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Research Article

Evaluation of summer thermal comfort using in situ measurement and dynamic simulation, hot and arid climate in Algerian Saharan region as a case study

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ABSTRACT

The interest to ensure thermal comfort becomes one of the major challenges in the building sector, not only for the quality of interior ambiences, but also to minimize the energy rate consumed for heating and cooling systems. Th s paper presents the advantage of using the adaptive approach and numerical simulation to assess the level of thermal comfort of dwellings of different architectural typology in hot climate. For this purpose, the method is based on in situ measurements effected on two samples of traditional and contemporary typology; using anemometer instrument, where the climatic parameters measured inside and outside samples are: ambient temperature, relative humidity rate and air velocity. The simulation work is performed by Energy-Plus software; consequently experimental tests are realized on the local material in order to know their physical and thermal characteristics. The results obtained demonstrate the efficiency of the traditional passive devices, which are able to provide a comfortable thermal ambience without referring to the air conditioning system, with an operating temperature of 30.5°C and a satisfaction rate of 80%.

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INTRODUCTION

Currently, the energy issue is among the major preoccupations around the word, although the building sector is the most concerned because its important contribution to climate changes, with approximately releases of about 33% of the greenhouse gas emissions (GHG) [1]. In addition systems of heating, ventilation and air-conditioning (HVAC) consume about 16% -50% of total energy rate, the largest share among all other applications in the buildings [2].

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Locally, on the basis of statistics provided by the National Agency for Rationalization and Promotion of Energy, this sector accounts for 42% of fi al energy consumption [3]. So, this critical situation makes it essential to improve thermal conditions and integrate passive techniques in the design of the new buildings, using local resources and natural ventilation alternatives.

Several researches show that recourse to local resources and intelligent designs, by integrating passive devices and effici t operation can considerably reduce the energy demand [4,5]. Among them, the research on natural ventilation techniques in hot climate, using various typologies of wind sensors in hot and arid zones; carried out by Energy Laboratory (ENARGARID) at the University of Bechar in Algeria, with cooperation of the unit of research on materials and renewable energies [6]. In the same context, another published study concerned the potential of heat exchangers techniques, system earth-air (EHAHE), used to guarantee interior comfort in hot and cold seasons [7]. Given the above, it seems that the recourse to passive ventilation techniques becomes essential to reduce excessive energy consumption and improving good condition of air quality [8].

In southern Algeria and particularly in the study region, following the increase of demand for housing, the Saharan City is expanding and renewing profoundly its constructive forms. The contemporary dwellings mark the peak of this trend: high buildings with flat terraces replacing the courtyard and domed roof. Indeed, traditional materials give way to bricks and cement plaster [9]. In this perspective, the occupant of actual dwellings especially in the hot season, searching to ensure the thermal comfort by resorting to air conditioning systems, which is consuming non-renewable energies.

The present research evaluates the level of summer indoor thermal comfort for two dwellings of traditional and contemporary typology, during hottest day of summer 2019. The main objective is to test the impact of the traditional passive techniques on the level of indoor thermal comfort with the recourse only to natural ventilation based on comparative quantitative approach through in situ measurements and numerical simulation on Energy-Plus Software. The evaluation of the results obtained from measurements is carried with reference to adaptive model according to the operative temperature index as established by Humphrey and Dear [10, 11, 12, 13], and in light of research on adaptive thermal comfort, such as studies carried on the impact application of adaptive approach models, as well as dynamic modeling and simulation works of thermal comfort in building ventilate naturally [14, 15, 16].

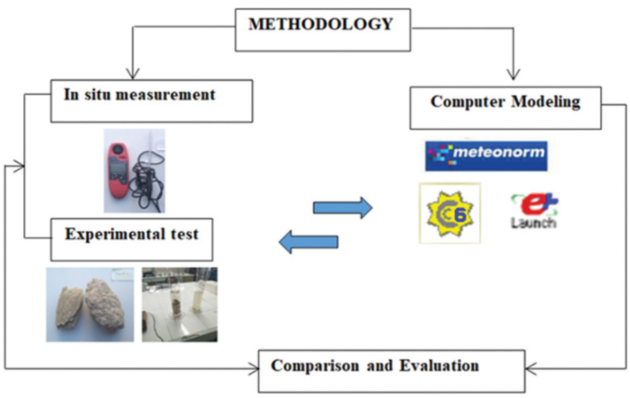


Figure 1. Flow chart of the methodology.

METHOD AND TECHNIQUE

As shown in Figure 1, the methodology followed is essentially based on comparative quantitative approach, preceded by description of climatic particularities of the region, in order to identify hottest period during summer months. Weather data is provided by national meteorological offic [17], and the psychometric diagram is established by climate consultant interface [18].

In situ Measurement

The measurements are carried out in two samples during hottest day of summer 2019; the fi st sample is a dwelling of traditional typology, built with local materials: sand rose stone and gypsum mortar, topped with the typical small cupolas. However, the second sample presented by semi-collective apartment of recent typology, built with recent materials: bricks and cement mortar, covered with a slab terrace and a decorative dome. The measured parameters are: Indoor ambient temperature (°C), Outside temperature (°C), Relative humidity % and air speed (*m*/*s*).

Adaptive Th rmal Comfort Approach

In accordance with Nikolopoulou and Stimeers, the concept of adaptation is presented by the progressive diminution of organism response to continuous stimulus exposures, also involving the necessary reactions to be adapted and survive in given environment [16]. With regard to Brager and De Dear; Humphreys and Nicol, the adaptive approach is developed from the results of in situ tests, which aim to diagnose the real performance of thermal environment conditioned essentially by climatic context, behavior of occupants and their expectations [13, 12].

In the same refl ction, Attia and Carlucci, state that occupants adapt to given environment by resorting of openings of walls and ceilings, whether by opening or using occultation. As well as by modifi ation of metabolic rate and heat loss, by clothing and controlling thermal environment [14]. So, in building cooled only with natural ventilation, the interior ambient temperature is more dependent by outside weather conditions.

In this research, thermal comfort criteria are evaluated according to the adaptive comfort standard developed by the American society of heating, refrigerating and air-conditioning engineers, (ASHRAE). Which is known as: handbook of thermal environmental conditions for human occupancy (ASHRAE-55 Standard), this standard is the fi st one that proposed the adaptive model in 2004 [19, 20].

