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Towards Net Zero Energy Buildings: building performance optimization, simulation and analysis

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Abstract. The European Union 2020 energy targets seems to be a progressive, however, it still needs to be worked upon. The implementation of Nearly Zero Energy Buildings (nZEBs) as the building target represents one of the biggest challenges to increase energy savings and minimize greenhouse gas emissions. In this paper detached house has been modelled using dynamic simulation tool and the energy efficiency measures, concerning different technologies for envelope systems and technical systems, were set up as parameters in dynamic simulation tool and simulated and analysed. The objective of this paper is to define the heating, cooling, and electricity demand of a residential building in a cold climate region. The façade parameters were optimized for the best possible energy performance, to be used as design guidelines for facades in low and nearly zero energy buildings for architects and engineers. The purpose of the study is to give guidelines of office buildings facade design from the perspective of energy-efficiency and daylighting to architects, engineers, real-estate developers, etc.

1. Introduction

The concept of the Net Zero Energy buildings has been increasing in the latest years. And it has been implemented in many areas, from fossil fuels [1] and nuclear energy to renewable energy[2]. In the building industry, net energy is often referred to as an equilibrium between buildings power consumption and energy produced by renewable systems. Different researchers have adopted the terms "ZEB (zero energy buildings)" and "NZEBs (zero energy net buildings). Marszal et al. [3] and Sartori et al. [4] have found detailed definitions and descriptions. The U.S. Department of Energy's Building Technology program and the EU Energy Performance Directive have adopted or consider ZEBs as their future energy building targets [4]. Several case studies worldwide have also shown that ZEBs can contribute to the alleviation of depletion of energy resources and environmental degradation [5] [6] [7]. A summary of some recent studies is shown in Table 1.

Table 1. Summary of recent ZEBs case studies using sustainable and renewable measures.

Reference	Sustainable measures	Building Type	Renewable and other solutions	Countries
[6]	Thermal insulation and low energy glazing	Residential	PV, PV with solar thermal and air/solar HP, PV with DH grid	Denmark
[8]	-	Residential	PV, BIPV, solar hot water, wind turbines	Hong Kong
[9]	high-performance windows, high thermal mass walls, water-cooled air conditioning.	Residential	-	Las Vegas

[10]	Thermal mass, sun shading, evaporative cooling.	Residential	Solar thermal hybrid HP, PV-powered reversible HP	Madrid and Shanghai
[11]	Thermal insulation, cavity wall and double glazing	Residential	-	United Kingdom
[13]	Solar shading, night ventilation, special design strategies to minimize summer overheating and reduce the need for cooling energy use.	Office	-	Switzerland
[14]	Thermal insulation, thermal mass, double glazing and lower WWR.	Residential	-	United Arab Emirates

Several analyses were done on the influence of façade design on the energy usage of buildings.
Poirazis et al. [15] conducted office building energy simulations studying window-to-wall ratios (WWR) between 30% and 100%, different glazing, shading and orientation options Buildings with a lower WWR have been concluded that they use less power. Motuziene and Joudis [16] carried out similar analyses in Lithuania regarding office buildings. The findings showed that the best possible WWR was of 20-40percent, but problems with daylight requirements were observed.
Susorova et al. [17] simulated office buildings in 7 different climates and concluded that in cold climates increasing WWR increases office buildings' total energy consumption. Tzempelikos et al. [18] have concluded that considerable energy savings can be achieved by combining optimal glazing, shading and controllable electrical lighting systems through energy simulations from the institutional building.
Johnson et al. [19] optimized the use of daylight and studied orientation sensitivity, window area, glazing properties, window management strategy, installed lighting power, and control strategy.and concluded that substantial savings can be achieved with auto-controlled lighting, but total energy consumption has to be considered because the analysed parameters greatly influence energy use of HVAC.
It is widely recognized that buildings in colder climates use more power to heat and ventilate buildings than those in warmer climates. For Nordic climate, the net primary energy use and the primary energy use for office building are 50- 70 and 85-100 kWh/m^{2}yr respectively.[24].

The purpose of the study is to give guidelines of office buildings facade design from the perspective of energy-efficiency and daylighting to architects, engineers, real-estate developers, etc.

