Periodica Polytechnica Mechanical Engineering, 69(3), pp. 242–251, 2025

Parametric Analysis of Facade Characteristics and Natural Ventilation Strategies in a Budapest Office Building

Boreyheh Khorshidi[1]*, Tamás Csoknyai[1]

[1] Department of Building Service and Process Engineering, Faculty of Mechanical Engineering, Budapest University of Technology and Economics, Műegyetem rkp. 3., H-1111 Budapest, Hungary
* Corresponding author, e-mail: boreyheh.khorshidi@edu.bme.hu

Received: 20 May 2025, Accepted: 05 June 2025, Published online: 30 June 2025

Abstract

This study investigates the impact of window glazing, window-to-wall ratio (WWR), natural ventilation strategies, and shading on energy efficiency and lighting performance in a case study office building in Budapest, Hungary. Using DesignBuilder software for building performance simulation, various configurations of double and triple glazing, with and without shading, are analyzed across WWRs of 10% and 50%. The study evaluates heating, cooling, and lighting energy consumption to identify design strategies that optimise energy performance and visual comfort. Results indicate that triple glazing with shading and a 50% WWR delivers the most efficient performance by reducing electricity consumption through effective solar heat gain control and enhanced daylighting. In contrast, unshaded large glazing areas lead to higher cooling demand, decreasing overall efficiency despite improved daylight access. Additionally, the study examines three natural ventilation strategies for summer: (1) constant ACH of 0.5 during day and night, (2) high daytime ACH with minimized nighttime ACH, and (3) continuous high ACH. Findings show that the second strategy provides the best thermal comfort but results in the highest energy use, while the first scenario achieves the lowest energy consumption at the expense of comfort. The third approach offers a balanced compromise between comfort and energy performance. These findings highlight the importance of combining façade design elements with appropriate ventilation strategies to maintain thermal comfort and reduce energy consumption in office buildings.

Keywords

window glazing, window-to-wall ratio, lighting performance, energy efficiency, air change rate

1 Introduction

Optimizing thermal performance and energy consumption plays a vital role in modern building design and energy efficiency. Building energy modelling (BEM) has become an essential tool for optimizing energy performance in buildings. BEM allows for simulating building performance under various design, material, and operational scenarios to evaluate energy consumption, thermal comfort, and daylight utilization [1].

This research advances the existing body of knowledge by examining a concise, yet practical integration of façade design and natural ventilation strategies specifically adapted to office buildings in Hungary. Distinct from previous studies that predominantly address either façade configurations or energy performance in isolation, this study incorporates a comprehensive thermal comfort analysis under varying ventilation rates and diverse combinations of glazing, shading, and window-to-wall ratios (WWR).

Buildings account for a significant portion of global energy consumption, with heating, cooling, and lighting contributing heavily to operational energy demand. In the European Union, buildings account for 40% of energy consumption and 36% of the total CO_2 emissions [2].

In Hungary, these statistics equally hold [3]. Consequently, understanding how building envelope characteristics, particularly window types, shading strategies, and window-to-wall ratios (WWR), influence building energy performance is essential. Beyond building envelope characteristics, ventilation approaches especially natural ventilation and variations in air change rates (ACH) constitute a critical factor affecting the overall energy performance of buildings.

Barkhudaryan et al. [4] proposed a stochastic methodology to examine the impact of varying air change rates on building energy consumption and associated CO_2 emissions, revealing that even modest changes in ACH can have

Cite this article as: Khorshidi, B., Csoknyai, T. "Parametric Analysis of Facade Characteristics and Natural Ventilation Strategies in a Budapest Office Building", Periodica Polytechnica Mechanical Engineering, 69(3), pp. 242–251, 2025. https://doi.org/10.3311/PPme.41046

a substantial effect on heating and cooling energy demands. Likewise, Ayoobi et al. [5] conducted simulation-based analyses to assess the effectiveness of natural ventilation strategies in arid and semi-arid climatic regions, reporting that optimized approaches to natural ventilation achieved electricity savings of up to 42.5% during the summer months.

Present research project focuses on modelling and analyzing these parameters with a particular attention to the role of windows, to better understand their impact on the energy performance and lighting conditions of a typical office building located in Budapest, Hungary.

The thermal performance of windows is determined by factors like U value (thermal transmittance), solar heat gain coefficient (SHGC), and visible light transmittance (VLT). Glazing is known to play a significant role in building energy performance, acting as both a source of heat loss and gain while also influencing the availability of natural light [6].

Triple glazed windows, which incorporate an additional insulating air gap, offer lower U-values than double-glazed windows, reducing heat transfer in both hot and cold climates [7]. However, triple-glazing also tends to reduce daylight penetration compared to double-glazing, which can increase reliance on artificial lighting [8]. The climatic conditions have a high influence on the choice between single, double, or triple-glazing windows.

Thus, the choice between double and triple glazing can also be influenced by the importance of daylighting versus thermal insulation. The WWR defines how much of a building's façade is occupied by windows, significantly impacting energy consumption. Higher WWR typically improves daylighting potential, reducing lighting energy demand during daytime hours. However, it also increases thermal loads, as windows have higher U-values than walls, making thermal losses and solar gains more pronounced [9, 10].