Th s standard is developed through several empirical and experimental investigations; it can calculate the interior temperature value by considering many factors in order to approximate optimal comfort conditions such as: changing clothes, activity and position, or adjustment of interior ambience by controlling energy fans. Overall, these parameters related to both factors:

Factors Related to Indoor Th rmal Conditions

A comfort temperature is defi ed by the following equation [19]:

$$Tc = a * To + b \tag{1}$$

Where:

Tc : Comfort temperature (°C).

To : Average of exterior air temperature for the last 30 days (°C).

a and b are the coeffici ts of the equation.

According to the interpretation of Brager and Dear [13]:

$$Tc = 0.31 * To + 17.8 \tag{2}$$

As interpreted by Nicol and Humphrey [12]:

$$Tc = 0.53 * To + 11.9 \tag{3}$$

According to the ASHRAE-55, 2010, the comfort zone defi ed by the standard is the area around the neutrality line, and it represents the upper and lower confortable temperature. The 90 % and 80 % acceptability, with an ideal comfort temperature of 2-3 added on either side of the line of neutrality, which is considered to be an acceptable limit. If fan are available, another 2°C can be added on both sides to calculate the comfort zone values, especially in hot and arid climate.

The temperature range identifi d corresponds to the acceptability limits of 90% and 80 %, which reach about 30 [15, 16]. To calculate the adaptive thermal comfort of 80% of acceptability limit inside building, the following equation is used [15]:

$$80\ \%\ acceptability\ higher\ limits = Tc + 3.5\ °C \tag{4}$$

$$80\ \%\ acceptability\ lower\ limits = Tc - 3.5\ °C \tag{5}$$

The indoor operating temperature is calculated as follows: [15]

$$Top = \frac{Tair + Twalls}{2} \tag{6}$$

Where:

Top : operating temperature (°C).

$Tair$: Indoor ambient temperature (°C).

$Twalls$: Wall temperature (°C).

Th s method is applicable only for naturally ventilated spaces, controlled with occupants. The ASHRAE standard 55-2010 indicates some necessary implications as follow [21]:

- No mechanical cooling system installed.
- The rage of metabolic rate is about 1.0 to 1.3 met.
- Occupants can adapt their clothing to interior thermal conditions within the rage of 0,5 to 1.0 Clo.

Occupant-related Factors

The metabolic rate varies according to the occupant's activity. The unit is the met, it represents the energy dissipated from unit area of a person's skin and it is equivalent to: 58.2 . Table 1, provides metabolic rates for different Activities [21].

Instruments and Tools

Instrument used during company

As shown in figu e 2, the instrument used in measurement company is presented by anemometer type: Amprobe-TMA5 equipped with: humidity sensor and a precision thermistor, outside probe for measuring temperature of walls and fl ors, it also includes mini ventilator measuring air speed. Th s instrument is placed in a center of space at the height of 1.5 below the ceiling and facing the door.

Range and specifi ations [22]:

- Ambient temperature: from 0 to 50 (32to 122).
- Relative humidity: 5% to 95%
- Air velocity: 0.5 to 44.7 MPH, 60 to 3937 FT/M, 0.4 to 38.8 KNT, 1.1 to 20.0 M/S, 0.7 to 72.0 KMH, 1 to 8 BF.

Material experimentation

Physical and thermal characterization tests carried on original material, in order to know thermal conductivity index and density value that are necessary for numerical simulation work. Although thermal conductivity values are provided for recent materials, tests are based on original

Table 1. Metabolic rate by activity [21]

Activity	Metabolic rate (Met)
Sitting (silent)	1
Reading (seated)	1
Write	1
Stand up	1.2
Walk	1.7

material of the traditional sample: the sand rose stone. So, with reference to thermal characterization of local materials researches in Saharan context [23, 24]; an experimental test is carried out using heat fl w method on a stone sample taken from ruined dwelling.

Measuring principle of thermal conductivity

As shown in figu e 3(a), the test is performed by applying a heat fl w; which passes through the stone sample. A gradient of temperature is applied to the front face ($T1$), while the temperature of the other face ($T2$) is kept constant by cooling [23, 25]. For this purpose: The stone sample is cut in rectangular form of 10/8 of dimensions and a thickness of 6*cm*, placed between two media: one of the extremities is exposed to a heat source presented by an electrical resistance that emits a heat fl w (Q), so produce a thermal gradient according to the thickness of the sample; while the other extremity is exposed to a cold-water circuit. Two thermocouple sensors are attached to the sample extremities and separated by distance (d) or thickness of the sample, measuring the temperature variation during the test period. In addition, the stone sample extremities are insulated with Tefl n to eliminate heat loss. Due to low thickness and insulation of sample sides, it is considered that heat propagation is one-dimensional, from the front to the back, only according to distance (d).

According to Furrier, the thermal conductivity value is given by the following formula [26, 27]:

$$\boldsymbol{\lambda} = \frac{\mathbf{Q} * \mathbf{d}}{\mathbf{S} * (\mathbf{T1} - \mathbf{T2})} \tag{7}$$

Q : Heat flux (w/m^2)
d : Thi kness (m).
$T1$: Front panel temperature (°C).
$T2$: Temperature of the rear face (°C).

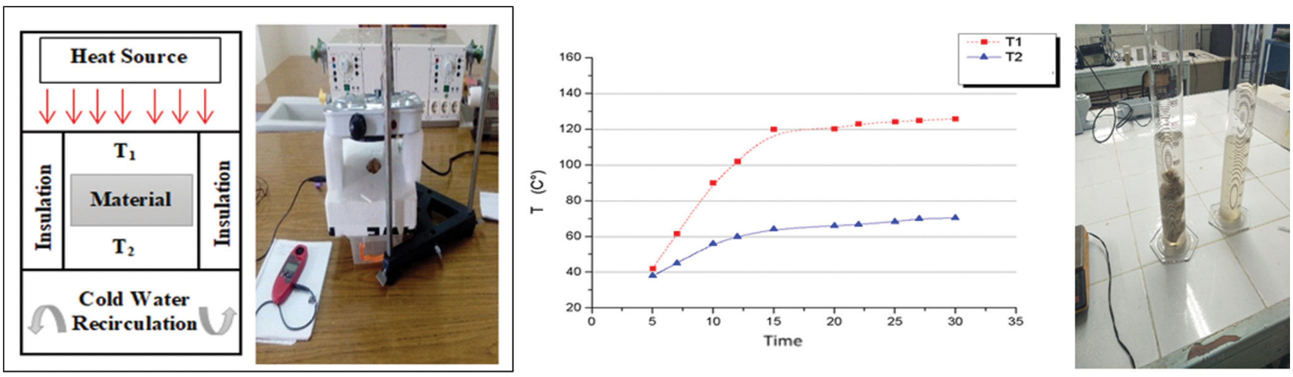
The graph in figu e 3 (b), shows the temperature evolution at the material interfaces ($T1$, $T2$). By applying a heat flux of 40w, temperature $T1$ increases gradually until it reaches the value of 120 °C it stabilizes while $T2$ on reverse interface increases but it keeps an important interval, caused by the thermal capacity of the materials to store heat during a given time. So, by the application of equation (7) getting thermal conductivity value of:

