Application of ISO/DIS 52016-3 for Dynamic Shadings in an Office Building

Alireza Norouziasas[1], Ramin Rahif[2], Mohamed Hamdy[1], Shady Attia[2]
[1] Department of Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway
[2] Sustainable Building Design Lab, Dept. UEE, Faculty of Applied Sciences, University of Liège, Belgium

Abstract

Adaptive building envelope technologies can improve buildings' energy efficiency while maintaining a comfortable indoor environment. However, with the growing trend of developing new technologies for building performance management, adaptive facades have become more relevant for balancing user comfort and energy load. There are several ways to control adaptive building envelope elements, but there is currently no standard method for evaluating control schemes, especially for dynamic shadings. The recently issued ISO/DIS 52016-3 offers default control for comparing the energy consumption of different buildings, considering adaptive building envelope elements. This article aims to enhance the energy efficiency of an office building with adaptive facades. The study involves simulations of four scenarios using Energy Management Systems and EnergyPlus in a Brussels office space: no shading, fixed shading with static control, roller blinds, and Venetian blinds with automatic control techniques suggested by ISO/DIS 52016-3. The results show that roller blinds reduce annual cooling loads by 63.9%, 44.12%, and 8.2% compared to no shading, fixed shading, and Venetian blind scenarios. Moreover, the risk of overheating hours was decreased by 88.9% when roller blinds were considered, compared to the no-shading condition.

Highlights

- Evaluation and comparison of thermal performance of an office building with adaptive façade (dynamic shading) in accordance with ISO/DIS 52016-3
- Testing widely used shading technologies (roller blinds and Venetian blinds) under ISO/DIS 52016-3 control strategies

Introduction

According to statistics supplied by the International Energy Agency (IEA) (IEA, 2013), the building sector is responsible for the highest proportion of global energy use in Europe, at forty percent. The cooling and heating energy consumption of urban buildings is strongly dependent on their facades, which include walls and glass windows. Regarding this, the window is a crucial facade element that greatly effects the energy demand of the building and accounts for 40% of the energy consumption of buildings (Norouziasas, Yin, et al., 2023; Rahif et al., 2022). Solar radiation penetrating windows increase cooling demands in a hot region while decreasing heating demands in a heating-dominated climate. In addition, even in continental climes, unmanaged solar gains, especially for office buildings, can result in overheating. Controlling solar radiation through windows and translucent facades can significantly alter buildings' heating and cooling energy requirements.

A variety of solutions are considered to lower the energy demand and avoid the risk of overheating. Utilizing shading devices based on building orientation, location, window characteristics, is one of the solutions (Mahar et al., 2020; Norouziasas et al., 2022; Pilechiha et al., 2022; Piraei et al., 2022). Whether a building's static or dynamic shading devices can dramatically affect its energy use. Different types and positions of shading systems exist, such as Venetian blinds, roller shades, louvers, and interior shades. In addition, they include a range of solar-optical and daylight qualities. Using exterior fixed shading lowers customers' look out, daylight performance, and solar gains during the cold season, necessitating additional space heating and resulting in increased electrical lighting usage (De Luca et al., 2018). Therefore, shading devices should be meticulously developed to reduce energy usage and maximize user comfort.

The adaptive facades (AFs) provide buildings with a multipurpose capacity to balance energy demand and human comfort (Norouziasas, 2021; Tabadkani et al., 2021). Several research have proven and presented the capabilities and possibilities of AF. According to (Perino & Serra, 2015), the use of AFs ensured a step-change improvement in the built environment's energy performance and increased use of renewable energy. (Loonen et al., 2013) developed AFs as a climate adaptive building shell (CABS), whose functionality changed regularly in response to indoor and outdoor environment control variables. The findings of a study conducted by (Attia, Bilir, et al., 2019) in the form of interviews with 27 facade specialists revealed that indoor and outdoor control variables should be used to improve occupant comfort and building energy performance.

The adaptive facades can be controlled manually (through interfaces) or automatically via installed sensors. There are two primary control methods that use automatically controlled shading devices: open-loop and closed-loop. In open-loop controls, feedback from the indoor environment is not considered, whereas feedback from

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both the outdoor and indoor environments is considered in closed-loop controls.

