

THERMAL PERFORMANCE EVALUATION OF TRADITIONAL BUILDINGS FLAT ROOFS IN A HOT AND ARID CLIMATE OF ALGERIA



M'hamed Mahdad¹, Aghiles Hammas¹, Said Abboudi²

¹ National Centre of Studies and Integrated Research on Building Engineering, Algiers, Algeria

² Université de Bourgogne Franche Comté, Belfort, France

Abstract: This investigation aims to apply the analytical method of admittance for determining the thermal performance of composite flat roofs in traditional houses located in the southern region of Algeria, characterized by hot and arid climate conditions. The effect of adding insulation to the composition of flat roofs in traditional houses is studied by varying its, type, location and thickness. In this study, nine configurations of composite flat roof systems were manufactured using multiple layers with five types of insulations. Moreover, different dynamical thermal parameters are analyzed in this study, namely time lag (TL), decrement factor (DF), admittance (Y), transmittance (U), and surface factor (SF). The main results revealed that the roof configuration of R8 with insulation based on formaldehyde board presents a high value of TL (9.94 hours) and the lowest value of DF (0.1). In contrast, the configurations without insulation addition (R1, R2, and R3) display the lowest values of TL (4.91, 4.74, and 4.81, respectively) and the highest values of DF (0.59, 0.63, and 0.62, respectively). This research is useful for clearly understanding the thermal performance of composite flat roofs for the improvement of the energetic efficiency of traditional buildings.

Keywords: Thermal insulation, flat roofs, dynamic thermal properties, decrement factor, time lag.

M'hamed Mahdad*

E-mail: mahdadcnrib@gmail.com

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Introduction

In Algeria, the general construction rules and the choice of suitable materials for manufacturing buildings mainly depend on the climate conditions of the considered region [1,2]. However, the use of the same building concept and materials in different regions of the north and south of Algeria, which are characterized by different climates – Mediterranean in the north and the Sahara of hot and arid climates in the south, creates an uncomfortable situation for the sustainability of building elements [3,4]. The main solution adopted to improve the thermal comfort of Algerian construction is the use of heaters and air conditioners, particularly during the summer and winter seasons, which involves a high energy consumption [5-8].

Recently, the use of thermal insulation in wall or flat roof configurations has been proposed as the most economical and sustainable solution for buildings located in regions characterized by arid and hot climates [7,9,10]. In contrast, there are few experimental works about the position of thermal insulation in wall or flat roofs configurations and its optimal thickness adequate for the traditional houses located in hot and arid regions [4,11,12]. On the other hand, much attention has been focused during the recent decades on the role of thermal insulation in regulating heat transfer and on researching the analytical methods to be used to analyze the thermal performance parameters of heat transfer through the building envelope [6,13-15]. For this purpose, there are several methods applied for deducing the values of DF and TL, each with its physical interpretation [16,17].

These analytical resolution methods provide exact solutions and represent a suitable approach for computerized applications [13,16]. However, it cannot be extended with numerical approaches, which are generally approximate solutions to a physical problem [13,18]. The most interesting analysis is mainly focused on studying the dynamic thermal properties of walls using the Fourier complex analytical method [13,14].

Indeed, there are several analytical methods, such as the transfer function method (TFM), the cooling load temperature difference method (CLTD), and the total equivalent temperature difference method (TETD), that have been used in the study to model heat transfer and the thermal inertia of composite walls and roofs [19-21]. Accordingly, an efficient analytical solution based on the Fourier analysis (Fast Fourier Transform-FFT) with periodic boundary conditions for the translation of the behavior of heat transfer in composite walls (marble, concrete block, plaster) has been reported by Daouas *et al.* [22], which investigated the best thermal performance of walls according to the hot climatic zones of Tunisia. In addition, Kameni Nematchoua *et al.* [23] investigated the thermal modeling of a building located in the equatorial and tropical climate of Cameroon by using a periodic solution Fourier analysis for the propagation of heat flux through a composite wall. The theoretical methodology on time-varying heat gains through the walls and flat roofs of buildings was initially developed by Yumrutaş *et al.* [24]. Different configurations of walls and flat roofs were studied to determine the TETD values of various configurations of walls and flat roofs in the context of Turkey's climate. The sinusoidal variation was considered for explaining the external temperature diffusion using the finite Fourier transform (FFT). Subsequently, much research work was carried out using the Fourier complex method to assess heat transfer through multilayer walls and roofs [25]. This method was also used by Kaşka *et al.* [26] to analyze the TL, DF, and the TETD parameters for multilayer walls and flat roofs of buildings made of different materials and insulation (concrete, plaster, sandwich XPS).

