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Comparison of simplified and detailed window models in office building energy simulations

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Abstract

The aim of this study is to quantify the gap between the simulated energy need of an office building with simplified and detailed glazing models. We studied triple, quadruple and quintuple windows and concluded that differences in energy need of similar cases with different glazing models reached 1.9 and 6.4 kWh/m^2 in space heating and cooling needs respectively. Significant relative differences in heating and cooling were up to 14% and 40% respectively. Largest differences appeared with triple glazing and smallest with quadruple glazing. Compared to detailed window models standard triple and quadruple glazing models resulted in lower heating and higher cooling needs, whereas in case of quintuple windows the results were the opposite.

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1. Introduction

Energy simulations of building are a wide-spread method for assessing new buildings energy performance. Simulations are conducted to analyze different building solutions' effect on energy efficiency and indoor climate. However, calculated and measured energy uses rarely match and amongst the causes of the differences are the inaccuracy of simulation models used.

Numerous façade analyses have been conducted in recent years that have used both simplified and more detailed methodologies. Poirazis et al. [1] used simulation software IDA ICE 3.0 to show that increasing glazed of office building facades also increases energy use. Grynning et al. [2] calculated the U- and g-values of glazing, which

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assure the positive effect of window area on the energy use of a building. They compared three methods in their investigation and concluded that results depended on the method used. Petersen [3] 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. Arıcı et al. [4] carried out a numerical study of the properties of double, triple and quadruple glazing and pointed out that the nature of energy balance of glazing depends on external conditions.

Generally energy specialists use standard 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. The purpose of our study is to quantify the gap between the calculated energy need of an office building model with simplified and detailed glazing models. Similar work was also done in [5] using a model of a single-family building. We composed a generic open-plan office floor model in IDA ICE 4.6 [6] with triple, quadruple and quintuple windows with varying sizes. All cases were created with both standard glazing and detailed glazing models of which the latter took into account the changing external and internal conditions while simulating the energy balance of glazing. The results presented in this article are the bases for further work regarding the effect of window model on the outcome of façade analysis.

2. Methods

2.1. Generic office floor model

Energy simulations were conducted on the basis of a generic open-plan office single floor model similar to the ones we used in [7] The floor model was divided into 5 zones - 4 orientated to south, west, east and north respectively and in addition one in the middle of the building. The longer zones consisted of 12 room modules of 2.4 m and shorter ones of 5 room modules, resulting in inner dimensions of the floor 33.6 x 16.8 m. In all cases ideal heaters and coolers were used and mechanical supply and exhaust ventilation with heat recovery was used. Total of 34 occupants were in the perimeter zones i.e. 2 persons per module and installed power of plug loads and lighting was 12 and 7 W/m^2 respectively. The working hours were from 7:00 to 18:00 on weekdays and the usage factor of heat gains during working hours was 55%. Ventilation air flow rate was 2 l/s per floor m^2 and the air handling unit worked from 6:00 to 19:00 on weekdays with constant supply air temperature 18 °C. The energy simulations were conducted with well-validated simulation tool IDA ICE 4.6 [6] using the Estonian methodology for energy calculations [8] and the test reference year of Estonia[9].

2.2. Studied facade cases

We studied the behavior of triple, quadruple and quintuple glazing with varying window sizes. Each office module had one window with height of 1.8 meters and the bottom edge was 0.9 meters from the floor. The minimum window size was chosen so that the average daylight factor in the control zone was 2% as required in [10]

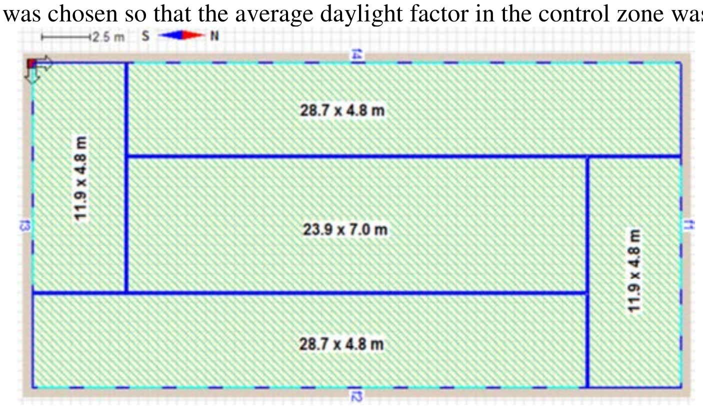

Fig. 1. The generic model of the open-plan office floor. Light blue lines at the perimeter mark the position of windows.

Table 1. Glass pane properties of detailed window models.

