POLITECNICO DI MILANO

SCHOOL OF URBAN ARCHITECTURE AND CONSTRUCTION ENGINEERING

MASTER OF SCIENCE IN BUILDING AND ARCHITECTURAL ENGINEERING
BUILDING ENGINEERING TRACK

CONTROL ALGORITHM FOR DYNAMIC SOLAR SHADINGS

A SIMULATION STUDY FOR THE EXTENSION OF ISO/DIS 52016-3 TO OFFICE BUILDINGS

SUPERVISOR

PROF. ALESSANDRO DAMA

CO-SUPERVISOR

PROF. SHADY ATTIA

STUDENT

AURORA LUIGIA TERESA BERTINI

STUDENT ID 953046

ACADEMIC YEAR 2022/2023

Abstract

Nel 2019 il settore edilizio si è rivelato responsabile dell'emissione di 12GtCO_2, il 21% delle emissioni totali di gas serra. Per raggiungere la carbon neutrality entro il 2050, il parco edilizio europeo deve essere rinnovato ad un ritmo più sostenuto. Una delle possibili soluzioni da adottare per raggiungere questo obiettivo è l'installazione di schermature solari adattive.

Questo studio si concentra sull'impatto delle schermature solari su un ufficio singolo ubicato in due località caratterizzate da un clima temperato: Liegi (Belgio) e Milano (Italia). Il lavoro si pone come obiettivo l'implementazione di una strategia di controllo ottimale per delle Veneziane e delle tende esterne. Sulla base dell'ISO/DIS 52016-3, è stato studiato un algoritmo multicriterio che consentisse di bilanciare comfort visivo, fabbisogno energetico per riscaldamento, raffrescamento e illuminazione artificiale, e soddisfazione dell'utente.

Due strategie di controllo sono state progettate: una comprensiva e una priva della valutazione del rischio abbagliamento. Entrambe integrano illuminamento orizzontale sul piano di lavoro, occupazione, temperature operante interna e irradianza verticale sulla finestra. Gli algoritmi sono stati applicati e validati attraverso un modello realizzato in DesignBuilder.

Con il controllo dell'abbagliamento, il vantaggio maggiore dell'installazione delle schermature adattive consiste nel miglioramento del comfort visivo, in termini di rischio abbagliamento e di controllo della quantità di luce entrante nell'ufficio. Tuttavia, si registra un aumento del fabbisogno energetico totale annuale, indipendentemente dalla schermatura considerata.

Nel caso invece della strategia di controllo priva di valutazione dell'abbagliamento, si osserva l'importanza del controllo dei carichi termici. Un risultato più apprezzabile si registra a Milano, dove vi è un fabbisogno di raffrescamento maggiore.

Parole chiave

facciate dinamiche, controllo multicriterio, soddisfazione dell'utente, comfort visivo, fabbisogno energetico

Punti salienti

- Si sviluppa una strategia di controllo per uffici ubicati in un clima temperato.
- Si garantisce comfort visivo all'interno dell'ufficio. Tuttavia, si registra un incremento del fabbisogno per l'illuminazione artificiale e del riscaldamento rispetto al caso base che non prevede schermature.
- Si evidenzia l'importanza di un approccio multicriterio nella selezione della strategia di controllo ottimale.
- Si comparano tende esterne, Veneziane con lamelle orizzontali e Veneziane con lamelle a 45° in termini di comfort visivo, impatto sul fabbisogno energetico e contatto visivo dell'occupante con l'ambiente esterno.

Thesis Abstract

In 2019, the building sector was responsible for the emission of 12GtCO2, equivalent to 21% of global GHG emissions. The building sector must change pace to achieve European carbon neutrality by 2050. One of the possible solutions to reach this goal is the adoption of dynamic solar shadings in buildings.

This study focuses on a single office in two locations characterised by a temperate climate: Liège (Belgium) and Milan (Italy). The work aims to implement an optimal control strategy for external Venetian and Roller blinds. A multi-criteria approach based on ISO/DIS 52016-3 is adopted to balance visual comfort, heating, artificial lighting and cooling energy needs, and users' satisfaction.

Two control strategies have been designed: one with and one without glare evaluation. They both integrate horizontal illuminance, room occupancy, indoor operative temperature and vertical irradiance. The control algorithms are applied and validated on a DesignBuilder model.

With the control strategy including glare control, the main advantage is the improvement of the user's visual comfort in terms of light quantity and discomfort glare. However, a total yearly energy needs increase is registered independently from the considered shading.

Instead, if glare is not included in the control strategy, we can observe the importance of the control of thermal loads. A more significant result is obtained for Milan, where cooling energy needs are higher.

Keywords

dynamic façades, multi-criteria control, users' satisfaction, visual comfort, energy needs

Highlights

- A solar shading control strategy for office buildings in a temperate climate has been developed.

- Indoor visual comfort is improved. However, heating and artificial lighting needs increase compared to the base case without shadings.
- The importance of integrated evaluations when selecting a shading strategy is illustrated.
- A comparison between horizontal Venetian blinds, Venetian blinds with a slat angle of 45° and Roller blinds is conducted. Shadings are compared in terms of energy needs, visual comfort, user's outside view.

Thesis Summary

This dissertation deals with the development of a control algorithm for two different shading technologies installed in a single office in Liège (Belgium) and Milan (Italy). The work is based on a modelling approach and, therefore, on coding and numerical simulations.

In the first chapter, the work is positioned in its context. Research objectives have been defined according to what is needed today in the field of shading technologies. Their innovative component and impacts on the stakeholders involved are described.

In the second chapter, the state of the art is analysed. The contribution of similar studies is analysed, individuating their strengths and limitations. Gaps that still must be filled are outlined, and the instruments available to make a step forward are described.

In the third chapter, the methodology adopted in this study is described. Firstly, the case study is described. From the climate analysis, the criticalities of the studied office are highlighted. The adopted interventions to solve them are described and justified. The boundary conditions and hypothesis are outlined. It allows us to clearly state what is included in the research and what is out of its scope.

The variables included in the algorithm are described, explaining why they have been chosen, how they are measured and how they can be included in the numerical model.

The research is articulated in four main steps: data collection, data analysis, instrument development, and application. In the first phase, data about the office and shading systems are raised and used to develop the numerical model of the office. The steps followed and the model's main features are discussed to allow the work's reproducibility. Then, the control algorithm is developed, and the procedure followed to code is written down in detail. Finally, the control algorithm is applied to the model for the four studied cases (no shadings, overhang, Venetian blinds, and Roller blinds) and the two selected locations (Liège and Milan).

In the fourth chapter, the results of the simulations are analysed. For both locations, the shading technologies are compared with the base case and the overhangs regarding energy needs, visual comfort, and user satisfaction.

Those results are discussed in the fifth chapter, where the research outcomes are compared with the previous studies carried out in the academic field. Based on the evidence raised from this work, recommendations for the stakeholders involved in the study are listed. This chapter is also dedicated to a discussion of the work itself, analysing its strengths and limitations and its short and long-term impacts on stakeholders.

This latter discussion brought us to conclude the work, suggesting what must be done in the dynamic solar shadings field and raising questions to be answered in future works.

Foreword

I am Aurora Bertini, a Double Degree student enrolled in Politecnico di Milano and CentraleSupélec.

I am an Italian Building Engineer. I love challenges, overcoming limits, and following non-linear and non-conventional paths. I am ambitious and curious. I am a multi-potential girl: I like arts and maths, rational and emotions. I have a strong sense of ethics and empathy, which is why I love nature and helping people.

This attitude made me passionate about building envelope design and everything dynamic. This latter conjugates structural and thermodynamic calculation, the beauty of architecture, and the well-being of people using the building. Thanks to the dynamic characteristic, it is possible to exploit at its maximum what the environment provides us for free, reducing the energy consumption of buildings.

These are why I chose to work on this cutting-edge research topic, which still needs to be investigated to express its potential fully.

Since it is a complex subject, much support has been needed in the past months. That is why I would like to express my heartfelt gratitude to my Supervisor, Prof. Shady Attia, who allowed me to deal with this topic, trusted me, and whose suggestions led me to all-around growth.

Other special thanks go to my Supervisor, Prof. Alessandro Dama, who agreed to help me in the second part of the work and allowed me to go deeper into the topic.

I would like to thank all the Sustainable Building Design Lab members for the technical and human support I received during the first months of this journey. A special thought goes to Dr. Deepak Amaripadath and (almost) Dr. Ramin Rahif, colleagues who tolerated me daily in the office and friends outside the lab.

Thanks to my parents, my brother and my cousin Raffaella, who always supported me when I was at home, and especially when I was abroad and far from them. It is hard to deal with all my energy, dreams and plans. It is hard to keep up with the pace at which my brain produces the craziest ideas. It is hard to stay next to me when I complain about things not going as I want. However, I hope that the results I have obtained until now could make you proud of who I am and what I have become.

A special place in my heart is also for my grandparents, who are not physically here with me today, but that would have celebrated this great achievement with their most beautiful and biggest smiles, as they always did.

Thanks to my boyfriend Riccardo, who listened, understood and stood by my side on the most challenging days and supported me in all my choices, even those that were bringing me far from him. He is the most beautiful heart I could have ever desired next to mine and the most beautiful eyes to look to the future with.

And finally, thanks to my friends that shared with me this crazy journey in Milan and France. I will never forget all the days and nights spent on the pc for the group projects and the funny travels and moments we spent together.

Aurora Luigia Teresa Bertini, Milan, 18/07/2023

Abbreviations/Acronyms

BC	Base case
DGI	Discomfort Glare Index
EMS	Energy Management System
OH	Overhang
RB	Roller blinds
VB	Venetian blinds
VB0	Venetian blinds with slat angle of 0°
VB45	Venetian blinds with slat angle of 45°

Table of Contents

List of Figures

List of Tables

1 Introduction

In this section, the problem tackled in this study is described. From the context analysis, it is possible to list gaps still present in the literature.

Starting from those latter, the focus of the study is defined. The objectives and the research questions the study aims to answer are presented, accentuating the relevance and impact of the results obtained in the short and the long term.

1.1 Background information and problem statement

In 2019 the building sector was responsible for 31% of the global final energy demand, 18% of global energy demand, and the emission of 12 GtCO2, corresponding to 21% of global GHG emissions (Intergovernmental Panel on Climate Change (IPCC), 2022). Increasing temperatures induced by climate change will lead to an even higher cooling demand. The building sector needs then to change pace.

To achieve climate neutrality by 2050, the European Union is guiding the building sector towards improving energy efficiency. In article 13 of the Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings, the European Commission has stated to adopt by 31st December 2025 a delegated act requiring the application of a scheme for rating the smart readiness of non-residential buildings (European Commission, 2021).

A possible solution to reduce the environmental impact of buildings and achieve European goals is the introduction of dynamic solar shadings in office buildings. This technological solution can improve visual comfort for users close to windows while minimising office buildings' energy needs. The problem is finding a balance among these latter aspects while providing a user-accepted control strategy. This latter, as suggested by Karlsen et al. (Karlsen et al., 2016), passes by guaranteeing the user a good view of the outside and daylight, which is sometimes in conflict with the achievement of indoor visual comfort, as well as the reduction of the energy demand.

However, as Tabadkani et al. suggested (Tabadkani, Tsangrassoulis, et al., 2020), the scientific literature mainly investigated cold climate areas. Moreover, most researchers focused on developing automatic control for daylight harvesting to reduce either electrical lighting or cooling/heating loads. None adopted a multi-criteria approach that combines daylight, view, glare, and lighting/energy saving altogether.

This study will compare Venetian blinds (VB) and Roller blinds (RB) to a base case without solar shadings and one with a fixed overhang (OH) in two different locations (Liège and Milan). Per each of the two types of shadings, the following question will be investigated: what is the optimal shading control strategy in a temperate climate to maximise office occupants' satisfaction and visual comfort while reducing the annual building energy need for heating, cooling and artificial lighting?

Practically, it means to answer the question here below:

- How do we hierarchise daylight, glare, users' preferences, and energy needs?
- How does the control strategy influence visual comfort and annual energy needs?

In order to find a solution to this problem, a modelling approach will be adopted: a numerical model will be implemented on DesignBuilder. The control algorithm will be coded on the Energy Management System tool for DesignBuilder, and tested on the office model.

1.2 Relevance of the research topic

This research's significance lies in applying a multi-criteria approach that will consider visual comfort, energy savings, and user satisfaction. Moreover, this study will be conducted in a temperate region, while the scientific literature mainly investigated cold climate areas, as suggested by Tabadkani et al. (Tabadkani, Tsangrassoulis, et al., 2020). Finally, the results of this study will contribute to the implementation of the ISO/DIS 52016-3 and will be one of the first to apply this Standard.

Considering the project's complexity, this study will also involve and impact multiple stakeholders. Firstly, the study puts at the centre the occupants of an office building, particularly the ones seated next to windows, which are much more affected by visual discomfort.

Secondly, the results will be addressed to producers of shading devices (e.g., Somfy-France, Velux-Denmark, Griesser-Switzerland, Weinor-Germany), solar shading associations (e.g., ES-SO), façade engineers (e.g., Buro Happold, Arup, ABT, Gebrüder Schneider) and facility managers (e.g., ISS, Aremis, Spacewell).

The study developed in academic research will take inspiration from and contribute to the scientific researchers working on solar shading simulation and analysis (e.g., SDB Lab, ULiege, office 0/442).

Finally, this work will be material for discussion for the experts involved in writing the ISO/DIS 52016-3 (e.g., D. Van Dijk, F. Favoino).

1.3 Research Objectives

Within this framework, the present study aims to guarantee visual comfort to the users through a control strategy that maximises the office users' satisfaction and minimises the energy demand of the office building.

To achieve this goal, the design and implementation of a multi-criteria control strategy are needed. The following features characterise it:

- during working hours avoids glare while ensuring daylight supply and view of the outside
- minimise the building energy needs outside working hours, limiting heat gains during Summer and heat losses during Winter

In the short term, the work allows for implementing a multi-criteria control algorithm for solar shadings in offices that could be reused in further studies on more complicated adaptive façades.

In the long term, the work:

- will contribute to the development of a new and cost-efficient solar shading
- will provide façade designers with new solutions that could contribute to delivering more efficient office buildings
- will help to formulate recommendations to facility managers for the adoption of more user-accepted and people-centric control strategies for dynamic solar shadings in offices

- will contribute to solving the European energy and climate crisis, providing a people-centric and intelligent solution for building renovation.

The organisational chart of the study, with the main work packages, is reported in Annex 1: Organisational chart.

A resume of the essential features of the study described in this chapter is finally proposed in the Quad Chart (Figure 1.1).

AIMS AND OBJECTIVES

- Guarantee visual comfort and user's satisfaction
- Minimise the energy needs of the office
- Implement a control strategy that:
  - during working hours avoids glare, while ensuring daylight supply and view to the outside
  - minimises the energy need outside working hours
  - gives the user the possibility to override the automatic control

STAKEHOLDERS

- This study puts at the center the occupants of an office building, particularly the ones seated next to windows, which are much more affected by visual discomfort.
- The results will be addressed to producers of shading devices (e.g., Somfy-France, Velux-Denmark, Griesser-Switzerland, Weinor-Germany), solar shading associations (e.g., ES-SO), façade engineers (e.g., Buro Happold, Arup, ABT, Gebrüder Schneider) and facility managers (e.g., ISS, Aremis, Spacewell)
- The work will take inspiration from and give a contribution to the scientific researchers working on solar shading simulation and analysis (e.g., SDB Lab, ULiege, office 0/442)
- Finally, this work will deal with the ISO 52016-3 and its community (e.g., D. Van Dijk, F. Favoino)

INNOVATION

- Cold climate has been the most investigated area
- Most of the literature is focused on the development of an automatic control for daylight harvesting to reduce either electrical lighting, or cooling/heating loads
- Any study investigated daylight, view, glare, lighting/energy saving altogether (Tabadkani et al., 2020)
- This research:
  - will be one of the first applying the ISO 52016-3
  - will be carried out in a temperate region
  - will consider visual comfort, energy savings and user's satisfaction altogether.

IMPACT

- In the short term:
  - implement a control algorithm for solar shadings in offices, which balances visual comfort, energy savings and user's satisfaction, and that could be reused in further studies on more complicated adaptive façade systems
  - reduce the use of HVAC systems to guarantee the user's comfort
- In the long term:
  - develop a new and cost-efficient solar shading
  - provide new solutions to façade designers to deliver more efficient office buildings in Belgium
  - provide recommendations to facility managers for a more user-accepted adoption of control strategies for dynamic solar shadings in offices

Figure 1.1 Quad Chart

2 Literature review

In this section, the state of the art is analysed. The main challenges related to shading control design are described, individuating the essential suggestions provided by literature and the most appropriate instruments to tackle this topic. This description is followed by an analysis of what gaps still have to be filled, allowing us to clarify the relevance assumed in this context by the present research.

2.1 State of the art of the theories/concepts of the study

The building envelope is the physical barrier between the inside and outside of a building. It is directly exposed to weather elements and their short- and long-term variations, which affect the users' comfort and the building energy consumption in a contradicting way.

To find a balance between comfort and energy needs, adaptive façades have been developed. Being automatically controlled, they can adapt to the variations of the environmental conditions, maximising occupant's visual comfort and reducing the energy need of the building.

To design such a system, first, the proper solar shading and material must be selected. As suggested by Beck et al. (Beck et al., 2010), the choice depends on multiple factors: climate, orientation of the building, prevailing wind conditions, height of the building, character of the building, regional preferences, building's construction details, user expectation and behaviour.

Secondly, the effectiveness of this solution passes through the implementation of a proper control strategy. Automatic control allows for better management lighting, energy loads, and user comfort with respect to manual control systems. However, the results depend on the climate we study (if heating or cooling dominated) (Thalfeldt & Kurnitski, 2015)

Moreover, to be effective, the control design must include occupant-façade interaction (Luna-Navarro et al., 2020) and the occupant's perception of comfort (Day et al., 2019). Users are more satisfied if automatic control complies with their preferences, for example, thanks to the possibility of overruling it (Attia et al., 2018) or having a view of the outside. Several studies confirm that occupants can tolerate short periods of glare discomfort if the view is available (Tabadkani, Roetzel, et al., 2020).

However, the occupant-façade interaction adds significant complexity to the control design, needing a multi-disciplinary approach. This topic becomes even more delicate if we consider that it deals with ethics and privacy (Luna-Navarro et al., 2020). In any case, designers and researchers will have to deal with it: according to Attia et al. (Attia et al., 2018), this user-centred approach will help the penetration of this technology in the market, in an epoque in which dynamic shadings are still considered as a technological trend rather than an architectural element often neglected (Al-Masrani & Al-Obaidi, 2019).

This latter perception of dynamic shadings also results from the multiple challenges that still need to be faced. These later are mostly referred to the control strategy design and the parameters that should be considered in the simulation process and in the physical installation.

2.2 Similar studies

Thalfeldt and Kurnitski (Thalfeldt & Kurnitski, 2015) focused on minimizing the energy demand, discovering that total irradiance on façades is insufficient to implement an effective control strategy. On the contrary, shading control strategies based on indoor conditions are the most energy-effective, mainly if based on PI controllers.

Choi et al. (Choi et al., 2017) also focused on illuminance satisfaction and glare protection, finding out that when solar radiation is high, shadings mostly remain fully closed. This situation will keep users from looking outside for a long time, limiting their satisfaction. In this sense, Xiong et al. (Xiong et al., 2019) proposed multi-objective and single-objective optimisation strategies to manage lighting demand minimisation and personalised shading control (and so users' satisfaction). However, even if these strategies can be extended to thermal preferences, they remain challenging to implement.

A complete study has been conducted by Karlsen et al. (Karlsen et al., 2016). They considered a combination of internal and external shadings, simulation and full-scale experiments, and different control strategies according to the occupancy schedule to find a compromise between energy use and indoor environmental performance. Thanks to this approach, the slat angle was less than 45° for a significant part of the time, guaranteeing a good view of the outside, thermal comfort, and daylight sufficiency while reducing the energy demand.

Day et al. (Day et al., 2019) further analysed user participation in the control design, focusing on subjective visual comfort perception and the effects of daylight performance and automation on the user's experience. The results showed that the satisfaction level depended on the position in the office and the type of shadings. The possibility of overruling the shading control increased the perceived level of productivity. Finally, higher access to daylight increased perceived productivity and satisfaction.

Instead, Kwon et al. (Kwon et al., 2019) focused on both visual and thermal comfort linked to occupant satisfaction. Also in this case, higher controllability of shadings and lighting increased the level of satisfaction (both visual and thermal). On the contrary, occupants who did not have control of shadings and lighting in the working place were the most dissatisfied in terms of light quality and view to the outside, showing that occupants should have control over the office environment.

The ISO/DIS 52016-3(2022) could help to comply with all the needs evoked until now (International Organization for Standardization, 2022). It provides a methodology for calculating energy needs for heating and cooling, considering the integration of adaptive building envelope elements.

It also contains reference scenarios for the implementation of shading control algorithms. They are elaborated for different shading technologies (VB and RB) and building uses (residential and non-residential).

Parameters included in the reference scenario and their relative thresholds are defined according to the literature. Sensors to measure them in real applications are chosen according to the available technologies. Among the parameters included, the human input has been integrated into control algorithms. It has been modelled considering that users try to override the control algorithm when there is not enough daylight in the room.

Combining the parameters included in the scenario, 144 combinations can be obtained. However, only 20 are relevant and are associated with a different extension of the shading and into a different slat angle.

The application of this new Standard will help find the researched balance between automatic control and user satisfaction, visual comfort, and energy needs to take full advantage of the installation of solar shading.

The list of the paper analysed is given in Annex 2: Literature Review Matrix.

2.3 Software available

The literature's most used software for building energy modelling is Rhinoceros and DesignBuilder. It is possible to code a control algorithm for solar shadings in both. Grasshopper, Ladybug, and Honeybee plug-ins are needed in the first case. In the second case, the code is on Energy Management System (EMS) instead.

It is possible to make both the model and control algorithm on Rhinoceros (Mahdi Valitabar et al., 2022) or DesignBuilder (Tabadkani, Tsangrassoulis, et al., 2020).

Rhinoceros is a software conceived to design complex shapes and innovative shading systems. The advantage of the package Rhinoceros, Grasshopper, Honeybee, and Ladybug is the possibility to design and study non-traditional shadings. In addition, the integration of a control algorithm does not require a high level of coding expertise, being it a graphical algorithm editor (Figure 2.1).

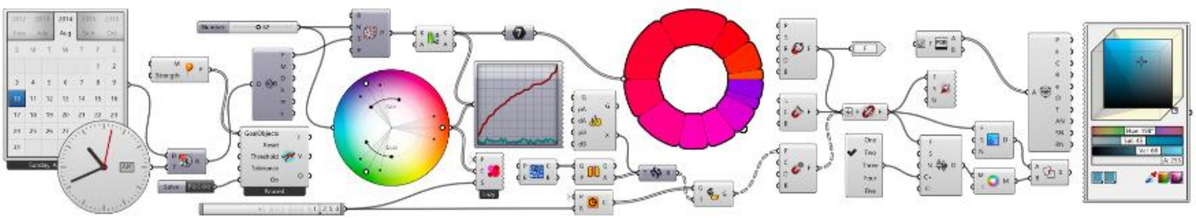


Figure 2.1 Example of algorithm on Grasshopper

On DesignBuilder, instead, it is possible to analyse only standard shading systems. The advantage is that the modelling interface is intuitive: the user is guided in designing all building components, from the envelope and its materials to the HVAC and lighting system. Moreover, built-in shading control strategies can be overridden by coding on EMS. In this case, the algorithm must be totally written in coding language.

Another software available on the market is ESBO, a tool released by the European Solar Shading Organisation. It has been specifically designed to analyse the impact of solar shadings on building energy and thermal performance. Also in this case, only traditional shading systems can be analysed, and there are built-in control strategies. However, glare and temperature are not included in control strategies, and it is impossible to customise the latter. Therefore, for this study, this software has not been taken into further consideration.

2.4 Knowledge gap

The main number of gaps is detected in the control strategy design. Few studies employed a multivariable control strategy. However, this methodology based on a hierarchy of multiple factors (e.g., indoor space activity, climatic zone, and user requirements) is fundamental to successfully designing shading (Al-Masrani & Al-Obaidi, 2019).

In this context, most studies focused on daylight performance. Instead, thermal performance analysis was limited (Al-Masrani & Al-Obaidi, 2019), the view was neglected in 2/3 of the studies due to its difficult quantification, and none of the studies adopting a closed-loop control considered user preferences as an input (Tabadkani, Roetzel, et al., 2020). Therefore, the main control inputs are daylighting and glare, and most of the literature on automatic control is focused on daylight to reduce artificial lighting or heating and cooling energy (Tabadkani, Roetzel, et al., 2020).

On the contrary, a compromise between human comfort and energy savings would be the best solution. However, none of the studies investigated daylight, view, glare, lighting, and energy savings altogether (Tabadkani, Roetzel, et al., 2020).

Therefore, an integrated automatic control to cover human comfort objectives and energy altogether is needed (Tabadkani, Roetzel, et al., 2020), together with a general design solution for satisfactory interaction strategies (Luna-Navarro et al., 2020).

This is what this study aims to do: define the control strategy that optimises and properly hierarchise light quantity and glare comfort, heating, cooling and artificial lighting energy needs, and user satisfaction.

The relevance of this work is not only related to the application of a multi-criteria approach, but also to the contribution to the implementation of the ISO/DIS 52016-3 scenario for non-residential buildings, which is still under development.

2.5 Concepts and variables of your research

This work will be divided into two parts: developing a numerical model of the office and coding the control strategy.

In the model, we will integrate the climate conditions of the locations and the technical specifications of the building envelope and shadings.

In the control algorithm, we will consider horizontal illuminance on the working plane, discomfort glare index (DGI) at the head level, office occupancy schedule, indoor operative temperature, and vertical solar irradiance on the window.

The hierarchisation and integration of these variables into the control algorithm will affect, on one side, the office's energy needs. On the other side, it will affect the conditions of the user in the office in terms of visual comfort and user satisfaction, related to the outside view.

The implementation and definition of the optimal control algorithm will have an impact not only on the specific case study, but also on solar shading producers, façade designers, and facility managers. Finally, it will contribute to developing the DIS/ISO control scenarios for solar shadings in non-residential buildings.

3 Methodology

In this section, the methodological approach is described and justified. Firstly, the case study is analysed, starting from the climatic context and moving to the building and, finally, to the office. This preliminary study reveals the problems affecting the office and its user and their relative solutions.

Secondly, the assumptions, the boundary conditions, and the variables considered in the research are clearly stated and justified. The main steps of the research are discussed: data collection and analysis, algorithm implementation, application, and validation. Data collection refers to the specification gathering about the office and shadings. This information (together with indications of ISO Standards) is later used to implement the numerical model. Finally, the control algorithm is coded and applied to the numerical model. The results obtained at each step allowed us to validate the model and the code.

3.1 Description of the research design and methods

The focus of this research is:

- defining an optimal control strategy for two different types of external solar shadings (VB and RB) installed in a single office located in a temperate climate;
- compare the performance of the two selected technologies in terms of visual comfort and energy needs;
- evaluate the shading performance in two different locations (Liège and Milan).

The aim is to implement a control algorithm that minimises energy needs and visual discomfort and maximises the durability of the system and the users' satisfaction, with the final goal to provide a shading solution to be installed in the studied office in two different locations.

Finding a solution to this problem means understanding:

- the impact of the control algorithms on energy needs, visual comfort, and user satisfaction;

- how to hierarchise energy needs, visual comfort, and user satisfaction in the control algorithm;
- the effectiveness of the same control strategy in different locations.

In this perspective, a modelling approach has been adopted. This strategy is based on realising a model of the studied building, on which the control algorithm is then applied.

In the context of this work, this methodological approach has been applied according to the following steps:

- data collection about the site, the building, and the solar shadings
- implementation of the building model
- design and coding of the shading control algorithm
- application of the algorithm to the model
- validation of the model and the algorithm.

