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Cite as: AIP Conference Proceedings **2056**, 020016 (2018); https://doi.org/10.1063/1.5084989
Published Online: 20 December 2018

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The Reduction of Energy Requirement by Adapting the Mosques Building Envelope for the Six Climatic Zones of Morocco

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Abstract : The control of the climatic conditions in the cult buildings; especially the mosque; proves arduous because open doors generally and the variation of the occupants number. Indeed, air conditioning systems are not often effective. The integration and optimization of passive solutions via the envelope can be the solution to this problem. In the present paper, a detailed energy and environmental analysis of a Mosque building, is investigated. The dynamic simulations using TRNSYS software are conducted under the new climatic zoning of Morocco. The effect of integrating of two alternatives techniques such as "lightweight concrete" and "cool roof" into the Mosque building on the energy needs are evaluated and discussed. Results obtained show that using the lightweight concrete technique with olive pomace or with cork or with hemp leads to reduce the total annual energy need by about 9.5 % ,12.7 % , 22.5 %, respectively. Moreover, integrating the cool roof technique by modifying the reflectance coefficient from 0.5 to 0.9, the reduction of energy demand attained 43%. We can see that with simple passive envelope strategies, it is possible to reduce more than 50% of energy needs and approaching the optimal comfort conditions.

INTRODUCTION

The mosques are important buildings in the Muslim community around the world. They are normally built in a simple rectangular shape which length is directed towards "Qiblah", that is towards the Mecca. In general, mosques have carpeted floors and other walls have interior surfaces covered with materials with high reflectance coefficient, such as plaster or marble or tiles. Unlike other types of buildings, mosques are characterized by a single intermittent occupation. They are normally occupied five times a day throughout the year with an average occupation of 45 to 60 minutes. With the exceptions of the "Dhuhr" prayer of each Friday and the "Tarawih" prayer of the month of Ramadan where the occupation lasts longer. The thermal comfort during the summer and winter inside mosques is highly dependent on their energy needs. These energy needs are highly dependent on several parameters which are the external climatic conditions, the daily profiles of the different loads namely lighting, occupants, air infiltration and air conditioning systems. It is important to note that lighting, occupancy and air conditioning loads are simultaneous. The

1st International Congress on Solar Energy Research, Technology and Applications (ICSERTA 2018)
AIP Conf. Proc. 2056, 020016-1–020016-15; https://doi.org/10.1063/1.5084989
Published by AIP Publishing. 978-0-7354-1784-7/$30.00

air change rate varies according the opening and closing scenario of the doors and windows during the occupation period.

In Morocco, the energy demand has increased by 60% between 2002 and 2012 [1]. The residential and tertiary sectors represent a third (33.1%) of Morocco's total consumption[1]. In order to reduce these figures, Morocco has signed a convention for the implementation of the project "green mosques". This project aims to reduce the energy consumption by about 12% in 2020 and 15% in 2030, while rehabilitating about 15,000 mosques [2].

The purpose of this study is to contribute to enhance the indoor environment in mosques while reducing the energy consumption and the carbon dioxide emissions.

The building envelope behaves as an interface between the inside and the outside; it functions as a thermal barrier. The building envelope has an important role in determining the amount of energy required to maintain comfortable indoor conditions by relative to the external environment [3]. Maintaining inner comfort within mosques requires a significant amount of energy. The latter can be reduced by effective operating strategies of HVAC systems [4]. After modeling the energy simulation of the mosque, I. Budaiwi et al, concluded that an HVAC operating strategy can reduce 23% of the annual cooling consumption, and a 30% reduction is achieved by an operational zoning system [4]. Thermo-physical and operational characteristics and climatic conditions allow us to identify the thermal performance of buildings. After using the operational strategies and redevelopment of the mosque envelope, M. Budaiwi et al [5] achieved significant reductions in terms of energy savings; a 26% reduction in annual cooling energy is achieved by applying roof and wall insulation and reducing air infiltration to 0.5 ACH. A combination of operational air conditioning and the remodeling of the envelope achieved approximately 48% reduction [5]. The results obtained by Xi Meng et al, show that wall insulation for buildings that are characterized by intermittent occupancy reduces daily cooling loads by 44 to 55% relative to the building of continuous occupancy. M. Krarti et al, [6] have evaluated the economic and environmental impacts of energy efficiency programs associated with new and existing buildings in the Kingdom of Saudi Arabia (KSA). They concluded that, thanks to the energy retrofit program, a significant reduction in electricity consumption of 10 054 GWh / year and peak demand of 2 290 MW and carbon emissions of 7.611 million tons / year of an energy retrofit program are obtained. The work of Noor et al [7] aimed to review research on the thermal insulation performance in practical applications. However, lightweight concrete or aerated concrete with polystyrene beads have a thermal conductivity ranging from 0.07 to 0.33 $W.m^{-1}.K^{-1}$. Hakan Demir et al[8] evaluated and compared some insulation lightened materials produced in the envelope. They concluded that the use of these materials provides a significant indoor environment while reducing the energy consumption.

The roof that is the subject of our study is the component most exposed to solar radiation and represents about 42% of the total area. To do this, we assessed the effectiveness of the two passive cooling techniques, the Cool Roof coating technique and the redevelopment of the ordinary concrete layer, using light concrete with local materials to improve Moroccan agricultural products.

In the context of sustainable development and environmental conservation, the new requirements for thermal regulations in the building sector that have been introduced lead researchers to new building materials that respect the environment to produce energy-efficient systems ensuring a comfort of habitat. This research focuses on the integration of local materials derived from renewable and recyclable plant products such as olive pomace, cork and hemp. Olive growing plays an important role in Moroccan agriculture, with plantations covering more than 50% of the total agricultural area and the entire national territory. The olive pomace that we introduced in this study are products extracted during the first olive extraction (56% dry matter, 28% pulp, oil and almond)[9]. The second material that we have evaluated is lightened concrete with cork, Morocco is considered among the four main producers in the world with 91% of the total world production of cork. It is a low-density product, resistant to fire and a good thermal, acoustic and vibratory insulation. The third material is Hemp lightweight concrete, the latter is cultivated in Morocco since the 15th century. In 2003, surveys estimated the area under hemp cultivation at 134 000 ha in 2003 [10]. Hemp, textile hemp, industrial hemp or agricultural hemp is a cultivated variety of the Cannabacae family. Other factors that can influence heat gains through the roof are reflectivity and thermal emissivity.