In the case of Algeria, the use of insulation and the investigation of the thermal performance of flat composite roofs investigated in traditional buildings are weakly explored. Nowadays, the building of external flat roofs based on the insulation and local materials carried out in arid and hot regions of Algeria generally meets different problems due to the absence of scientific research about this subject. The review of the current state of knowledge in the field of heat transfer in composite flat roofs based on insulations (cork, polystyrene, polyurethane, etc.) and local materials (earth blocks, plaster, lime mortar) revealed that there are very few studies focused on this subject [5]. For this purpose, the present study aims to determine the thermal performances of composite flat roofs of traditional houses in Algerian climatic conditions by using an analytical method of admittance. Compared to other analytical methods of resolution, the admittance method, based on the transmission matrix, has advantages, in particular a format of the matrix favorable to the storage of databases and analysis of modelling information [26-29]. This method takes into account the effects of dynamic conditions on heat transfer through the wall or roof and the calculation of heat flows on the inside and outside of a wall or roof as a function of surface temperatures [29-31]. Thus, as a main objective of this study, the analytical method was applied in order to investigate the dynamic thermal parameters of external composite flat roofs of traditional constructions located in the Southern Algeria regions characterized by hot and arid climates. During this work, the best combination of composite flat roof systems can be found using the determination effects of different factors, such as the influence of the insulation layer, their position, thickness, and the variation effect of the thermal insulation layer in composite roofs on the thermal dynamic parameters like TL, DF, Y, U, and F over a 24-hour period.

Methodology

The cyclic-response admittance method

This study is based on the analytical method of admittances, which is based on complex Fourier analysis [14]. This method focuses on one-dimensional transient thermal conduction through a flat roof with two time-dependent boundary conditions and an initial condition.

$$\rho C_p \frac{\partial T(x, t)}{\partial t} = \lambda \frac{\partial^2 T(x, t)}{\partial x^2} \quad 0 < x < L, \quad t > 0, \quad (1)$$

λ , ρ and C_p are the thermal conductivity, density and specific heat, respectively.

The boundary conditions are given:

$$-\lambda \frac{\partial T}{\partial x}(0, t) = h_i [T(0, t) - T_i] \quad \text{for } x = 0, \quad t > 0, \quad (2)$$

$$-\lambda \frac{\partial T}{\partial x}(L, t) = h_o [T_o(t) - T(L, t)] \quad \text{for } x = L, \quad t > 0, \quad (3)$$

where (h_i, T_i) and (h_o, T_o) are respectively the heat transfer coefficient and the temperatures on the inside and outside surface [1,5].

The initial condition is as follows:

$$T(x, 0) = T_0 \quad \text{for } t = 0, \quad 0 \leq x \leq L. \quad (4)$$

A space- and time-independent solution is used for the resolution of equation (1) with boundary and initial conditions (2), (3), and (4). It allows describing the dependence in the imaginary domain of temperatures and thermal flows on both sides of an opaque wall. The solution is sought in the following form [13,14]:

$$T(x, t) = A \cdot \exp\left(\frac{x}{\xi}\right) \exp\left(\frac{t}{\zeta}\right), \quad (5)$$

where ξ and ζ have units of distance and time, respectively.

The combination of both equations (5) and (1), the relation of: $\xi^2 = \alpha \zeta$ can be deduced. Where α is the thermal diffusivity of the roof. For a structure subjected to periodic excitation of period P, periodic solution becomes:

$$\xi^2 = \frac{\alpha P}{2j\pi}, \quad \text{where } j^2 = -1 \quad (6)$$

Thus, it can be obtained a periodic solution with-period P.

$$\frac{x}{\xi} = \frac{x}{\pm (\alpha P / j 2\pi)^{1/2}} = \pm (i + j) \left(\frac{\pi \rho C_p x^2}{\lambda P} \right)^{1/2} \quad (7)$$

In this case, the matrix relationship between flux and internal and external temperatures is given [13].

$$\begin{bmatrix} T_{pi} \\ q_{pi} \end{bmatrix} = \begin{bmatrix} E_{11} & E_{12} \\ E_{21} & E_{22} \end{bmatrix} \begin{bmatrix} T_{po} \\ q_{po} \end{bmatrix}. \quad (8)$$

T_{pi} , q_{pi} , T_{po} and q_{po} indicate the temperature and heat flux at both internal and external surfaces, respectively. R_i and R_o represent the inside and outside of each studied configuration.

The transfer matrix is defined below:

$$\begin{bmatrix} E_{11} & E_{12} \\ E_{21} & E_{22} \end{bmatrix} = \begin{bmatrix} 1 & -R_i \\ 0 & 1 \end{bmatrix} \begin{bmatrix} (A_1 + jA_2) & (A_3 + jA_3)/a \\ a \times (-A_4 + jA_3) & (A_1 + jA_2) \end{bmatrix} \begin{bmatrix} 1 & -R_o \\ 0 & 1 \end{bmatrix}. \quad (9)$$

The cyclic thickness z and the characteristic of the admittance slab are the two parameters that appear in the definition of the transmission matrix (Eqs. (10) and (11)):

$$z = \sqrt{\frac{\pi L^2}{\alpha P}} = \sqrt{\frac{\omega L^2}{2\alpha}}, \quad (10)$$

$$a = \sqrt{j\omega\lambda\rho C_p}. \quad (11)$$

The thermal transmittance, U, is calculated using

$$U = \frac{1}{R_i + R_c + R_o} = \frac{1}{R_i + \left(\frac{L_1}{\lambda_1}\right) + \left(\frac{L_2}{\lambda_2}\right) + \dots + R_o}, \quad (12)$$

where L_1 and L_2 are the thicknesses of the roof layers.