Data collection about the site, the building, and the shading allowed us to make an accurate model of the building. Particularly:

- the climatic conditions of the site have been based on the weather files already available in DesignBuilder;
- the features of the building (e.g., plans, sections and elevations, materials used for the envelope, and type of glazing) have been provided by the Technical Designer of the University;
- the shading performances have been taken from Renson datasheets in the case of screens and from literature in the case of Venetian blinds.

This information has been integrated into the building model realised on DesignBuilder. This software allows to perform energy and daylight analysis and develop custom controls via an integrated coding feature: the Energy Management System (EMS).

In this case, using EMS, it has been possible to code the shading control algorithm for the two types of shading, apply them to the model, and visualise the simulation results without using multiple software simultaneously.

The model and code validation have been favoured by the possibility of visualising the results in tables and graphs directly on DesignBuilder.

A detailed analysis of the impacts of the control algorithm on the considered variables required, instead, a post-process of the simulation results. This analysis has been conducted on Microsoft Excel and allowed to:

- analyse the effects of the control strategy on visual comfort and energy needs
- define the advantages and disadvantages of the installation of dynamic VB and RB;
- formulate final recommendations for stakeholders.

3.2 Study conceptual framework

After studying the literature, the work focused on data collection about the site, the building, and solar shadings that could be installed in the building.

That information allowed us to:

- analyse the climate of the site and the consequences on the studied building
- define the characteristics of the studied office in terms of orientation, characteristics of opaque and glazed technical elements, the recommended levels of illuminance according to the performed activity, and the temperature setpoints
- choose the type of shadings to be analysed.

Knowing the characteristics of the case study, it has been possible to make the model of the building on DesignBuilder and to define the control strategy to adopt, getting the benefit of the existing strengths and trying to ameliorate the identified weak points of the building.

The control strategy has been separated into two parts:

- during working hours, where the primary aim is to provide visual comfort to the users while maximising their satisfaction
- outside working hours, where the focus is the minimisation of energy needs.

This verbal consideration has been transferred into coding language in EMS on DesignBuilder, where the control algorithm has been written.

The control algorithm was applied to the model, and simulations were run.

The simulation results have been visualised in tables and graphs on EnergyPlus Result Viewer to validate the model and the algorithms. Finally, data have been post-processed in Excel to analyse the impacts of the control algorithm and the shading behaviour at different time scales (year, month, week and day).

The graphical representation of the adopted methodology and the step followed can be observed in Figure 3.1.

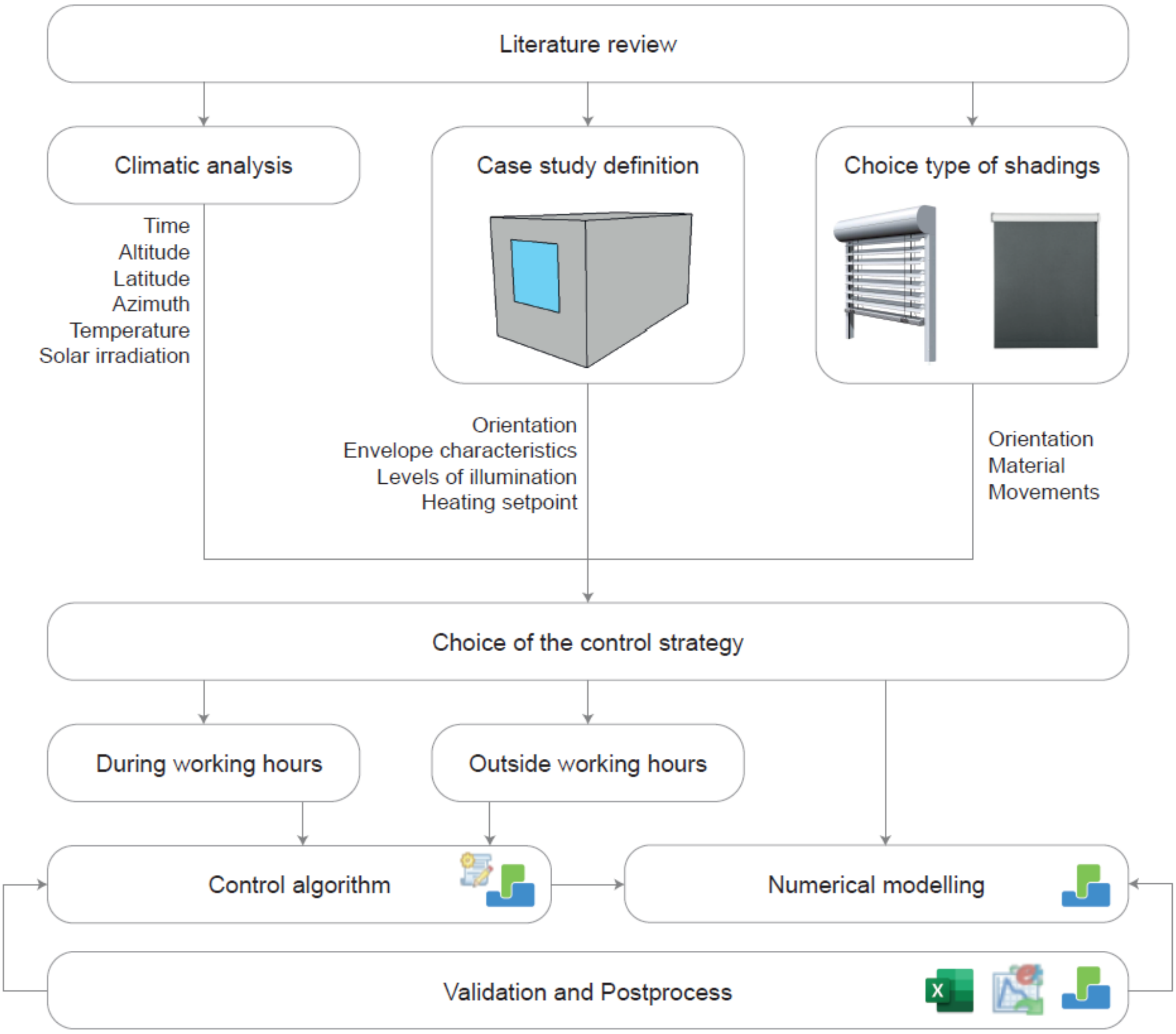


Figure 3.1 Study Conceptual Framework

3.3 Case study

The research focuses on a single office in building B52 of Liège University. This building is located in the Quartier Polytech 1, Allée de la Découverte 9, 4000 Liège, Belgium (50°35'N, 5°33'E) (Figure 3.2).

The office is positioned at level 0 of the building and has a South orientation. The desk is positioned under the window, and the worker is facing the window. Hence the worker is exposed to visual discomfort in all seasons.

In order to ameliorate the working conditions of the user, dynamic solar shadings are identified as a possible solution.

Due to office's window type, two solar shading technologies have been selected: VB and RB. The aim is to design a control strategy to ameliorate the user's visual comfort and satisfaction without negatively affecting the office's energy needs.

The strategy will be tested in two different locations, Liège and Milan, keeping the same office and shading features.

Figure 3.2 Localisation of the case study and photo of the building

3.3.1 Climatic analysis of the site – Liège (Belgium)

The climatic analysis of Liège has been performed using the .epw file of Beek, which was the weather file associated with Bierset-Liège Airport in DesignBuilder. The analysis of data has been done using the software Climate Consultant. The most relevant graphs obtained can be found in Annex 4: Climatic analysis of the site – Liège (Belgium).

According to the Koeppen-Geiger climate classification (Peel et al., 2007), Liège is characterised by a Cfb climate, i.e., a temperate ocenanic climate, marked by cool summers and mild winters for the latitude.

The hottest months are July and August. In the first, the maximum average temperature is observed, while in August the maximum temperature touches 36°C.

Temperatures exceed the comfort range (20-24°C) from May to September. However, while in May and September high temperatures are registered in a limited number of days, between June and August high temperatures are registered more frequently and interest the totality of the working hours.

The effect of solar radiation must be added to that of temperature. In fact, in the hottest months of the year, the highest solar radiation is registered, determining an increase in the heat gains in the office.

As for wind, the prevailing direction is observed at South-West, while the minimum number of hours is registered on the axis South-East/North-West. This minimises, the effect of cooling by natural ventilation during the hot season.

Finally, in terms of global horizontal illuminance, during the overall year, the monthly average illuminance is above 1000 lux, with a peak of 3700 lux in July. The maximum absolute value registered is 96000 lux, which, being so high, would determine a high risk of glare discomfort inside the office.

The installation of a shading system appears fundamental to ameliorate the visual comfort of the worker.

According to the Givoni diagram, when external air temperature passes 20°C, this technology is the most effective solution to adopt.

Considering that the climatic analysis is done on a representative meteorological year (that does not consider the effects of climate change), the installation of solar shading is supposed to be even more relevant to limit overheating in Summer.

3.3.2 Climatic analysis of the site – Milan (Italy)

The climatic analysis of the site has been performed using the .epw file of Milan. The analysis of data has been done using the software Climate Consultant. The most relevant graphs are in Annex 5: Climatic analysis of the site – Milan (Italy).

Milan is characterised by a Cfa climate, i.e., a humid subtropical climate, with hot and humid summers and cool to mild winters (Peel et al., 2007).

July is the hottest month of the year. In fact, the average maximum temperature arrives at 33°C. Moreover, in this month, the highest solar radiation is registered.

From May to September, temperatures exceed the comfort range (20-26°C). In May and September, this occurs in a limited number of hours. On the opposite, between June and August, temperatures can remain above 27°C for the totality of the working hours.

The prevailing wind direction is North.

Finally, in terms of global horizontal illuminance, the monthly average illuminance is constantly above 800 lux, with a peak of 3600 lux in July. The maximum absolute value registered is 74000 lux, which would induce a high risk of glare discomfort inside the office. Hence, also in this location, the installation of a shading system appears fundamental to ameliorate the visual comfort of the worker.

3.3.3 Description of the case study

The research focuses on a single office in building B52 of the University of Liège.

The building comprises three blocks: two parallel blocks at North-West and South-East of the building and a central block that connects those latter.

The first two blocks have their main axis in the direction N-S and are occupied by offices and laboratories. The central block, instead, is characterised by a vast circulation space and a library.

The office analysed is positioned in the South-East block. This wing is built on five levels, from -2 to +2. Level -1 is at the street level, at an altitude of -3.24m.

The office is positioned at level 0. Having the floors above the ground level at an height of 3.24m, the office is at an altitude of 0.00m.

The office has an internal dimension of 3.10 x 5.40m. Its main axis is in the direction N-S. It is adjacent with offices at W and E, with a corridor at N and with the outside at S. Upside and above it adjoins with other offices. The window is 160x160cm, and, for security reasons, it can be opened only when the room is occupied.

The office is occupied by a single person, who works at a distance of 1.3m from the window, facing this latter (Figure 3.3). For this reason, the worker is exposed to a high glare discomfort throughout the year.

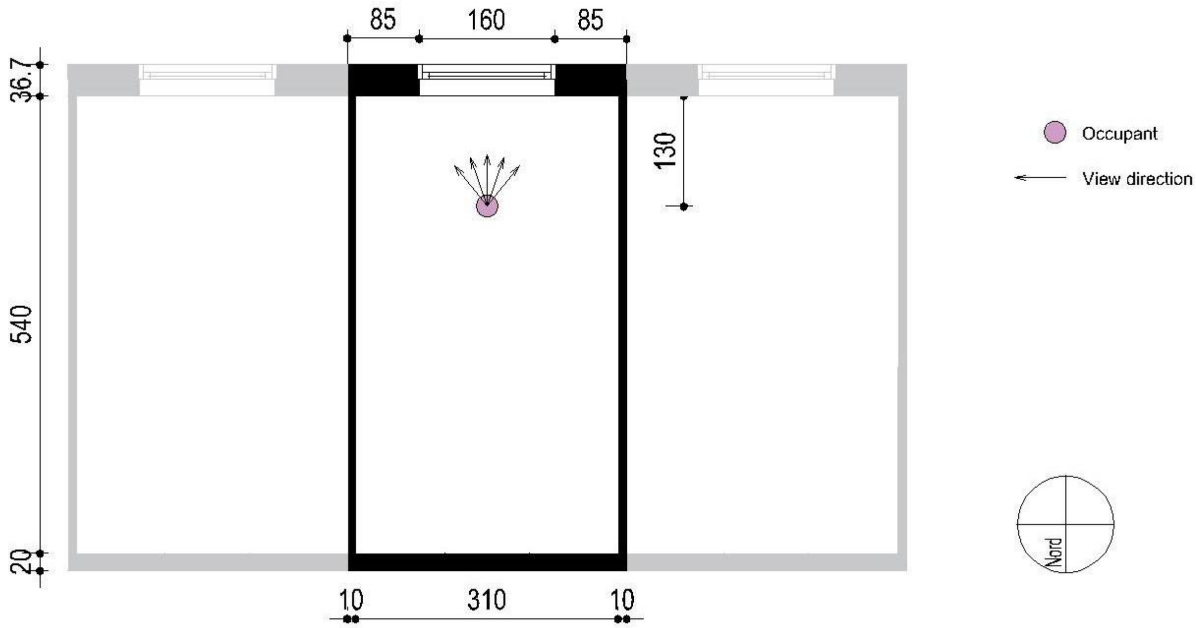


Figure 3.3 Plan of the office

3.3.4 Choice of the type of shadings

The choice of shading depends on multiple factors. As reported by Beck et al., it depends on: climate, building orientation, prevailing wind conditions, height of the building, character of the building, regional preferences, building construction details, user expectations and behaviour.

In this case, the height is limited, being the office at level 0, at 3.24m from the street level. Moreover, as described in paragraph 3.3.1, the office is protected from the wind. Therefore, external solar shadings have been adopted.

The type of window opening affected the choice of shadings in terms of technology and fixing mechanism.

The window installed in the office has a horizontal pivot opening. This prevents the installation of a shading system fixed on the extradox of the window.

The adopted solution is, therefore, a shading system fixed on the window frame that can turn solidly with the window.

The choice of the shading type, instead, has been based on recommendations of the commercial office of solar shading producers. The two possibilities selected for this case study have been VB and RB (Figure 3.4).

RB have been the most recommended solution. They can be mounted with a block in the lateral guides to prevent the screen from rolling down into the motor by gravity when the window is fully open.

This is not the case for VB: slats can turn around their axis by gravity, and, not having a block in their guides, they can roll down into the motor and damage it if the user activates the shading. For this reason, producers do not guarantee this product for application to this case study.

However, it has been observed that the window is fully open only for cleaning and maintenance. For this reason, VB have also been kept as a solution to investigate.

As for the colour, a grey-color screen has been selected to preserve the building character given by its stainless steel finishing.

Finally, a tissue made of glass fibre and PVC has been chosen for the RB. In fact, when the screen is rolled down, this type of tissue allows the user to have a good view of the outside while resulting fully opaque from the outside.

In addition to the dynamic shadings, the performance of an overhang (OH) has been considered. The overhang has been dimensioned according to the sun elevation at 12.00 for the Spring equinox in Liège to get benefit of solar gains during Winter and limit these latter during Summer. We obtained an OH depth of 1m.

Figure 3.4 Selected solar shadings. On the left, solar screens. On the right, Venetian blinds

3.3.5 Choice of the control strategy

The control strategy adopted for the two types of shading is the same. It is a multi-criteria control strategy aiming to maximise the visual comfort of the worker and his/her view of the outside. At the same time, it must not significantly impact the office's energy needs.

To satisfy those requirements, the control strategy adopted is the following:

- during working hours, the crucial aspect to consider will be maximising the user's comfort. Visual comfort must be the priority throughout the year, providing correct illuminance on the desk and avoiding glare. In Summer, this requirement must be combined with the limitation of solar gains and the impact on the view to the outside.
- outside working hours, the focus will be on minimising energy needs. during Winter, it means getting advantage of solar gains that, on the contrary, must be limited during Summer.

As can be seen, the requirements to be satisfied bring us to make different choices regarding shading control: to limit glare, we will need to roll down the shading during working hours, but this will limit the availability of natural daylight and the vision to the outside. On the other hand, to maximise heat gains during Winter and reduce the heating needs, we will need to roll up the shadings, implying a high glare discomfort for the worker.

Hence, satisfying all the requirements needs to define hierarchies and find an optimum trade-off among all the parameters considered. This is the core of this research.

3.4 Operationalization

The control strategy is based on multiple criteria to be satisfied. It implies the combination of multiple variables, both independent and dependent.

The independent variables are the ones that designers cannot control (e.g., the weather conditions) or assumed by themselves (e.g., the control strategy).

The dependent variables, instead, depend on the value assumed by the independent variables (e.g., the visual and thermal comfort).

For each variable, which is the general aspect that must be tackled, a sub-variable is defined to specify what the research will deal with. To each sub-variable, an indicator is associated, which expresses how the sub-variable will be quantified.

Finally, for each indicator, it is defined:

- an instrument to experimentally measure the indicator
- a tool to explain how to include and analyse the indicator in the numerical model
- a protocol to follow during the modelling and/or the experimental phase.

In this case, the variables to be considered have been chosen according to the possibility of measuring them. In fact, the research wants to provide a solution that could be installed in the office. Therefore, starting from the modelling stage, the experimental application has been considered, and so has the availability of adequate equipment.

Table 3.1 and

Table 3.2 list the independent and dependent variables considered in the study, with relative indicators, instruments, tools, and protocols.

In the following paragraphs, only the most relative choices will be discussed.

Table 3.1 Independent variables considered in the study, with relative sub-variables, indicators, units of measure, instruments, tools and protocols

Independent variables						
Variable	Sub-variable	Indicator	Unit	Instrument	Tool	Protocol
Control strategy	Control algorithm	Shading movements	-	Programmable controller	EMS	ISO/DIS 52016-3
Indoor conditions	Light quantity	Horizontal illuminance on workplane	lux	Luxmeter	DesignBuilder	EN 12464-1
	Glare	Discomfort Glare Index (DGI)	-	Luminance meter	DesignBuilder	Hopkinson scale
	Temperature	Operative temperature	°C	Air temperature sensor Globe temperature sensor	DesignBuilder	ISO 17772
	Room occupancy	Desk presence	-	Presence sensor	DesignBuilder	-
External conditions	Solar irradiance	Vertical irradiance on the window	W/m2	Pyranometer	DesignBuilder	-

Table 3.2 Dependent variables considered in the study, with relative sub-variables, indicators, units of measure, instruments, tools and protocols

Dependent variables						
Variable	Sub-variable	Indicator	Unit	Instrument	Tool	Protocol
User's satisfaction	View to the outside	Hours with activated shading	hours/ year	-	EMS	-
Visual comfort	Glare	Hours above the glare setpoint	lux	Luminance meter	DesignBuilder	EN 16798-1
	Light quantity	Hours below/above the horizontal illuminance setpoints	-	Luxmeter	DesignBuilder	EN 16798-1
Energy need	Heating	Annual heating need	kWh/m2/ year	-	DesignBuilder	ISO 52016-1
	Cooling	Annual cooling need	kWh/m2/ year	-	DesignBuilder	ISO 52016-1
	Lighting	Annual lighting need	kWh/m2/ year	-	DesignBuilder	-

3.4.1 Independent variables and indicators

3.4.1.1 Light quantity

Providing the correct amount of light allows the occupants to properly perform their tasks in the indoor environment.

Multiple indices can be chosen to evaluate the quantity of light (Tabadkani, Roetzel, et al., 2020).

In this study, the Horizontal illuminance on the work plane (E_h) has been chosen.

Considering a point P on a surface, the illuminance is defined as the ratio between the light flux arriving on an infinitesimal surface around P and the area of that surface:

$$E_h = \frac{\varphi}{A}$$

The adoption of this index depends on multiple reasons:

- it is the only index that considers the contribution of both natural and artificial light.
- it is the index considered in the EN 12464-1 for the standardisation of lighting of workplaces, which also defines the minimum illuminance threshold (500 lux for offices where the main activity is writing, typing, reading, and data processing)
- in the ISO/DIS 52016-3, this metric is used to individuate the Daylight mode in the control algorithm scenarios
- together with the DGI, it is the only index available in DesignBuilder to evaluate visual comfort, which can be included in the control algorithm design.

However, this metric also has some limitations (Tabadkani, Tsangrassoulis, et al., 2020):

- it cannot be used to evaluate daylight availability, as it does not distinguish between the contribution of natural and electrical lighting
- it cannot be used to evaluate glare since its mathematical equation is independent of the observer

- it depends on the surface orientation.

3.4.1.2 Glare

Glare is defined as the "unpleasant sensation produced by bright areas within the visual field, such as lit surfaces, parts of the luminaires, windows and/or roof lights" (*Light and Lighting. Lighting of Work Places. Part 1 Indoor Work Places*, 2021).

In the presence of openings, glare can be caused by direct sunlight or by a high luminance level in the field of view seen through openings.

There is no standardised metric to analyse discomfort glare. This is also because the scientific community still has to deeply understand this phenomenon (Tabadkani, Tsangrassoulis, et al., 2020).

In this study, the first option considered was the Vertical Illuminance at the head level. The principle is the same as the Horizontal illuminance but applied on a vertical surface. Experimentally, it can be easily measured using a lux meter positioned just behind the worker, at the level of his head (i.e., 1.20m).

However, DesignBuilder's only index available to evaluate discomfort glare is the Discomfort Glare Index (DGI). Therefore, DGI has to be adopted, even if it is more complicated to calculate and experimentally measure.

DGI is an index built to calculate discomfort glare generated by windows (Piccolo & Simone, 2009). The indexes already available (e.g., British Glare Index – BGI, CIE Glare Index – CGI, and Unified Glare Rating – UGR) had been built for artificial lighting sources, and applying them to window discomfort glare had a main weakness: in case of large glare surfaces, these latter occupy a big part of the observers' view. Therefore, the eye experiences less contrast effect and glare perception. Moreover, in the case of windows with a beautiful view of the outside and for moderate glare levels, people have more tolerance to discomfort glare compared to the glare generated by artificial lighting.

For these reasons, DGI index was elaborated. It depends on the background and window luminance and on their position in the view field of the observer. These parameters are linked together as follows:

$$DGI = 10\log_{10}\left[0.478\sum_{i=1}^{n}\frac{L_{s,i}^{1,6}\cdot \Omega_{s,i}^{0.8}}{L_b + 0.07\omega^{0.5}\cdot L_{win}}\right]$$

where:

- $L_{s,i}$ is the luminance intensity of the *i*-th source of glare
- $\Omega_{s,i}$ is the solid angle subtended by the *i*-th glare source, modified according to the position of the source in the view field
- $L_{b,i}$ is the luminance of the background
- ω is the solid angle including every source from the observer point of view
- L_{win} is the luminance intensity of windows

According to Hopkinson's scale, the maximum recommended value in offices is 22. Below 16, glare is imperceptible, while above 28 it becomes intolerable (Piccolo & Simone, 2009). In this study, the limit of 22 at 1.20m (Tabadkani, Tsangrassoulis, et al., 2020) has been considered in the calculation of the number of hours with discomfort glare.

However, while analysing the results obtained from simulation, it must be considered that this index tends to overestimate the discomfort glare in real sky conditions s (Piccolo & Simone, 2009).

3.4.2 Dependent variables and indicators

3.4.2.1 Visual comfort

According to EN 16798-1, comfort is met if the parameter does not overcome its defined threshold for more than 5% of occupied hours.

Therefore, the discomfort percentage is obtained by reducing by 5% the total discomfort hours registered in the year.

In the case of glare, discomfort is registered if DGI > 22. In the case of light quantity, we consider having discomfort in two cases:

- if the horizontal illuminance on the work plane is lower than 500 lux, which is the minimum illuminance required by EN 12464-1
- if the horizontal illuminance it is higher than 2000 lux, which is the threshold corresponding to a too bright environment (Nabil & Mardaljevic, 2006).

3.4.3 Instruments

A real dynamic shading system is composed of four elements:

- sensors
- controller
- actuator
- motorised shading.

Sensors measure the values of the selected independent variables and send them to the controller.

The controller is the brain of the system. It processes the values received by the sensors and, according to the algorithm designed, sends a signal to the actuator (i.e., a switch): 1 if the shading has to be rolled up, 0 if it must be rolled down.

The actuator is then connected to the shading motor, which will move the shading according to the signal sent.

A scheme with all instruments used and their signals transfers is represented in Figure 3.5.

In this work, only variables measurable in the field have been included in the study. It allows to study a solution that can be effectively installed in the office in the future.

The equipment specifications are not provided, as this latter focused on the numerical modelling of the shading system.

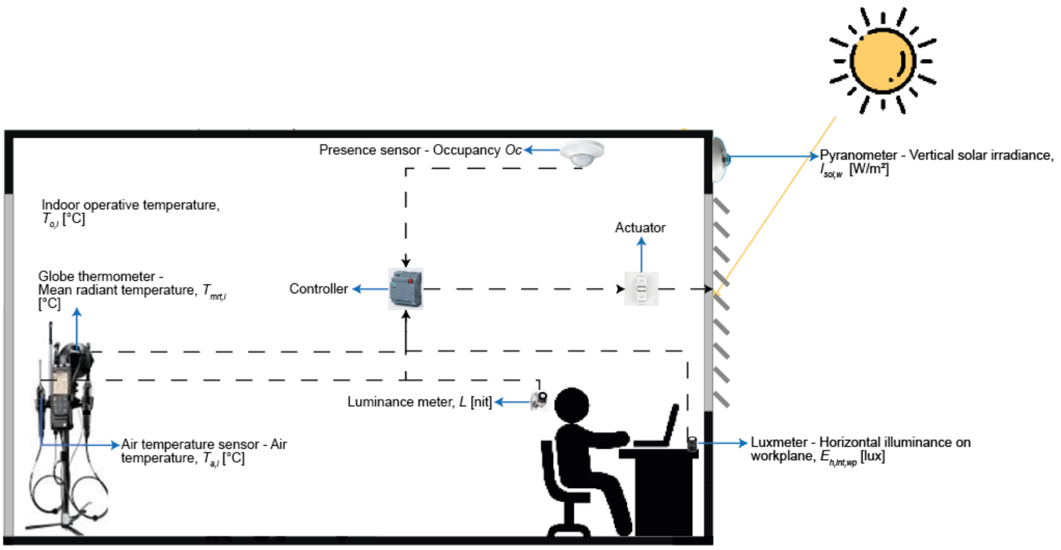


Figure 3.5 Operationalisation scheme

3.4.4 Tools

For this study, both the model and the algorithm have been done on DesignBuilder V.7.0.1.6. In fact, only traditional shadings need to be analysed, and the modelling process is more guided and intuitive.

DesignBuilder includes different modules. The ones considered in this study are:

- 3-D Modeller, to build the geometry of the office, to define users' activities, envelope and shading characteristics, and heating and lighting type.
- Simulation, for the assessment of the energy needs and for the calculation of visual comfort parameters
- Scripting, to write the code for the control algorithm in the EMS language.

The 3-D Modeller module is very intuitive. Labels related to each element to be modelled are positioned on the top of the screen. Opening and filling them in succession allows us to realise a complete and detailed building model.

As for shading systems, it is possible to choose default shadings from a drop-down list or to make a custom one with the characteristics of the chosen types of shading. Shadings can be customised only in terms of visual and thermal performance but not in terms of shape (only standard shading can be analysed).

It is also possible to choose a built-in shading control strategy. However, these strategies depend only on one or two parameters. This is why a custom control algorithm had to be coded in the scripting module.

The simulation module is based on the EnergyPlus simulation engine. It allows us to make dynamic simulations, access site weather data, and assess energy needs and indoor comfort at hourly, daily, monthly, and annual intervals (DesignBuilder Software Ltd - Simulation, n.d.).

The advantage of this module is the possibility to access the source code, analyse it and understand what is going on in the software. Thanks to the Scripting module, it is possible to code in EMS and customise the simulation and its outputs.

In the EMS environment, sensors, actuators, variables, outputs, and program syntax are available in built-in lists, which facilitates the writing of the code. EMS reads settings of the DesignBuilder model written in the EnergyPlus source code and, by recalling the names of variables and zones of the source code, allows to override this latter. In this case, it allowed for introducing a more complex shading control algorithm into the model compared to the built-in ones.