The new ISO 52016-3 standard addresses the following three adaptive building envelope technologies: active solar shadings, chromogenic glazings, and active ventilative facades. These technologies are commonly used in building envelopes and were chosen based on their existing or prospective market share and differentiation in functionality and control scenarios as determined by the research undertaken by (Attia, S., Favoino, F., Loonen, R. C. G. M., Petrovski, A., & Monge-Barrio, 2021; Attia et al., 2018, 2020; Attia, Garat, et al., 2019). The newly proposed ISO 52016-3 utilized the same hourly calculation approach as ISO 52016-1 to estimate the energy requirements of buildings for heating and cooling, internal temperatures, and sensible and latent heat loads. Since adaptive building envelope elements must be managed by control strategies, it is impossible to compare the energy performance of two buildings without the default control methods. In order to compare the energy performance of buildings and thermal and visual comfort, ISO 52016-3 stipulated a series of default control techniques with varying degrees of complexity.

Researchers have not yet been able to evaluate the effectiveness of the default control strategies provided by ISO 52016-3, despite the fact that few studies have studied the building energy requirement based on ISO 52016-1. Therefore, the most significant contribution of this work is to improve the energy performance of buildings with adaptive exterior features by expanding current knowledge of the constraints and opportunities of the new ISO 52016-3. The uniqueness of this study is based on the following objectives:

i. Evaluation of static and dynamic shading device impacts on heating, cooling, lighting loads, operational temperature, and interior air temperature for a Belgian office building.

ii. A comparison of commonly used shading devices (roller blinds and Venetian blinds) with the control strategies offered by ISO 52016-3.

iii. Recommendations for selecting an automated control strategy to reduce energy loads in an office building per ISO 52016-3.

iv. Provide recommendations for enhancing ISO 52016-3.

Therefore, considering the importance of providing a standardized way to assess buildings' energy use through control strategies regarding the adaptive façade elements, especially for dynamic shadings, this research implemented and compared the control strategies provided by ISO 52016-3 for different shading technologies. A recent study by (Norouziasas, Tabadkani, et al., 2023) considered implementing control strategies suggested by ISO 52016-3 for dynamic shadings (Venetian blinds and Roller blinds). The results have been taken into account in this paper.

Methodology

The phases of this research are data collection, parametric analysis, and dynamic simulations. After that, the effectiveness of fully automated control strategies for exterior roller blinds and Venetian blinds was evaluated. South-facing office space in an existing high-performance office building in Brussels was selected to conduct energy simulations. The outcomes of two scenarios involving roller blinds and Venetian blinds controlled automatically by strategies proposed by ISO/DIS 52016-3 were evaluated for various orientations. In order to better comprehend the effects of control strategies and shading devices on the energy requirements of buildings, two additional scenarios, including no shading and fixed shading, were considered. The heating and cooling loads, internal temperatures (indoor air temperature and indoor operative temperature) covered by ISO/DIS 52016-3, and artificial lighting demand covered by EN 15193-1 with exterior roller blinds and Venetian blinds were reported. Furthermore, the present study selected the Indoor Overheating Degree (IOD) as a metric to assess the thermal performance of the case study building in a more comprehensive way. Grasshopper was used to create the model, while Ladybug-tools were utilized for the simulation procedure. Using EnergyPlus's EMS function, the control strategies were executed independently for each window.

Case study

Since the Energy Performance of Building Directive (EPBD) is concerned with the Member States of the European Union (EU) (EU, 2018), Brussels Capital Region in Belgium, as the capital of Europe, a case study was chosen at this location. The building was constructed to provide a passive office for the Clinique Saint-Pierre in Ottignies. The construction area is about 3,090 m² of offices, meeting rooms, multipurpose spaces, and 1,140 m² of basement and parking spaces. The selected case study building is presented in Figure 1.

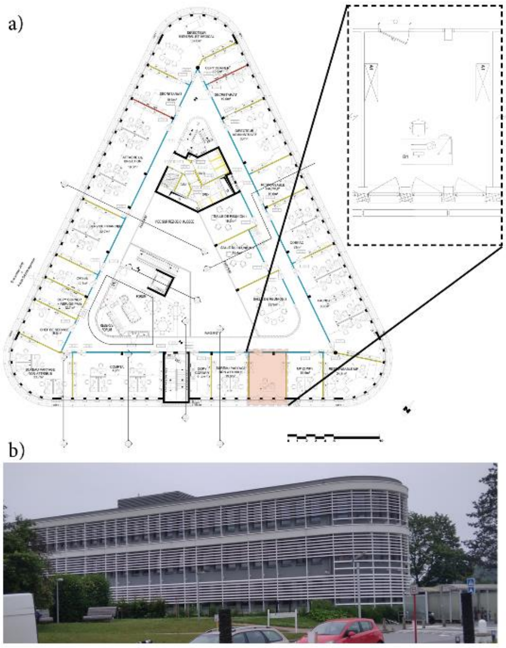

Figure 1: Case study building; a) First-floor plan of Clinique Saint-Pierre building with highlighted selected office; b) Perspective view of the building.

