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Optimum insulation thickness for external walls on different orientations considering the speed and direction of the wind

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HIGHLIGHTS

- Determination of optimum insulation thickness on external walls.
- Calculation of heating and cooling transmission loads based on transient heat flow.
- Statistical analysis of wind data related to wind speed and direction.
- Study of external walls with different orientation and composition.
- Economic analysis based on life cycle saving method for the selected walls.

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ABSTRACT

Thermal insulation is generally installed in the envelope of residential buildings to improve their thermal performance. However, the selection of the optimum insulation thickness requires a detailed thermal energy and economic analysis. This paper determines the optimum insulation thickness for external walls of different composition and orientation, considering both the heating and cooling period and taking into account the wind speed and direction. Three types of composite, thermally insulated walls have been selected. Annual heating and cooling transmission loads are being calculated based on transient heat flow through the external walls and by using hourly climatic data of the city of Athens, Greece. The available wind speed and direction data have been statistically analyzed for the assessment of the prevalent wind directions in the area. An economic analysis, based on the life cycle savings method has been performed for each configuration, various thicknesses of insulation material and different orientations. The optimum insulation thickness for any type of wall and orientation was found to be between 7.1 cm and 10.1 cm. Furthermore, a sensitivity analysis indicates whether changes of the economic parameters affect the optimum insulation thickness.

1. Introduction

The heating and cooling loads of buildings play a very important role on the transmission and use of energy, as well as in environmental pollution. Buildings in Europe account for about 40% of the European Union's total final energy consumption and about one third of the total energy-related CO_2 emissions, figures which are even higher in some EU countries depending on the mix of fuels used for electricity generation [1,2].

In recent years, much attention has been given to the importance of energy efficiency improvement measures for residential buildings, meant to reduce the heating and cooling load, in order for the buildings to become a contributor towards stalling climate change and the reduction of energy use.

An important action of the European Commission towards the decrease of energy use by the buildings (including residential sector) is the European Directive 2002/91/EC on the Energy Performance of Buildings (EPBD) and the EPBD recast (Directive 2010/31/EC). EPBD has been partially adopted by the Greek legislation since 2008, including the buildings of residential and tertiary sectors, yet it was practically enacted in 2010 after the publication of the necessary supportive legislative framework and technical instructions [3].

One of the most efficient measures to reduce the thermal losses of the building envelope, according to the requirements of the new regulation, is the insulation of the external walls [2,4]. However, increasing the thickness of insulation leads to lower thermal losses but simultaneously increases the cost of the insulation, raising the capital cost of the building. Moreover, when increasing the

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thickness of insulation, there is a point beyond which the cost of the insulation will be over the monetary benefits of the energy saved. Thus, by considering the difference between the life cycle cost of a conventional heating and cooling system and the life cycle cost of the insulation plus auxiliary energy system, for several thicknesses and over the lifetime of the building, a maximum monetary benefit will be obtained and the thickness corresponding to it will be the economically optimum thickness of the insulation.

Several studies have been performed on the subject of optimum insulation thickness, each taking a different approach for the calculation of the thermal performance of the wall. Some are based on the Degree-Days concept [5–13], while others use numerical [14–17] or analytical methods [18,19] for transient heat flow through the walls of the building. Generally, the results and conclusions from these studies are site specific and applicable only to local climatic conditions, financial parameters, as well as construction and insulation materials. For instance, Bolattürk [8] studied the optimum insulation thickness of building walls using the degree-hour method, depending on the annual cooling and heating loads, for different base temperatures of various cities within the first climatic zone of Turkey. Al-Sanea and Zedan [15] used a dynamic time-dependent model based on the finite-volume implicit method to compute the annual transmission losses through the wall under steady-periodic conditions for climatic conditions of Riyadh. Daouas [19] used an analytical method to calculate the optimum insulation thickness of walls for different orientations in the Tunisian climate, taking into consideration the effect of solar radiation but not of the wind speed and direction. In addition, a methodology has been developed for the optimization of thermal insulation solutions, based on the primary energy consumption, environmental impact and the financial cost of building elements and materials [20,21].

