Numerical simulation of heat transfer through the building facades of buildings located in the city of Bechar

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ABSTRACT
This study deals with the transient heat transfer in a multi-layered building wall through the facades of the buildings located in the city of Bechar (south-west Algeria). The physical model is presented to find the variation of the transient temperature in these structures and the heat flux through these elements, which depends on the air temperature of the inner surface and the instantaneous climatic conditions of the air outside. Comsol Multiphysics based on the finite element method is designed to perform numerical simulations. The measured hourly ambient air temperatures and the solar radiation flux on the horizontal surface for the city of Bechar Algeria are using during the hottest period (July 2015), and also using the properties Thermodynamics of each component of the structure. The validation of the analytical model with this simulation is verified in this document. The calculations carried out for different multilayer building walls which are commonly used in the south of Algeria to determine the thermal behavior of these structures and the influence of radiation heat flux on these elements.

1. INTRODUCTION

The envelope acts as a thermal filter to create a microclimate inside the building, independent of external weather fluctuations. The composition of the envelope is a determining element of the characteristics of this filter. As the building's interior environments cannot always meet the occupant's comfort requirements, the response of the building is corrected by heating or air conditioning units acting as controlled sources of heat or cold. In all cases, heating and cooling equipment consumes energy.

The cooling load of buildings includes much of the overall energy consumption during the summer. In many buildings, heat gain from the external walls and roofs is an important part of the total cooling load because they are exposed to the climatic conditions such as convection and solar heat flux. Therefore, estimation of the heat gain to a space through the external walls and roofs is the essential step in the calculation of cooling load and of air conditioning [1,2]. However, estimation of the heat gain in the conditioned space is quite complicated and time consuming as it is highly transient due to the thermal storage effects of the constructions and under constant external conditions and still more the dependence of Heat gain on the locality, shape, and orientation of buildings complicates the problem [3]. To eliminate these problems, methods for calculating the cooling load are developed

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taking into account the hourly variation outdoor conditions as well as solar radiation, thermal inertia of the building, and variation of the heat loss coefficient of the building [1].

The energy consumed for air conditioning constitutes an important part of the energy bill in Algeria, notably in Bechar, a city in southern Algeria, characterized by its arid climate, with strong seasonal thermal amplitudes, but which imposes long periods Air conditioning throughout the year. The individual building represents nearly 70% of the existing habitat and more than 80% of the homes classified as poorly insulated in the town of Bechar. These buildings have characteristic resemblances of the constructions, among them the facades of baked clay bricks. The vertical opaque walls present themselves as one of the primary sources of loss and the study of heat transfer in these walls makes it possible to understand the interests of these walls and to choose from adequate thermal insulation. In this work it is proposed to study thermally a multi-layer wall, typical of the individual houses of the town of Bechar, in order to understand its dynamic thermal characteristics during the summer period. These are three types of walls: the first type is a single wall consisting of brick 15 cm thick linked by a mortar on the outside and plaster on the inside, the second type consisting of two walls of brick from 10 cm thick separated by the polystyrene of thickness 5 cm bound by a mortar on the outside and plaster on the inside and the third type the same as the previous one replacing the polystyrene by the blade of air.

The objective of this study is to analyze and evaluate the temperature of the different multilayer walls of the typological construction of the region taking into account the climatic conditions during a warmer period of the city of Bechar. To do this, we use a Comsol Multiphysics numerical simulation code based on the finite element method.

2. MODEL DESCRIPTION

The theoretical model consists of a solution of the transient heat transfer problem for a multilayer wall, the estimation of the solar radiation fluxes on the facade surfaces and the heat fluxes through these structures. The geometric configuration of a multi-layer building wall is shown in Figure.1. The wall section consists of a finite number of layers with different thicknesses and thermo-physical properties (Table1), which are typically used in the construction of facades of houses in south-west Algeria (town of Bechar). The right side of the wall is exposed to ambient air, which is maintained at a fixed air temperature inside the T_{air}. It is; there is heat transfer by convection between the wall and the air inside, which relates directly to the air conditioning charge needed to maintain the temperature of the design inside. The left side of the wall is exposed to a periodic temperature of the external ambient air T(t) and the solar radiation flux $I_T(t)$. There is heat transfer by both convection and radiation between the wall and the outside air.

