Journal of Building Engineering 9 (2017) 155–163

Contents lists available at ScienceDirect

Journal of Building Engineering

journal homepage: www.elsevier.com/locate/jobe

The determination of the most economical combination between external wall and the optimum insulation material in Cameroonian's buildings

Fohagui Fodoup Cyrille Vincelas*, Tchuen Ghislain

University of Dschang, IUT-FV, LISIE/LETS, PO. Box 134, Bandjoun, Cameroon

ARTICLE INFO

Keywords:
External wall
Degree-days concept
Optimum insulation thickness
Most economical
Energy savings

ABSTRACT

This paper presents a comparative study for the determination of the most economical combination between external wall and optimum insulation thickness for energy saving into buildings. Using the degree-day's concept, the yearly cooling transmission loads of the building was determined. The P_1-P_2 method was used in economic analysis to find out the optimum insulation thickness, energy savings, and payback period for buildings in that locality. Expanded polystyrene was first chosen and used for five typical wall structures (sundry earth block (SEB), hollow concrete block (HCB), compressed earth block (CEB), heavyweight concrete block (HWCB), and stone). Then the investigation was extended to six other insulation materials. As results, It was found that the lowest value of optimum insulation thickness (7.6 cm) and energy savings (48 $/m^2) were obtained for sundry earth block for expanded polystyrene while the payback period (3.23 years) was the highest for the same wall structure. The association of sundry earth block with extruded polystyrene was found to be more economical (23 $/m^2 for minimum cost) with an optimum thickness of 9 cm and 69% of energy savings compared to other wall types.

1. Introduction

Energy consumption of buildings worldwide is increasing due to climate change and the development of new building standard. Substantial shares of energy consumed into buildings go towards heating and cooling loads of buildings. These thermal loads are largely due to heat gain of the building envelope. The reduction of such heat transmission through the building envelope can effectively reduce energy consumption into building. A passive and most effective method of reducing these loads is achieved by applying thermal insulation to the external wall of the building. A thicker insulation results in decreasing the heat transmission load and increases the cost of insulation installation. Thus, the determination of the insulation thickness which minimizes the total cost for insulation and cooling or heating the building over its lifetime is imperative [1].

The determination of such optimum thermal insulation thickness is governed by several design features including the orientation of the wall, the exterior surface, the type of thermal insulating material and the type of external wall type. Several studies were carried out on the evaluation of optimum insulation thickness on the building walls based on the above mentioned design features. Most of the studies calculate the transmission load by using the well-known methods including the degree day concept and dynamic heat transfer models. For instance, Daouas [2], Ozel [3], and Nematchoua [4] investigated the influence of wall orientation on optimum insulation thickness of external walls by using the life cycle cost analysis. In their studies, transmission load was estimated by using the dynamic heat transfer model. As result, a lower optimum insulation thickness of 10.1, 5.5, and 9.25 cm was obtained from Daouas, Ozel, and Nematchoua, respectively. Energy savings of 71.33%, 63.5% and 80.91%, were found by each author, respectively.

Yu et al. [5] examined the impact of the color of exterior surface on optimum insulation thickness, energy saving, and payback period by using P_1-P_2 method. The study was carried out in four typical cities of china and the determination of the transmission load was based on the degree-days concept. The results show that surface color has discrepant impacts on the optimum insulation thickness in different cities. According to their results, the maximum life cycle savings were 54.4 $/m^2 in Shanghai, 54.8 $/m^2 in Changsha and 41.5 $/m^2 in Shaoguan (with a deep-colored northeast wall), and 39.0 $/m^2 in Chengdu (with a light-colored northwest wall). Similarly, Ozel [6] considering both cooling and heating transmission loads and using dynamic heat transfer method concluded that solar absorptivity has insignificant impacts on the optimum insulation thickness in the climatic condition of Elazig, Turkey. Wati et al. [7] emphasized that the shade of building site has a significant effect on optimum insulation thickness, energy savings, and payback period. Their study was carried out in the climatic condition of

* Corresponding author.
E-mail address: fohacyrille@yahoo.fr (F.F. Cyrille Vincelas).

http://dx.doi.org/10.1016/j.jobe.2016.12.008
Received 22 August 2016; Received in revised form 16 November 2016; Accepted 26 December 2016
Available online 29 December 2016
2352-7102/

Nomenclature

COP	energy efficiency ratio of cooling system (%)
CDD	cooling degree-days (°C days)
CEB	compressed earth block
C_{ins}	insulation cost ($/m^3)
C_t	total cost ($/m^2)
DD	degree-days (°C)
d	inflation rate
E_{cool}	require annual cooling energy
E_{heat}	require annual heating energy
H	lower value of fuel
HCB	hollow concrete block
HVAC	heating ventilating air conditioning
HWCB	heavyweight concrete block
HDD	heating degree-days (°C days)
h_i	inside convective heat transfer coefficient (W/m^2 K)
h_0	outside convection heat transfer coefficient (W/m^2 K)
i	interest rate
I_t	global radiation (W/m^2)
k	thermal conductivity of insulation material (W/m K)
η	energy efficiency of heating system (%)
PWF	present-worth factor
Q	heat flux (W)
R_W	total thermal resistance of wall layers without insulation (m^2 K/W)
SEB	sundry earth block
T	temperature (°C)
T_0	daily mean temperature (°C)
U	overall heat transfer coefficient (W/m^2 K)
x	thickness (m)
x_{op}	optimum insulation thickness

Cameroon, the cooling transmission loads were estimated by using the dynamic heat transfer method. The concluded that, an increase of the level of shade leads to a decrease of both the energy savings and the optimum insulation thickness; and the payback period increases significantly.

