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Dynamic Simulation of a Green House in Marrakech Region

Abstract: *This study deals with dynamic simulation of a villa type house located in Marrakech region (Morocco) which was designed as a green house with several passive systems and techniques and local materials. Simulations were carried out during one year using TRNSYS software with the multi-zone model (TRNBuild). The effects of integrated passive systems and materials on air temperature in the building were analyzed for both configurations: real house versus standard one. The latter refers to materials commonly used in Marrakech region. The results indicate that the high inertia and thermal insulation of the studied building lower air temperature inside the building by 6 to 8°C during hot season. In contrast air temperature inside the building is very low during almost the coldest period of winter.*

Keywords*: Building; TRNSYS, Thermal Insulation, Thermal Inertia*

1. Introduction

Population growth has led to a big leap on the building sector as an accommodating space to a tremendous human growth all over the world making sector consumes up to 36% of the total energy in national scale [1] that makes this sector the first concern for any study aiming to reducing power consumption and improving the efficiency of energy in residential buildings.

In light of the need for thermal energy saving in terms of heating/cooling uses, the objective here is to determine the effect of using these passive components in order to achieve a thermal comfort that corresponds to the requirements at low energy cost, taking into consideration the climate features by the proposed design of the building [2] .

In designing a passive house, one of most important aspect to consider is the selection of materials that have, high thermal storage capacity, thermal insulation efficiency, and a balance of the two. The choice is not easy to make notably when the building falls in a semi-arid region [3].

Martin et al [4] conducted a monitoring of abandoned building with thick exterior walls (50cm) and compared it with a modern standard building in Soria province in Spain, monitoring results showed better indoor conditions inside the traditional houses. During summer, thermal comfort can be acquired with no energy consumption traditional but not inside the modern one. During winter, the inner temperature is likely to be more stable inside the traditional houses; but none of them were able to provide thermal comfort without energy consumption.

Kolaitis et al [5] made a comparison simulation study using TRNSYS 16 between internal and external thermal insulation for 99.6 m^2 apartment located at a mid-level of an old multi-storey building in Greece, both simulation were compared to a standard wall (with no insulation) both external and internal thermal insulation have been found to significantly reduce (by 21–89%) the annual total HVAC energy consumption. Another comparison made by Stazi [6] was carried out through the monitoring of 3 residential multi-storey buildings in Italy characterized by a low percentage of fenestration (<15%) and with different types of traditional wall fabric constructions made of solid brick masonry, unfilled brick–block cavity wall , and cavity wall with minimal existing insulation. Comparative analytical dynamic assessments were also performed for different insulation methods .The results of the monitoring showed that in the summer, envelopes with solid brick masonry or cavity wall with minimal existing insulation, have lower internal temperatures, compared with unfilled brick–block cavity wall envelopes; in the winter all the envelopes perform badly and never achieve a thermal comfort so that the occupants of the building needed heating for few hours during the day. Meanwhile, the cavity wall with minimal existing insulation performs better than the others (thanks to its low thermal transmittance). The insulation perform as a significant factor to be considered in construction, increasing the thickness of an external building wall's insulation, increases its thermal resistance and hence the energy load decreases [7] , for instance , extruded polystyrene is widely used as an insulator , the optimum thickness recommended for cooling in northern side 3.1cm and for the southern side 3.6cm [8] , while for heating using 3.4cm for both northern and southern façades leads to better insulation [9], but insulators made from natural raw materials such as hemp are likely to become a suitable alternative to commonly used insulators made from different materials (polystyrene or polyurethane). Measurements showed that properties of insulating board from organic fibbers are fully comparable to common insulating boards made from other materials [10] .However, these insulators as a natural resource have a risk for microbial and other contaminants, and their quality should be monitored regularly. Careful procedures during harvesting, processing, manufacturing, building and maintenance of buildings are required in order to avoid the risk of negative effects caused by moisture and free water [11].

