A STUDY ON OPTIMUM INSULATION THICKNESS IN WALLS AND ENERGY SAVINGS BASED ON DEGREE DAY APPROACH FOR THREE DIFFERENT DEMOSITES IN EUROPE

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ABSTRACT

In the last decade, the energy industry has been facing major changes mostly because of concerns about sustainability. Countries worldwide, especially industrialized nations have been forced to improve the energy efficiency in several sectors with high energy consumption. The building industry is a major sector for energy consumption in the world.

Using thermal insulation in buildings helps to reduce the reliance on mechanical/electrical systems to operate buildings comfortably and therefore, conserves energy and the associated natural resources. An energy cost is an operating cost, and great energy savings can be achieved by using thermal insulation with little capital expenditure (only about 5% of the building construction cost). This does not only reduce operating cost but also reduces HVAC equipment initial cost due to reduced equipment size required. The use of thermal insulation not only saves energy operating cost, but also results in environmental benefits as reliance upon mechanical means with the associated emitted pollutants are reduced. The use of thermal insulation can reduce disturbing noise from neighboring spaces or from outside. This will enhance the acoustical comfort of insulated buildings, etc.

The optimum economic thickness is the value that provides the minimum total life-cycle cost. The thickness depends on the following parameters: the building type, function, shape, orientation, construction materials, climatic conditions, insulation material and cost, energy type and cost and the type and efficiency of the air-conditioning system.

This study, based on research conducted under the EU FP7 project, presents optimum insulation thickness calculation assessment for building envelop in three different demo-sites located in Europe. The study provides an economic and energy cost optimization, which has positive effects on reducing the energy demand and GHG emissions. Results show how the retrofitting actions can contribute to low energy and zero emission cities and urban areas, taking into account the technological availability for building retrofitting.

Keywords: energy saving, insulation, retrofitting, building

INTRODUCTION

Energy is essential for economic and social development and improved quality of life in all countries. Energy demand started with the Industrial Revolution. European energy need increased in parallel to growing technology and started to emphasis on the importance for the most needed concept day by day.

After the energy crisis occurred in 1970s, the importance of energy increased for the countries. The saving energy use studies started. The countries which have natural sources conducted studies to use their resources in the best way. Other countries tried to create various technics. Consequently renewable energy forms emerged.

The energy consumption of buildings has become a relevant international issue and different policy measures for energy saving are under discussion in many countries. In the EU, buildings account for about the 40% of the total energy consumption and they represent the largest sector in all end-users area, followed by transport with the 33% [1]; whereas in terms of CO_2 emission, buildings are responsible for about 36% of it. It is estimated that the residential sector alone represented about 25% (in 2011) of the final energy consumption in EU. [2]

Energy in households is consumed for different purposes, such as hot water, cooking and appliances, but the dominant energy end-use in Europe (responsible for around 70% of total consumption in households) is space heating. Among all the solutions proposed to the energy problems in buildings, experts agree that building insulation is the least-cost option for reducing energy consumption and CO_2 emissions. The determination of the optimum thickness of the building insulation materials has been a subject of interest for many years among the scientific community. The optimum insulation thickness depends on a large number of parameters. The scientific studies are primarily focused on analyzing the effect of the climatic parameters, the orientation, the thermal mass, the fuels and other parameters. [3]

The main goal of the insulation thickness studies is to optimize thermal insulation thickness based on degree-day heat loss analysis. The concept of optimum thermal insulation thickness considers both the initial cost of the insulation and the energy savings over the life cycle of the insulation material. The optimum insulation thickness corresponds to the value that provides minimum total life cycle cost. The analyses for optimum insulation thickness are commonly based on some parameters such as heating and cooling loads, the cost and the lifetime of the insulation materials, efficiencies of heating and cooling systems and the inflation rate. However, heating and cooling demands of buildings are mostly considered sufficient input parameters in order to perform an optimization work. In literature, generally the degree-day or degree-hour concept is used to predict the heating and cooling loads of buildings since the approach is quite simple.

METHODOLOGY

The concept of economic thermal insulation thickness considers the initial cost of the insulation system plus the ongoing value of energy savings over the expected service lifetime of the insulation.

The thickness is a function of the following: the building type, function, shape, orientation, construction materials, climatic conditions, insulation material and cost, energy type and cost, and the type and efficiency of air-conditioning system. [4]

In most studies, the optimum insulation thickness computations were performed based mainly on the heating and cooling loads and other parameters such as the costs of the insulation material and energy efficiencies of the heating and cooling systems, the lifetime and the current inflation and discount rates. For that reason, the annual heating and cooling energy requirements of a building were the main inputs required to analyze the optimum insulation thickness. Most studies estimate the heating and cooling energy requirements by the degree-time concept (degree-day, DD or degree-hour, DH), which is one of the simplest methods applied under static conditions. [5] On the other hand, only a limited number of analytical techniques were applied to analyze the transient behavior of multilayer building envelopes. [6]

$$HDD = \sum_{days}(T_b - T_0)^+ \quad (1)$$

$$CDD = \sum_{days}(T_0 - T_b)^+ \quad (2)$$

where Tb is the base temperature and To is the daily mean outdoor air temperature. The plus sign above the parentheses indicates that only positive values are to be counted. The heating and cooling degree-hours can be calculated in a similar manner with the hourly instead of the daily data.

