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Economical optimization of energy-efficient timber buildings: Case study for single family timber house in Slovenia

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ABSTRACT

The paper presents an approach in the determination of the most economically efficient building from the viewpoint of the costs of envelope's composition, the present value of heating costs and the costs incurred in fitting out the boiler room (hereinafter: the costs of the boiler room). The process of determination starts with the selection of a certain building in the phase of project engineering, next different combinations of envelope composition are numerically analysed and finally the optimal solution or approximation of that solution is defined on the basis of the analysed results. The approach is presented on the simulation case of a single-storey house. The result of the study is presented by a set of parameters showing different costs of building envelope from the point of initial investment for a selected energy demand of building. In the second step we calculated the present value costs of heating and compared them with the additional cost of initial investment in the envelope and additional investment in the building's boiler room in order to determine which combination of envelope and heating system is the most economically efficient.

1. Introduction

Increasing energy demand, environmental pollution and consequently legal requirements present some of the main reasons for energy-efficient construction. Slovenian national environmental legislation is subjected to European directives, especially the Energy Performance of Buildings Directive (EPDB) by which the EU tries to follow the Kyoto protocol. In the European Union, the building stock is responsible for about 40% of primary energy consumption and about 25% of CO2 emissions [1,2], which shows a relatively high potential for a reduction of energy consumption and GHG emissions caused by buildings. Based on existing facts describing energy consumption of buildings many authors [3–5] point to the need for energy-efficient construction. Schnieders and Hermelink [6] suggest that passive houses offer a viable option to meet the remaining energy demand only with renewable sources. It necessary to lower energy consumption oil consumption in EU consequently and other countries because of GHG emissions and continuation of current trends in oil production and price levels is likely to continue posing great challenges to systems that cannot reduce their petroleum requirements in kind [7]. It can be emphasised that more research and developments are needed to tackle the energy problem and to reduce the emission, for reasonable standard of living for our world [8]. At present, the world energy situation is getting grim and China's energy supply pressure is also growing [9]. It can be pointed out that only in the last 10 years, the energy demands have been doubled, while the current energy resources would not meet the market request. This situation put more pressure on scientists and communities to work harder to increase the use of the renewable energy with the highest efficiency from each resource [10].

The paper describes how to reduce costs by determining the optimal composition of a building's envelope. The building envelope determines the energy exchange between outdoor and indoor spaces and hence governs the overall energy performance of the building [11]. An optimal envelope in our case presents a solution where the initial investment costs of the envelope are lowest and

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yet it still enables the same energy performance as other envelope compositions which are more expensive. Therefore, an economic analysis to determine the optimal composition of envelope will be carried out through the comparison of costs for different envelope combinations assuring the same building's energy demand.

Many authors have already concluded that energy-efficient or improved buildings bring economic benefits with regard to lower future costs. Sartori and Hestnes [12] showed that operating energy represents by far the largest part of energy demand in a building during its life cycle. They showed that it is important to reduce the energy demand of a building. The results of research conducted in Switzerland by Jakob [5] showed that the costs of heat energy and distribution can be reduced by the construction of energy-efficient buildings. On the basis of inspection of eleven existing apartment buildings Audenaert et al. [13] established that the most economically efficient building in Switzerland was a low-energy house. They have shown from the view of initial investment costs and costs for heating for a period of 20 years, that low-energy houses cost 4% more than standard houses and that passive houses are 16% more expensive. The higher value of energy-efficient buildings on the real estate market was also found during a study in Romania [14] where energy-efficient buildings were 2–3% more expensive than similar energy-wasteful buildings. Research carried out by El Ahmine et al. [15] shows that investing in a passive house is justified. The results have shown that investment in timber passive houses can be assimilated into standard brick-concrete buildings in 10 years' time taking into account the initial investment and energy consumption costs. Initial investment in a passive house is 15% higher than in a standard one. Daouas et al. [16] studied the most economically efficient insulation thickness for Tunisia's climate and found an investment refund period in façade insulation. It was ascertained that the most economically efficient facade thickness is 5.7 cm with regard to life cycle cost analysis over 30 years. In Greece [17], thermal insulation and low-infiltration strategies reduced energy consumption by 20–40% and 20%, respectively. Pulselli et al. [18] have estimated and compared different types of walls and their impact on energy use in different energy zones and ascertained that a correct building envelope must be designed in such a way as to take into account the climatic zone in which it is built. They concluded that building envelopes should be designed to enhance energetic performances relative to local climate conditions. Gieseler et al. [19] have found the optimal envelope composition with regard to costs and proved the optimal thermal insulation levels for floor, roof or bottom floor with the help of a model for Germany's climate. Energy savings of 31.4% and peak-load savings of 36.8% from the base case were recorded for high-rise apartments in the hot and humid climate of Hong Kong by implementing passive energy-efficient strategies. The strategies include adding extruded polystyrene (EPS) thermal insulation in walls, whitewashing external walls, reflective coated glass window glazing, 1.5 m overhangs and wing walls to all windows [20]. It is necessary to pay attention on glazing surfaces. Daylight optimization at an early design stage can be referred to a way of designing architectural forms that take advantage of the prevailing urban context, such as existing shadow masks, to achieve a comfortable interior environment while minimizing energy use and reliance on artificial lighting systems [21]. To achieve better energy efficiency it is necessary to be up to date with late technology and making comparison between energy-efficient buildings [22].