0.87 $w/(m.k)$ Subsequently, thermal resistance of each type of wall is calculated as follows: [26, 27].

$$R = \frac{d}{\lambda} \tag{8}$$

Where $d(m)$ the thickness of building walls, (λ) thermal conductivity $w/(m.k)$

Figure 2. measuring instrument.



(a) (b) (c)

Figure 3. Experimental Tests of local material. (a) Experimental device of thermal conductivity, (b) Temperature evolution at the interfaces and (c) Density test.

The Density: the physical characteristic of matter presented by mass and volume and can differ between materials according to their nature. The amount of substance contained in object is called mass; its measurement is usually given in grams (g) or kilograms (kg). While, volume is the amount of space occupied by substance; its unit are liter (l), cubic meter (m^3) and gallon (gal) [28]. So:

$$\rho s = \frac{M}{V} \tag{9}$$

With: M mass (g) and V volume (cm^3)

Density of the stone is calculated in reference to the volume obtained by test presented in the figu e 3(c), fi stly the stone sample is weighed, then two graduated specimens filled with the same volume of water, the stone sample is placed in one of the specimens and by difference; the volume stone is obtained. So, by applying equation (9) we get the density value of: 2.51 g/cm^3

Software

Energy Plus Software

Many building design software has been developed to simulate the thermal behavior of buildings for energy efficiency, the application of these tools has led to important progress in reducing energy consumption used for heating and cooling system. Among them appear ENERGY-PLUS, which occupied an important range in the simulation fi lds; a famous software used by architects, engineering's and specialists to simulate both the consumption needs of energy for cooling and heating as well as lighting; also to study the water bracing loads in buildings. The program interface is based on a console which reads the inputs and writes the outputs in text file. It is available in several versions and lived with set of subprograms including: IDF, editor interface which allows to entering necessary data using text format. EP-launch, editor for managing input-output data and consulting vertex modeling. EP-compare, in order to compare multiples results from different simulations. In this present research the version used is: 8.0.4 [29].

Climate consultant

Simulation program, based on annuals climatic data for given region in EPW format, provided by National Metrology Offi . Climate consultant translates and simulates this raw climatic data into various meaning full graphics. In the present research, the version used is 6.0 [18].

Presentation Of The Region

The study region is characterized by specific architectural typology, however all terraces of houses are covered with various domes and vaults, figu e 4(b). The city of thousand and thousand cupolas is the name given by Isabel Eberhard to El Oued-Souf region, during his tourist visit to lower Algerian Sahara, [30, 31].

Location and geographical character:

As shown in figu e 4(a), the study region is located in the South-East of Algeria, bounded from the North by a series of Chotts: Melghir and Marouane, from south by the dunes of Great Oriental Erg, from the West by the vast oasis of Oued Righ and from the East by Tunisian borders [32].

(a) (b)

Figure 4. Presentation of the region. (a) Geographic situation [33], (b) Traditional architecture with volte and copula [34].

Climatic Context and Psychometric Diagram

The card of the climatic zones in figu e 5(a) indicates that the study region located in zone E3; which characterized by dry and arid climate with: dryness, high temperature, scarcity of rain and violent sand winds [35]. Overall, temperatures vary during the year from 5 - 45 °*C*, as shown in Figure 5(b), the very hot season lasts about three months, from June to August, with an average maximum temperature of 42 °*C* and a minimum of 27 °*C*. While the cold season last from November to March, with minimum average temperature of 5 °*C*, and maximum of 16 °*C*. In addition, the region is usually exposed to active wind movement, the most violent is called: Sirocco, which is very hot and dry, blowing from South side and cause many damages (desiccation, dehydration) [36].

Figure 5(c), shows the psychometric diagram of the region, provided by Climate Consultant version 6.0. Based on three different climatic contexts displayed simultaneously, indicating the well- being state of occupants in spaces, including the following characters: average annual temperature, relative humidity range. Th s climatic model is developed from the manual ASHRAE standard; comfort model, 2005. The diagram simulation helped to identify total number of hours and percentage time, registered in various building strategies, approximately 13 ranges showed in different colors. For the study region, the graph shows that annually only 19.5% located in comfort zone.

PRESENTATION OF SAMPLES:

Dwelling with Traditional Typology

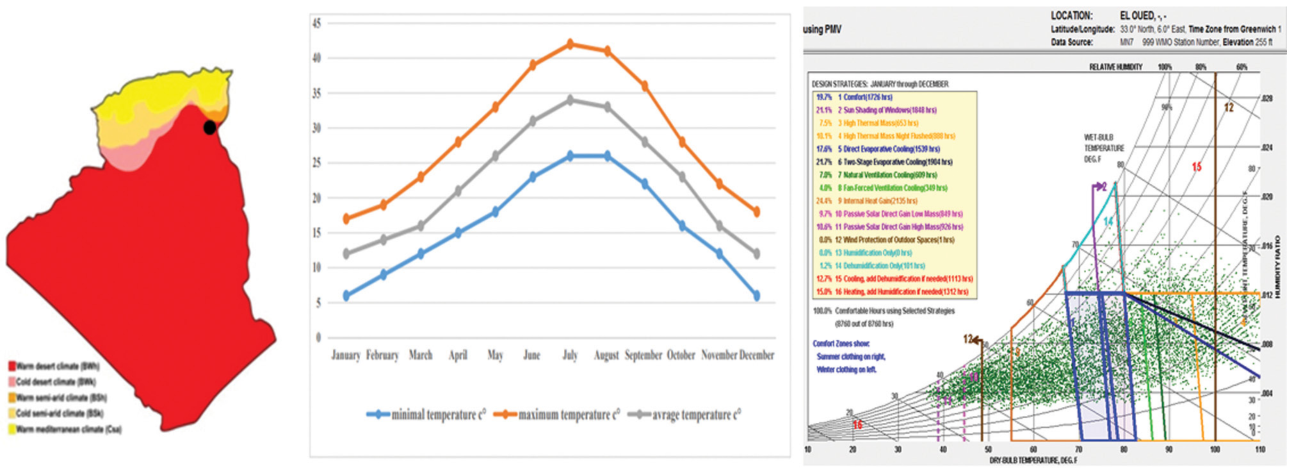
As shown in figu e 6 the fi st sample presented by mono block, of 10.3*m* /12.8*m* of dimensions, located in the historical district of the region called (Laachech); which is characterized by compact morphology, and covered streets. The selected sample is limited to one level, structured into three bedrooms and semi-open space called (Sabbat), kitchen and bathroom; all's organized around a large central courtyard covered with sand. The roof is made with elongated vaults and medium sized domes, with 1m of diameter and 0.8*m* of height with ventilation openings. Walls of about 55cm, built with sand rose stone and gypsum mortar. The space chosen for measurements and simulation work is the living room, with dimension of: 4/3.5*m*, it also comprises a single glazed window of 4*mm* of thickness and dimension of 0.8/0.8*m*, with thick wooden frame, a heavy wooden door with dimension of: 1/1.2*m*. These openings are located on the South- East face which opens into the central courtyard.

Local materials:

View the nature of soil which lacks stone and clay, only local materials are fully exploited noting: rose stone sands named (louss) and gypsum stone (tafza) [37]. The fi st stone is presented as a hard concretization of sand particles, in free forms gives sand rose but in continuous sedimentation produces resistant slab. Th s one constitutes the principal material of construction to build walls, fl ors, and foundation. The second stone is little light, found buried under sand in form of plate, especially in the Northern part of the region. Removed and burned in incinerators, then stuck. So with sifting give a good coating, used as strong binder. Figure 6.

Dwelling with contemporary typology:

As shown in figu e 7, the second sample is a semi collective dwelling built in recent materials, located in recent neighborhood of the region, composed of ordinary rooms:



(a) (b) (c)

Figure 5. Climatic context of the region. (a) Major Climate zone in Algeria [35], (b) Average and extreme temperature [17] and (c) psychometric diagram applied to the study air [18].

Figure 6. The traditional dwelling.

Figure 7. The contemporary dwelling.

two bedrooms, living room, kitchen, and bathroom that are articulated around a corridor, it also includes a veranda space. The openings are little wide compared to the traditional type protected by occultation (Moucharabiehs). The building was mainly constructed as reinforced concrete skeleton system with hollow block fl or (16+4). The masonry is made of hollow brick and cement mortar; the exterior walls are made in double walls of 30 *cm* of thickness with 5 *cm* air gap and 2 *cm* cement plasters on the outside and inside. The space concerned by measurements and simulation is the living room, with the following dimensions: 4.5/3.5 *cm* and 2.8m, 2.8*m* of heights under ceilings, it has two external walls, with a window of 0.9/1m of dimensions on the south facing, built in wood and single glazing of 0.02/0.05*mm*. It also includes a French window door of 1.2/2.2*m* that opens onto the veranda, a single entrance gate of 0.9/2.2*m* that opens onto the corridor. Th s apartment is covered with a 0.16*m* of hollow bricks and 0.04*m* of solid concrete slab with decorative dome of 1.2*m* of diameter.

Sequence of Measures

The measurements were carried out with an anemometer from six o'clock of the morning (6:00 am) to midnight, (00:00 pm), the interval is fi ed at one hour between measurements. The instrument is placed in the center of space at height of 1.40***m***, the ventilator is oriented towards the door; the ventilation conditions are regulate according lifestyle of occupants:

Sample 1: Traditional dwelling.

The gate of the house is kept open.

The sand of the courtyard and the entrance (squiffa) is sprinkled with water.

The gates of the measured spaces are open and protected by drapes.

Windows are closed from 12:00 to 15:00 am.

No mechanical cooling system is activated.

Sample 2: Contemporary dwelling.

Living room door is kept open all day.

The window and the door that opens onto the veranda closed from 12.00 to 15.00 am.

No mechanical cooling system is activated.

The Occupant detail is provided by Table 2.

NUMERICAL SIMULATION

The recourse to simulation work is necessary in the design process of effici t buildings, because it facilitates the evaluation of different energetic alternatives. Also to estimate the thermal comfort range of occupants, so it constitutes a perform tool for decision and design. The numerical simulation supposes that simulated results refl ct really the thermal behavior of buildings. Therefore to confi m this hypothesis, the comparative study between in situ measurements and simulation results seems important. In this research, the simulation work is carried out with ENERGY-PLUS, as indicated above referenced software and famous in energetic fi lds. Its manipulation requires the introduction of several parameters related to both occupants and their climatic environment:

Input data:

<u>Site and location:</u>

- Geographical coordinates: Longitude: 6°51´47″ East, Attitude: 33°21´21″ North, Altitude: 84 *m*
- Architectural typology: the modeling is carried out by the vertex system.
- Climate and average temperature: climate data are taken from the interface meteonorme-7 in EPW format.

<u>Characteristic of building materials:</u>

The sand rose stone that has been the subject of thermal and physical experimentation presents the following values: thermal conductivity of: $0.87 w/(m.k)$, total resistance of 0.82 $(m^2.k)/w$ and the density of: 2.5 g/cm^3. For recent materials the values are taken from the thermal regulation of buildings [38], table 3.

<u>Natural ventilation condition,</u> infiltration rate:

Energy plus indicate that default values more than 1.0.0.0, which produces a constant air infiltration rate under all this conditions: air conditioning and heating, active systems, occupancy and behavior of individuals. Generally these parameters affect signifi antly the thermal performance of building. So it is necessary to identify with precision and detail, in order to avoiding mistakes and ensure excellent level of comfort and energy needs.