In general, conventional roofs have albedo values between 0.05 and 0.25[11] , they absorb a large part of the solar radiation. As a result, their surface temperature can reach 65 °C, leading to an increase of indoor air temperature to 40 °C [12]. Reducing the absorption of solar radiation is an old technique that can be done with a white paint to increase the thermal reflectivity of the roof. Recently, researchers have identified this technique for passive cooling of buildings at the neighborhood, city or larger scale[13]. However, R. Lapiza et al [14] found that this technique significantly reduces the temperature of the roof surface by 23.6 ° C and therefore a reduction of indoor temperature in commercial buildings. Z. Romani et al. [16] deduced that the Fes and Ifrane cities require strong insulation with a low coefficient of transmission of walls and ceiling. However, poor insulation of Errachidia city is sufficient and for other cities in Morocco, an average value of the transmission coefficient is recommended [15]. Among the solutions to reduce greenhouse gas emissions around the world is the installation of cold roofs and fresh pavements [16]. H.Akbari et al. achieved For existing buildings in the metropolitan area of Hyderabad, an annual energy reduction of about 20 to 22 kW.h.m^{-2}, by setting up a white roof compared to a black surface roof [17] and white coated concrete roof achieved a more pronounced reduction that may have gone up to 26%. In agreement with the databases of the scientific research on Cool Coatings, no study has been carried out on the evaluation of this technique in Morocco [18].

The main objective of our study is to investigate the indoor climate of a mosque, reduce the annual energy requirement and carbon dioxide emissions by combining some passive techniques such as "lightweight concrete" with pomace olive or cork or hemp, and "cool roof" technique by modifying the coefficient of reflectance. The dynamic simulations using TRNSYS software are conducted under the climatic zoning of Morocco.

METHODS

Meteorological data

The subdivision of the Moroccan territory into homogeneous climatic zones was made based on the analysis of climatic data recorded by 37 meteorological stations. The table 1 below represents the general characteristics of the Moroccan climatic zones: the representing cities of each zone (six zones shown in **FIGURE 1**), their situation by contribution to the northern and western part of Morocco (latitude and longitude) as well as the type of climate.

TABLE 1: Characteristics of Morocco's six climatic zones.

Climatic zones	Representing city	Coordinates	Climate
(1)	Agadir	30’ 25° N 36° W	Subtropical, semiarid
(2)	Tangier	35’ 46° N 5’ 48° W	Mediterranean, hot
(3)	Fez	34’ 03° N 4’58° W	Mediterranean, continental
(4)	Ifrane	33’ 32° N 5’ 06° W	Humid temperate climate
(5)	Marrakech	31’ 37° N 8’ 00° W	Semiarid
(6)	Errachidia	31’ 55° N 4’ 25° W	Hot desert

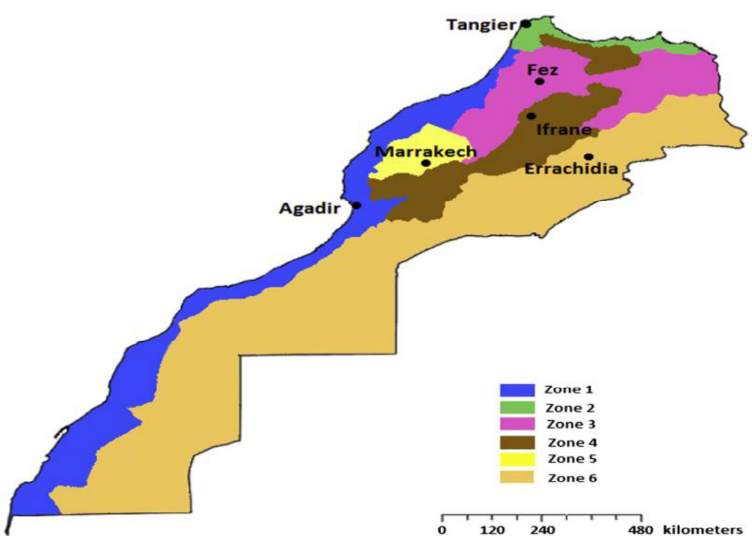
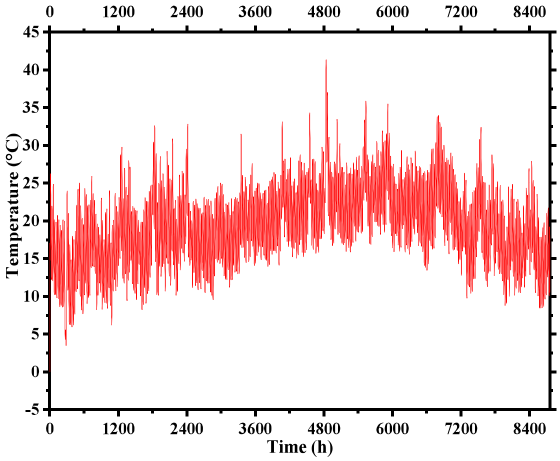
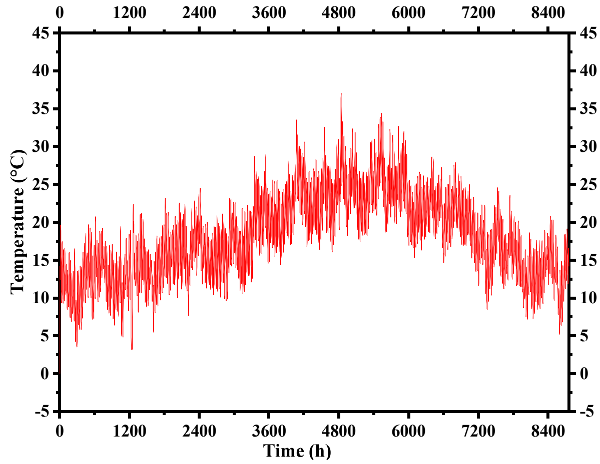


FIGURE 1: Climatic zoning of Morocco [19]

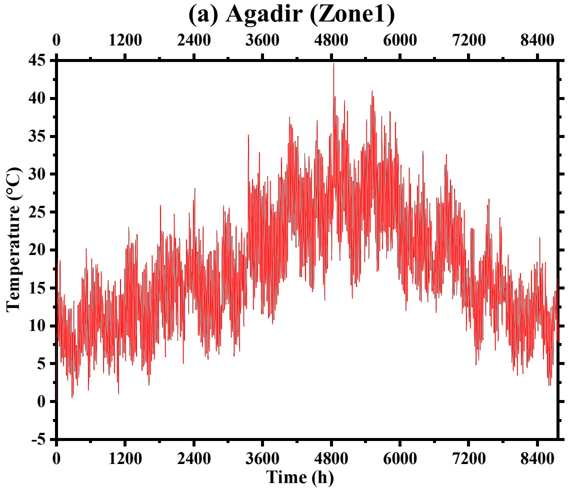
The need to study the impact of climatic conditions for the six climatic zones is justified in FIGURE 2, which shows the variation in ambient temperature during a typical year by using Meteonorm database.



