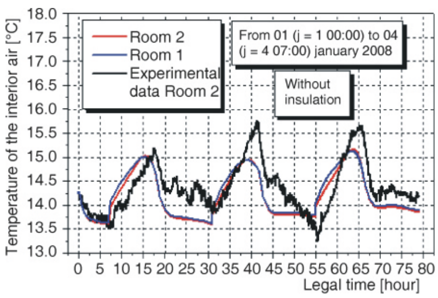


Figure 10. Temperature of the interior air

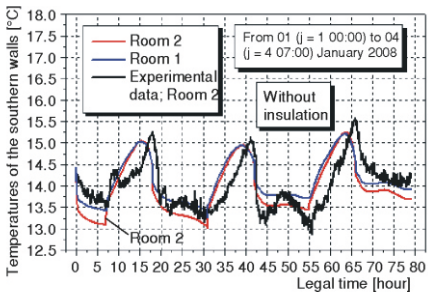


Figure 11. Temperature of the southern wall

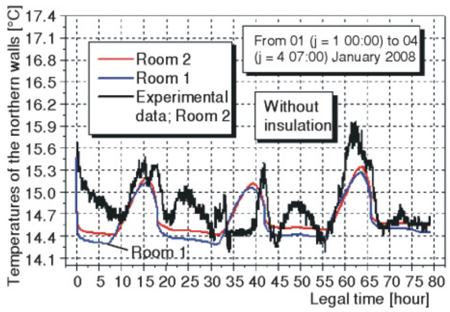


Figure 12. Temperature of the northern wall

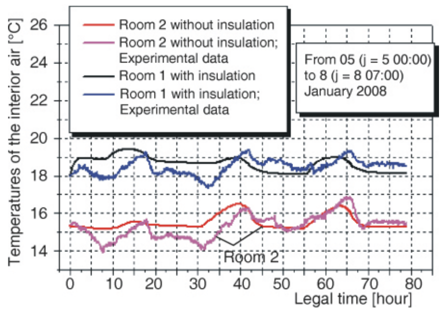


Figure 13. Temperature of the interior air

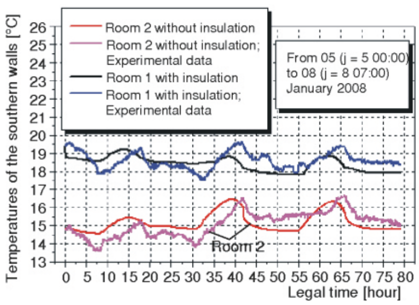


Figure 14. Temperature of the southern wall

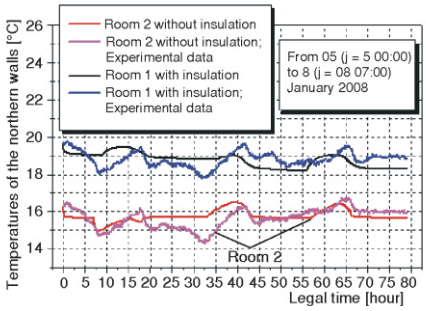


Figure 15. Temperature of the northern wall

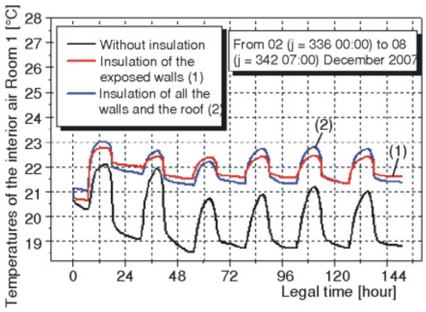


Figure 16. Temperature of the interior air – Room 1

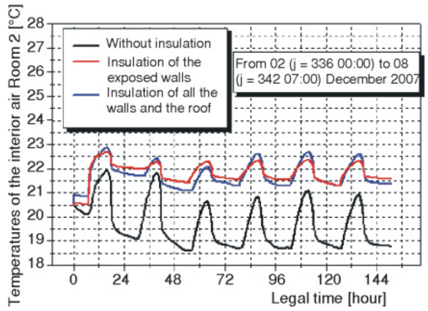


Figure 17. Temperature of the interior air – Room 2

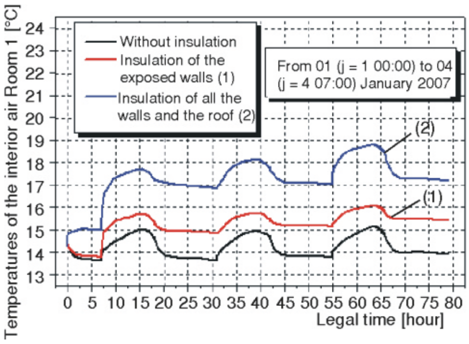


Figure 18. Temperature of the interior air – Room 1

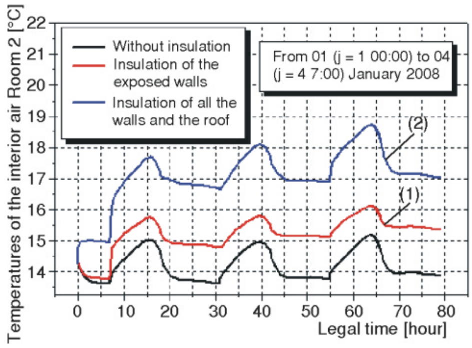
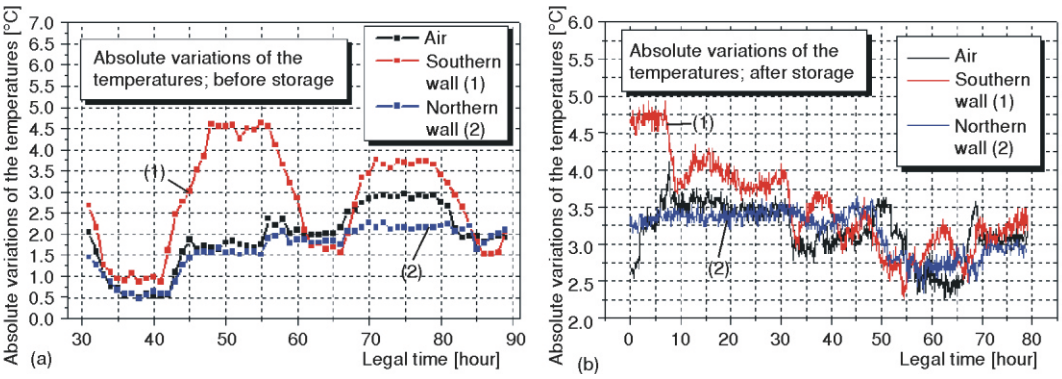


Figure 19. Temperature of the interior air – Room 2

models permitting evaluation of energetic performances of apartment rooms are proposed. It should also be noted that these models describe only heat exchanges. In this piece of work zonal air stratification and wind influence on air infiltration, water droplets diffusion through wall cavities, state changes are not dealt with. Humidity varying factor is not taken into account either. It is the envelop which is exclusively studied. Theoretical results are introduced by figs. 16, 17, 18, and 19.

According to the found results it can be concluded that the insulation of walls and roof reduces the impact of cold temperatures during winter period, thus enabling the thermal comfort to be achieved. The current question which imposes itself is to what extent the theory is consistent with the experimental results? The monitored and recorded temperatures of the solar house located at our research unite that are plotted on the previously mentioned graphs answer this