2. Methodology

2.1. Simulation method

This research study has used IES-VE dynamic simulation software. Key façade factors that influence the energy performance of buildings in particular, such as window types, wall insulation, WW**,** and shading systems, were configured in the case of a theoretical model of office floor and alternatively for the best achievable energy performance-**b**uilding geometry. Over the last 50 years, the IES-VE simulation tool has evolved into a robust and reliable simulation environment [25]. IES-VE has a sophisticated energy performance assessment capability compared to similar energy simulation tools [25]

2.2. Simulation weather file and climate

This research study has used the Finnish test reference year (TRY2012) as a weather data for energy simulations. Finland has the temperate coniferous-mixed forest zone with cold, wet winters and it comes under climate zone 1. According to the National Building Code of Finland (NBCF) for energy performance and heating power demand calculations of buildings [27] [28], Finland is divided into four separate climate zones (I–IV). The annual average temperature for Helsinki / Vantaa region is + 5.4°C [26].

2.3. Case study

Energy simulations were conducted based on a generic open-plan office three-floor model that was divided into 5 zones – 4 orientated to south, west, east and north respectively and in addition one in the middle of the building (figure. 1). Energy simulations were carried out based on a generic 3-story model of open-plan offices divided into 5 zones-4 oriented to south, west, east and north, plus one in the middle.

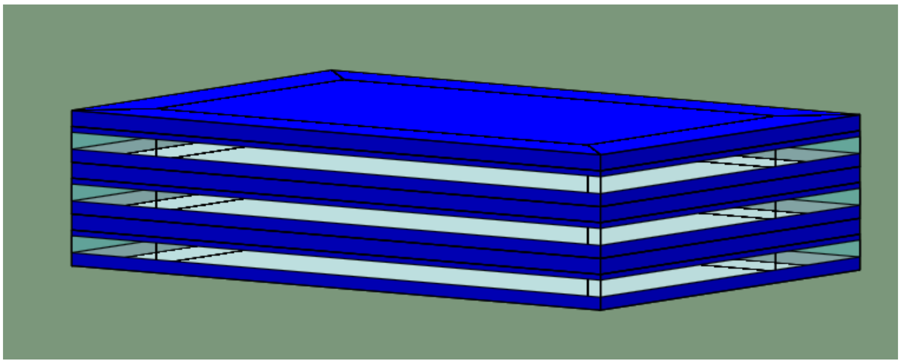


Figure 1. The generic 3D view of a single floor of the office.

Table 2 shows the initial data considered for the simulation. Lighting and shading control principles were adopted from [29]. The energy simulations were conducted with well-validated simulation tool IES-VE [25] and the test reference year of Helsinki was used [30]. The primary energy factor for district heating is 0.9 and for electricity 2.0.

Table 2 . Simulation data for simulation.

Data	
Occupant density	5 (W/m^2)
Equipment density	12 (W/m^2)
Lighting density	5 (W/m^2)
Heating and Cooling set point	21, 25 °C
Air flow rate	1.5(l/(sec.m^2))
Radiators efficiency	0.97
Heat source (district heating) efficiency	1.0
Mechanical Cooling SEER	3.0
Ventilation SFP,	1.3 kW/(m^3/s)
Heat recovery efficiency	80

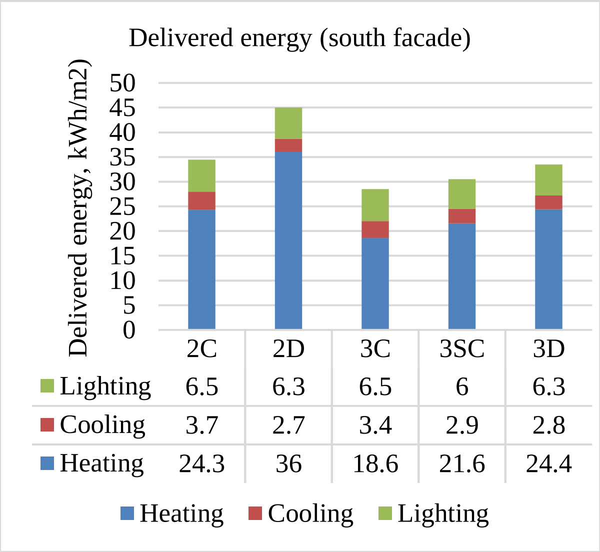
Table 3 gives a description of all the variants of the studied glazing. The window widths are selected as to not exceed 2 % of average daylight factor, with a step of 50 mm. The ECMs are listed in the table 3. All the chosen glazing is argon gas filling. The names of the ECM are compiled according to the first number as no. of panes followed by the characteristic; C" for clear highly transparent and "D" for tinted solar protection windows e.g. "2C" represents double glazed window.

