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Simulation Investigation of Natural Ventilation on the Thermal Comfort in Arid Regions: Case Ghardaïa

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ABSTRACT

Building aeration ventilation may contribute to achieve thermal comfort there by economizing huge amount of electricity that would be supplied using conventional air conditioning systems. Natural ventilation maintains thermal equilibrium between heating and cooling balances. They may also be used in conjunction with other systems in certain circumstances. Model governing equation of physical phenomena enabling description the thermo-aeraulic behaviour. Based on the measurements in winter and summer periods of several physical parameters like the wind velocity and the ambient temperature, the influence of infiltration rate on the thermal comfort were demonstrated. The present study is the simulation investigation the evolution of internal multi-zone temperature of Saharan building in Ghardaïa (32°38 N, 3°78 E), Algeria. Building construction process should take advantage of many practices characterizing location traditional construction. Specifically, satisfaction of seasonal thermal comfort requirement (heating, cooling) and favour maximum solar passive gains. The results showed that the major factor for the reduction of the internal temperature of the studied building is the natural ventilation including the thermal comfort range (20-27)℃.

1. INTRODUCTION

The consequences of global warming are reduced by bioclimatic buildings based on suitable ventilation. An ecological impact by the use of this type of buildings have as little energy consumed, the reduction of greenhouse gas emissions [1]. Natural ventilation can be considered as a solution for reducing urban energy consumption. The design of buildings plays a relevant role in ensuring sustainable ventilation [2].

The ventilation systems are used to achieve thermal comfort regardless of the meteorological conditions. The heating and ventilation are key parameters for achieving thermal comfort. Thermo-aeraulic modeling is essential to determine values adapted to better overall thermal performance, and to evaluate the architectural performance of a typical Saharan building [3, 4].

The exchange rate regulates the transfer between different compartments: external, envelope, system, interior, but also the ground. Consequently, the purifying function of the ventilation will depend on the overall state (or quality) of the various compartments. This state is variable over time, so that the effectiveness of ventilation in the broad sense will also fluctuate at different temporal scales (in the day, depending on the season, or even more randomly) [5].

The impact of the air change rate on health in fact reflects the ambivalence as a source of pollution from the outside to the indoor environment and a significant sink of indoor air pollutants. The rate of air exchange must be sufficiently high to reduce the concentration of the internal pollutants brought by the presence of the occupants but also those related to their activities and to the building and its equipment [6]. An optimal decrease in indoor temperatures and its daily fluctuations by a suitable orientation [7].

The natural ventilation performance of the building is remarkably improved by the application of permeability in the form of terraces. On the other hand, they showed that the major influence on natural ventilation performance comes from the depth of the terrace [8]. A significant degradation of the operating temperature of the house between 2℃ and 3℃ resulting from night ventilation [9]. The ventilation rate improved by about 10% and this was due to the operation of a multi-opening system during the summer period [10]. A numerical study of wind tunnel testing to designate thermal comfort as for air quality [11].

The cooling load reduction and indoor temperature reduction as validating factors for natural ventilation. Furthermore, they demonstrated that a clear difference in the impact of natural ventilation that results from the difference in the airtightness of the building [12]. The proper ventilation rate in hospitals corresponds to an opening area of 8% of the floor area of the space [13]. The depending on the suitable comfort and floor model, an increase in annual hours of thermal comfort from 0.5 to 35% [14]. The quantified nocturnal ventilation resulting from convective and radiative phenomena with well-defined boundary conditions using the CFD software Fluent 14.0 [15]. Our objective in this paper to demonstrated the influence of infiltration rate on the thermal comfort in the studied building in the southern Algeria.

2. METHODOLOGY

The area of typical Mozabite house do not exceed on average 100 m^2, Figure 1. It is 15 m height two story building with extended terrace. It is also constructed with a courtyard allowing illumination through a dedicated opening. According to decree established in 1743 measures have to be taken such that walls obtruding light rays to neighboring are avoided. The façade is very important in traditional Mozabit live; it is an essential construction element. The word façade is also used to describe the structure of wall for example heavy façade, light façade keeping the meaning of the word away from its usual description of construction aspect.