In an office building context, where daylighting is desirable for visual comfort and productivity, balancing WWR is necessary to optimise daylight utilization while minimizing unwanted heat gain and loss. Studies in similar climates highlight that WWR between 30% and 50% can provide acceptable daylighting without causing excessive energy penalties if shading and glazing type are optimized [11].

But larger windows cause glare, particularly in office settings where computer use is common. Proper daylighting design considers not only energy savings but also occupant comfort factors like glare control and thermal comfort near windows. This interplay between energy efficiency and visual comfort requires integrated design solutions.

Shading is important in office buildings, where controlling glare, optimizing daylight, and reducing solar heat gains are essential for ensuring both comfort and energy efficiency [12]. Adding shading devices reduces unwanted heat gains but may also obstruct beneficial daylight therefore this complicated relationship is to be evaluated for optimization.

Static systems, such as overhangs and louvers, are frequently used in Central Europe to block high-angle summer sun while allowing low-angle winter sun to enter. These systems, like the 1-meter overhang used in this project, provide passive solar control, which reduces cooling loads in summer [13]. Dynamic shading systems, such as motorized blinds or electrochromic glazing, offer greater adaptability to changing weather and user preferences, further improving energy performance daylighting quality [14].

However, they are more expensive and require ongoing maintenance, making them less common in mid-sized office buildings [15]. According to Tzempelikos et al. [16] combining automated blinds with manual override systems achieves optimal energy savings and user satisfaction, though this approach is more common in high-end buildings than in typical offices.

The combined effect of glazing type, WWR, and shading on energy performance highlights the importance of integrated façade design. No single strategy optimizes all performance metrics, requiring designers to evaluate trade-offs between daylight, thermal comfort, and energy use. For instance, larger windows improve daylight but require more shading to avoid overheating, especially if low-performance glazing is used. These metrics optimization is especially important in climates such as Hungary's, where office buildings must respond to both cold winters and warm summers, requiring careful design strategies to maintain year-round comfort while minimizing energy use.

Heating, ventilation, and air conditioning (HVAC) systems are responsible for approximately 50% of the total energy consumption in buildings [17]. Since public buildings are particularly affected by the significant increase in indoor heat and the increasing demand for ventilation and thermal comfort, natural ventilation in these buildings has significant potential and offers a highly energy-efficient alternative for heat dissipation and effective indoor air exchange [18].

Integrating bioclimatic design principles with simulation techniques facilitates the identification of cost-effective passive cooling strategies, such as natural ventilation and shading systems. This approach enhances the energy efficiency of building retrofits while effectively address climate change.

Tools like DesignBuilder, used in this project, integrate building geometry, material properties, internal loads, and HVAC systems to predict energy use across heating, cooling, lighting, and equipment loads. The façade design highly influences energy performance, particularly the glazing systems, shading elements, and overall window-to-wall ratio (WWR). As buildings increasingly strive for nearly zero energy (NZEB) compliance, understanding these envelope parameters becomes crucial in balancing energy efficiency, occupant comfort, and daylighting [19].

Using DesignBuilder software, this study evaluates a range of scenarios involving different window glazing, shading devices, and window-to-wall ratios to assess their impact on annual energy consumption, daylight penetration, and indoor comfort levels.

The aim of this research paper is to analyse the impact of window glazing, WWR and shading on energy efficiency and lighting performance in an office building located in Budapest, Hungary. Using DesignBuilder software, the study evaluates various configurations of double and triple glazing, with and without shading, across 10% and 50% WWRs. Furthermore, the study includes simulation scenarios with varying natural ventilation rates to evaluate their impact on cooling in summer months, and overall energy consumption. The objective is to identify the optimal balance between energy consumption for heating, cooling, and lighting while ensuring occupant visual comfort.

By comparing different scenarios, the research provides insights into how facade design choices affect solar heat gain, daylight penetration, and overall energy performance.

The results of this research provide valuable insights for researchers, architects, engineers, designers, and energy consultants seeking to optimise facade design in office buildings. By understanding how different combinations of window glazing, shading, and window-to wall ratios affect annual energy consumption and lighting performance, one can make more informed decisions that balance energy efficiency, and occupant comfort in support of the development of more energy efficient buildings by offering a data-driven framework for evaluating glazing and shading strategies thereby reducing the EU's existing energy inefficient building stock which currently accounts for 75% of the total buildings [2].

2 Methodology

2.1 Case study

The problem is discussed within a case study, an office building located in Budapest, Hungary, with the specific site chosen as Budapest/Pestszentl (latitude 47.43 and longitude 19.18) in DesignBuilder. The building comprises 10 private offices, with a north-south orientation. It is classified under Office Category II [20]. Fig. 1 presents the building model developed in DesignBuilder. The office building is a three-story structure with dimensions of 30 metres in length, 18 metres in width, and a floor height of 3.5 metres. It has a total floor area of 1455.68 m^2, with a net conditioned floor area of 1489.60 m^2. In this study, external measurements were used for modelling in DesignBuilder.