3. METHODOLOGY

The temperature T (x,y,t) of the different points of each material is governed by the Fourier equation. The thermal properties of the wall components are assumed to be isotropic and independent of time and temperature. On the inside and outside of the wall, convective and radiative conditions are established, translated by global coefficients of exchange he and hi. The convective components of the latter are defined according to the following respective expressions:

For summer conditions where $v < 4.88$ m/s:

$$h_e = 5.62 + 3.91\, v \tag{1}$$

v: Wind speed (m/s).

We will take the measured average speed of the month of July 2015

v= 0,1 m/s.

According to Nansteel [5]:

$$h_i = 2.03 \left(\frac{|Tair - Tsi|}{2\, H}\right)^{0.22} \tag{2}$$

T_{air}: Indoor ambient temperature considered 25ºC.

T_{si}: Average temperature of the inside surface of the wall (ºC).

And thanks to the effect of the temperature gradient between the outdoor and indoor environments, the wall is subjected to the following heat transfer mechanisms

- Conduction in each continuous material.
- It is assumed that the outer and inner faces are respectively subjected to a Total flux (convective and radiative) and convective flux,
- An adiabatic condition is assumed along the perimeter of the wall.
- There is no generation of heat in each layer of walls.
- There is perfect contact between the layers; therefore, the interface resistance is negligible.
- The variation of thermal and physical properties is negligible

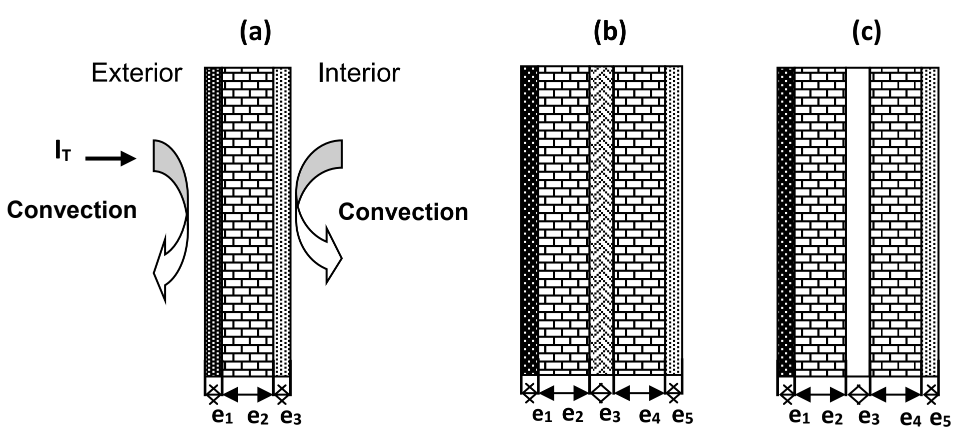


Figure 1, Configurations studied (a)simple wall; (b)multi layer wall with polystyrene; (c)multi layer wall with air knife

Table 1. Dimension of wall layers and thermal properties of materials used

Configurations	**Thickness (mm)**	**Material**	**K [(W/m.K)]**	**Rho [(kg/m^3)]**	**c [(J/kg.K)]**
(a) Simple wall	e1=25	Cement plaster	0.80	1900	850
	e2=150	Clay brick	1.15	1900	864
	e3=25	Interior Plaster	0.57	1150	1000
(b) Multi layer wall	e1=25	Cement plaster	0.80	1900	850
with polystyrene	e2=100	Clay brick	1.15	1900	864
	e3=40	Expanded	0.04	18	1380
	e4=100	polystyrene			
	e5=25	Clay brick	1.15	1900	864
		Interior Plaster	0.57	1150	1000
(c) Multi layer wall	e1=25	Cement plaster	0.80	1900	850
with air knife	e2=100	Clay brick	1.15	1900	864
	e3=40	air knife	0.047	1	1000
	e4=100	Clay brick	1.15	1900	864
	e5= 25	Interior Plaster	0.57	1150	1000

4. CLIMATIC DATA

The climatic conditions used in the simulation are the climate data of the Bechar city in July 2015. Concerning the measurements of the instantaneous outdoor air temperatures and the solar radiation flux on a horizontal surface of each minute recorded by the meteorological station located in the ENERGARID laboratory of the University of Bechar, during a period of 23 to 31 July 2015. Inside the air temperature is considered comfort temperature 25°C. The use of the measured instantaneous values of the outside air temperature and the radiant heat flux on the horizontal surface are shown in figures. 2 and 3. However, it is understood from these figures. The Bechar region is characterized by a warm and dry climate and very high diurnal thermal amplitude. Indeed, the maximum temperatures can reach 46°C during the day, for daytime amplitude in the vicinity of 15°C and a high level of sunshine that reaches 1000 W/m². These climatic conditions in turn promote discomfort.