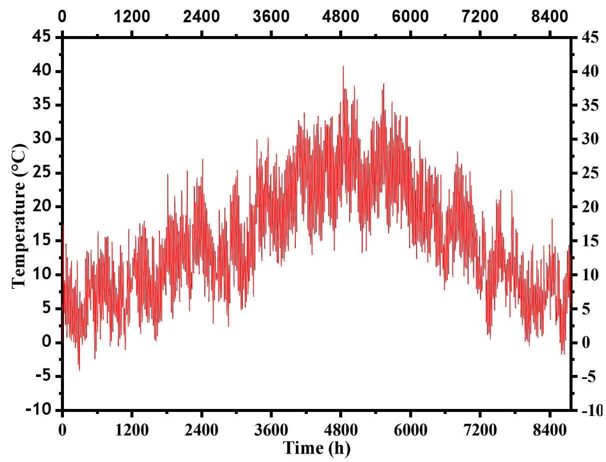
(a) Agadir (Zone1)



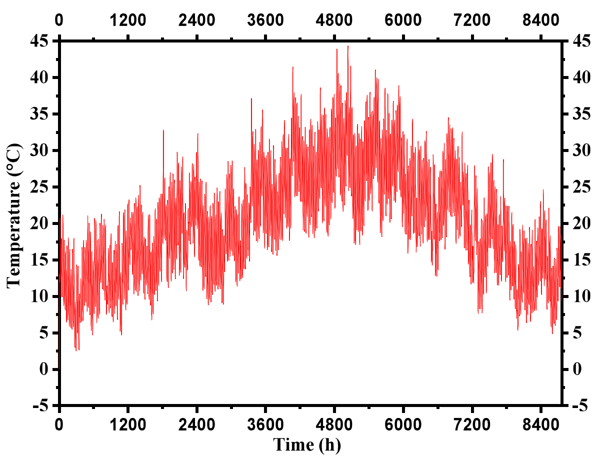
(b) Tangier (Zone2)



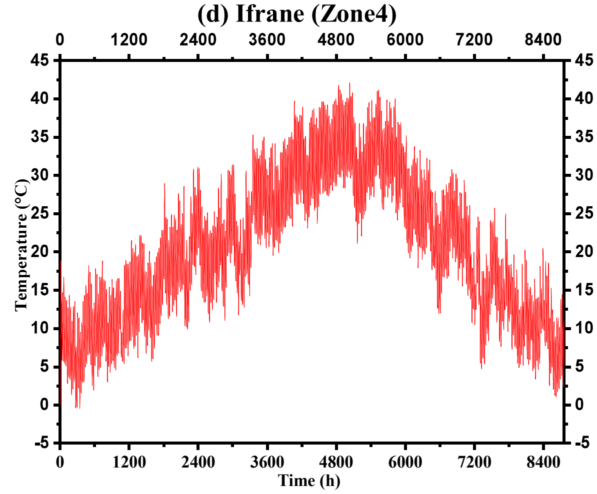
(c) Fez (Zone3)



(d) Ifrane (Zone4)



(e) Marrakech (Zone5)



(f) Errachidia (Zone6)

FIGURE 2: The external ambient temperature for the six climatic zones for a typical year.

Building description

Generally, the mosques are defined by three essential components: Mihrab, Minbar and Minaret.

- Mihrab: is often located in the middle of the Qiblah wall (i.e wall perpendicular to the direction of the Kaaba in Makkah).
- Minbar: is an important part of the prayer hall, where the Imam (leader of prayer) gives his sermon at Friday's prayer. It is generally located on the right side of the mosque.
- Minaret: is an architectural element of the mosque, its purpose is to provide a high point to the muezzin (the person responsible for launching the call to prayer) for the 5 calls to prayer.

The mosque that is the object of our study exists in Morocco. Its floor surface is 505.25 m^2, its height is 7.5 m, the glass surface is 42 m^2 (simple glazing) evenly distributed on the four facades. Other features of the mosque are shown in the following table 2.

TABLE 2: Data on the mosque studied

Component	Mosque
Location	6 zones
Type of use	Daily
Dimensions of mosque (L*W*H)	23.5*21.5*7.5 (3789.375 m^3)
Floor Area	505.25 m^2
Windows area	42 m^2
Height	7.5 m
Capacity (Persons)	505 (1 m^2/person)
Windows glazing type	Cleat single glazing

The internal thermal gains of the building are also due to the occupants who emit a heat flow 185 (W) with 90 (W) sensible heat and 95 (W) for latent heat. The occupants have a light activity corresponding to 1.6 Met.

The mosque is occupied five times a day show in table 3. With the exception of the "Dhuhr" prayer of each Friday because of the sermon and prayer of "Tarawih" of the month of Ramadan where the occupation of the mosque lasts longer.

TABLE 3: Operating profile for a mosque

	Fajr	Dhuhr	Asr	Maghreb	Ishae
Prayer duration			45-60 min		

Physical model

In order to carry out the simulation, detailed about physical and thermal properties are needed. Table 4, 5 and 6 present the details of the buildings components (Exterior wall, Roof and ground).

TABLE 4: Thermophysical characteristics of the envelope of the mosque studied (Base case)

Building component	Material (layers)	Thickness (m)	Thermal conductivity ($kJ.h^{-1}.m^{-1}.K^{-1}$)	Density ($kg.m^{-3}$)	Thermal capacity, ($kJ.kg^{-1}.K^{-1}$)
Exterior wall	Stone layer	0.030	10.44	2550	1
	Mortar	0.020	6.48	2500	1
	Hollow brick	0.070	0.7056	938	0.740
	Air gap	0.050	Thermal resistance (0.11 m2.C.W^{-1})		1.008
	Hollow brick	0.070	0.7056	938	0.740
	Mortar	0.020	6.48	2500	1
Roof	Mortar	0.010	6.48	2500	1
	Concrete	0.200	7.56	2500	0.8
	Mortar	0.020	6.48	2500	1
	Cement plaster	0.070	2.016	1350	1
Ground	Stone	0.060	5	2000	1
	Concrete	0.120	7.560	2500	0.8
	Mortar	0.070	6.48	2500	1
	tiles	0.020	4.68	2300	0.84
	Wood	0.020	0.864	1000	1.600

For the lightweight concrete technique, the following scenarios presented in Table5, 6 and 7 are evaluated in this study.