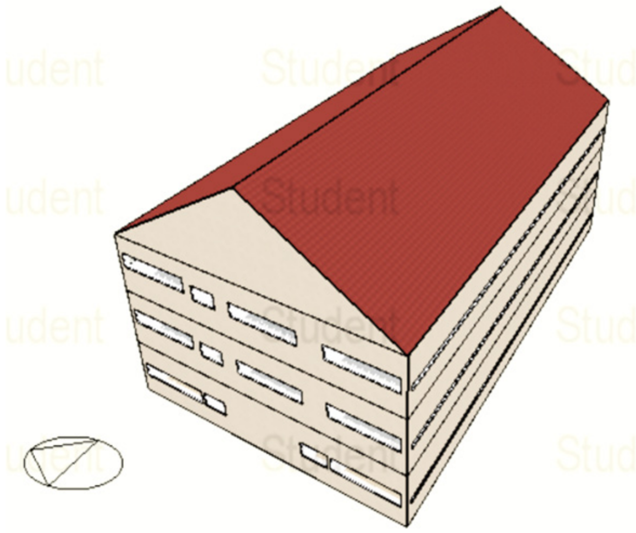

Fig. 1 visualised view of the office building

The HVAC system template for this building is VRF (Variable Refrigerant Flow), heat recovery, and DOAS (Dedicated Outdoor Air System). VRF (Air-Cooled) is a variable refrigerant flow HVAC system with the capability for heat recovery. While a DOAS ensures an independent fresh air supply to maintain indoor air quality. In this study, the simple HVAC was considered for simulation.

2.2 Simulation

This study examines the impact of various window glazing and two different window-to-wall ratios in two scenarios, with and without shading, on energy consumption and lighting in office buildings using DesignBuilder software for building performance simulation. In addition, three different air change rate scenarios were assessed and their effect on energy consumption and thermal comfort hours were evaluated by simulation.

The selected design parameters were chosen to reflect realistic and regionally relevant retrofit options for office buildings in Hungary. The two window-to-wall ratios (10% and 50%) represent the lower limit required for renovated façades and the higher end commonly observed in modern office buildings. Double and triple glazing types reflect typical upgrade choices in existing buildings, while the 1 m fixed overhang is a simple, cost-effective shading solution that can be retrofitted without altering the primary structure. Ventilation scenarios, baseline hygiene rate of 0.5 h^{-1} [21], mixed-mode strategy with night-purge, and aggressive daytime cross-ventilation up to 9 h^{-1} [22] were selected based on documented practices in Central-European climates. The combination of these discrete levels provides a balanced yet tractable parametric space that captures realistic retrofit strategies while allowing comparison across comfort and energy performance dimensions. Table 1 [23] presents the parameter settings for the base case building, in accordance with Hungarian and European standards.

In this study, method based on predetermined ventilation flow rates is applied as the default approach, though specific ventilation strategies vary depending on the thermal zone template. For office spaces, fresh air supply is set at 14 l/s per person, with mechanical ventilation at 1.4 l/(s·m²) [20]. Ventilation rates for other zones are determined based on their respective template specifications. Metabolic activity templates were assigned to each zone based on its intended function. In this study, the office building was assumed to accommodate 60 occupants within a total area of 1455.68 m², resulting in an overall occupancy density of 0.04 persons per square meter.

2.2.1. Zoning

The office building consists of various thermal zones across three floors, including offices, toilets, elevators, stairways, halls, and corridors, with a reception on the ground floor. Different templates assigned to each thermal zone in the activity tab in DesignBuilder: a generic office template for offices, a circulation area template for hallways, corridors, stairways, and elevators, a toilet template for restrooms, and a reception template for the reception area. Heating and cooling setpoints, as well as setbacks, specified based on these templates, while other settings remain at default. Office equipment also configured in DesignBuilder. Fig. 2 shows the different zones of the office building.

Table 1 Total parameter setting for base case building

Parameter	Value	Unit	References
External Wall U Value	0.24	W/m² K	[23]
Slab under attic and hiding space	0.17	W/m² K	[23]
Office Equipment Power Density	12	W/m²	[20]
Lighting power density	2.5	W/m²	Design Builder
Heating system seasonal COP	2.5	No unit	Design Builder
Cooling system seasonal COP	3	No unit	Design Builder

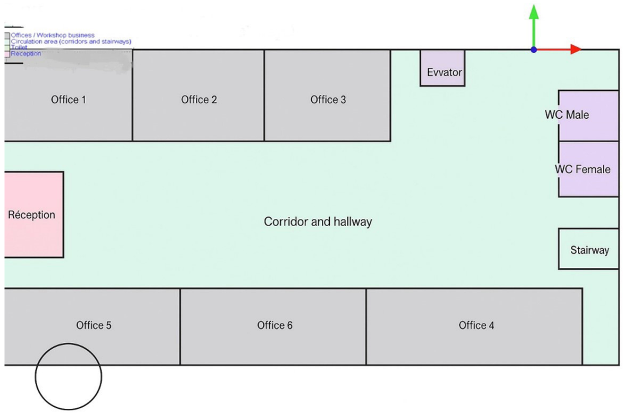

Fig. 2 Plan view of the ground floor of the office building

2.2.2. Construction parameters

The typical construction material used in this simulation. Table 2 shows the construction materials for base case building [24, 25].

