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Energy saving potential of glazed space: Sensitivity analysis

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ABSTRACT

This study focuses on the impact of different types of glazed balconies on the energy consumption of buildings in northern climatic conditions. The starting point was a glazed balcony in a typical Finnish block of flats of the 1970s, whose impact on the energy consumption of the building was analysed with the IDA-ICE 4.6.1 software based on 156 different calculation cases. In light of the results of the sensitivity analysis, the five key factors affecting the energy engineering design of a glazed space are the integration of the space to the building's ventilation system, heat losses from the building to the balcony and from the balcony to outdoor air, the air tightness of the balcony and the absorption coefficients of its surfaces. Research has shown that higher energy savings in kilowatt hours can be achieved in a northern than a southern climate although percentage-wise savings are higher, for example, in Central Europe than in Finland. Thus, the determination of energy savings by kilowatt hour gives a better idea of the true significance of balcony glazing in a building than a percentage-wise analysis.

1. Introduction

Large glazed spaces have been architecturally and structurally interesting building details for centuries [1–3]. Their attraction has been based on the large size of the spaces, novel architectural solutions and interesting details. However, these spaces have not usually been built solely for architectural reasons but functional requirements have also been set for them as they have served as hospital waiting areas, or as reception areas of office buildings. The design of such spaces is based on the required indoor air conditions, such as minimum acceptable indoor air temperature, desired average temperature and maximum acceptable temperature. They determine the implemented solution, which takes into account issues such as heat losses of the building and the space, storage of solar radiation, solar protection and minimisation of cooling and heating needs, if the required indoor conditions cannot be achieved without an external energy source [4].

Glazed spaces in Finland are not usually big and impressive structures but quite simple and rather small spaces, such as glazed balconies. According to information received from the manufacturers, more than 500,000 of them have been installed in this country. Comparison of this figure to the housing database of Statistics Finland reveals that about 70% of Finnish flat balconies are glazed. As a rule, glazing has not been installed to improve indoor temperature conditions, nor has the glazed space been designed for maximum thermal comfort, but the basic idea in our northern climate has been to improve the usability of the space and protect the balcony structures enclosed by the glazing [5]. Therefore, no special requirements for the indoor air conditions of glazed balconies have been presented in Finland.

The most typical Finnish balcony solution consists of stacked balconies on separate foundations protruding from the facade [6] implemented as an uninsulated precast concrete structure with untight single glazing [7]. For this reason, continuous heating of the balcony is uneconomical [8] and very rare in these latitudes. It is also typical in Finland that the energy saving and overheating impacts of balcony glazing are not known and therefore some residents keep their balcony glazing partly open through the winter, reducing the energy saving impact, and fully closed during summer, which causes overheating problems [9,10]. Thus, practical advice on the energy and indoor climate impacts and optimal use of glazing is needed. The need of such information has also been observed in previous studies [4,11].

The purpose of this study is to reveal the factors affecting the energy engineering design of glazed spaces and the magnitude of their impacts in northern climate by sensitivity analysis. In the same context, we also intend to indicate the factors with the greatest impact on the energy efficiency of buildings and produce

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information that allows improving the impact of energy efficiency measures undertaken in renovation and new construction. The basic case is a typical Finnish prefabricated concrete block of flats completed in the 1970s with protruding balconies.

2. Factors affecting the thermal conditions of glazed spaces—Background

One factor that affects the temperature conditions of glazed spaces is the location of a building. It has virtually no effect on the ability of the glazed space to store solar radiation [4], but a different location changes outdoor air conditions which may have a significant impact on the energy savings achieved by the glazed space. It is typical of cloudy and rainy climatic conditions that the share of diffuse radiation of short-wave solar radiation is large [12]. In windy areas glazing plays an important role as a thermal buffer zone, reducing heat losses by transmission and infiltration [13]. Rain falling on the glazing is also of significance because it cools down the exterior surface of the glazed structure and increases heat losses to outdoor air. Spray irrigation is actually used as a cooling method in warm climates [14].

The basic principle regarding location is that the more southern and milder the climate is, the bigger the energy savings percentage-wise. This is due to the increased amount of energy absorbed by the space due to the increased intensity of solar radiation [15]. However, the energy savings in kilowatt hours decrease simultaneously [16]. The highest energy savings are possible in a sunny and cold climate [13], such as that of the Southern European Alps. From the point of view of the availability of solar energy it is important that the space is appropriately orientated towards the equator ($\pm 30^{\circ}$), although it has been observed that orientation does not play a major role as an energy saving issue [17].