The thermal admittance, Y , is calculated as:

$$Y_c = -\frac{E_{22}}{E_{12}}; \quad Y = |Y_c|. \quad (13)$$

The DF f is calculated using the following equation:

$$f_h = \frac{Y_{12}}{U} = -\frac{1}{UE_{12}}; \quad f = |f_h|. \quad (14)$$

Φ presents the TL obtained between the timing of the peak inside temperature and the peak heat transfer out of the outer surface, calculated using the relationship:

$$\phi = \frac{12}{\pi} \arctan\left(\frac{\text{Im}(F_c)}{\text{Re}(F_c)}\right) = \frac{12}{\pi} \arctan\left(\frac{\text{Im}\left(-\frac{1}{UE_{12}}\right)}{\text{Re}\left(-\frac{1}{UE_{12}}\right)}\right). \quad (15)$$

On the other hand, the surface factor (F) is calculated as follows:

$$F_c = 1 - R_{int} \frac{E_{11}}{E_{22}}, \quad F = |F_c|. \quad (16)$$

In this investigation, the dynamic thermal parameters of composite roofs (TL, DF, U, Y, F) are calculated using the Matlab program. The different calculations are performed for a different system roof subjected to an external sine excitation period of $P=24\text{h}$ and an internal temperature of $T_i=25^\circ\text{C}$. The values of the internal R_i and external R_o thermal resistances are $R_i = 0.045$ and $R_o = 0.11 \text{ m}^2\text{KW}^{-1}$ [5]. The effect of the humidity parameter of flat roofs was not considered in the analysis.

Climatic conditions

The Adrar region, located in southern Algeria, is characterized by a hot and arid climate. The buildings of this region generally present a traditional character, particularly those manufactured with local materials such as earth, stone, and plaster (Fig.1) [2,3].



Fig. 1. A traditional house example with a flat roof in the Adrar city

On the other hand, in this region of Southern Algeria, the climate is extremely arid, with winter cold at night and the days remaining hot ($25\text{-}27^\circ\text{C}$) [32]. The annual temperature evolution from 2006 to 2016 in the Algerian arid regions, such as Adrar city, located in southern Algeria, is summarized in Figure 2. In addition, given the climatic context of this region, the roofing system used in house construction is flat, utilizing materials available in the region (Fig.2). As a result, the maximum temperature increases to 46°C in summer, and the minimum to 5°C in winter, and the general rainfall is very low, rarely exceeding 40 mm annually but sometimes reaching a maximum of 80 mm. The relative humidity ranges between 10% in summer and 40% in winter. Sandstorms are generally frequent and blow at high speeds exceeding 70 km/h [33].

