Simulation of the Thermal Inertia of a Wall Under the Saharan Winter Climatic Conditions of Algeria

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Abstract: Thisworkinvolvesthestudyand the modelingofheat transferin awall subjectedtoaconditionofsolar radiationinwinteronthe outside. Anoptimalproposalis clearedfrom this studybased onthe searched objectives. Wealso analyzedtheinfluenceof heat transferonmaterials selectionand optimizationofthe thickness ofsuchabuilding envelopeinsouthwestAlgeria. The operationof thenumerical codedevelopedoncasesrelatedto theprobleminthehome.The simulation resultsarepresentedexamplesofbuildinginreal operating conditions(solar input, temperature, accumulated heat, etc....) and areingoodagreementwiththoseofthe literature. In the established periodic regime, the temperature of the outer face varies from 21.23°C to 56.01°C, the temperature in the middle of the wall varies from 14.96°C to 22.02°C. Therefore, the amplitude of the quasi-steady state is 17.39°C. The heat stored and returned inside the room varies from 136.61 W/m² to 177.73 W/m²; the amplitude of the quasi-stationary regime is 20.56 W/m².

Keywords: Thermal inertia, sunshine, passive heating, modelling.

1. Introduction

The south-west of Algeria, the area retained in this study, is characterized by a Saharan climate (zone D). With strong insolation, exceeding 3500 H/year, and intense direct solar radiation, which can reach 1100 W/m2 on a horizontal plane, the climate presents a very contrasting thermal regime.In summer, the temperature easily exceeds 45°C in the shade, and the relative humidity remains low at around 27%. In addition, in winter the outside temperature can drop to -5°C at night with rare and irregular rainfall.

Given that the problem studied is still topical and given the work presented by E. Wurtz [2], Y. Tamene1 et al [8], C. Maalouf et al., and Hami K., et al. [1,3], Prabal Talukdar et al., and S.A. Al-Sanea et al., [6,7] and as well as the study made by K. Hami et al [4, 5] for the case of a Trombe wall subjected to a winter solar flux, we proposed to develop a code which, allowed us to study the heat transfer through the exterior wall of a dwelling. We also analyzed the influence of heat transfer on the choice of material and the optimization of their thickness. The exploitation of the digital code is developed in cases relating to the problem posed in the habitat. The simulation results are presented on examples of buildings under real operating conditions (solar gain, temperatures, accumulated heat …).

2. Method

Let us consider a flat wall facing due south made of a homogeneous and isotropic material whose lateral dimensions are large compared to its thickness e (Figure 1). The initial temperature distribution is assumed to be uniform; its face x = 0 is suddenly brought into contact with, a variation of the heat flux due to winter sunshine (January month) in the south-west Algerian zone. The sky is considered to be serene, the relative direct insolation is between 80 and 100%, the face x = e is assumed to be maintained at a temperature Tin.

$$\varphi_s(t) = 800.\sin(\pi.t / 36000) = \text{flux solaire (W/m²)} \quad (1)$$

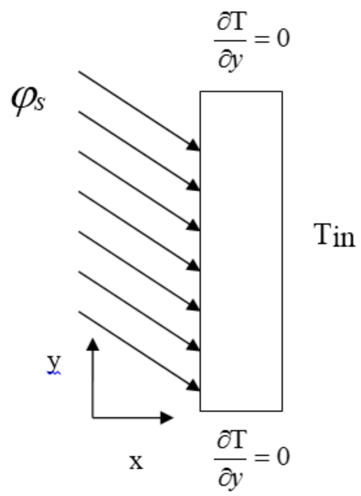
- The time (being expressed in (s).
- φ_s: incident solar flux on the wall in (W/m²)
- 36000 (s) = 10 (H): the sunshine time. This corresponds to the day length in winter in the southwestern Algerian zone.
- The instantaneous temperature distribution, T(x,y,t), is the solution of the system of differential equations (2). (Σbeing the domain [0, *e*]) et (Σ^* being the domain [0, *H*]) in the general case it is $(\forall x \in \Sigma)$ et $(\forall y \in \Sigma^*)$:

$$\begin{cases} \dfrac{\partial \mathrm{T}}{\partial t} = a \cdot \left(\dfrac{\partial^2 \mathrm{T}}{\partial x^2} + \dfrac{\partial^2 \mathrm{T}}{\partial y^2} \right) \\ En \rightarrow x = 0 - k \cdot \dfrac{\partial \mathrm{T}(0, H, t)}{\partial x} = \varphi_s \\ En \rightarrow x = e \rightarrow \mathrm{T}(e, H, t) = \mathrm{T}_{in} \\ A \rightarrow t = 0 \rightarrow \mathrm{T}(x, y, 0) = 0°C \end{cases} \qquad (2)$$

$$\phi_s = 800 \cdot \sin\left(\frac{\pi \cdot t}{36000} \right) \quad ; \quad 0 < t < 36000 \qquad (3)$$

$$\varphi_s = 0 \quad ; \quad 36000 \le t \le 86400 \qquad (4)$$

Figure .1 Physical model.



Where :

- $a = \dfrac{k}{\rho \cdot C}$: is the thermal diffusivity,
- P : the density,
- C : the specific heat,
- k : thermal conductivity.

The duration of the simulation is one week. The resolution of the system of equations (2) equipped with boundary and initial conditions is discretized using the finite volume method, according to the 1st-order-implicit numerical scheme. The equations of the algebraic system obtained were solved by the iterative method of Gauss-Seidel.

In order to fully understand the phenomena involved, we will first study the parameters that influence the establishment of the periodic regime, the second part is devoted to the calculation of the temperature field of the system according to types of construction (heavy, medium, and light). In the third and last part of this work, we carry out a comparative study between the instantaneous heat transmitted through the wall and the heat returned to the room.

3. Results and Discussions

The evolution of the temperature field for a type of heavy construction (cf. e ≥ 40 cm) represented in figure 3, comprises two successive phases, the transitory phase, which strongly depends on the initial state of the system and the steady state phase established periodic, independent of the initial state of the system.The duration of the transient regime depends on the time constant, which is by definition the fundamental constant of the thermal system. It makes it possible to predict the duration of transient phenomena of which the system may be the seat (we have shown that ρ depends only on the physical characteristics of the system (k, ρ, C),its configuration and its thermal connections (internal or external). Indeed, it's generally considered that from $t \geq 3\tau$ (Figure 2), the characteristics of the thermal field (amplitude and phase) no longer evolve and are independent of the initial state.The relative importance of these two phases depends on the period P, if P >>τ as in the case of a light construction (e ≤ 10 cm) (Figure 3), the periodic regime is established almost immediately and one can neglect the transient phase, on the contrary, if P <τ the latter extends over several periods.

Figure. 2 Evolution of the temperature field (case e =40 cm)
(Establishment of the periodic regime)

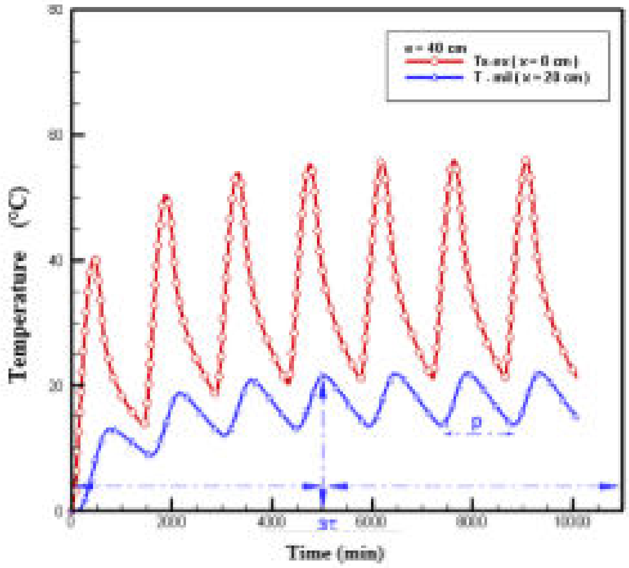


Figure. 3 Evolution of the temperature field (case e =10 cm)
(Establishment of the periodic regime)