TABLE 5: Thermophysical characteristics of materials constituting the roof (Scenario 1: lightweight concrete with pomace olive) [20]

Building component	Material (layers)	Thickness (m)	Thermal conductivity , ($kJ.h^{-1}.m^{-1}.K^{-1}$)	Density, ($kg.m^{-3}$)	Thermal capacity, ($kJ.kg^{-1}.K^{-1}$)
Roof	Mortar	0.010	6.48	2500	1
	Concrete with raw pomace	0.200	1.296	1848	0.638
	Mortar	0.020	6.48	2500	1
	Cement plaster	0.070	2.016	1350	1

TABLE 6: Thermophysical characteristics of materials constituting the roof (Scenario 2: lightweight concrete with Cork) [20]

Building component	Material (layers)	Thickness (m)	Thermal conductivity ($kJ.h^{-1}.m^{-1}.K^{-1}$)	Density, ($kg.m^{-3}$)	Thermal capacity, ($kJ.kg^{-1}.K^{-1}$)
Roof	Mortar	0.010	6.48	2500	1
	Concrete with Cork	0.200	0.864	1664	0.468
	Mortar	0.020	6.48	2500	1
	Cement plaster	0.070	2.016	1350	1

TABLE 7: Thermophysical characteristics of materials constituting the roof (**Scenario 3**: lightweight concrete with hemp) [20]

Building component	Material (layers)	Thickness (m)	Thermal conductivity , ($kJ.h^{-1}.m^{-1}.K^{-1}$)	Density, ($kg.m^{-3}$)	Thermal capacity, ($kJ.kg^{-1}.K^{-1}$)
Roof	Mortar	0.010	6.48	2500	1
	Concrete with hemp	0.200	0.864	1664	0.468
	Mortar	0.020	6.48	2500	1
	Cement plaster	0.070	2.016	1350	1

The study approach

After selecting the type of building and determining the parameters that influence the performance of the building, the energy assessment of the mosque in different climatic zones of the Moroccan territory is determined using dynamic thermal simulation with the TRNSYS software[21].

In order to define the building, all its features must be entered in type 56 (TRNBUILD) of the TRNSYS software. This interface describes all the building components. It is then necessary to specify the composition of all the walls (walls, floor and roof), their orientations, the glazed surfaces and the types of glazing used. It is also necessary to define the initial conditions of the studied area, the heating and cooling control parameters as well as the free gains (solar and internal).

The thermal balance of a thermal zone, represented by an air node can be expressed as follows [21].

$$\mathrm{Q = Qsurf + Qair + Qcplg + Qgain + Qsolar + Qcond} \tag{1}$$

Where Qsurf the convective gain from surfaces ($kJ.h^{-1}$) given by the following relation:

$$\mathrm{Qsurf = Uw,i \times\ Aw,i\ (Tw,i - Ta)} \tag{2}$$

With Uw,i is the transmission coefficient ($kJ.\ h^{-1}m^{-2}\ K^{-1}$), Aw,i the inside wall area (m^2), Tw,i and Ta are respectively the interior surface temperature of the wall and the indoor ambient temperature of the mosque (K).

Qair is the heat gain through infiltration from outside and ventilation user's defined source, like HVAC system (kJ.h-1) given by :

$$\mathrm{Qair = V\rho Cp(T0 - Ta)} \tag{3}$$

With V is the infiltration and ventilation flow rate in (m^3/h), Cp *is* the heat capacity of the air ($kJ.kg^{-1}.K^{-1}$)and ρ is the density in ($kg.m^{-3}$),

Qcplg is the gain due to (connective) airflow from air node j or boundary condition ($kJ.h^{-1}$) given by:

$$\mathrm{Qcplg = V\rho Cp(Tzone,i - Tair)} \tag{4}$$

With Tzone,i and Tair are; the temperature of air entering zone (i) across walls or windows from the adjacent zone and air temperature, respectively.

Qgain is the internal gain (by lighting and persons present) ($kJ.h^{-1}$),

Qsolar can be considered as the fraction of solar radiation entering an airnode through external windows which is immediately transferred as a convective gain to the internal air ($kJ.h^{-1}$).

Qcond is the rate of heat transmitted through the envelope, ($kJ.h^{-1}$).

The temperature which measures the thermal operative zone takes into account both the temperature of the indoor air and the average temperature of the inner surfaces of the envelope, is the operative temperature (Top) [22] which can be calculated using equation (5):

$$\mathrm{Top} = \mathrm{Aop} \times \mathrm{Tair} + (1 - \mathrm{Aop}) \times \mathrm{Tsurf} \tag{5}$$

With is Aop the weighting factor for the operative temperature of the mosque, it depends on the speed of the air inside the mosque and Tsurf is the average temperature of the different interior surfaces.

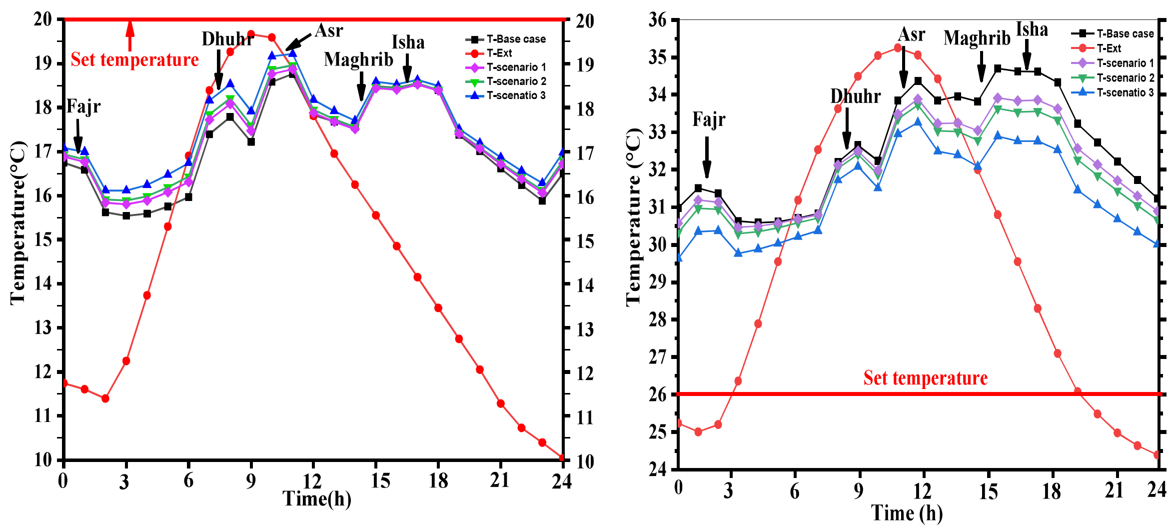
RESULT AND DISCUSSION

Comfort assessment

The graphs below, figure 3 and 4, illustrate the difference between the outdoor temperature and the operative temperature for the three studied scenarios.