The heat losses in buildings generally occur through external walls, windows, ceiling, floors and air infiltration. The heat loss from windows due to the infiltration is not taken into account since the insulation does not affect that heat loss. On the other hand, in these calculations only the heat loss from external walls is considered. Heat loss from per unit area of external wall is;

$$q = U * (T_b - T_o) \quad (3)$$

where U-value is the overall heat transfer coefficient.
The annual heat loss per unit area can be obtained from;

$$q_A = 86400 * DD * U \quad (4)$$

Annual energy requirement;

$$E_A = \frac{86400 * q_A * DD}{\eta} \quad (5)$$

After the evaluation the yearly heat demands to calculate cost accounting, the Present-Worth Factor (PWF) will be used.

If i < g;

$$r = \frac{(i-g)}{(1+g)} \quad (6)$$

If i > g;

$$r = \frac{(g-i)}{(1+i)} \quad (7)$$

$$PWF = \frac{(1+r)^N - 1}{r * (1+r)^N} \quad (8)$$

Total cost formula;

$$C_T = \frac{86400 * DD * PWF * C_f}{\left(R_{wt} + \frac{x}{k}\right) * H_U * \eta} + C_i * x_{opt} \quad (9)$$

$$x_{opt} = \left(\frac{86400 * DD * C_f * PWF * k}{H_U * C_i * \eta}\right)^{\frac{1}{2}} - k * R_{wt} \quad (10)$$

IMPLEMENTATION OF INSULATION THICKNESS OPTIMIZATION PROCEDURES IN THE DEMO SITES

In this section, calculations are made for three demo sites. Valladolid (Spain), Soma (Turkey) and Lund (Sweden) are considered.

Parameter		Valladolid	Soma	Lund
HDD	Heating degree day	3121 (20°C)	1783 (18°C)	3277 (17°C)
Fuel type		Biomass(Wood Chips)	Lignite	Biogas
η (%)	Fuel efficiency	0.80	0.65	0.8
Cf (€/kWh)	Fuel price	0.25	0.092	0.09
LHV (J/m^3)	Lower Heating Value	6.00E+06	2.30E+07	3.97E+07
Insulation material		EPS	EPS	Mineral wool
k (W/mK)	Conductivity	0.037	0.04	0.036
Ci (€/m^3)	Insulation material cost	40	70	60-90
ρ (kg/m^3)	Density	15-20	20	20-50
General information				
i (%)	Interest rate	0.3	0.8	0.3
g (%)	Inflation rate	4	0.749	1.1
N (year)	Lifetime of the system	20	20	20
Rwt (m^{2}K/W)	Total wall thermal resistance	0.7353	0.56179	2.5

Table 1 : Parameters used in each demo site

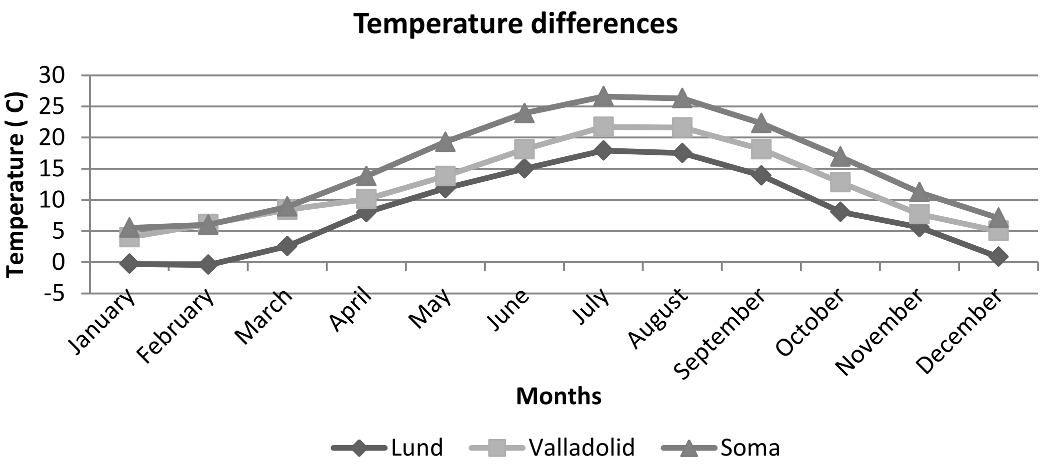

Figure 1 : Monthly average temperatures in Lund, Valladolid and Soma

The external wall's thermal characteristics information is given in the table below;

	Valladolid	Soma	Lund
External wall	1.36 W/m^{2}C	1.78 W/m^{2}C	0.35 W/m^{2}C

Table 2: Existing U values for external wall for each demo site

RESULTS

With regard to equations given above, the results are as follows;