Figure 1 depicts the various perspective views of the chosen building and the location of the chosen office room on the floor plan. The case study building received passive house certification via the Project Certified Passive House Platform (PHPP). A document describes the characteristics and performance of passive house buildings based on monitored values (Feist et al., 2001). It is important to note that passive house standards in each country have distinct characteristics. In Germany, for instance, the passive house standard stipulates that the indoor air temperature should not exceed 25℃ for more than 10% of the occupied time, whereas in Belgium, it should not exceed 5% of the occupied time.

Climate

The climate files from ASHRAE IWE2C have been collected and utilized as EnergyPlus Weather File (EPW) in the building simulations for the implementation of automated control scenarios, particularly ISO 52016-3. For the climate of Brussels (50° 51′ N, 4° 21′ E), the simulation was conducted. The Koppen climate classification classifies the climate of Brussels as Oceanic (Cfb), with warm summers and cool winters.

Description of the test case

A south-facing office room from the reference case study building has been chosen for energy simulations. The selected office was bordered on the west and east by two other rooms (Figure 1). The model represented a single-zone office space on the first floor of the reference building with dimensions of 5.55 m × 4.00 m × 3.40 m (depth × width × height). The three-windows on south wall was unobstructed and exposed to the outdoor environment. The windows have identical dimensions, with a height of 2 meters and a width of 0.93 meters at a sill height of 0.8 meters. It was assumed that the interior walls, roof, and floor were adiabatic surfaces. In addition, different orientations are investigated to determine the effect of ISO 52016-3 control strategies on the energy consumption of buildings. In general, four orientations, East, West, North, and South, have been parametrically simulated with additional variations in shading materials that will be explained accordingly.

The transparent part of the façade was triple glazing windows with low emissivity coating. The exterior wall and window properties are shown in table 1. The external wall facing the south consists of two layers and a thickness of 450 mm. The exterior wall was constructed with 200 mm of cast concrete, and 250 mm extruded polystyrene-CO_2 blowing (XPS) insulation on the outer surface, with a U-value of 0.123 W/m^2.K. The external wall also has three triple-glazing windows, resulting in a Window to Wall Ratio (WWR) of 40%. Windows are made of low-emissivity triple-glazing with an average window U-value of 0.50 W/m^2, Solar Heat Gain Coefficient (SHGC) of 0.50, and 0.661 of light transmission. The same setting except the shading control strategies has been considered during a year in all simulations.

Table 1: Properties of the office room considered for energy simulation.

Parameters	Heading 3
Space type	Single Office Space
Roof/Ground floor	Adiabatic
Interior walls	Adiabatic
Exterior wall	U-Value: 0.123 W/m^{2}k
Window	U-Value: 0.5 W/m^{2}k, SHGC: 0.50, VT: 0.661
Internal loads Equipment	12.9 W/m^2
Infiltration ratio	0.6 ac/h
Lighting density	2 W/m^2
Number of people	1 occupant
Solar distribution	Full interior and exterior (with reflections)
Shadow calculation method	Time step frequency
Heating set-point/set-back	21 ℃ / 12 ℃
Cooling set-point/set-back	25 ℃ / 35 ℃

Internal lighting, occupancy, and equipment loads are considered based on the building's actual condition. The weekday work hours are from 8:00 am to 6:00 pm, in accordance with the occupancy rate in IES LM-83-12 (IES Daylight Metrics Committee, 2012). One user occupies the office and is seated facing the window. As a result, the occupancy load in a room is 0.045 ppl/m^2 and the internal equipment load is 12.9 W/m^2 due to the computer and printer. The electric lighting is a dimmable lamp with a target illuminance of 500lux at a task height of 75 cm from the floor. The peak power consumption of artificial lighting is 2 W/m^2.

According to the actual building system, an air-cooled chiller has been assigned to the reference model Fan Coil Unit (4-Pipe) for the HVAC system. During occupied hours, setpoint temperatures of 21 ℃ and 25 ℃ are considered for controlling the heating and cooling, respectively, while setback temperatures of 12℃ and 35℃ are considered for unoccupied hours. For the exterior facade, the infiltration rate at 50 pascals, equal to 0.6 ac/h, was considered. In addition, since this study examines various automated control scenarios, the Air Handling Unit (AHU) and Domestic Hot Water (DHW) are excluded from this model.

The office model was developed to analyze and compare the impact of various automated controls on the energy consumption of buildings. This study considered three shading operations, including fixed shading, no shading, and dynamic shadings. Since the exterior facades of the case study building already had fixed horizontal louvres installed, the fixed shading operation was assumed as the base case model.