Based on the results of the operative temperature, it can be deduced that during the five periods of occupation, ie the five daily prayers, the mosque can be uncomfortable compared to external climatic constraints. By respecting the thermal regulation of constructions in Morocco, ie considering the temperature of set point in summer 26 ° C and that of the winter 20 ° C [23] , we can note on the Figures 3 and 4 that the comfort conditions are not reached for all the zones and in particular for the climatic zone of Errachidia (hot desert climate) and for that of Marrakech (semi-arid climate), where the roof (42% of the total area) does not protect the building against external heat input.

During a typical day in the summer, replacing the ordinary concrete with concrete lightened with cork, or olive pomace or hemp, led to reduced operative temperature respectively of about 1 ° C, 1 ° C and 2 ° C (Figure 3b). Whereas in winter, the operative temperature decreases respectively of about 0.5 ° C, 0.5 ° C and 1 ° C for Scenarios 1, 2 and 3 (Figure 3-a).

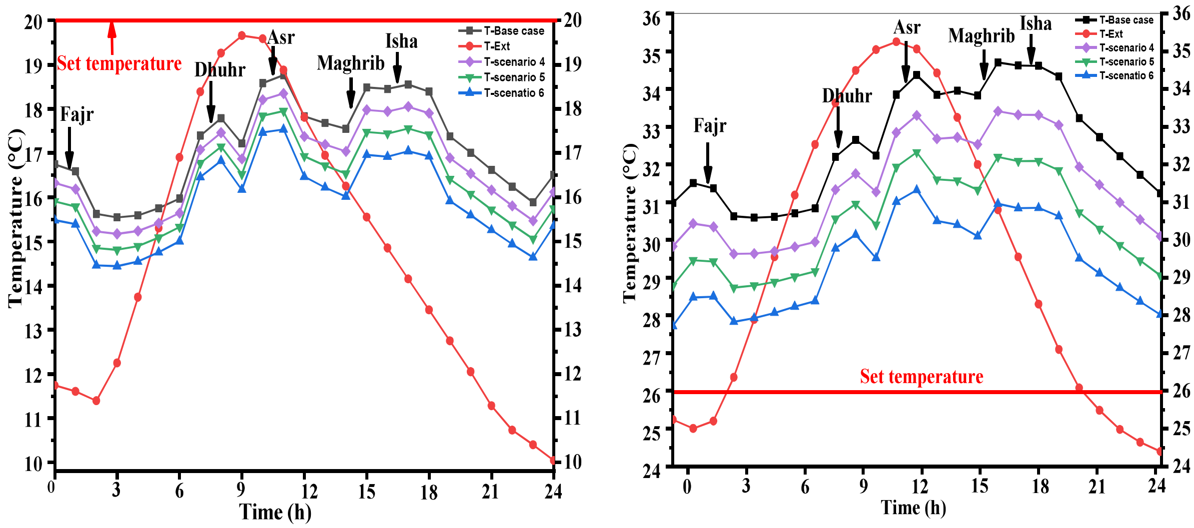


(a) Winter period-Zone 2-　　**(b)** Summer period-Zone 2-

FIGURE 3: Outdoor and operative temperature variation for the three scenarios of lightweight concrete during the two typical days of year (one typical day in summer and one typical day in winter).

Figure 4 (b) shows the evolution of the operative temperature for a typical day of August using the technique of coating "Cool Roof". The variation of the reflection coefficient of the outer roof surface from the value 0.5 (50% of reflected radiation) to 0.9 (90% of reflected radiation) leads to reduce this operative temperature for a mosque of the city of Tangier from 1 ° C to 4 ° C.

On the other hand, Figure 4 (a) shows that the decrease of the operative temperature is not very significant in winter. This can be justified by lower solar gains, which depend on the position of the sun and its height during the winter period.



(a) Winter period-Zone 2-

(b) Summer period-Zone 2-

FIGURE 4: Outdoor and operative temperature variation for the three scenarios of "Cool Roof" technique during the two typical days of year (one typical day in summer and one typical day in winter).

Building energy needs

The heating and cooling requirements represent the amount of energy required to maintain the operative temperature desired in the mosque. Figure 5 shows the monthly building energy needs (cooling and heating) of the mosque for the three reduced concrete scenarios for Morocco's six climatic zones.

The replacement of ordinary concrete with that lightened with olive cake or with cork or with hemp allows a reduction in the value of the U surface transmission coefficient of the roof of 2.149 $W.m^{-2}.K^{-1}$ respectively to 1.723 $W.m^{-2}.K^{-1}$, 1.539 $W.m^{-2}.K^{-1}$, 1.062 $W.m^{-2}.K^{-1}$. This allows a significant reduction in the monthly energy consumption of air conditioning in summer and heating in winter.

The most significant reduction is obtained by changing the normal concrete layer with concrete lightened with hemp (Scenario 3) and considered for all climate zones.

It can be seen from Figure 5 that the reduction in energy requirements is also strongly dependent on the external climatic conditions of the area. For example, in the city of Agadir (zone 1), characterized by a subtropical and semi-arid climate, energy needs are higher for air conditioning in summer than for heating in winter (Figure 5-A). On the other hand, for the city of Ifrane (zone 4) the energy needs are more important for heating than for air conditioning. Indeed, this city is known for its humid climate and its very cold winter periods (figure 5-D).

According to figure 5-E, it appears that no heating is needed in Marrakech-city during the months of December, January and February. However, in Tangier and Fez cities this demand of heating continues until April.

