

Study and Characterization of Thermal Comfort in a Desert Climate

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Abstract: The objective major of this numerical study is the characterization of thermal comfort in new habitable architectures located in a completely desert area. This numerical characterization is intended to determine the parameters that affect the thermal comfort for the occupants of these architectures in this region. To achieve this objective, a numerical model describing the thermal exchanges taking place in a model of a habitable envelope has been developed. This model is based on thermal balances established at the level each wall of the habitat. The numerical models developed have been validated using climatic data recently measured in the renewable energy research unit of the Saharan medium at Adrar ‘URER’MS’. A well detailed analysis of the some parameters that influence the thermal comfort in this architecture was raised and discussed. The fundamental equations governing thermal exchanges have been concretized by an implicit finite difference method, based on the nodal procedure. The system of algebraic equations obtained was solved by the iterative Gaussian method. The results of the numerical simulation have shown that the material currently used in the construction of this architecture of Adrar region, as well as the current climatological conditions, are the main causes of the thermal discomfort.

Keywords: Finite difference, Numerical models, Adrar region, Characterization, Thermal discomfort, Heat exchange.

1. INTRODUCTION

Environmental issues and energy consumption are increasingly alarming global concerns today. It is essential to adopt solutions to obtain more energy-efficient and sustainable buildings, both new and existing. The use of solar energy is a means of improving the use of natural energy, which can reduce energy consumption [1]. The energy performance of a habitat can be estimated by performing thermodynamic simulations that take into account different conventional assumptions such as: the weather, occupancy, temperature set points, and uses of the window and shutter by the occupants and even the architecture of the habitats. The experience feedbacks in the habitable envelope with high energy performance highlight significant differences in energy consumption between forecasts and summer overheating [2]. Ryzhov and al [3] in his recent study, he approached the importance of renewable energy exploitation, more specifically the solar energy in buildings. He attributed the strategy that promotes reduced energy consumption and environmentally friendly techniques.

The development of a good energy concept for a house involves the search for a balance between reinforced insulation, compactness, passive solar gains, thermal inertia and comfort,

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indoor air quality and investment cost. This has been the subject of specific attention since the pre-project phase and most often requires the use of premature studies [4].

The essential function of a house is to ensure an interior ambiance well suited to our needs and our comfort. The inhabitant often places his comfort before saving energy. It is therefore necessary to plan the construction and installations to consume less energy while ensuring adequate comfort [5].

Saheli and al [6] studied the influence of climatic conditions on the local heating efficiency of a building installed in the South Algeria. Furthermore, Benhammou and al [7,8] analyzed the thermal behavior of a housing submitted to periodic solicitations under hot and dry climate. This analysis was made for the hottest July in the summer season, in order to examine the effect combined of the heat insulation and the passive cooling by EAHE on the thermal performances of the livable envelopes for desert regions in the South Algeria.

This numerical study consists of visualizing not only the impact of climatic conditions and building materials used in Adrar region's architecture on thermal comfort, but also its effects on the main heat transfer mechanisms related to the thermal comfort process. In addition, from the results of digital investigation of different variables such as: the internal temperature, external temperature and the density of the solar flux, we show ourselves such an approach which allows improving the thermal comfort in this architecture.

2. DOMESTIC ARCHITECTURE

The raw earth is a material available everywhere in the planet. It is the universal material the privileged and the easiest handled by the human being to make a shelter while several millennia. Globally, earthen houses today house more than a third of the world's population [9]. This construction material, respects the man and the environment, is perfectly recyclable. It ensures thermal comfort by its characteristics and offers advantageous economic convenience.

Algeria, this vast territory has experienced diversified land architecture according to the diversity of climatic zones. The domestic conception of Adrar region, south-west of the Sahara, differs from that of Algiers, or that of M'zab valley at Ghardaïa, at the lower Sahara. The model of earth allows a real diversity of architectural language [9]. Unfortunately, since the floods of 2009, the use of this material is banned, and replaced by cement (reinforced concrete). This material seen as modernity symbol and social promotion. In figure 2.1, we present the new architecture of Adrar region which is based on reinforced concrete without total control of thermal insulation.



Fig. 2.1. New reinforced concrete architecture in Adrar region.

On the other hand, in figure 2.2 we present the old architecture of this region. This architecture allows a thermal insulation based on the raw earth. The latter played the role of an insulating material against thermal discomfort.



Fig. 2.2. The old architecture with raw earth in Adrar region.

3. CLIMATOLOGICAL CHARACTERISTICS

Adrar has a typical hot desert climate of the hyper-dry Saharan zone. It's the heart of Sahara, with a hot, very long summer and a hot short, moderate winter. The annual average of precipitation in this region reaches hardly 14 - 15 mm, falling essentially in autumn or to spring [10].

The maximal average temperatures are 46 - 48 °C in July (the hottest month), what makes of Adrar one of the world hottest cities. As an example: the peak of record temperature was established on Monday, July 9th, 2018 with a temperature of 65 °C [11,12,13].

3.1. Solar data of the typical day chosen in Adrar region

Table 3.1 presents the astronomical data for the designated typical day. Noting that these data will be used to calculate the different densities of solar flux influencing heat exchange in habitable envelope. These data were recently measured by a radiometric station to in the renewable energy research unit in the Saharan medium of Adrar ‘URER'MS’. This autonomous radiometric measuring station was realized at the end of 2010. Furthermore, it measures the global radiation parameters on three plans (Horizontal, Inclined at the latitude of the place and optimal monthly) and the ambient temperature. Figure 3.1 present a local image of this radiometric station in Adrar site.



Fig. 3.1. Local picture of Adrar radiometric station.

Table 3.1. Astronomical Data of the Typical Day [12].

<i>Typical day (July 17, 2014)</i>	
Maximum ambient temperature in (°C)	47,70
Minimum ambient temperature in (°C)	32,50
Average ambient temperature in (°C)	40,70
Maximum flux in (W/m ²)	1051,00
Average flow in (W/m ²)	323,00
Average wind speed in (m/s)	5,80
Duration of the day in (h)	14,00
The time sunrise in (h)	5,00
The time sunset in (h)	19,00
The sun declination in (°)	-13°,12'
The time correction in (minute)	17',97''

The hourly distribution of the wind speeds represents an indicator for the wind potential. This knowledge allows the estimation of the wind energy available on the site. The figure 3.2 represents the frequency distribution of average speeds measured for day given in percentage term for Adrar site. The analysis of these curves shows that site of Adrar has important wind energy potential and which is more favorable to exploitation of this energy type for electricity production. The reached average speed is from 5 to 6m/s in July.

enerMENA High Precision Meteorological Station in Adrar, Algeria - 1 min, juillet 17 2014