Researchers have used a hollow core slab or floor to increase the thermal capacity of the building. A hollow core with ventilated slab uses the air as the heat transfer medium that can potentially supply conditioned air to the space. During the summer, outside air is used to decrease the temperature of the slab at night, so that the slab can absorb heat during the daytime [12]. Shaw et al. [13] reported that the active use of the thermal properties of the mass within the ventilated slab had a thermal comfort advantage because the increased radiant heat transfer between the occupant and the space allowing the occupants to feel cooler at the same air temperature. Zmeureanu and Fazio [14] developed a mathematical model for this system type and presented a case study for a single zone office in Montreal, Canada. The model considered two-dimensional heat transfer in the hollow core slab cores that were simplified as two parallel slab plates sharing the air passing cavity. The heat transfer coefficient along the air path was assumed to be a constant value. The authors concluded that the system reduced by over 35% the daily total cooling load.

The objective of this study is to evaluate the effect of uncommonly used construction materials in ZITOUNE villa.

2. Building description

The building is a villa type one with a floor area of 184m^{2}, located in Bengrir, 70 km from Marrakech to the north, it consists of two floors, with four façades (see figure 6). Composition of the walls and roofs is given in Table 1. Thermo physical properties of the materials are indicated in Table 2.

Table 1: ZITOUNE Villa walls constitutions

External walls	Internal walls	Roof GND Floor	Roof 1st Floor
Mortar 2cm Bouskoura Rock 40cm Hemp insulation 10cm Porphyry layer 10cm	Mortar 2cm Bouskoura Rock 40cm Mortar 2cm	Plaster 1cm Hourdis slab 16cm Reinforced concrete 4cm Cement Mortar 10cm Ceramic 1cm	Plaster 1cm Hourdis slab 16cm Reinforced concrete 4cm Hollow core slab 5cm Hourdis slab 16cm Reinforced concrete 4cm Cement Mortar 10cm Ceramic 1cm

Table 2: Thermo physical properties of constituent materials of villa ZITOUNE [15]

Materials	Thermal Capacity (kJ/kg K)	Thermal Conductivity (W/m K)	Density (kg/m³)
Mortar	0,84	1,15	2000
Hourdis	0,65	0,963	1300
Reinforced concrete	0,92	1,755	2300
Plaster	1	0,351	1500
Ceramic	0,70	1,70	2300
Hollow core	1,227	0,024	1,204
BOUSKOURA Rock	0,8	2,205	2400
Porphyry	1	3,5	2600
Hemp insulator	1,6	0,038	40

3. Building simulation

TRNSYS software was used to simulate the villa ZITOUNE. A 3D geometry was carried out by the plug-in TRNSYS3D for Google Sketch Up. The thermal behavior of the house was simulated through the Multizones Building Model (Type 56) during one year.

Another simulation configuration to be called STANDARD, consisting of Roof GND for both floors, and an external wall with 2cm of Mortar, 20cm of concrete blocks and another 2 cm of Mortar in its external side. Internal standard walls consist of 2cm of Mortar for both sides and earthenware bricks of 20cm. These components refer to standard construction materials commonly used in modern houses in Marrakech. Thermal and physical properties of all construction materials were taken from TRNSYS software libraries [15].

The building simulation was performed under real climatic conditions with data measured during 2009 in Marrakech. As Bengrir climate is close to Marrakech one, it is believed that this data is relevant. Table 3 presents the mean temperature recorded in Marrakech in 2009. It is noticed that the minimal temperature occurs during January (-1.8°C) even that this month is sunny compared to December. During February and December, the minimum air temperature approaches 0°C. The coldest months are December, January and February. On the other hand, the maximal temperature occurs during July, which is the sunniest month , the weather in 2009, began to be hot starting from March whereas hottest moths are from April to August During these five months air mean temperature increases by about 4°C each month, while it decreases suddenly by 4.9°C in September. It is important to notice the great oscillation of temperature, which is a characteristic of Marrakech climate. The amplitude of these oscillations may reach 29.5°C (in July). The minimum of this amplitude is 23.2°C, which occurs in three months (January, February and September) [16].