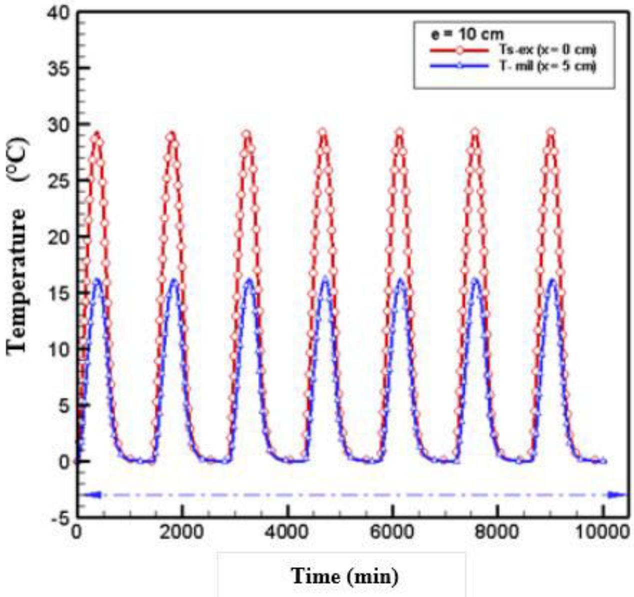


Figure. 4 Temporal variation of the outside surface temperature and in the middle of the wall (case - e = 10 cm).

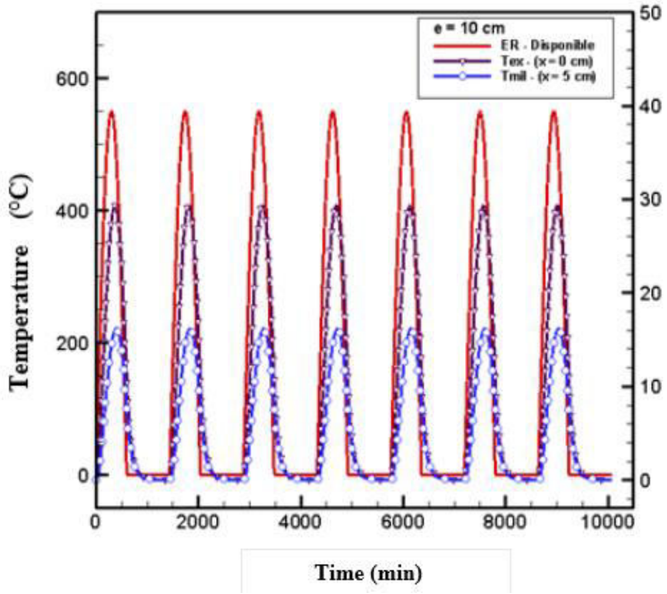


Figure. 5 Temporal variation of the outside surface temperature and in the middle of the wall (case - e = 20 cm).

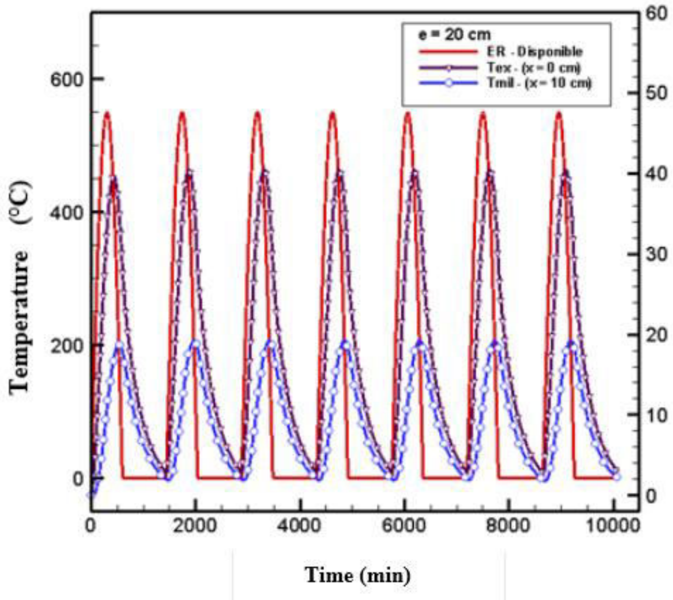
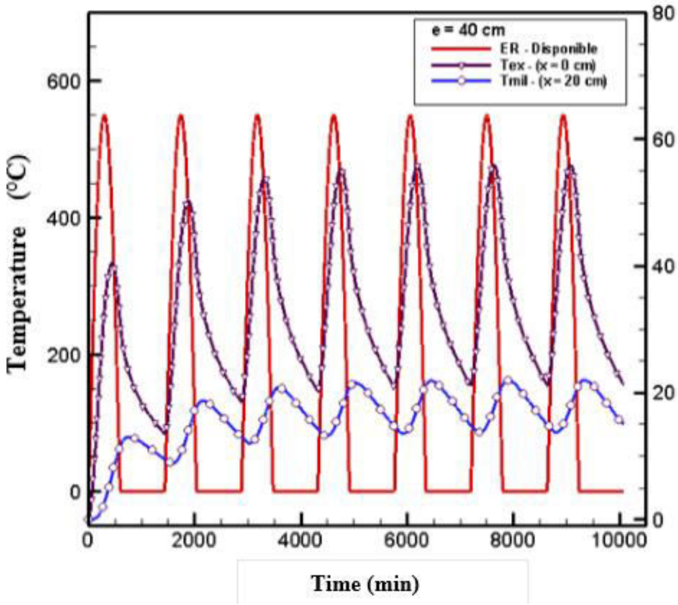