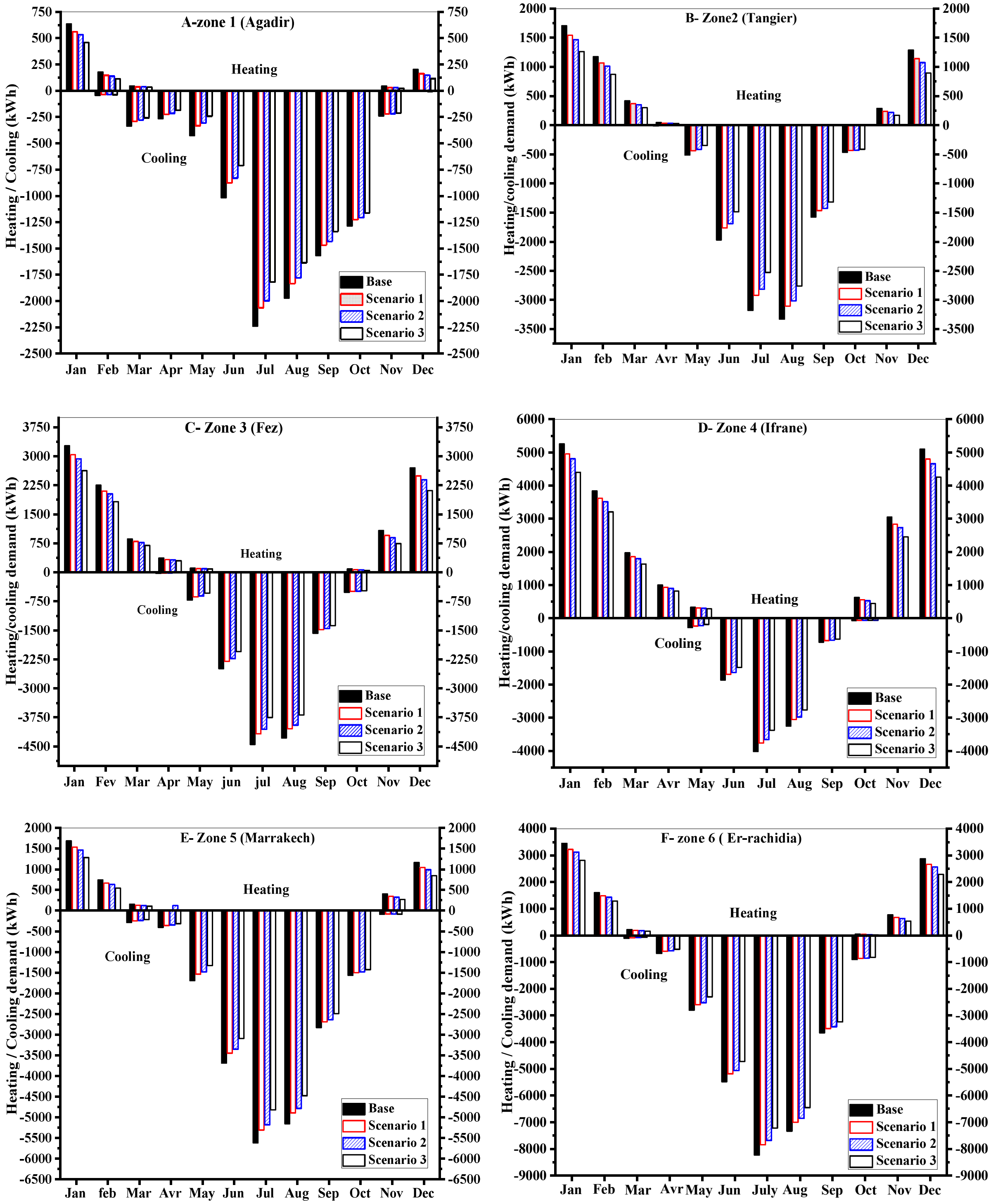


FIGURE 5: Monthly heating and cooling energy of the mosque for the three scenario of lightweight concrete in the six climatic zones.

The impact on annual energy needs due to the replacement of ordinary concrete by that lightened by light ones such as olive pomace or cork or hemp is presented in Figure 6.

By replacing standard concrete with lightweight concrete with olive cake, the reduction in annual energy needs is 9.41% for the city of Agadir (zone 1). While with concrete lightened with cork or hemp, this reduction reached 13% and 23% respectively.

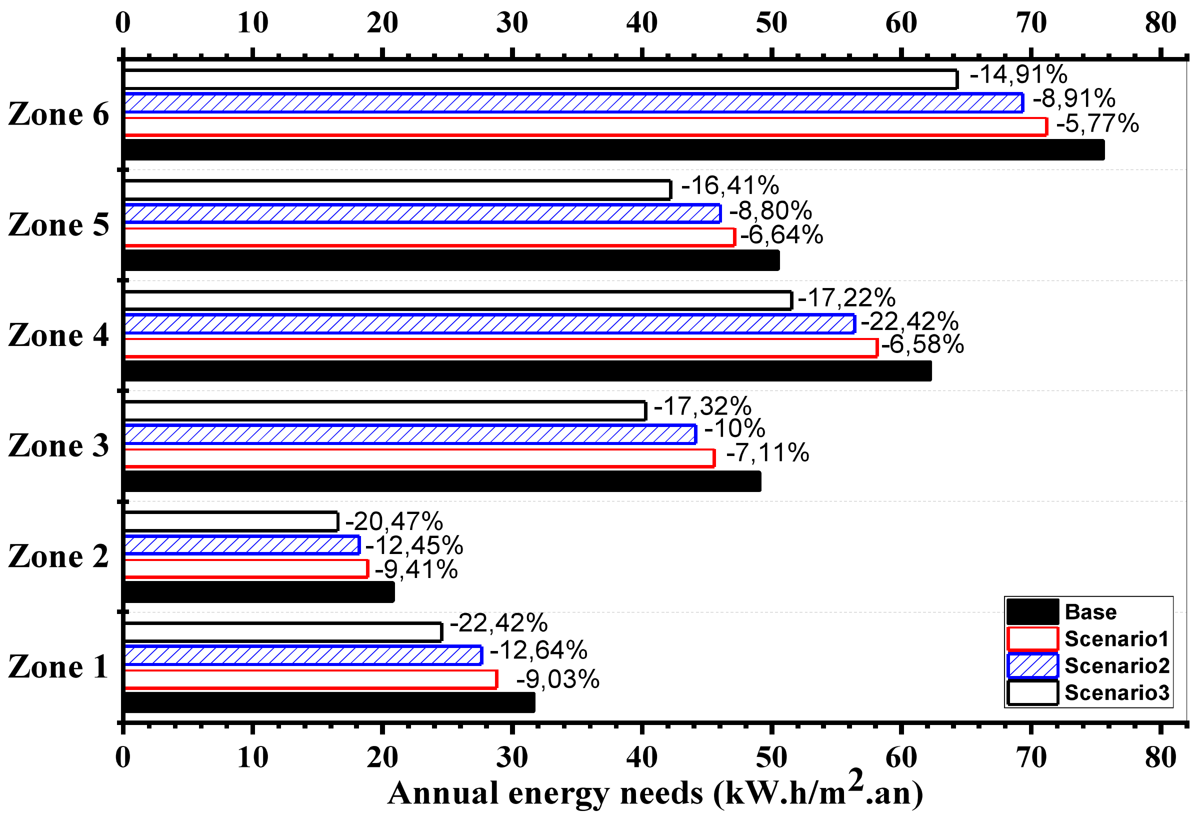


FIGURE 6: Change in annual energy needs of the mosque with alternatives of lightweight concrete.