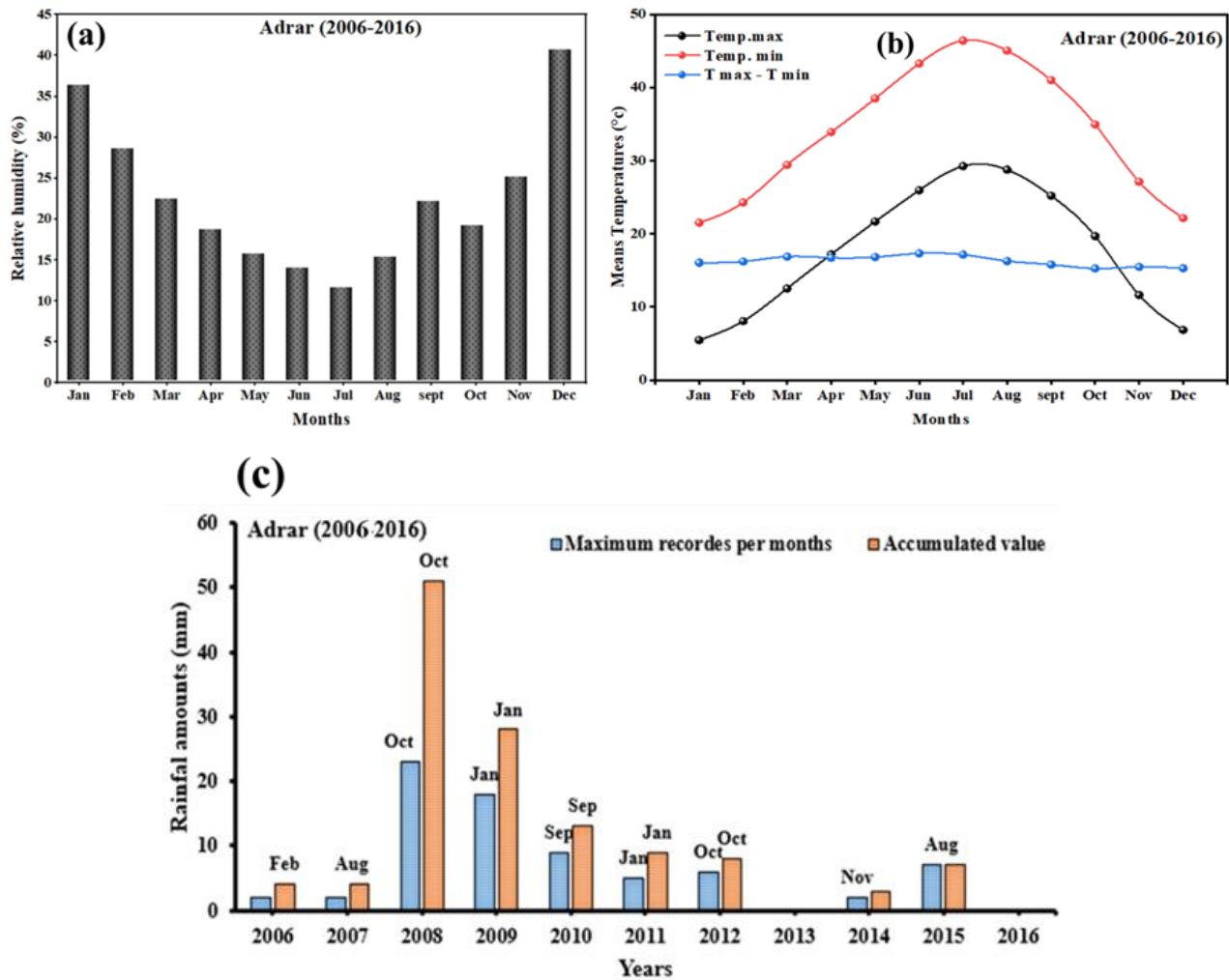


Fig. 2. Evolution of annual temperature from 2006 to 2016 in the Adrar city: (a) relative humidity, (b) mean temperatures, and (c) rainfalls [33]

Thermo-physical properties of materials

In the present study, dynamic parameters of Y , U , DF , TL , and F are examined for different building materials that compose the flat roofs of traditional constructions located in the hot and arid climate of southern Algeria. For the technical aspects of the construction, the fundamental principle of Saharan flat roof design is the use of local raw materials. In general, the rules of construction in southern Algeria consist of laying a layer of mortar (a mixture of cement and lime) as a protective waterproofing layer, followed by another local material (plaster concrete, volcanic ash, lime, pozzolanic concrete, clay, tuff, sand, clinker, etc.) as a reinforcement layer, CNERIB-DTR E-4.1¹.

The schematic roofs indicated in Figure 3 illustrate the horizontal reinforced concrete that may incorporate thermal insulation layers and other mortar layers in their exterior or interior surface. The reinforced concrete layers have a constant thickness of 0.15 m, and they may be put in two layers of thickness $x = 0.075$ m. The total thickness of this type of flat roof is usually 0.23 m.

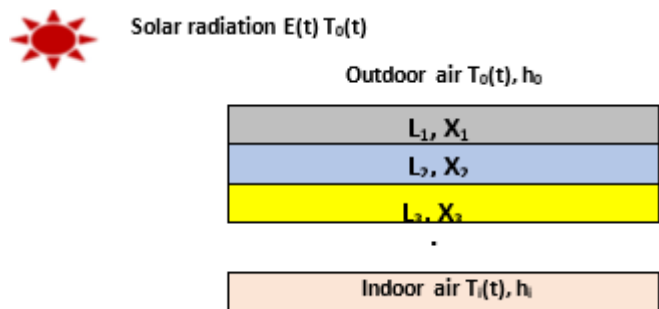


Fig. 3. Schematic representation of a flat roof

¹ DTR E 4-1. Travaux d'étanchéité Des Toitures Terrasses et Toitures Inclinées-Support Maçonnerie. CNERIB, 2018 Algiers, Algeria.

The waterproofing of these flat roofs is ensured by a layer of lime mortar, which is a type of mortar not accessible to terraces typical of the climate of arid regions. The thermal insulation consists of a material ensuring thermal inertia, placed so as to give a slope of 0.5 to 1 %. According to DTR E 4.1, there are three categories of flat roofs in Algeria, classified according to slope².

Table 1 summarizes the thermophysical characteristics of the investigated materials of thermal conductivity, specific heat, and density. The properties of materials selected in the present study for the configuration of different flat roof systems are the same as those used in the construction of traditional house roofs in southern Algeria³ [5,17]. The common materials used for the construction include lime mortar stabilized (LM), reinforced cement concrete (RC), gypsum plaster (GP), and mortar stabilized. Five insulation materials such as expanded polystyrene, cork, date palm, and mineral wool, were selected. The insulation used in this work is noted by IS.

Table 1. Thermophysical properties of some common construction materials of flat roofs⁴ [17].

Materials name	Code	Thermal Conductivity λ (W/m K)	Specific heat (J/Kg,K)	Density (kg/m ³)
Lime mortar stabilized	LM	0.720	840	1800
Reinforced cement concrete	RC	1.37	880	2076
Stabilized earth concrete	SC	1.15	936	1700
Inside gypsum plastering	GP	0.35	936	750
Polystyrene board	IS1	0.040	1400	30
Palm Fiberboard	IS2	0.040	840	80
Foam Glassboard	IS3	0.055	700	160
Formaldehyde board	IS4	0.030	1674	30
Polyurethane board	IS5	0.027	1400	55

Configurations of composite flat roofs

This work focuses on studying different composite flat roofs built with cement-based materials and thermal insulation. In order to give more details about the best combination of composite configuration roofs, different layers of insulating materials have been integrated into the flat roofs compositions to assess a possible improvement in thermal performance. Table 2 summarizes the different configurations considered for the composite roofs proposed.

Table 2. Configurations of the flat roofs

Roof	Thickness of the roof from outside to inside (m)
R1	0.15 RC + 0.03 GP
R2	0.025 SEC + 0.15 RC + 0.005 GP
R3	0.025 LM + 0.15 RC + 0.005 GP
R4	0.025 LM + 0.15 RC + 0.04 IS + 0.015 GP
R5	0.025 LM + 0.04 IS + 0.15 RC + 0.015 GP
R6	0.025 LM + 0.075 RC + 0.04 IS + 0.075 RC + 0.015 GP
R7	0.025 LM + 0.02 IS + 0.15 RC + 0.02 IS + 0.015 GP
R8	0.025 LM + 0.075 RC + 0.02 IS + 0.075 RC + 0.02 IS + 0.015 GP
R9	0.025 LM + 0.02 IS + 0.075 RC + 0.02 IS + 0.075 RC + 0.015 GP

²DTR E 4-1. Travaux d'étanchéité Des Toitures Terrasses et Toitures Inclinées-Support Maçonnerie. CNERIB, 2018 Algiers, Algeria.