Table 2 Construction materials: External walls, internal partitions, semi-exposed ceiling (Slab under attic and hiding space), and ground floor

Parameter	Thickness [m]	λ [W/mk]	References
External walls			
External rendering	0.019	0.5	[24]
EPS expanded polystyrene (Standard)	0.040	0.035	[24]
Brickwork inner	0.25	0.62	[25]
Plaster (Lightweight)	0.013	0.16	[24]
U -value	0.545	W/m² K	
Internal partitions			
Plaster (Lightweight),	0.013	0.16	[24]
Brickwork inner	0.1	0.62	[25]
Plaster (Lightweight),	0.013	0.16	[24]
U -value	1.713	W/m² K	
Semi-exposed ceiling			
Concrete, Reinforced (with 2% steel) (outer layer)	0.15	2.5	[24]
Mineral fiber /wool (Inner layer)	0.27	0.038	[25]
U -value	0.137	W/m² K	
Ground floor			
Sand and gravel	0.2	2	[24]
Concrete, Reinforced (with 2% steel)	0.1	2.5	[24]
Bitumen, pure	0.03	0.17	[24]
EPS Expanded Polystyrene (Standard)	0.1	0.04	[24]
Polyethylene foil	0.05	0.5	[24]
Cement/plaster/mortar - cement screed	0.07	1.4	[25]
U -value	0.315	W/m² K	

2.2.3. Opening

In this study, a glazing template with triple-pane windows selected, incorporating low-emissivity (LoE) coatings (e2=e5=0.1) and clear glass (Clr). Each pane has a thickness of 3mm, the outer pane glass, middle pane glass, and inner pane glass, with two insulating argon gas layers of 13 mm between them. The preferred window height is 1.5 m, with a glazing ratio of 30%. For the base model, the window-to-wall ratio is set at 10%. Both double and triple glazing window configurations analyzed across different scenarios. The detailed characteristics of the windows presented in Table 3.

Shading plays a crucial role in maintaining indoor environmental quality throughout both summer and winter. It serves as an effective strategy for regulating solar radiation, optimizing natural daylighting, minimizing glare, and controlling solar heat gain, thereby improving energy efficiency and occupant comfort. In office buildings, particularly in cold climates, shading remains essential to mitigate glare-related discomfort. In this study, a local shading system with 1.0 m overhang characteristics was implemented outside.

2.2.4. Lighting

The lighting and daylight control strategy follows the TM59 standard [26], with general lighting and control settings verified in DesignBuilder. In compliance with the MSZ-EN-16798-1:2019 standard [20], the required illuminance levels are 500 lux for office spaces, 100 lux for corridors, hallways, elevators, and stairways, and 200 lux for restrooms. The kitchen area adopts the same lighting level as office spaces. The chosen luminaire type in DesignBuilder is suspended, and the lighting control system follows a linear/off control strategy, ensuring that lights switch off entirely when the minimum dimming threshold is reached.

Table 3 Double and Triple glazing window characteristics

Triple glazing	
Total solar transmission (SHGC)	0.474
Direct solar transmission	0.358
Light transmission	0.661
U-value (W/m^2 K)	0.780
Double glazing	
Total solar transmission (SHGC)	0.597
Direct solar transmission	0.538
Light transmission	0.769
U-value (W/m^2 K)	1.512

2.2.5. Air change rate (ACH) different scenarios

We considered three scenarios for natural ventilation:

1. Scenario 1 [21]:
   $ACH_{\text{Summer, during day and night}}$: 0.5 (1/h)
2. Scenario 2 [22]:
   $ACH_{\text{Summer, during day}}$: 9 (1/h)
   $ACH_{\text{Summer, during night}}$: 0.2 (1/h)
3. Scenario 3 [27]:
   $ACH_{\text{Summer, during day and night}}$: 9 (1/h)

The natural operation only operates when the outdoor temperature is less than indoor temperature. The schedule was defined according to these scenarios. In DesignBuilder we set the temperature setpoints are 22 °C for heating (with a setback temperature of 18 °C) and 24 °C for cooling (with a setback temperature of 26 °C) according to DesignBuilder template. Shading was implemented during daytime hours across all scenarios. To facilitate this approach, window shading was utilized instead of local shading, as it allows for the application of distinct schedules for daytime and nighttime periods.

3 Results and discussion

3.1. Triple Glazing + Shading (Base Case, WWR 10%)

The study begins with a base model featuring triple-pane windows, a 1-meter overhang, and a window-to-wall ratio of 10%. Initial simulations confirm that the building is well-insulated, maintaining an indoor temperature of approximately 22 °C. Heating and cooling system design simulations were conducted under worst-case conditions to determine capacity requirements, revealing that the heating system requires 109 kW. The simulation results showed the annual energy consumption is recorded at 52181 kWh for heating, 11048 kWh for cooling, and 23979 kWh for lighting. Additionally, the analysis shows the implementation of shading effectively reduces cooling energy demand by minimizing solar heat gain; however, it slightly increases lighting energy consumption due to reduced natural daylight penetration.

3.2. Double Glazing (WWR 10%)

This case features double-glazed windows without shading and a window to-wall ratio of 10%. The results indicate that the double-glazing scenario with a 10% window-to-wall ratio demonstrates lower overall electricity and lighting energy consumption compared to the base case. This reduction is primarily attributed to the limited glazed area, which minimizes the reliance on active solar control measures. However, the lower insulation performance of double glazing, in comparison to triple glazing, leads to an increase in heating energy consumption in colder period to maintain indoor thermal comfort.