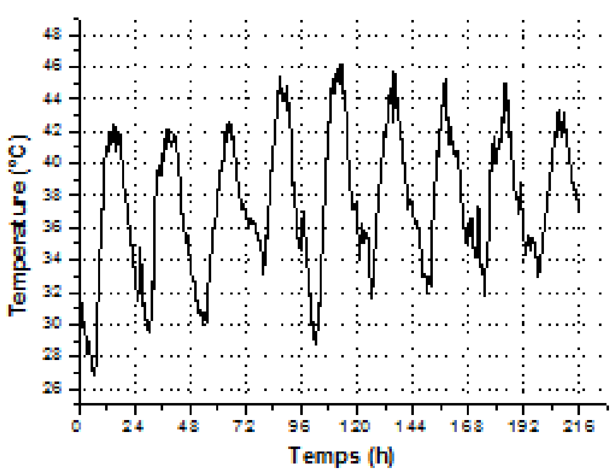


Figure 2. Measured temperature from July 23 to 31, 2015

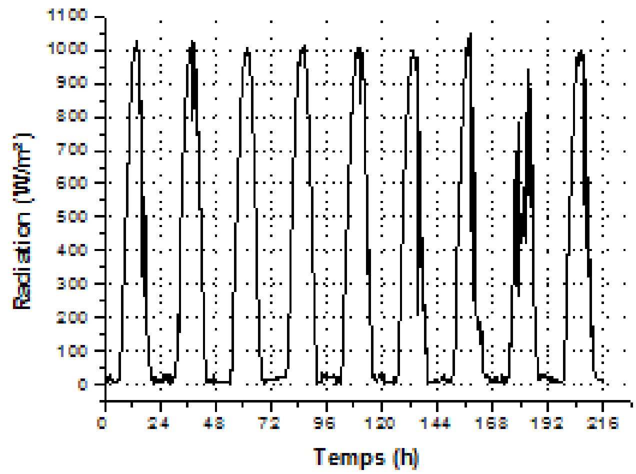


Figure 3. Radiation measured from July 23 to 31, 2015

5. VALIDATION OF THE MODEL

We study a test to compare the results of the one-dimensional version of the computational code used Comsol Multiphysics with certain results well known in the literature. This is a problem of a monolayer wall governed by the heat equation without source term, with constant thermo physical properties.

$$\begin{cases} \rho C_P \dfrac{\partial T}{\partial t} = \lambda \dfrac{\partial^2 T}{\partial x^2} \\ T = T_C \ \ in \ \ x = 0 \\ T = T_f \ \ in \ \ x = L \\ T = T_f \ \ at \ \ t = 0 \end{cases} \tag{3}$$

The parameters are: T_C=20°C, T_f=10°C, L=0.05 m, λ=36.8 $Wm^{-1}.K^{-1}$, ρ=4000 $kg.m^{-3}$ and C_p=780 $J.kg^{-1}.K^{-1}$. A small time step (Δt = 0.01s) is required to ensure accuracy on the finite difference scheme.

On the other hand, the analytical resolution makes it possible to obtain the following expression of the temperature:

$$\frac{T(x,t) - T_F}{T_C - T_F} = \left[erfc\left(\frac{x}{2\sqrt{\propto t}}\right) - erfc\left(\frac{2L - x}{2\sqrt{\propto t}}\right) + erfc\left(\frac{2L + x}{2\sqrt{\propto t}}\right)\right] \tag{4}$$

With erfc the complementary error function and $\alpha = \frac{\lambda}{\rho C_P}$ the thermal diffusivity of the medium.

The temperature profile is shown in figure 4. The numerical results of the computational code and the analytical solution overlap perfectly. The comparison test carried out on the numerical and analytical resolution of the heat equation in a simple wall shows a very good agreement between the results of the calculation code used and the results of the analytical solution carried out by a Matlab program. 'Indicate the temperature profile as a function of time (Figure 4).