question clearly. The concordance between theory and real world is so encouraging. As can be seen from figs. 20 (a) and (b) which represent the temperature differences of walls and interior air of the two rooms with and without insulation, the maximum absolute temperatures differences in the worst cases are in the order of ±1 °C. It can also be concluded from this comparison that effect and impact of thermal insulation are manifested in the first place on southern walls then northern ones and finally on interior air in particular in the case where the interior air had not been cooled enough yet. In essence it is assumed in this case that this effect manifests clearly on surfaces and space which are most cold.



Figures 20. Absolute variations of the temperature: (a) before storage and (b) after storage

Theoretically, it has been confirmed that thermal insulation of the two exposed walls suffices only in the case where the cold does not penetrate and yet does not crossed the walls. In contrast if the cold had already overwhelmed the entire apartment then all internal surfaces should be insulated. In some case the ground also needs to be insulated (see figs. 17, 18, and 19). As consequence, if the cold had already crossed and penetrated the whole piece then the difference in temperature would be the contribution of thermal insulation rather than the effect of thermal inertia. This can be justified by the fact that room looses its thermal inertia. For example, if we want to keep the tea or the coffee with the heat, we use one covers tea or a thermos flask.

General conclusions

In this article, the effects, impacts and influences of thermal insulation upon thermal comfort are presented. In conclusion these work and research activities made possible to draw some fundamental norms and criteria that are important to achieve a better insulation. In addition to that the following conclusion is made.