The results presented in Figure 7 show that the "cool roof" technique can significantly reduce the monthly energy consumption required for air conditioning for the six climate zones considered. Based on the results obtained and presented in Figure 7, it can also be deduced that the increase of the reflectivity coefficient (from 0.3 to 0.5, 0.7 and 0.9) significantly reduces the necessary energy consumption for air conditioning.

All these reductions in energy requirements obtained during the summer are reversed in winter for the six zones studied with an overconsumption of energy for heating. This is induced by the implementation of the Cool Roof technique which increases the reflection coefficient and therefore the absorption coefficient of the external surface of the roof is low and therefore, the solar gains are reduced.

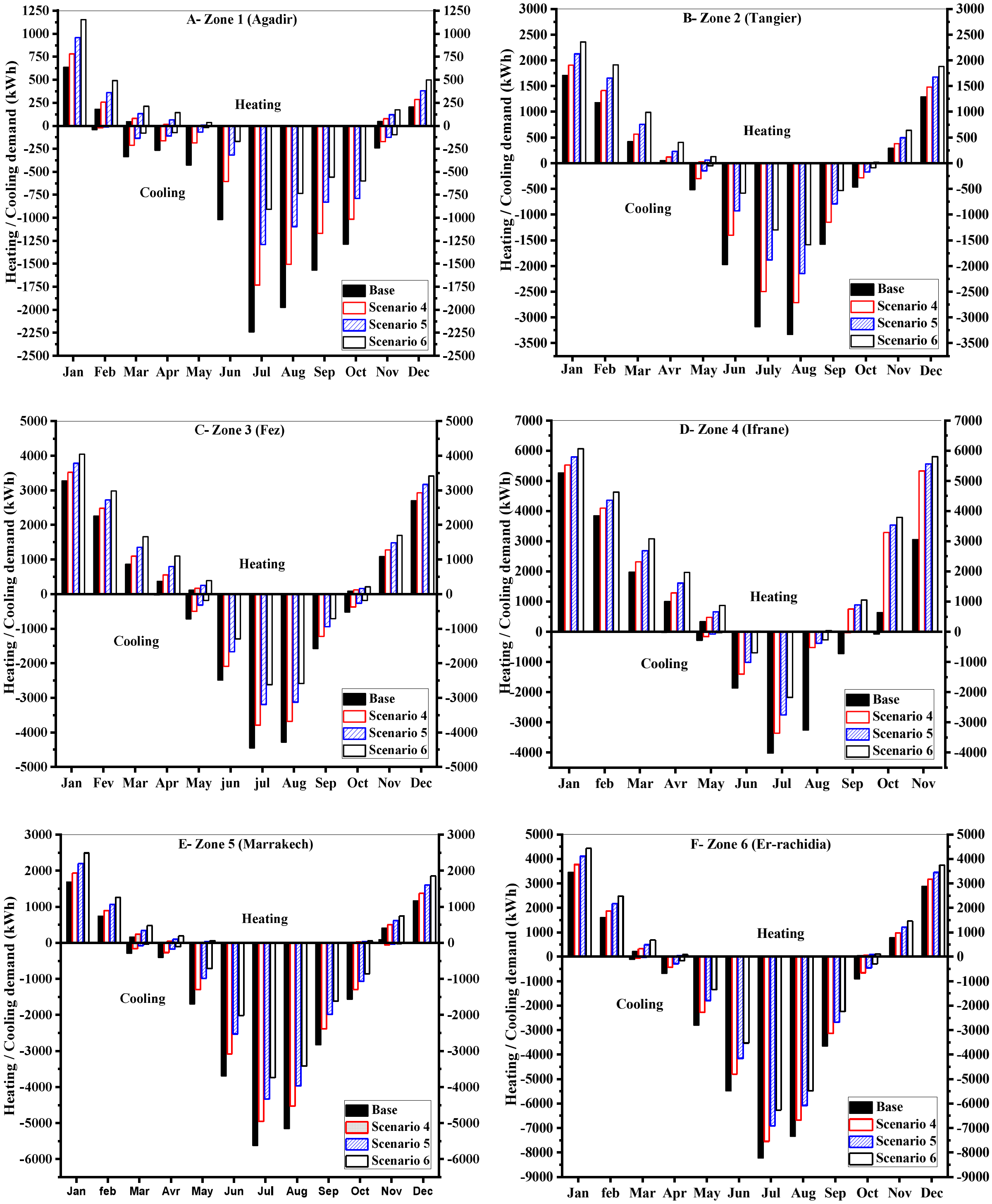


FIGURE 7: Monthly heating and cooling energy needs of the mosque for the three scenario of the Cool Roof technique the six climatic zones.

According to the detailed analysis of Figure 7, it can be concluded that the technique of "Cool Roof" has a positive and negative impact on the energy needs of heating in winter and cooling in summer. We can also deduce the results presented in Figure 8 that even the negative effects generating overuse of heating, the technique of "Cool Roof" always reduces the total annual energy needs. For example, for the city of Ifrane (zone 4) the increase in the reflection coefficient of the external surface of the roof clearly affects the energy consumption. As this reflection coefficient increases from 0.5 (scenario 4) to 0.7 (scenario 5) and 0.9 (scenario 6), the reduction in total annual charges gradually decreases.

