Energy and Buildings 127 (2016) 242–251

Contents lists available at ScienceDirect

Energy and Buildings

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

Detailed and simplified window model and opening effects on optimal window size and heating need

Martin Thalfeldt [a,*], Jarek Kurnitski [a,b], Hendrik Voll [a]

[a] Tallinn University of Technology, Faculty of Civil Engineering, Ehitajate tee 5, 19086 Tallinn, Estonia
[b] Aalto University, School of Engineering, Rakentajanaukio 4 A, FI-02150 Espoo, Finland

ARTICLE INFO

Article history:
Received 25 June 2015
Received in revised form 31 May 2016
Accepted 1 June 2016
Available online 2 June 2016

Keywords:
Energy simulations
Windows
Glazing
Façade design
Energy efficiency
Indoor climate

ABSTRACT

The purpose of this study is to quantify the gap between the calculated energy need of a building model with simplified and detailed windows and suggest a method for reducing the gap. A model of a detached house in the cold climate of Estonia was composed and its energy needs with triple and quadruple windows was studied. The window sizes and opening strategies were also varied and all cases were modelled with simplified and detailed window models of which the latter were modelled pane by pane according to the methodology of ISO 15009. Simplified window models resulted in heating need lower by up to 7% and cooling need higher by up to 23%. The optimal window sizes of South facing triple windows remarkably depended on the glazing model and window opening strategy used. Therefore using simplified window models and inappropriate methodology might lead to inadequate facade design. In case of triple windows multiplying the U-value of simplified window models by 1.15 minimized the mismatch in calculated heating needs with different window models. It is recommended to use detailed window models to be used in simulations of mechanically cooled buildings.

1. Introduction

Several countries in the European Union require making energy simulations to prove new buildings' compliance with energy performance minimum requirements. Expected energy use is calculated, however it rarely complies with actual measured consumption. Reducing the gap between calculated and measured energy is currently one of the main problems faced in the field of building energy analyses.

Façades have a large effect on the building energy use while the size and properties of glazed areas are especially important. Numerous papers on optimizing window areas have been published. Thalfeldt et al. [1] and Pikas et al. [2] studied cold climate office building facades with several glazing types and optimized the total cost of investment and energy over a 20 year period. It was concluded that triple windows with areas that assure the required daylight factor 2% is the financially feasible solution and in case of four and five pane windows, larger window areas could be used to optimize energy use. In the study published in 2011, Jaber and Ajib [3] studied various window types and sizes in three different climates with Berlin being the coldest. They concluded that window design, especially glazing choices, is a critical factor to effectively utilize solar energy. At that time, double glazed windows were the most economically reasonable choice and triple windows showed best performance regarding energy use. Persson et al. [4] studied the window sizes of dwellings in a cold climate and pointed out that the window size of South-oriented windows does not have a remarkable effect on heating need and smaller windows might be reasonable to reduce over-heating and cooling needs. Gasparella et al. [5] analyzed the energy performance of a single-family house in four different European climates with varying window types and sizes. They pointed out that large glazed areas with low thermal and high solar transmittance improve winter performance and worsen summer performance. The latter could be improved by installing selective shading systems. On the other hand, Ihm et al. [6] suggested imposing an upper threhold level for the solar heat gain coefficient for windows of residential buildings after modelling a building in two major South-Korean climate zones. Vanhoutteghem et al. [7] studied various facade window parameters' effect on energy use, thermal indoor environment and daylighting in Danish nearly zero-energy single-family houses. They concluded that in well-insulated houses increasing g-values above 0.3–0.4 has a limited effect on reducing heating demand and U-values between 0.3–0.5 W/(m^2 K) are needed for using large glazed areas. They said that windows have to be carefully dimensioned to reach the

* Corresponding author.
E-mail addresses: martin.thalfeldt@ttu.ee, martin.thalfeldt@gmail.com (M. Thalfeldt).

http://dx.doi.org/10.1016/j.enbuild.2016.06.002
0378-7788/

daylight target without overheating South-oriented rooms. Similar suggestions were given by Skarning et al. [8] for the climate of Denmark and they added that slighly higher U-values could be used in the climate of Rome. Skarning et al. [8] also pointed out that focus should be set on minimizing thermal transmittance of glazing and frames instead of maximizing solar gains in South-oriented rooms, which increases the risk of overheating. Opening windows is an effective method to reduce overheating according to Mavrogianni et al. [9] and Rijal et al. [10]. Rijal et al. concluded that people open windows, when indoor and outdoor temperatures increase and they developed an adaptive algorithm for window-opening behaviour.

