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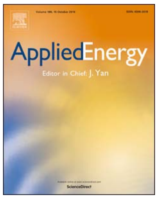

Improvement of the summer cooling induced by an earth-to-air heat exchanger integrated in a residential building under hot and arid climate

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HIGHLIGHTS

- A dynamic model successfully validated for modelling residential buildings equipped with EAHE is developed.
- The building indoor conditions in summer can be significantly enhanced by using EAHE and insulation.
- The insulated light buildings are more effective than the insulated heavy buildings in hot and arid climate.
- Effect of building materials, including insulation materials, combined with that of EAHE is also investigated.
- Due to its influence, the building geometrical aspect is a parameter which should be carefully chosen.

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ABSTRACT

This paper aims to investigate the impact of the thermal insulation on the cooling effectiveness of the Earth-to-Air Heat Exchanger systems under hot and arid climate. For that, the dynamic behaviour of two identical buildings submitted to the same exterior solicitations and equipped with an EAHE is presented in detail. To achieve the objective of this study, two transient models are developed; one for modelling the EAHE and the other for describing the thermal behaviour of buildings. The set of differential equations corresponding to different components of the system is solved using the technique of Complex Finite Fourier Transform. The findings indicate that when the insulated building is equipped with an EAHE, the effect of the thermal insulation will be combined with that of EAHE and the resulting effect will be more important, so that the reduction in the indoor air maximal temperature can be greater than 11°C and the reduction rate in the amplitude of the indoor air temperature increases until 91%. In addition, it is found that the thermal performances of the building outer walls represented usually by the decrement factor and the time-lag can be more improved using insulation layers within these components. On the other hand, the investigation conducted on the effect of the building materials showed that in Saharan climate, the light buildings such as those constructed with autoclaved aerated concrete blocks are more performing compared to the heavy buildings in which the outer walls must be judiciously insulated with a material of high thermal resistance. However, it is shown that the insulation with air cavities is an effective and economic solution for the light buildings in hot and arid regions.

1. Introduction

Energy consumption in buildings represents 40% of the total global primary energy what corresponds to 24% of the world CO_2 emissions [1]. The most important part of the energy consumed in buildings is used for heating and cooling. In the Sahara regions, the climate is very hot in summer so that the demand of energy for air-conditioning is higher in this season. In the developing countries like Algeria, the energy consumption in buildings is in continuous growth [2], which results that the demand often exceeds the supply, especially in the summer season. The excessive consumption of energy in buildings is due mainly to the bad thermal quality of construction; especially in the building envelope walls [3]. Therefore, the improvement of the building thermal performance by using passive techniques is the key of economical and ecological solutions for the problem due to the excessive consumption of energy in buildings. In this context, there is a need to focus the research efforts for the integration of passive techniques in buildings taking into account the specificity of the Saharan

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Nomenclature

Latin symbols

AAC	autoclaved aerated concrete block
CB	cinder block
COP	coefficient of performance
Cp	specific heat (J/kg K)
D	diameter (m)
DNI	direct Normal Irradiation (W/m^2)
DHI	diffuse horizontal irradiation (W/m^2)
GHI	global horizontal irradiation (W/m^2)
h	heat transfer coefficient by convection or conduction
hc	convective heat transfer coefficient inside the buried pipes (W/m^2 K)
HCB	Hollow Clay block
I	solar irradiation (W/m^2)
IB	insulated building
k	whole number
L	layer thickness (m), pipe length (m)
$\dot{m}$	mass flow rate (kg/s)
MAE	Main Absolute Error
N	number of layers
n	layer number in the multilayer wall
P	period of time (s)
Pr	Prandtl number
$\dot{Q}$	heat flux (W)
Re	Reynolds number
RMSE	Root Mean Square Error
S	surface (m^2)
SHGC	solar heat gain coefficient due to the beam solar irradiation
$SHGC_d$	solar heat gain coefficient due to the diffuse solar irradiation
$SHGC_{OP}$	solar heat gain coefficient transferred through the frame of the window
t	time (s or hr)
T	temperature (K)
TETD	Total Equivalent Temperature Differential (°C)
U	overall heat transfer coefficient (W/m K)
UB	uninsulated building
V	building interior volume (m^3)
$\dot{V}$	ventilation rate (m^3/s)
W	blower power (W)
x	coordinate (m)

Greek symbols

α	thermal diffusivity (m^2/s)
β	surface absorptance for solar radiation
ρ	density (kg/m^3), ground reflectivity
ΔR	long-wave radiation from the sky (W)
ε	hemispherical emittance of surface
λ	thermal conductivity (W/m K)
θ	incidence angle of the solar radiation (rad)
φ	tilt angle of surface (rad)
δ	thermal depth (m)

Subscripts

a	air
comf	comfort
day	daily
Blow	blower
G	ground, glazing
i	interior
ia	indoor air
inf	infiltration
ins	insulation
o	outer
OP	opaque
p	pipe
s	solar radiation, disturbed soil
soil	undisturbed soil
t	total
vent	ventilation

climate. In the literature, numerous theoretical and experimental works [4,5] are performed throughout the world in order to improve the building thermal performance, taking into account the climatic constraints influencing on their indoor thermal comfort by using economic means such as local building materials, thermal insulation, passive cooling and heating systems [6], phase change materials (PCM) [7,8].

On the other hand, Bekkouche et al. [9] affirmed in their study conducted on a building in an arid and hot region in Algeria that a suitable orientation of fenestrations and the use of shading process such as eaves in hot seasons can improve sensitively the building indoor conditions. In another work, the authors [10] proved that owing to their high thermal resistance, the hollow bricks are thermally more effective than the stone bricks though these last are characterized by high thermal inertia. On the same subject, Daouas et al. [11] performed a comparative investigation on two types of wall: one built in bricks and the other in stone. These walls can include an insulation layer and they were submitted to the same climatic conditions of the Tunis town in Tunisia. To achieve this study, an analytical model based on the Complex Finite Fourier Transform (CFFT) was developed. The results showed that the wall in stone including in sandwich an insulation layer in expanded polystyrene with optimal thickness of 5.7 cm provided a higher level of the indoor thermal comfort compared to its homologous in bricks. Nganya et al. [12] studied a bio-climatic building adapted to the humid tropical climate of Cameroon. This house was built with local bricks in the earth and the roofing is made in aluminium sheet. It is found that such building provides an acceptable indoor thermal comfort.

Air gap made between two blocks of bricks in the outer walls acts as an insulation layer. Effectively, this technique is widely used throughout the world. Its effectiveness was examined by Daouas et al. [13] using multilayer walls with different orientations including an air space. In this respect, it should be underlined that an interesting and thorough review of the applications of air layers in the building envelope walls was performed by Zhang et al. [14]. This study revealed that the air space integrated with the building envelope acts as an insulation material or a ventilation channel. So, according to their applications in building envelopes, the air cavities can be classified into three categories: unventilated air space, naturally ventilated air space and mechanically ventilated air space. Moreover, one of the advanced and promising technologies in building development, that currently receive an attractive and increasing attention by the researchers, is the integration of the hybrid photovoltaic-thermal panels on the building envelope walls to improve the indoor thermal comfort. Indeed, these devices can be integrated on the roof to create a ventilation channel in which the photovoltaic panels act as an absorbing plate in the daytime and as a radiant plate in the night. Thus, the induced ventilation flow rate cools the roof during the daytime because the temperature of the flowing air is low compared to that of the roof exterior surface. Overnight, the hot indoor air circulating inside the ventilation channel loses its heat to the photovoltaic panel which, in turn, dissipates its heat by