Figure 1. View building in Ghardaia region

Facade wall and other supports have been given special consideration through history of Mozabite traditional construction even before the façade word becomes commonly employed. More often Mozabite house living room is equipped with a window or front door to facilitate quick ventilation especially odor and heat evacuation during summer time. These facilities are to be always operational without undermining building protection against intruders. Common corridors and staircases are ventilated with a dedicated opening enabling natural evacuation [16].

2.1 Climate analysis of Ghardaïa city

Ghardaïa is a desert region (32.36°N, 3.81°W), with a semi-arid climate characterized by hot, dry summers and harsh cold winters, Figure 2. The site is characterized by an important solar radiation, where the global recorded solar radiation ranges from 2000 - 2100 kWh/square meter [17]. This allows solar energy applications both in the installation of CSP, PV solar power plants and even working on heating and cooling buildings.

Figure 2. Location of studied site: Ghardaïa [18]

The nature of Ghardaïa's climate is semi-arid with minimum and maximum air temperatures ranging from 14-47°C and 2-37°C in summer and winter respectively. The daily global solar radiation varies between a minimum of 2.185 MJ/m^2 and a maximum of 27.266 MJ/m^2, and the annual daily average is approximately 20.361 MJ/m^2 [19].

The presentation of the variation of the meteorological data including the monthly average global solar radiation, the ambient temperature and the relative humidity over a period 2014-2017 in Ghardaïa (date period of the experiments included).