3.5 Boundary conditions and hypothesis

This study will consider a single office built in a temperate climate and oriented towards South. The worker faces the window and is exposed to glare discomfort during the year.

Two different shading systems are tested: VB and RB. A multi-criteria control algorithm is designed based on the values of vertical solar irradiance on the window, horizontal illuminance on the work plane, DGI value at the head level, indoor operative temperature, and occupancy of the office.

The office is equipped with a cooling system and mechanical ventilation. Natural ventilation is only possible during the day, as it happens in the reality of the case study.

Being the research carried out on a real case study:

- ventilation is only allowed during the day. The evaluation of the nocturnal passive cooling effect given by natural ventilation is out of the scope of the study.
- the type of glazing and its characteristics are invariant, and their impact on shading performance is not considered.
- OH depth is the same for the two locations.
- the orientation of the office is invariant. The impact of the room orientation on the shading performance is not analysed.
- the position of the user and his/her orientation is not changed.
- the variation of the activity type or the number of occupants is out of the scope.

Being the study focused on the control algorithm design and the analysis of its performance on the visual and energy performance of the office:

- the heating and cooling systems are auto-sized by the software, and their type is not changed among the different simulations. The impact of the variation of the heating, cooling and lighting system type is not analysed.

Since the sun azimuth and elevation sensor are very expensive, the sun's position will not be measured and so considered in the control strategy. Therefore, we will assume that the slat angle of Venetian blinds will be fixed.

Finally, for a software limit, we also assume that the shading can be only or totally rolled up or down. It is not possible to partially shade the window.

3.6 Data collection

3.6.1 Technical specifications of the technical elements

Starting from the stratigraphy provided by the Technical Designer of Liège University:

- the thermal transmittance of the opaque technical elements has been calculated by hand and compared with the results obtained by the calculation tool www.ubakus.de
- the optical, thermal, and energy performance of the glazing have been calculated using the AGC glass configurator (Homepage | Glass Configurator, n.d.)

In the Annex 6: Envelope properties calculation, the stratigraphy of the opaque technical elements is provided. Material, thickness, and thermal conductivity of each layer is given and their value have been used as input for the thermal transmittance calculation. The results reports are provided in the appendix.

Table 3.3 resumes the U-values obtained for the opaque elements of the envelope. Table 3.4 resumes the most relevant properties of the window frame and its glazing.

Table 3.3 Thermal transmittance of the opaque technical elements of the office envelope

Technical element	**U-value [W/m^{2}K]**
External wall	0.416
Internal wall – Adjacent to office	2.869
Internal wall – Adjacent to corridor	2.288
Floor	1.873

Table 3.4 Characteristics and performance of the window frame and glass

Frame	
Material	Wood
Glass	
Stratigraphy	6-12(air)-4 with solar control
Light transmittance	70%
Solar energy transmittance	36%
Shading Coefficient	0.41
U-value	1.5 W/m^{2}K

3.6.2 Technical specifications of dynamic solar shadings

The performances and characteristics of the RB have been taken from Renson datasheets.

The chosen model is the Fixscreen 100, which is motorised and can be mounted on the window frame.

The fabric chosen is made of 42% of glass fiber and 58% of PVC. This composition allows the user to view the outside even if the shading is rolled down. In the same time, from the exterior the shading looks fully opaque.

Among the possible types of fabrics, Sergé tissue has been chosen. In fact, they have the highest openness factor (5%) and, therefore, the lowest impact on the view to the outside.

The chosen color is SCM36, which guarantees the highest thermal comfort, visual contact with the exterior, and visual comfort for workers in terms of reflection on the screen and light contrast.

The most relevant performance of the shading is resumed in Table 3.5.

The complete datasheet, instead, is shown in Annex 7: Shading datasheets.

Table 3.5 Main properties of the chosen solar screen

Thickness	0.0055m
Light transmittance	11.6%
Openness factor	5%
Solar energy transmittance	12.4%
Solar energy reflection	59.8%

As for VB, the characteristics have been taken from literature (Tabadkani, Tsangrassoulis, et al., 2020) and from the datasheet provided by MHZ and reported in the Annex 7: Shading datasheets. Two different slat angles are considered: 0°, which allows the visual contact to the outside even when the shading is activated, and 45°.

The main features of the shading are reported in Table 3.6.

Table 3.6 Main properties of the selected Venetian blinds

Distance glass-shading	0.035m
Slat depth	0.025m
Slat distance	0.01875m
Slat thickness	0.00022m
Thermal conductivity	221 W/mK
Slat angle	0/45°
Slat reflectance	90%

3.7 Data analysis

3.7.1 Standards and protocols

EN 12464-1, Light and lighting – Lighting of workplaces: in table 34 we find that the minimum average horizontal illuminance is 500 lux for offices where the main activity is writing, typing, reading and data processing. This value is evaluated at a height of 0.80m.

ISO 17772-1: Energy performance of buildings – Indoor environmental quality: from the Table H2, the operative setpoints for heating and cooling are respectively 20 and 26°C.

EN 16798-1: Energy performance of buildings – Ventilation of buildings: it indicates how to calculate percentage discomfort. It considers comfort is guaranteed if less than 5% of occupied hours exceed the discomfort threshold.

CENED manual: chapter 5 explains the rules to define the dimensions of the thermal zone to be analysed.

ISO/DIS 52016-3, Energy performance of buildings – Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads – Part 3: Calculation procedures regarding adaptive building envelope elements: it integrates shadings into building energy calculations, and provides scenarios for the design of shading control algorithm.

3.7.2 Description of the modelling procedure

The model includes only the analysed office and not the overall building. In fact, to analyse the effect of shadings on the office performance, the office envelope neighbouring the other offices and the corridor must be adiabatic. Therefore, no difference is registered between the simulation results obtained from the model with the office alone and the model where the office is part of the building.

The rest of the discussion is therefore focused on single office modelling.

3.7.2.1 Layout

To define the size of the office, the external measurements convention has been adopted. The block is therefore sized using the outer dimensions. Surfaces used for thermal calculations are derived from the outer geometry, air volumes, and floor areas from the inner geometry (DesignBuilder Softare Ltd, 2021).

According to the Cened manual, in the case of heated rooms, the gross area of the thermal zone must include the floor area of the zone and:

- the overall thickness of perimetral walls if they neighbour with the outside or with non-heated zones
- half thickness of walls if they neighbour with heated zones.

The same reasoning has been applied to the floors.

Moreover, in the presence of an inspectable false ceiling, the depth of the false ceiling must be included in the zone net height.

As the “Inner zone volume calculation method” has been adopted, the false ceiling has not been included in the stratigraphy of the ceiling. This solution allowed us to include the depth of the false ceiling in the inner geometry calculation.

The final dimensions of the zone resulting from these considerations are shown in Figure 3.6.

Figure 3.6 Definition of gross and net surface and volume and size of the office used in the model

3.7.2.2 Activity and heat gains

The simulation inputs are listed in Table 3.7. Where the Standard is not indicated, default values of the template of DesignBuilder have been used.

As for the constraints to using natural ventilation, they have been introduced to limit the heat losses during Winter and heat gains during Summer.

A remark must be made on integrating the glare and illuminance sensors into the model. In DesignBuilder, it is possible to introduce a maximum of two light sensors per zone but positioned at the same height.

In this case, glare had to be evaluated at 1.20m and with two different user orientations (135° and 180°, i.e., oblique and perpendicular to the window plane), while horizontal illuminance on the desk level (0.80m). To overcome the limitations of the software, more copies of the office have been made:

- Two copies measure DGI at the head level (at 1.3m from the internal wall surface) at 135° and 180° when the shading is not activated
- One copy evaluates the horizontal illuminance at the desk level (at 1.3m from the internal wall surface) when the shading is activated
- One copy is used for energy calculations and to evaluate the horizontal illuminance inside the office according to the shading status
- Two copies are used to measure the DGI at the head level according to the shading status.

Table 3.7 Simulation inputs and heat gains

Parameter	**Value**	**Standard**
Occupancy schedule	Mon-Fri, 08.00-18.00	/
Heating setpoint	20°C	ISO 17772-1
Cooling setpoint	26°C	ISO 17772-1
Natural ventilation – Indoor maximum temperature	27°C	/
Natural ventilation – Outdoor minimum temperature	15°C	/
Natural ventilation – Outdoor maximum temperature	25°C	/
Desidered illuminance level	500 lux at 0.80m	EN 12464-1
Discomfort glare index	22 at 1.20m	Hopkinson’s scale
Equipment gain	11,77 W/m^2	“Generic working area” DesignBuilder occupancy template
Lighting gain	11 W/m^2	/
People gain	123 W/person	“Generic working area” DesignBuilder occupancy template
Ventilation + Infiltration gain	0.85 vol/h	EN 16798-3

3.7.2.3 Construction and openings

Building envelope technical elements and shadings have been modelled according to the stratigraphies in Annex 6: Envelope properties calculation and the data reported in the paragraph 3.6.

3.7.2.4 HVAC and artificial lighting

For the heating and cooling system, not being the core of the study, the autosize option has been chosen. We assumed a COP of 3.9 and 2.9 for heating and cooling systems, respectively.

Humidity and air quality are controlled by mechanical ventilation, which is active during the occupation time. This system is coupled with the possibility of using natural ventilation in warm outdoor conditions (when the temperature is between 15 and 25°C).

As for artificial lighting, lighting control has been activated to evaluate the impact of control strategies on artificial lighting needs. Two control points have been considered. One at 1.30m from the façade and one 1.30 from the opposite wall. In both points, lights are turned on when horizontal illuminance on the work plane is lower than 600 lux.

A 1-step control has been modelled, i.e., lights can have three states: on, off, and half power. However, we have to highlight that it does not correspond to the reality of the office, where the lighting control is not present, and lights are turned on and off manually.

Finally, it has been considered that the operating schedule of building services corresponds to the occupancy schedule (Mon-Fri, 08.00 – 18.00).

3.8 Instrument Development

The objective of the shading control is to maximise the user’s comfort and satisfaction and minimise the office's energy needs.

To combine these requirements, the control algorithm has been built, privileging the user’s comfort when the office is occupied and minimising energy needs when the office is empty.

User’s comfort and minimisation of energy needs have different meanings according to the season. If in Winter, minimising energy needs means maximising heat gains during the day, the opposite is necessary for Summer. Therefore, in Summer, the minimisation of energy needs will go in parallel with the maximisation of visual comfort, but not of the users’ satisfaction (being the shading all the time down). The opposite occurs in Winter.

To deal with these different scenarios and elaborate a control algorithm valid independently from the season and the location, multiple parameters had to be introduced in the control algorithm: vertical irradiance on the façade, horizontal illuminance on the work plane, DGI at the head level, occupancy and indoor operative temperature.

Particularly:

- occupancy allows making a different strategy between occupied and unoccupied hours
- vertical irradiance and horizontal illuminance allow making a distinction in the control strategy between day and night
- the indoor operative temperature has been included in the strategy to control solar gains and heat losses through the season, allowing to characterise the thermal conditions of the office
- DGI prevents discomfort glare. For this purpose, horizontal illuminance was insufficient. It is true that with a high level of horizontal illuminance, also the DGI is high. However, as described in paragraph 3.4.1.2, DGI depends on environmental factors whose variation cannot be detected by analysing horizontal illuminance values.

In order to evaluate the impact of visual comfort on energy needs and shading activation time, two different control algorithms have been designed: one including the glare evaluation and one focusing on thermal loads and illuminance.

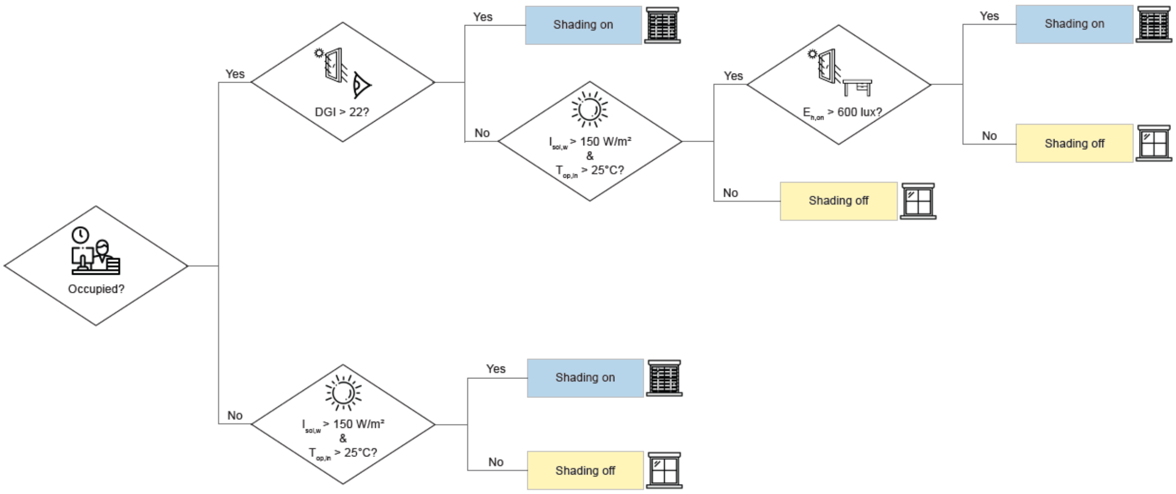


Figure 3.7 Control algorithm - Strategy with glare

Figure 3.7 shows the adopted control strategy when glare evaluation is included in the algorithm.

The logic of the shading control algorithm is described here below:

1. We check if the office is occupied to privilege energy needs minimisation when it is not occupied and the user's comfort when it is occupied.

If the office is occupied:

2. we evaluate the DGI at the head level in two different user positions: 180° and 135°. If we are in a condition of discomfort in both situations, shadings are activated. Otherwise, we consider thermal loads.
3. Thermal loads combine solar gains higher than 150W/m2 and an indoor operative temperature higher than 25°C. This solution allows us to take advantage of solar gains during Winter days (rolling up the shading) and minimises solar gains during Summer days.
4. To avoid lights being turned on and to counterbalance the minimisation of the solar gains with the increase of lighting gains, we check if, by activating the shading, the horizontal illuminance is still sufficient. If this happens, and lights do not have to be turned on, shadings can be activated.

If the office is not occupied:

5. We focus on the minimisation of thermal loads in order to avoid overheating and prevent higher cooling loads when the system turns on Mondays and in the morning.

Two remarks about the control strategy can be made:

- DGI evaluation in step 2 is always done when the shading is off. This allows us to avoid fluctuations in the shading activation profile because, when the shading is on, DGI drops under 22, and the shading is deactivated for the algorithm's logic.
- In step 4, horizontal illuminance is always evaluated with the shading on to prevent artificial lighting from being turned on due to the shading activation.

If glare is not included in the control strategy (Figure 3.8), the algorithm's logic is the same described above, but without step 2.

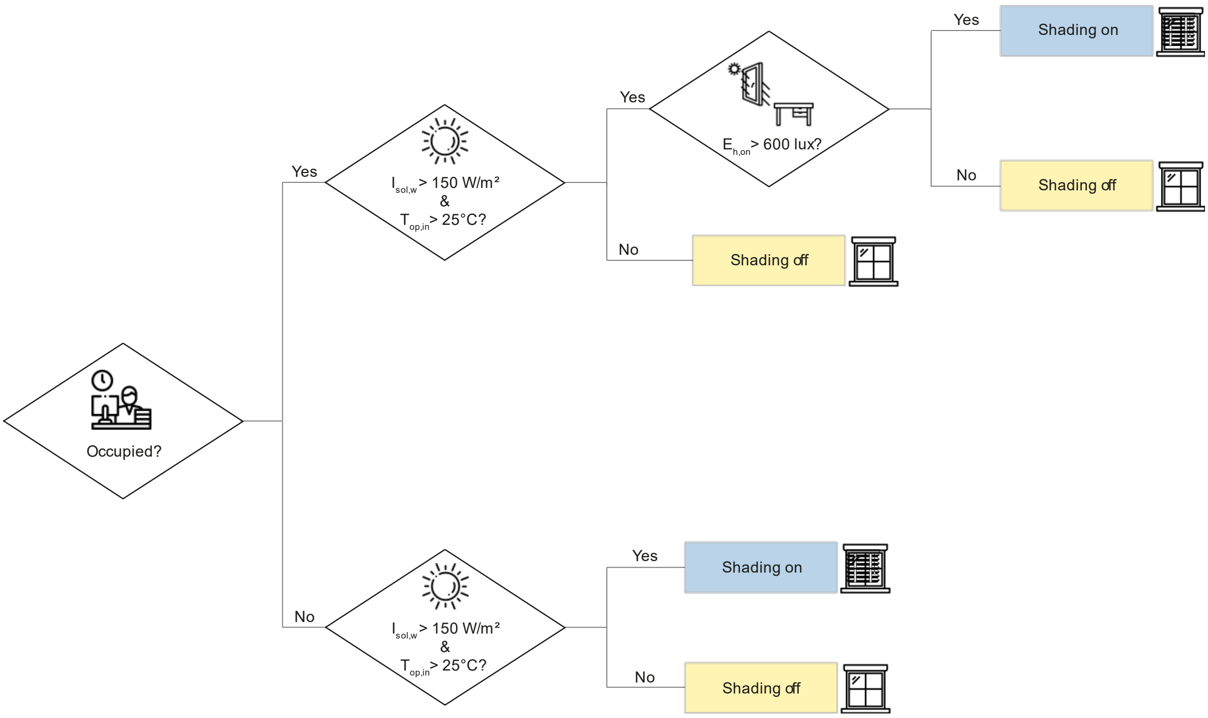


Figure 3.8 Control algorithm - Strategy without glare

The setpoints chosen for the different parameters are shown in Table 3.8.

Table 3.8 Thresholds adopted for the parameters included in the shading control algorithm

Parameter	Value	Reference
Vertical irradiance on the window	150 W/m^2	
Horizontal illuminance – Shading on	600 lux at 0.80m	/
Occupancy	0 = occupied 1 = unoccupied	/
Indoor operative temperature	25°C	/
Discomfort glare index	22 at 1.20m	Hopkinson's scale

As for solar irradiance, the setpoint chosen was taken from the literature (Karlsen et al., 2016).

Regarding horizontal illuminance, 600 lux have been selected instead of 500 lux provided by Standards. In fact, this latter value refers to the minimum that has to be provided by artificial lighting. Instead, in the case of natural lighting, users tend to request a higher level of illuminance on the work plane.

The operative temperature setpoints have been chosen to have optimal control of shadings in the early morning. The cooling setpoint of 25°C allows for rolling down the shadings in the early morning when solar gains are already present and the office is still unoccupied. This contributes to limiting overheating during the day, being the effect of solar gains perceptible in the room some hours later due to the inertia of the building.

The algorithm was first written in block diagrams and then coded in EMS using an if-else structure. A remark related to the code can be made: to consider solar irradiance, in DesignBuilder, it is possible to choose between solar irradiance on the façade and solar irradiance on the window. In this case, solar irradiance on the window has been chosen. This is because, in the future, solar shadings must be installed on the whole façade of the building. If shading were controlled with the solar irradiance on the façade, it would not be possible to consider the different conditions in which the offices can be due to the shadows of the trees. Instead, with solar irradiance on the window, it is possible to control the shading of each office independently.

No distinction has been made between algorithms for VB and RB. In both cases, the only movement allowed for the shading is up/down, not including the slat control for Venetian blinds in the study.

3.9 Application

Four cases have been simulated:

- Case 0: office without shadings
- Case 1: office with OH
- Case 2a: office with VB with slat angle of 45° (VB45)
- Case 2b: office with VB with slat angle of 0° (VB0)
- Case 3: office with RB

Simulations have been run for a typical meteorological year with an hourly and 30-minutes timestep.

Per each timestep, the following outputs have been obtained:

- indoor and outdoor temperatures
- heat gains and losses per m^2
- heating, cooling and artificial lighting loads per m^2
- weather conditions (e.g., solar irradiance, wind velocity, position of the sun)
- horizontal illuminance and DGI levels at the position of the sensor
- shading status

These results have been post-processed in Excel.

Total monthly and annual energy needs have been calculated according to the following formula:

$$E_n = \frac{E_h}{COP_h} + \frac{E_c}{COP_c} + E_l$$

where E_h is the thermal energy need for heating, E_c is the thermal energy need for cooling, E_l is lighting energy need, and COP_h and COP_c the two COPs of heating and cooling systems, respectively.

The number of occupied hours with horizontal illuminance lower than 500 lux and higher than 2000 lux has been defined to define visual discomfort. At the same time, for glare, we considered the number of hours with a DGI higher than 22.

The percentage of discomfort hours over the total occupied hours has been calculated for each indicator. Then, according to ISO 16798-1, it has been lowered by 5%.

The percentages of discomfort hours and the annual energy needs of the office have been used to compare the shading solutions in both Liège and Milan.

3.10 Quality criteria

3.10.1 Validation of the model and of the control algorithms

Validation has been done on the model and the control algorithm.

To see if the model was working, the model was checked without shadings. Heat gains values have been analysed to see if heating, cooling, lighting, natural ventilation, people, and equipment gains corresponded to the defined schedules.

Then, shadings were included in the model. To see if they were working as desired, built-in strategies of DesignBuilder have been used. As the shading movement was not included in the simulation outputs of DesignBuilder, the model has been validated by comparing the values of horizontal illuminance and DGI between the case with shadings and the base case. It allowed checking if the shading was actually rolled down in the timesteps where it was supposed to be activated.

As for the code's validation, the software automatically performed the first check. If syntax errors were contained in the code or instructions were given to inexisting variables, the code was not running.

In addition, a specific EMS variable quantifying the shading movement has been later coded to validate the code. This way, it was possible to check if the shading movement respected the algorithm's rules and the thresholds of shading activation and deactivation.

3.10.2 Reproducibility

The code of the control algorithm is available in the Annex 8: EMS Code.

4 Results

In this section, the primary outcomes of the research are presented. Firstly, results are presented separately for Liège and Milan, analysing shading activation profiles and comparing energy needs and visual comfort performance of the different shading technologies and control strategies.

Then, the results of the two locations are compared on a yearly basis.

4.1 Analysis of the results obtained for Liège

4.1.1 Shading behaviour

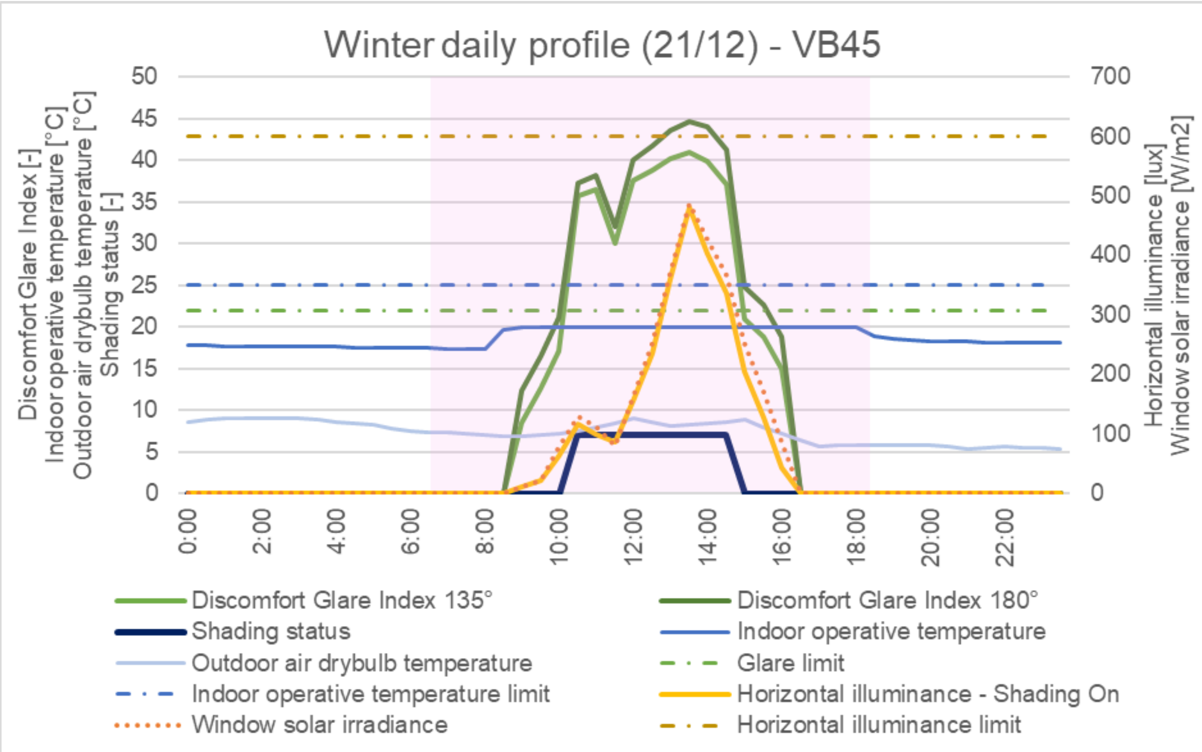


Figure 4.1 Analysis of the shading behaviour during Winter for Venetian blinds with a slat angle of 45°. Case of Liège.

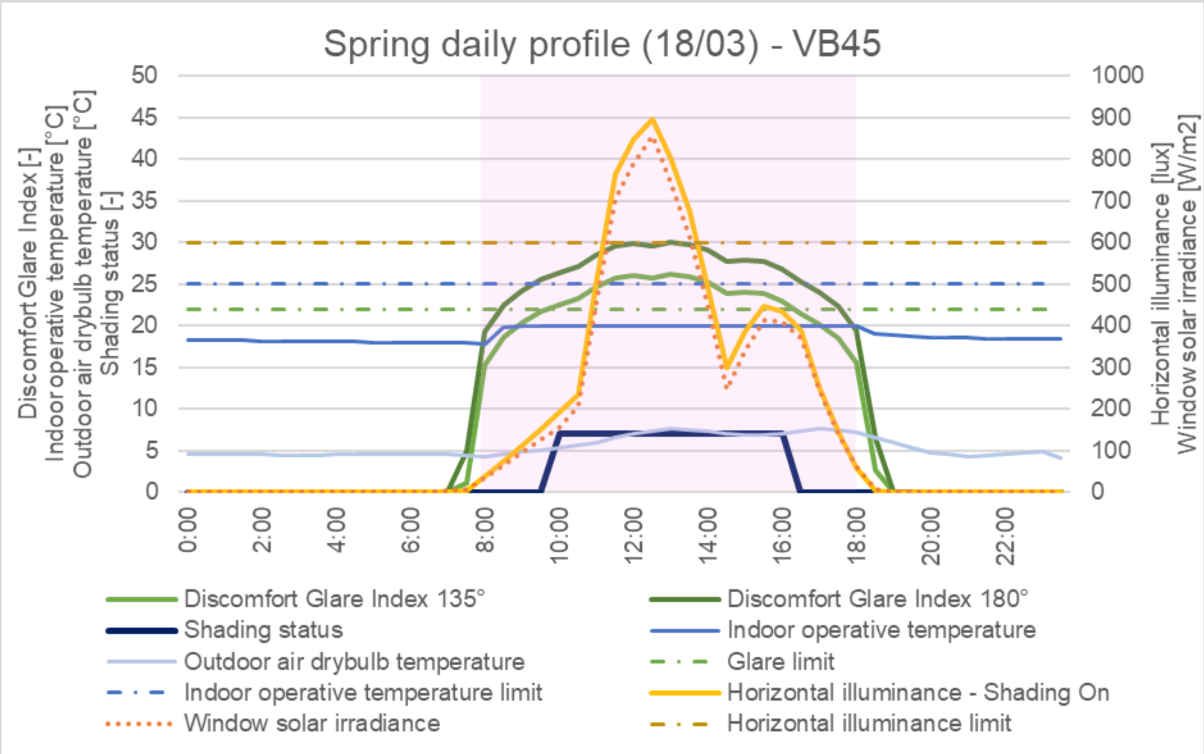


Figure 4.2 Analysis of the shading behaviour during Spring for Venetian blinds with a slat angle of 45°. Case of Liège.