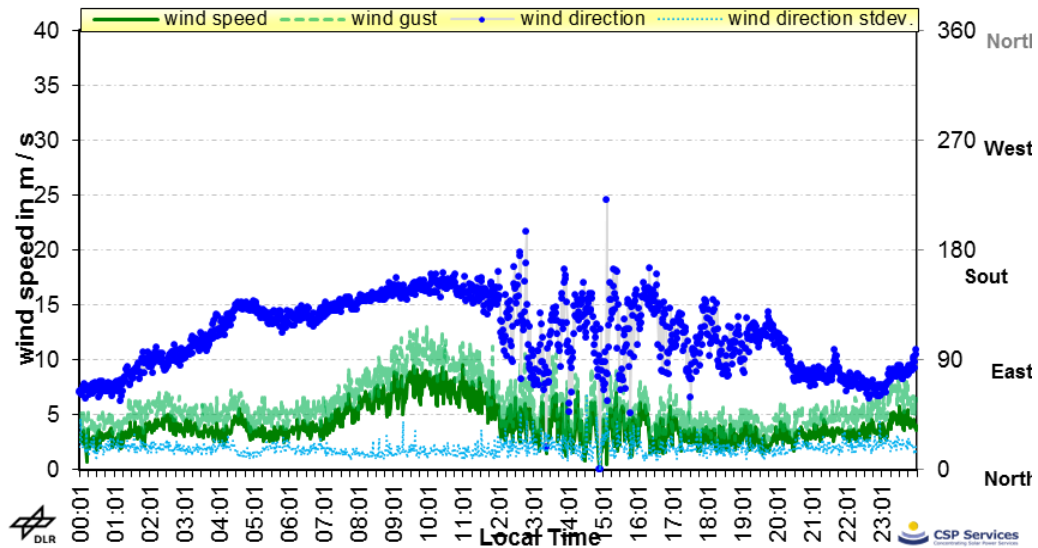


Fig.3.2. Hourly evolution of the average wind speed [12].

4. DESCRIPTION OF PHYSICAL MODEL

The physical model used in this study is a parallelepiped-type habitable envelope composed of a single four-facade room, see Figure 4.1. The construction is located on a surface of 20m². This room is built according to the following standards:

- The walls of the room are constructed of a light structure usually, 15 cm of block full of cement.
- The floor slab is placed on a flat earth. It is cast directly onto a 4cm layer of thermal insulation.
- The roof consists of a slab of reinforced concrete.

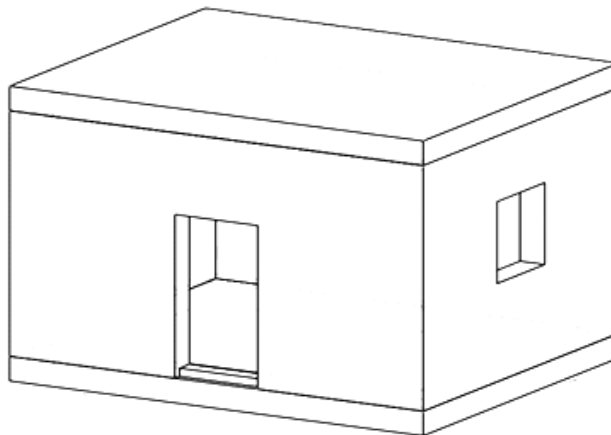


Fig.4.1. Sketch of the piece studied.

5. IMPLEMENTATION OF MODEL AND RESOLUTION

In this numerical study, we have opted for the nodal method use, which makes it possible to establish a thermal network equivalent to the modeling element. Conductive, convective and radiative processes are considered in global form (conservation of the heat flux). According to on the complexity of the network adopted, one can to incorporate all or part of the heat transfer phenomena, which allows predicting, with more precision, the thermal behavior of

the studied part [14]. The phenomenological equation of heat relative to an infinitesimal volume makes it possible to write [15,16,17]:

$$\rho \cdot Cp \frac{\partial T}{\partial t} d\tau + \text{div}(\phi) \cdot d\tau = P \cdot d\tau \quad (5.1)$$

With;

$\frac{\partial T}{\partial t}$: is the rate of variation of stored energy in $d\tau$;

$\text{div}(\phi)$: is the outgoing flow in $d\tau$;

$P \cdot d\tau$: is the energy flow generated.

By integrating this expression on a volume V_i at temperature T_i , the energy balance is written [15-18,19,20]:

$$\rho \cdot Cp_i \cdot \frac{\partial T_i}{\partial t} = \varphi_{\text{conduction}} + \varphi_{\text{air}} + \varphi_{\text{convection}} + \varphi_{\text{radiance}} + P_i \quad (5.2)$$

Or;

Cp_i : is the calorific capacity of the volume V_i

P_i : is the source of flux dissipated in the volume V_i

$\varphi_{\text{conduction}}$, φ_{air} , $\varphi_{\text{convection}}$ and $\varphi_{\text{radiation}}$: are the flows exchanged between V_i and its environment by conduction, fluidic transport, convection and radiation. Figure 5.1 shows the different modes of heat transfer in the study room.

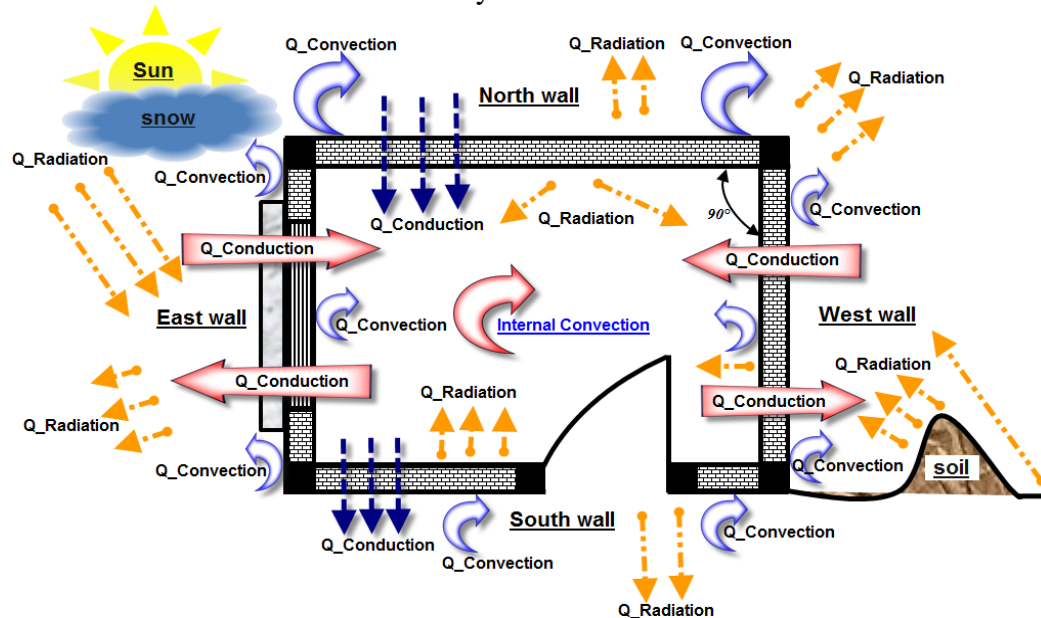


Fig.5.1. Description of the different modes of heat transfer for the studied room.

The analog schematization, we allow to propose an electric circuit amounting to the thermal system to be able to apply the law of Ohm [21,22,23,24].