Pane	Thermal conductivity, W/(mK)	Total shortwave transmittance, -	Outside		Inside	
			Total shortwave reflectance, -	Longwave emissivity, -	Total shortwave reflectance, -	Longwave emissivity, -
Low-e	1.0	0.62	0.23	0.89	0.27	0.03
Clear	1.0	0.85	0.08	0.89	0.08	0.89

Table 2. The properties of studied window types and the U-value of external wall used with respective window types.

No of panes	Glazing U-value[a], $W/(m^2K)$	Gas filling	Gap width, mm	Glazing g-value	Frame U-value, $W/(m^2K)$	Window U-value, $W/(m^2K)$	External wall U-value, $W/(m^2K)$
3	0.55	90% Ar	18	0.45	0.8	0.59	0.16
4	0.29	95% Kry	15	0.34	0.32	0.29	0.13
5	0.21	95% Kry	15	0.25	0.21	0.21	0.09

[a] - The U-value of standard windows remained constant during simulations and is given according to calculations of ISO 15099:2003/E at internal and external temperature difference of 20 °C. The U-value was dynamic during simulations in case of detailed windows and was calculated also according to ISO 15099:2003/E.

and the calculations are described in our previous work [7]. Quadruple and quintuple glazing are not economically reasonable, however they might be one possible solution to design and build nearly zero energy buildings in the future. It is reasonable to increase the external wall insulation thickness while improving windows. Based on our previous work we chose appropriate external wall U-values for each window type [11] and they are also provided in table 2. The window width was increased with a step of 0.3 meters up to width of 2.4 meters. The investigated window sizes for different glazing types were:

- 3 pane window widths 1.05, 1.2, 1.5, … 2.4 meters; window-to-wall ratio 24% … 55%
- 4 pane window widths 1.15, 1.2, 1.5, … 2.4 meters; window-to-wall ratio 26% … 55%
- 5 pane window widths 1.3, 1.5, … 2.4 meters; window-to-wall ratio 30% … 55%

We created detailed window models in IDA ICE and glazing consisted of highly transparent panes, which had a low-emissivity coating on a pane in each gap. Table 1 describes the parameters of panes, whereas each glazing had one clear pane and other panes had low-emissivity coatings. Table 2 describes the parameters of windows at standard conditions determined in ISO 15009 [12] i.e. at temperature difference of 20 ° C. The simulation software used the methodology of ISO 15009 for calculating the energy balance of detailed glazing models and constant window parameters given in table 2 were used for calculations with standard glazing models. Another important difference is that standard glazing models use and an angle dependence to calculate the solar transmittance and absorptance of glazing, while the energy balance of detailed window models is calculated based on physical formulas. Each pane and their interactions of detailed glazing are taken into account with detailed window models.

3. Results

The analysis show that similarly to detached houses [5] using standard triple and quadruple window models result in lower heating needs and higher cooling needs. However in case of 5 pane windows, the results are the opposite – standard quintuple glazing results in higher heating need and lower cooling need. Figure 2 presents space heating and cooling energy needs with standard and detailed glazing models in case of south, east, west and north oriented zones respectively. The proportions of heating and cooling vary depending on the façade orientation and window type. Therefore simulated total energy need could be higher with either glazing model type in comparison to the other.

Total energy need with triple windows was generally higher with standard glazing models in south, east and west facades due to relatively large proportions of cooling energy. In south the difference ranged between 0.8-4.9 kWh/m^2, in east between 0.1-1.1 kWh/m^2, in west between 0.0-1.6 kWh/m^2, whereas total energy need was slightly lower with standard glazing in east and west orientated zones with small triple windows. The results were the opposite in the north façade as heating need dominated. Triple standard glazing in north façade resulted in lower total energy need by 0.9-1.1 kWh/m^2. In case of quadruple glazing, the only orientation where detailed models provided lower total energy need was the south, where the difference was between 0.2-1.2 kWh/m^2. In east detailed glazing resulted in higher energy need by 0.3-0.5 kWh/m^2, in west by 0.4-0.8 kWh/m^2 and in north by 0.1-0.2 kWh/m^2. In the north façade, smaller standard 5 pane windows resulted in total energy need higher by up to 0.2 kWh/m^2 and in case of larger standard windows the energy need was smaller by up to 0.4 kWh/m^2.