RESULTS AND DISCUSSION:

The measurements presented in the graph of figu e 8(a), show that ambient indoor temperature measured in traditional sample increases slightly with amplitude of 4.5 °*C*, between maximum and minimum value, while the temperature measured at the exterior at street level increases with amplitude of 15 °*C* between maximum value 41 °*C* and minimum 26 °*C*. Th s interior amplitude is justifi d mainly by two main elements:

Firstly, the shapes of domed roof serves to breaking san ray's and distribute them over entire spherical surface, so half of the roof is always shaded. From inside, by pressure difference; hot air rises upwards then it is routed to inside through ventilation openings, which promotes regular renewal air inside spaces and consequently stability of temperature degrees.

In addition, important thermal inertia of massive walls, built in sand rose material and gypsum-mortar with 55 cm of thickness, guaranteeing the insulation of envelope throughout the day, slowing the penetration of heat and always leaving a large gap between the inside and outside temperature. Th s considerable thickness promotes a good

Table 2. Occupant detail and metabolic rate

Space	Number of people during measurement	Activity	Clothes	Metabolic rate (met)
Living-room (traditional dwelling)	1	Repos	Light summer clothing	1
Living-room (contemporary dwelling)	1	Repos		1

Table 3. Thermal property of materials

	Material	Th rmal conductivity	Th ckness	Th rmal resistance	Total thermal resistance
External wall traditional sample	Sand pink	0.87	50	0.57	0.82
	Gypsum	0.4	5	0.25	
External wall contemporary sample	hollow-block	1.15	20	0.23	0.51
	air gap	0.27	5	0.18	
	outside coating	0.4	2	0.1	

thermal phase shift by gathered heat during the hour's day and releasing it at night; this clearly tested in the early morning hours with high temperature values.

Thermal phase shift is related to thermal inertia, which is the time tacked by material to reach environment temperature. Concretely, as material is dense, as it takes time to reach environment temperature, so presented a good heat insulator. Contrary, as material is light, as it heat faster and insulate against cold [39].

On the basis of physical and thermal characterization tests, carried out on sand rose stone, this material presented thermal conductivity of: 0.87$w/(m.k)$ and thermal resistance of: 0,57 $(m^2.k)/w$ Added that the gypsum mortar used as binder stone and for exterior and interior plaster also acted as a good thermal insulator [40].

In agreement with Izard opinion, in hot and arid regions, it is necessary to create walls with high thermal inertia; witch having the capacity to storing heats during the day, so reduce feeling of discomfort caused by fluctuations of temperature [41].

Other factors contribute to this variance, related to location and spatial organization:

The location of this traditional house in historical district: the old one of the regions, with compact morphology and irregular and narrow streets, where all houses are joined together to form a compact mass, which reduces the peripheral sunlight of exterior surfaces. In addition, the majorities of these streets are covered by vaults; consequently provide shade during hot periods and creates a comfortable microclimate. So in dense and compact environment, there is little space for sand vortices and direct diffuse solar radiation, which are two major constraints of hot and arid contexts [42].

As shown in Figure 7, the spatial organization of the house is centered on large central courtyard, which is proportionally wide in relation to other spaces, thus ensuring

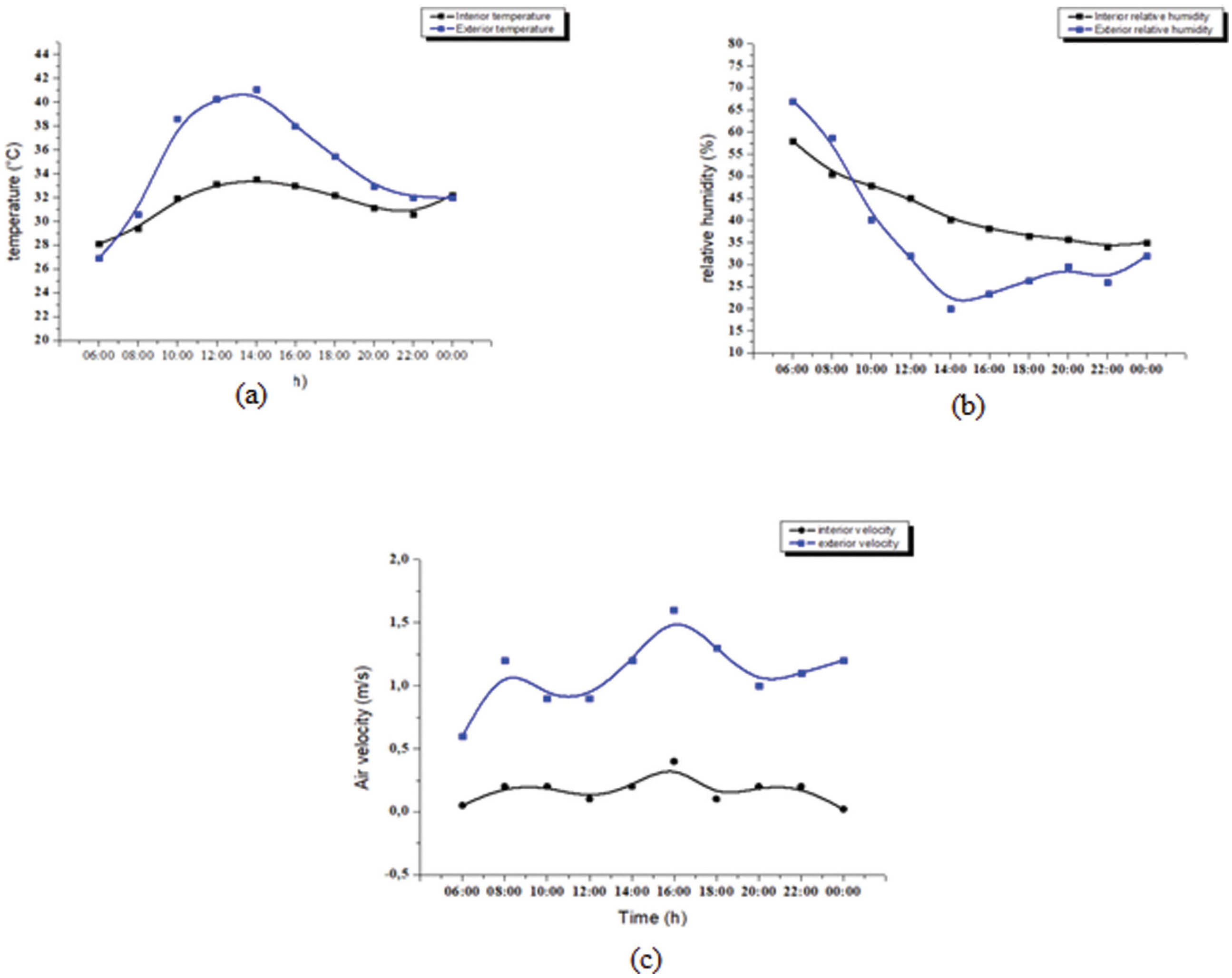


Figure 8. Variation of the climatic parameters of the traditional dwelling. (a) Variation of interior and exterior temperature for the traditional dwelling, (b) Variation of interior and exterior relative humidity the traditional dwelling and (c): Variation of the interior and exterior air velocity of the traditional dwelling.