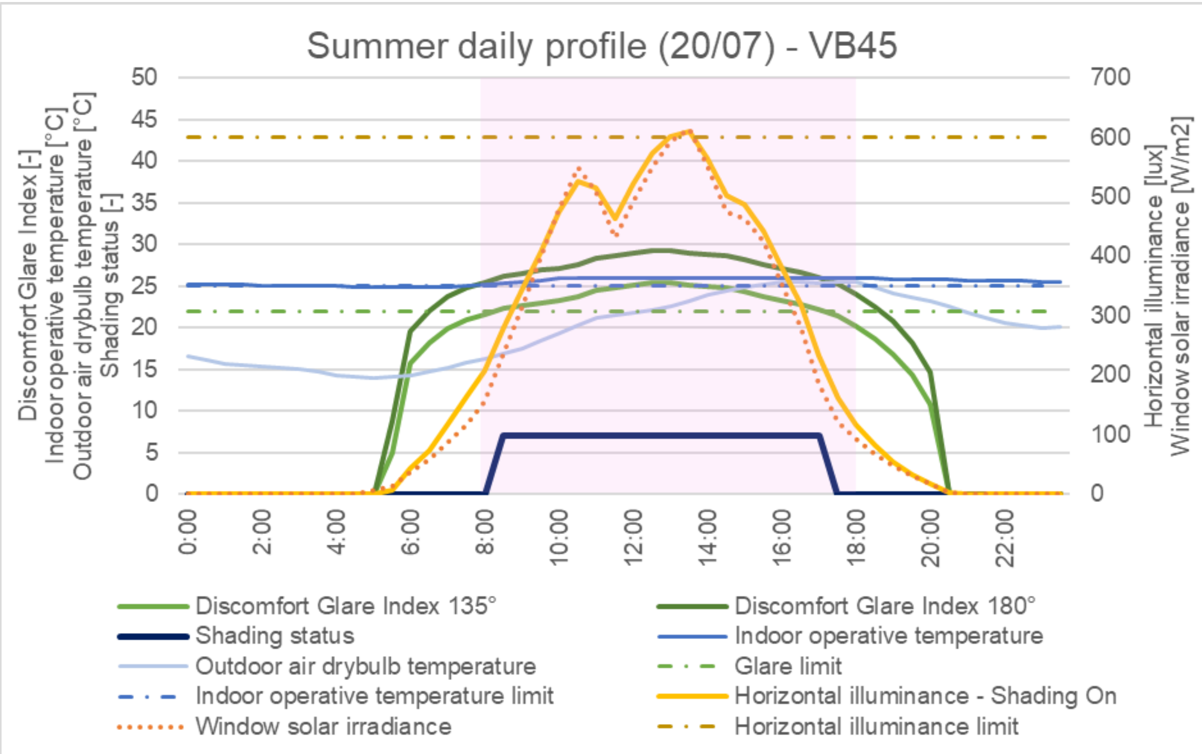


Figure 4.3 Analysis of the shading behaviour during Summer for Venetian blinds with a slat angle of 45°. Case of Liège.

Figure 4.1 shows the activation profile of the Venetian blind with a slat angle of 45° during Winter.

We can observe that shading is activated on the 21st of December from 10.30 am to 2.30 pm because DGI is above the threshold of 22 for both 135 and 180° orientations.

During Spring (Figure 4.2), the shading activation time is extended until 10 am and 4 pm, always because of DGI values.

Finally, during Summer (Figure 4.3), shading is activated almost all working hours, from 8.30 am to 5 pm. The cause of the activation is always given by the high DGI values in both 180° and 135°.

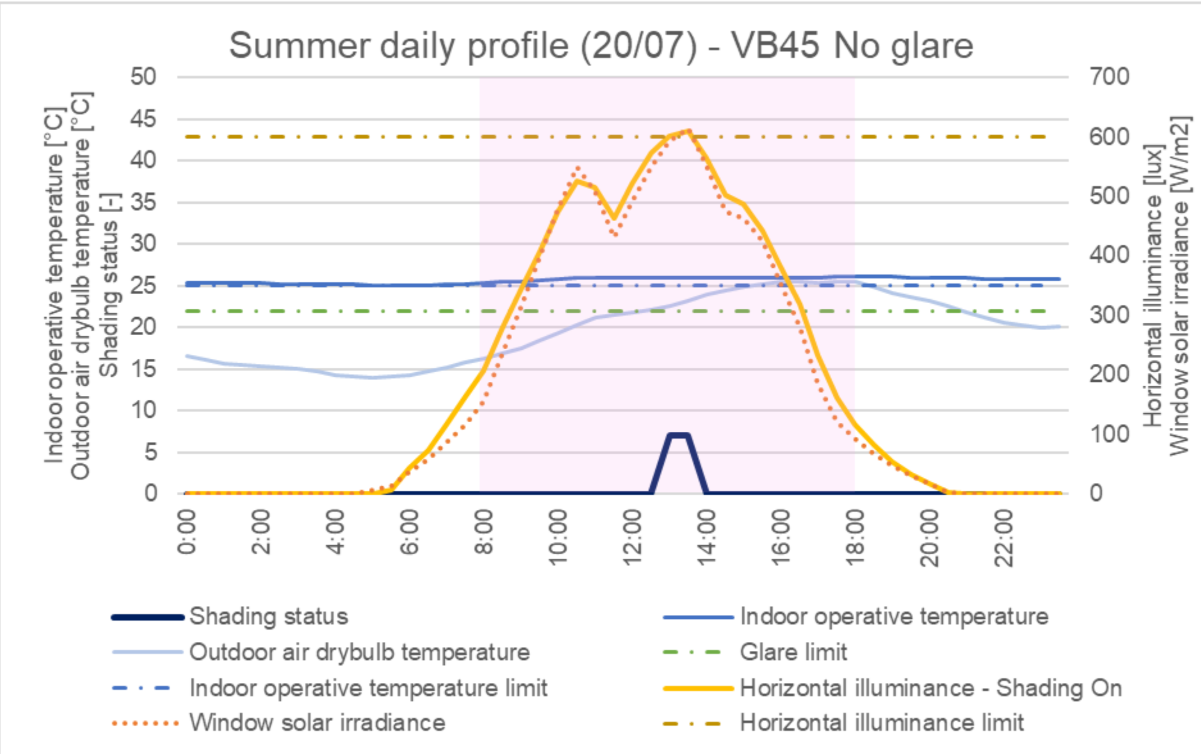


Figure 4.4 Analysis of the shading behaviour during Summer for Venetian blinds with a slat angle of 45°without glare evaluation. Case of Liège.

Figure 4.4 shows the shading activation profile during Summer if glare is not included in the control strategy. We can observe that the activation time is limited between 1 and 1.30 pm because, in those hours, the indoor operative temperature is above 25°C, vertical irradiance on the window is higher than 150 W/m^2, and, if the shading is activated, we have 600 lux of horizontal illuminance on the work plane.

4.1.2 Effects of shadings on the office energy balance

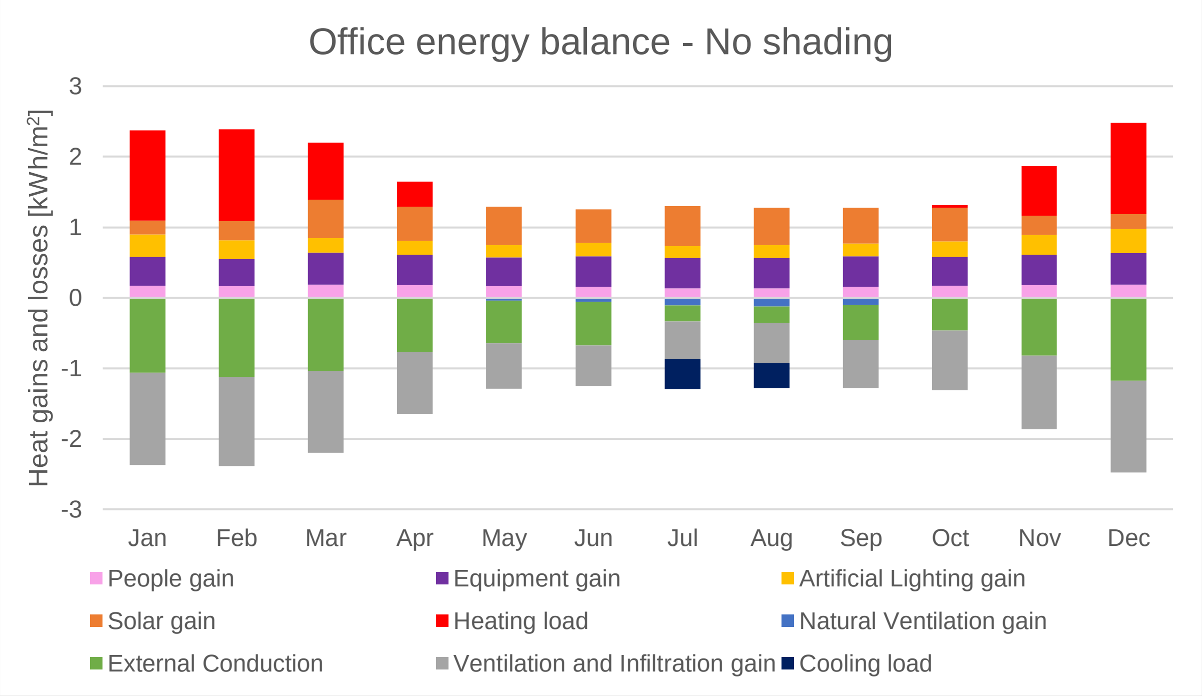


Figure 4.5 Office energy balance without shadings. Case of Liège.

Figure 4.5 shows the energy balance of the office when no shading is installed.

The heating season starts in October and ends in April. The highest heating load is registered in December (1.296 kWh/m^2) when the highest heat losses for conduction, infiltration and ventilation occur (-2.479 kWh/m^2).

The cooling season lasts only for two months, July and August. The highest cooling load is registered in July (-0.368kWh/m^2) when the highest solar gains are observed.

In May, June and September, heat gains can be compensated without using cooling systems, thanks to the positive contribution of natural ventilation.

People and equipment gains are constant throughout the year. Instead, artificial lighting reduces with the increase of solar gains.

Internal gains are always higher than solar gains.

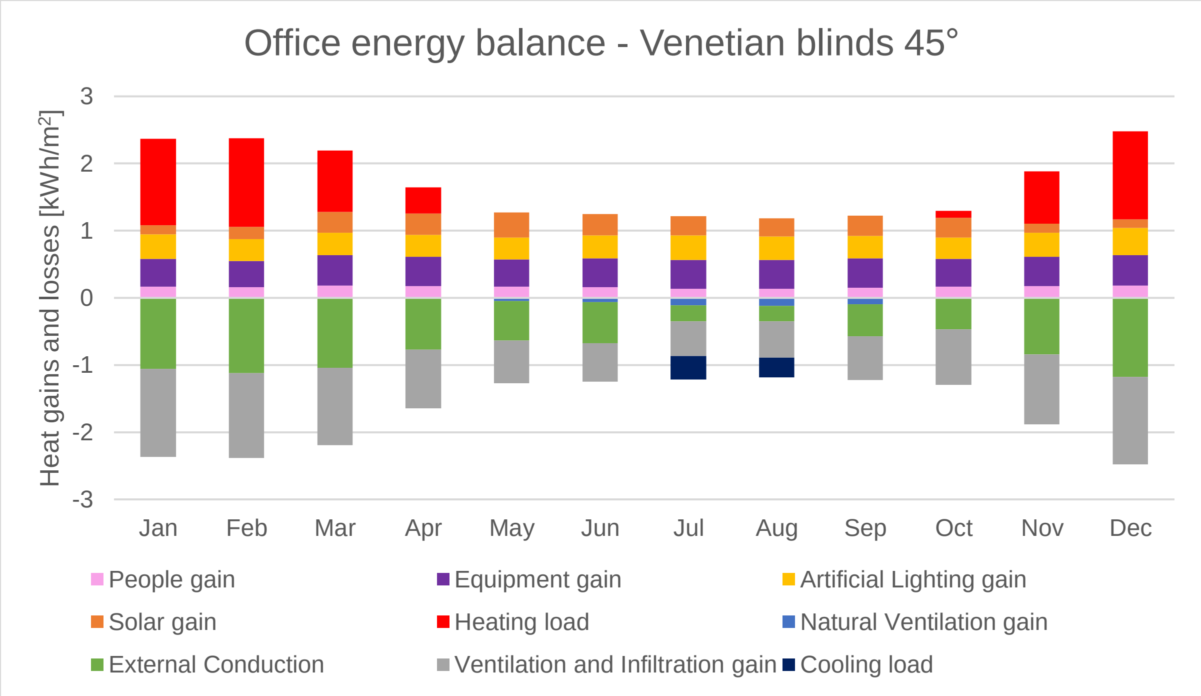


Figure 4.6 Office energy balance with Venetian blinds (slat angle 45°). Case of Liège.

Figure 4.6 shows the energy balance of the office when VB are installed with a slat angle of 45°.

The heating season starts in October and ends in April. The highest heating load is registered in February (1.320 kWh/m^2). However, the highest heat losses for conduction, infiltration and ventilation occur in December (-1.420 kWh/m^2). This is because we have a higher lighting gain in December than in February (0.407 kWh/m^2 against 0.325 kWh/m^2).

Cooling is necessary only in July and August. The highest cooling load is registered in July (-0.346 kWh/m^2) due to the higher lighting and solar gains.

Also in this case, heat gains can be compensated in May, June and September without the use of cooling systems, thanks to the positive contribution of natural ventilation.

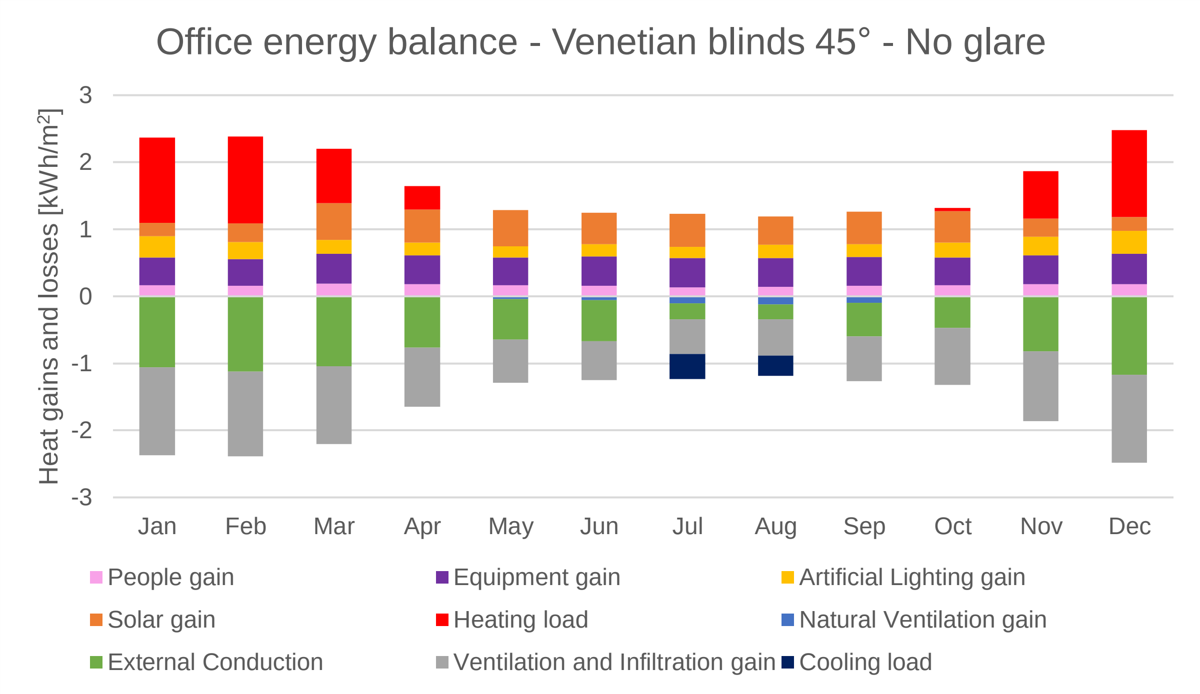


Figure 4.7 Office energy balance with Venetian blinds (slat angle 45°). Control strategy without glare. Case of Liège.

Figure 4.7 shows the energy balance of the office when VB are installed with a slat angle of 45° and with a control strategy not including glare.

Regarding heating load, we have the same results obtained in the base case without shading. The only difference is observed in Summer, from June to September. In this case, thanks to the activation of the shading, we have a reduction in the solar gains, allowing us to reduce the cooling load compared to the base case.

Table 4.1 Comparison of heating and cooling loads for the different shadings and control strategies. Case of Liège.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BC	1.275	1.295	0.809	0.352	0	0	-0.436	-0.354	0	0.042	0.704	1.296
OH	1.285	1.322	0.929	0.466	0	0	-0.235	-0.257	0	0.100	0.737	1.305
VB45	1.287	1.320	0.909	0.386	0	0	-0.346	-0.291	0	0.104	0.772	1.306
VB45 NoGlare	1.275	1.295	0.809	0.351	0	0	-0.368	-0.302	0	0.045	0.704	1.296
VB0	1.264	1.294	0.853	0.356	0	0	-0.370	-0.318	0	0.060	0.709	1.289
VB0 NoGlare	1.276	1.295	0.809	0.351	0	0	-0.342	-0.302	0	0.044	0.704	1.296
RB	1.288	1.324	0.912	0.406	0	0	-0.247	-0.258	0	0.102	0.773	1.312
RB NoGlare	1.275	1.295	0.809	0.351	0	0	-0.354	-0.309	0	0.043	0.704	1.296

Table 4.1 compares the results obtained for the different types of shading and control strategies regarding heating and cooling load.

We can observe that the RB registers the highest heating load, while VB with a slat angle of 0° registers the lowest heating load, allowing to lower the values registered in the BC. In terms of cooling load, the case without shading registers the highest values. The best results are obtained with RB.

Comparing the strategies with and without glare, we can observe that we do not register any significant variation compared to the BC in terms of the heating load. This is due to the type of control strategy adopted that allows the activation of shadings only with an indoor operative temperature higher than 25°C, a condition not reached during Winter.

During Summer, instead, the strategy without glare guarantees better results in cooling load only with VB0.

Table 4.2 Comparison of lighting gains for the different shadings and control strategies. Case of Liège.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BC	0.319	0.259	0.206	0.194	0.170	0.185	0.161	0.182	0.182	0.220	0.281	0.340
OH	0.332	0.283	0.248	0.238	0.220	0.228	0.220	0.234	0.222	0.248	0.302	0.350
VB45	0.368	0.325	0.333	0.331	0.320	0.344	0.361	0.343	0.339	0.316	0.359	0.407
VB45 NoGlare	0.319	0.259	0.206	0.194	0.170	0.185	0.169	0.197	0.191	0.220	0.281	0.340
VB0	0.349	0.301	0.300	0.302	0.276	0.299	0.289	0.302	0.297	0.292	0.332	0.369
VB0 NoGlare	0.319	0.259	0.206	0.194	0.170	0.188	0.216	0.222	0.195	0.220	0.281	0.340
RB	0.373	0.336	0.366	0.346	0.328	0.344	0.366	0.355	0.360	0.341	0.380	0.412
RB NoGlare	0.319	0.259	0.206	0.194	0.170	0.185	0.161	0.182	0.182	0.220	0.281	0.340

Table 4.3 Comparison of solar gains for the different shadings and control strategies. Case of Liège.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BC	0.196	0.279	0.547	0.487	0.544	0.479	0.571	0.530	0.512	0.474	0.270	0.208
OH	0.166	0.220	0.382	0.313	0.342	0.322	0.354	0.331	0.345	0.358	0.226	0.180
VB45	0.133	0.182	0.313	0.316	0.373	0.316	0.289	0.272	0.297	0.297	0.139	0.128
VB45 NoGlare	0.196	0.279	0.547	0.487	0.544	0.473	0.496	0.423	0.487	0.474	0.270	0.208
VB0	0.172	0.230	0.392	0.373	0.430	0.372	0.376	0.347	0.368	0.377	0.214	0.178
VB0 NoGlare	0.196	0.279	0.547	0.487	0.544	0.471	0.422	0.401	0.487	0.474	0.270	0.208
RB	0.123	0.163	0.268	0.271	0.317	0.257	0.190	0.210	0.249	0.269	0.115	0.113
RB NoGlare	0.196	0.279	0.547	0.487	0.544	0.471	0.488	0.437	0.512	0.474	0.270	0.208

Table 4.2 and Table 4.3 compare the results obtained for the different shading and control strategies for lighting and solar gains, respectively.

Without shadings, we register the lowest lighting gains and the highest solar gains. Instead, with RB, we register the highest increase in lighting loads and the highest decrease in solar gains throughout the year, compared to the BC.

During Winter, the decrease in solar gains due to shading activation is higher than the increase in lighting gains, explaining the higher heating loads registered.

During Summer, the significant reduction in solar gains justifies the significant reduction in cooling load described above.

4.1.3 Effects on energy needs

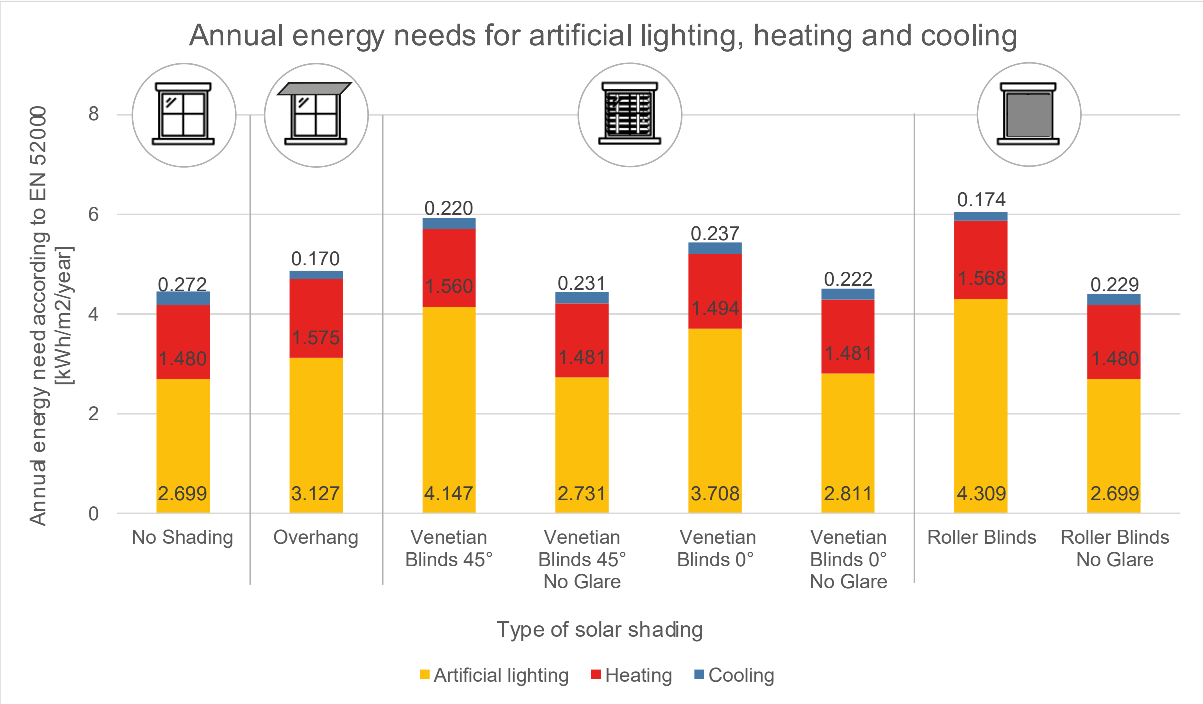


Figure 4.8 Comparison of annual energy needs between the base case without shadings, and the cases with the integration of Venetian blinds with a slat angle of 0° and 45°, and of Roller blinds. Case of Liège.

Figure 4.8 compares the annual energy needs for lighting, heating and cooling for the selected shading technologies and the two control algorithms.

The installation of shading technologies determines the increase of the total annual energy needs in all cases, except for VB45 and RB controlled with the strategy without glare. This is mainly due to the significant increase in the lighting energy needs, compared to the BC, which is not compensated by an equivalent reduction (in absolute value) in the heating and cooling energy needs.

The highest increase in total energy needs is observed with RB (+36%), for which we observe an increase in lighting and heating energy needs compared to the BC of +60% and +6%, respectively. On the other hand, with the same technology, we register the highest decrease in cooling energy needs among the dynamic shading solutions (-36%).

The highest total annual energy needs reduction is registered with RB controlled with the strategy without glare (-0.9%). In fact, in this case, heating and lighting are the same as the BC, while cooling is reduced by 16%.

In all strategies including glare evaluation, heating energy needs increase compared to the base case. The highest increase is registered with RB (+6%). Instead, due to the logic of the strategy, where shadings are controlled with the strategy that does not include glare, heating energy needs are the same as the base case.

We always register a reduction compared to the BC regarding cooling energy needs. In this case, the maximum is registered with RB (-36%), while the less effective solution is the VB0 (-13%).

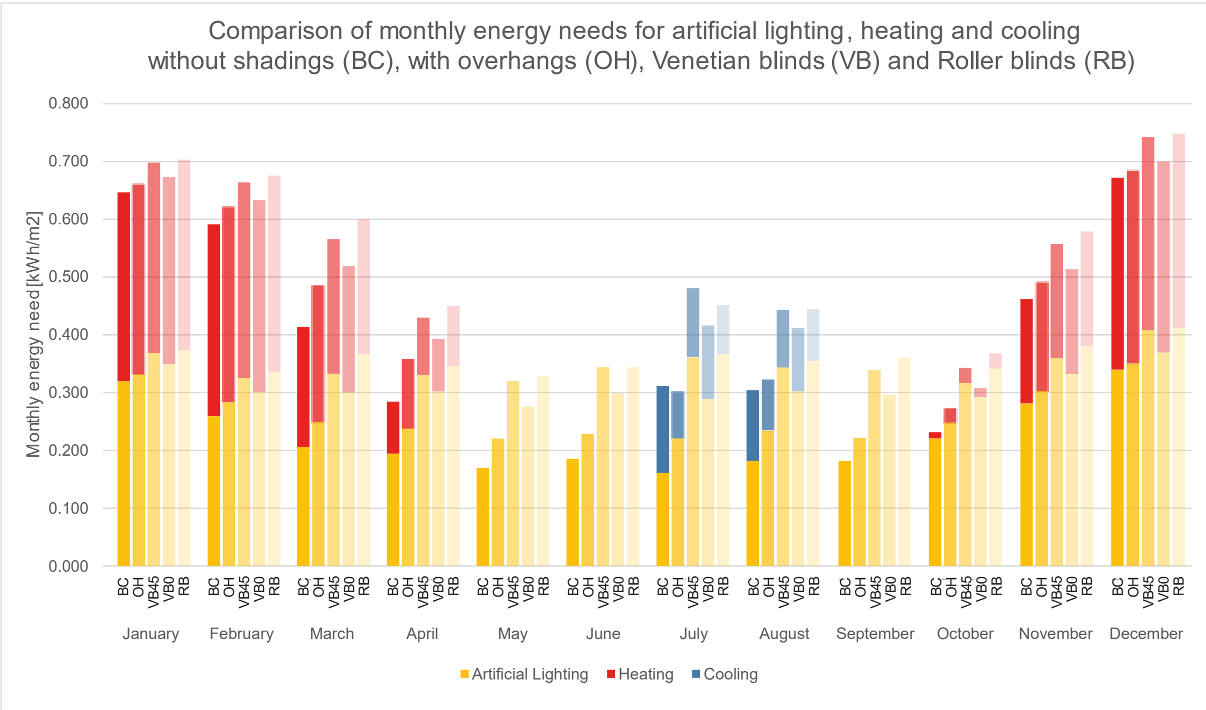


Figure 4.9 Comparison of monthy energy needs for heating, cooling and artificial lighting between the cases without shadings, OH, VB and RB with control strategies including glare evaluation. Case of Liège.