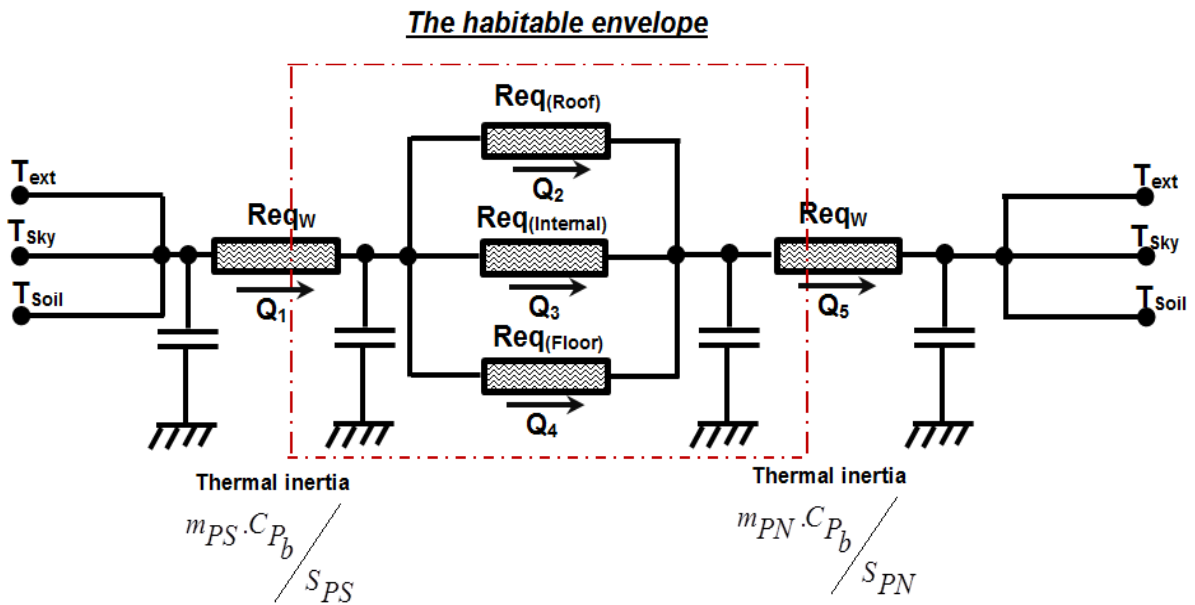


Fig.5.2. Electrical map of the studied room.

And:

T_{ext} : External ambient temperature in ($^{\circ}$ C);

T_{sky} : Temperature of the celestial vault in ($^{\circ}$ C);

T_{soil} : Soil temperature in ($^{\circ}$ C).

As a condition the limits of the room studied, consideration was given to the ground temperature equal to the external ambient temperature. In addition, the temperature of the celestial vault is calculated by the following formula [25,26]:

$$T_{sky} = 0,0552 \times T_{amb}^{1,5} \tag{5.3}$$

Indeed, the coefficient of external convection is given by [25,26]:

$$h_{C_{ext}} = 5,7 \times 3,8 \times V_{windspeed} \tag{5.4}$$

The law enforcement of Ohm, in every knot of the studied room, gives the system of following equations [17-20]:

- **Thermal balances of external facades of the studied room**

$$\left[\begin{array}{l} \frac{m_{PS} \cdot Cp_b}{S_{PS}} \cdot \frac{dT_{PSE}}{\Delta t} = h_{C_{ext}} \cdot \Delta T + \frac{\lambda_b}{e} \cdot \Delta T + hr_{VC-PSE} \cdot \Delta T + hr_{SOL-PSE} \cdot \Delta T + P_{absor} \\ \frac{m_{PS} \cdot Cp_b}{S_{PN}} \cdot \frac{T_{PNE}}{\Delta t} = h_{C_{ext}} \cdot \Delta T + \frac{\lambda_b}{e} \cdot \Delta T + hr_{VC-PNE} \cdot \Delta T + hr_{SOL-PNE} \cdot \Delta T + P_{absor} \\ \frac{m_{PO} \cdot Cp_b}{S_{PO}} \cdot \frac{dT_{POE}}{\Delta t} = h_{C_{ext}} \cdot \Delta T + \frac{\lambda_b}{e} \cdot \Delta T + hr_{VC-POE} \cdot \Delta T + hr_{SOL-POE} \cdot \Delta T + P_{absor} \\ \frac{m_{PFP} \cdot Cp_b}{S_{PFP}} \cdot \frac{dT_{PFPE}}{\Delta t} = h_{C_{ext}} \cdot \Delta T + \frac{\lambda_b}{e} \cdot \Delta T + hr_{VC-PFPE} \cdot \Delta T + P_{absor} \\ \frac{m_{PE} \cdot Cp_b}{S_{PE}} \cdot \frac{dT_{PEE}}{\Delta t} = hr_{ext} \cdot \Delta T + \frac{\lambda_b}{e} \cdot \Delta T + hr_{VC-PEE} \cdot \Delta T + hr_{SOL-PEE} \cdot \Delta T + P_{absor} \end{array} \right] \tag{5.5}$$

• **Thermal balance of interior facades of the studied room**

$$\left[\begin{array}{l}
 \frac{m_{PS} \cdot Cp_b}{S_{PS}} \cdot \frac{dT_{PSI}}{\Delta t} = h_{C_{int}} \cdot \Delta T + \frac{\lambda_b}{e} \cdot \Delta T + h_{r_{PSI-PNI}} \cdot \Delta T + h_{r_{PSI-POI}} \cdot \Delta T + \\
 \qquad \qquad \qquad h_{r_{PSI-PEI}} \cdot \Delta T + h_{r_{PSI-PFPI}} \cdot \Delta T + h_{r_{PSI-PIP}} \cdot \Delta T \\
 \frac{m_{PN} \cdot Cp_b}{S_{PN}} \cdot \frac{dT_{PNI}}{\Delta t} = h_{C_{int}} \cdot \Delta T + \frac{\lambda_b}{e} \cdot \Delta T + h_{r_{PNI-PSI}} \cdot \Delta T + h_{r_{PNI-PEI}} \cdot \Delta T + \\
 \qquad \qquad \qquad h_{r_{PNI-POI}} \cdot \Delta T + h_{r_{PNI-PFPI}} \cdot \Delta T + h_{r_{PNI-PIP}} \cdot \Delta T \\
 \frac{m_{PO} \cdot Cp_b}{S_{PO}} \cdot \frac{dT_{POI}}{\Delta t} = h_{C_{int}} \cdot \Delta T + \frac{\lambda_b}{e} \cdot \Delta T + h_{r_{POI-PSI}} \cdot \Delta T + h_{r_{POI-PNI}} \cdot \Delta T + \\
 \qquad \qquad \qquad h_{r_{POI-PEI}} \cdot \Delta T + h_{r_{POI-PFPI}} \cdot \Delta T + h_{r_{POI-PIP}} \cdot \Delta T \\
 \frac{m_{PFP} \cdot Cp_b}{S_{PFP}} \cdot \frac{dT_{PFPI}}{\Delta t} = h_{C_{int}} \cdot \Delta T + \frac{\lambda_b}{e} \cdot \Delta T + h_{r_{PFPI-PSI}} \cdot \Delta T + h_{r_{PFPI-PNI}} \cdot \Delta T + \\
 \qquad \qquad \qquad h_{r_{PFPI-POI}} \cdot \Delta T + h_{r_{PFPI-PEI}} \cdot \Delta T + h_{r_{PFPI-PIP}} \cdot \Delta T \\
 \frac{m_{PE} \cdot Cp_b}{S_{PE}} \cdot \frac{dT_{PEI}}{\Delta t} = h_{C_{int}} \cdot \Delta T + \frac{\lambda_b}{e} \cdot \Delta T + h_{r_{PEI-PSI}} \cdot \Delta T + h_{r_{PEI-PNI}} \cdot \Delta T + \\
 \qquad \qquad \qquad h_{r_{PEI-POI}} \cdot \Delta T + h_{r_{PEI-PFPI}} \cdot \Delta T + h_{r_{PEI-PIP}} \cdot \Delta T \\
 m_a \cdot Cp_a \cdot \frac{dT_{int}}{\Delta t} = h_{C_1} \cdot S_{PS} \cdot \Delta T + h_{C_2} \cdot S_{PN} \cdot \Delta T + h_{C_3} \cdot S_{PO} \cdot \Delta T + \\
 \qquad \qquad \qquad h_{C_4} \cdot S_{PE} \cdot \Delta T + h_{C_5} \cdot S_{PFP} \cdot \Delta T + h_{C_6} \cdot S_{PIP} \cdot \Delta T
 \end{array} \right] \quad (5.6)$$