Table 3: measured meteorological data for Marrakech in 2009 [Agdal Station]

Month	Maximal Temperature (°C)	Minimal Temperature (°C)	Mean Temperature (°C)	Global solar radiation on a horizontal surface (W/m^2)	Daily mean solar radiation on a horizontal surface (kW.m-²/day)
January	21.4	-1.8	8.6	92 865	3.00
February	25.0	1.8	11.8	138 217	3.73
March	30.9	4.4	15.3	205 253	4.61
April	33.9	4.8	16.4	214 418	6.09
May	34.7	8.2	20.7	158 082	6.62
June	40.9	12.0	24.5	102 545	6.61
July	44.0	14.5	28.7	92 8650	6.92
August	42.5	15.8	27.0	138 217	6.61
September	36.0	11.4	21.9	205 253	5.27
October	34.6	11.4	21.3	214 418	4.46
November	30.4	4.6	15.8	158 082	3.42
December	24.3	0.8	12 .7	85 678	2.76

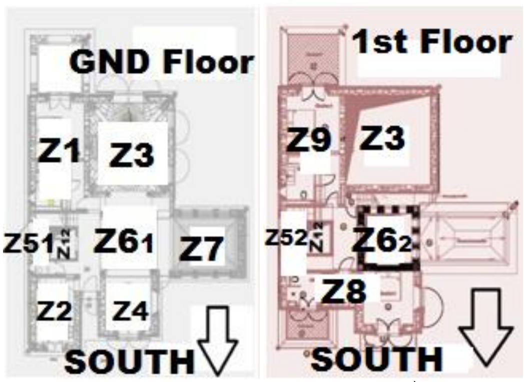

Figure 1: 2D plans for GND and 1st Floor

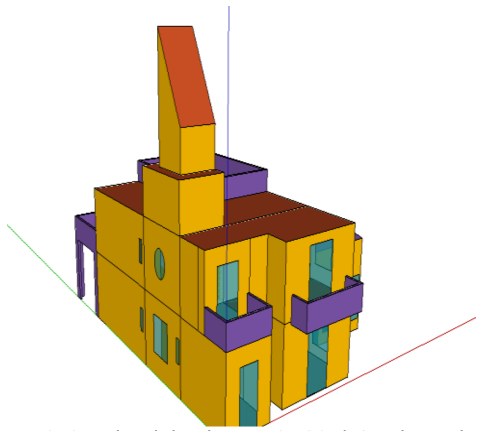

Figure 2: 3D Plan (Plug-in TRNSYS3D) Southern view

The villa was divided into 12 zones (Figure 1) odd numbers refer to northern side, even ones refer to southern side. The initial air temperature and humidity in all zones were taken to be 10°C and 50%. Simulations were conducted under conditions of unoccupancy and constant soil temperature of 18.73°C, which is the average ambient air temperature during 2009. The hollow core slab was not ventilated. Widow's shutters and wooden doors were closed with no infiltrations.

