Energy 108 (2016) 201–211

Contents lists available at ScienceDirect

Energy

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

Influence of the building shape on the energy performance of timber-glass buildings in different climatic conditions

Miroslav Premrov [a], Vesna Žegarac Leskovar [a, *], Klara Mihalič [b]

[a] University of Maribor, Faculty of Civil Engineering, Slovenia
[b] MEng, Lineal d.o.o., Slovenia

ARTICLE INFO

Article history:
Received 23 January 2015
Received in revised form
5 May 2015
Accepted 6 May 2015
Available online 29 May 2015

Keywords:
Shape factor
Glazing size
Energy demand
Timber-glass buildings
Climate conditions

ABSTRACT

Designing timber-frame houses with enlarged glazing mostly placed on the south side of the building offers numerous possibilities of creating structures with a highly attractive shape. Nevertheless, some general design guidelines claim that a non-compact building shape usually results in the increased energy demand for heating, [1]. The aim of the present research therefore is to demonstrate possible avoidance of the latter energy related problem. The research is based on a case study of a one-storey timber-frame house, taking into account the climate data for three different European cities, those of Ljubljana, Munich (Muenchen) and Helsinki, whose average annual temperature and solar potential differ significantly. Apart from the climate data, the main variable parameters are the building's shape factor (F_s) and the AGAW (glazing-to-wall area ratios) in the south façade of the building. With the ground floor area and the heated volume remaining constant, the parametric analysis is carried out for different building shapes, i.e. square, rectangular, L, T and U, with the three-layer insulating glass placed in the south façade only. The results point out that the total annual energy demand for heating and cooling depends on the increasing shape factor to a considerably higher extent in cold climate conditions with a lower solar potential (Helsinki). On the other hand, the analysis of the regions with a higher average annual temperature (Ljubljana) and solar potential in the heating period shows that the influence of highly attractive building shapes on the energy demand is evidently less important, especially when using the appropriate size and position of the insulating glazing.

1. Introduction

Witnessing an intensive focus of the sciences of civil engineering and architecture on searching for new ecological solutions and construction methods that would allow for higher energy-efficiency and, consequently, for reduced environmental burdening, new combinations of old building materials, such as timber and glass, are gaining ever more support. The measures employed to save energy vary in nature, and the decision maker is required to establish an optimal solution, taking into account multiple and usually competitive objectives such as energy consumption, financial costs, environmental performance, renewable energy utilization, etc., Diakaki et al. [2]. Many investigations have been carried out toward 100% renewable and sustainable energy [3,4], an extended overview of many other published recently can be found for example in Refs. [5,6]. Commercial and residential buildings consume almost 40% of the primary energy in the United States or Europe, and nearly 30% in China. Through integrating the technologies of energy-efficient and renewable energy utilization in building, NZEB (net zero energy building), which is an innovative concept for high-performance building, is proposed supported by an application of LCA (Life Cycle Assesment) in NZEB evaluation, Deng et al. [7].

Timber and glass were formerly rather neglected as construction materials. Timber is a live organisms' product and thus a natural material exposed to parasites and bacteria. Alternate exposure to humidity makes timber unsustainable while its organic structure accounts for its inhomogeneity which is a rather negative construction-related feature. Another specific area is timber's fire resistance. The all characteristics mentioned above are said to be the main drawbacks of using timber in construction in the past. The energy aspect of glass was because of its high thermal transmittance often treated as a weak point in the past which arise in high transmission losses through window openings. Additionally, due to a relative low tensile strength and low ductility glass was

* Corresponding author.
E-mail addresses: vesna.zegarac@um.si, vesna@imagine.si (V. Žegarac Leskovar).

http://dx.doi.org/10.1016/j.energy.2015.05.027
0360-5442/

also not considered as a primary load-bearing structural material. However with suitable technological development and appropriate use, timber and glass are nowadays becoming essential construction materials as far as energy efficiency is concerned. Their combined use is extremely complicated, from the energy efficiency aspect on the one hand and from the structural viewpoint on the other. A good knowledge of their advantages and drawbacks is thus vitally important.