– During cold period, the thermal losses are slew down by the provided insulation thus favorising the achievement of thermal comfort.
– In winter however, despite the shining time the temperatures of walls internal surfaces remains the coldest ones. This phenomenon is better known by thermal inertia.

In this sense, recalling the example of ball, big, and heavy. Unlike small ball, it is difficult to make it move but once launched it would be difficult to stop it. Stone (walls) unlike metal took a relatively long time in order to be cooled but once cooled it took also a long time in order to be heated.

– As is well known the winter periods are characterized by night hours slightly longer than daylight hours. This condition favors cold absorption over night and has a significant impact on walls since they are made of stones which are characterized by high calorific capacity. Thus walls have an enormous capacity to store cold. This situation encourages internal surfaces to remain cold despite sunshine presence.
– Thermal insulation fulfills its intended goal which is achieving the thermal comfort only if it is implemented before the beginning of cold period. It follows that under this condition insulation has to be applied only to the exposed walls to the Sun.
– To sum up the norms and principles of bioclimatic conception have to be carefully respected during building construction at the specified site. Based upon the analysis of found results it is strongly recommended to avoid construction using stones in area similar to Ghardaia from climatic view point. This is because the stones possesses a high heat absorption coefficient and huge capacity to store thermal energy. Therefore the use of hollow bricks is preferred and proposed for construction.
– The comparison shows that the found results by implementing such model are to some extent satisfactory. The numerical results obtained by simulating and executing the elaborated program put in evidence the power and efficiency of this software package (Matlab 6.5).

Acknowledgment

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Nomenclature

C – specific heat, [$Jkg^{-1}K^{-1}$]
e – wall thickness, [m]
$F_{i\text{-}j}$ – form factor between surfaces i and j
G – total incident irradiation, [Wm^{-2}]
Q_{cvext} – heat flux exchanged by radiation with the ambient
Q_{cvij} – heat flux exchanged by convection, [W], [$Q_{cv} = h_{cvij}S_i(T_i - T_j)$]
Q_{rciel} – heat flux exchanged by radiation with the sky
Q_{riciel} – $= h_{riciel}S_i(T_i - T_{ciel})$; $h_{r2ciel} = \varepsilon_2\sigma(T_{ciel} + T_2)(T_2^2 \quad T_{ciel}^2)(T_2 - T_{ciel})/(T_2 - T_{am})$; $T_{ciel} = 0.0552\,T_{am}^{1.5}$
Q_{rij} – heat flux exchanged by radiation, [W], [$= h_{rij}S_i(T_i - T_j) = F_{ij}S_i(T_i^4 \quad T_j^4)$]
Q_{rsol} – heat flux exchanged by irradiation with the external ground
S – surface, [m^2]
T – temperature, [K]
v – volume, [m^3]

Greek letters

a – absorption coefficient
λ – thermal conductivity, [$WK^{-1}m^{-1}$]
ρ – density, [kgm^{-3}]
σ – Stephane-Boltzmann constant

Subscripts

a – cement
b – stones
c – plaster
d – tiling
e – concret
f – the window
g – the hollow block
h – sand
p – the door

Some physical characteristics

$e_a = 0.015$ m; $e_b = 0.4$ m; $e_c = 0.01$ m; $e_d = 0.025$ m; $e_e = 0.02$ m; $e_f = 0.04$ m; $e_g = 0.2$ m; $e_h = 0.045$ m; $e_i = 0.1$ m; $e_{air} = 0.04$ m
$\rho_a = 2000$ kg/m^3; $\rho_c = 825$ kg/m^3; $\rho_d = 2300$ kg/m^3; $\rho_f = 2300$ kg/m^3; $\rho_{air} = 1.2$ kg/m^3; $\rho_{poly} = 29$ kg/m^3
$\lambda_a = 1.15$ W/Km; $\lambda_b = 2.8$ W/Km; $\lambda_c = 0.25$ W/Km; $\lambda_d = 2.4$ W/Km; $\lambda_e = 2$ W/Km; $\lambda_f = 1.4$ W/Km; $\lambda_g = 1.1$ W/Km; $\lambda_i = 1.1$ W/Km; $\lambda_{air} = 0.026$ W/Km; $\lambda_{poly} = 0.04$ W/Km
$C_a = 871$ J/kgK; $C_c = 1000$ J/kgK; $C_f = 875$ J/KgK; $C_d = 875$ J/kgK; $C_{air} = 1008$ J/kgK

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