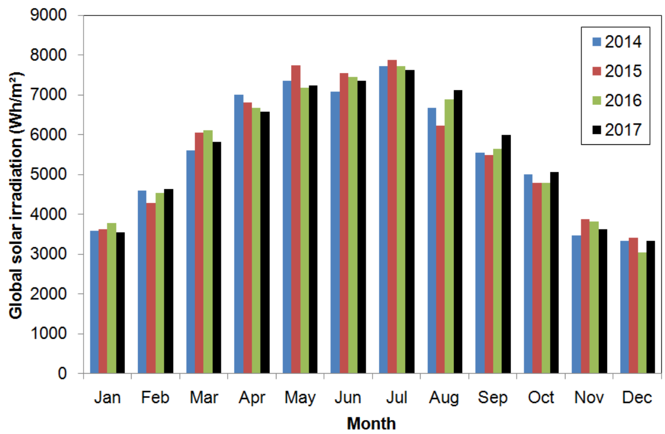


Figure 3. Monthly evolution of the global solar radiation

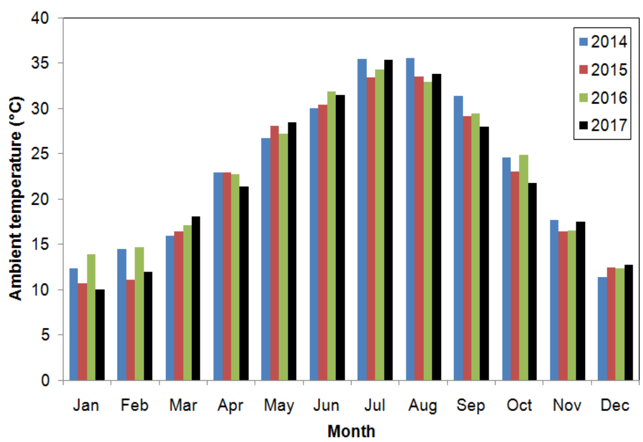


Figure 4. Monthly evolution of the ambient temperature

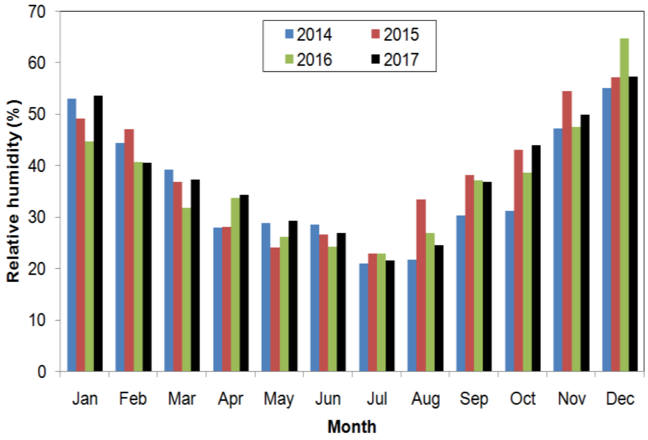


Figure 5. Monthly evolution of the relative humidity

According to the Figures 3, 4 and 5, the similar profile of the three climatic parameters [17]: the global solar irradiation and the ambient temperature, with values measured in summer period, which it is varied between (6935-7873) Wh/m², and (27.8-35.4)°C corresponding to the range of relative humidity of (20.9-29.4)%. On the other hand, in the winter period, the maximum monthly average of solar radiation is 4465 Wh/m². The maximum monthly mean ambient temperature is 14.8°C and the minimum average monthly relative humidity is 42%.

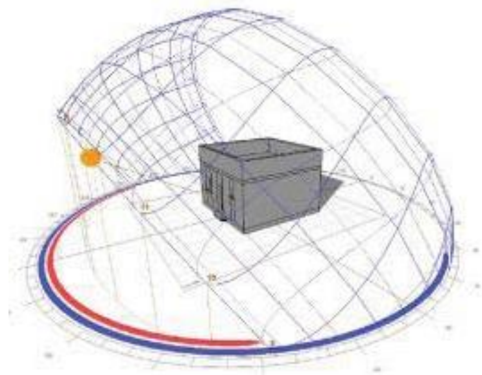
2.2 Building case study

Through the building envelope which allows the thermal separation between the interior and exterior ambient, to store heat in the building, and as a distributor of interior and exterior air, the essential factor to give the suitable space of the energy efficiency of the buildings, it is the adequate choice of the materials of construction [7].

We carried out an experimental study of building void of inhabitant of typical Mozabite house using well calibrated meteorological station. Meteorological data recorded over two typical days of winter and summer are chosen to investigate building thermal balance.

The dimension of this opening is (0.5 x house volume [m^3]/3600) [m²]. These openings are fitted only on façade. The area of opening is nearly 3.88 m². The Table 1 gives technical sheet of proposed house, such as the surface of each piece, Figure 6.

(a)



(b)

Figure 6. (a) Plan of case study house [4], and (b) 3D view of the studied building

Table 1. House technical sheet [16]

Components	Surface (m²)
Living room	17
Kitchen	9.40
Room 1	11.20
Room 2	10.80
Bathroom	3.20
W.C	2.60
Housekeeping	0.30
Circulation	13.80
S-housing	68.30
Courtyard	10.80
S-Useful	79.10
S-constructed	89.90

Table 2. Composition, thickness and global thermal transmission coefficients characterizing building envelope [16]

	Composition	Thickness (cm)	Thermal transmission coefficients U (w/m² K)
Outer walls	Plaster	1.5	0.247
	Hallow bricks	30	
	Insulating material	10	
	Mortar	1.5	
Inner walls	Plaster	1.5	0.86
	Hallow bricks	20	
	Mortar	1.5	
Flooring	Tiles	10	0.348
	Cement	1	
	Stone	6	
	Slab	24	
	Insulating material	10	
Ceiling	Plaster	1.5	0.348
	filler	12	
	Insulating material	10	
	Mortar cement	3	

The presence of openings in these buildings may be exploited to favour natural ventilation over night during summer. Living room facility is always fitted with operable window or otherwise door in order to obtain an important ventilation to evacuate heat and odor over the summer [16].