As a natural raw material requiring minimal energy input into the process of becoming construction material, timber shows indisputable environmental excellence. It certainly represents one of the best choices for energy-efficient construction, since it also functions as a material with good thermal transmittance properties, if compared to other construction materials. On the other hand, the use of glazing in buildings has always contributed to openness and better daylight situation of interiors. Although characterized by weak thermal properties in the past, glass has been gaining an ever greater significance as a building material due to its improved thermal, optical and strength properties, resulting from years of development. The features of both building materials presented above lead to the development of a new type of structures, the so called timber-glass buildings, suitable for the construction of energy-efficient buildings where an optimal proportion and appropriate orientation of the glazing surfaces play an important part due to exploitation of solar radiation as a source of renewable energy within the passive use of energy for heating. The latter can contribute to higher thermal gains which in turn influence the reduction of the building's total energy demand. A further advantage lies in substantial contribution to the living comfort, not only in a sense of the energy demand for heating and cooling, but also according to improved daylight. Unfortunately, a desire for energy generation through solar gains is often in conflict with some other functional requirements, such as prevention of overheating in cases where considerably high amounts of solar gains could lead to the requirement for additional cooling during the summer period, Wurm [8]. However, the thermal performance can be treated as one of the main disadvantages of large transparent façades if these are not correctly designed. The thermal transmission of glass elements is usually significantly higher than that of external timber-frame wall elements. It is therefore of utmost importance to determine the optimal size of glazing placed in the envelope elements and to consider every single parameter necessary for a complete energy treatment of the building, with a careful balance between the above mentioned advantages and disadvantages.

The issue of determining the optimal proportion and orientation of the glazing surfaces is rather complex. A research on the optimal glazing size, based on a case study of a two-storey timber-frame house, carried out in Žegarac Leskovar and Premrov [9] presents the analytical functional dependence of the AGAW (glazing-to-wall-area ratio) on the thermal transmittance coefficient of the external wall (U_{wall}) of the building. This relation allows a selection of any external wall element with a specific U_{wall} and consequently a selection of the optimal AGAW value, which decreases with the increase of the U_{wall}. For instance, the optimal AGAW for the south oriented three-pane insulating glazing installed in a timber-frame house with external wall elements of $U_{wall} = 0.10$ W/m^{2}K is between 34% and 38%, while the glazing surface for walls with $U_{wall} = 0.18$ W/m^{2}K should cover almost 54% of the south façade. However, the findings of the study are applicable only to simple rectangular-shaped buildings. Further economic analysis on the simulation case of a timber-frame house with the optimal size of glazing is presented in Soršak et al. [10]. 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.

Planning timber-frame houses with enlarged glazing surfaces offers many possibilities of designing structures with highly attractive shapes, which are more fragmented than those having a simple rectangular shape. However, some of the existing studies prove that an attractive and dynamic design leads to the increase of the building skin surface, which may result in higher heat transmission losses. For example, the impact of RC (relative compactness) on the building's annual cooling energy demand and the total annual energy demand was investigated by Al Anzi et al. [11], whose research involved a prototypical building with over 20 floors based in Kuwait. Several building models with various shapes (L, U, T, cut shape, cross shape, trapezoid) were chosen for the simulation analysis. The results of the study indicate that the energy use decreases as the relative compactness increases, if a building without windows is considered. Moreover, the study focuses on the influence of the window-to-wall area ratio and on that of orientation exerted on the energy use, with the analysis being carried out for various window sizes and glazing types. In this field, Depecker et al. [12] studied the relationship between shape and energy requirements during the winter season in two French localities with different climate conditions. They found no correlation between the energy consumption of a building and its shape in a mild climate. Albatici and Passerini [13] were encouraged to research new indicators of energy performance in mild and warm climate conditions in relation to the building shape. Heating requirements of buildings with different shapes placed in the Italian territory were presented in their research which was based on a monthly method and confirms that compactness is more important in cold localities than in warm ones. Danielski et al. [14] analysed the impact of the shape factor on the final energy demand by using five existing apartment buildings with different values of the shape factor. Simulations were carried out for different scenarios considering three variations of the thermal envelope and four climate zones. The findings indicate that the shape factor has a higher impact on the specific heat demand in buildings with lower thermal envelope properties (higher U-value) and in those located in colder climates. On the contrary, the shape factor influence is found to be diminishing in non-Nordic climates with the annual average outdoor temperatures above 14 °C for buildings with a high U-value of the thermal envelope and those above 11 °C for buildings with a low U-value envelope properties. Apart from the latter, the majority of the existing studies consider the influence of the shape factor on the building energy demand for similar climatic regions. The issue of the current study is thus to analyse the energy behaviour of a building with altering shape factors for different macroclimatic zones.

The first, theoretical part of the paper, briefly describes the present research considering the influence of different variable parameters, such as the glazing size and the building shape on the energy performance of buildings. Chapter 2 contains basic principles of energy flows in buildings, supported by main equations to be used further in the analysis, which are followed, in Chapter 3, by the explanation of parameters influencing the architectural geometry of the building. The second, analysing part of the paper, Chapter 4, consists of an extensive parametric numerical analysis of the building's architectural geometry and its impact on the energy flows through the building skin within three different macroclimatic zones. Concluding with Chapter 5, the focus is set on general findings to be linked with a set of basic guidelines providing architects with a tool for a quick estimation of the energy performance of timber-glass buildings with highly attractive shapes, in addition to that of rectangular-shaped ones.