This research also simulated the model without shading devices to analyze dynamic shading's effects. Two ISO 52016-3 control strategies for two dynamic shading technologies were used. ISO 52016-3 covers Venetian blinds (T1) and roller blinds (T2), according to the literature. This study simulated no shading, fixed shading (base case), roller blinds, and Venetian blinds corresponding to S1, S2, S3, and S4, respectively. ISO 52016-3 criteria were used to evaluate the effects of exterior roller and Venetian blinds on heating, cooling,

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lighting, and air temperature. Table 2 describes the scenarios.

Table 2: Properties of the office room considered for energy simulation.

Scenario	Description
Scenario 1 (S1): No shading	No solar shading was applied for the simulation
Scenario 2 (S2): Fixed shading (base case)	Based on the case study building, fixed shading was modelled and simulated as a base case model
Scenario 3 (S3): Roller blinds (T2)	According to the control strategy suggested by ISO 52016-3 for roller blinds
Scenario 4 (S4): Venetian blinds (T1)	According to the control strategy suggested by ISO 52016-3 for Venetian blinds

ISO 52016-3 controls the adaptive facade elements based on the window's solar radiation, horizontal solar radiation, operative temperature, and exterior solar irradiance. The detailed flowchart of control strategies suggested by ISO 52016-3 provided in a study by (Norouziasas, Tabadkani, et al., 2023). Additionally, the ISO 52016-3 control conditions included occupancy and daylight. Various sensors control the exterior roller and Venetian blinds at each time step. Six office sensors performed ISO control strategies. Solar irradiance on window (W/m^2), task level illuminance (lux), external global illuminance, exterior air temperature (°C), internal air temperature (°C), and view luminance (Cd/m^2) sensors were placed throughout the room. Figure 2 shows ISO 52016-3's automatic control algorithm sensors schematically.

An asymmetric multizonal metric called the Indoor Overheating Degree (IOD) [°C] collects cooling degree hours throughout the total number of hours that the zones are occupied (Hamdy et al., 2017). The formula utilized for the computation of IOD is as follows:

$$IOD \equiv \frac{\sum_{z=1}^{Z}\sum_{i=1}^{N_{occ}(z)}\left[\left(T_{in,z,i}-T_{comf,upper,z,i}\right)^{+}\times h_{i,z}\right]}{\sum_{z=1}^{Z}\sum_{i=1}^{N_{occ}(z)} t_{i,z}} \qquad (3)$$

Where Z [-] is the total number of building zones, z is zone counter, $N_{occ}(z)$ [-] is the total number of occupied hours in zone z, i is hour counter, $T_{in,o,z}$ [°C] is the indoor operative temperature in zone z at hour i, $T_{comf,upper,z,i}$ [°C] is maximum comfort threshold in zone z at hour i, $T_{comf,lower,z,i}$ [°C] is the minimum comfort threshold in zone z at hour i.

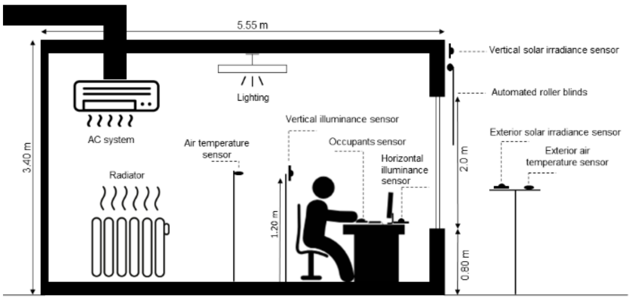

Figure 2: Schematic presentation of sensor placements under the ISO 52016-3-recommended control method.(Norouziasas, Tabadkani, et al., 2023)

Results

Figure 3 illustrates the annual performance of the solar shading control strategies in terms of energy consumption for the selected office space in Brussels.

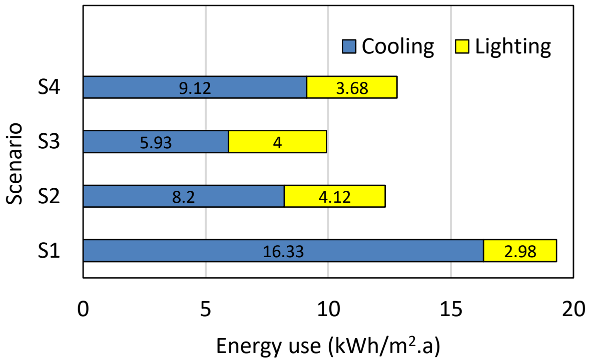

Figure 3: Annual energy use of each scenario

The condition with no shading (S1) had the highest energy consumption, with an annual energy consumption of 19.31 kWh/m^2, followed by Venetian blinds in S4 with a value of 12.8 kWh/m^2. Considering fixed shading, the total energy consumption was 12.32 kWh/m^{2}a. The shading devices with the best performance were roller blinds, with a total energy consumption of 9.93 kWh/m^{2}a. Nevertheless, the total energy consumption for automatic control scenarios was lower than that of fixed solar shading in roller blinds. The total energy used in scenario 2 (fixed shading) was 11.75 kWh/m^{2}a. Therefore, the simulation results revealed that roller blinds performed better than Venetian blinds in the considered office buildings. Notably, since the selected office room was well-insulated and all surfaces except the south wall were adiabatic, the heating energy consumption for the chosen case study was minimal (about zero). Therefore, heating demand results were not included in Figure 3.