3.3. Double Glazing (WWR 50%)

This case examines the performance of double-glazed windows without shading. The findings indicate that the 50% window-to-wall ratio scenario results in higher overall electricity consumption due to increased solar heat gain, which raises cooling demand in summer and heating demand in winter. However, this configuration reduces lighting electricity consumption, particularly during a typical summer week, as the larger glazed area allows for greater natural daylight penetration. In winter, lighting electricity consumption remains nearly equivalent to that of the base case.

3.4. Double Glazing + Shading (WWR 10%)

Comparison of the electricity and lighting consumption of two configurations: double glazing with shading and triple glazing with shading, both maintaining the same window-to-wall ratio indicated that the addition of shading increases lighting electricity consumption during a typical summer week due to reduced daylight penetration, while in winter, lighting consumption remains unchanged compared to the unshaded scenario. Furthermore, shading leads to a reduction in cooling energy demand during summer, whereas heating consumption remains unaffected. The overall electricity consumption difference between triple glazing with shading and double glazing with shading is marginal, as shading effectively regulates solar heat gain in both cases. However, the triple glazing with shading configuration may result in slightly higher lighting electricity consumption due to diminished natural light availability, necessitating greater reliance on artificial lighting.

3.5. Double Glazing + Shading (WWR 50%)

A comparison between this case and the base case reveals that the 50% window-to-wall ratio allows for greater natural light penetration, thereby reducing the reliance on artificial lighting. Meanwhile, the addition of shading effectively controls solar heat gain, contributing to overall energy efficiency.

3.6. Triple Glazing (WWR 10%)

This case exhibits lower electricity consumption compared to the base model. While shading effectively reduces solar heat gain, it also restricts natural daylight penetration, increasing the demand for artificial lighting. Consequently, lighting electricity consumption is higher in the base scenario.

3.7. Triple Glazing (WWR 50%)

The electricity consumption between the base case and this case does not exhibit a significant difference. The interaction between window-to-wall ratio, shading, and natural light availability influences variations in electricity usage. The triple glazing (WWR 50%) achieves an optimal balance, despite the larger window area, lighting electricity consumption remains lower due to increased natural light availability.

3.8. Triple Glazing + Shading (WWR 50%)

A 50% window-to-wall ratio enhances shading effectiveness and optimizes natural daylight utilization, thereby reducing the reliance on artificial lighting and air conditioning. Consequently, this configuration leads to lower overall electricity consumption compared to the base model. Table 4 and Figs. 3-6 show the simulation results.

Table 4 Annual heating, cooling, lighting, and total energy consumption in different scenarios

Type of the windows	No Shading/ Shading	WWR %	Heating (kWh/m^2)	Cooling (kWh/m^2)	Lighting (kWh/m^2)	Total energy (electricity) consumption (kWh/m^2)
Double glazing	No shading	10%	33.5	8.95	14.4	114.75
		50%	33.16	13.9	10.1	116.98
	Shading	10%	33.60	8.16	20.2	119.6
		50%	33.6	9.7	12.06	113.6
Triple glazing	No shading	10%	32.8	8.7	15.8	115.2
		50%	32.2	12.7	11.03	115.2
Triple glazing (Base model)	Shading	10%	32.86	8.2	21.3	119.9
Triple glazing		50%	32.6	9.4	13.1	113.1

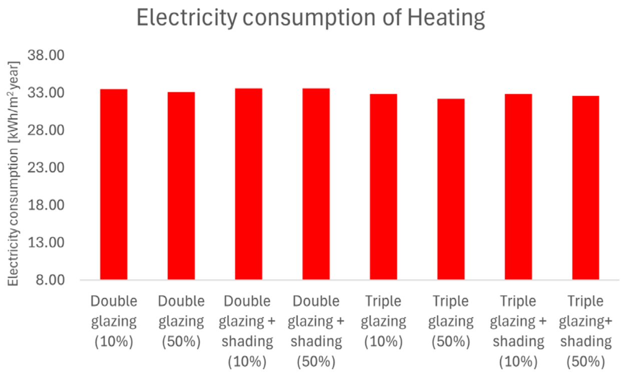

Fig. 3 Comparison heating consumption for different scenarios, Double glazing (10%, 50%), Double glazing + shading (10%, 50%), Triple glazing (10%, 50%), Triple glazing + shading (10%, 50%)

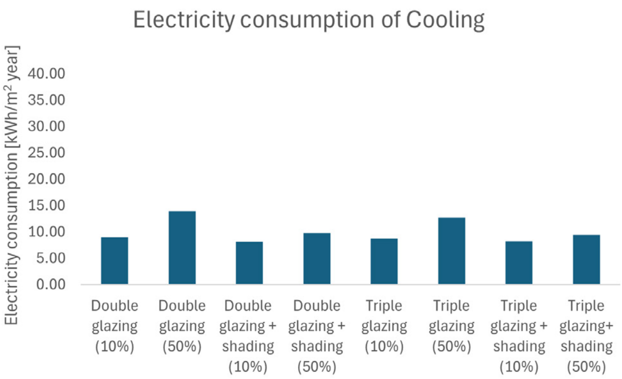

Fig. 4 Comparison cooling consumption for different scenarios, Double glazing (10%, 50%), Double glazing + shading (10%, 50%), Triple glazing (10%, 50%), Triple glazing + shading (10%, 50%)