³DTR C3-2/4. Réglementation Thermique Des Bâtiments d'habitation, Règle de Calcul Des Déperditions Calorifiques, Algiers, Algeria. CNERIB. Algiers 2017, Algeria.

⁴ Ibid.

Figure 4 presents the configuration of different flat roofs considered with different combinations and positions of insulation materials in the wall system. To achieve this, nine (09) configuration systems of flat roofs with different traditional and durable building materials based on thermal insulation are considered in this work. The different insulating materials of the study were placed in different positions inside and outside the roofs. A total thickness of 4 cm of insulation was placed as one or two layers (each one 2 cm) at different locations in the 23 cm total-thickness composite roof system.

In this study, the contact between layers in the case of flat composite roofs is considered to be perfect. It can be noted that the considered roofs are subject to heat transfer in just one direction.

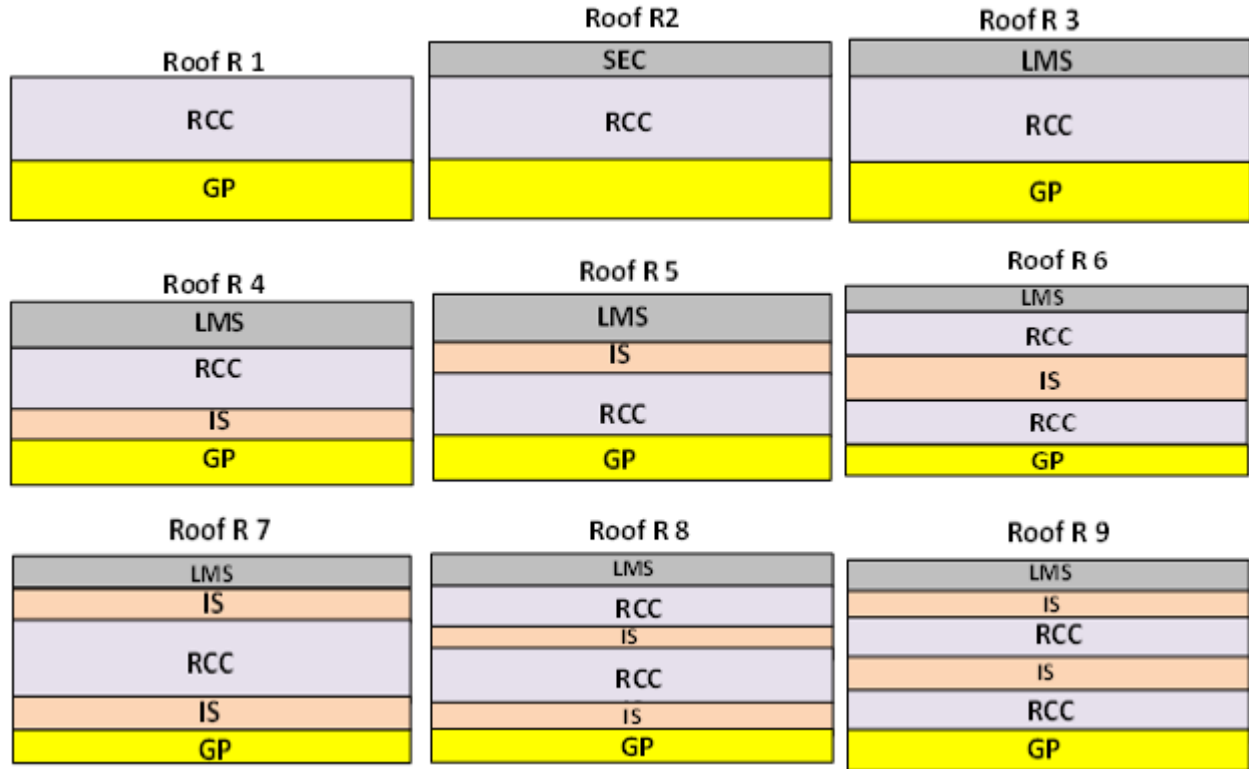


Fig. 4. Configuration of the composite flat roofs

Results and Discussion

Thermal inertia parameters

Figure 5 shows the effect of the thickness of the considered materials on the variations of DF and TL results. The findings of this study indicate that the DF values of different studied materials decrease with increasing their thicknesses, which is not the same for the TL parameter; the increase of material thickness increases linearly its values of TL. This is because the variation in thickness involves a phase change in the temperature distribution of the interior and exterior spaces.