Fixed shading had a cooling load of 8.2 kWh/m^{2}a. S1 had the highest total cooling consumption compared to the other scenarios, with a value of 16.33 kWh/m^{2}a. In contrast, roller blinds required the least amount of cooling compared to other scenarios. With roller blinds and Venetian blinds, the annual cooling consumption of ISO 52016-3 was 5.93 kWh/m^{2}a and 9.12 kWh/m^{2}a, respectively. Roller blinds and Venetian blinds differ significantly (57.4%) in their cooling consumption. Results confirmed that when the cooling demand were considered the roller blinds performed better than Venetian blinds.

Table 3: The frequency of internal air temperature during a year for each scenario.

Indoor air temperature [°C]	Frequency [%]			
	S1: No shading	S2: Fixed shading	S3: Roller blinds	S4: Venetian blinds
24	0.14	0.31	0.67	2.43
24.5	0.63	0.75	1.46	5.22

25	40.29	38.55	37.07	44.47
25.5	31.85	36.12	40.39	33.76
26	4.39	6.29	11.74	8.93
26.5	4.51	8.72	7.37	4.51
27	7.68	7.45	1.26	0.23
27.5	7.21	1.80	0.03	0.00
28	2.84	0.00	0.00	0.00
28.5	0.43	0.00	0.00	0.00

Table 3 shows the frequencies and standard normal distribution of internal temperature for all scenarios. For each scenario, the annual mean value of the interior air temperature was determined. No shading, fixed shading, roller blinds, and Venetian blinds had respective mean values of 25.48 ℃, 25.33 ℃, 25.19 ℃, and 25.04 ℃. 70% of the time, the internal air temperature was observed to be 25 ℃ or 25.5 ℃. Approximately 28% of the time in S1, the indoor air temperature exceeded 26 ℃ for higher temperatures. In S2, S3, and S4, the frequency of temperatures above 26 ℃ was 24.2%, 20.3%, and 13.6%, respectively. Also obtained was the standard deviation for each scenario.

In order to comprehend the thermal comfort performance of each scenario, the effects of each control scenario on operative temperature were compared, and the results are shown in Figure 4. The swarm chart provides a visual representation of the distributional characteristics of indoor operation temperature for each control scenario. The mean operative temperatures for control scenarios involving no shading, fixed shading, roller blinds, and Venetian blinds were 26 ℃, 25.6 ℃, 25.3 ℃, and 25.4 ℃, respectively.

In addition, the minimum and maximum values of operational temperature were recorded as 26.2 ℃ and 27.9 ℃, respectively, for roller blinds and S1. Similarly, the control scenario with no shading had the lowest minimum temperature with a value of 24.1 ℃ . Comparatively, the highest minimum temperature of 24.3℃ occurred in situations with both roller blinds and fixed shading.

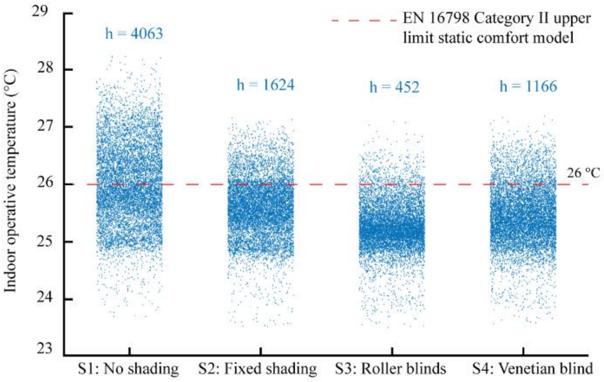

Figure 4: Distribution of indoor operative temperature for each scenario according to EN16798 category II.