Figure 4.9 compares the energy needs for heating, cooling and artificial lighting obtained with the strategies including glare evaluation.

We can observe that, for all months, we register an increase in the total energy needs due to the increase in artificial lighting needs. VB with a slat angle of 0°

provides the best results among the other dynamic shading technologies, thanks to a lower increase in artificial lighting needs.

RB and VB with a slat angle of 45° provide similar results. The use of RB implies higher lighting energy needs compared to VB45, resulting in higher monthly energy needs. The only exception is registered in July when RB allow a greater cooling energy needs reduction.

The only reduction in energy needs compared to the BC is observed in July with the OH (-3%), when a significant reduction in cooling energy needs is observed (-46%).

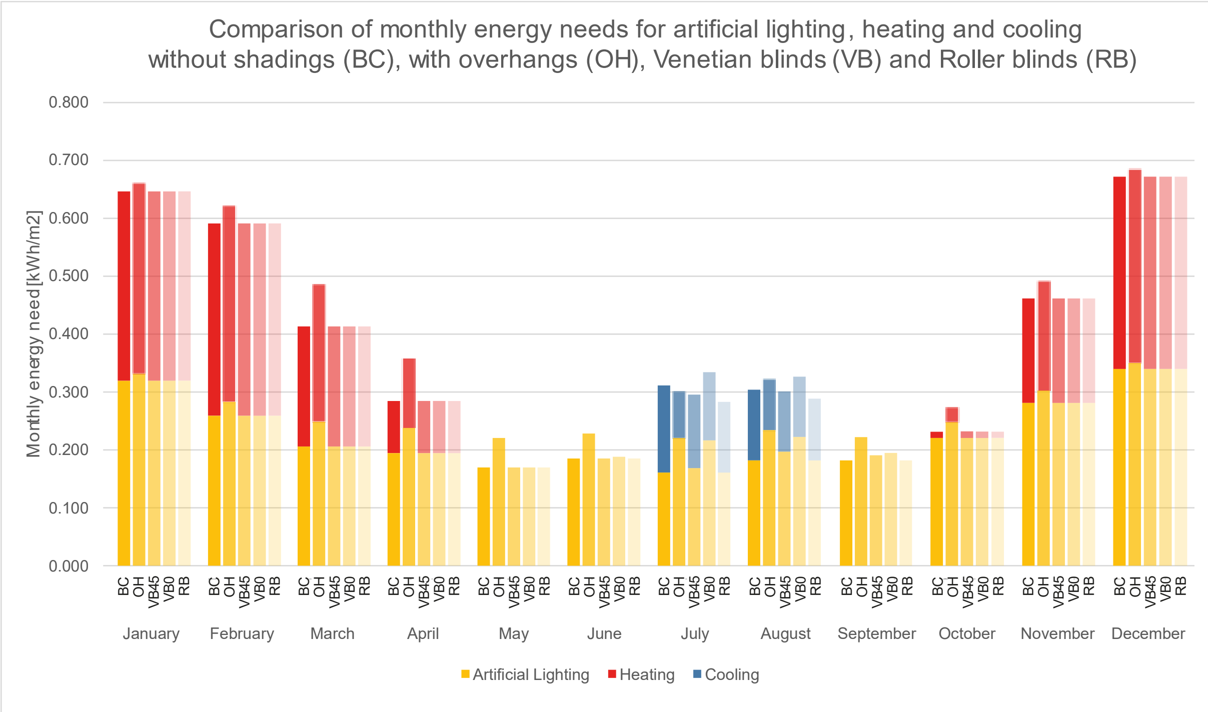


Figure 4.10 Comparison of monthy energy needs for heating, cooling and artificial lighting between the cases without shadings, OH, VB and RB with control strategies without glare evaluation. Case of Liège.

Figure 4.10 compares the energy needs for heating, cooling and artificial lighting obtained with the strategies not including glare evaluation.

Due to the algorithm's logic, shadings are activated only during Summer. Hence, we have the same energy needs as the BC between October and May.

During Summer, instead, the activation of shadings induces an increase in artificial lighting needs, but lower than in the case with glare evaluation (Figure 4.9).

For VB45 and RB, thanks to the reduction in cooling energy needs, we register a decrease in the total monthly energy needs in July and August compared to the BC.

4.1.4 Effects of shadings on visual discomfort

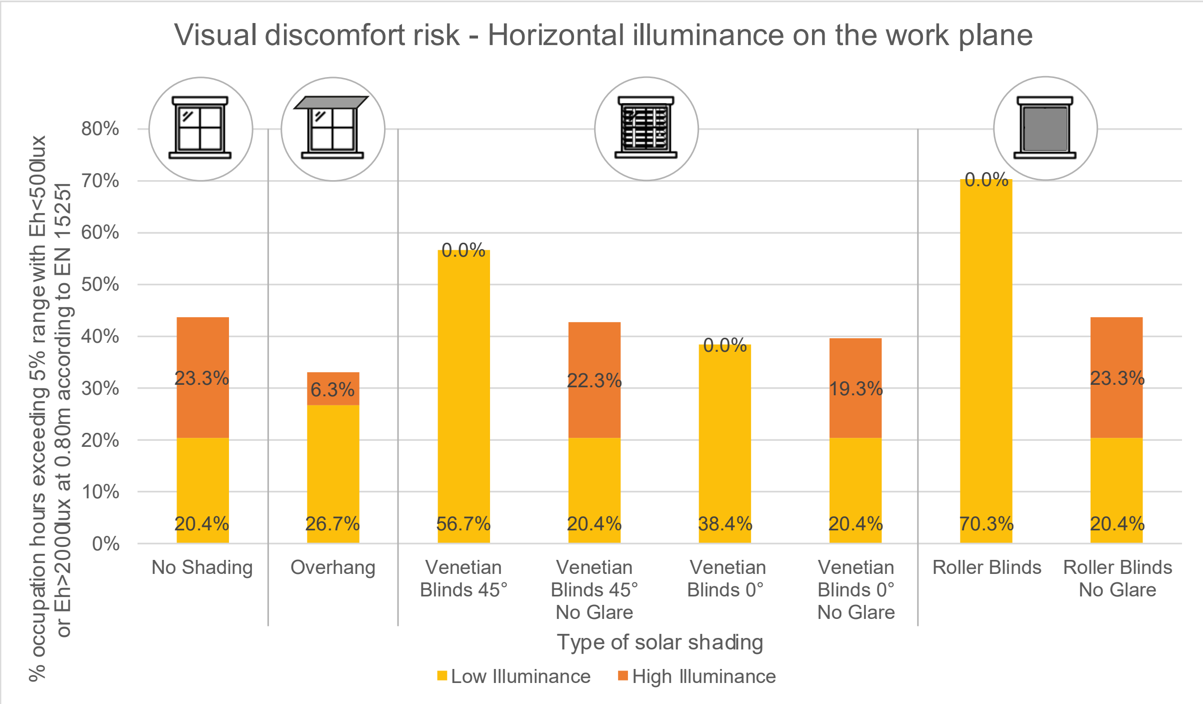


Figure 4.11 Comparison of the impacts of shadings on yearly visual discomfort hours compared to the base case (no shading). Analysis of discomfort hours due to high and low illuminance on the work plane. Case of Liège.

Figure 4.11 compares the discomfort hours due to a too-high or too-low illuminance on the work plane for different shading solutions and control strategies.

In the BC, we have 43.7% of discomfort hours. 20.4% are due to a low level of illuminance (lower than 500 lux); 23.3% are due to a high level of illuminance (higher than 2000 lux).

The OH is the shading solution that allows the most significant reduction in the total amount of discomfort hours (-10.7%).

With dynamic shadings, if glare evaluation is included in the control strategy, discomfort given by high illuminance is brought to 0 in all cases. However, due to the increase in the hours with low illuminance, a global reduction in discomfort hours is registered only with VB0 (-5.3%). The worst result is obtained with RB, where we arrive at 70.3% of discomfort hours (+26.6% compared to the BC).

On the opposite, if glare is not considered in the control strategy, what remains unchanged is the percentage of discomfort hours given by a low level of illuminance. A reduction in the discomfort hours is obtained with VB45 and VB0 due to the decrease in the hours with high illuminance levels (-1 and -4%, respectively). No difference is observed in the case of RB.

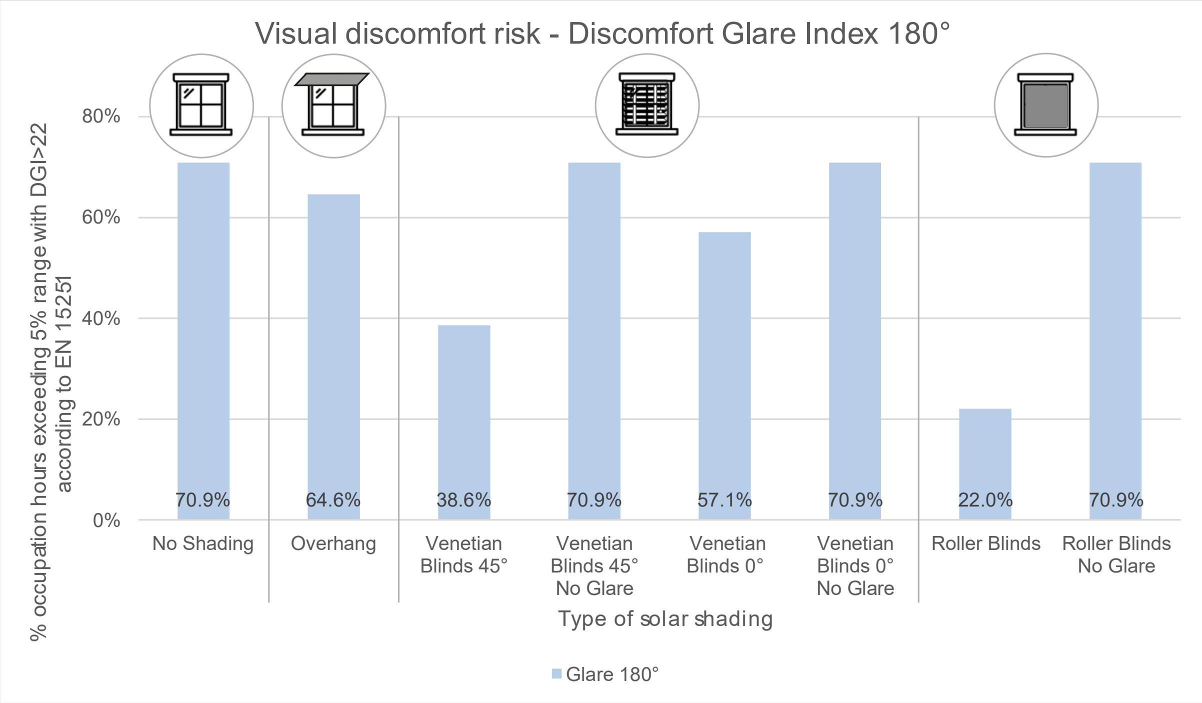


Figure 4.12 Comparison of the impacts of shadings on yearly visual discomfort hours compared to the base case (no shading). Analysis of discomfort hours due to glare, with the user orientation at 180°. Case of Liège.

Figure 4.12 compares the discomfort hours due to glare for different shading solutions and control strategies.

When the user faces the window, discomfort is registered for 70.9% of the occupation hours if shadings are not installed.

The OH allows for reducing the discomfort hours by 6.3%. Instead, installing shadings decreases the discomfort hours to 38.6%, 57.1% and 22% with VB45, VB0 and RB, respectively.

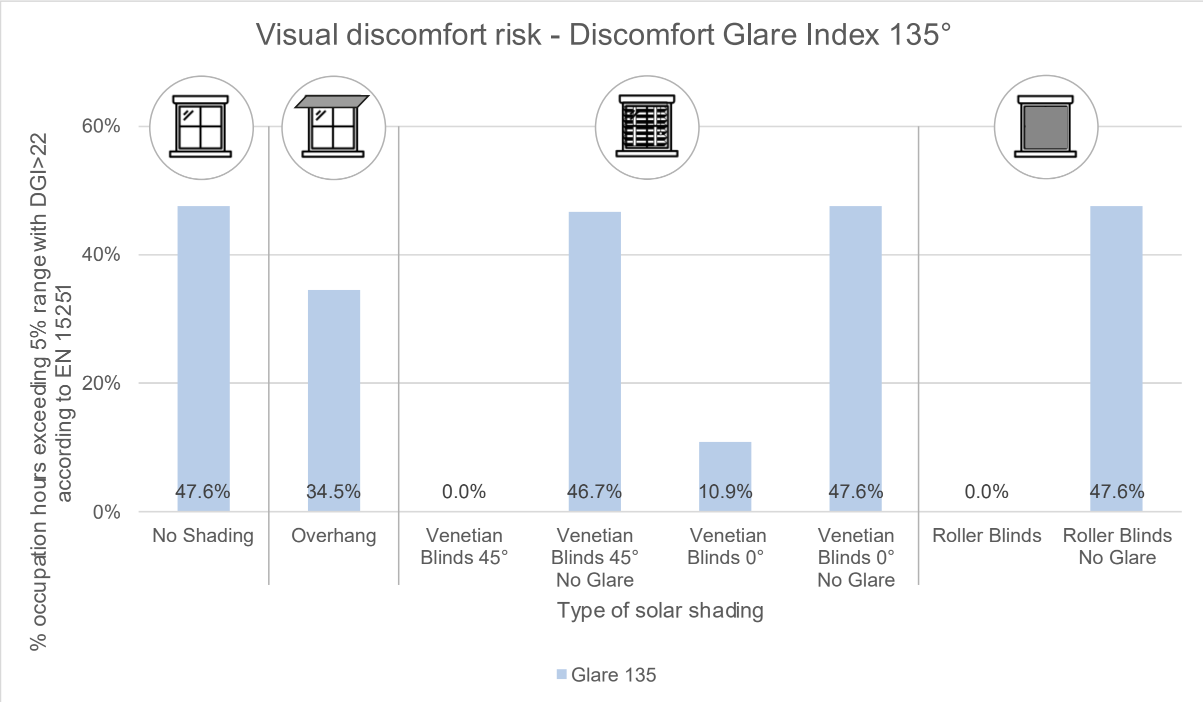


Figure 4.13 Comparison of the impacts of shadings on yearly visual discomfort hours compared to the base case (no shading). Analysis of discomfort hours due to glare, with the user orientation at 135°. Case of Liège.

Figure 4.13 compares the discomfort hours due to glare for different shading solutions and control strategies.

When the user has an orientation of 135°, discomfort is registered for 47.6% of the occupation hours if shadings are not installed. With the OH, this percentage drops to 34.5%.

Finally, with VB45 and RB, the discomfort hours are brought to 0, while for VB0 we still have 10.9% of discomfort hours.

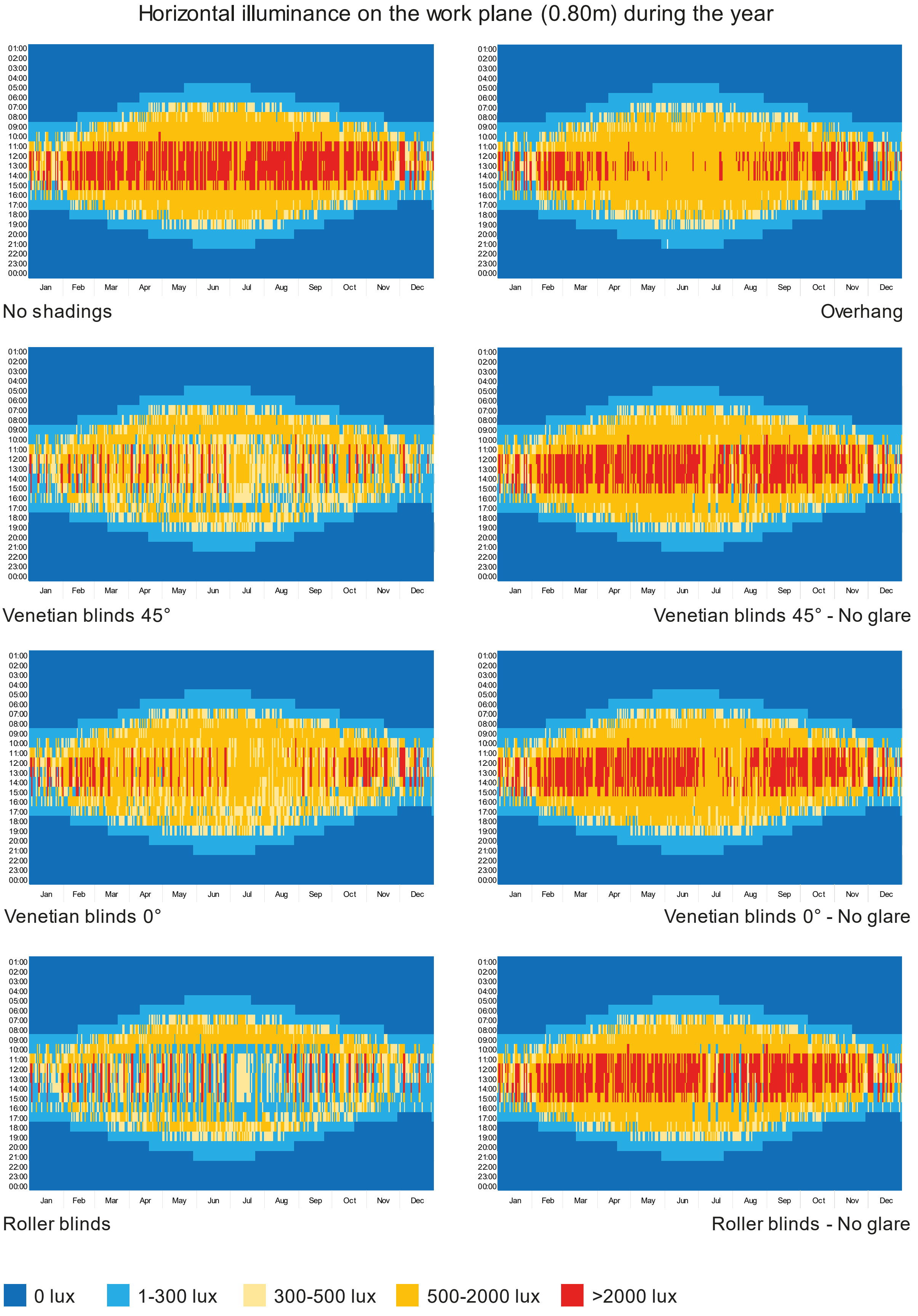


Figure 4.14 Comparison of visual performance of shadings throughout the year and the day. Analysis of the horizontal illuminance on the work plane. Case of Liège.

Discomfort glare index at the head level (1.20m) and at 180° during the year

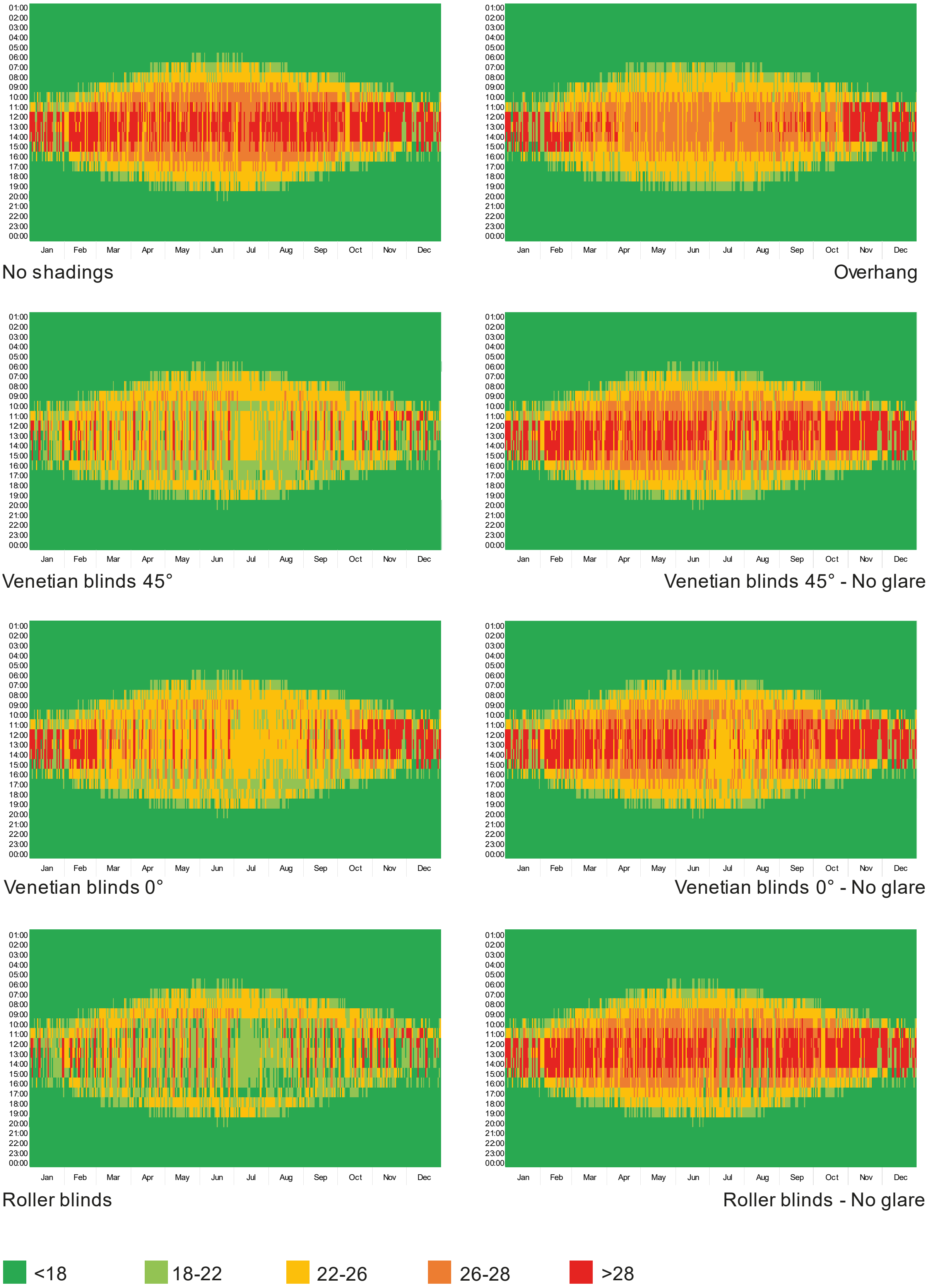


Figure 4.15 Comparison of visual performance of shadings throughout the year and the day. Analysis of the glare with a user orientation of 180°. Case of Liège.

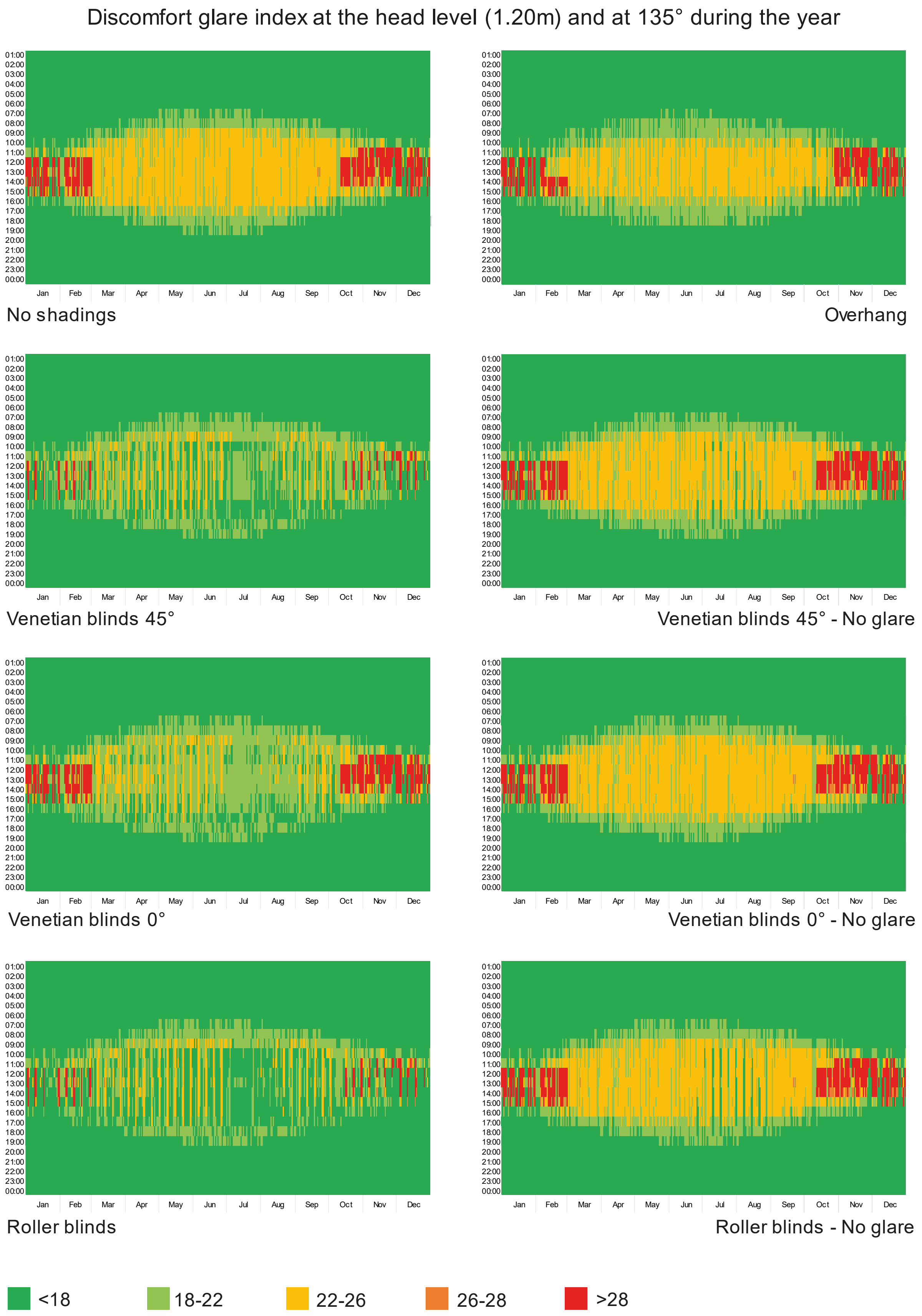


Figure 4.16 Comparison of visual performance of shadings throughout the year and the day. Analysis of the glare with a user orientation of 135°. Case of Liège.

From the annual progression of the horizontal illuminance on the work plane (Figure 4.14), , we can observe that shadings reduce discomfort due to high illuminance levels in the central hours of the day. This advantage is guaranteed throughout the year if glare evaluation is included in the strategy. If glare is not considered in the control strategy, a remarkable improvement in visual comfort is observed only with VB0 during Summer.

The OH appears less effective during Winter. The same is for VB0 if compared with VB45. On the contrary, the activation of RB significantly reduces the level of horizontal illuminance, reaching more frequently the range 1-300lux also in the central hours of the day.

The same considerations are valid for glare for 180° and 135° orientations (Figure 4.15 and Figure 4.16). RB provide the best reduction in terms of glare discomfort. When considering the 180° orientation, RB allow to keep the DGI between 18 and 22 during the central hours of the day. This value drops to values lower than 18 for most of the year if we consider the 135° orientation.

4.1.5 Comparison of the energy needs and comfort performances

Table 4.4 Comparison of the results obtained for base case (no shading), Venetian blinds, and Roller blinds in terms of energy needs, visual comfort, and user satisfaction. Case of Liège.