As a building with a specific energy demand can be constructed of various combinations of envelope composition, the basic aim of the current study is to determine the optimal envelope composition at a selected value of energy indicator for timber buildings in the phase of building planning with regard to initial investment costs. The developed approach takes place in three steps. Firstly, constant parameters and limits such as location, orientation, climate zone etc., are defined. A case study is carried out on a simulation model of an existing building, which fulfils the minimum requirements of Slovenian national legislation related to the energy performance of buildings [23]. The basic variable parameters influencing the energy demand of the simulation model are the composition of the envelope. In the next substeps we start reducing the heat transfer coefficient of the variable envelope parameters. The paper presents the solutions of various parameter combinations with regard to energy efficiency and initial investment costs of building envelope. The investment costs are based on data derived from local Slovenian companies for the construction of timber buildings. In the second and third steps we calculated the PV of costs for heating and the cost of the boiler room.

2. Energy efficiency and timber-frame buildings

2.1. Energy-efficient building

An energy-efficient building has to feature a correct architectural design, which enables passive building strategies, such as solar loads, natural ventilation and other climatic conditions in order to reduce the energy demand. In combination with correct architectural design and the use of low-energy materials and technologies an apartment building uses less energy for heating or cooling. Many different measures can have an impact on the efficient use of energy [24]:

- thermal technical building characteristics,
- introducing technologies for the exploitation of renewable energy sources,
- efficient low-energy systems of building installations;

Besides technical characteristics the selection of an appropriate concept of building design is of prime importance, where appropriate building orientations, shape factor, exposure to solar radiation, quality and share of glazing have to be selected according to macro- and microclimate data. Researching the optimal glazing size has already been presented in a study [25,26], where the most favourable proportion at a certain thermal conductivity of walls according to energy demands for heating and cooling has been determined for an individual timber house. The proper architectural design of a building envelope can significantly reduce the energy usage through day lighting, reduced HVAC loads, etc.[27].

In this paper we used Slovenian national legislation as a starting point in our observations because we operate with costs in Slovenia and the case study is located in Slovenia. Slovenian national legislation follows the EU directive on building energy efficiency EPDB 2002/91/ES and new directive EPDB 2010/31/EU. According to national rules[23] the energy efficiency of a building is achieved, when the following basic conditions prescribed by Eqs. (1)–(3) are satisfied and the maximal U-value of each envelope composition is lower, as prescribed.

(a) Annual specific demand for heating of a building (Qh) for residential buildings

$$\mathrm{Qh} \leq 45 + 60 f_{(0)} - 4.4 T_{(L)} \tag{1}$$

where $f_{(0)}$ or the so-called shape factor represents a ratio of the thermal envelope surface to heated volume of a building and $T_{(\mathrm{L})}$ is the average annual external air temperature.

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