Moreover, Figure 4 depicts Category II's maximum and minimum indoor operative temperature fixed thresholds of 26℃ and 20℃ based on the EN16798 static comfort model for the office room. When a high solar incident occurs on the facade, the operation of the automated shading device prevents solar radiation from entering the interior. Therefore, indoor operative temperatures were considerably closer to the comfortable range in S3 and S4 when the shading devices were closed. Consequently, not closing the shading devices for the S1 and S2 revealed that their operative temperature ranges (25.5-26.5 ℃ and 25.3-25.9 ℃, respectively) were below the comfortable operative temperature (23-26 ℃). According to the results, the roller blinds provided the best indoor temperature performance, with a maximum of 26,2 ℃ being reached for a limited time. The correspondence value was followed by 26.7 ℃ for Venetian blinds and 26.9 ℃ for fixed shading. The number of exceeded hours of operation temperature based on the upper limit of the EN16798 static comfort model is also shown. The worst-case scenario was S1 (no shading), frequently exceeding the EN 16798 category II upper limit. In this scenario, even though the mean indoor operative temperature was 25.9 ℃, more than half of the values exceeded the upper comfort limit. The highest uncomfortable hours were related to the S1 with 4063 hours. The uncomfortable hours for S2, S3, and S4 were 1624, 452, and 1166, respectively. Considering the uncomfortable hours, S3 provided a more comfortable operative temperature compared to other scenarios. Furthermore, in S3 and S4, the uncomfortable hours decreased by 88.9% and 71.3%, respectively, compared to the no shading condition.

The simulation of S2, S3, and S4 was conducted in various orientations to comprehensively evaluate the influence of shading technologies and ISO 52016-3 control strategies. The study assessed several parameters including the maximum operative temperature, cooling load, lighting loads, number of hours when the room was occupied and exceeded the recommended levels, and the Indoor Overheating Degree (IOD). The evaluation was conducted for fixed shading, roller blinds, and Venetian blinds and results are presented in Table 4.

According to the data presented in Table 4, the highest operative temperature recorded for scenario 03 was 27.1 ℃ which occurred when the room was oriented towards the south. In the S2, following the adjustment of shading, the highest recorded indoor operative temperature was 26.4 ℃ for the southern orientation. For the northern, western, and eastern orientations, the corresponding maximum indoor operative temperatures were 25.77 ℃, 26.25 ℃, and 26.31 ℃, respectively. The maximum operative temperature was observed in instances where the building facade was oriented towards the south, across all scenarios.

The cooling load demonstrated a similar pattern, whereby the south oriented had the highest value while the north oriented had the lowest value. In S2, a reduction of 24.14% in cooling load was observed on the north façade in comparison to the south façade. The percentage decrease associated with S3 was 25.12%, while that of S4 was 27.2%. The lighting load in S2, S3, and S4 showed an ascending trend from the south to the north, with increments of 19.18%, 8.5%, and 7.34%, respectively.

Table 4: summarizing the maximum operative temperature, IOD, cooling loads, lighting loads, and number of exceeded hours of operative temperature for the case study in S2, S3, and S4 when different orientation was considered.

S2 (Fixed shading)				
Orientation	**South**	**North**	**West**	**East**
Max. Op. temperature [℃]	26.4	25.77	26.25	26.31
IOD [℃]	0.015	0	0.002	0.002
Cooling load [kWh/m^2.a]	8.2	6.22	7.61	7.59
Lighting load [kWh/m^2.a]	4.12	4.91	4.50	4.48
Number of exceeded hours	351	0	114	68
S3 (Roller blinds)				
Orientation	**South**	**North**	**West**	**East**
Max. Op. temperature [℃]	27.10	26.77	26.87	26.88
IOD [℃]	0.009	0	0.003	0.002
Cooling load [kWh/m^2.a]	5.93	4.44	5.36	4.14
Lighting load [kWh/m^2.a]	4	4.34	4.22	4.20
Number of exceeded hours	159	0	57	29
S4 (Venetian blinds)				
Orientation	**South**	**North**	**West**	**East**
Max. Op. temperature [℃]	27.12	25.79	27.01	26.78
IOD [℃]	0.009	0	0.004	0.002
Cooling load [kWh/m^2.a]	9.12	6.64	8.18	8.28
Lighting load [kWh/m^2.a]	3.68	3.95	3.79	3.75
Number of exceeded hours	290	0	108	100

Of the various scenarios and orientations that were evaluated, it was found that S2, which was oriented towards the south and had 351 operative temperature hours, resulted in the lowest number of hours of thermal comfort for occupants during occupied space. In the south, there were 159 and 290 hours respectively of hours that were over the limit for S3 and S4. For example, where the orientation of the room was deemed to be facing north, there were no instances of overheating observed.