Table 2 describes the different layers of materials that constitute each studied building's exterior roof and exterior wall. Recent experimental research studies have been conducted to determine the thermo-physical properties of the material used [19, 20]

3. THEORETICAL REFERENCE

The sum of the interior convective loads, the convective heat transfer from the surfaces of each zone, the heat transfers resulting from both air mixing between zones and from the infiltration of exterior air and the flow rate of the air systems, the all of these mentioned parameters represent the energy stored in the area (see Eq. (1)).

The thermal energy balance of air of a given building area [21]. The internal temperature of the studied area is calculated by a special program in order to solve the Eq. (1). The solution is as follows [22]:

$$C_z \frac{dT_z}{dt} = \sum_{i=1}^{Nsl} \dot{Q}_i + \sum_{i=1}^{Nsurfaces} h_i A_i (T_{si} - T_z) + \sum_{i=1}^{Nzones} \dot{m}_i C_p (T_{zi} - T_z) + \dot{m}_{inf} C_p (T_\infty - T_z) + \dot{Q}_{sys} \quad (1)$$

$$\begin{aligned} T_z^t = {} & \left(T_z^{t-\delta t} - \frac{\sum_{i=1}^{N_{sl}} \dot{Q}_i + \sum_{i=1}^{N_{surfaces}} h_i A_i T_{si} + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p T_{zi} + \dot{m}_{inf} C_p T_\infty + \dot{m}_{sys} C_p T_{sup}}{\sum_{i=1}^{N_{surfaces}} h_i A_i + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p + \dot{m}_{inf} C_p + \dot{m}_{sys} C_p} \right) \\ & \times \exp\left(-\frac{\sum_{i=1}^{N_{surfaces}} h_i A_i + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p + \dot{m}_{inf} C_p + \dot{m}_{sys} C_p}{C_z} \delta t \right) \\ & + \frac{\sum_{i=1}^{N_{sl}} \dot{Q}_i + \sum_{i=1}^{N_{surfaces}} h_i A_i T_{si} + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p T_{zi} + \dot{m}_{inf} C_p T_\infty + \dot{m}_{sys} C_p T_{sup}}{\sum_{i=1}^{N_{surfaces}} h_i A_i + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p + \dot{m}_{inf} C_p + \dot{m}_{sys} C_p} \end{aligned} \quad (2)$$

The flow rate resulting from the infiltration, $\dot{V}_{inf}$ is given by [23]:

$$\dot{V}_{inf} = (F_{schedule}) \frac{A_L}{1000} \sqrt{C_s |T_\infty - T_z| + C_w (s_{wind})^2} \quad (3)$$

The Runge-Kutta of the fourth order is investigated to solve the ordinary differential equation that governs energetic balance of air of a given building part with Matlab software.

4. RESULTS AND DISCUSSION

Analyses of the simulated data are supported to the evaluation of the indoor temperature in the study area. In order to established a comparison between two scenarios: winter and summer periods (9 and 10 December 2016, and 13 and 14 of July 2016).

Figures 7 and 8 represent the variations in wind speed (m/s) for selected winter and summer days (December 09th-10th 2016, July 13th-14th 2016). These measured values were interpolated using a smoothing program (MATLAB language).

