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Optimal economic thickness of various insulation materials for different orientations of external walls considering the wind characteristics

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A B S T R A C T

The economic optimum insulation thickness of various insulation materials for external walls of different topologies and orientations was determined, taking into account the heating and cooling period and the speed and direction of the wind. Annual heating and cooling transmission loads are being calculated based on transient heat flow through the external walls and by using hourly climatic data for an entire typical meteorological year of the city of Larnaca, Cyprus. The available wind speed and direction data have been statistically analysed for the assessment of the prevalent wind directions in the area. The optimisation is carried out using the Life Cycle Savings method. According to the results, the north-facing walls offer the greatest economic benefit compared to the corresponding wall types of different orientation, regardless of the insulation thickness. They also have the shortest payback period. The optimum insulation thickness calculated for any wall topology and orientation varies from 4.25 cm to 15.5 cm, and the payback period varies from 5.47 years to 12.11 years.

1. Introduction

A large share of the final energy consumption, over 40%, in the EU-27 is consumed by the existing building stock while dwellings are responsible for 66.62% of this [1]. According to EuroACE [2] 57% of the consumed energy in buildings is used for space heating, 25% for the production of DHW (domestic hot water), 11% for electronic devices and lighting and 7% by electric ovens and cookers.

Thus, the consequent need to increase the energy performance of dwellings is an important instrument in the efforts to reduce Europe's dependency on energy imports and reduce CO_2 (carbon dioxide) emissions. As a result the European Commission prepared a number of legislative tools one of which is Directive 2010/31/EU where the impact of buildings on energy consumption in the long-term is emphasised. Due to their long renovation cycle, buildings should meet minimum energy performance requirements adapted to the local climate of each Member State. Consequently, it is stated that Member States should set minimum requirements for the energy performance of buildings and building elements with a view to achieving a cost-optimal balance between the investments involved and the energy savings throughout the lifecycle of the building. Member States should also enable and encourage architects and engineers to properly consider the optimal combination of ECM (energy conservation measures) when planning, designing, building and renovating industrial buildings or dwellings.

In the last two decades considerable work has been carried out by the international scientific community on the evaluation of various ECM for buildings. Some of the main studies are summarised as follows.

Balaras et al. [3] identified the most efficient ECM for application in domestic dwellings in Greece. The results for each ECM examined were: thermal insulation of external walls (savings 33–60% for space heating), thermal insulation of roofs (savings 2–14% for space heating), installation of double glazing with inert gas filling in the gap (savings 14–20% for space heating),

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installation of external shading (savings 10–20% for electric energy consumption for cooling), installation of ceiling fans (savings 60% of electric energy consumption for cooling) and replacement of old A/C units (savings of 72% of electric energy consumption for cooling).

Jaber and Ajib [4] discussed the implementation of several ECM such as building orientation, size of windows, shading, and insulation thickness (rock wool) to a typical dwelling in Jordan. In this work the TRNSYS was used and the optimisation parameter was LCC (life cycle cost). The results showed that a reduction of 28% on the annual energy consumption of the dwelling could be achieved by combining best orientation (passive façade facing South), optimum size of windows and shading device (window area 30% of the South facade area, 20% of the East facade and 10% for both North and West facades), and optimum insulation thickness (0.22 m of rock wool on both walls and ceilings).

Cabeza et al. [5] studied the performance of insulation materials in Mediterranean constructions. An experimental setup consisting of four test cubicles was constructed in Puigverd de Lleida (Spain) for the investigations. The test cubicles were conditioned using oil radiators in winter and air conditioners in summer. The results of this study showed that with optimum insulation levels, energy reduction of up to 64% could be achieved for cooling in the summer and 37% for heating in winter.

Jaber and Ajib [6] examined the optimum type and size of windows in terms of both energy and investment cost for three different climatic zones (Amman, Aqaba and Berlin) using TRNSYS. The results indicated that triple glazing provided the best energy performance of all glazing types investigated but was not economically feasible for all the climates examined. Double glazing with U-value equal to 2.83 W/m^{2}K achieved the minimum life cycle cost in locations with hot summer and mild winter climates while double glazing with U-value equal to 1.4 W/m^{2}K was the best choice for locations with mild summers and cold winters. It was also shown that optimised glazing could achieve energy savings of 21%, 20% and 24% for Amman, Aqaba and Berlin, respectively.