Upon comparison of IOD values, it was observed that the southern oriented façade of S2 exhibited the highest IOD value of 0.015 ℃. The IOD values for S3 and S4 were found to be equivalent, with a recorded value of 0.009 ℃. This value was observed to be the minimum among the south-facing facades. The research findings indicate that the likelihood of overheating was elevated by 40% as a result of the transition from a static shading device (i.e. fixed shading) to a dynamic shading device (i.e. roller blinds and Venetian blinds). The results indicate that the implementation of shading technologies and ISO control strategies can be effective in mitigating the potential for overheating.

Discussion

Findings and recommendations

In comparison to fixed shading, demand rose by 10.62%. In addition, the lighting demand of offices with roller blinds and Venetian blinds decreased by 2.91% and 10.68%, respectively, compared to offices with fixed shading. The total energy consumption of the office space studied with roller blinds, Venetian blinds, and fixed shading was 9.93 kWh/m^2.a, 12.80 kWh/m^2.a, and 12.33 kWh/m^2.a, respectively. Therefore, fixed shading was superior to Venetian blinds in terms of total energy consumption. Our findings contradict prior research in this field. It should be noted, however, that the differences in results are dependent on the fixed shading design. Fixed shading could be a single "brise-soleil" or fixed louvers, as in this study. De Luca et al. (De Luca et al., 2018) examined the effect of static and dynamic shadings on the energy consumption of office buildings. Their findings revealed that dynamic blinds performed more consistently than fixed shadings. (Carletti et al., 2016) experimental analysis of an office building concluded that automated Venetian blinds provide superior indoor thermal and lighting performance than other shading devices. The results of this study, however, demonstrated that roller blinds performed better than Venetian blinds.

(EN 16798-1, 2019) specifies 20–26 ℃ as the comfortable operational temperature range for office building category II. Figure 4 showed that roller blinds operated best at 25-25.5 ℃. ISO control considered operative temperature, external solar radiation, and glare incidence (in the case of non-residential buildings). Fixed and no shading allow direct solar radiation into the office. Thus, S3 and S4 had a more comfortable indoor operative temperature range than S1 and S2 (S1 and S2).

In contrast, the scenario with fixed shading and an operative temperature range of 25,3 to 29,9 ℃ offered an indoor operative temperature range comparable to that of a Venetian blind. Due to the absence of shading devices, the worst case scenario was observed for the operative temperature range of 25.5 to 26.5 ℃, demonstrating the ability of automated control scenarios to achieve a comfortable operative temperature.

The uncomfortable hours exponentialy decreased when dynamic shadings were employed with the control strategy suggested by ISO 52016-3 (S3 and S4) compared to the no shading condition (S1). The results indicated that by implanting control strategy provided by ISO52016-3 the risk of over heating can be reduced effectively.

Note that the primary purpose of these results is to demonstrate the value of ISO 52016-3 and its application to building simulation. Using shadings with different solar and visual properties will alter the outcomes.

The following recommendations can be derived from the calculations for the selected examples:

1. It is recommended to select the shading device technology between exterior roller blinds and Venetian blinds in order to reduce the energy demand of office buildings in oceanic temperate climates by implementing exterior roller blinds.
2. To provide a thermally comfortable indoor environment, it is recommended that the office room's

shading be controlled automatically to prevent the loss of operative temperature.

3. Since the energy demand of the office room with automated Venetian blinds and fixed shading was very similar, designers and engineers are strongly encouraged to conduct additional research and simulation at an early design stage in order to select the most efficient shading devices.

Strengths and limitations

This study has a number of strengths that can be mentioned. The first strength of this paper was that the authors utilized a calibrated, high-performance office space for the case study. The second strength was the novel and ongoing development of ISO 52016-3 implementation. ISO 52016-3 accompanies ISO 52016-1 by incorporating the adaptive element of the facade into the energy calculation of buildings. Only a few studies, including (Attia et al., 2022) analyzed different control strategies of this new ISO 52016-3 that have been published yet. This study implemented ISO 52016-3 automated control strategies using cutting-edge software. According to the literature, few studies have compared the energy efficiency of roller and Venetian blinds. The fourth strength of this study was a thorough comparison of ISO 52016-3 control strategies on heating, cooling, internal air temperature, and operative temperature for two dynamic shading elements (roller blinds and Venetian blinds). Standard experts revised and reviewed the model in this study to validate and implement control strategies (ISO 52016-3 committee members).

We are cognizant of the potential limitations of our research. The first involves implementing automated control strategies for shading device control. Adaptive facade elements were difficult to model based on the study's multi-criteria and automatic control strategies. To implement the control strategies suggested by ISO 52016-3 required a great deal of coding and scripting, as well as the connection of various software. The second was associated with occupant participation in the control strategies. There was no actual interaction between occupants and automated control strategies, and the investigated control strategies were primarily sensor-based. There were few studies about the new ISO 52016-3 in the literature, and there is a lack of factual data, such as the setpoints for controlling and activating automated shading devices. The fourth limitation of the study may be the thermal transfer of the walls and roof of the office space under consideration. As stated in the methodology, the interior walls and roof were assumed to be adiabatic, which did not reflect the actual office conditions. These constraints highlight the difficulty of gathering information on automated control strategies.