maximum ventilation and lighting to the surrounding spaces. Equipped with fountain and a palm tree; that favors freshness throughout the day; it is also covered with a thick layer of sand because it becomes a place to sleep at night. However dwelling with central courtyard responds positively to climatic constraints in a warm context, because its central configur tion generates a microclimate [43, 44], it works like a thermal regulator, and during the night cold air pushes warm air upwards through small orifices Contrary, during the day when upper part of house is rather sunny, so it is warmer than the rest of dwelling; cold air masses remain in the lower spaces due to the difference in pressure.

In regard to the humidity factor, the measurements on the graph of figu e 8(b) indicate a high rate measured during the early morning hours, justifi d mainly by the amount of heat propagate throughout night by walls. In added insuffici cy of natural ventilation, because all openings are closed and the inhabitants leave the rooms to sleep in the central courtyard covered with sand (Nomadism at night). From this time this humidity level begins to decrease gradually with the opening of doors and windows and ventilation from the courtyard and the openings of the domes. Returning to the psychometric diagram; the comfort zone is limited by a humidity level of 45 and 60%, the humidity inside the room is globally stabilized at an interval between 47.5 and 37.5%, this is caused by the effect of the gypsum plaster used which allows the steam to pass through, it absorbs humidity from the air throughout the day and gives it back at night; therefore, it regulates the degree of humidity in the case of strong fluctuations [40].

In relation to interior air speed, as shown in figu e 8(c), values measured inside the room vary between 0.1m/s and 0.2m/s in maximum, while outside value reaches 0.6m/s at maximum. In accordance with Givoni approach [45], as well as the research of Dear and Bragger [13] in ventilation fi lds, generally the values of air speed conditions in winter season should not exceed: V air = 0.15m/s, while in summer seasons can go-up to 0.25m/s. Noting that for the yard, the maximum measured speed value is 0.6 m/s which favor ventilation, especially with existence of water source and the occasional watering of the sand.

Returning to second sample, in contrast to traditional sample, semi-collective dwelling appears sensitive to outside fluctuation temperatures, this is clearly noticed from the measurements presented in the graph of figu e 9(a), where the amplitude is acceptable during the fi st hours of the morning, but from afternoon, interior ambient temperature approaches the outside values with deviation of 3, which means that the materials composing walls their thickness (30) are not able to store the amount of heat absorbed, so the space heats-up quickly. As indicated in the table, total thermal resistance of recent walls is lower than traditional, so the cinder block and cement plaster represent bad choice that should be avoided at most in hot climate areas. In addition, with the existence of an artific al dome above the ceiling, the amount of heat stored inside the dome penetrates through the ceiling and contributes to the heating of space.

Compared to outside humidity values, the measured values are almost stable inside the room with a rate of 40-50% during all hours of measurement except that from: 8 p.m., noting a slight decrease. Th s stability is due to the air renewal in the living room and the nature of materials constituting the internal walls. Figure 9(b).

Airspeed values measured inside the living room are in range of: 0.2m/s - 0.35m/s, this is caused by two essential factors: air movement between veranda door and window in front, as well as the exposure of lodgment to active wind movements. Figure 9(c).

According to the Adaptive Approach

Compliantly with equations which defi e the comfort temperature for naturally ventilated buildings as follows:

According to Dear and Bragger interpretation: by the application of the equation (2).

For the maximum outdoor temperature value: $To = 42°C$ the comfort temperature value is $Tc = 30.8°C$.
For the minimum outdoor temperature value: $To = 28°C$ the comfort temperature value $Tc = 26.48°C$.

According to the interpretation of Nicol and Humphrey: by the application of the equation (3).

For the maximum outdoor temperature value: $To = 42°C$, $Tc = 34.42°C$.
For the minimum outdoor temperature value: $To = 28°C$, $Tc = 26.74°C$.

So: the operating temperature calculated on the basis of in situ measurements is as follows: equation (6)

Traditional sample:

Maximum interior temperature: $Tint = 34°C$.
Minimum interior temperature: $Tint = 27°C$.

Contemporary sample:

Maximum interior temperature: $Tint = 37.6°C$.
Minimum interior temperature: $Tint = 26°C$.

Figure 10 presented The projection of the values relative to the operating temperature and the mean external temperature in the graph available in the Building and Environment Center website, the traditional dwelling reaches 80% of satisfaction, with an indoor operating temperature of 30.5°C and an air velocity of 0.2m/s [15].