Explanation		Valladolid	Soma	Lund
r	Interest rate adapted for inflation rate	2.8461	0.0291	0.6154
PWF	Present Worth Factor	0.3513	14.9937	1.6249
x opt (m)	Optimum insulation thickness	0.042	0.0679	0.06

Table 3: Optimum insulation thickness calculation results

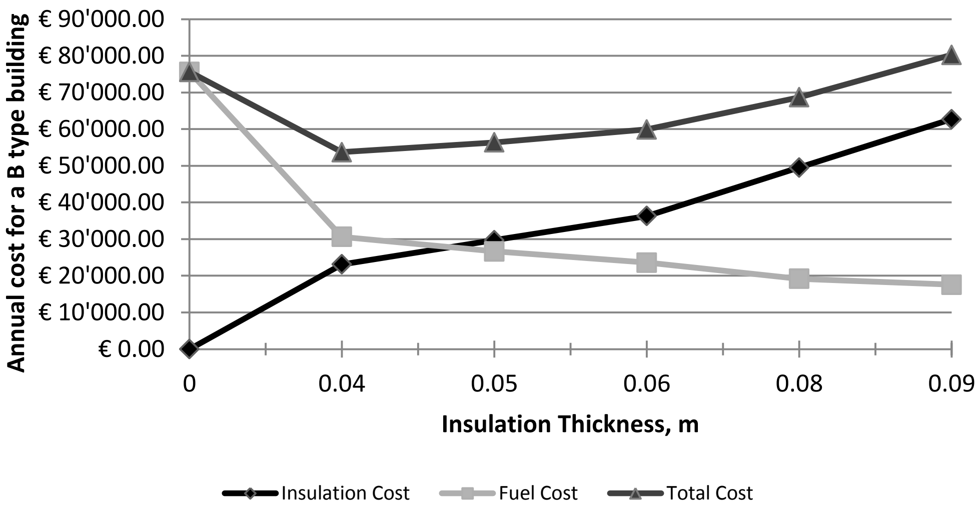

Figure 2: Annual costs versus insulation thickness in Valladolid demo site

For Valladolid, optimum thickness is 5cm according to calculations. Also in Valladolid, comparing to the existing conditions, 2 Mtce/year will be saved. For 20 year, the saved energy equals 40 Mtce.

For Lund, the used fuel is already more efficient and its lower heating value is really high. By the way, the U value for façade is too low. In Lund demo site, one of the external wall type already has 10 cm EPS. It has to be highlighted that besides EU FP7 project aims to focuse on reducing the energy demand, reducing GHG emissions and increasing the use of renewable energy sources by developing and implementing innovative technologies for building renovation are also important. Thereby, in Lund, insulation thickness affects other results as a reference model.

In Linero District, comparison with the existing condition, 17605 kWh-gas/year will be saved. For 20 year, it equals to 23.59 Mtoe for Lund.

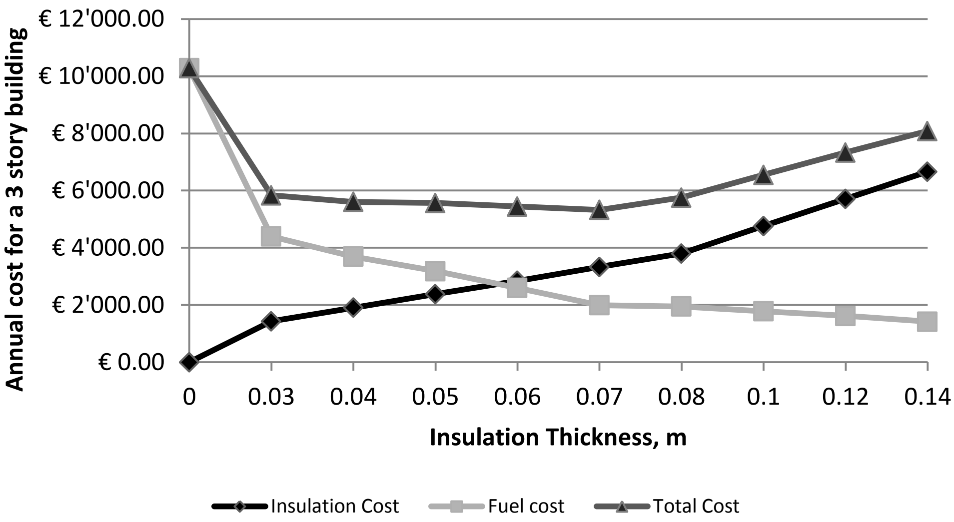

Figure 3: Heating and annual costs versus insulation thicknesses for 3 story building for Soma

For Soma, optimum insulation thickness is 7cm with regard to calculations. For 20 year, saved energy equals 133.09 Mtce for Soma demo site.

One of the aim for this study is that view and focusing on environmental aspects, the retrofitting uptake of low efficient building has impact in terms of CO_2 emissions reduction, and improvement of the indoor air quality. Under these circumstances, both substantially energy saved and CO_2 emissions are reduced for three demo sites.

In this study, optimal insulation thicknesses for different type of buildings are determined. Thanks to this calculations, energetic and economic cost optimization can be made, which has positive effects on reducing the energy demand and GHG emissions.

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