To maximise the temperature difference between the glazed space and outdoor air, it is really important to optimise the balcony type and size, as well as the thermal insulation capacity and air-tightness of the structures. As a balcony type a recessed glazed balcony is superior to a protruding balcony because it has a smaller exterior glazing and profits more from the building heat losses and solar energy absorbed by the walls that connect the balcony space to the interior space [17,18]. Increasing the length of a balcony also increases heat losses from the building to the balcony. In general, a long and narrow balcony is recommended for maximising energy savings and natural light [19].

The material properties of the glazed space and the building external wall affect the energy savings gained by the glazed space. According to Ref. [20], for example, the thermal conductivity of the wall has a strong influence on the heat flux through the wall, but the density and heat capacitance (C) do not affect the values of the heat flow or the air and wall temperatures greatly [20], albeit heat capacitance affects temperature variations and thermal comfort of the space [4]. By contrast, the absorption coefficients of the surfaces and the ability of the space to store solar radiation have a strong impact on the interior temperatures of the glazed space and achieved energy savings [4].

External obstructions and solar shading affect the solar radiation stored in the glazed space. The presence of shadings during the winter months increases the thermal resistance of the sunspace external walls and blocks radiation exchange between sunspace walls and deep sky [15,21]. In summer, relatively large glazed areas of glazed balconies can lead to overheating of the balcony or the adjacent rooms [8] even in northern climates [22] in the absence of shading.

The air-tightness of the balcony has a marked impact on the temperatures of the glazed space. Ventilation with outdoor air removes a fraction of the energy absorbed and consequently lowers the temperature of the sunspace [15]. The air exchange rate of untight glazed spaces varies daily and is highly dependent on the temperature difference between the glazed space and outdoor air as well as wind conditions [4]. The building's ventilation solution also affects the end result. From the point of view of the heating energy savings of a building it is advisable to integrate the glazed space with the mechanical exhaust ventilation and thus utilise the glazed balcony as a supply air pre-heater [13]. In this case summer time overheating of the glazed space could cause also warming of the adjacent flat, if the supply air terminals between the glazed balcony and the flat are not easily closable [23]. A recommended solution for preventing the glazed space temperature rise is the use of appropriate solar shading [22] and opening of the glazing [24].

3. Research materials and methods

3.1. IDA-ICE simulation

The energy engineering analysis of glazed spaces is a special calculation case, and no commercial energy simulation software has been designed specifically for it. Thus, used simulation software is usually validated before it is used to model glazed spaces. An important aspect of the calculations is that the dynamic simulation software should take daily and yearly climatic variations into account, model the spaces geometrically, divide solar radiation into direct and diffuse radiation and correctly distribute solar radiation into the space and the adjoining building as well as through window structures. Surface resistances must also be calculated as temperature-dependent variables and more attention be paid to long-wave sky radiation calculations than in normal energy calculation [4]. The IDA-ICE 4.6.1 software used in this study incorporates the above features [25]. The software as many other whole building energy simulation tools is based on the building geometrical description, which provides the basis for a more detailed calculation of the distribution of solar radiation in and between rooms. The software calculates energy balances dynamically taking into account climatic variations and a dynamically varying time-step. The software solves heat balance equations according to the user defined building geometry, construction, HVAC conditions and internal heat loads. Software allows use of measured climate and weather file containing the information about air temperature, relative humidity, wind direction and speed, direct normal radiation and diffuse (sky) radiation on a horizontal surface and calculates for example solar radiation based on the building location and sun position in the sky. Accuracy of the IDA-ICE simulation tool has been examined in many validation studies in recent years [26–36]. Accordingly, selection of the IDA-ICE as the simulation tool for highly glazed space simulation is well grounded [26,28,37,38].

3.2. The modelled building and its main parameters at the beginning of the simulation

The idea of the simulation study was to create a base model which represents the typical building in Finland as well as possible. Then, a sensitivity analysis was conducted by making successive changes to the base model and performing re-simulations after each step. The variables were chosen from parameters found in a literature review to have an impact on the energy savings achieved by balcony glazing. This analysis was used to determine the relative effect of each individual parameter on building energy consumption. The final analysis included 34 calculation variables and 2 to 35 calculation cases for each. The total number of calculation cases in the sensitivity analyses was 156. The sensitivity analyses covered a wider scope than any of the studies presented in Section 2.