Parameter	**BC**	**OH**	**VB45**	**VB45 No glare**	**VB0**	**VB0 No glare**	**RB**	**RB No glare**
Heating annual energy need [kWh/m2/year]	1.480	1.575	1.560	1.481	1.494	1.481	1.568	1.480
Artificial lighting annual energy need [kWh/m2/year]	2.699	3.127	4.147	2.731	3.708	2.811	4.309	2.699
Cooling annual energy need [kWh/m2/year]	0.272	0.170	0.220	0.231	0.237	0.222	0.174	0.229
Total annual energy need [kWh/m2/year]	**4.451**	**4.872**	**5.927**	**4.443**	**5.439**	**4.514**	**6.051**	**4.408**
Low illuminance discomfort hours [%]	20.4	26.7	56.7	20.4	38.4	20.4	70.3	20.4
High illuminance discomfort hours [%]	23.3	6.3	0	22.3	0	19.3	0	23.3
Total illuminance discomfort hours [%]	**43.7**	**33**	**56.7**	**42.7**	**38.4**	**39.7**	**70.3**	**43.7**
Discomfort glare hours 180°[%]	70.9	64.6	38.6	70.9	57.1	70.9	22	70.9
Discomfort glare hours 135°[%]	47.6	34.5	0	46.7	10.9	47.6	0	47.6
Shading activation hours during working hours [%]	/	/	51	1	51	6	51	0

Comparing energy performance and user comfort results resumed in Table 4.4, we can see that the installation of shadings implies an increase in the energy need of the office if glare is included in the control strategy. An inverse trend is registered for the visual comfort parameters, for which we can significantly improve glare and illuminance control. In the case of illuminance control, VB0 provide the best performance among dynamic shadings, reducing discomfort hours from 43.7% to 38.4% of the total working hours. OH provides the best performance among all shadings.

In the case of glare control, instead, the best performance is provided by RB, allowing to limit glare discomfort at 22% of working hours for the user's orientation at 180°. Instead, the worst is given by VB0, where we still have 10.9% of discomfort hours at 135° even with the glare evaluation included in the control strategy.

When glare is included in the control strategy, shadings are activated for 51% of the occupied hours, a percentage reduced to 1-6% when glare is not considered.

4.2 Effects of shadings in Milan

4.2.1 Shading behaviour in Milan

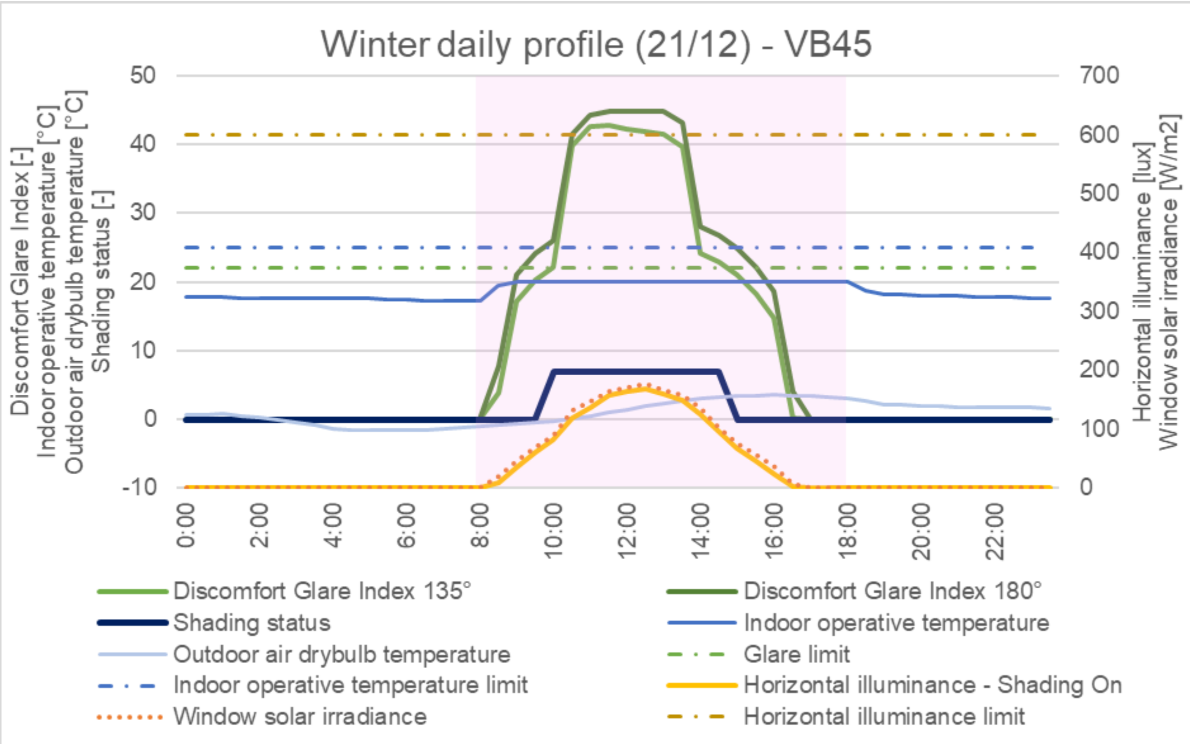


Figure 4.17 Analysis of the shading behaviour during Winter for Venetian blinds with a slat angle of 45°. Case of Milan.

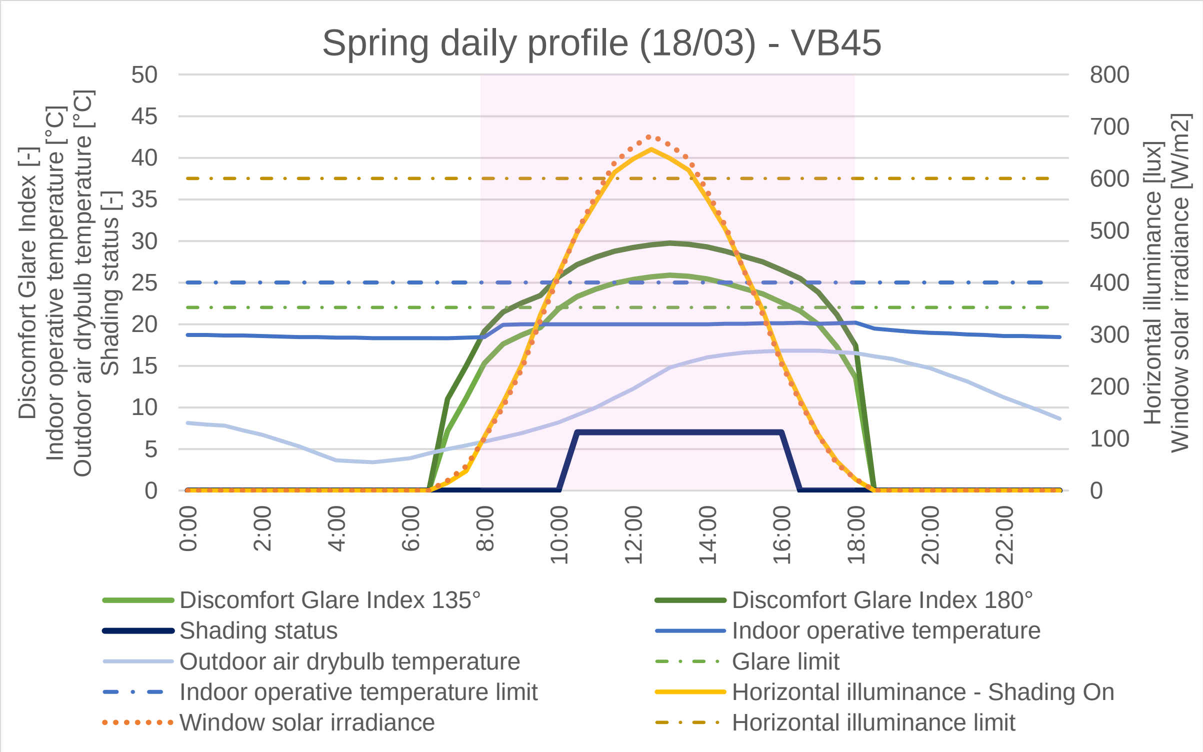


Figure 4.18 Analysis of the shading behaviour during Spring for Venetian blinds with a slat angle of 45. Case of Milan.

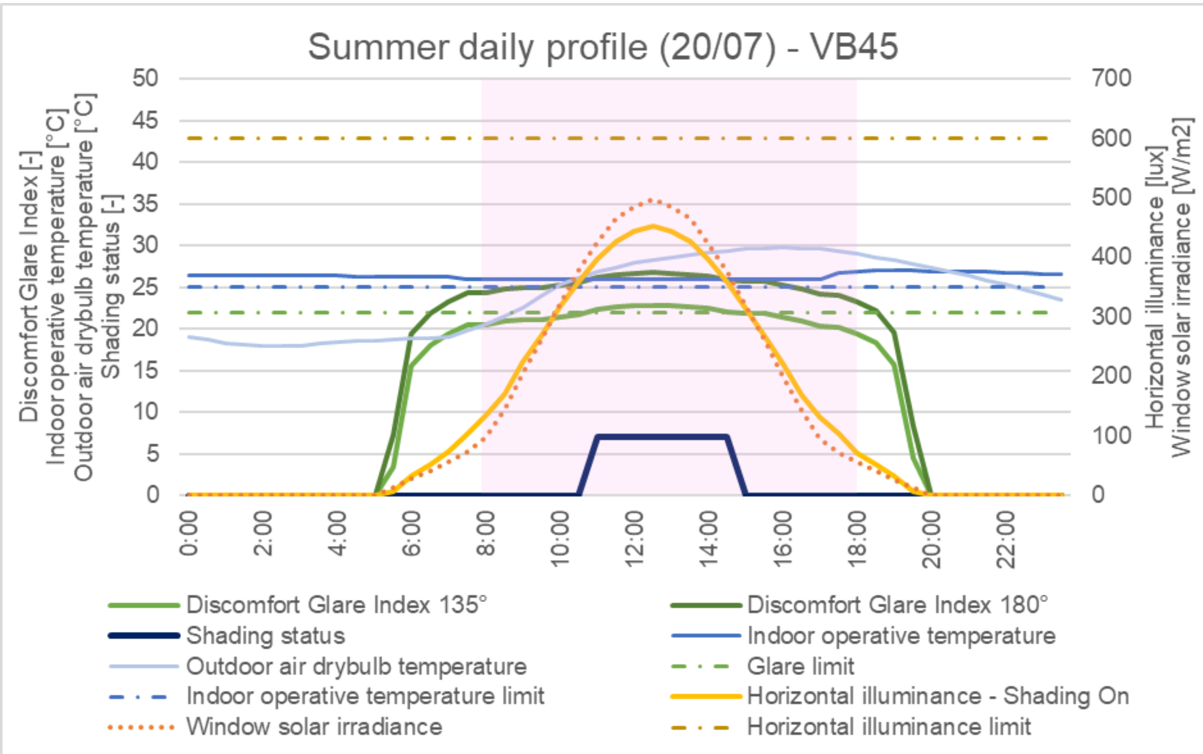


Figure 4.19 Analysis of the shading behaviour during Summer for Venetian blinds with a slat angle of 45. Case of Milan.

Figure 4.17 shows the activation profile of the Venetian blind with a slat angle of 45° during Winter in Milan (21st of December).

On the 21st of December, shading is activated from 10 am to 2.30 pm because DGI is greater than 22 for both 135 and 180° orientations.

On the 18th of March (Figure 4.18), the shading activation time is extended to 4 pm, always because of DGI values. In fact, the temperature is always lower than 25°C.

Finally, on the 20th of July (Figure 4.19), shading is activated from 10.30 to 2.30 pm because DGI is higher than 22 for 180° and 135° orientations.

In this case, indoor operative temperature is higher than 25°C all day, and solar irradiance is higher than 150W/m² for most working hours. However, shading is not activated because we do not reach the 600lux threshold for the horizontal illuminance on the work plane.

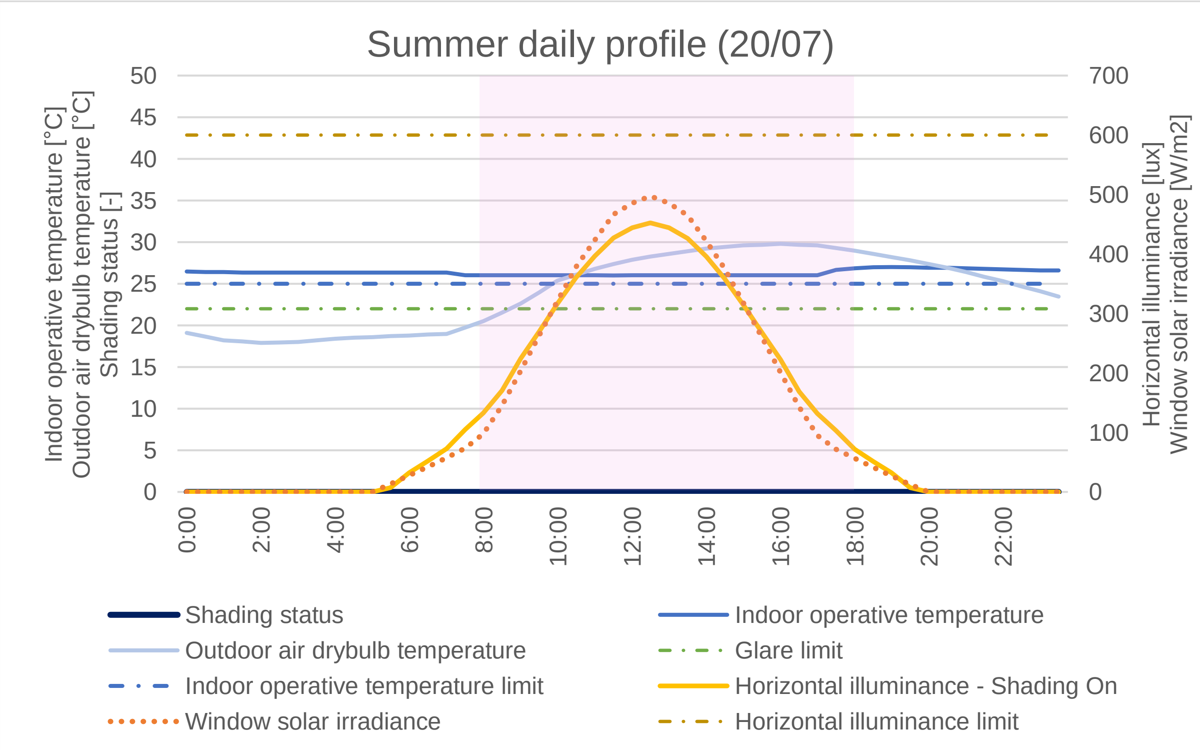


Figure 4.20 Analysis of the shading behaviour during Summer for Venetian blinds with a slat angle of 45°without glare evaluation. Case of Milan.

Figure 4.20 shows the shading activation profile on the 20th of July if glare is not included in the control strategy. We can observe that, in this case, shading is not activated. The indoor operative temperature is above 25°C, and the vertical irradiance on the window is higher than 150 W/m^2. However, if the shading is activated, we do not have 600 lux of horizontal illuminance on the work plane.

4.2.2 Effects of shadings on the office energy balance

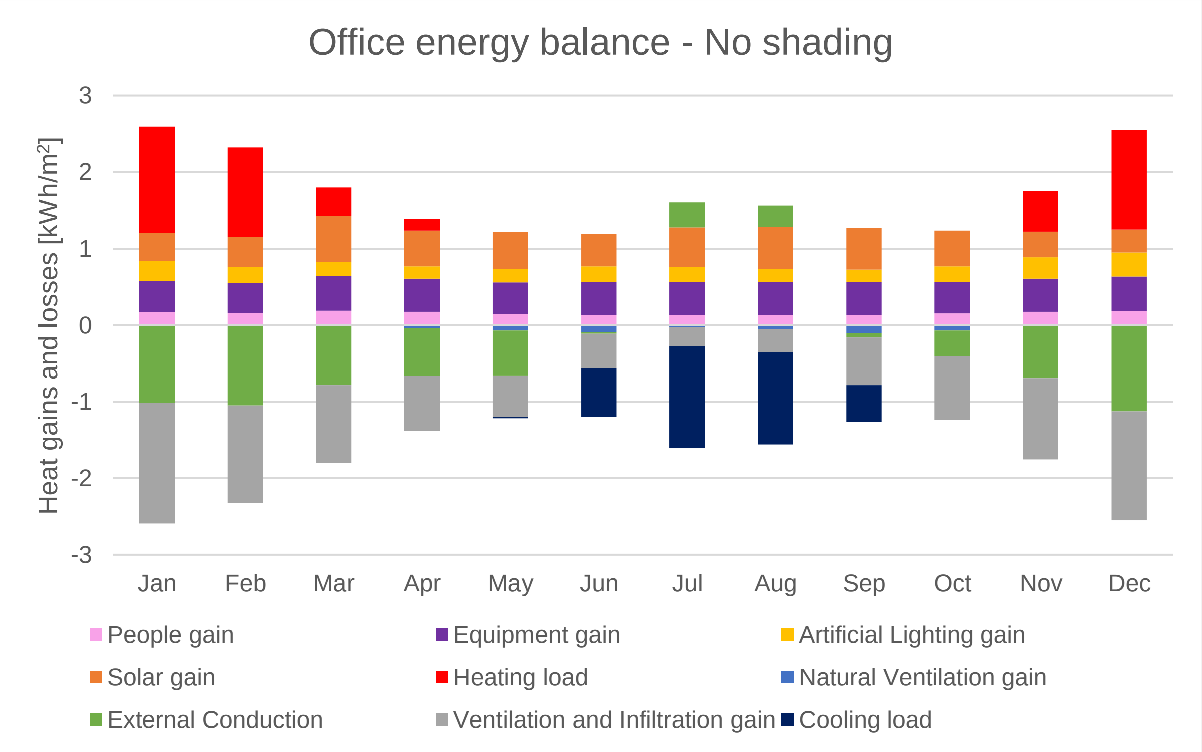


Figure 4.21 Office energy balance without shadings. Case of Milan.

Figure 4.21 shows the energy balance of the office when no shading is installed.

The heating season lasts from November to April. The highest heating load is registered in January (1.387 kWh/m^2) when the highest heat losses for conduction, infiltration and ventilation occur (-2.591 kWh/m^2).

Cooling is needed from May to September. The highest cooling load is registered in July (-1.337 kWh/m^2), where, due to the high external temperatures, natural ventilation is not available.

Heat gains can be compensated with natural ventilation (without cooling systems) only in October.

People and equipment gains are constant throughout the year. Instead, artificial lighting reduces with the increase of solar gains. The sum of those internal gains is always higher than solar gains.

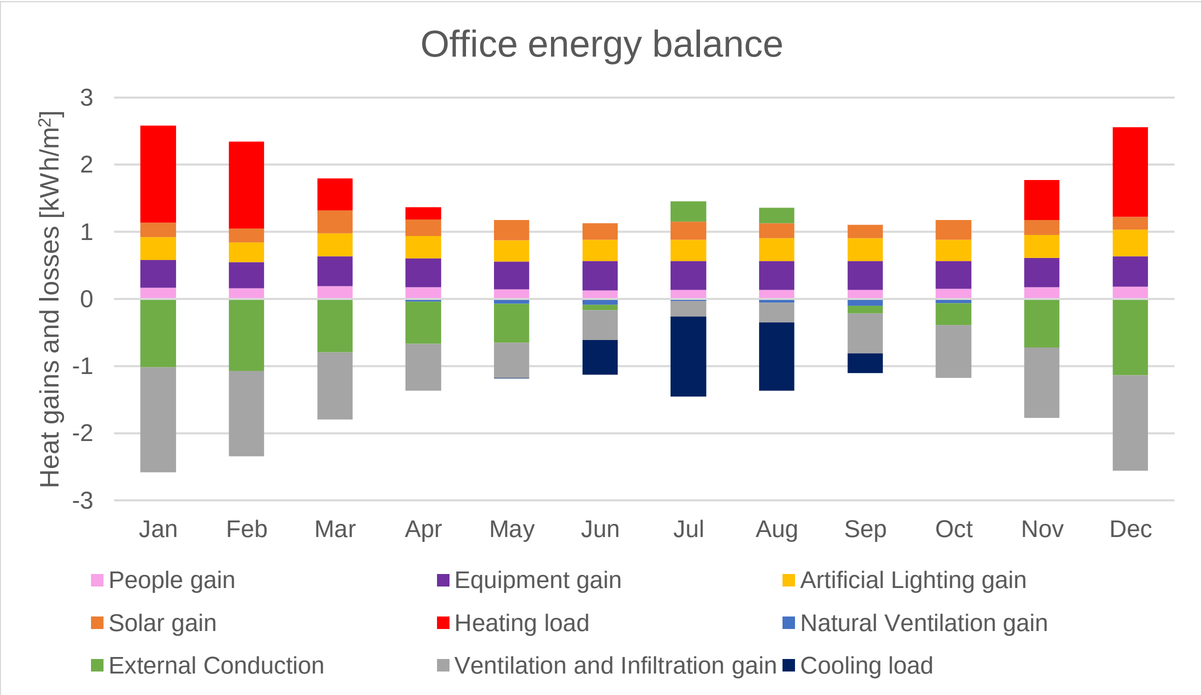


Figure 4.22 Office energy balance with Venetian blinds (slat angle 45°). Case of Milan.

Figure 4.22 shows the energy balance of the office when VB are installed with a slat angle of 45°.

Also in this case, the heating season starts in November and ends in April. The highest heating load is always registered in January (1.452 kWh/m^2) when the highest heat losses for conduction, infiltration and ventilation occur (-2.585 kWh/m^2).

Cooling is still necessary from May to September, with a peak in July (-1.995 kWh/m^2).

Also in this case, in October, natural ventilation compensates heat gains, avoiding the use of cooling systems.

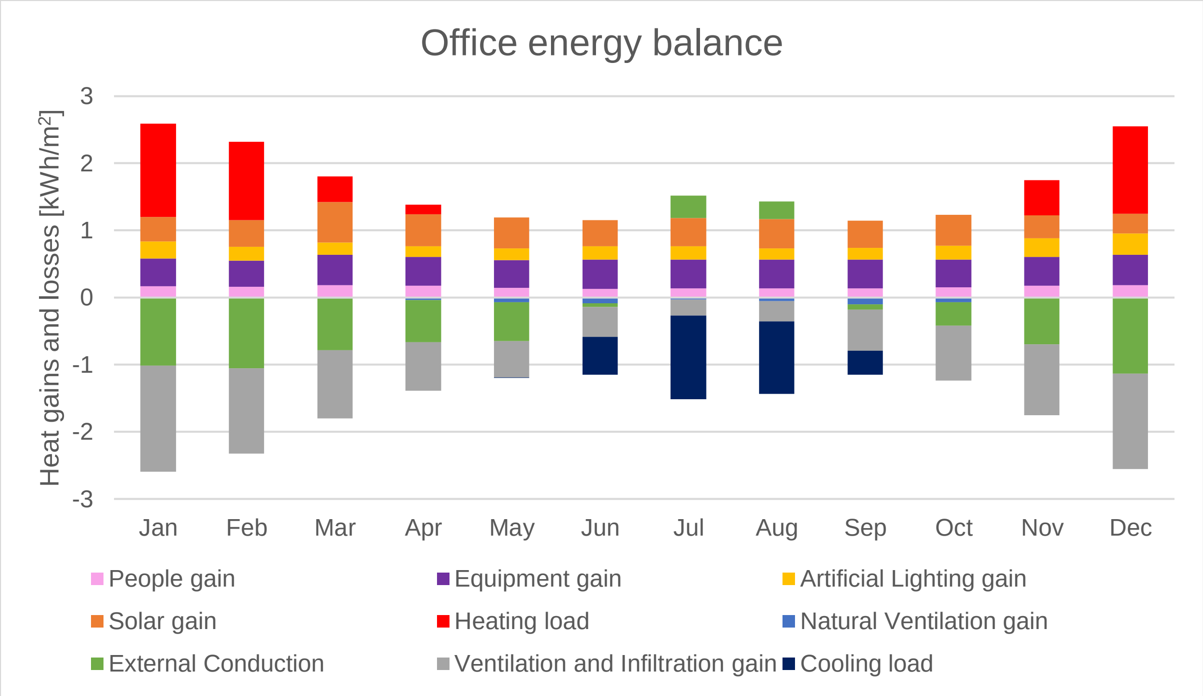


Figure 4.23 Office energy balance with Venetian blinds (slat angle 45°). Control strategy without glare. Case of Milan.

Figure 4.23 shows the energy balance of the office when VB are installed with a slat angle of 45° and with a control strategy not including glare.

Regarding heating load, the results are the same as the BC without shadings. The only difference is observed in the cooling season: compared to the base case, thanks to the use of shadings, we have a reduction in the solar gains and hence of the cooling load.

Table 4.5 Comparison of heating and cooling loads for the different shadings and control strategies. Case of Milan.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BC	1.387	1.172	0.377	0.147	-0.016	-0.630	-1.337	-1.205	-0.480	0	0.530	1.302
OH	1.418	1.252	0.551	0.217	0	-0.397	-1.101	-0.945	-0.291	0	0.592	1.330
VB45	1.452	1.288	0.482	0.182	-0.001	-0.516	-1.195	-1.013	-0.293	0	0.594	1.334
VB45 NoGlare	1.387	1.172	0.377	0.147	-0.011	-0.561	-1.253	-1.081	-0.357	0	0.531	1.302
VB0	1.397	1.213	0.435	0.168	-0.005	-0.562	-1.224	-1.083	-0.348	0	0.544	1.304
VB0 NoGlare	1.387	1.172	0.377	0.147	-0.004	-0.530	-1.211	-1.058	-0.332	0	0.531	1.302
RB	1.451	1.278	0.481	0.186	0	-0.458	-1.142	-0.960	-0.259	0	0.594	1.346
RB NoGlare	1.387	1.172	0.377	0.147	-0.010	-0.547	-1.237	-1.067	-0.364	0	0.531	1.302

Table 4.5 compares the results obtained for the different types of shading and control strategies regarding heating and cooling load.

During the heating season, the installation of shadings has a negative impact on heating energy needs if glare is included in the control strategy. If glare is considered, VB0 is the solution that provides the lowest increase in heating needs. Instead, if glare is not considered, we obtain the same results as the BC.

Conversely, during Summer, the highest cooling loads are obtained in BC. The cooling energy needs are lower than the BC for every other solution. OH is the solution providing the highest reduction in cooling energy needs. Among the dynamic shadings, the best results are obtained with RB. Finally, if glare is not considered, the strategy that guarantees the best results is VB0.

Table 4.6 Comparison of lighting gains for the different shadings and control strategies. Case of Milan.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BC	0.255	0.206	0.181	0.160	0.178	0.202	0.196	0.163	0.159	0.206	0.275	0.317
OH	0.281	0.227	0.225	0.236	0.220	0.234	0.240	0.233	0.232	0.235	0.303	0.333
VB45	0.339	0.291	0.342	0.326	0.317	0.318	0.316	0.341	0.342	0.316	0.346	0.402
VB45 NoGlare	0.255	0.206	0.181	0.160	0.178	0.202	0.196	0.166	0.173	0.206	0.275	0.317
VB0	0.309	0.270	0.290	0.267	0.261	0.273	0.251	0.266	0.272	0.285	0.324	0.359
VB0 NoGlare	0.255	0.206	0.181	0.160	0.184	0.214	0.215	0.216	0.230	0.207	0.275	0.317
RB	0.359	0.323	0.373	0.336	0.317	0.318	0.316	0.343	0.353	0.335	0.361	0.403
RB NoGlare	0.255	0.206	0.181	0.160	0.178	0.202	0.196	0.163	0.159	0.206	0.275	0.317

Table 4.7 Comparison of solar gains for the different shadings and control strategies. Case of Milan.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BC	0.368	0.393	0.604	0.469	0.481	0.430	0.514	0.551	0.544	0.467	0.338	0.299
OH	0.290	0.288	0.381	0.258	0.268	0.257	0.284	0.286	0.313	0.326	0.261	0.244
VB45	0.215	0.209	0.337	0.252	0.304	0.249	0.267	0.225	0.198	0.292	0.223	0.183
VB45 NoGlare	0.368	0.393	0.604	0.469	0.462	0.385	0.427	0.439	0.407	0.464	0.338	0.299
VB0	0.299	0.290	0.427	0.322	0.368	0.310	0.345	0.334	0.310	0.354	0.282	0.251
VB0 NoGlare	0.368	0.393	0.604	0.469	0.446	0.347	0.367	0.364	0.337	0.462	0.338	0.299
RB	0.194	0.185	0.301	0.219	0.266	0.204	0.213	0.168	0.150	0.269	0.208	0.167
RB NoGlare	0.368	0.393	0.604	0.469	0.458	0.374	0.406	0.429	0.433	0.459	0.338	0.299

Table 4.6 and Table 4.7 compare the results obtained for the different shading and control strategies regarding lighting and solar gains, respectively.