The most important factors affecting the optimum insulation thickness are: the climatic conditions, the insulation material type and cost, type and efficiency of the heating and cooling systems, the type of consumed energy and cost, the orientation of external walls, the level of indoor thermal comfort, the lifetime of the building and, finally, the inflation and discount rates.

Due to the high dependence of the insulation thickness on local climatic conditions, several scientific studies have been conducted at various geographical regions [19,22–25], each aimed to offer insight on the thermal performance of the building walls located in the region, so that optimisations on the composition of external building walls may be performed for that particular area.

Furthermore, in regions with hot summers and cool winters, increasing the thickness of the insulation reduces the thermal requirements but also may cause the internal temperature to increase undesirably and thus the cooling load during hot seasons may increase, which would not happen with less insulation. In addition, increased ambient temperatures which occur during the summer due to urban heat island effect [26] have resulted to the extensive usage of mechanical air-conditioning with a direct impact on peak electrical energy consumption [27–29].

The buildings constructed in Greece before 1980 correspond to 74.6% of the total building stock and are not thermally insulated, while according to 1990 data for Greek dwellings, 95% of the external walls are not insulated [2]. Moreover, the Greek climate is characterized by cool winters and hot summers and thus the study of the optimal insulation thickness could provide useful results for other regions sharing similar climatic characteristics as well.

Additionally, to our knowledge, no published information relating the effect of wind speed and direction on optimum insulation thickness at building walls exists to this date.

The aim of this work is to determine the optimum insulation thickness for external walls of different composition and orientation for the city of Athens in Greece, taking into account both the heating and the cooling period, as well as the speed and direction of the wind.

2. Methodology

2.1. Climatic zones

Greece is situated at the most south-eastern part of Europe and has a Mediterranean climate, characterized by hot, dry summers and cool, wet winters.

According to the new regulation regarding EPBD, there are four climatic zones in Greece based on heating degree-days, with a different maximum allowable *U*-value for external vertical walls in contact with outdoor air, as shown in Table 1.

The warmest zone (A) is at the southern part of the country, while the coldest (D) is at the north and on high altitude areas. From climatic zone B, the city of Athens has been selected and the relevant weather data, including solar irradiance at horizontal surface, ambient temperature, relative humidity, wind speed and direction, have been used to assess the heating and cooling period.

2.2. Multilayer walls

Although the climatic conditions between the four climatic zones are completely different, the type of construction and the materials of the exterior walls are about the same. Hollow bricks are the most common and widely used material for the construction of no-load bearing external walls in Greece and in other Mediterranean countries.

Considering that there is a large number of exterior walls without insulation, while the majority of the external walls of new buildings feature cavity wall insulation, the following three different configurations of external walls have been selected and also are graphically displayed in Fig. 1:

Interior plaster, brick, insulation material and exterior plaster (Ext).
Interior plaster, cavity wall insulation and exterior plaster (Mid).
Interior plaster, insulation material, brick, and exterior plaster (Int).

Configurations (a) and (c) could be a viable option for future interventions on the large number of existing uninsulated exterior walls, while configuration (b) is the most widely used in modern constructions.

For all configurations, the assumed total thickness for brick is 20 cm, while the thickness for interior plaster is 2 cm and for exterior plaster is 2 cm.

The values of thermophysical properties of each material used for the simulation have been derived from the wall library available in [30] and from [21,31], while they are shown in Table 2. The conduction heat transfer is being treated as one-dimensional and the thermophysical properties of building materials are independent of their temperature.

Table 1
Climatic zones in Greece.

Climatic zone	Heating degree-days (K-days)	*U*-value (W/m^2 K)
A	601–1100	0.60
B	1101–1600	0.50
C	1601–2200	0.45
D	2201–2620	0.40