Figure. 6 Temporal variation of the outside surface temperature and in the middle of the wall (case - e = 40 cm)



The results of the simulation represented in the figures (4, 5, and 6) show the influence of sunshine on the three types of construction (heavy, medium, and light), the temperature of the external face increases with the increase in the thickness. The initial temperature of the wall is 0°C. The duration of the simulation is one week. When the regime becomes established, the variation of this temperature is also periodic, damped (stored), and out of phase (delayed). The temperature of the outer face of the heavy wall is higher and damper than the other walls (medium and light). For example for the heavy wall, in the established periodic regime, the temperature of the outer face varies from 21.23°C to 56.01°C, the temperature in the middle of the wall varies from 14.96°C to 22.02°C. Therefore, the amplitude of the quasi-stationary regime is 17.39°C, (the amplitude of the temperature of the outer face of the quasi-stationary regime is calculated by: (T_{avr} = (T_{max}-T_{min}) / 2). For the phase shift (delay), its value is (7H 10min) compared to the available solar gains.

Figure. 7 Temperature field for the sunshine period (respectively between 1 hour and 10 hours).

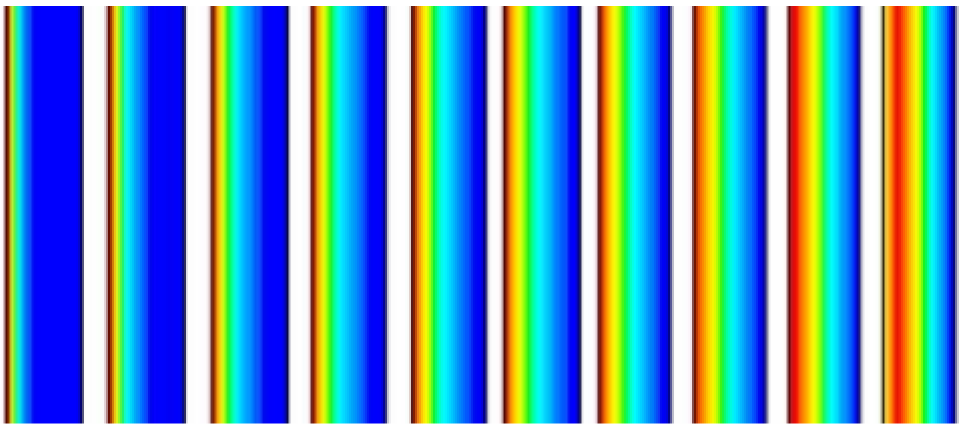


Figure.8 Evolution over time of heat (stored/released) according to winter solar gains for the three types of construction.