Without shadings, we register the lowest lighting gains and the highest solar gains. Instead, with RB, we register the highest increase in lighting loads and the highest decrease in solar gains throughout the year, compared to the BC. Solutions not considering glare provide the same results during the heating season.

During Winter, the decrease (in absolute value) in solar gains due to the shading activation is higher than the increase in lighting gains. This justifies the higher heating load registered with dynamic shadings with glare control.

During Summer, the significant reduction in solar gains justifies the reduction in cooling load described before.

4.2.3 Effects on energy needs

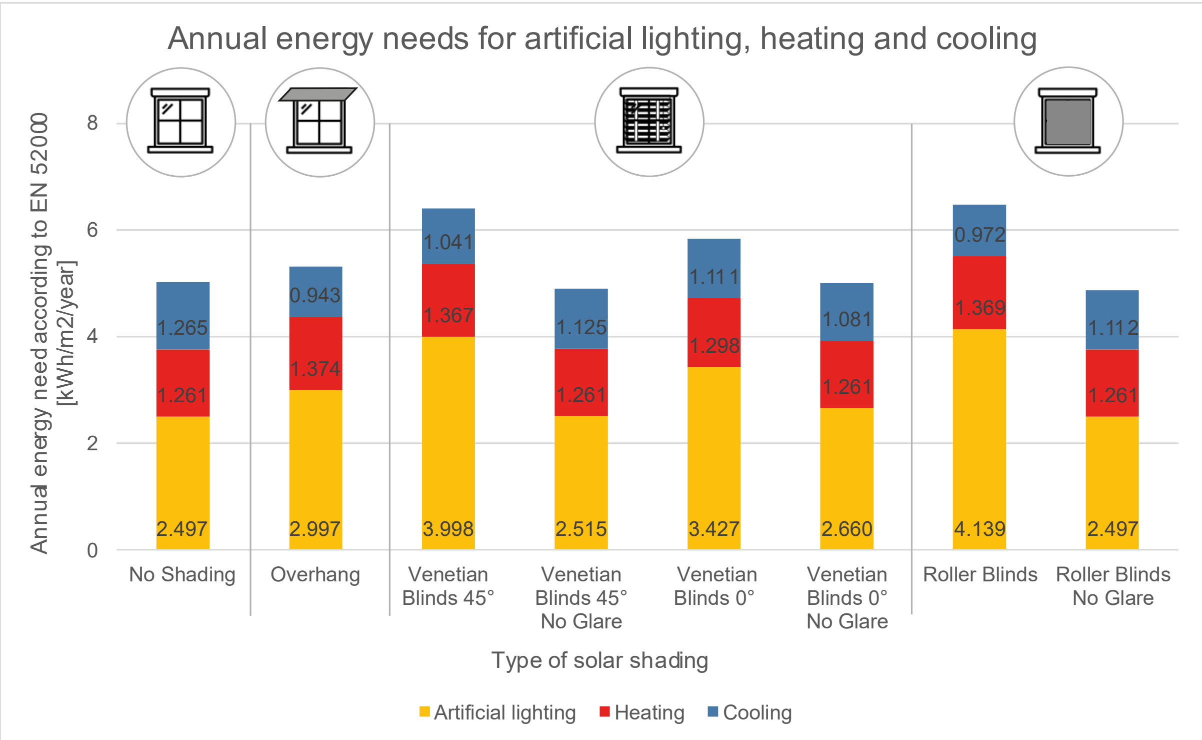


Figure 4.24 Comparison of annual energy needs between the base case without shadings, and the cases with the integration of Venetian blinds with a slat angle of 0° and 45°, and of Roller blinds. Case of Milan.

Figure 4.24 compares the annual energy needs for lighting, heating and cooling for the selected shading technologies and the two control algorithms.

The installation of shading technologies determines the increase of the total annual energy needs if glare is included in the control strategy. This is caused by the increase in the lighting and heating energy needs, which is not compensated by a sufficient reduction in cooling energy needs.

The highest increase in total energy needs is observed with RB (+29%), with an increase in lighting and heating energy needs of +66% and +9%, respectively (compared to the BC). On the other hand, with the same technology, we register the highest decrease in cooling energy needs among the dynamic shading solutions (-23%).

The highest total annual energy needs reduction is registered with RB with glare control (-3%). This is because heating and lighting are the same in the BC, while cooling is reduced by 12%.

In all strategies including glare evaluation, heating energy needs increase compared to the BC. RB and VB provide equivalent results (+9%). When the control strategy does not include glare evaluation, heating energy needs are the same as the BC.

Regarding cooling energy needs, we always register a reduction compared to the BC. The best results are provided by OH (-25%). Among the dynamic solutions with glare evaluation, the highest reduction is registered with RB (-23%) and the lowest with VB0 (-12%). If glare is not considered, we register a lower reduction in cooling needs compared to the other dynamic shading solutions. In this case, VB0 provide the best results due to its higher activation time.

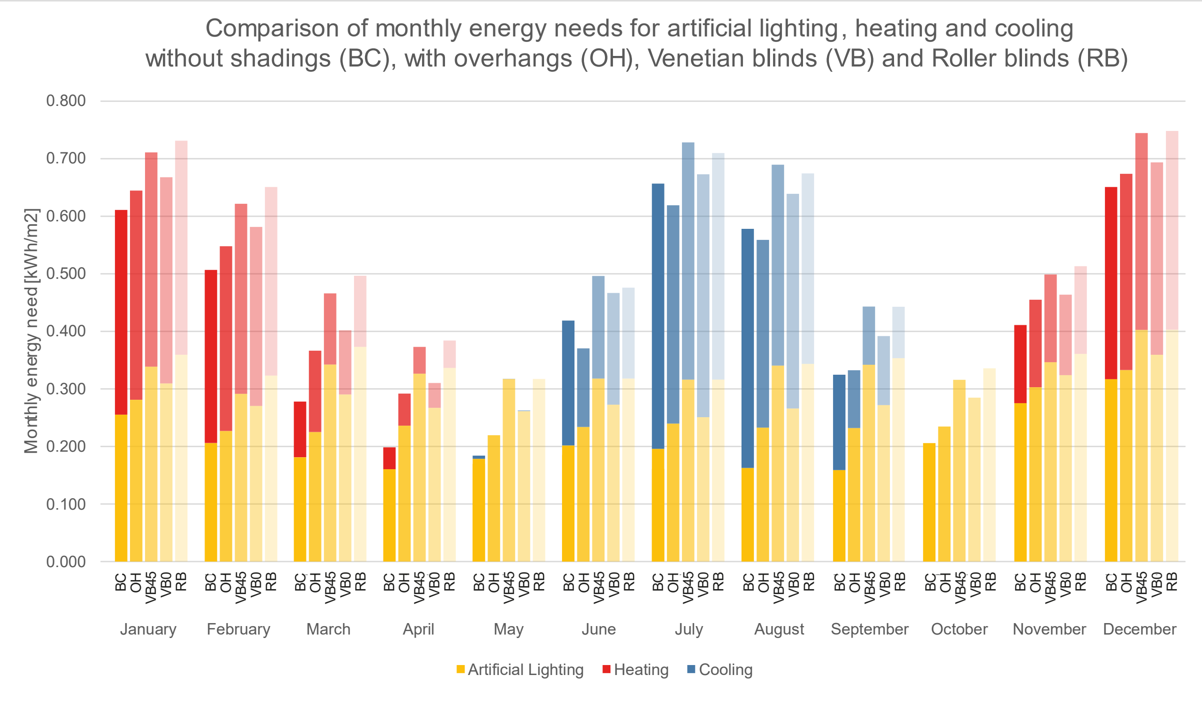


Figure 4.25 Comparison of monthy energy needs for heating, cooling and artificial lighting between the cases without shadings, OH, VB and RB with control strategies including glare evaluation. Case of Milan.

Figure 4.25 compares the energy needs for heating, cooling and artificial lighting obtained with the strategies including glare evaluation.

Total energy needs increase in all months for all solutions, except for the OH, which lowers the total energy needs in June, July, and August. VB with a slat angle of 0° provides the best results among the dynamic shading technologies, thanks to a lower increase in artificial lighting needs than the BC.

RB and VB with a slat angle of 45° provide similar results. RB are more effective during Summer, while VB are more effective during Winter.

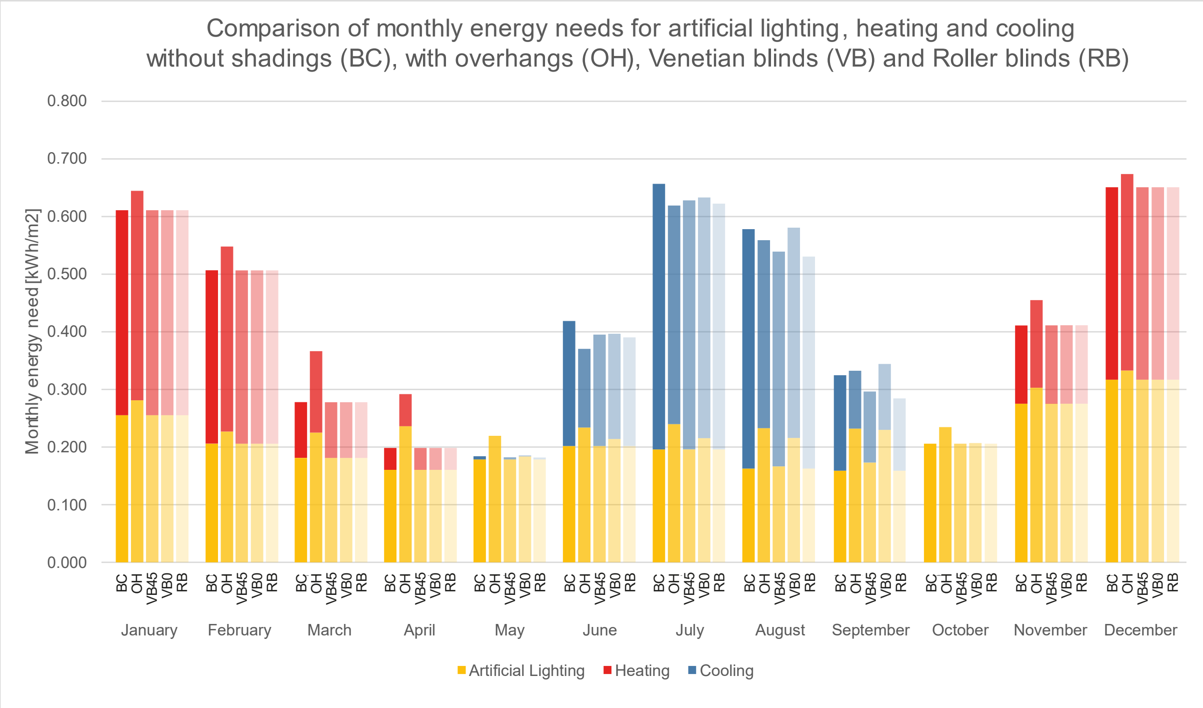


Figure 4.26 Comparison of monthy energy needs for heating, cooling and artificial lighting between the cases without shadings, OH, VB and RB with control strategies without glare evaluation. Case of Milan.

Figure 4.26 compares the energy needs for heating, cooling and artificial lighting obtained with the strategies not including glare evaluation.

Due to the algorithm's logic, shadings are activated only during Summer, when the activation of shadings induces an increase in artificial lighting needs, but lower than in the case with glare evaluation (Figure 4.25).

In June and July, all shading solutions lower the cooling energy needs. In August and September, VB45 and RB are the only effective dynamic shadings, thanks to their limited impact on the lighting energy needs.

4.2.4 Effects of shadings on visual discomfort

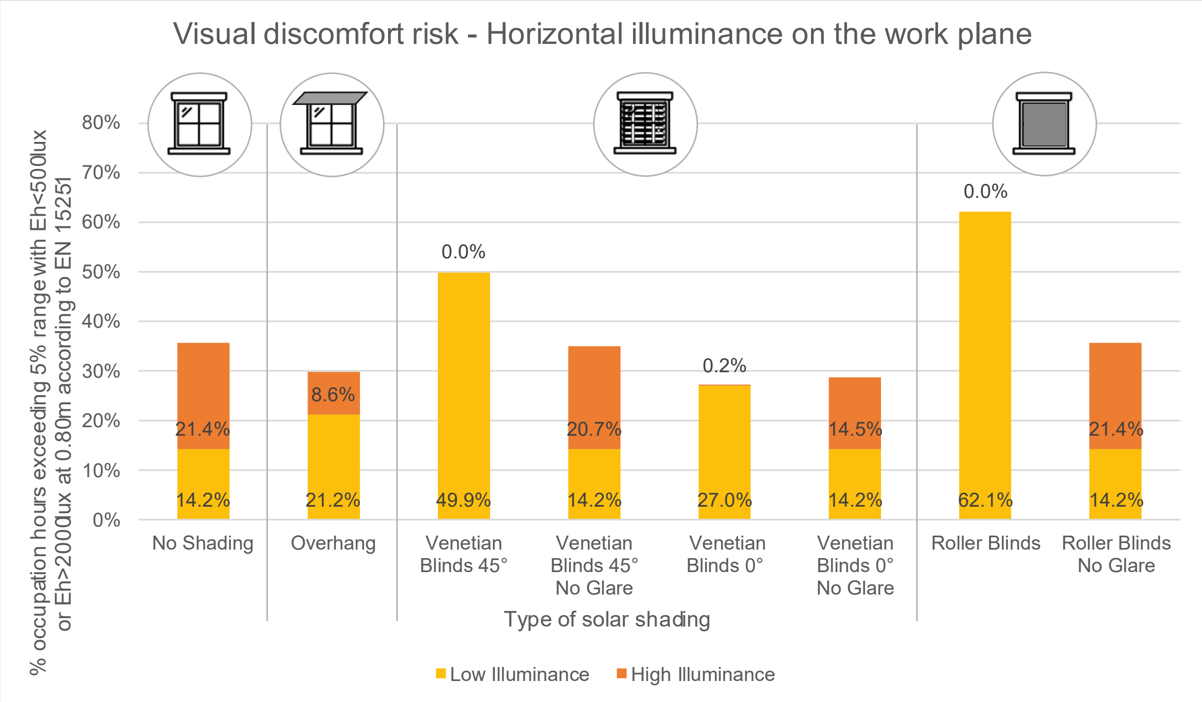


Figure 4.27 Comparison of the impacts of shadings on yearly visual discomfort hours compared to the base case (no shading). Analysis of discomfort hours due to high and low illuminance on the work plane. Case of Milan.

Figure 4.27 compares the discomfort hours due to a too-high or too-low illuminance on the work plane for different shading solutions and control strategies.

In the BC, we have 35.6% of discomfort hours. 14.2% are due to a low level of illuminance, while 21.4% to a high level.

With dynamic shadings, if glare evaluation is included in the control strategy, discomfort given by high illuminance is brought to 0% for VB45 and RB and 0.2% for VB0. However, due to the increase in the hours with low illuminance, only with VB0 we have a global reduction in discomfort hours (-8.4%). The worst result is obtained with RB, for which we have 62.1% of discomfort hours (+26.5% compared to the BC).

If glare is not considered, the percentage of low-illuminance discomfort hours is the same as the BC. High-illuminance discomfort hours are reduced with VB45 and VB0 (-0.7 and -6.9%, respectively). No variation is observed for RB.

Finally, also OH is effective in the reduction of discomfort hours (-5.4%), thanks to the significant reduction in high-illuminance discomfort hours (-12.8%) that compensates the increase in low-illuminance discomfort hours (+7%).

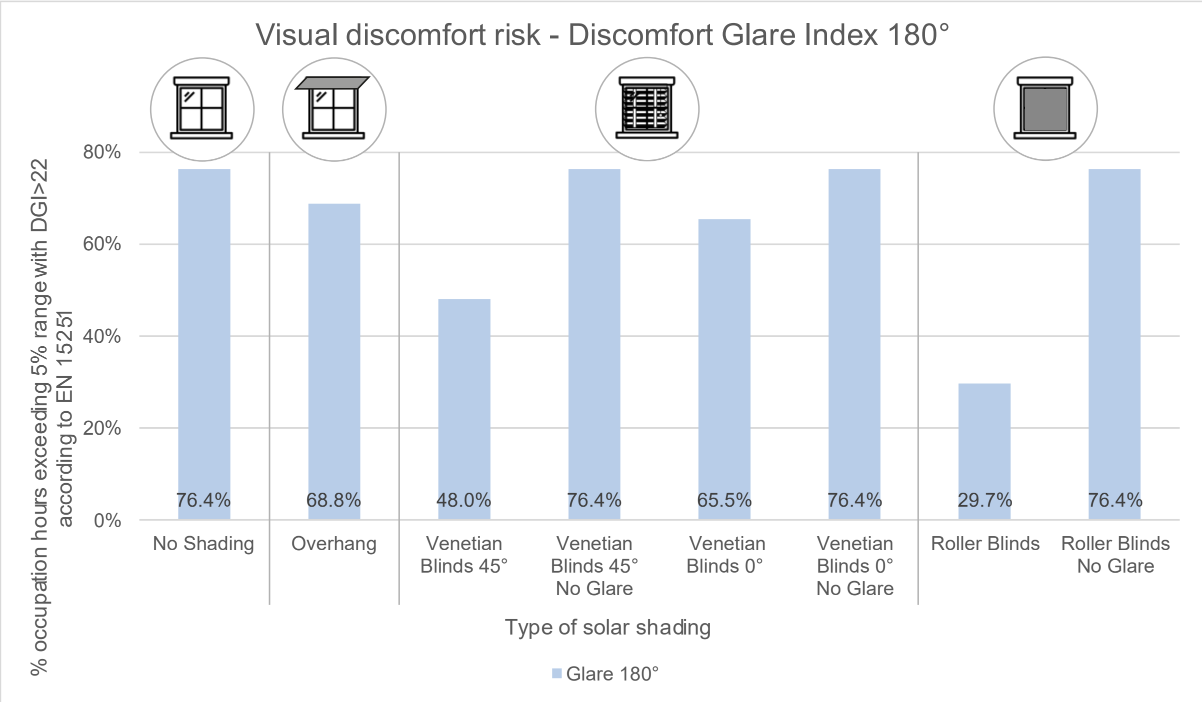


Figure 4.28 Comparison of the impacts of shadings on yearly visual discomfort hours compared to the base case (no shading). Analysis of discomfort hours due to glare, with the user orientation at 180°. Case of Milan.

Figure 4.28 compares the discomfort hours due to glare for different shading solutions and control strategies.

When the user faces the window and shadings are not installed, the user is in a discomfort condition for 76.4% of the working hours.

The OH allows to reduce the discomfort hours by 7.6%. Instead, installing shadings with glare control reduces the discomfort hours to 48.0%, 65.5% and 29.7% with VB45, VB0 and RB, respectively.

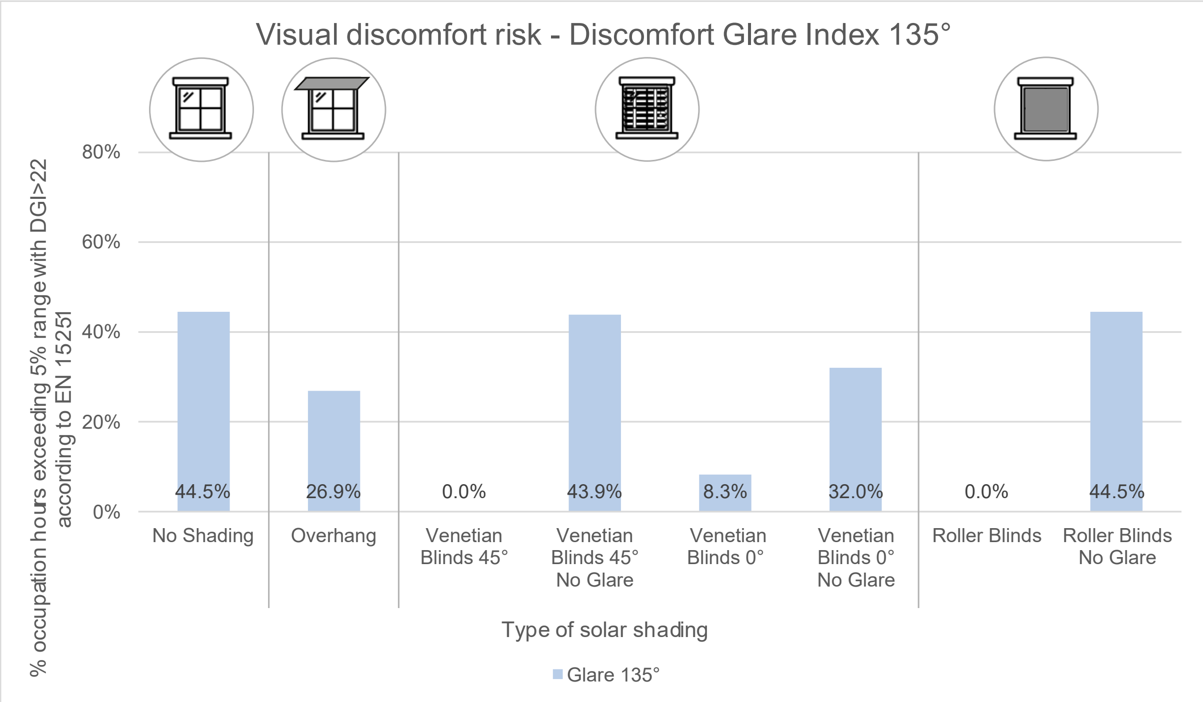


Figure 4.29 Comparison of the impacts of shadings on yearly visual discomfort hours compared to the base case (no shading). Analysis of discomfort hours due to glare, with the user orientation at 135°. Case of Milan.

Figure 4.29 compares the discomfort hours due to glare for different shading solutions and control strategies when the user is oblique to the window.

In the BC, discomfort is registered for 44.5% of the occupation hours. With the integration of an OH, this percentage is reduced to 26.9%.

Finally, with VB45 and RB, the discomfort hours are brought to 0%, while for VB0 we still have 8.3% of discomfort hours.

VB45 and VB0 impact discomfort glare even if glare control is not included in the control strategy. However, compared to the other dynamic solutions, the reduction in discomfort hours is less significant (-0.6 and -11.5%, respectively).

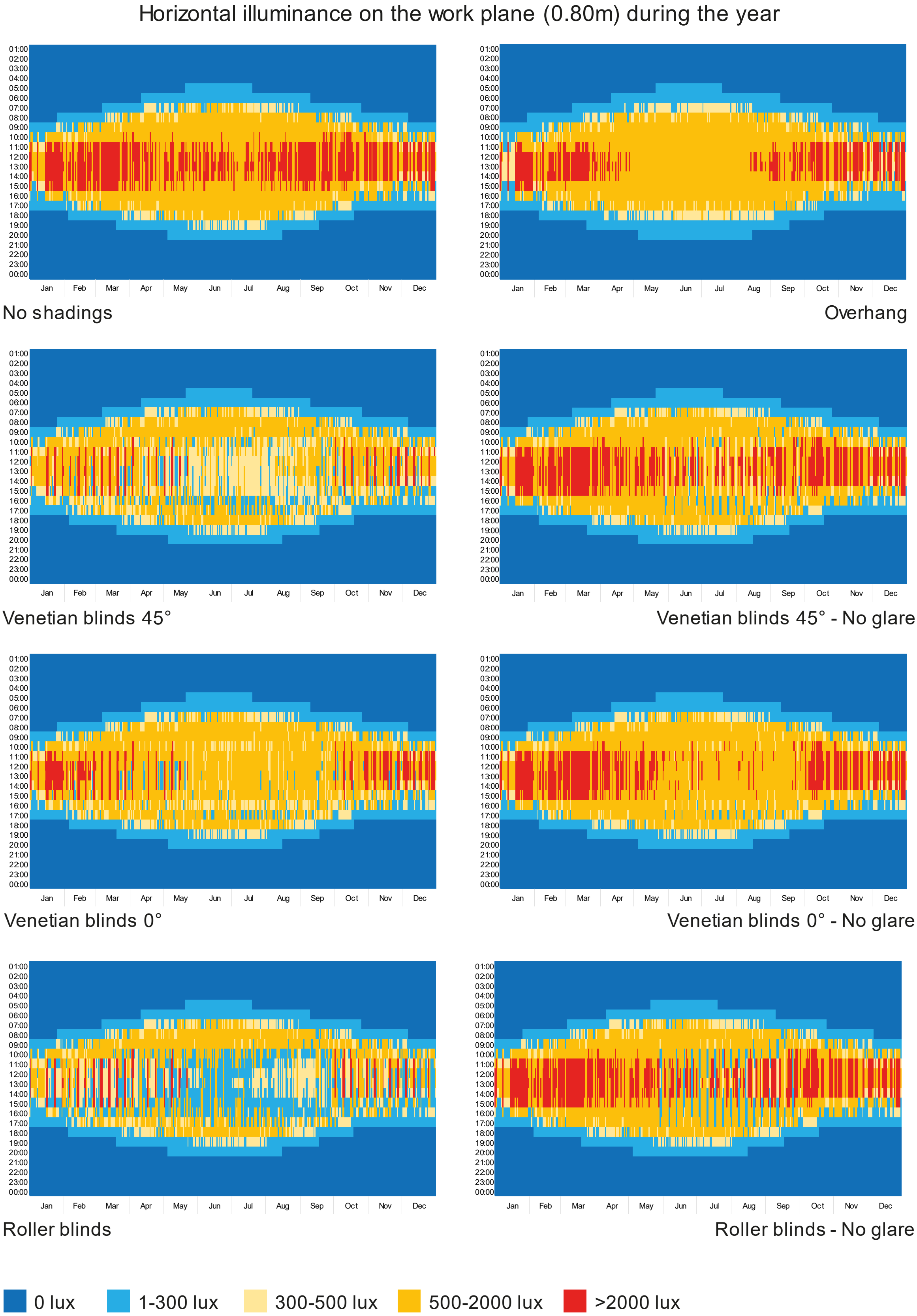


Figure 4.30 Comparison of visual performance of shadings throughout the year and the day. Analysis of the horizontal illuminance on the work plane. Case of Milan.