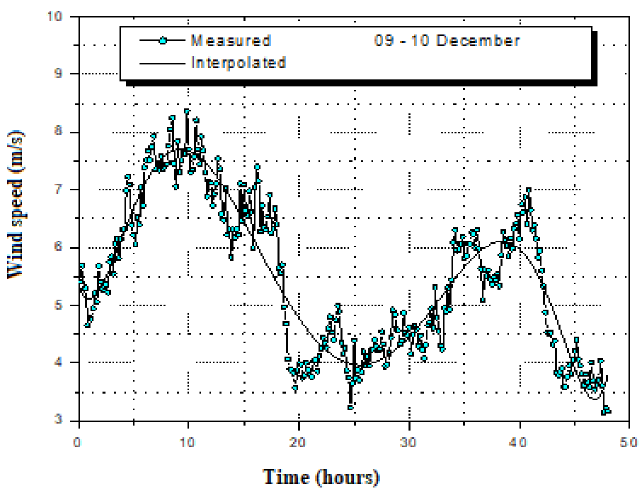


Figure 7. Wind speed between 09 and 10 December

Figures 9 and 10 represent the variations in ambient temperature (°C) for selected winter and summer days (December 09th-10th 2016, July 13th-14th 2016).

The ambient temperature is interpolated in the same way as the wind speed.