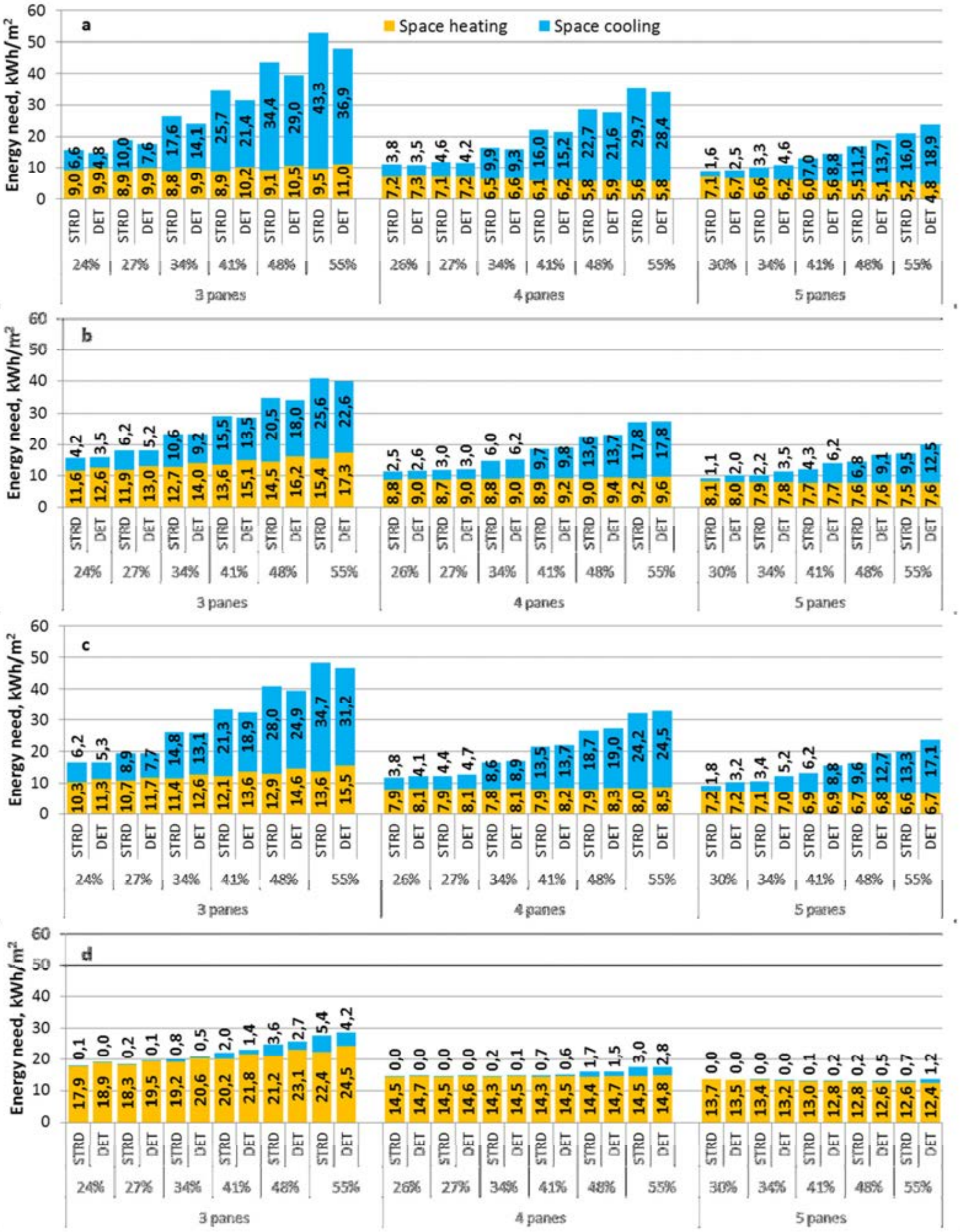

Fig. 2. Space heating and cooling needs in the (a) south, (b) east, (c) west and (d) north oriented zones in case of standard and detailed window models. Code: STRD – standard window model, DET – detailed window model; 24% means window-to-wall ratio 24%.

Analysis of heating and cooling need demonstrated that differences in heating are smaller than in cooling. Figure 3 presents the simulated energy need difference of detailed window models from respective standard window models. Values over 50% are not presented in figure 3b, because the absolute difference was under 0.4 kWh/m^2 in all such cases and increasing the range of vertical axis would have made the figure harder to read. Largest differences in heating energy appeared with triple glazing and the increase with detailed glazing ranged between 0.9-1.9 kWh/m^2 i.e. 9.3-13.8%. In case of 4 and 5 pane windows the differences in heating need remained within 0.5 kWh/m^2 i.e. 0.1-8.2%. Detailed windows resulted in lower cooling need by up to 6.4 kWh/m^2 in case of large south oriented triple windows and in higher cooling need by up to 3.8 kWh/m^2 in case of large quintuple windows in the west façade. Cooling energy difference with quadruple glazing remained below 1.3 kWh/m^2. Relative differences in cooling energy were higher with smaller windows and thereby also cooling needs. Therefore bringing out the largest differences in cooling energy is not reasonable, but if absolute difference in cooling energy was higher than 1 kWh/m^2, then the relative differences up to 40% occurred.