The algebraic equations systems resulting from the discretization of transfer equations in both habitat environments (external and internal) are expressed in the form of matrices that can be written as: $A \cdot x = B$. This equations system is solved by using the iterative numerical method of Gauss.

$$\left[\begin{array}{cccccccccccc}
 A_{11} & A_{12} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
 A_{21} & A_{22} & 0 & A_{24} & 0 & A_{26} & 0 & A_{28} & 0 & A_{210} & A_{211} & 0 \\
 0 & 0 & A_{33} & A_{34} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
 0 & A_{42} & A_{43} & A_{44} & 0 & A_{46} & 0 & A_{48} & 0 & A_{410} & A_{411} & 0 \\
 0 & 0 & 0 & 0 & A_{55} & A_{56} & 0 & 0 & 0 & 0 & 0 & 0 \\
 0 & A_{62} & 0 & A_{64} & A_{65} & A_{66} & 0 & A_{68} & 0 & A_{610} & A_{611} & 0 \\
 0 & 0 & 0 & 0 & 0 & 0 & A_{77} & A_{78} & 0 & 0 & 0 & 0 \\
 0 & A_{82} & 0 & A_{84} & 0 & A_{86} & A_{87} & A_{88} & 0 & A_{810} & A_{811} & 0 \\
 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & A_{99} & A_{910} & 0 & 0 \\
 0 & A_{102} & 0 & A_{104} & 0 & A_{106} & 0 & A_{108} & A_{109} & A_{1010} & A_{1011} & 0 \\
 0 & A_{112} & 0 & A_{114} & 0 & A_{116} & 0 & A_{118} & 0 & A_{1110} & A_{1111} & 0
 \end{array} \right] \times \left[\begin{array}{c}
 T_{PSE}^{t+\Delta t} \\
 T_{PSI}^{t+\Delta t} \\
 T_{PNE}^{t+\Delta t} \\
 T_{PNI}^{t+\Delta t} \\
 T_{POE}^{t+\Delta t} \\
 T_{POI}^{t+\Delta t} \\
 T_{PFPE}^{t+\Delta t} \\
 T_{PFPI}^{t+\Delta t} \\
 T_{PEE}^{t+\Delta t} \\
 T_{PEI}^{t+\Delta t} \\
 T_{A2}^{t+\Delta t}
 \end{array} \right] = \left[\begin{array}{c}
 B_1 \\
 B_2 \\
 B_3 \\
 B_4 \\
 B_5 \\
 B_6 \\
 B_7 \\
 B_8 \\
 B_9 \\
 B_{10} \\
 B_{11}
 \end{array} \right] \quad (5.7)$$

Or:

$$A_{11} = T_{PSE}^{t+\Delta t} = \left(\frac{m_{PS} \cdot Cp_{PS}}{S_{PS}} \cdot \frac{1}{\Delta t} + h_{C_{ext}} + \frac{\lambda_b}{e} + h_{r_{VC-PSE}} + h_{r_{SOL-PSE}} \right) \quad (5.8)$$

$$A_{12} = T_{PSI}^{t+\Delta t} = \left(-\frac{\lambda_b}{e} \right) \tag{5.9}$$

$$B_1 = \left(\frac{m_{PS} \cdot Cp_b}{S_{PS}} \cdot \frac{T_{PSE}^t}{\Delta t} + h_{C_{ext}} \cdot T_{ext}^t + h_{r_{VC-PSE}} \cdot T_{VC}^t + h_{r_{SOL-PSE}} \cdot T_{SOL}^t + FSG_{PS} \right) \tag{5.10}$$

$$A_{22} = T_{PSI}^{t+\Delta t} = \left(\frac{m_{PS} \cdot Cp_b}{S_{PS}} \cdot \frac{1}{\Delta t} + h_{C_{int}} + \frac{\lambda_b}{e} + h_{r_{PSI-PNI}} + h_{r_{PSI-POI}} + h_{r_{PSI-PEI}} + h_{r_{PSI-PFPI}} + h_{r_{PSI-PIP}} \right) \tag{5.11}$$

$$A_{24} = T_{PNI}^{t+\Delta t} = \left(-h_{r_{PSI-PNI}} \right) \tag{5.12}$$

The temperature of the thermal comfort (T_C) for a habitable one makes it possible to estimate the heating needs [27]. However, based on the bibliographic synthesis that was conducted in order to find a suitable model for the calculation of the comfort temperature, we opted for a relationship that was established between the comfort temperature (T_C), internal temperature (T_{int}) and mean radiant wall temperature (T_{PI}), as follows [28,29]:

$$T_C = \frac{T_{int} + \sum_{n=1}^{n=6} T_{PI}}{2} \tag{5.13}$$

$$\sum_{n=1}^{n=6} T_{PI} = T_{PSI} + T_{PNI} + T_{PEI} + T_{POI} + T_{PFPI} + T_{PPI} \tag{5.14}$$

Taking into account the air as a transmission fluid between the ambience and the room facades. Table 2 shows the physico-thermal properties of the air that were taken during the numerical simulation.

Table 5.1. The Air Thermal Properties [29].

λ	Thermal conductivity in (W.m ⁻¹ .K ⁻¹)	0,0262
Cp	Specific heat in (J.Kg ⁻¹ .K ⁻¹)	1006
ρ	Density in (Kg.m ⁻³)	1,177
μ	Dynamic viscosity in (Kg.m ⁻¹ .s ⁻¹)	1,85.10 ⁻⁵
ν	Kinematic viscosity in (m ² .s ⁻¹)	1,75.10 ⁻⁵
Pr	Number of Prandtl	0,708

6. FLOW CHART OF NUMERICAL MODELING

The calculation of the different heat transfer parameters within the habitable envelope under consideration is based on the following steps:

- Introduction of climatic data of the considered region for the selected typical day.
- Calculation of the geometrical and astronomical parameters of the sun in the considered typical day.
- Introduction of climate data such as: the average amount of the ambient solar flux and the ambient temperature of the considered day.
- Determination of solar radiation incidence angles for each facade of the habitat as a function of the hour angle and the position of the sun in the sky.

- Computation of the amount of solar flux density for of all the house facades.

The numerical tests carried out during the development of the computer code in FORTRAN language led to the retention of a time step of 300 seconds. In figure 6.1, we show the computational steps developed in the numerical simulation code.

