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A comparative study on optimum insulation thickness of walls and energy savings in equatorial and tropical climate

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Abstract

The increase outdoor temperature acts directly on the indoor climate of buildings. In Cameroon, the energy consumption demand in the buildings sector has been rapidly increasing in recent years; so well that energy supply does not always satisfy demand. Thermal insulation technology can be one of the leading methods for reducing energy consumption in these new buildings. However, choosing the thickness of the insulation material often causes high insulation costs. In the present study, the optimum insulation thickness, energy saving and payback period were calculated for buildings in Yaoundé and Garoua cities, located in two climatic regions in Cameroon. The economic model including the cost of insulation material and the present value of energy consumption and the cost over a life time of 22 years of the building, were used to find the optimum insulation thickness, energy saving, and payback period. Materials that extruded polystyrene were chosen and used for two typical wall structures (concrete block (HCB) and compressed stabilized earth block wall (CSEB)). The early cooling transmission loads, according to wall orientations and percentage of radiation blocked were calculated using the explicit finite-difference method under steady periodic conditions. As a result, it was found that the west- and east-facing walls are the least favourite in the cooling season, whereas the south and north orientations are the most economical. Although wall orientation had a significant effect on the optimum insulation thickness, it had a more significant effect on energy savings. In equatorial region (Yaoundé), for south orientation, the optimum insulation thickness was 0.08 m for an energy savings of 51.69 $/m2. Meanwhile, in tropical region (Garoua), for north orientation, the optimum insulation thickness was 0.11 m for an energy savings of 97.82 $/m2.

Keywords: Energy savings; Optimum insulation; Equatorial and tropical climate; Buildings; Wall orientation

1. Introduction

One of the most efficient ways to reduce the transmission rate of heat and energy consumption to cool and heat buildings is the use of an appropriated thermal insulation in the building envelope. An optimum thickness of insulation offers minimum total cost, including the cost of insulation and energy consumption on the building life (Daouas, 2011). In Cameroon, energy consumption in modern and traditional buildings has considerably increased in recent years, and unfortunately, no measure has been taken by the Cameroon government to improve the thermal quality

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Nomenclature

As	annual energy savings ($\$m^2$)
c	specific heat ($Jkg^{-1}\,K^{-1}$)
C	cost ($)
COP	coefficient of performance of air-conditioning system
CDD	degree-days (°C days)
g	inflation rate (%)
h	combined heat transfer coefficient ($Wm^{-2}\,K^{-1}$)
H	monthly average of daily global radiation on horizontal surface ($MJ\,m^{-2}\,day^{-1}$)
H_o	monthly average of daily extraterrestrial radiation on horizontal surface ($MJ\,m^{-2}\,day^{-1}$)
H_d	monthly average of daily diffuse radiation on horizontal surface ($MJ\,m^{-2}\,day^{-1}$)
L	wall thickness (m)
L_{op}	optimum insulation thickness (m)
I	interest rate (%), order of node
I_{total}	solar radiations on the horizontal surface (W m2)
I_b	direct solar radiations on the horizontal surface (W m2)
I_d	diffuse solar radiations on the horizontal surface (W m2)
I_0	hourly extraterrestrial radiation (W m2)
N	number of nodes
n	lifetime of building (years)
M	number of layers of composite wall
p_b	payback period (years)
q_i	heat flux density at indoor surface of the wall (W m2)
Q_c	annual cooling transmission load ($MJ\,m^{-2}$)
sd	shade level
t	time (s)
T	temperature (C)
x	coordinate direction normal to wall (m)

Greek symbols

α	solar absorptivity of outside surface of wall
γ	surface azimuth angle (°)
δ	declination angle (°)
λ	thermal conductivity ($W\,m^{-1}\,K^{-1}$)
ϕ	latitude (°)
w	hour angle (°)
w_s	sunset-hour angle for a horizontal surface (°)
ρ	density of material ($kg\,m^3$)
ρ_r	ground reflectivity

Subscripts

el	electricity
enr	energy
I	inside
ins	insulation
max	maximum value
min	minimum value
o	outside
sa	solar-air
t	total

of the building envelope. A comfortable environment is necessary for an individual's health and productivity in a building (Kameni Nematchoua, 2014). A considerable applied insulation thickness on the external walls of the buildings results in significantly lower heat load transmission. The cost of the insulation material increases linearly with the thickness of the insulation material (Ozel, 2011). In 2008, it has been shown that more than 50% of the consumed total energy in the building has been dedicated to heating and cooling (Kameni Nematchoua, 2015). This percentage is going to rise in the coming years, as the global population continues to increase (Kameni Nematchoua, 2015). Thermal insulation is also solicited to reduce the loss of heat in buildings through the envelope.

Meanwhile, the use of the most efficient energy to cool buildings is the best measure to preserve energy and protect environment (Azmi Aktacir et al., 2010). There are many studies in the literature on the determination of optimum insulation thickness on building walls, and most of them had used the degree day (or degree hour) to calculate the thickness (Ucar and Balo, 2009, 2010; Comakli and Yüksel, 2003; Dombayci et al., 2006; Daouas et al., 2010; Bolattürk, 2008; Yu et al., 2009; Ghrab-Morcos, 0000). For instance, Bolattürk (Bolattürk, 2006) analysed the use of insulation on the external walls of buildings during many seasons, and found that the building inertia influences indoor comfort. A good selection of construction materials is very important at the time of conception of building. Tsilingiris (Tsilingiris, 2003) developed a numerical algorithm for the cooling load calculation, while Granja and Labaki (2003) presented a periodic solution of the heat flow through a flat roof using Fourier analysis. These results have facilitated the calculation of architects. Furthermore, Dombayci et al. (2006) found the optimum insulation thickness of the external wall for different energy sources and different insulation materials. The study by Mohsen et al. (2001) showed that the insulation of external walls and roofs can increase energy saving by up to 77%. Meanwhile, Naouel Daouas et al. (2010) found that the most profitable case for insulation is the stone/brick sandwich wall and expanded polystyrene, with an optimum thickness of 5.7 cm, which achieved energy savings up to 58% with a payback period of 3.11 years. This work, has allowed to improve the results obtained in Tsilingiris

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