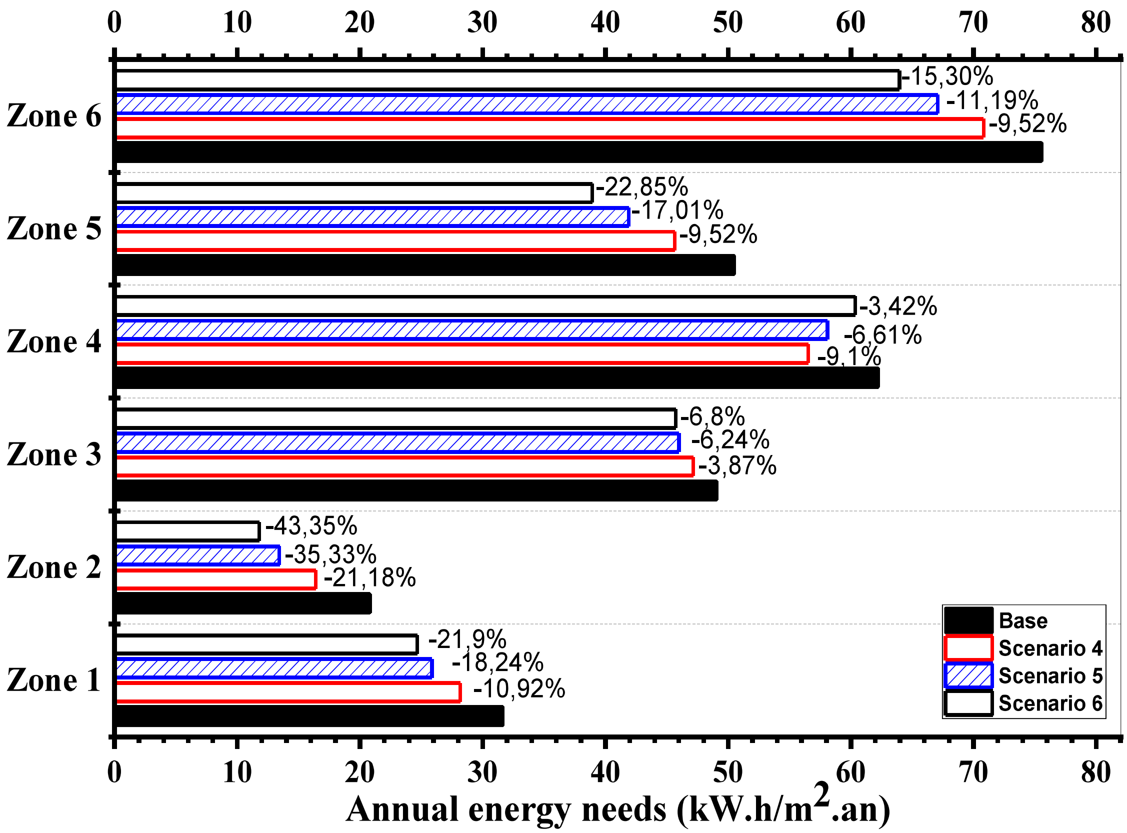


FIGURE 8: Change in annual energy needs of the mosque with alternatives of Cool Roof technique.

Environmental impact

The global concern is to limit global warming by reducing greenhouse gas emissions and contributing to sustainable development for the benefit of all communities around the world.

Greenhouse gas emissions and in particular CO2, N2O and CH4 emissions from heating and cooling are calculated according to the construction method and the energy efficiency measures implemented. The specific factor of electricity in Morocco, according to the latest statistics, is 0.66526. It represents the CO2, CH4 and NO2 emissions per kWh of electricity consumed, respectively equal to: 0.66238 kg.CO2 / kWh, 0.00000974 kg.CH4 / kWh and 0.00000883 kg.N2O/kWh [24].

We adopted the emission factor for the tertiary sector, which enabled us to determine the quantity of carbon dioxide emissions produced per unit of energy consumed for cooling and heating the mosque studied.

Figure 6 (A and B) below shows the annual quantities avoided in kg.CO2.eq due to the reduction of the annual energy consumption of the six alternatives studied in the six climatic zones of the Moroccan territory.

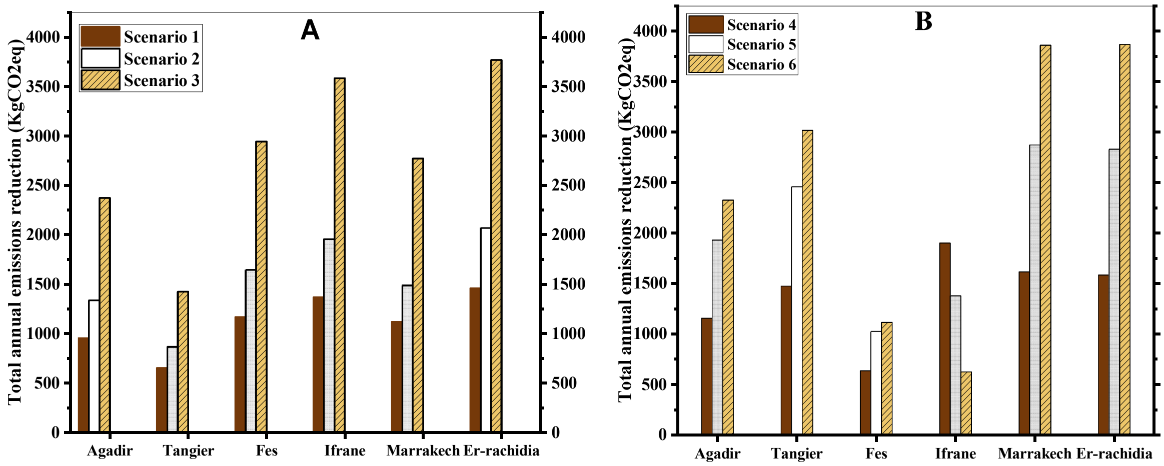


FIGURE 9: The reduction of the annual carbon dioxide emissions with: A) Lightweight concrete; B) Cool roof technique.

CONCLUSION

The purpose of this study was to analyze the impact on energy efficiency of two passive constructive solutions, on the one hand the use of a "Cool Roof" coating for the roof and, on the other hand, the replacement of ordinary concrete by lightened concrete with olive pomace, or cork or hemp for buildings with a large volume such as mosques. The objective of this numerical study based on dynamic simulations using the TRNSYS software is the prediction of the operative temperature, the annual energy needs of cooling and heating and the carbon dioxide emissions for all the climatic zones of the country, Morocco.

According to the results obtained by dynamic numerical simulations for a typical mosque of Morocco as an intermittent building of high volume and low height, the following conclusions can be formulated.

- Efficiency of passive cooling techniques:

The energy performance of the mosque studied can be improved by the implementation of the two construction techniques, lightweight concrete and "Cool Roof" technique. They reduce summer discomfort by reducing the operative temperature, ie the comfort temperature, and they reduce the annual energy needs of cooling and heating energy and also reduce carbon dioxide emissions.

- The choice of construction technique depends on the needs of the decision maker:

According to the thermal regulation of buildings in Morocco (RTCM), each climate zone is characterized by its energy needs for heating in winter and for cooling in summer. Therefore, it is necessary to specify the requirements before proceeding with the application of the technique to avoid the negative impact on energy consumption.

In conclusion, the "Cool Roof" technique can be considered effective in improving the energy performance of this type of building with a large volume, reducing their energy consumption and offering environmental benefits more than the ordinary roof case.

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