Indeed, it appears that out of the five (05) insulators studied, the results showed that both thermal insulation of foam Glassboard (IS3) and formaldehyde board (IS4) have the lowest values of DF and the highest value of TL (Fig.5). For the thickness of 40 cm, the values for DF vary in the range of 0.21–0.29, and TL values increase from 0.41 to 11.98 hours. It was also revealed in this study that the thermal inertia parameters TL and DF depend mainly on the intrinsic properties of the materials making up the roof, like thermal conductivity, specific heat capacity, density, and thickness. Similar findings are obtained by previous works which studying the relationship between thermo-physical properties and thermal inertia parameters [13,34,35]. The same conclusion is obtained by Balaji et al. (2019) [14], in particular with regard to the relationship between the time lag and the decrement factor with the thermal properties of materials and the thickness of insulating materials.

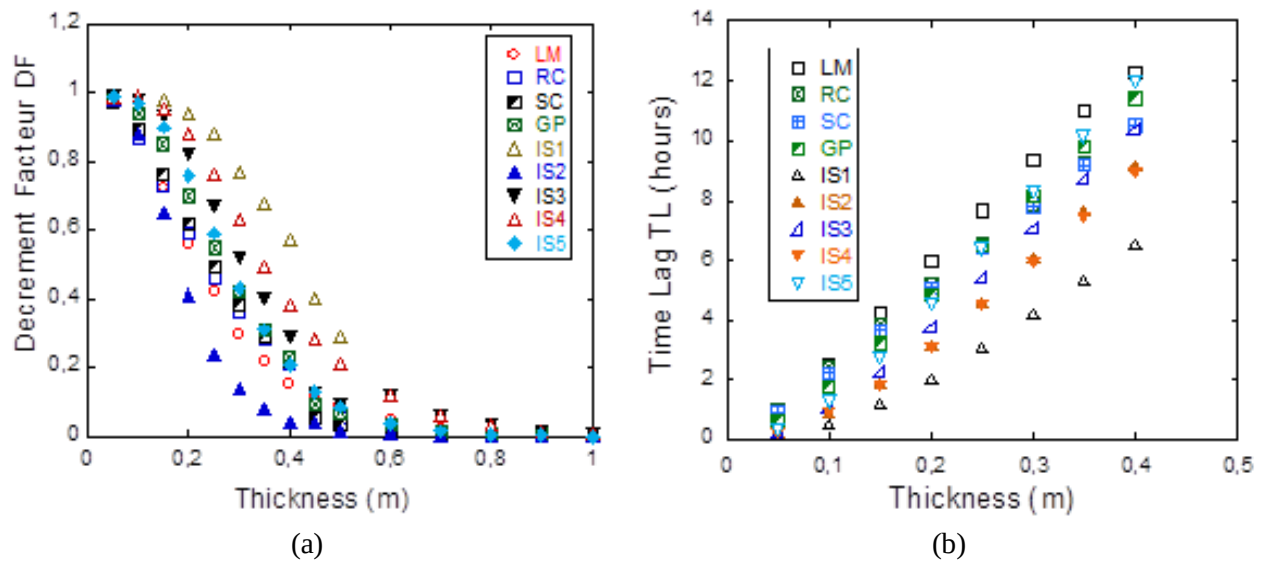


Fig. 5. Effect of thickness on (a) the DF and (b) TL of building and insulating materials

Transmittance and thermal admittance

Figures 6 (a) and (b) indicate the variation of the values of thermal transmittance and thermal admittance as a function of different fixed thicknesses of investigated materials.

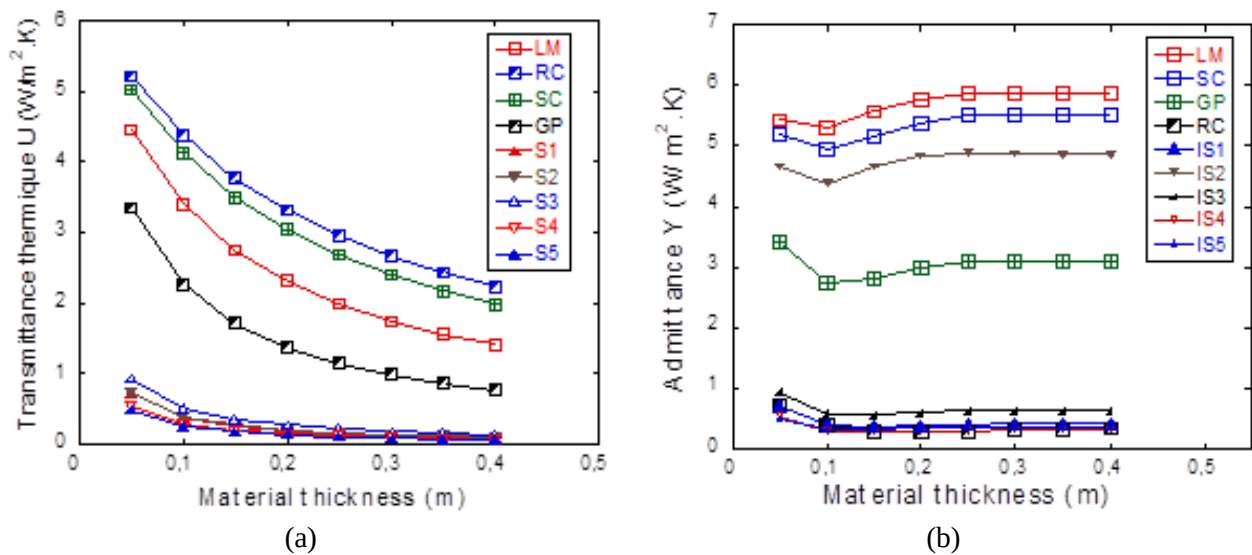


Fig. 6. Effect of thickness on the U (a) and (b) Y of building and insulating materials