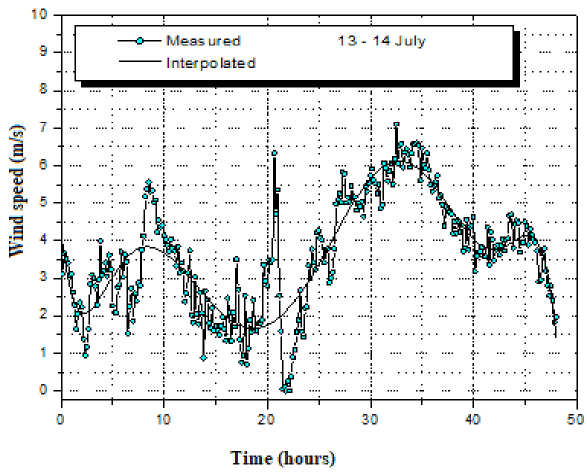


Figure 8. Wind speed between 13 and 14 July

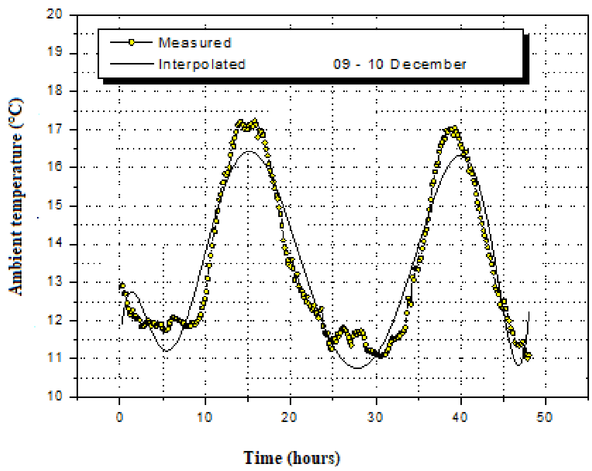


Figure 9. Ambient temperature between 09 and 10 December

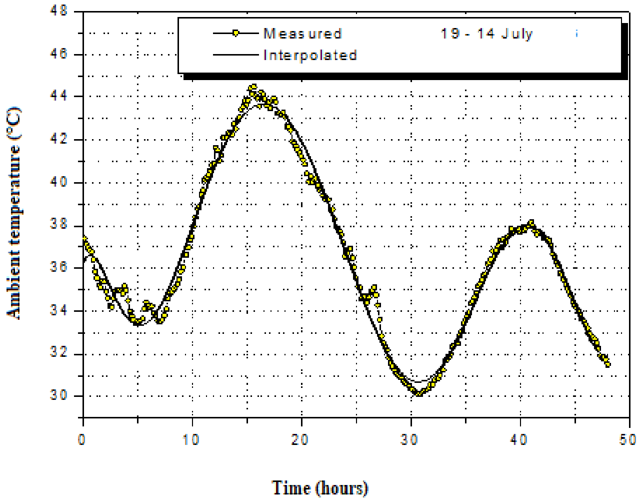


Figure 10. Ambient temperature between 13 and 14 July

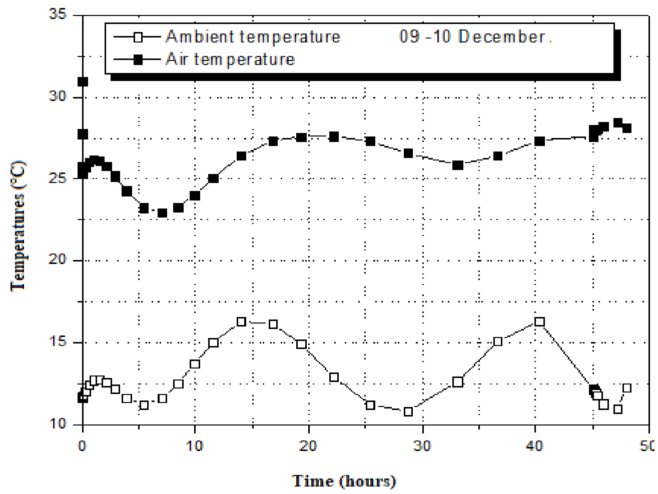


Figure 11. Air temperature between 09 and 10 December

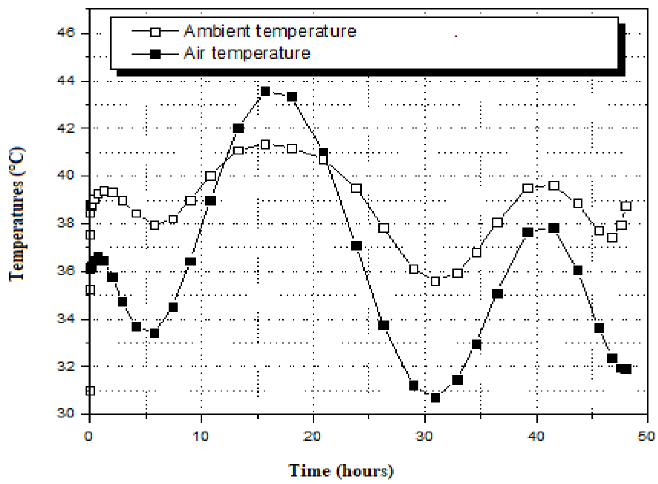


Figure 12. Air temperature between 13 and 14 July

The interpolation of the wind speed and the ambient temperature leads to polynomials which represent these two physical quantities, the latter (polynomials) will be injected into the simulation program.

The simulation made it possible to have on the one hand: the evolution of the temperature of the indoor air during the winter and summer periods showed schematically in Figures 11 and 12, respectively.

