Alam, Sadaf; Lahdelma, Risto

Towards net zero energy buildings: building performance optimization, simulation and analysis

Published in:
10th International Conference on Indoor Air Quality, Ventilation and Energy Conservation in Buildings

DOI:
10.1088/1757-899X/609/7/072061

Published: 23/10/2019

Document Version
Publisher's PDF, also known as Version of record

Published under the following license:
CC BY

Please cite the original version:
Alam, S., & Lahdelma, R. (2019). Towards net zero energy buildings: building performance optimization, simulation and analysis. In 10th International Conference on Indoor Air Quality, Ventilation and Energy Conservation in Buildings Article 072061 (IOP Conference series: Materials Science and Engineering; Vol. 609, No. 7). Institute of Physics Publishing. https://doi.org/10.1088/1757-899X/609/7/072061
Towards Net Zero Energy Buildings: building performance optimization, simulation and analysis

To cite this article: Sadaf Alam and Risto Lahdelma 2019 IOP Conf. Ser.: Mater. Sci. Eng. 609 072061

View the article online for updates and enhancements.
Towards Net Zero Energy Buildings: building performance optimization, simulation and analysis

Sadaf Alam¹*, Risto Lahdelma¹
¹Aalto University, Department of Mechanical Engineering, School of Engineering, Espoo, Finland
*cr.sadafalam@gmail.com

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.

| 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 |
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 20-40 percent, 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/m²yr respectively [24].

The purpose of the study is to give guidelines of office buildings façade 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, WWR, and shading systems, were configured in the case of a theoretical model of office floor and alternatively for the best achievable energy performance-building 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](image)

**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.

| Data                        |       |
|-----------------------------|-------|
| Occupant density            | 5 (W/m²) |
| Equipment density           | 12 (W/m²) |
| Lighting density            | 5 (W/m²) |
| Heating and Cooling set point | 21, 25 °C |
| Air flow rate               | 1.5(l/sec.m³) |
| Radiators efficiency       | 0.97 |
| Heat source (district heating) efficiency | 1.0 |
| Mechanical Cooling SEER    | 3.0 |
| Ventilation SFP,            | 1.3 kW/(m³/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/m²·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.
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 2. Delivered energy for the glazing types (South, east, west and north façade)

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.

References

[1] C. J. Cleveland, “Net energy from the extraction of oil and gas in the United States,” *Energy*, vol. 30, no. 5, pp. 769–782, 2005.
[2] R. H. Crawford and G. J. Treloar, “Net energy analysis of solar and conventional domestic hot water systems in Melbourne, Australia,” *Sol. Energy*, vol. 76, no. 1–3, pp. 159–163, 2004.
[3] A. J. Marszal, J. Bourrelle, E. Musall, P. Heiselberg, A. Gustavsen, and K. Voss, “Net Zero Energy Buildings - Calculation Methodologies Versus National Building Codes,” vol. 2, no. December 2018, pp. 1–8, 2016.
[4] I. Sartori, A. Napolitano, and K. Voss, “Net zero energy buildings: A consistent definition framework,” *Energy Build.*, vol. 48, pp. 220–232, 2012.
[5] J. Minor and K. Hallinan, “Renewable energy design and performance of LEED EB platinum building for zero energy performance,” *ASHRAE Trans.*, vol. 117, no. PART 2, pp. 43–50, 2011.
[6] A. J. Marszal and P. Heiselberg, “Life cycle cost analysis of a multi-story residential Net Zero Energy Building in Denmark,” *Energy*, vol. 36, no. 9, pp. 5600–5609, 2011.
[7] M. Bojić, N. Nikolić, D. Nikolić, J. Skerlić, and I. Miletić, “Toward a positive-net-energy residential building in Serbian conditions,” *Appl. Energy*, vol. 88, no. 7, pp. 2407–2419, 2011.
[8] K. F. Fong and C. K. Lee, “Towards net-zero energy design for low-rise residential buildings in subtropical Hong Kong,” *Appl. Energy*, vol. 93, pp. 686–694, 2012.
[9] L. Zhu, R. Hurt, D. Correa, and R. Boehm, “Comprehensive energy and economic analyses on a zero energy house versus a conventional house,” *Energy*, vol. 34, no. 9, pp. 1043–1053, 2009.
[10] S. Deng, A. Dalibard, M. Martin, Y. J. Dai, U. Eicker, and R. Z. Wang, “Energy supply concepts for zero energy residential buildings in a humid and dry climate,” *Energy Convers. Manag.*, vol. 52, no. 6, pp. 2455–2460, 2011.
[11] M. R. Gaterell and M. E. McEvoy, “The impact of climate change uncertainties on the performance of energy efficiency measures applied to dwellings,” *Energy Build.*, vol. 37, no. 9, pp. 982–995, 2005.
[12] M. F. Jentsch, A. B. S. Bahaj, and P. A. B. James, “Climate change future proofing of buildings-Generation and assessment of building simulation weather files,” *Energy Build.*, vol. 40, no. 12, pp. 2148–2168, 2008.
[13] R. M. Pulselli, E. Simoncini, and N. Marchettini, “Energy and emery-based cost-benefit evaluation of building envelopes relative to geographical location and climate,” *Build. Environ.*, vol. 44, no. 5, pp. 920–928, 2009.
[14] H. Radhi, “Evaluating the potential impact of global warming on the UAE residential buildings – A contribution to reducing the CO2 emissions,” Build. Environ., vol. 44, no. 12, pp. 2451–2462, 2009.