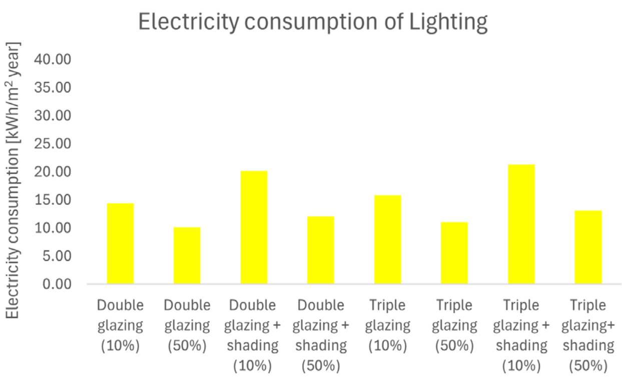

Fig. 5 Comparison lighting consumption for different scenarios, Double glazing (10%, 50%), Double glazing + shading (10%, 50%), Triple glazing (10%, 50%), Triple glazing + shading (10%, 50%)

3.9. Natural ventilation strategies

In comparative analysis, Scenario 2 demonstrates the highest level of thermal comfort, with discomfort hours reduced to 465 due to a high daytime ventilation rate of 9 air changes per hour. Conversely, the result of Scenario 1, which applies a significantly lower ventilation rate (0.5 ACH) during day and night, shows the greatest thermal discomfort, with 656 hours not meeting ASHRAE 55-2004 standards [28]. Scenario 3, featuring continuous high ventilation (9 ACH) during both day and night, represents a balanced approach, achieving moderate improvement in comfort (528 discomfort hours). This scenario suggests that integrating night-time ventilation can enhance indoor comfort and reduce peak cooling loads without significantly

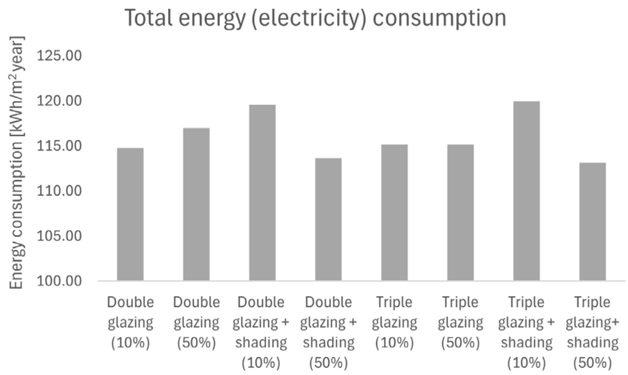

Fig. 6 Comparison total energy consumption for different scenarios, Double glazing (10%, 50%), Double glazing + shading (10%, 50%), Triple glazing (10%, 50%), Triple glazing + shading (10%, 50%)

Table 5 and Fig. 7 show the simulation results for natural ventilation scenarios.

Table 5 Simulation results of three ventilation strategies for summer period: Cooling, total energy consumption, and discomfort hours

Discomfort hours	
Scenario 1	656
Scenario 2	465
Scenario 3	528

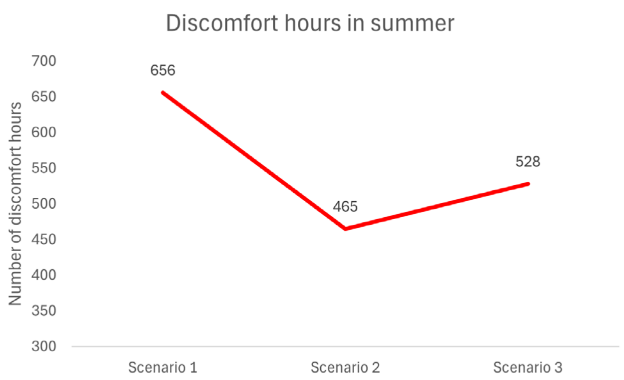

Fig. 7 Comparison discomfort hours for different scenarios, Scenario 1 (ACH summer, during day and night: 0.5 (1/h)), Scenario 2 (ACH summer, during day: 9 (1/h), and during night: 0.2 (1/h)), Scenario 3 (ACH summer, during day and night: 9 (1/h))

4 Conclusion

This research explores the influence of window glazing, window-to-wall ratio, and shading, as well as ventilation rates on thermal comfort and energy performance in office buildings. Results reveal that triple glazing with shading and a 50% WWR provides the most energy-efficient solution, whereas configurations prioritizing daylighting like triple glazing without shading and 50% WWR can significantly increase cooling demands. Shading plays a crucial role in balancing cooling and lighting needs, while higher WWR enhances daylight but increases cooling demand. For instance, implementing triple glazing with a 10% window-to-wall ratio, even without the application of shading devices, results in reduced cooling energy demand; however, it simultaneously leads to higher electricity consumption for lighting due to insufficient natural daylight availability.