Implication on practice and future works

These findings have significant managerial ramifications. To implement the control strategies in a real-world setting, user-friendly software is required based on the findings. Our findings are impractical, and the designer will not employ such difficult-to-simulate standards. Also consistent with Loonen's (Loonen et al., 2017) findings in his review paper on adaptive facades. He stated that we need more accessible and streamlined control strategies to facilitate the incorporation of standard and alternative technologies into mainstream simulation software. According to the findings of this study, automated shading devices are not always the solution to reducing office buildings' energy consumption.

In certain instances, such as the case study used in this investigation, fixed shading can have a significant impact on the energy demand of a building. The solution would be more cost effective for building owners and occupants. A spreadsheet is provided in ISO 52016-1 to demonstrate and validate calculation procedures (van Dijk, 2019). (van Dijk, 2021) A new version incorporating the control algorithms of (EN) ISO 52016-3 is in development. We anticipate utilizing and comparing this instrument.

This research has generated several questions requiring additional investigation. First, to determine the most important shading device control parameters, ISO 52016-3 recommends a detailed sensitivity analysis of its control strategies. Second, real experimental testing facilities are recommended to testify and compare results with numerical analysis. Third, according to the literature, ISO 52016-3 covered dynamic shadings, chromogenic glazing, and ventilative facades. Thus, future research should implement ISO 52016-3 control strategies for other facade technologies. Fourth, since the case study building in Brussels was in an oceanic temperate climate zone, ISO 52016-3 control strategies were applied to this climate zone. Thus, future research should assess ISO 52016-3 automatic control strategies in various climate zones. Fifth, as mentioned earlier, this study only examined a case study with two selected technologies in a specific climate to verify ISO 52016-3-recommended control strategies. Thus, a comprehensive parametric study must test all standard variations and their consistency.

In addition to the above future works, a future study could compare and evaluate the energy and comfort performance deviations of ISO 52016-3's control strategies versus those of EnergyPlus's default and simplified (built-in) control strategies.

Conclusion

As stated in the literature, there is no standardized method for evaluating control systems for adaptable façade elements, particularly dynamic shadings. Furthermore, it would be unfair to make comparisons between the energy use of buildings employing different adaptive façade technologies without ensuring that the control strategies for each technology are optimized. As a result, ISO 52016-3 provided several default control strategies to contrast the energy requirements of buildings. Therefore, this paper aims to advance current understanding of the limitations and opportunities associated with the new ISO 52016 standard and improve the energy efficiency of office buildings that use adaptive envelope components.

The stages of this research are sequential, starting with data collection and ending with parametric analysis and dynamic simulations. Following that, the effectiveness of

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fully automated control strategies for exterior Venetian and roller blinds was assessed. Energy simulations were conducted in a south-facing office space in a high-performance office building in Brussels. For various orientations, the outcomes of two scenarios involving Venetian blinds and roller blinds that were automatically controlled by ISO 52016-3 strategies were evaluated. To comprehend the impacts of control methods and shading devices on building energy requirements, two additional scenarios—fixed shading and no shading—were also taken into account. The results of the energy demand for the building, including the heating and cooling loads, internal temperatures (indoor air temperature and indoor operative temperature), covered by ISO 52016-3, and artificial lighting demand, covered by EN 15193-1 with exterior roller blinds and Venetian blinds, were reported. Different software was employed to carry out the simulation. The model was made in Grasshopper, and Ladybug-tools, a built-in Grasshopper plugin, was used for the simulation process. Using EnergyPlus' EMS feature, the control strategies were applied separately for each window. According to the study's findings, the ISO 52016-3 control plan with roller blinds produced the lowest cooling demand of 5.93 kWh/m^2.a for the example cases and shadings that were selected.

Venetian blinds and fixed shading, with 8.2 kWh/m^2.a and 9.12 kWh/m^2.a, respectively, came in second and third. The office room chosen had the lowest energy demand when roller blinds were used. To the fixed shading scenario, which was considered the base case, it reduced the office room's cooling usage by 32.13%. Venetian blinds, as opposed to fixed shading, had a cooling demand increase of 10.62%. The roller blinds outperform other options in terms of creating a comfortable indoor environment. Moreover, roller blinds and venetian blind using control strategies of ISO 52016-3 was reduced the risk of overheating by 40% compared to the fixed shading based on IOD analysis.

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