Applied Thermal Engineering 50 (2013) 217–224

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

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

Determination of optimum insulation thickness of external walls with two different methods in cooling applications

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HIGHLIGHTS

- The optimum insulation thickness on external walls is analyzed in cooling applications.
- One of the methods is the degree-hours method (Method 1).
- The other is the annual equivalent full load cooling hours operation (Method 2).
- The energy saving is overestimated by Method 2.
- The optimum insulation thickness and payback period are overestimated by Method 1.

ARTICLE INFO

Article history:
Received 21 January 2011
Accepted 13 June 2012
Available online 30 June 2012

Keywords:
Cooling applications
Thermal insulation
External wall
Optimum insulation thickness
LCC analysis

ABSTRACT

Thermal insulation is one of the most effective energy conservation for the cooling applications. For this reason, determination of the optimum thickness of insulation and its selection is the main subject of many engineering investigations. In this study, the optimum insulation thickness on the external walls in the cooling applications is analyzed based on two different methods used to determine annual energy consumption. One of the methods is the degree-hours method (Method 1) that is the simplest and most intuitive way of estimating the annual energy consumption of a building. The other is the method (Method 2) which using the annual equivalent full load cooling hours operation of system. In this paper, a Life Cycle Cost (LCC) analysis is used to evaluate accuracy of these methods, and the results are compared. The results show that the life cycle savings are overestimated by up to 44% in Method 2, while the optimum insulation thickness and payback period are respectively overestimated by up to 74% and 69% in Method 1.

1. Introduction

Energy consumption is rapidly increasing in worldwide because of expanding population, urbanization, immigration to big cities and improvement of life standards. The energy consumption is inevitable for decreasing of life standards at industrialized countries and recovering the situation in the developing countries; but energy can be used more efficiently, and also renewable energy consumption can be performed. The energy consumption is higher in some areas such as industrial, building, transportation and agriculture. The building sector has the widest energy consumption. In many countries, the energy demand for heating and cooling of buildings has the biggest part compared with the others. Energy saving is very important for the energy strategy of a country. It has become compulsory due to the limited energy sources and environmental pollution arisen from using fuels.

Turkey is one of the fastest growing energy markets in the world. Annual electricity demand growth rate became 6.6% between 1995 and 2004, and it will be 8.5% between 2005 and 2015 according to the project. It was estimated that the electricity consumption increased 4 folds from 150 billion kW h to 499 billion kW h in 2004. It was about 38,500 MW in 2005, and the installed capacity is required to increase 3 folds about 96,000 MW by 2020 [1]. Turkey has dynamic economical development and rapid population growth. It also has macro-economic, and especially monetary, instability. The net effect of these factors is that energy demand of Turkey is increasing approximately every year due to the need of investment is not adequate for that growth and the investment requirement to cover the growing demand has not been forthcoming at the desired pace, and is expected to continue

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1359-4311/$ – see front matter
http://dx.doi.org/10.1016/j.applthermaleng.2012.06.031

growing. On the other hand, meeting energy demand is very significant in Turkey [2]. Energy savings are more vital for Turkey which imports most of the energy used up. An important part of energy which consumed in Turkey is used in heating and gradually in cooling applications [3].

In Turkey, cooling systems are used in almost all dwelling and commercial buildings. These systems are used to cool the space or room in a building due to hot air outside building and to absorb heat produced by people and appliances from inside building in order to provide comfortable working environment. Since these systems are operated continuously all the time, the energy consumption and cost for these systems are quite high. Therefore, building sectors in Turkey have to spend lots of money for electricity of cooling systems every year.

The external walls and roof of a building are the interface between indoor and outdoor environment. Buildings should be insulated according to outside environment conditions and inside thermal comfort. In general, thermal insulation is used in the components of building envelope in order to decrease energy consumption and costs in space cooling. The cooling cost decreases while the insulation cost increases owing to thickness. Thus, the fuel cost will be the lowest value at optimum thickness of the insulation. There will be no energy savings to increase additional insulation beyond the economic thickness. Thermal insulation products that are natural or human made, display some characteristics which are changeable according to products' nature and effected from heat interval. Thermal insulation materials like other natural or man-made materials exhibit temperature dependent properties that vary with the nature of the material and the influencing temperature range.

In Turkey, the buildings have an important part of the energy consumption. TS 825 "Thermal Insulation Rules in Buildings" standard [4] stipulates minimum requirements so as to limit the need for cooling and heating energies in buildings. Besides, insulation cost with availability of material and application convenience is an important factor in the choice of insulation materials.