[15] H. Poirazis, Å. Blomsterberg, and M. Wall, “Energy simulations for glazed office buildings in Sweden,” Energy Build., vol. 40, no. 7, pp. 1161–1170, 2008.

[16] E. S. J. Violeta Motuzienė, “SIMULATION BASED COMPLEX ENERGY ASSESSMENT OF OFFICE BUILDING FENESTRATION,” J. Civ. Eng. Manag., pp. 345–351, 2010.

[17] I. Susorova, M. Tabibzadeh, A. Rahman, H. L. Clack, and M. Elmineiri, “The effect of geometry factors on fenestration energy performance and energy savings in office buildings,” Energy Build., vol. 57, pp. 6–13, 2013.

[18] A. Tzempelikos, A. K. Athienitis, and P. Karava, “Simulation of façade and envelope design options for a new institutional building,” Sol. Energy, vol. 81, no. 9, pp. 1088–1103, 2007.

[19] R. Johnson, R. Sullivan, S. Selkowitz, S. Nozaki, C. Conner, and D. Arasteh, “Glazing energy performance and design optimization with daylighting,” Energy Build., vol. 6, no. 4, pp. 305–317, 1984.

[20] A. Boyano, P. Hernandez, and O. Wolf, “Energy demands and potential savings in European office buildings: Case studies based on EnergyPlus simulations,” Energy Build., vol. 65, pp. 19–28, 2013.

[21] C. Franzetti, G. Fraisse, and G. Achard, “Influence of the coupling between daylight and artificial lighting on thermal loads in office buildings,” Energy Build., vol. 36, no. 2, pp. 117–126, 2004.

[22] S. Gryning, A. Gustavsen, B. Time, and B. P. Jelle, “Windows in the buildings of tomorrow: Energy losers or energy gainers?,” Energy Build., vol. 61, pp. 185–192, 2013.

[23] T. Hootman, Net Zero Energy Design: A Guide for Commercial Architecture. Wiley, 2012.

[24] M. A. Shameri, M. A. Alghoul, O. Elayeb, M. F. M. Zain, M. S. Alrubaih, H. Amir, and K. Sopian, “Daylighting characteristics of existing double-skin façade office buildings,” Energy Build., vol. 59, pp. 279–286, 2013.

[25] T. Kalamees, K. Jylhä, H. Tietäväinen, J. Jokisalo, S. Ilomets, R. Hyvönen, and S. Saku, “Development of weighting factors for climate variables for selecting the energy reference year according to the en ISO 15927-4 standard,” Energy Build., vol. 47, pp. 53–60, 2012.

[26] “NBCF, National Building Code of Finland, Part D3, Energy Management in Buildings, Regulations, and Guidelines, Ministry of the Environment, Helsinki,2012, Available at http://www.finlex.fi/data/normit/37188-D3-2012 Suomi.pdf (in Finnish).”

[27] Ympäristöministeriö, “D5 Rakennuksen energiankulutuksen ja lämmitystehon- tarpeen laskenta,” 2013.

[28] “Solar shading REHVA Guidebook 12 presentation at 12th Annual Engineers Association workshop Lisboa on Oct 25th.”

[29] T. Kalamees and J. Kurnitski, “Estonian test reference year for energy calculations,” Proc. Est. Acad. Sci. Eng., vol. 12, pp. 40–58, 2006.