The Y values explain the relationship between the complex magnitude of the change in heat flow on one side of the structure and the complex magnitude of the temperature fluctuation on the same side of the structure. The thermal transmittance defines the ratio of individual physical quantities on one side of the wall to the other [13]. As a result, increasing the thickness of the materials significantly decreases the values of both parameters of Y and U. This is mainly due to the great capacity of materials/insulators to absorb and store heat. The Formaldehyde board (IS4) insulation has the lowest values of Y for all thicknesses among the five materials studied, followed by IS3 and IS5. On the other hand, the U values of IS4 insulation decrease from 0.28 to 0.14 $\text{W/m}^2 \cdot \text{K}$ for thickness from 10 to 20 cm.

Indeed, the best dynamic thermal performances are obtained for IS4 and IS5 insulation. Thus, these insulations exhibited almost the same thermal performance. Similar results are also observed in the literature [18] on thermal admittance and thermal transmittance values.

Surface factor

Figure 7 shows the variation of the surface factor values as a function of the thickness of the studied materials and insulations. This factor generally explains the capacity of the surface element to absorb the incident radiative heat and to estimate if using equation (16). According to the obtained results, the F-factor values of the insulation are much higher than the other studied materials of LM, RC, SC, and GP. In the case of the thermal insulation materials, the formaldehyde and polyurethane board (IS4 and IS5) are characterized by high thermal performance, which translates to the high values of surface factors, 0.95 and 0.96, respectively. This could be attributed also to the high density and surface heat capacity properties of this insulator, which shows significant variations in physical properties compared to other materials. In the case of materials such as lime mortar and inside gypsum mortar (LM and GP), the calculated surface factor F is in the range of 0.46 and 0.65, respectively. These results have been in previous searches proved by Balaji et al. [14] and Kalinović et al. [28].

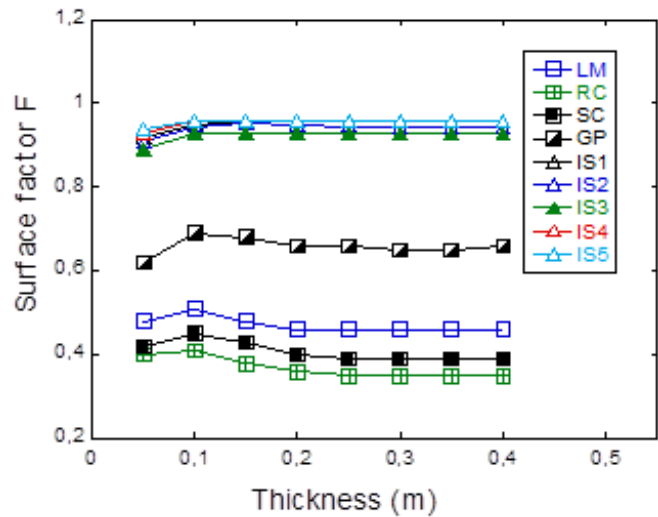


Fig. 7. Variation effect of thickness composite roofs on the surface factor values

Insulation configuration on the composite roofs

The selected materials in this work are mainly those most commonly used in the construction of roofs for traditional buildings, such as those made of earth blocks or natural stone, located particularly in southern Algeria (Table 2). The dynamic thermal performance of the respective composite and roof systems is shown in Figure 8.

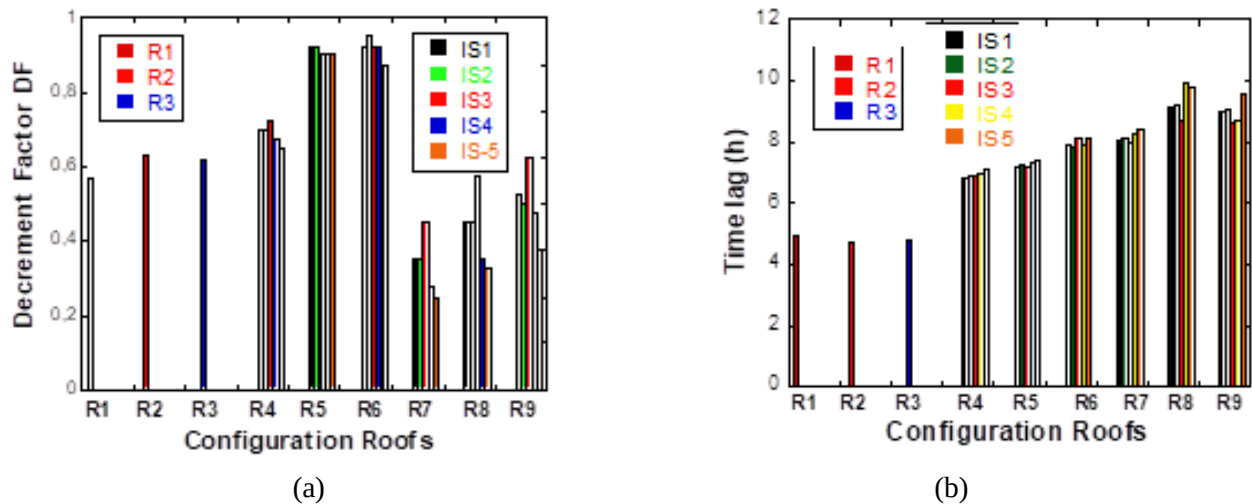


Fig. 8. Effect of insulation position on the DF (a) and (b) TL parameters for different configurations