Life Cycle Cost (LCC) analysis is often applied to energy technologies and building projects. The LCC analysis can show that spending more initially on additional building insulation can produce a net savings (due to reduced heating and cooling costs) over the lifetime of a building. The concept of LCC is used to determine the optimum insulation thickness in order to take effects of the change in interest and inflation that directly affect both the cost of insulation materials and fuels.

In cooling applications, determining of the annual energy demands for LCC analysis and the optimum insulation thickness are a very significant situation. The energy demands can be defined by the degree-time or annual equivalent full load cooling hours.

The topic of degree time is applied for many practical applications such as power production, energy supply demand consumption, expanding of business and agriculture. Also, variation in space heating/cooling needs can be measured in degree-time methods using the design and outdoor temperatures. The degree-time is one of the proper methods to use in order to forecast energy consumption of residential heating/cooling [5].

The annual heating and cooling requirements of buildings in different regions can be obtained by means of the degree-days or degree-hours concepts. The heating/cooling degree-days or degree-hours are determined by using long-term measured data. Cooling degree-days are an indicator of the energy demand to cool buildings. This indicator is calculated by subtracting 18 °C (65 °F) from the average daily or hourly temperature, and summing only positive values over a fixed period such as an entire year. An analogous indicator for the energy demand for heating is represented by heating degree-days or degree-hours. Heating degree-days or degree-hours are widely used in building energy management. For the construction of building performance lines, it is necessary to have the correct building design temperature with the meteorological station as close as possible to the building being monitored. Applications of the degree time methods are used together with optimum insulation thickness in many studies. In these applications, either degree-days (i.e., [3,6,7]) or degree-hours (i.e., [8–10]) are performed. Besides, in some studies [11,12], annual heating and cooling consumptions in buildings are calculated by considering solar radiation.

As far as the optimization of insulation thickness is concerned, various studies can be categorized into four groups as: (i) the optimization of optimum insulation thickness according to LCC analysis by determining of annual heating/cooling energy demands [6,8,9,11–15], (ii) the optimization of optimum insulation thickness by using various fuels for energy saving [3,7,16–18], (iii) the effects on environment of the optimization of optimum insulation thickness [19,20], and (iv) the effects on fuels of the optimization of optimum insulation thickness according to exergy analyses [21,22].

In this study, a comparison between optimum insulation thickness and results of LCC analysis is made by using two different methods, which determined the annual energy requirement in cooling applications. A government office on housing in Turkey has issued a new regulation in 1999 [4]. "Thermal Insulation Rules in Buildings" for setting certain standards for insulating buildings according to four climate regions are chosen. The fourth region has the most severe winter conditions with respect to the first region. Representative city from first climatic zone is chosen to make this a comprehensive study as the results of selected city may be conveniently used to make reasonable estimation for other cities. The city of Mersin located in first region of Turkey is chosen as a model city. Besides, three different insulation materials (styrofoam, rock wool and glass wool) are used. Firstly, annual cooling energy demand of cooling space is determined by degree-hours with using long-term measured data. Second one is determined by the annual equivalent full load cooling hours operation which will be explained in chapter of Material and methods (see [8,10] for detail information). Furthermore, an optimization model is performed depending on LCC analysis via P_1–P_2 method. By using the optimization model, optimum insulation thicknesses, saving and payback period for exterior walls of buildings are calculated for electricity tariff and results obtained from this study are presented with comparisons.

2. Material and methods

2.1. The structure of the external walls

The cooling applications are applied to cool the space or room in the buildings due to hot air outside building and to absorb heat produced by people and appliances from inside building in order to provide comfortable environment. Since these applications are operated continuously all the time in the temperate countries, the energy consumption and cost for these applications are quite high. Consequently, the cooling sectors need to spend a lot of money for electricity for each cooling system every year. Any reduction in this cooling load results in reducing the electricity consumption by cooling system. Therefore, a proper insulation material with the objective of achieving the acceptable comfort for building occupants and the reduced cooling load is imperative. Insulation is made to estimate the heat gains in a building. Heat load of a building is calculated in terms of these gains. Heat gains in buildings consist of the characteristics of building (i.e., transmission and ventilation in the external walls, roof, door and windows, etc.), the characteristics of cooling system, climate conditions, outside air