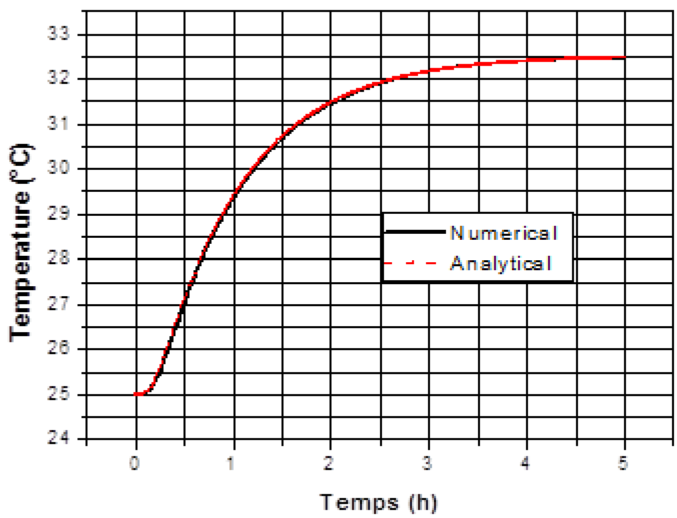


Figure 4. Numerical and Analytical temperature profile

6. RESULTS AND DISCUSSION

Figures 5, 6 and 7 show the temperature variation during the period 23 to 31 July 2015 halfway up the face of the different layers of the wall for the three configurations. The temperature varies in the same manner as that of the external face, in the configuration (a) the thermal resistance is particularly low against the configurations (b) and (c) are more efficient due to the reinforcement of the thermal insulation respectively by polystyrene and the air layer, increasing the heat resistance of the material. Note also that the peak temperature at the external surface of the wall during the summer period taking into account the solar radiation reaching 59°C at 13:00 of the day July 27, 2015.

During this day in the wall type (a) in Figure 5, the temperature of the outer surface varies from 34°C to 55°C and the inner surface varies from 26°C to 32°C is a temperature reduction rate of 23,5% to 42%. In type walls (b) and (c) Figures 6 and 7, the temperature of the outer surface ranges from 36°C to 59°C and the inner surface varies from 26°C to 27°C or a reduction rate temperature from 27.7% to 54%.

The heat flows at mid-height in function of the thickness of different types of wall to four times a day are shown in Figure 8. The heat flux reaches 200 W / m² to 13.00 at the outer interface type of wall (a) with a gap of 180 W / m² at midnight because of significant value to the temperature, and gradually decreases to the inside of the wall with a gap of 160 W / m², also at 08:00 the heat flux has the same profile as the rush hour but point of view it is worth less than one. Against by the two periods that are the heat flux undergoes a linear fall in the outer layer (e1) with a large conductive resistance then increases slightly due to the heat stored (stored) during the day. However, the other two walls (b) and (c) have the same heat flux profiles conductive. It is noted that the flow linearly decreases through the two outer layers (e1) and (e2) but with different values depending on the time of day, at 13.00 peak heat flow is higher compared to other time. From the insulating layer (e3) the flow becomes almost invariable.

Figure 9 shows the flow of heat through the walls studied during the peak period 13.00 shows that the thermal resistance of the two walls (b) and (c) are lower than that of single-wall due to the presence of the insulating layer (air knife and polystyrene) and also the increase of the wall thickness.

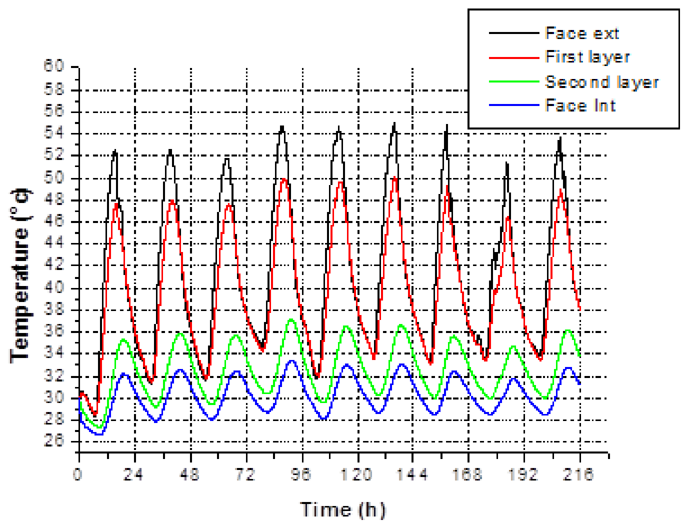


Figure 5. Temperature with radiation of different layers at mid-height of the simple wall (a) from 23 to 31/07/2015