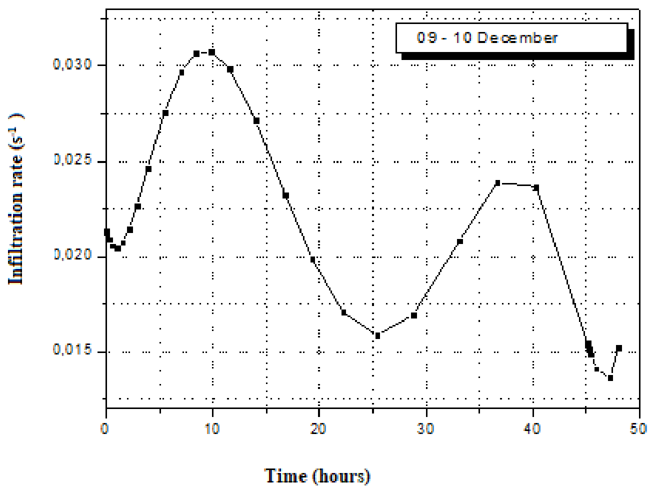


Figure 13. Infiltration rate between 09 and 10 December

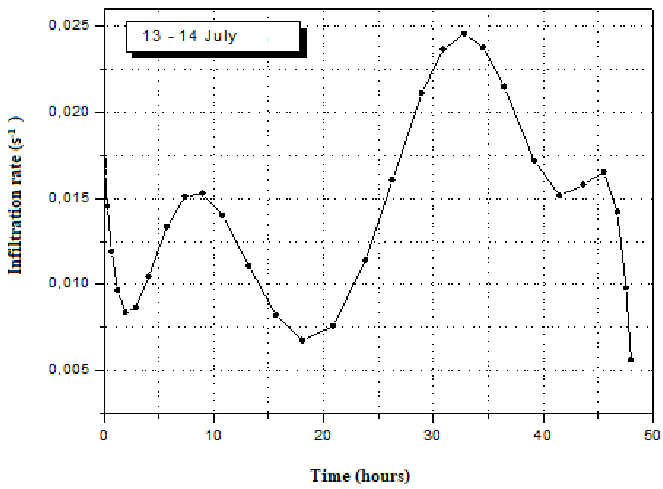


Figure 14. Infiltration rate between 13 and 14 July

During the winter season (Figure 11), the warmer interior air rises in the building and escapes in height, through windows, ventilation openings or the like. Climbing creates depression at the bottom of the building, causing cold air to enter. A large difference between the indoor air temperature and the ambient temperature of about 12°C (see Figure 11).

The thermal draft takes place when a temperature difference causes a difference in the density of the air between the inlet and the outlet of the duct. This effect is accentuated by a higher chimney height. On the other hand, during the summer season (Figure 12), the chimney effect is reversed, but generally lower due to the smaller temperature difference between the interior and exterior (about 5°C).

And on the other hand: the variation of the infiltration rate of the outside air during the two winter and summer periods respectively (see Figures 13 and 14).

For clarification, for the high values infiltration rates the both summer and winter period, the internal temperature of the building is diminished, the opposite is the case for the minimum infiltration values, hence the importance of natural ventilation for building ventilation.

5. CONCLUSIONS

Thermo-aeraulic experimentation is essential to determine global thermal performance values and to understand the functioning of different conceived assembles under Saharan meteorological conditions.

This study has confirmed that the good natural ventilation allowed for optimization of internal air temperature of buildings.

Natural ventilation either passive or aided is prominent potential in favour for architecture. It provides architectural conception an upper hand over machine and technology and allows to architects to regain its place as principal actor in project conception.

In further studies, we will study the both mechanical and hybrid ventilations and its influences on the thermal comfort in the buildings.

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NOMENCLATURE

A_i	area of the zone surface i, m²
A_L	effective air leakage area, cm^2
Cp	specific heat of the air, J/(kg.k)
C_s	coefficient for stack-induced infiltration (L/s)²/(cm^4 k)
C_w	coefficient for wind-induced infiltration, (L/s)²/(cm^4 (m/s)²)
C_z	air capacitance, J/k
$F_{schedule}$	value from a user-defined schedule [0,1]
h_i	heat transfer coefficient, W/m². k
$\dot{m}_{inf}$	mass air flow due to infiltration, kg/s
$\dot{m}_i$	mass air flow due to inter zone air mixing, kg/s
$\dot{m}_{sys}$	mass air flow of the systems, kg/s
$\dot{Q}_i$	convective internal loads, J/s
$\dot{Q}_{sys}$	energy of the air systems, W
s_{wind}	local wind speed, m/s
t	time (s)
T_z	indoor air temperature, K
T_z^t	indoor air temperature at the time step t, K
$T_z^{t-\delta t}$	indoor air temperature at the previous time step t, K
T_{zi}	temperature in zone i, K
T_{si}	temperature in surface i, K
T_∞	outdoor air temperature, K
T_{sup}	temperature of the supply air, K
$\dot{Q}_i$	convective internal loads, J/s
$\dot{Q}_{sys}$	air energy systems output, J/s

Subscripts

inf	infiltration
i	interzone
sys	system
w	wind
sup	supply air
z	zone