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Research Paper

A study on residential energy requirement and the effect of the glazing on the optimum insulation thickness

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HIGHLIGHTS

- The inertia associated with thermal insulation performs up to 70% energy saving.
- The effect of the glazing on optimum insulation thickness is investigated.
- The optimum insulation thicknesses vary between 1 cm and 2.5 cm.

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ABSTRACT

This work focuses on experimental and numerical study of a prototype building to study its thermal behavior and to compare its energy performance with those of a classical home in Algeria. Yearly cooling and heating transmission loads are calculated according to the increase of the thickness of the expanded polystyrene insulation for three different structure materials. The effect of the type of the glazing and the percentage of glazing in the wall has been studied to determine the optimum thickness of the insulation. The results of the thermal simulation showed that the inertia associated with good thermal insulation has an important role in improving thermal comfort and can reach up to 70% energy savings on heating and air conditioning. The results for cooling show that the optimum insulation thickness of expanded polystyrene vary between 1 cm and 2.5 cm, the energy savings vary between 0.5 and 1.5 $/m^2 depending on the type and the percentage of the window in the wall.

1. Introduction

In Algeria, the building sector is the largest consumer of energy among the economic sectors, with 42% of final energy [1]. It is therefore necessary to manage and control this energy consumption to reduce the energy requirements of the residential sector while maintaining the same level of thermal comfort. Improving the envelope thermal insulation offers a better solution to ensure thermal comfort and significantly reduce energy consumption for the heating and cooling of buildings [2–7].

Many studies have investigated the effect of building materials and insulation on energy efficiency of buildings. Among these studies, Ferrante and Cascella [2] have undertaken a study for the design of new housing in the periurban context of Tricase, Italy. The results showed that it is possible to design houses with zero energy and zero CO_2 emissions in the mediterranean climate and it was envisaged that local materials and techniques of traditional architecture can be solutions to ensure the energy efficiency of buildings.

Mohsen and Akash [3] have provided some indications of the general state of the energy consumption in the residential sector and trends in Jordan. The results of this work show that the use of polystyrene insulation in the walls and roof improves the energy performance of buildings and can achieve energy savings that can reach 76.8% on heating.

Stazi et al. [8] achieved the experimental work comparing the energy performance of three different constructions of traditional walls and a dynamic simulation work to identify the optimum thermal insulation strategies. The results show that the introduction of a conventional outer insulating layer can cause overheating problems in the summer period. This problem can be overcomed with the use of a ventilated outer insulation layer, leading to an optimum solution with improved thermal comfort and reduced energy consumption.

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Nomenclature

CA	yearly total cost of energy ($/m^2·year)	Cp	heat capacity (kJ/kg·K)
CA, C	yearly energy cost for cooling per unit area, ($/m^2·year)	Li	insulation thickness (m)
CA, H	yearly energy cost for heating per unit area ($/m^2·year)	N	lifetime of building (years)
Ci	cost of insulation material per unit volume ($/m^3)	PWF	present worth factor
CE	cost of electricity ($/kW h)	Qg	total heat gain per year (W/m^2)
CF	cost of fuel ($/kg)	Ql	total heat loss per year (W/m^2)
CDD	cooling degree-days (°C·days)	r	effective interest rate
COP	coefficient of performance of air-conditioning system	t	time (s)
Hu	lower heating value of the fuel (J/m^3)	T	temperature (°C)
HDD	heating degree-days (°C·days)	U	overall heat-transfer coefficient (W/m^2·K)
λ	thermal conductivity (W/m·K)	δ	percentage of the surface of the window in the wall
ρ	density (kg/m^3)		

Several research studies have been performed to determine the optimal thickness of the thermal insulation of the building envelope and to study its effect on the reduction of energy consumption [9–22]. Among these studies, Ozel [11] conducted a study on the thermal performance and the optimum thickness of the thermal insulation of walls with different structural materials under dynamic temperature conditions. The numerical results for five building materials and two different insulating materials, show that optimum insulation thicknesses vary between 2 and 8.2 cm, the energy savings vary between 2.78 and 102.16 $/m^2, and payback periods vary between 1.32 and 10.33 years.