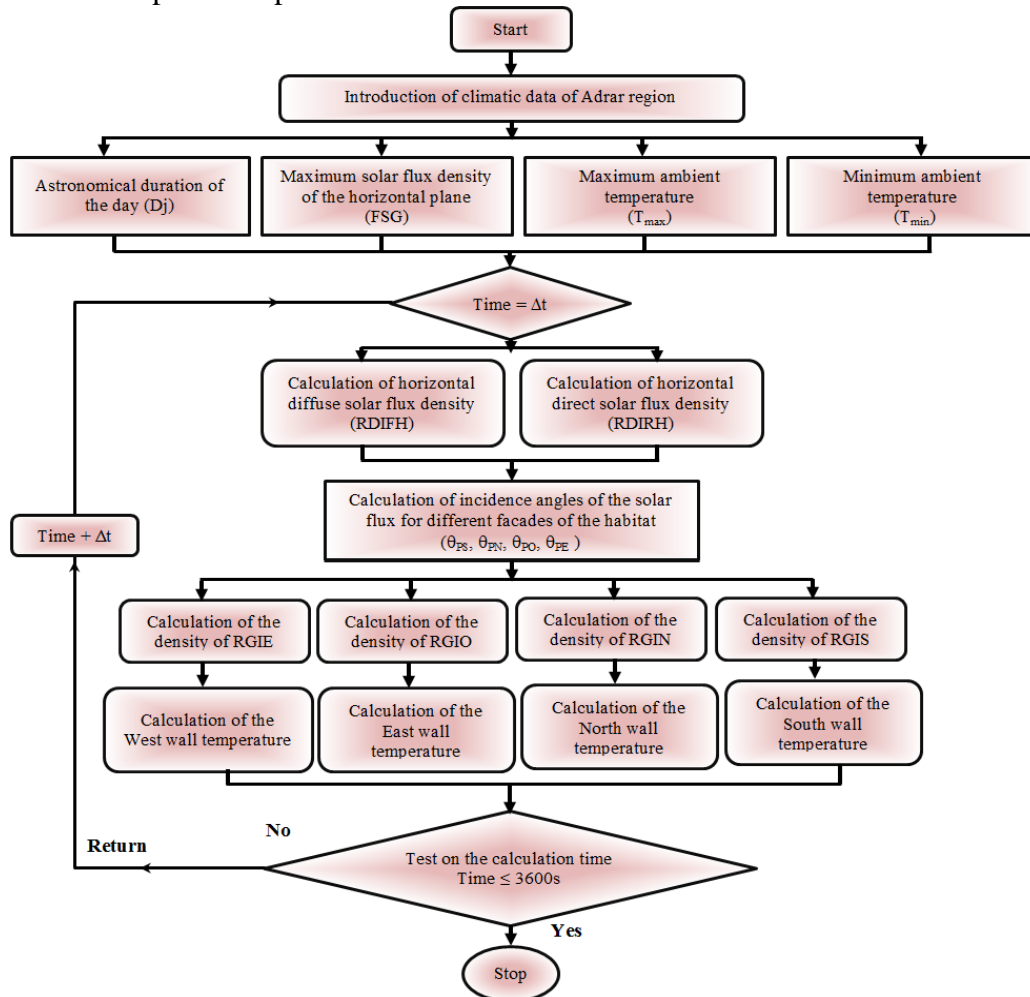


Fig.6.1. Flow chart of calculation steps in the habitat performed by the developed FORTRAN code.

7. RESULTS AND DISCUSSION

7.1. Internal evolution of temperature of the room

Figure 7.1 shows the hourly variation of the temperature of different internal facades of the room during the typical day. It can be seen that the thermal inertia of the concrete plays a very important role in the heat transfer at the walls. Indeed, the ceiling temperature (TPFP) is greater compared to the temperatures of the other internal faces of the South walls (TPSI), West (TPOI), North (TPNI) and East (TPEI). This is due to the conjugation of two essential factors that led to this increase in temperature: in the first place, the walls thickness of the room which involves the elevation of the thermal inertia and secondly, the inclination angle of the roof facade which is equal to 0° .

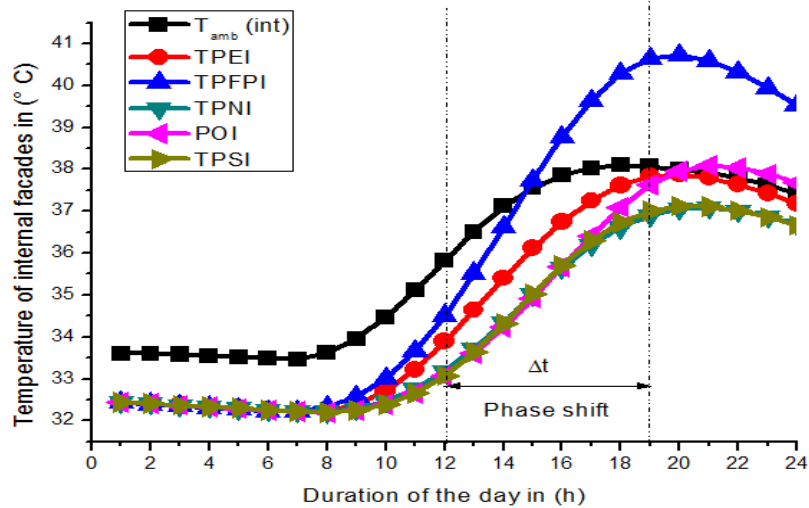


Fig.7.1. Internal evolution of air temperature in the room, according to the local time.

7.2. Internal evolution of temperature according to building materials

To use construction materials wisely, it is essential to know their thermal properties. The thermo-physical properties of the materials used in this study are shown in Table 7.1. The thermal capacity of a wall is especially useful if it is placed in the interior of the room and isolated from the external climatic conditions. To build in strong inertia, it is therefore to use heavy materials inside the room in order to store the solar heat and to attenuate the internal temperature variations [30]. Conversely, the temperature of a room with low inertia increases rapidly at the slightest ray of sun without the possibility of storing solar heat. Internal temperature differences will be significant and the risk of overheating will be high. Strong inertia is especially useful in case of permanent occupation. Low inertia can be interesting for habitable environments with intermittent use [30,31].