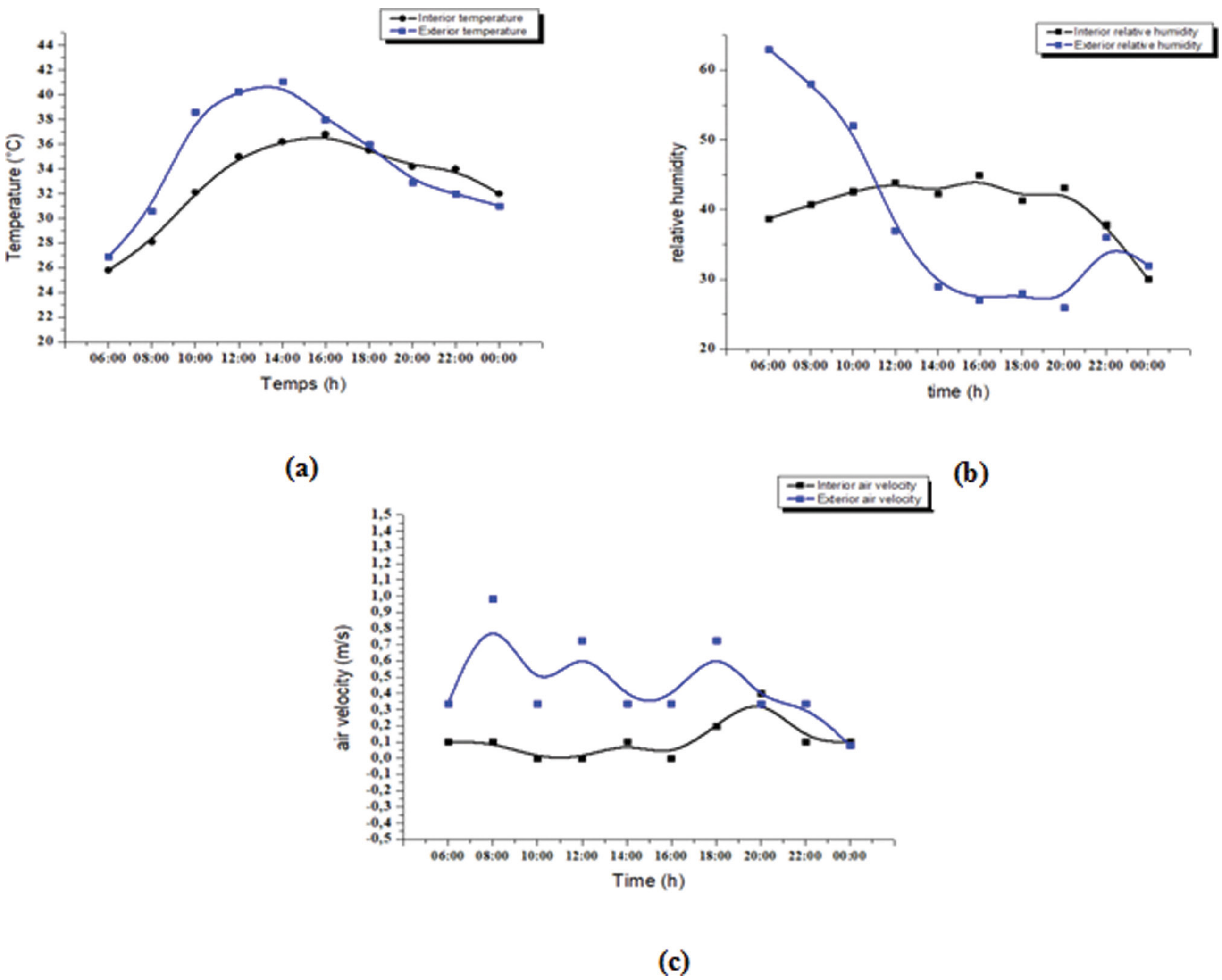


Figure 9. Variation of the climatic parameters of the contemporary dwelling. (a) Variation of interior and exterior temperature of the contemporary dwelling, (b) Variation of interior and exterior humidity of the contemporary dwelling and (c) Variation of the interior and exterior air velocity of the contemporary dwelling.

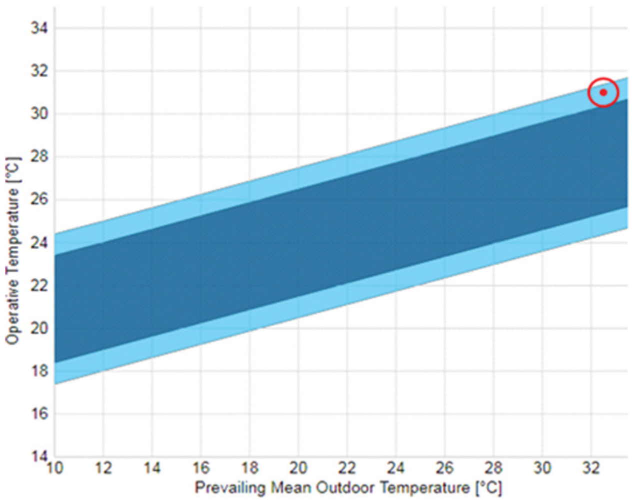
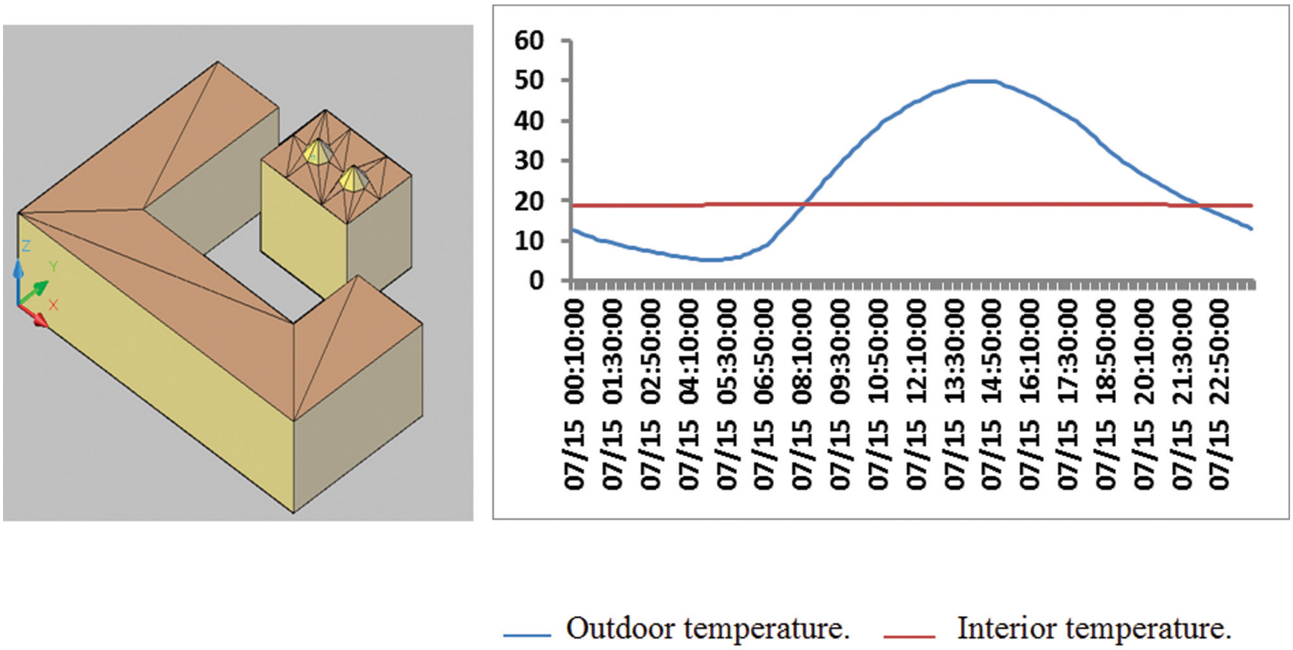


Figure 10. Application of adaptive model on the traditional dwelling [18].