Daouas et al. [14] determined the optimal insulation thickness for exterior walls of buildings in Tunisia by applying the analytical method. The results show that the most profitable case is the stone/brick sandwich wall and expanded polystyrene for insulation, with an optimum thickness of 5.7 cm.

Wati et al. [15] studied the influence of external shading in optimum insulation thickness of building walls in a tropical area. It is found that increasing the shade reduces the thickness of optimal insulation at an average rate of 0.035 cm, 0.029 cm and 0.036 cm per percentage of solar radiation blocked for south, north, east/west oriented wall, respectively.

Bojić et al. [23] conducted an optimization study of the thermal insulation on a small residential house in Serbia. For thermal insulation application, the energy payback period is low. According to the life cycle time, the energy payback period varies from 0.84 to 2.7 years for the mineral wool, and from 3.18 to 5.21 years for the polystyrene.

Mahlia and Iqbal [24] estimated the potential cost savings and emission reductions achieved by the introduction of thermal insulation with optimal thicknesses and air gaps in the walls of a building located in the Maldives. It was found that the fibreglass urethane (roof deck) as an insulation material with the optimum thickness and with an air gap of 6 cm in the wall led to the biggest reduction of 77.26%.

In this study, an experimental investigation was carried out on the thermal performance of a low energy consumption prototype building built by the CNERIB in 2010 within the MED-ENEC project (Mediterranean Energy Efficiency in the Construction sector). To do this, measuring instruments have been installed in order to measure the temperature of the inner face of the walls and the air temperature. In addition, numerical modeling of the prototype building was done using the TRNSYS dynamic simulation software to study the thermal behavior and compare energy performance, which result in the thermal comfort and the energy consumption of heating and air conditioning, with those of a classical building in Algeria.

The effects of the thickness of expanded polystyrene insulation on the exterior walls on the energy requirements and total cost have been studied.

To the knowledge of the authors, there is no work in the literature about the optimization of the insulation walls containing windows, while a wall generally has windows. The effect of the type of the glazing and the percentage of glazing in the wall has been studied to determine the optimum thickness of the insulation.

Three different structural materials have been studied namely hollow bricks, stabilized earth bricks and concrete. Using the optimization model, the optimum insulation thickness for exterior walls of buildings was calculated for electricity and two different types of fuels, namely, natural gas and butane gas. The optimum thickness of insulation and energy savings for the city of Algiers were determined according to the type of fuel over a building lifetime of 30 years.

2. Methodology for determining the optimum thickness

2.1. The structure of the external walls

The external walls used in determining the optimum insulation thickness are made in a single structure material, coated on the outside with cement mortar and on the inside with plaster coating. A thermal insulation layer is positioned on the outside of the walls. Three structure materials were studied: hollow brick, concrete and stabilized earth brick (SEB).

Fig. 1 shows the different layers of exterior wall with hollow brick. The wall structure consists of 2 cm inside plaster coating (λ = 0.35 W/m·K), 20 cm horizontal hollow brick (λ = 0.48 W/m·K), insulating material is expanded polystyrene (λ = 0.046 W/m·K) and 2 cm of cement mortar (λ = 1.4 W/m·K).

2.2. Case study

The optimization study was performed for the climatic region of Algiers (Latitude 36.70N, Longitude 03.30E). This climate zone is characterized by cool winters and hot-humid summers [25]. The annual heating and cooling degree-days in this study are taken for base temperatures of 20 °C for heating and 24 °C for cooling. The annual cooling degree days are CDD = 357 and the annual heating degree days are HDD = 1388. The outdoor air temperatures are obtained by averaging daily measurements provided by the " Météonorme 7" software over the years 2000–2009.

2.3. Mathematical formulation

The optimum insulation thickness is calculated based on the estimated heating and cooling transmission loads. The heating and cooling transmission loads per unit area of external wall are given by the degree-days model, applied under static conditions.