The effects of the type of insulation material on optimum insulation were studied by many authors. Al-Sanea et al. [8] investigated the influence of the type of insulation material on its optimum thickness for building walls under steady periodic conditions in Saudi Arabia. Their study was based on the present worth analysis in order to minimize the total cost. Their findings reveal that, between the six insulation material examined, the most economical insulator is that made of molded polystyrene with an optimum thickness of 9.3 cm. Likewise, Shanmuga et al. [9] optimized the insulation thickness on wall of buildings by using the degree day's concept. Their study was carried out in five cities located in India by comparing three different insulation materials. According to their results, expanded polystyrene was found to be a suitable material for all five cities. On the other hand, Mahlia et al. [10] compared the savings yield by the used of six insulation materials through a life cycle cost analysis in Malaysia. With regard to the results, the fiberglass-urethane is the most economic insulation material amongst the six others, with a saving of up to 71.773 $/m^2.

Dombayci et al. [11] considering different energy sources and two insulation materials in turkey determined the optimum insulation thicknesses for external walls. Their study was based on heating degree day's concept. They found that, the use of coal and expanded polystyrene as energy source and insulation material, respectively, leads to the optimum case. Using the optimum insulation thickness, the savings and the payback period obtained were 14.09 $/m^2 and 1.43 years, respectively. Al-Sanea et al. [12] used dynamic heat transfer model to study the influence of the electricity cost on the optimum insulation thickness for building walls. They observed that the optimum insulation thickness for different electricity tariffs varies linearly with minimum total cost. Using life cycle cost analysis in a similar study for different fuel types, Bolatturk [13] shows that: (1) the energy savings lies between 22–79%; (2) the optimum thickness lies between 2 and 17 cm and (3) the payback period lies between 1.3 and 4.5 years depending on the fuel type. Ozbalta et al. [14] determined the optimum insulation thickness and savings for some building envelopes by considering four different types of energy sources and expanded polystyrene as insulation material for coldest city of Turkey. The calculation was carried out through the P_1-P_2 method by using the heating degree day's concept. According to their results, optimum thickness and energy savings are more significant when costly fuel is used.

The effect of the wall type on optimum insulation thickness was investigated in few studies [13–15]. Subhash et al. [15] determined the payback period and the optimum insulation thickness for different types of walls with glass wool as insulation material. They found that, the payback periods lay between 1.17 and 1.53 years and the optimum insulation thicknesses in between 15.4 and 17.03 cm with respect to external wall material. In a similar study, Nematchoua et al. [4] compared the optimum insulation of extrude polystyrene with two different wall types (Hollow concrete block (HCB) and compressed stabilized earth block (CSEB)) in Cameroon by using life cycle analysis. Their findings reveal that, the optimum insulation thickness obtained for the case of HCB is greater than that of CSEB, while the payback period is smaller for the case of HCB compared to that of CSEB wall.

As can be seen from the literature survey, most attractive studies aiming to determine the optimum insulation thickness have been carried out. But, however, these studies no actually investigate the most economical combination between external wall and insulation material to achieve energy efficiency of buildings in Cameroon. One of own characters in this work, compare to others similar study was to select the most economical combination between available external wall and insulation material.

The present study aims to find out the optimum insulation thicknesses of external wall, energy savings and payback periods with respect to the wall and insulation types. The study is carried out in the coastal region of Cameroon, under the tropical climate by considering five wall types and seven insulation materials.

2. Methodology

2.1. The structure of external walls

In this study, the common materials used for the construction of external walls of buildings in Cameroon including hollow concrete block (HCB), sundry earth block (SDEB), heavyweight concrete block (HWCB), compressed earth block (CEB), and stone as shown in Fig. 1 are considered [16]. From the exterior to the interior, the insulated composite wall consist of 20 mm-thick layer of cement plaster, 200 mm-thick layer of each building material and 20 mm-thick layer of plaster board with an insulation layer of variable thickness placed on the outside surface as shown in Fig. 2. Seven different insulation materials are selected including expanded polystyrene, extruded polystyrene, foamed polyvinyl chloride, foamed polyurethane, perlite, rock wool, and glass wool.

2.2. Calculation of degree-days

In the tropical climates, heat gains through the envelope of buildings are mostly determined using the degree-days method. In