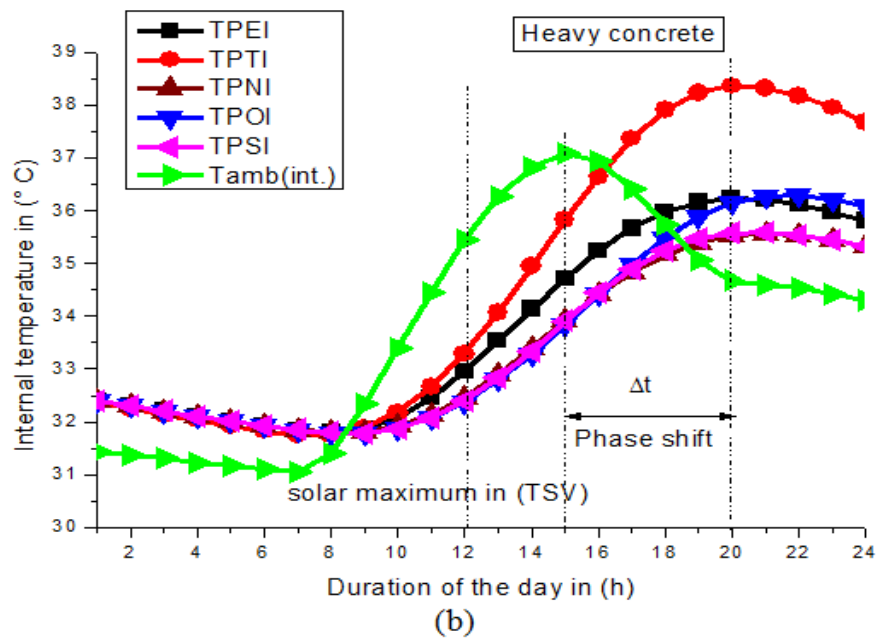
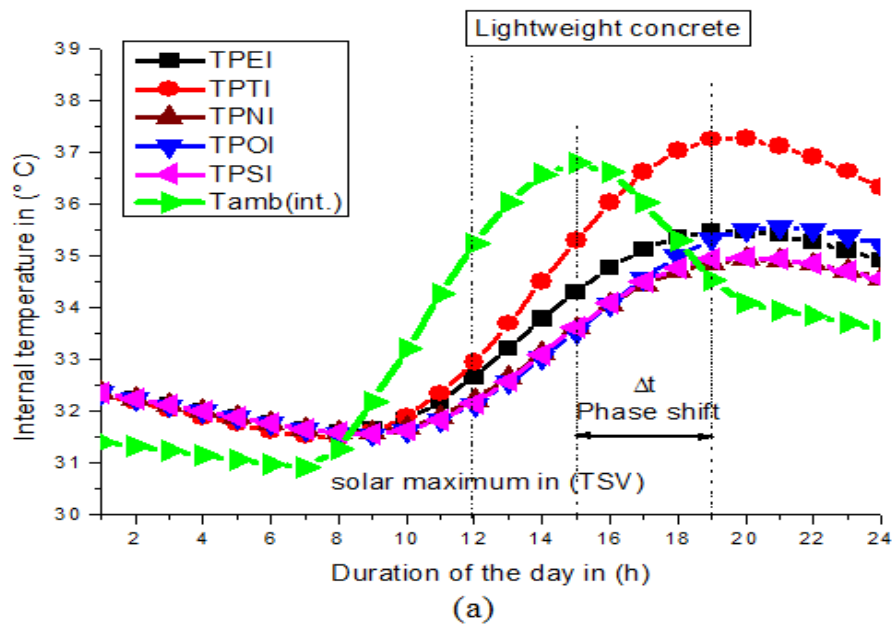
Table.7.1. Thermophysical Properties of Building Materials [30,31].

	<i>Heavy concrete</i>	<i>Lightweight concrete</i>	<i>Concrete stone</i>	<i>Light wood</i>	<i>Heavy wood</i>
Thermal conductivity λ (W.m ⁻¹ . K ⁻¹)	1,75	1,00	1,40	0,14	0,20
Density ρ (Kg.m ⁻³)	2200	1500	1895	540	800
Specific heat c_p (J.kg ⁻¹ . K ⁻¹)	1000	1000	1000	2400	2700
Emissivity ε	0,54	0,54	0,54	0,86	0,86
Absorption coefficient α	0,6	0,6	0,6	0,07	0,07

Figure 7.2 illustrates the thermal capacity effect of solar energy storage in the room wall of for different building materials (light concrete, heavy concrete, stone concrete, light wood and heavy wood). It can be noted that for all habitable rooms built with high thermal capacity materials such as lightweight concrete (see Fig. 7.2(a)), heavy concrete (see Fig. 7.2(b)) and concrete stone (see Fig 7.2(c)), the temperature of its internal space is optimal in the month of July because of the thermal inertia of these materials. Indeed, it is well observed in figures (see Fig. 7.2(a), Fig.7.2(b) and Fig.7.2(c)) that the temperature of the internal ambience varies between 37°C and 38,5°C.

In addition, if the construction of habitable rooms is based on low heat capacity materials, the temperature of the internal space varies around 34°C and 35°C because of the thermal inertia of this building materials type (heavy wood (see Fig. 7.2(d)) and light wood (see Fig. 7.2(e)). Furthermore, it is noted that the temperature of the internal facades for building

materials with high thermal capacity is very high compared to the internal facades of buildings with low heat capacity materials.



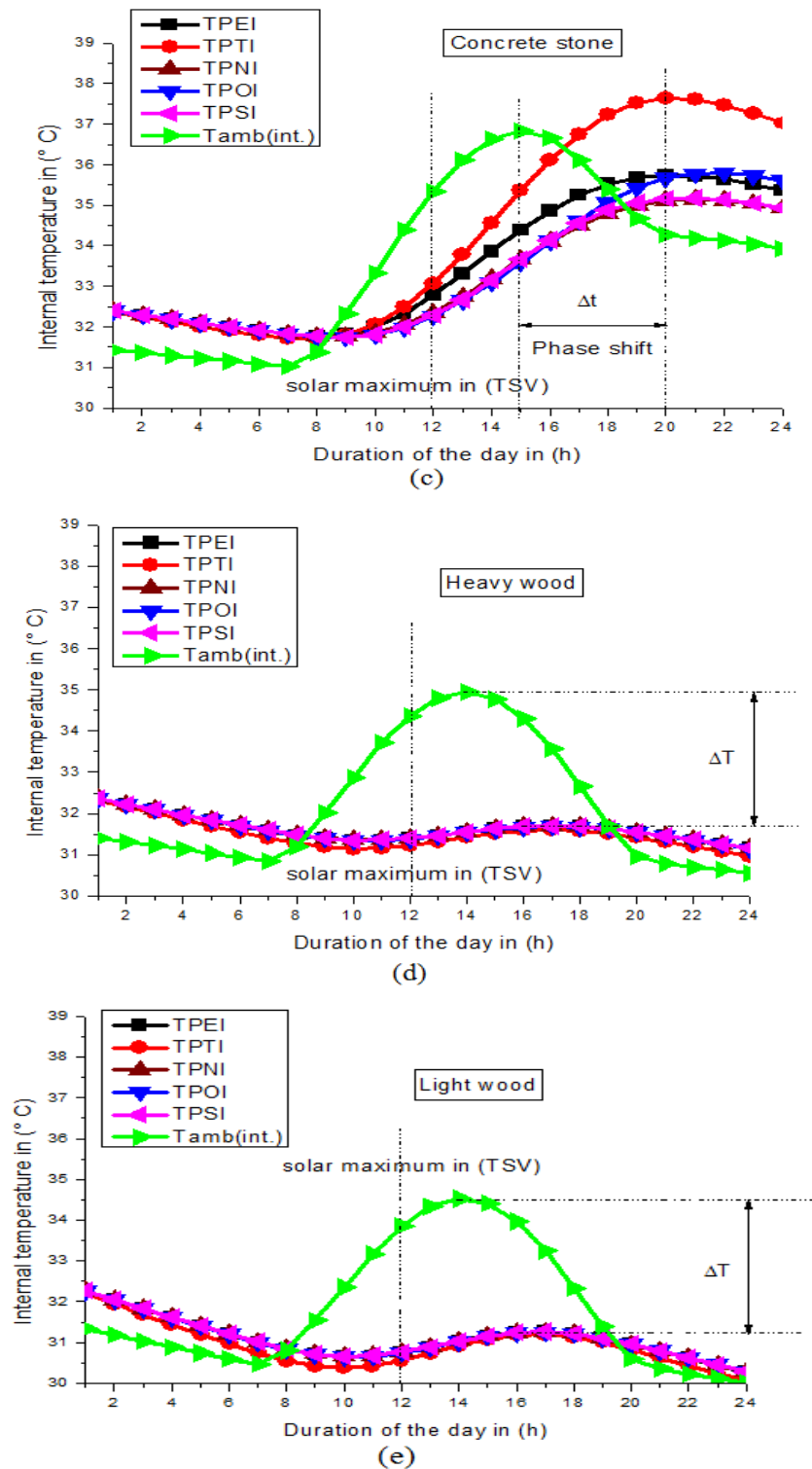


Fig.7.2. Evolution of temperature of the room internal facades for different building materials.

