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Effects of wall configuration on building energy performance subject to different climatic zones of China ☆

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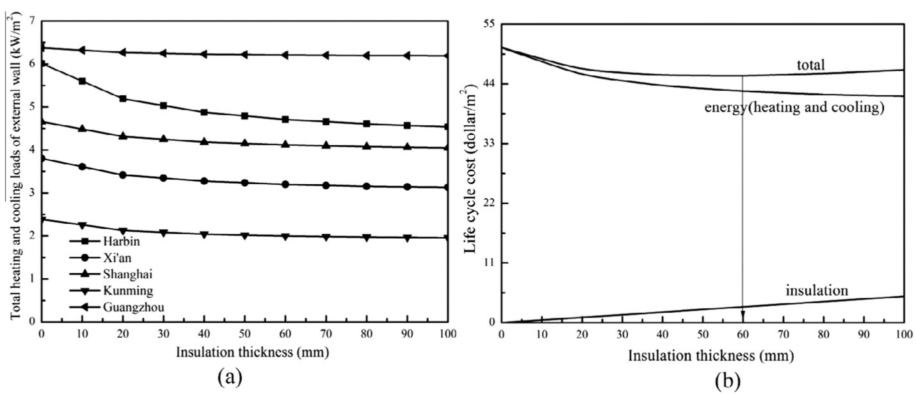
HIGHLIGHTS

- The annual heating and cooling loads according to the five climatic zones in China are discussed.
- The effects of insulation thickness on building energy saving are studied accordingly.
- The optimum insulation thicknesses of external wall are obtained for different climatic zones.
- The effects of insulation position on time lag and decrement factor are simulated.

GRAPHICAL ABSTRACT

(a) Total heating and cooling loads of external wall vs insulation thickness, and (b) determination of optimum insulation thickness.



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ABSTRACT

Building energy plays a significant role in total energy consumption in China. It is widely recognized that the insulation performance of the external envelops is a critical factor for energy consumption of building air conditioning system. In this study, the effects of building external wall's insulation thickness and position on the heating and cooling loads of a commercial building studied for five cities from different climatic zones of China, namely, Harbin, Xi'an, Shanghai, Kunming and Guangzhou, are investigated numerically. The wall's optimum insulation thicknesses of the building simulated in these cities are determined by the life cycle cost analysis (LCCA) method. Meanwhile, the different positions of insulation layer embedded in the wall are investigated in terms of the time lag and decrement factor. The results show that the increase of insulation thickness has a significant effect on the building heating load, inversely it exhibits a relatively small effect on the building cooling load. The analysis indicates that building energy savings vary from different climatic zones. For a given wall insulation and the same building conditions, the largest building energy savings are achieved in Harbin, and energy savings of other cities follow the order of Xi'an, Shanghai, Kunming and Guangzhou. The variation of building energy savings in

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Nomenclature

A_i	amplitude of the temperature wave on the inner surface of the wall (°C)
A_o	amplitude of the outdoor air temperature wave (°C)
c_p	specific heat of the wall material (kJ/kg K)
C	the insulation cost per unit area ($/m^2)
C_c	total energy consumption cost for cooling per unit area of external wall ($/m^2)
C_e	cost of electricity ($/kW h)
C_f	cost of fuel ($/kg)
C_h	total energy consumption cost for heating per unit area of external wall ($/m^2)
C_i	cost of insulation material per unit volume ($/m^3)
COP_h	energy efficiency ratio of the heating system
COP_c	energy efficiency ratio of the cooling system
d	discount rate
D	ratio of down payment to initial investment
E	energy savings of annual building heating and cooling with thermal insulation (kW h/m^2)
E_1	annual building heating and cooling loads without thermal insulation (kW h/m^2)
E_2	the annual building heating and cooling loads with thermal insulation (kW h/m^2)
f	decrement factor
F	heat transfer area (m^2)
h_i	heat transfer coefficient of wall inner surface (W/m^2 K)
h_o	heat transfer coefficient of wall outer surface (W/m^2 K)
H	lower heating value of the fuel (kJ/kg)
i	inflation rate
k	heat transfer coefficient (W/m^2 K)
LCT	life cycle total cost ($/m^2)
M_s	ratio of first year miscellaneous costs to initial investment
N	economic analysis period (year)
P_1	present worth factor
Q_c	total cooling load in per unit area of external wall (kW h/m^2)
Q_h	total heating load in per unit area of external wall (kW h/m^2)
R_v	ratio of resale value at the end of the analysis period to initial investment
t_{Ti}^{max}	time in hours when the inside wall temperature is maximum (h)
t_{To}^{max}	time in hours when the outdoor air temperature is maximum (h)
T_i	indoor air temperature (°C)
T_i^{max}	maximum of indoor surface temperature (°C)
T_i^{min}	minimum of indoor surface temperature (°C)
T_o	outdoor air temperature (°C)
T_o^{max}	maximum of outdoor air temperature (°C)
T_o^{min}	minimum of outdoor air temperature (°C)
$T_{x=0}(t)$	wall inner surface temperature (°C)
$T_{x=L}(t)$	wall outer surface temperature (°C)

Greek symbols

λ	thermal conductivity (W/m K)
ρ	density (kg/m^3)
η	efficiency of the heating system
Φ	time lag (h)

Subscripts

c	cooling system
e	electricity
f	fuel
h	heating system
i	inside
o	outside

Guangzhou is insignificant along with the increase of the insulation thickness. Using expanded polystyrene as insulation layer material, the optimum insulation layers of the building in Harbin, Xi'an, Shanghai, Kunming and Guangzhou are founded to be 80 mm, 60 mm, 40 mm, 40 mm, and 20 mm, respectively.

1. Introduction

General building energy consumption includes three parts: construction, employment and demolishment. Energy consumption in operation (namely, energy consumption of HVAC, lighting, power and water supply and drainage) is larger than those in construction and demolishment. The most effective measure, which achieves building energy efficient, is to reduce employment energy consumption. Energy-efficiency renovation for existing building and designing energy-efficient buildings is based on accurate energy consumption calculation, which is the way to alleviate the disparities between energy shortage and economic development. As "building energy efficiency" has been put forward in recent years, researchers paid their attention to the accurate evaluation of building energy consumption, and many software of simulating building energy consumption, such as DOE-2, EnergyPlus, eQUEST and DeST, were developed. The software DeST developed by Tsinghua University is able to calculate and analyze the yearly cooling and heating loads at different outdoor climate conditions, external envelops configuration and insulation layer thickness.

Many researchers have studied the effects of optimum insulation thickness on energy performance. It is widely recognized that the option of optimum insulation thickness depends mainly on the accurate determination of the heating and cooling loads. The early studies used degree-days concept which is a simple and crude model to calculate loads, and this method ignores the solar radiation and thermal inertia of the building [1–5]. The accurate results are needed to select the optimum insulation thickness, however, only limited number of cases were solved based on the analytical methods [6–9]. Al-Sanea et al. [10] used a dynamic heat-transfer model to study the optimum insulation-thickness in building walls. This method provided an accurate solution for transient heat transfer. Analytical and dynamic methods are believed to obtain highly accurate results on the determination of optimum insulation thickness. Life cycle costs analysis (LCCA) is another effective method to calculate the optimum thickness which is based on

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