The study highlights the trade-offs between thermal comfort, daylighting, and energy efficiency in office buildings. The evaluation of various window configurations and shading strategies highlights the trade-offs in energy consumption. The base model featuring triple glazing, a 1m overhang, and a 10% window-to-wall ratio demonstrates effective insulation but faces challenges such as heat loss and increased electricity demand. Comparisons across different cases underscore the role of shading in controlling solar heat gain. While double glazing with shading and a 10% window-to-wall ratio increases reliance on artificial lighting, triple glazing with shading and a 50% window-to wall ratio achieves a balance between shading effectiveness and natural daylight utilization, leading to lower overall electricity consumption. The choice of configuration depends on priorities: if minimizing electricity consumption is the primary goal, triple glazing with shading and a 50% window-to-wall ratio is preferable. However, if maximizing natural daylight is the priority, triple glazing with a 50% window-to-wall ratio without shading is more suitable. A comprehensive assessment considering both energy efficiency and occupant comfort is essential for an informed decision.

On the other hand, ventilation strategies implemented during the summer period significantly impact both thermal comfort and energy performance. The second scenario, characterized by a high daytime air change rate (9 ACH) and a reduced nighttime rate (0.2 ACH), yields the most favorable thermal comfort outcomes, with 465 hours of discomfort. Furthermore, the first scenario, which maintains a consistently low ventilation rate (0.5 ACH) throughout the day and night, achieves the highest level of thermal discomfort (656 hours). The last scenario, applying a continuous high ventilation rate (9 ACH) during both day and night, presents a balanced approach, offering moderate thermal comfort (528 discomfort hours).

This study demonstrated that combining optimized façade configurations with natural ventilation strategies can significantly improve energy performance and thermal comfort in this office building in Budapest. Triple glazing with shading and a 50% window-to-wall ratio performed best overall, while modest night-time ventilation (0.2 ACH) notably reduced discomfort.

This study has several limitations. Firstly, its findings cannot be fully generalized, as it is based on a specific case study. Additionally, the analysis considers only two window-to-wall ratios and evaluates two types of shading with one control type. Moreover, the analysis in this study is limited by the use of a fixed set of predefined ventilation scenarios with constant air change rates, which may not fully reflect the dynamic or adaptive ventilation strategies commonly applied in real-world contexts. Moreover, the scope of the investigation is restricted to summer conditions, without consideration of seasonal or transitiona periods that could affect ventilation performance across different climate zones. The simulations also assume optimal operation and control of ventilation systems, omitting potential influences such as occupant behaviour, no shading scenario for ventilation strategies, or fluctuations in indoor pollutant concentrations. Additionally, interactions between ventilation and other critical building parameters such as internal heat gains, occupancy patterns, and air infiltration were not comprehensively explored.

References

[1] Roodkoly, S. H., Fard, Z. Q., Tahsildoost, M., Zomorodian, Z. Karami, M. "Development of a simulation based ANN framework for predicting energy consumption metrics: a case study of an office building", Energy Efficiency, 17(1), 5, 2024. https://doi.org/10.1007/s12053-024-10185-1

[2] Pohoryles, D. A., Bournas, D. A., Da Porto, F., Santarsiero, G., Triantafillou, T., Thanasis, O., Bjørn Petter, J. "Integrated Techniques for the Seismic Strengthening and Energy Efficiency of Existing Buildings", Publications Office of the European Union, 2022. ISBN 978-92-76-49257-3 https://doi.org/10.2760/86567