7.3. Evolution of the thermal comfort temperature

Figure 7.3 shows the hourly change in temperature of thermal comfort of different building materials as a function of local time. From this illustration, it can be seen that the choice of construction material has a significant influence on the hourly evolution of the thermal comfort temperature. Indeed, when one uses for example the concretes selected categories in this study as building material with these dry climatological conditions, and without control of thermal insulation, the comfort temperature will exceed the conventional norms. That is to say, undesirable overheating of the habitable

environment with a temperature of 39°C at 15h00 in the afternoon as illustrated in figure 8 for the three categories of concrete (heavy, light and stone). On the other hand, the exploitation of other building materials such as the categories of wood (heavy and light) in this region with the same climatic conditions will help to get closer to the conventional values of the comfortable temperature in the environment. Habitable, since the maximum temperature obtained using the wood does not exceed 37°C (value obtained at 15h00 pm).

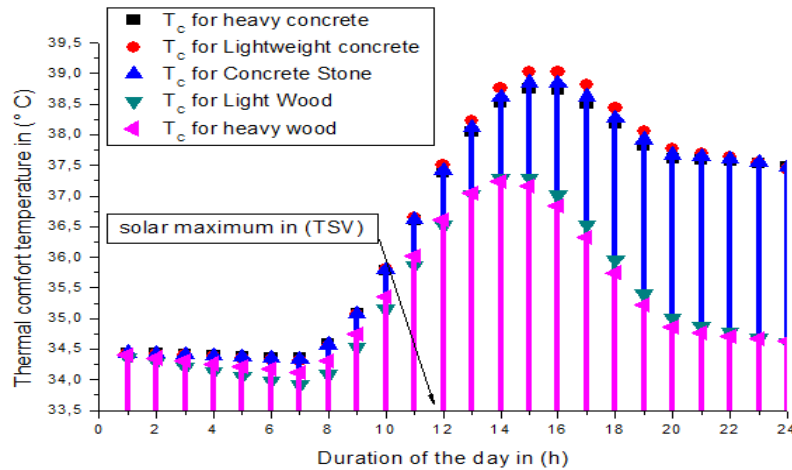


Fig.7.3. Evolution of the thermal comfort temperature in the room for different building materials in a typical day.

7.4. Overlay on the psychrometric chart

Figure 7.4 shows the superimposition on the psychrometric chart of temperature of thermal comfort within the room for different building materials in the typical day (July 17th, 2014). It can be seen that the thermal comfort temperature of concrete structures (heavy, light and stone) is positioned in the area of thermal discomfort and the need for evaporation. While for both types of wood (heavy and light) is positioned in the same area as that of the concrete categories, except that the comfort temperature for a concrete construction varies between 38°C and 39°C and the temperature of a wood construction varies between 34°C and 36°C. Noting that these thermal comfort temperatures were calculated for the typical day of July 17th, 2014, which is the hottest day of the summer season in Adrar region.

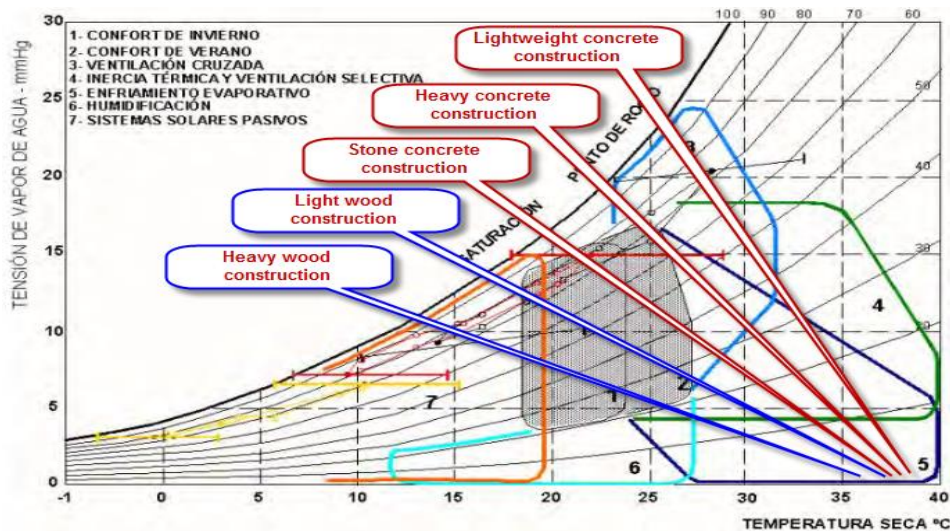


Fig.7.4. Super-positioning temperatures of thermal comfort of the room for different building materials during the typical day.

8. CONCLUSION

Thermal comfort is an essential element for the well-being of the occupant in his built environment. Taking it into account that the habitat implies there different aspects. However, after the numerical examination of the temperatures of different internal facades of the habitable room, the change effect of the building materials on the evolution of the internal temperature and the superposition of the thermal comfort temperatures on the psychometric chart, it has been found that:

- The use of bare concrete as a building material in the current architecture of Adrar region, involves undesirable overheating. In addition, the same effect has been noted for wood in this region, but with temperatures a little closer to conventional temperatures of thermal comfort.
- The severe climatic conditions of this region contribute in a direct way to the thermal discomfort.

On the basis of this study, it is recommended that before beginning the construction of a habitable envelope in this desert region, it is imperative to undertake an overall revision of conventional standards for thermal comfort, in particular the respect for bioclimatic concepts.

On the other hand, we suggest:

- Ventilation and evaporative cooling during the summer season.
- Insulation and shading of the walls the most requested for excess solar radiation.