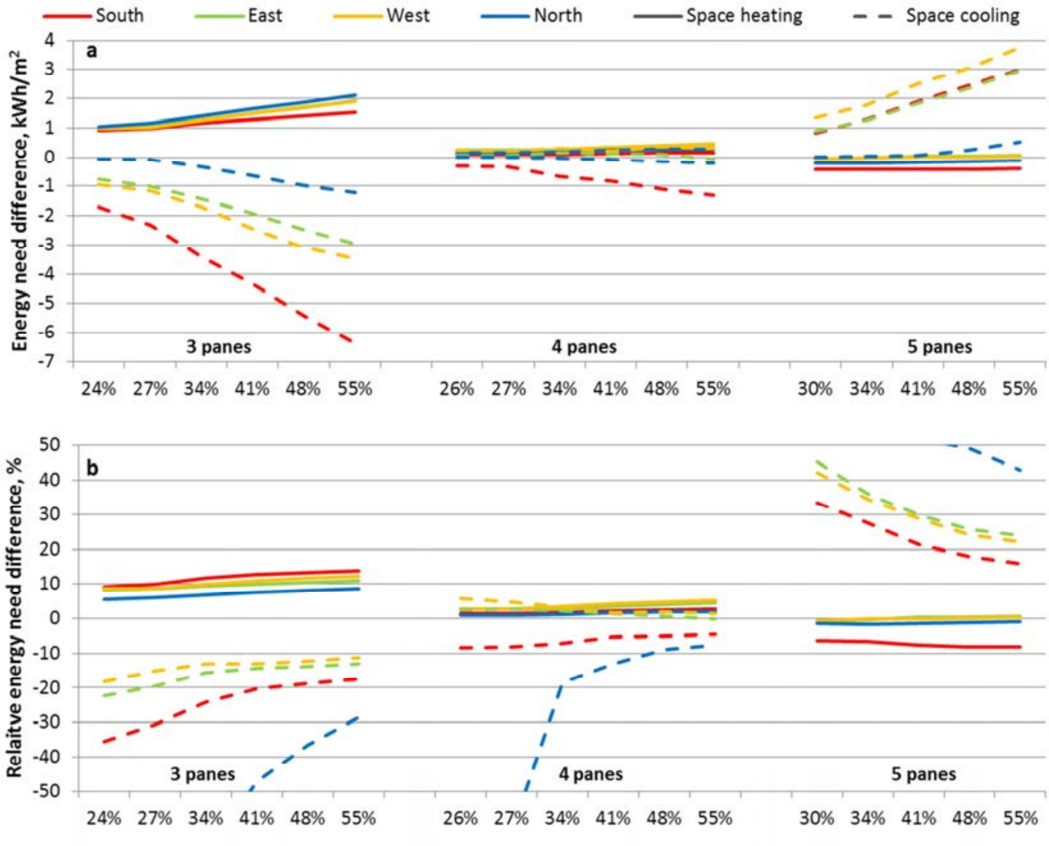

Fig. 3 Detailed window models space heating and cooling need difference from standard window models in zones with different orientations and window types. (a) energy need of detailed window models has been deducted from standard window models respective value; (b) value shows how much the energy need with detailed glazing differs from standard glazing. Code: 24% means window-to-wall ratio 24%.

4. Discussion and conclusions

In this paper we brought attention to the differences in the results of office building energy simulations if simplified standard glazing models of more accurate detailed glazing models are used. We conducted simulations using the cold climate of Estonia and highly transparent 3, 4 and 5 pane windows. The differences in energy needs were highest in case of both heating and cooling with triple glazing and with quintuple glazing in cooling energy needs. The largest difference in heating need was 1.9 kWh/m^2 i.e. 13.8% and 6.4 kWh/m^2 in cooling need, whereas highest relative differences in cooling were around 40%, when the absolute difference was above 1 kWh/m^2. Larger relative differences in cooling energy also occurred, but the absolute difference was small in those cases. Largest differences appeared with triple glazing and smallest with quadruple glazing. Compared to detailed window models standard triple and quadruple glazing models resulted in lower heating and higher cooling needs, whereas in case of quintuple windows the results were the opposite. The sum of space and cooling heating need could be higher in both glazing model cases depending on the number of panes and the size of the windows. Therefore it is difficult to suggest any correction factors for the parameters of standard glazing models as was done in [5].

We have identified the differences in the simulated energy need however it is unknown if the differences have significant effect on the outcome of office building façade analysis. The choice of heat and cooling sources affects the differences in delivered energy and also energy cost. In [7] and [11] we presented financially feasible solutions office building façade design, however standard window models were used. The outcome of this study revealed that in would be reasonable to repeat previous studies with detailed window models and compare the results to determine the importance of simulation models in façade analysis. Also our current work needs to be supplemented with similar analysis considering various solar shading solutions.

Right now it can be recommended to use detailed window models for design decision making typically being based on analyses with single floor models. For energy performance compliance assessment typically done with full building models the accuracy of standard window model may be seen satisfactory in office buildings in cold climates.

Acknowledgements

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