All the previously mentioned articles used energy simulations and it essential to determine that the used software is validated. Roux et al. [11] developed a glazed space simulation model and succesfully validated it. A dynamic energy and indoor climate modeling tool IDA-ICE [12] was used in the current analysis and several studies have also included this software. Bring et al. [13] have described the mathematical models used in IDA-ICE in Neutral Model Format that can be automatically translated into executable code for various simulation environments. In 2003–2007 Loutzenhiser et al. [14] validated several dynamic energy and indoor climate simulation tools and made suggestions for improving the softwares. IDA-ICE 4.0 was among the studied programs and it performed well in comparison with other softwares. Validation processes of IDA-ICE have been described in Ref. [15] and [16]. The detailed window model of IDA-ICE has been validated against ISO 15099 [17] and a modelling software Window [18], which is developed by Lawrence Berkley National Laboratory. Crawley et al. [19] compared 20 energy simulation softwares and the study indicated that IDA-ICE is suitable for analysis of glazed areas. Hilliaho et al. [20] measured air temperatures in glazed and unglazed balconies and compared them with simulated ones, which were obtained by using IDA-ICE 4.6. The correlation was good and highest modelling accuracy was reached by using detailed window and zone climate models.

Generally, energy specialists use simplified window models with constant U-values in energy simulations, however the thermal resistance of glazing varies depending on the outdoor temperature, wind speed and direction. Kurnitski et al. [21] showed in their article that the temperature difference between inside and outdoor conditions affects the thermal transmittance of glazing significantly. Petersen [22] calculated the heating energy of a building using a constant declared U-value of glazing and a more accurate dynamic U-value that varied for each hour of the climate year. Constant U-value could lead to significant under estimation of heating energy in cold climates and Petersen suggested using the described dynamic method for energy calculations. Several dynamic simulation softwares including IDA-ICE 4.6 [12] allow creating detailed glazing models consisting of panes, cavities and shading devices. Detailed window models take the changes in external conditions into account and calculate the energy balance of glazing more accurately than simple models. In Ref. [23] energy simulations were conducted to determine the differences in calculated energy use of a detached house in Estonia if simplified and detailed window models were used and concluded that gaps in heating and cooling needs were up to 7% and 23% respectively. The use of detailed glazing models was recommended, but also a correction factor of 1.15 was suggested for simplified triple glazing model, when calculating only the heating energy.

The purpose of this study is to quantify the gap between the calculated energy need of a building model with simplified and detailed windows and to suggest a method for reducing the gap. A model of a detached house in the cold climate of Tallinn, Estonia was composed and its energy needs with triple and quadruple windows were studied. The size of glazed area in the South and West façades was also varied. Cases with closed windows were compared to a model where windows were opened to reduce over-heating and a case with cooling was added. The difference in energy needs between models with simplified and detailed windows were compared, correction factors for simplified window U-values to reduce the gap in heating need were calculated and tested. Optimal window sizes with various glazing models and opening strategies were calculated and also over-heating degree hours during the summer period were investigated. In comparison to Ref. [23] the current article presents the results of West facade analysis and additional information regarding solar gain differences between models and studied summer-time over-heating was added.

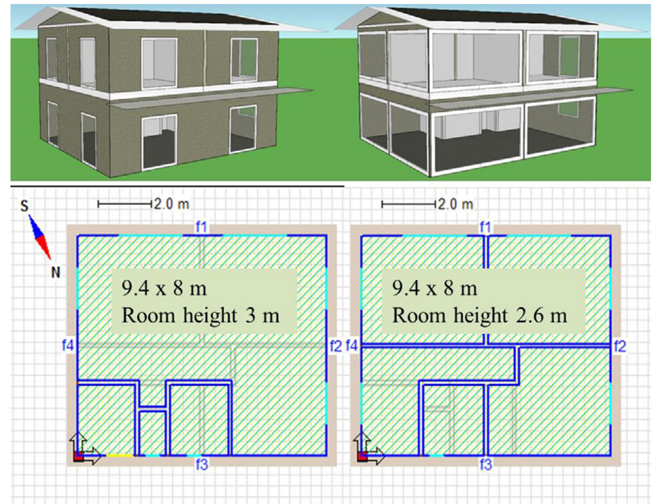

Fig. 1. The 3D view from South-West with minimum and maximum window sizes (top left and right respectively), first and second floor plans (bottom left and right respectively). The light blue lines on the perimeter of building envelope show the positioning of windows. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

2. Methods

The analysis was conducted in the following steps:

1. Simulations with a simple 2.5 × 4.0 m South facing zone model to determine the heat losses at design outdoor temperature and to verify the annual solar gains through different glazing models with number of panes ranging between 2 and 5
2. Energy and indoor environment simulations of a model of a detached house (Fig. 1) with triple and quadruple glazing, varying window sizes, simplified and detailed window models
3. Comparing the heating and cooling needs of models, that had simplified and detailed window models and were identical otherwise. Determining the gap between the energy needs of models with simplified and detailed windows
4. Determinining the window sizes that result in smallest heating and cooling needs, which were considered the optimal solution
5. Determining the correction factor for simplified triple glazing models and verifying the remaining mismatch in energy need calculations

2.1. Calculation principles of different glazing models

The used modelling software IDA-ICE offers the opportunity to use either simplified or detailed window models. The simplified window models are called Standard windows and their parameters are constant throughout the simulations, while the energy balance of detailed windows are modelled according to physical formulas. Simplified window model is based on common proper-