4. Results

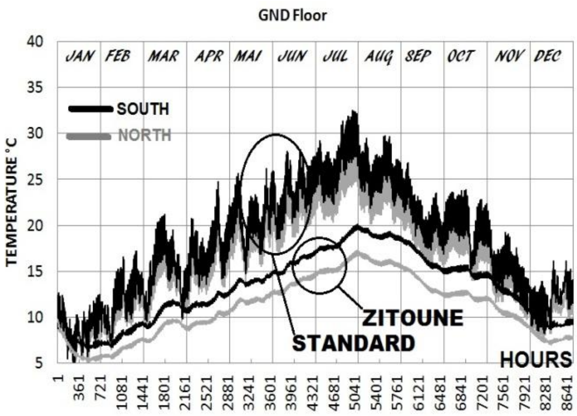

Figure 3: GND Floor temperatures

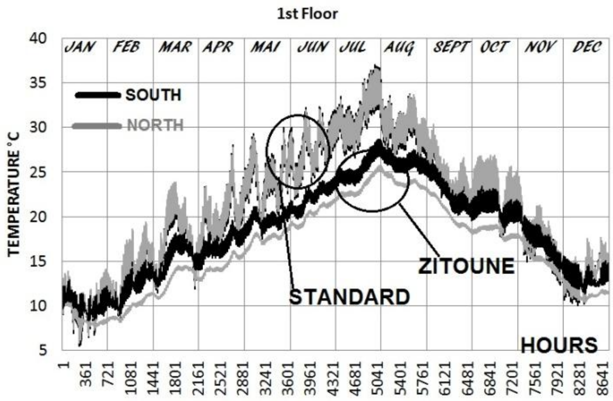

Figure 4: 1st Floor temperatures

For comparison purposes, we have selected 2 zones in each floor. One of them is the South side and the other in the North side of the building. Results show that the monthly averaged temperatures are approximately the same in the southern side for zones Z2 and Z4; and for the Northern side for zones Z1 and Z3. Thus, we consider Z2 to witness the Southern side and Z1 to witness the Northern one for the GND floor. By default Z8 and Z9 represent Southern and Northern sides for the 1st floor. Air temperature computed for these zones are compared for the two building's configurations: real (ZITOUNE) and standard one (STANDARD). Results are presented in figures 3 and 4. From these figures, it is clear that the amplitude of temperature oscillations for ZITOUNE is remarkably less than the STANDARD configuration; this is due to the high inertia of internal and external walls in ZITOUNE.

For the ground floor (Figure 3) during the cold season, according to Table 3, January was the coldest month in that season with an average air temperature of 8.6°C, in that time, the average temperatures for STANDARD configuration were 7.6°C and 8.6°C for Northern and Southern sides respectively, but for ZITOUNE ones they were 5.82°C and 7.3°C for Northern and Southern sides respectively, both configurations were cold with 1 to 2°C of difference. On the other hand, during the hot season, in July as the hottest month with an average temperature of 28.7°C, the average temperatures for STANDARD configuration were 23.9°C and 26.7°C for Northern and Southern sides respectively, but for ZITOUNE ones they were 16°C and 17.89°C for Northern and Southern sides respectively, ZITOUNE configuration maintained a thermal comfort during this season with a significant difference of 8 to 9°C.

For the 1st floor (Figure 4), during the cold season, the lowest average air temperature was in January, it was 8.6°C, in this period the average temperatures for STANDARD configuration were 9.9°C and 10.3°C for Northern and Southern sides respectively, but for ZITOUNE ones they were 8.7°C and 10°C for Northern and Southern sides respectively, both configurations were cold with 1 to 2°C of difference. On the other hand, during the hot season in July as the hottest month with an average temperature of 28.7°C, the average temperatures for STANDARD configuration were 30°C and 31.1°C for Northern and Southern sides respectively, but for ZITOUNE ones they were 23°C and 25.1°C for Northern and Southern sides respectively, ZITOUNE configuration was cooler than STANDARD one by a difference of 6 to 7°C during this season.

5. Conclusion

In this paper, a dynamic simulation of a villa type building located in Bengrir (70km to the North from Marrakech) was conducted with the multizones model of TRNSYS software. This building, called ZITOUNE integrates many passive and hybrid systems. The present study is focused on two of them: thermal inertia and hemp insulation of the walls. Results indicate that these systems have a remarkable effect on the reduction of air temperature inside the building as well as its dampening in comparison with STANDARD configuration of the building. This latter corresponds to that widely used in modern houses in Morocco. The reduction of air temperature especially in summer is profitable for thermal comfort. In contrast, it is not in winter, as air temperature inside ZITOUNE building is lower than that in STANDARD configuration. It is believed that is not realistic as the simulation conditions do not take into account solar gains.

This work is part of a study aiming to assess thermal performances of passive techniques integrated to the studied building, including the pebbles bed for inter-season heat/cool transfer, the hollow core slab, solar chimney and air tour.

Acknowledgements

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