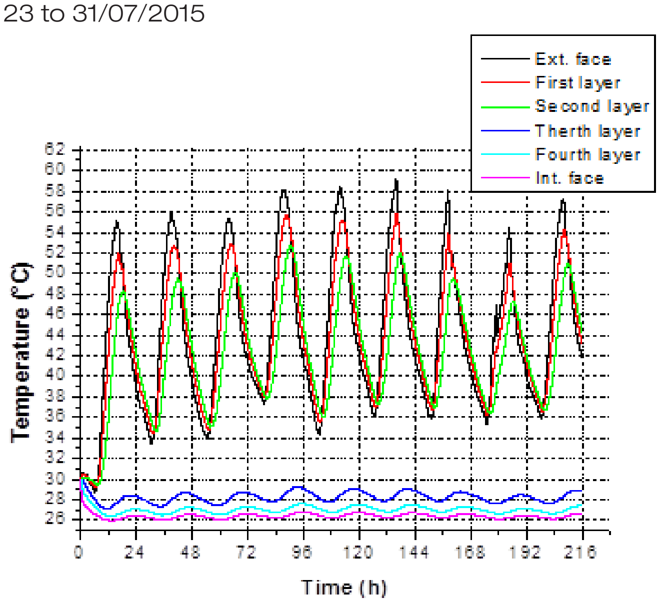


Figure 6. Temperature with radiation of different layers at mid-height of the multi layer wall with polystyrene (b) from 23 to 31/07/2015

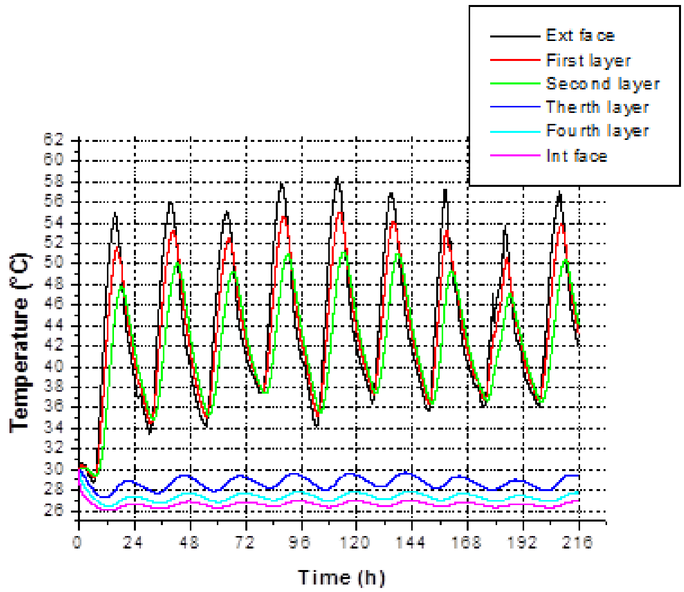
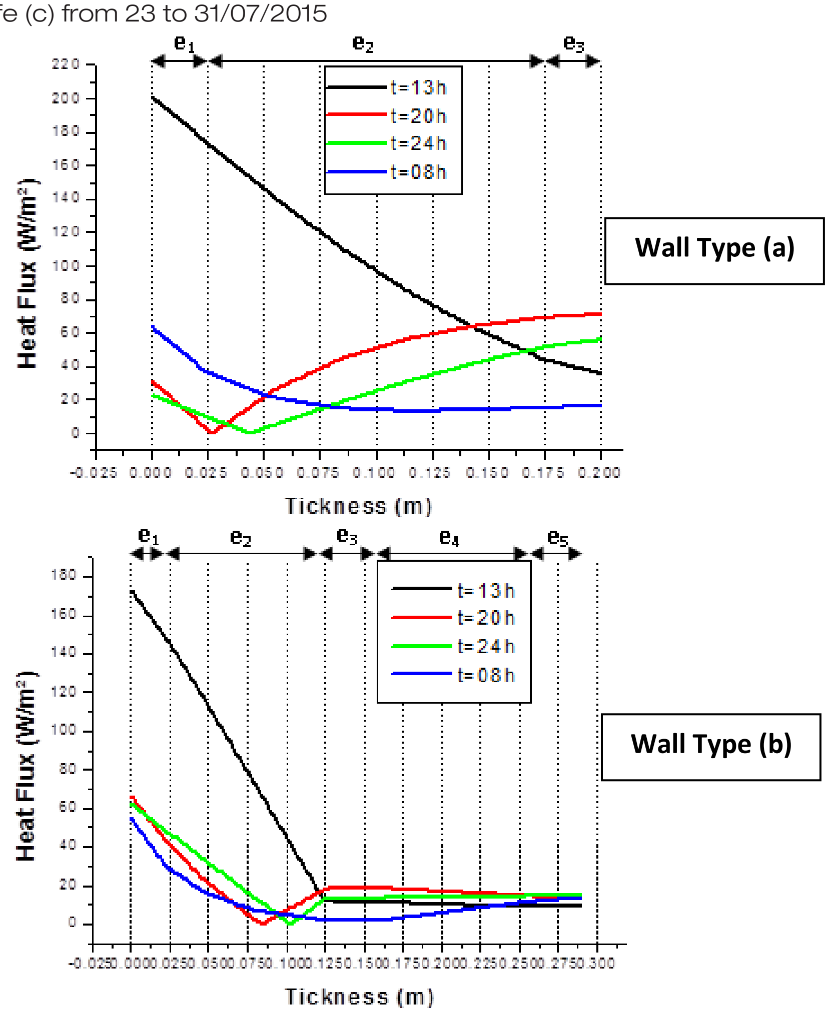