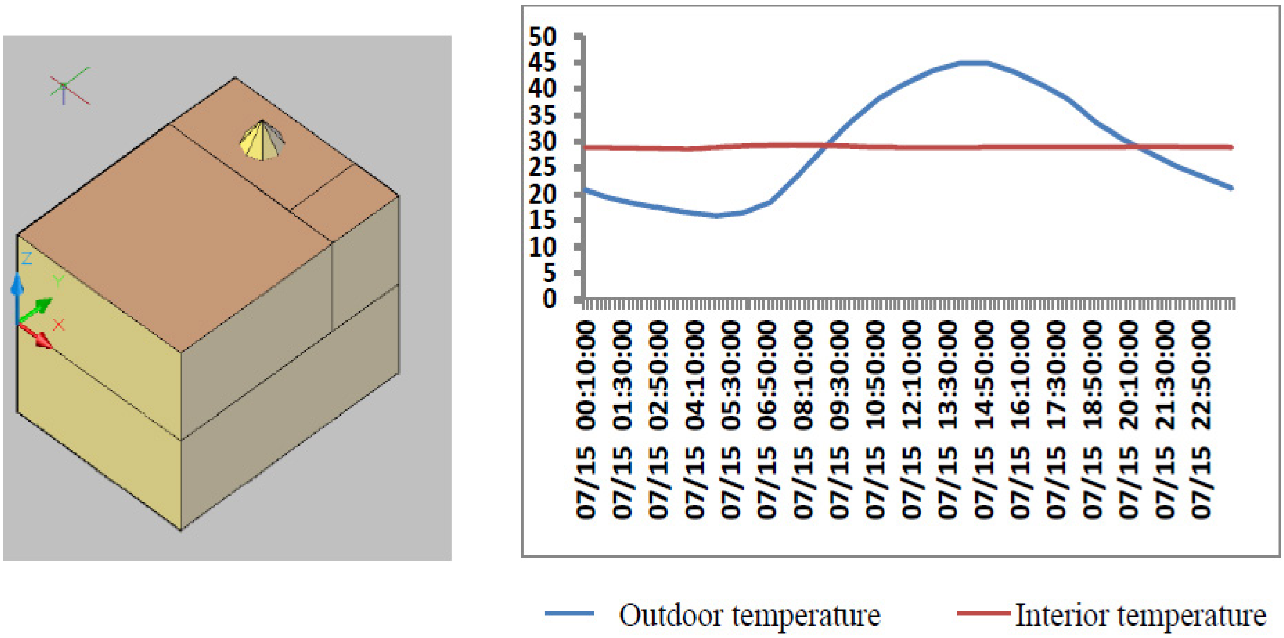
Comparison with Simulation

The figu es 11(a) and 12(a) show the results of modeling of tested dwellings on Energy-plus interface by vertex coordinates. The simulation results presented on figu e 11(b), 12(b) concord with the graphs of the measurements; except with difference of values, this is due to the precision of the measuring instrument. Noting that the temperature amplitude of the traditional sample on the graph remains stable throughout the simulated day with an ambient temperature about 20 Figure 11(b), While range temperature of contemporary sample differs during the day, with ambient temperature range about 29, Figure 12(b). The ventilation conditions of selected samples are kept in passive state. Physical properties of building materials are priced from thermal regulations, however for local materials; conductivity and density tacked from tests. Results indicates that temperature range in the traditional dwelling proves the effici cy of passive devices used, and corresponds with in



(a) (b)

Figure 11. Simulation of the traditional dwelling. (a) Modeling of the dwelling, (b) Variation of interior and exterior temperature during hottest day.



(a) (b)

Figure 12. Simulation of the contemporary dwelling. (a) Modeling of the dwelling, (b) Variation of interior and exterior temperature during hottest day.

situ temperature values as well as calculations provided by adaptive equations and model of thermal comfort.

CONCLUSION

Several researches have proved the performance of passive techniques on interior thermal comfort; so, in this global axis that the research objectives are focused. Based on thermal adaptive approach and simulation work, with a comparative method between two samples of different typology in hot climate.

From measurements carried on site during the hottest day of the summer 2019, we notice that the thermal behaviour is clearly different between the two dwellings tested and this is marked through the thermal amplitudes. Noting that thermal amplitude of traditional dwelling remains in the range of comfort, with a value of 4.5 °*C* while the external amplitude measured is 15 °*C*; contrary, the collective housing seems to be sensitive to the fluctuation of the outside temperatures.

The comparison of the graphs of the measured temperatures with the simulation results shows a concordance of the thermal behaviour except slight shift; this is due to precision of measuring instrument. The projection of the data calculated on the adaptive graph; provided by the center for the built environment (CBE) shows that the traditional dwelling is able to guarantee acceptable temperatures with operative temperature of: 30.5 °*C* under natural ventilation conditions.

Finally, this work opens the way to improve current building design strategies especially in hot climates, through integration of passive systems, also to perfect new materials based on the thermal qualities of locally available materials. Research perspectives inscribed in global state strategy to promote an ecological and comfortable regional architecture.

STATEMENT

In certifi ation, all data and evaluation models as well as measurement and simulation tools used in this research are includes in submitted paper.

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NOMENCLATURE

T	Temperature (°C).
Q	Heat flux (w/m^2).
d	Thi kness (m).
S	Surface (m^2).
λ	Thermal conductivity $w/(m.k)$
R	resistance $(m^2.k)/w$
ρ	Density (g/cm^3)
M	Mass (g)
V	Volume (cm^3)

NOTE

ASHRAE.	American Society of Heating, Refrigerating, and Air-Conditioning Engineers.
Clo.	Clothing insulation ($m^2.k/w$).
Met.	Metabolic rates (w/m^2).
DTR.	Thermal regulations for thermal buildings.
CBE.	Building and Environmental Center.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confi m that the data that supports the fi dings of this study are available within the article. Raw data that support the fi ding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential confli ts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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