Nomenclatures		Abbreviation		
e	The material thickness	m	PE	East wall
hc	Coefficient of internal heat exchange by convection	$W.m^{-2}.k^{-1}$	PN	North wall
m_{ps}	The south wall Mass	Kg	PO	West wall
P_{absor}	Amount of heat absorbed	W	PS	South wall
S_{PL}	South wall surface	m^2	PFP	The ceiling Wall
T_{amb}	Ambient temperature	$^{\circ}C$	PNI	Internal north wall
T_{sol}	Temperature of soil	$^{\circ}C$	PSI	Internal south wall
T_{air}	Air temperature	$^{\circ}C$	$PFPI$	Internal wall of the ceiling
ΔT	Temperature difference	$^{\circ}C$	PSE	External south wall
T_{int}	Full air temperature in the habitat	$^{\circ}C$	POE	External west wall
T_{ext}	Outside air temperature	$^{\circ}C$	PIP	Internal floor wall
T_b	Temperature of the concrete slab	$^{\circ}C$	PEE	Externe east wall
T_C	Thermal comfort temperature	$^{\circ}C$	$PFPE$	External wall of the ceiling
FSG	Global solar flux	W/m^2	M'zab	Region north of Sahara Algerian

REFERENCES

- [1] Dengjia W., Yanfeng L., Jing J., and Jiaping L., (2015). The optimized matching of passive solar energy supply and classroom thermal demand of rural primary and secondary school in northwest China, *Procedia Engineering Vol.* 121, 1089 – 1095.
- [2] Batier C., (2016). Confort thermique et énergie dans l'habitat social en milieu méditerranéen d'un modèle comportemental de l'occupant vers des stratégies architecturales, *Ph.D. Thesis*, Université of Montpellier, la France.

- [3] Ryzhov A., Ouerdane H., Gryazina E., Bischi A. and Turitsyn K., (2019). Model predictive control of indoor microclimate: Existing building stock comfort improvement, *Energy Conversion and Management Vol.179*, 219–228.
- [4] Alexis S., (2014). Etudes de systèmes énergétiques et optimisation énergétique de bâtiments basse énergie, *Master Thesis*, université of Lorraine, la France.
- [5] Errebai F., Derradji L., Maoudj Y. & Amara M., (2012). Confort thermique d'un local d'habitation : Simulation thermoaéraulique pour différents systèmes de chauffage, *Revue des Energies Renouvelables Vol. 15 N°1*, 91–102.
- [6] Sehli A., Hasni A. & M.Tamali, (2012). The potential of earth-air heat exchangers for low energy cooling of buildings in South Algeria, *Energy Procedia Vol.18*, 496–506.
- [7] Benhammou M., Draoui B. & Hamouda M., (2017). Improvement of the summer cooling induced by an earth-to-air heat exchanger integrated in a residential building under hot and arid climate, *Applied Energy Vol. 208*, 428–445.
- [8] Benhammou M., Draoui B., Zerrouki M. & Marif Y., (2015). Performance analysis of an earth-to-air heat exchanger assisted by a wind tower for passive cooling of buildings in arid and hot climate, *Energy Conversion and Management Vol. 91*, 1–11.
- [9] Boutabba H., Mili M., Boutabba S., (2016). L'architecture domestique en terre entre préservation et modernité: cas d'une ville oasienne d'Algérie (Aoulef) Domestic architecture in the ground between conservation and modernity: If an oasis city in Algeria, *J. Mater. Environ., Sci. N°7 (10)*, 3558-3570.
- [10] Chellali F., Khellaf A., Belouchrani A. & Recioui A., (2011). A contribution in the actualization of wind map of Algeria, *Renewable and Sustainable Energy Reviews Vol. 15*, 993–1002.
- [11] Oudrane A., (2011). Modélisation et caractérisation d'un système solaire destiné pour la production du chauffage des locaux, *Magister Thesis*, l'école polytechniques of Oran Maurice Audin, Algeria.
- [12] Radiometric station, (EnerMENA), Technical Report, (2014). *High Precision Meteorological Station of Research Unit for Renewable Energies in the Saharan Environment*, in Adrar, Algeria.
- [13] Peel M., Finlayson B. & MacMahon T. (2007) Updated world map of the Köppen-Geiger climate classification, In Hydrology and Earth System Sciences no 11, p. 1633, *Copernicus Publications pour European Geosciences Union*, Göttingen, ISSN 1027-5606.
- [14] Smaïl M., (2004). Modélisation électromagnétique et thermique des moteurs à induction, en tenant compte des harmoniques d'espace, *Ph.D. Thesis*, Université of lorraine, Nancy, la France.
- [15] Lutun J., (2012). Modélisation thermique des alternateurs automobiles, *Ph.D. Thesis*, Université of Grenoble, la France.
- [16] Jabbar A., Khalifa N. & Abbas E., (2009). A comparative performance study of some thermal storage materials used for solar space heating, *Energy and Buildings Vol. 41*, pp. 407–415.
- [17] Hernández-Pérez I., Álvarez G., Gilbert H., Xamán J., Chávez Y. and Shah B., (2014). Thermal performance of a concrete cool roof under different climatic conditions of Mexico, *Energy Procedia Vol. 57*, 1753 – 1762
- [18] Bekkouche S. & Benouaz T., (2014). Thermal resistances of local building materials and their effect upon the interior temperatures case of a building located in Ghardaïa region , *Construction and Building Materials Vol. 52*, 59–70.
- [19] Mezzhab A. & Bouzidi M., (2006). Computation of thermal comfort inside a passenger car compartment, *Applied Thermal Engineering Vol. 26*, 1697–1704.
- [20] Boukli M. A., Amara S., Chabane N. E., (2011). Thermal requirements and temperatures evolution in an ecological house, *Energy Procedia Vol. 6*, 110–121.

- [21] Peuser F., Remmers & Schnauss K., (2005). Installation solaires thermiques, conception et mise en œuvre, *Edité par Systèmes Solaires*, Solar Praxis et le Moniteur.
- [22] Bekkouche M. E. A., (2009). Modélisation du comportement thermique de quelques dispositifs solaires, *Ph.D. Thesis*, Université of Tlemcen, Algeria.
- [23] Amar B., (2010). Contribution à l'étude de séchage solaire de produits agricoles locaux, *Magister Thesis*, Université of Mentouri – Constantine, Algeria.
- [24] Virginia G., Valentina M., Phillip B., Clifford A., (2016). Inferring the thermal resistance and effective thermal mass distribution of a wall from in situ measurements to characterise heat transfer at both the interior and exterior surfaces, *Energy and Buildings*, doi.org/10.1016/j.enbuild.2016.10.043.
- [25] Oudjedi S., Boubghal A., Braham Chaouch W., Chergui T. et Belhamri A., (2008). Etude paramétrique d'un capteur solaire plan à air destiné au séchage (Partie: 2), *Revue des Energies Renouvelables SMSTS'08 Alger*, 255 – 266.
- [26] Basile K., Cossi N., (1999). Evaluation of the amount of the atmospheric humidity condensed naturally, *Renewable Energy Vol. 18*, 223-247.
- [27] Chandel S., Aggarwal R., (2012). Thermal Comfort Temperature Standards for Cold Regions, *Ashdin Publishing Innovative Energy Policies, Vol. 2*, Article ID E110201, pp. 5.
- [28] Humphreys M. A., (1978). Outdoor temperatures and comfort indoors, *Batiment International, Building Research and Practice Vol. 6*, pp. 92.
- [29] Sam F., (2012). Réhabilitation thermique d'un local dans une zone aride-Cas de Ghardaïa, *Magister Thesis*, université Mouloud Mammeri of Tizi Ouzou, Algeria.
- [30] Tixier N., (2012). Environnement thermique et maîtrise énergétique, *ENSAG*.
- [31] Mavromatidis L. E., M. EL Mankibi, (2012). Numerical estimation of time lags and decrement factors for wall complexes including multilayer thermal Insulation, in two different climatic zones, *Applied Energy Vol. 92*, 480–491.