Bolatturk [7] investigated the optimum insulation thickness on external walls of buildings based on annual heating and cooling loads for the city of Bursa, Turkey. The method employed was the degree-hours method which is one of the simplest methods of estimating the annual energy consumption of a building. The results showed that the use of insulation on building walls had greater impact for cooling rather than for heating for the climatic conditions investigated. The results show that for heating load, the optimum insulation thickness is between 0.016 and 0.027 m, the energy savings vary between 2.2 and 6.6 \$/m^2, and the payback periods vary between 4.2 and 5.5 years depending on the city. On the other hand, for cooling load, the insulation thickness is between 0.032 and 0.038 m producing annual energy savings of the order of 8.47 and 12.19 \$/m^2 and payback periods of between 3.4 and 3.8 years.

Papadopoulos et al. [8] studied a representative sample of 42 buildings (residential, public and mixed use) in Northern Greece over a 6 year period in order to determine the potential of the most efficient energy saving measures taking into consideration their economic viability. The two major areas for energy savings in these buildings were found to be the improvement of the central heating system and the improvement of the thermal insulation of the envelope of the building. The results of this work showed that an average energy saving of 28% was possible. The significance of energy prices to the economic viability of all energy saving measures was also highlighted in the study.

Nikolaidis et al. [9] evaluated the economic viability of various ECM for a detached dwelling in Larissa (Central Greece). Specifically, the reference dwelling has an area of 100 m^2, uses a heating oil burner with water radiators for heating and an electric water heater is used to cover the need for hot water. According to the results of the study, when using the IRR (internal rate of return) as the evaluation criterion the upgrading of artificial lighting was the most effective investment, while the insulation as well as the installation of an automatic temperature control system at the burner – boiler system follow next. On the other hand when the NPV is used as the evaluation criterion the insulation of the roof or the pilotis of the building constitute the most effective interventions.

Kolaitis et al. [10] performed a comparative assessment of internally and externally installed thermal insulation for energy efficient retrofitting of residential buildings for different locations. For this purpose TRNSYS was used to simulate a 99.6 m^2 one-storey apartment located at a mid-level of a multi-storey building. The climates used for the simulation were the Mediterranean climate and the Oceanic climate. The parameters examined were the annual heating and cooling energy requirements; the effect of insulation layer location, meteorological conditions and "energy conscious" occupant behaviour. According to the results of this study both cases of insulation (internal and external) were found to significantly reduce the total energy requirements by 56–89% in the Mediterranean climate region and by 21–47% in the Oceanic climate while on average, external insulation outperformed the internal insulation configuration by 8%.

Florides et al. [11] studied the energy flows in modern dwellings in Cyprus and examined measures to reduce the thermal load using TRNSYS. The measures examined were natural and controlled ventilation, solar shading, various types of glazing, orientation, shape of building, and thermal mass. The results showed that the roof is the most important structural element of buildings in a hot environment. LCC analysis showed that using roof insulation (0.025–0.05 m of polystyrene) could lead to short pay-back periods of between 3.5 and 5 years.

Kalogirou et al. [12] investigated the effects of thermal mass on the heating and cooling loads of dwellings in Cyprus. A typical four zone dwelling with an insulated roof was modelled using TRNSYS. The south wall was replaced by a thermal wall (a wall with large thermal mass). The simulation results showed a 47% reduction in heating load requirements, and a slight increase in the cooling load requirements.

Axaopoulos et al. [13] determined the optimum insulation thickness for external walls of different composition and orientation, considering both the heating and cooling period for the city of Athens, Greece. The optimum insulation thickness for the types of walls investigated was found to be between 7.1 cm and 10.1 cm.

To the best of our knowledge, none of these or other studies has defined the optimum insulation thickness at building walls, amongst all commercially available thermal insulation materials, in all directions relating the effect of wind speed and direction in Cyprus. The aim of this work is to determine the economical optimum insulation thickness of various insulation materials for external walls of different topologies and orientations for the city of Larnaca, Cyprus for an entire TMY (typical meteorological year), taking into account the heating and cooling transmission load and the speed and direction of the wind. The optimisation is carried out using the LCS (life cycle savings) method.

2. Cyprus building stock

Cyprus is the third largest island in the Mediterranean Sea and has the warmest climate in the Mediterranean part of the European Union. Larnaca's climate is a Mediterranean climate characterised