Table 3. Description of all the variants of studied glazing.

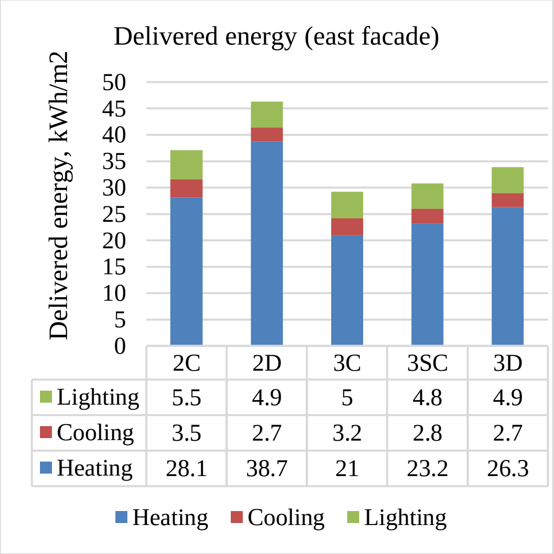
S.no	**Glazing type**				
		Gas filling	**U-Value, W/m^2-K)**	**g-Value**	**Visible transmittance**
1	**Double pane +low E, clear glazing with no shading**	Argon	1.1	0.61	0.78
2	Double pane +tinted solar protection windows, with no shading	Argon	1.0	0.27	0.51
3	Triple pane + clear glazing with no shading	Argon	0.54	0.49	0.7
4	Triple pane + low E, clear glazing with shading	Argon	0.54	0.49	0.7
5	Triple pane + low E, clear solar glazing with no shading	Argon	0.54	0.36	0.6
6	Triple pane + low E, tinted solar glazing with no shading	Argon	0.54	0.24	0.45

3. Results

Energy simulations were carried out for 4 orientation to south, west, east and north with the glazing options as disused in the case study.



	2C	2D	3C	3SC	3D
🟩 Lighting	6.5	6.3	6.5	6	6.3
🟥 Cooling	3.7	2.7	3.4	2.9	2.8
🟦 Heating	24.3	36	18.6	21.6	24.4



	2C	2D	3C	3SC	3D
🟩 Lighting	5.5	4.9	5	4.8	4.9
🟥 Cooling	3.5	2.7	3.2	2.8	2.7
🟦 Heating	28.1	38.7	21	23.2	26.3