Figure 7. Temperature with radiation of different layers at mid-height of the multi layer wall with air knife (c) from 23 to 31/07/2015



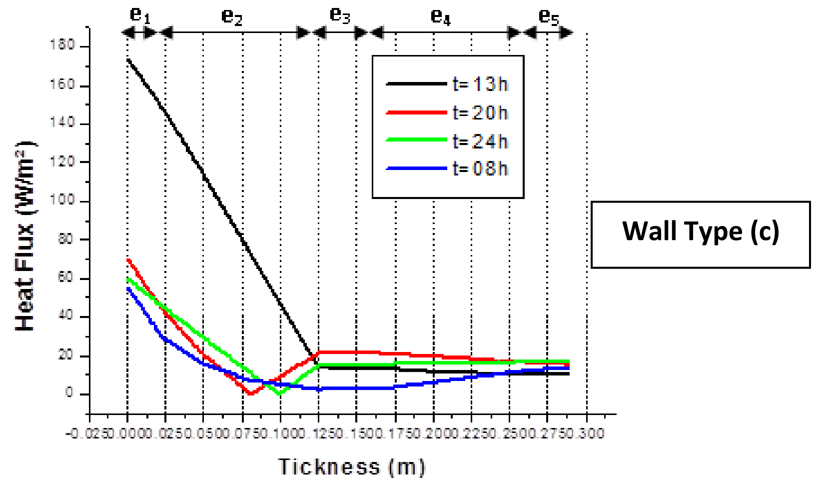


Figure 8. Heat flux as a function of the thickness of each wall type for different times of day

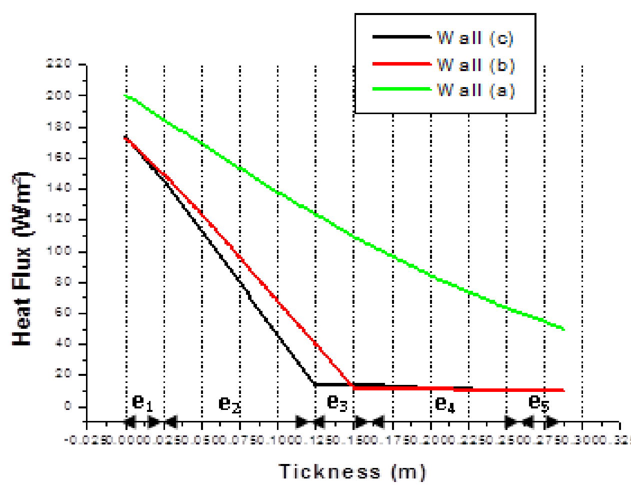


Figure 9. Heat flux as a function of the thickness of each wall type at time t = 13h00

4. CONCLUSION

In this work, we presented a study of heat transfer by conduction through three types of multilayer walls representing the facades of buildings as building models used in the town of Bechar. They are subjected to varying thermal conditions representing the climatic conditions in summer in the south west Algeria; which refers to a variable solar flux and convective heat transfer on the outside and inside.

The numerical results show that it is possible to use the type of wall (c) is more effective than the other two walls this can be justified by the fact that the insulation acts as a thermal barrier. The temperature profile varies according to the variation in that at the outer isreduced from one layer to the other of the outer face towards the inner face. At peak the maximum difference in temperature between the two extreme sides reached 20°C for the type of wall (a) and 30°C for the other two types.

Finally the harsh climate of the city of Bechar with the change in outside temperature day / night (amplitude 15°C) and high insolation in the day (1000W/m²) requires the use of a good thermal insulation and orientation building to ensure thermal comfort of users and reduce energy consumption.

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