[3] Hungarian Energy Efficiency Institute "Energy efficiency in Hungary", [online] Available at: https://mehi.hu/en/energy-efficiency-inhungary/ [Accessed: 24 June 2025]
[4] Barkhudaryan, N., Orosa, J. A., Roshan, G. "A new procedure to analyze the effect of air changes in building energy consumption", Journal of Environmental Health Science and Engineering, 12(1), 37, 2014. https://doi.org/10.1186/2052-336X-12-37
[5] Ayoobi, A. W., Ekimci, B. G., Inceoğlu, M. "A Comparative Study of Sustainable Cooling Approaches: Evaluating the Performance of Natural Ventilation Strategies in Arid and Semi-Arid Regions", Buildings, 14(12), 3995, 2024. https://doi.org/10.3390/buildings14123995
[6] Akram, M. W., Hasannuzaman, M., Cuce, E., Cuce, P. M. "Global technological advancement and challenges of glazed window, facade system and vertical greenery-based energy savings in buildings: A comprehensive review", Energy and Built Environment, 4(2), pp. 206–226, 2023. https://doi.org/10.1016/j.enbenv.2021.11.003
[7] Aruta, G., Ascione, F., Iovane, T., Mastellone, M. "Double-skin façades for the refurbishment of historic buildings: Energy-economic feasibility for different types of glazing and ventilation rates", Journal of Building Engineering, 103, 112125, 2025. https://doi.org/10.1016/j.jobe.2025.112125
[8] Innovative Aluminium And Glass "Comparison of Maintenance Requirements Between Double and Triple Glazing", [online] Available at: https://aluminiumwindowsanddoors.net.au/comparison-of-maintenance-requirements-between-double-and-triple-glazing/ [Accessed: 14 May 2025]
[9] Yang, Q., Liu, M., Shu, C., Mmereki, D., Uzzal Hossain, M., Zhan, X. "Impact Analysis of Window-Wall Ratio on Heating and Cooling Energy Consumption of Residential Buildings in Hot Summer and Cold Winter Zone in China", Journal of Engineering (United Kingdom), 2015(1), 538254, 2015. https://doi.org/10.1155/2015/538254
[10] Chen, Y., Li, D., He, D., Liu, Y., Taib, N., Sern, C. H. Y. "Seasonal thermal performance of double and triple glazed windows with effects of window opening area", Scientific Reports, 15(1), 7890, 2025. https://doi.org/10.1038/s41598-025-92600-w
[11] Jiang, Y., Qi, Z., Ran, S., Ma, Q., Dewancker, B. J., Gao, W. "A Study on the Daylighting, Energy Consumption, and Climate Adaptability of Curved Mesh Shading Based on the Parametric Performance Design Method", Sustainability , 16(13), 5549, 2024. https://doi.org/10.3390/su16135549
[12] Zheng, Y., Wu, J., Zhang, H., Lin, C., Li, Y., Cui, X., Shen, P. "A novel sun-shading design for indoor visual comfort and energy saving in typical office space in Shenzhen", Energy Build, 328, 115083, 2025. https://doi.org/10.1016/j.enbuild.2024.115083
[13] Preet, S., Mathur, J., Mathur, S. "Influence of geometric design parameters of double skin façade on its thermal and fluid dynamics behavior: A comprehensive review", Solar Energy, 236, pp. 249–279, 2022. https://doi.org/10.1016/j.solener.2022.02.055
[14] Amaral, A. R., Rodrigues, E., Gaspar, A. R., Gomes, Á. "A thermal performance parametric study of window type, orientation, size and shadowing effect", Sustainable Cities and Society, 26, pp. 456–465, 2016. https://doi.org/10.1016/j.scs.2016.05.014
[15] Krarti, M. "Energy Audit of Building Systems", CRC Press, 2020. ISBN 9781003011613 https://doi.org/10.1201/9781003011613
[16] Tzempelikos, A., Shen, H. "Comparative control strategies for roller shades with respect to daylighting and energy performance", Building and Environment, 67, pp. 179–192, 2013. https://doi.org/10.1016/j.buildenv.2013.05.016
[17] Lin, C.-M., Lin, S.-F., Liu, H.-Y., Tseng, K.-Y. "Applying the naïve Bayes classifier to HVAC energy prediction using hourly data", Microsystem Technologies, 28(1), pp. 121–135, 2022. https://doi.org/10.1007/s00542-019-04479-z
[18] Zhang, M., Han, W., He, Y., Xiong, J., Zhang, Y. "Natural Ventilation for Cooling Energy Saving: Typical Case of Public Building Design Optimization in Guangzhou, China", Applied Sciences, 14(2), 610, 2024. https://doi.org/10.3390/app14020610
[19] Krstić-Furundžić, A., Vujošević, M., Petrovski, A. "Energy and environmental performance of the office building facade scenarios", Energy, 183, pp. 437–447, 2019. https://doi.org/10.1016/j.energy.2019.05.231
[20] CEN "EN 16798-1:2019 Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics-Module M1-6", European Committee for Standardization, Brussels, Belgium, 2019.
[21] Brelih, N. "Ventilation rates and IAQ in national regulations", REHVA Journal, 2012. [online] Available at: https://www.rehva.eu/fileadmin/hvac-dictio/01-2012/ventilation-rates-and-iaq-in-national-regulations_rj1201.pdf [Accessed: 10 May 2025]
[22] Wargocki, P., Knudsen, H. N. "Saving energy for ventilation by careful selection of building materials", In: Rode, C. (ed.) Nordic Symposium on Building Physics: Proceedings, Copenhagen, Denmark, 2008, pp. 489–496. [online] Available at: https://www.researchgate.net/publication/237788363 [Accessed: 10 May 2025]
[23] National Legal Repository "7/2006. (V. 24.) TNM rendelet az épületek energetikai jellemzőinek meghatározásáról" (Decree No 7/2006 (24.V.) TNM on the determination of the energy performance of buildings private enterprise), Budapest, Hungary, 2006. [online] Available at: https://njt.hu/jogszabaly/2006-7-20-6F [Accessed: 10 May 2025] (in Hungarian)
[24] Design Builder "Product Overview", [online] Available at: https://designbuilder.co.uk/software/product-overview [Accessed: 05 June 2025]
[25] Chartered Institution of Building Services Engineers "Environmental design", CIBSE, 1999. ISBN 0900953969
[26] Bonfigli, C., Chorafa, M., Diamond, S., Eliades, C., Mylona, A., Taylor, B., Virk, D. "TM59 Standard TM59 Design Methodology for the Assessment of Overheating Risk in Homes", CIBSE, 2017. ISBN 9781912034185

[27] Breesch, H. "Natural Night Ventilation in Office Buildings: Performance Evaluation Based on Simulation, Uncertainty and Sensitivity Analysis", PhD Thesis, Ghent University, 2006. [online] Available at: https://www.researchgate.net/publication/292609931 [Accessed: 27 June 2025]

[28] ASHRAE "ASHRAE 55-2004 – Thermal Environmental Conditions for Human Occupancy (ANSI Approved)", American Society of Heating, Refrigerating and Air-Conditioning Engineers, Peachtree Corners, GA, USA, 2004.