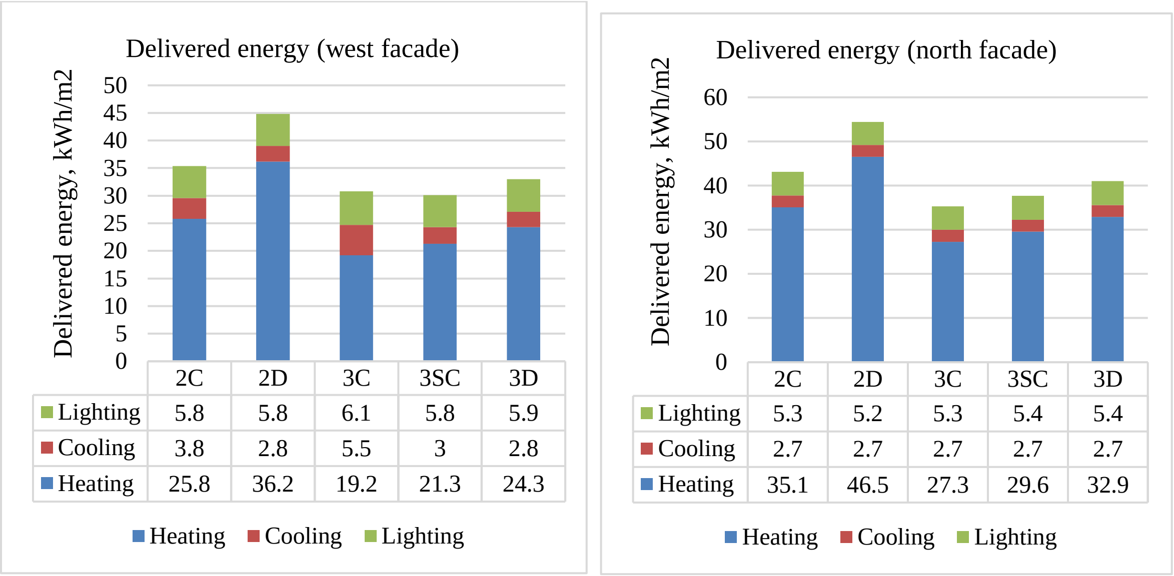


Figure 2. Delivered energy for the glazing types (South, east, west and north façade)

3.1. *Glazing*

As shown in figures 2 and 3, the energy usage was dominated by room heating and the windows and glazing were affected by their size. Results show that the next largest energy demand was supplied by air heating and cooling followed by lighting. Electricity for lighting varied by direction but for almost every glazing was the same. The energy requirement for space cooling mostly fluctuated but the influence on the total energy use was low.

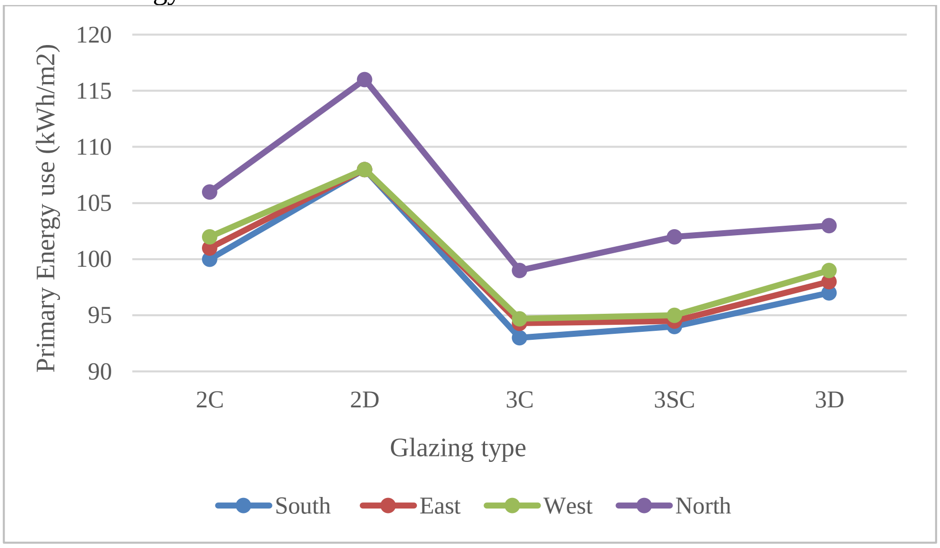


Figure 3. Primary energy for the glazing types (South, east, west and north façade)

In comparison to highly transparent glazing, clear solar protection windows showed slightly worse energy use on each façade. From figure 3, in case of similar U values highly transparent solar protection glazing results in better energy efficiency as compared to tinted solar protection. The most energy efficient cases (lowest primary energy, figure 3) were by orientation the following; For all the orientations, triple clear glass with 300 mm insulation thickness. Second, most energy efficient case was 3 SC with 300 mm insulation thickness for all the orientations

4. Conclusion

In this study detached house has been modelled using dynamic simulation tool and the energy efficiency measures, concerning different technologies for envelope systems, were set up as parameters in dynamic simulation tool and simulated and analysed. The façade parameters were optimized for the best possible energy performance, to be used as design guidelines for facades in low and nearly zero energy buildings for architects and engineers.

In the case of conventional windows, heating dominates the energy balance of office buildings, therefore the improved U values of windows also improved energy performance by increasing the number of panes and low emissivity coating. Comparing clear low emissivity lenses to tinted solar protection glasses and clear solar protection glasses with the high visible transmission, the best energy performance has been achieved with clear, low emissivity glasses and the second best with clear solar protection glasses which have followed the minimum daylight requirement determined by the minimum size of windows. The cooling load was also possible with a clear minimal emissivity glazing at a reasonable level. Therefore, all the best cases in this study were clearly glazing, where each gap between the plates was a low emission coated. The solutions provided can be used as a guideline for the designers to convert the objectives into technical solutions.

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