The values of these two factors mainly depend on the exterior and interior temperatures as well as the thermo-physical properties of the materials taken into account in the configuration of studied roofs. Figures 8 (a) and (b) indicate that the thermal inertia parameters of flat roofs, namely the DF and TL, strongly depend on the thermal characteristics of the insulating materials used and their position in the configuration system (towards the outside or inside) as well as the relative proportion of the material layers inserted in the roof. As a result, the highest values of TL occur in the case of the configuration of roofs (R7, R8, and R9), and the

lowest value is obtained for the roof (R1) without insulation. This confirms the importance of insulation incorporation in the flat roof system for improving the thermal performance of buildings.

The application of a lime-based plaster (LM and GP) with concrete blocks (RC) in a configuration with six layers (R8 and R9) in two concrete layers 0.075 m thick, respectively, and associated with two insulation layers with a thickness of 0.02 m represent the configurations with the best insulation characteristics and have given the best thermal dynamic performance. Indeed, flat roofs with two layers of insulation of 0.02 m based on formaldehyde board or polyurethane board (IS4 and IS5) give a good result. These systems (IS4 and IS5) are characterized by TL (9.94 and 9.76 hours) and DF factors (0.14 and 0.13).

On the other hand, the values of DF decrease significantly (65%) for configurations with insulation, which is not the same for configurations without insulation, and especially with roofs based on IS4 and IS5 insulations. This reduction of DF values is associated with an increase of TL values of about 3.5 to 4.50h for all systems of R3 (IS1, IS2, IS3, IS4) in comparison with the R3 configuration.

Conclusion

In this article, the thermal performance of composite flat roof systems used in traditional houses has been analyzed by studying their dynamic thermal parameters. An analytical method of admittance is proposed in order to define the dynamic thermal characteristics of the investigated composite flat roofs. The conclusions drawn can be summarized as:

- The adequate choice of building materials and their appropriate position in flat roof design plays an important role in the thermal comfort of the construction. Based on the analysis performed, it can be observed that the thermal inertia of some flat roofs selected reduces and delays effectively the effect of external conditions (temperatures) and is particularly suited to the climate where the temperature difference between day and night is important, as in the climatic conditions of the hot and arid regions of Algeria.
- The change in the roof configurations (R1 to R9) has a significant impact on the thermal performance of buildings, in particular the values of DF and TL. Thermal inertia parameters (TD and DF) improve with increasing thermal capacity and material layers to design the composite flat roof configuration. The flat roof systems with six layers and the insulations applied located in inside/middle or outside/middle positions were found to be the most appropriate configurations among the nine combinations tested to minimize the DF and maximize the TL. In addition, it was revealed that the thermophysical properties of materials and insulators (thermal conductivity, thermal capacity, and density) and their thicknesses have a very significant effect on the dynamic thermal characteristics as well as the admittance and transmittance parameters.
- The value of the surface factor is highly dependent on the thermal properties and thickness of the materials. Consequently, it can be noted that the insulating materials with low thermal conductivity applied to flat roofs have a higher surface factor and a high time lag.
- The formaldehyde and polyurethane board with a thickness of 0.04 m revealed better performance than the other selected thermal insulations, and they can be the suitable materials that can improve the thermal performance of buildings. According to most results, it can be noted that for a flat roof with the same structure and same total thickness but with different thicknesses of individual layers within the structure of the roof, the two configurations (R8 and R9) are the flat roofs with the best insulation characteristics. The values for DF in these configuration systems (R8 with IS4-IS5) oscillate in the range of 0.14–0.13 and have the highest TL, which varies between 9.94 and 9.76 hours, respectively. These configurations of flat roofs could be a viable and effective alternative to conventional roofs in hot and arid climatic regions. They were found to be useful and more efficient configurations that are capable of dampening the thermal waves of the outdoor environment exposed on the external face of the roof.

- Consequently, it has been concluded that the configuration with two thermal insulation layers with respective thicknesses of 0.02 m (outside) and 0.02 m (inside) placed between reinforced cement concrete RC with thicknesses of 0.15 m and exterior lime mortar LM (0.025 m) and with inside gypsum plastering GP (0.015 m) presents a higher time lag and lower decrement factor.

At the end of this work, it has been concluded that it was perfectly possible to design high-performance composite roofs with energy savings in the regions characterized by the arid and hot climate of Algeria. In future research, based on the methodology proposed in this work, evaluation of the dynamic thermal performance of roofs and walls of buildings can be performed in other climates of Algeria, both technically and economically.

Conflict of Interest

The authors declare no conflicts of interest.

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M'hamed Mahdad, researcher (Mechanical Engineering and Materials Science) (Algeria, Algiers)
- National Centre of Studies and Integrated Research on Building Engineering, mahdadcnerib@gmail.com
Aghiles Hammas, researcher (Mechanical Engineering and Materials Science) (Algeria, Algiers) - National
Centre of Studies and Integrated Research on Building Engineering, a.hammas@cnerib.edu.dz
Said Abboudi, researcher (Thermal Materials and Technology), Professor (France, Belfort) - Université de
Bourgogne Franche Comté, said.abboudi@utbm.fr