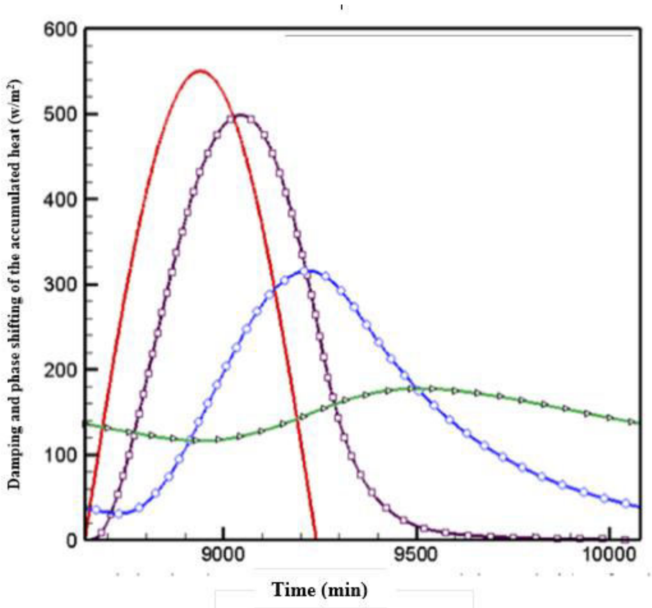


Figure 8 shows the evolution over time of the heat input due to sunshine in the room with or without thermal inertia: a comparison between the instantaneous heat transmitted through the wall and the heat returned to the room. When the regime becomes established, the variation of this heat (stored/released) is also periodic, damped (stored), and phase-shifted (delayed).For example, the heavy wall, in the established periodic regime, the heat stored and restored inside the room varies from 136.61 W/m² to 177.73 W/m², the amplitude of the quasi-stationary regime is 20.56 W/m², (the amplitude of the heat (stored/released) of the quasi-steady state is calculated according to: (ϕ_{ave}= (ϕ_{max} – ϕ_{min}) / 2).For the phase shift (the delay) of heat (stored/returned) by contributions to solar gains, its value is 14h 28min for heavy construction, (9H 25 min) for medium construction, and (6H 46 min) for light construction.

4. Recommendations

In the field of building, we seek to exploit the inertial behavior of materials to best manage thermal hazards. The outside temperature as well as the absorption of solar radiation by the walls vary periodically, on the scale of a day but also of a season. The temperature inside the building necessarily follows these variations, but the building envelope creates a phenomenon of thermal inertia, which is manifested by:

- Damping, which attenuates the effects of heat waves or extreme cold;
- A phase shift, linked to the characteristic time mentioned above, which makes it possible to delay the effects (example: in summer, the heat front of solar radiation enters the house at the end of the day rather than in the morning).

The damping and the phase shift are all the more marked as the thermal inertia is great.
We can distinguish two cases where the thermal inertia intervenes:

- Transmission inertia, which concerns the attenuation of the influence of external conditions, in particular the impact of solar radiation on the interior temperature of the building. This inertia is essentially based on thermal insulation with very low thermal diffusivity on the exterior side of the building envelope. The thermal resistance of the insulation but above all its diffusivity play an important role in this case;
- Inertia by absorption, which concerns the accumulation of heat or coolness in the partitions and walls of the structure in contact with the interior of the building. The thickness of the heavy walls does not matter too much beyond about fifteen centimeters per side (accumulation of heat near the surface).

5. Conclusion

The simulation results obtained allowed us to see the influence of the various parameters on the temperature of the outer surface and in the middle of the wall studied for the three types of construction (light, medium, and heavy) and thus to see the evolution over time of the heat returned to the room with or without thermal inertia. For this phenomenon of accumulation/release of heat to be possible, it is necessary on the one hand, to promote the use of heavy construction materials to ensure accumulation and on the other hand, to guarantee contact between them and the fresh air ventilation to evacuate accumulated heat. Therefore, the purpose of night ventilation is to discharge the heat accumulated in the building material as much as possible during the night and to allow a strong absorption of heat during the day. Light construction is ill-suited to the climate of the area studied.On the other hand, we are witnessing a good adaptation to the climate for heavy construction. The results obtained for the zone of the Algerian south-west using a heavy material (thermal inertia) directed in full south to ensure passive heating of the building, seem interesting to apply such a system.

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