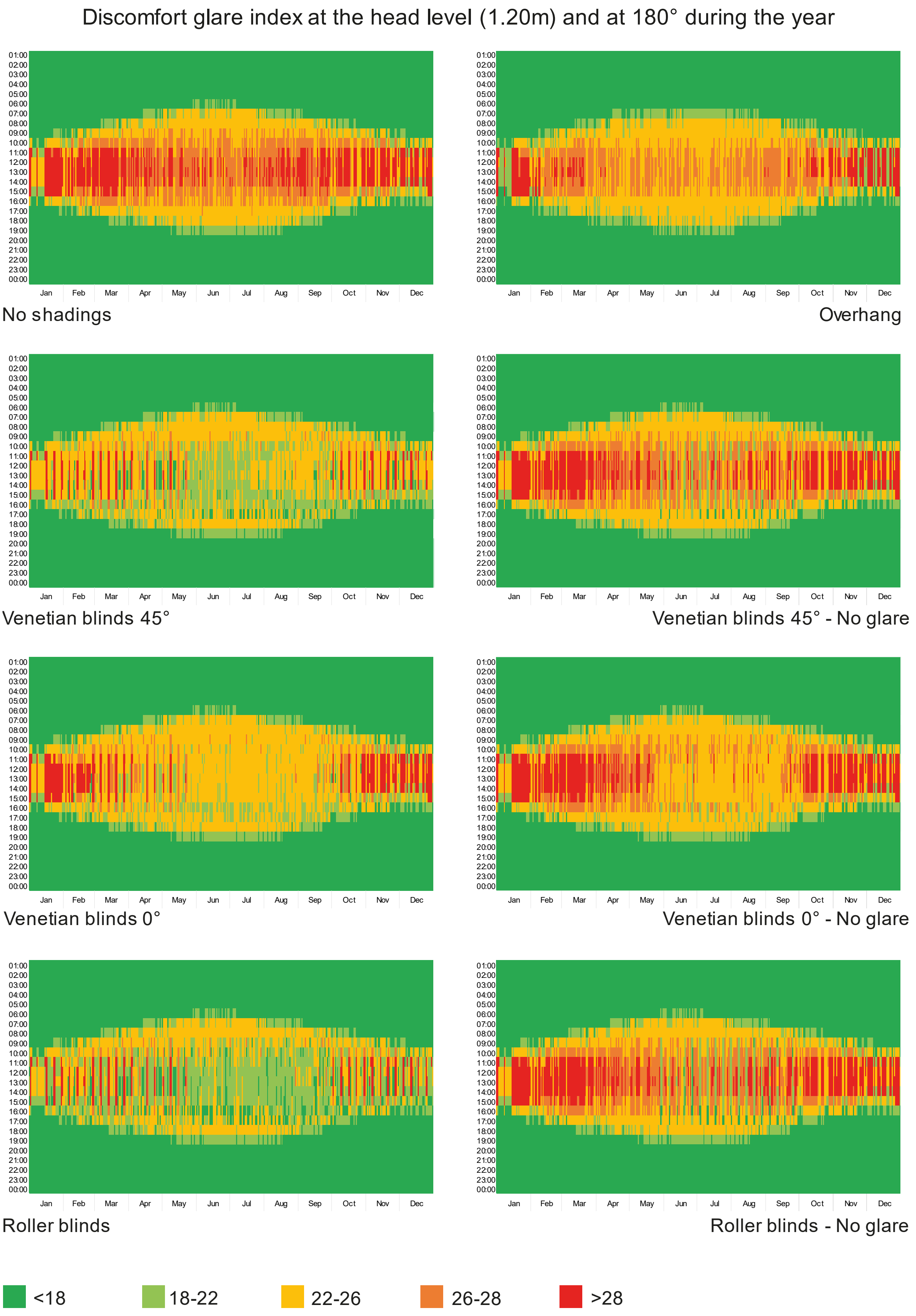


Figure 4.31 Comparison of visual performance of shadings throughout the year and the day. Analysis of the glare with a user orientation of 180°. Case of Milan.

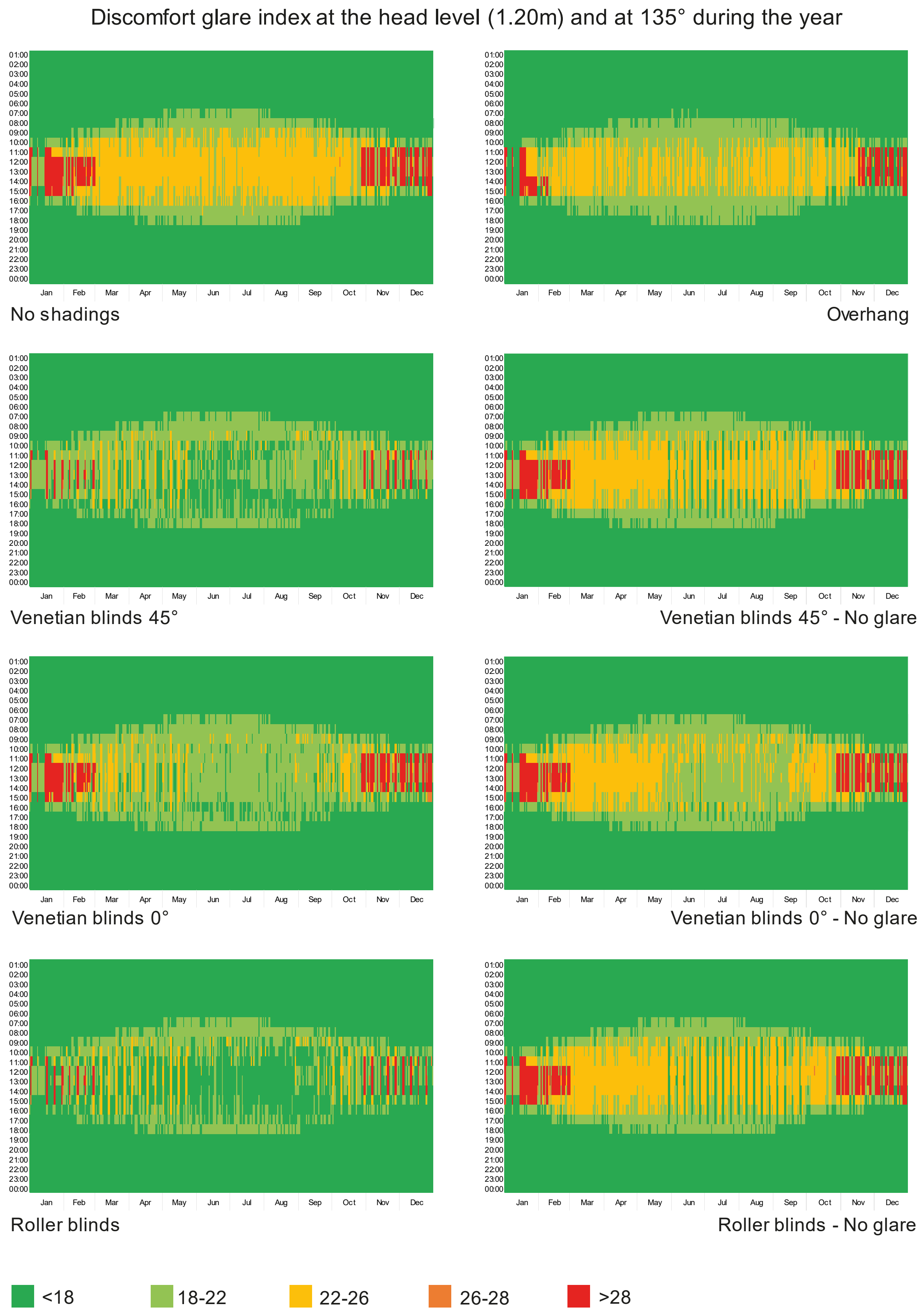


Figure 4.32 Comparison of visual performance of shadings throughout the year and the day. Analysis of the glare with a user orientation of 135°. Case of Milan.

Comparing the annual progression of the horizontal illuminance on the work plane of the different shadings (Figure 4.30), we can remark all solutions reduce discomfort in the central hours of the day. This advantage is guaranteed throughout the year if glare evaluation is included in the strategy. VB0 is the solution that reduces illuminance but keeps it between 600 and 2000 lux. This is not the case for RB, for which illuminance drops in the range of 1-300lux also in the central hours of the day.

The OH appears less effective during Winter. The same is for VB0 if compared with VB45.

If glare is not considered, the advantages are limited to Summer. In this case, the most remarkable improvement is observed with VB0 during Summer.

The same considerations are valid for glare for both orientations (Figure 4.31 and Figure 4.32). RB provide the best reduction in glare discomfort, followed by VB45. When considering the 180° orientation, RB allow to keep the DGI between 18 and 22 during the central hours of the day. This value drops to values lower than 18 for most of the year if we consider the 135° orientation.

4.2.5 Comparison of the energy needs and comfort performances

Table 4.8 Comparison of the results obtained for base case (no shading), Venetian blinds, and Roller blinds in terms of energy needs, visual comfort, and user satisfaction. Case of Milan.

Parameter	**BC**	**OH**	**VB45**	**VB45 No glare**	**VB0**	**VB0 No glare**	**RB**	**RB No glare**
Heating annual energy need [kWh/m2/year]	1.261	1.374	1.367	1.261	1.298	1.261	1.369	1.261
Artificial lighting annual energy need [kWh/m2/year]	2.497	2.997	3.998	2.515	3.427	2.660	4.139	2.497
Cooling annual energy need [kWh/m2/year]	1.265	0.943	1.041	1.125	1.111	1.081	0.972	1.112
Total annual energy need [kWh/m2/year]	**5.023**	**5.314**	**6.046**	**4.091**	**5.836**	**5.002**	**6.480**	**4.870**
Low illuminance discomfort hours [%]	14.2	21.2	49.9	14.2	27.0	14.2	62.1	14.2
High illuminance discomfort hours [%]	21.4	8.6	0.0	20.7	0.2	14.5	0.0	21.4
Total illuminance discomfort hours [%]	**35.6**	**29.8**	**49.9**	**34.9**	**27.2**	**28.7**	**62.1**	**35.6**
Discomfort glare hours 180°[%]	76.4	68.8	48.0	76.4	65.5	76.4	29.7	76.4
Discomfort glare hours 135°[%]	44.5	26.9	0.0	43.9	8.3	32.0	0.0	44.5
Shading activation hours during working hours [%]	/	/	50	1	50	13	50	0

Table 4.8 resumes the results obtained for Milan. The use of shadings determines an increase in the office's energy needs if glare is included in the control strategy. An inverse trend is registered for the visual comfort parameters. In the case of illuminance control, VB0 provide the best performance among dynamic shadings, reducing discomfort hours from 35.6% to 27.2% during working hours.

In the case of glare control, instead, the best performance is provided by RB, which, at parity of activation time, reduce glare discomfort hours to 29.7% of working hours for the user's orientation at 180°. With VB0, we still have 8.3% of discomfort hours at 135° even with the glare evaluation included in the control strategy and at parity of activation hours.

When glare is included in the control strategy, shadings are activated for 50% of the occupied hours. If glare is not considered, this percentage decreases to 13% for VB0 and 1% for VB45 and RB.

4.3 Comparison of the results obtained for Liège and Milan

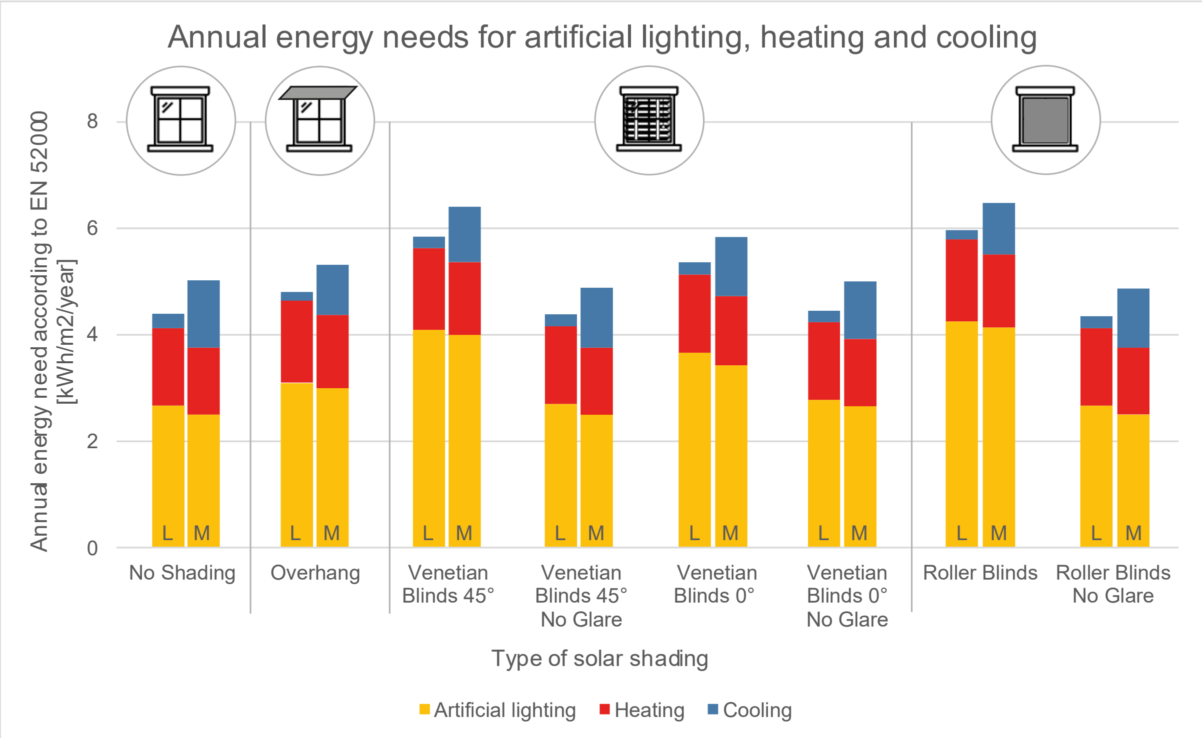


Figure 4.33 Comparison of the annual energy needs for artificial lighting, heating and cooling obtained with the different types of shadings and control strategies for Liège (L) and Milan (M).

Figure 4.33 compares the results obtained regarding annual energy needs for Liège and Milan with the selected shadings and control strategies.

In terms of artificial lighting and heating, Liège has higher energy needs than Milan. However, the significantly higher cooling energy needs make Milan the location with the highest total annual energy needs.

Regarding performance, different shadings and control strategies give the same trend in both locations: using shadings increases the annual artificial lighting and heating energy needs but reduces the cooling energy needs.

RB are, in both locations, the solution with the highest annual energy need, followed by VB45. Only the solutions that do not include glare evaluation in the control algorithm (except for VB0 in Liège) allow to reduce the total annual energy needs of the office.

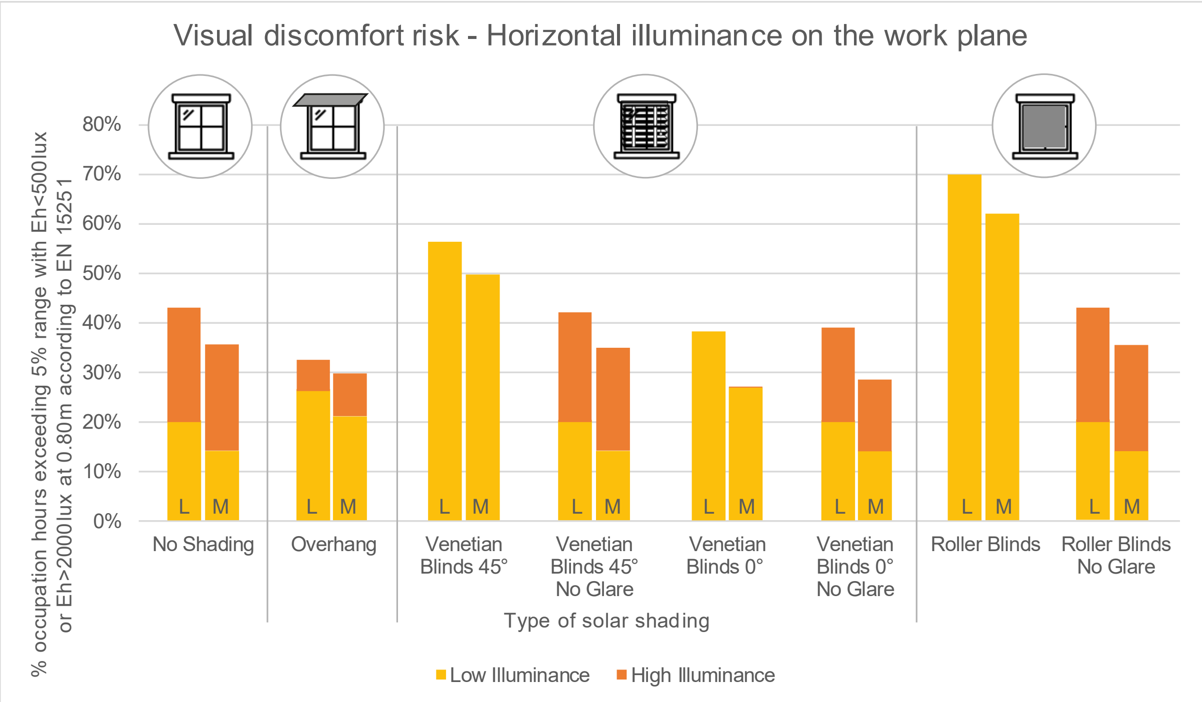


Figure 4.34 Impacts of shadings on yearly visual discomfort hours compared to the base case (no shading). Comparison of discomfort hours due to high and low illuminance on the work plane for Liège (L) and Milan (M).

In terms of visual discomfort (Figure 4.34), in Milan, we register a lower percentage of discomfort hours due to low and high illuminance levels, leading to a lower total amount of discomfort hours.

In both locations, we observe a reduction in the total discomfort hours with the installation of shadings if glare is not included in the control strategy. This is due to the reduction in the hours with a high level of illuminance.

If glare is considered in the algorithm, discomfort from a high illuminance level is brought to 0. However, a total discomfort hours benefit is obtained only with VB0, for which the total amount of discomfort hours is lower than the BC.

For both Milan and Liège, the worst result is obtained with RB, followed by VB45 (both with glare evaluation included in the control strategy). Conversely, the best results are obtained with OH for Liège and VB0 without glare for Milan.

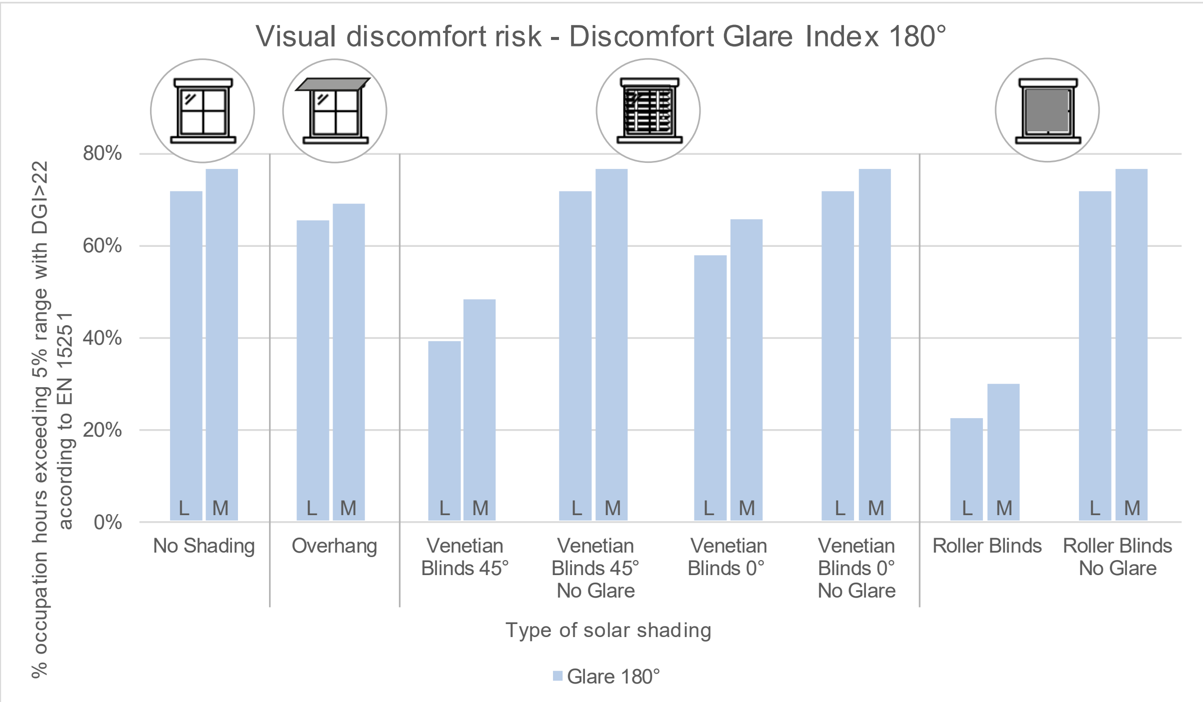


Figure 4.35 Impacts of shadings on yearly visual discomfort hours compared to the base case (no shading). Comparison of discomfort hours due to glare, with the user orientation at 180°, for Liège (L) and Milan (M).

In terms of discomfort glare (Figure 4.35), in Milan, we register a higher percentage of discomfort hours if the user faces the window.

In both locations, installing a shading system and including glare in its control strategy reduces discomfort hours. The best results are obtained with RB in both locations, while VB0 provide the worst. OH appears less effective in glare control than dynamic shadings in the two cities.

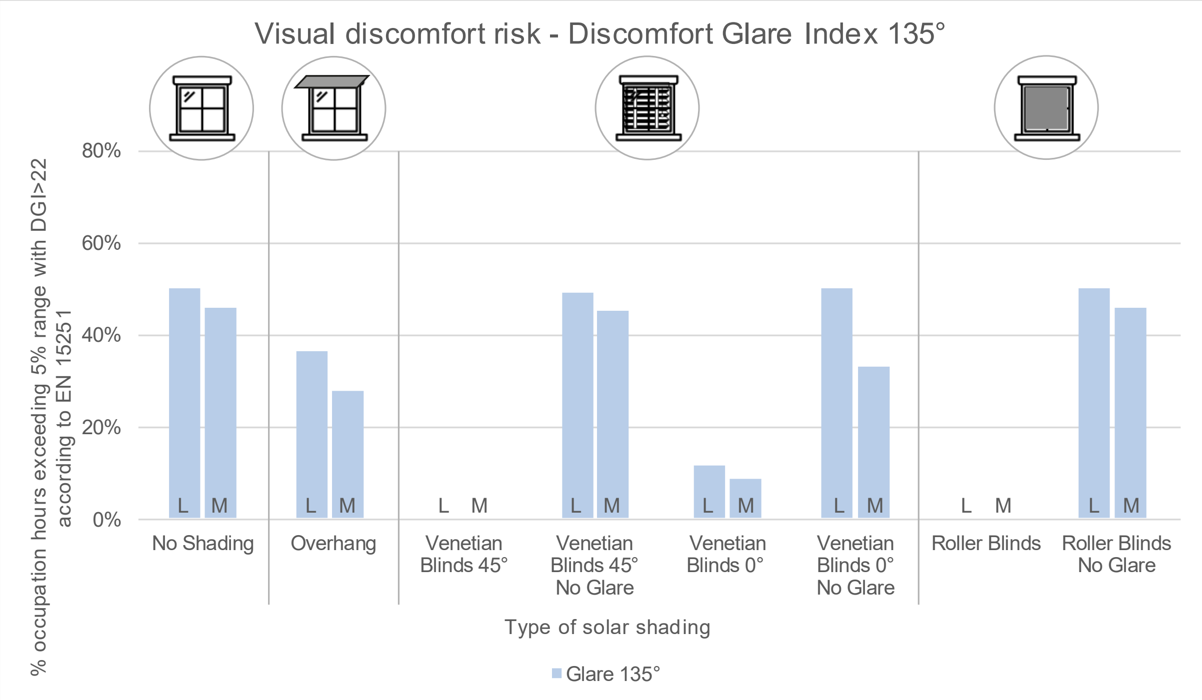


Figure 4.36 Impacts of shadings on yearly visual discomfort hours compared to the base case (no shading). Comparison of discomfort hours due to glare, with the user orientation at 135°, for Liège (L) and Milan (M).

With a user orientation of 135° (Figure 4.36), we observe an opposite situation compared to the orientation of 180°. In fact, we register a lower percentage of discomfort hours in Milan than in Liège.

In both locations, installing a shading system and including glare in its control strategy allows to bring to 0 the discomfort hour, except for VB0. The most remarkable aspect is the significantly better performance of VB without glare evaluation in Milan. This is because, in Milan, this shading solution has a higher activation time than in Liège. In all the other cases, the activation time is the same in both locations.

5 Discussion

In this chapter, we finally answer the research questions of this work. According to the findings, the optimal control strategy and the optimal shading technology are defined. A discussion is also conducted on the research itself, putting in evidence the strengths and limitations of the work and the possible improvements that could be made in the future.

5.1 Findings and recommendations

In this study, the following questions have been investigated:

- How can daylight, glare, users' preferences, and energy needs be hierarchized?
- How does the control strategy influence visual comfort and annual energy needs?
- Therefore, what is the optimal shading control strategy in a temperate climate to optimise office occupants' satisfaction, visual comfort, and building energy needs?

From the results obtained, we can answer as follows.

How can daylight, glare, users' preferences, and energy needs be hierarchized in the design of the control algorithm?

During working hours, visual comfort is considered the most crucial parameter. If DGI exceeds 22, shadings are activated to prevent discomfort glare. If comfort is guaranteed, then thermal loads are considered in order to optimise the office energy needs. Mainly during Summer, if solar radiation is high, shadings are activated to limit solar gains and hence reduce the cooling load. However, horizontal illuminance with the activated shading is evaluated to prevent the neutralisation of cooling needs reduction by an increase in lighting energy needs. If this latter is higher than 600lux, lighting is unnecessary, and shadings are activated.

Outside working hours, the main aim is to limit energy needs. Therefore, during Summer days, solar gains are blocked by the activation of shadings.

How does the control strategy influence visual comfort and annual energy needs?

Both in Liège and Milan, using solar shadings increases annual artificial lighting and heating energy need and reduces the cooling energy needs. Independently from the type of dynamic shading, if glare is included in the control strategy, the total annual energy needs increase compared to the BC. In this case, VB0 provide the best results, thanks to a lower increase in artificial lighting and heating energy needs. RB are the most effective in terms of cooling, thanks to their higher performance in reducing solar gains.

If glare evaluation is not included, the importance of the control of thermal loads can be more appreciated in Milan, where the cooling energy needs are higher.

In terms of visual comfort, considering DGI in the control algorithm allows to reduce glare discomfort hours. The most outstanding results are obtained for RB. VB0, instead, do not provide a good performance during Winter. An opposite trend is registered with horizontal illuminance. In this case, VB0 is the most effective solution, independently from glare evaluation in the control strategy. In fact, with both control algorithms, the total amount of discomfort hours is reduced compared to the BC. The worst situation instead is given by RB.

For all strategies with glare evaluation, the shading activation time is the same. However, with VB45, the user's satisfaction linked to the outside view is more limited. On the opposite, VB0 and RB allow the user to have a good view of the outside, guaranteeing greater satisfaction to the user.

What is the optimal shading control strategy in a temperate climate to optimise office occupants' satisfaction, visual comfort, and building energy needs?

Two control algorithms have been tested: one including glare evaluation, in addition to vertical irradiance, horizontal illuminance, occupancy, and indoor operative temperature, and one not considering glare.

In both locations, if glare is part of the control strategy, a significant improvement in visual comfort is registered for glare. However, we observe that VB0 are less effective during Winter compared to the other shading technologies.

Regarding light quantity, we register a reduction in the discomfort hours due to high illuminance levels with all strategies. However, only with VB0, we observe a reduction in the total discomfort hours compared to the BC.

Improving the user's visual comfort corresponds to an increase in the total annual energy needs compared to the BC. VB45 and RB provide an equivalent increase in the total annual energy needs. VB0 guarantees lower energy needs than the other shading solutions, thanks to a lower increase in artificial lighting and heating energy needs.

According to the results obtained, we can recommend the installation of solar shadings in offices built in a temperate climate. Despite the increase in energy needs, they guarantee a remarkable improvement in visual comfort for users close to windows.

5.2 Strength and Limitations

As anticipated in the chapter 1.1, the strength of this research is the application of a multi-criteria approach for developing the shading control strategy in a temperate climate. Differently from similar studies already carried out, as discussed in chapter 2.5, this control algorithm aims to optimise visual comfort, yearly heating, cooling and artificial lighting needs, and user satisfaction. These variables are also used to compare the two leading shading technologies installed in offices: VB and RB.

This study is also one of the first to apply the ISO/DIS 52016-3. Even if it is still under development, it has been possible to follow its directives regarding indicators to include in the control algorithm.

Moreover, as the control scenario for office buildings is still under development, this research's results can be used as a material of discussion for experts to develop the control algorithms for ISO/DIS 52016-3. In fact, the experts involved are implementing control scenarios according to results found in the literature.

On the other side, due to the limitations of the software used it has not been possible to apply the indications of the ISO/DIS 52016-3 totally. On DesignBuilder, glare discomfort can only be evaluated with DGI and not with vertical illuminance, as suggested by the Standard. Moreover, the slat angle of VB is fixed, differently from what was proposed by the Standard.

Finally, for the evaluation of glare and horizontal illuminance, the tools provided by EnergyPlus have been adopted.

5.3 Implications on practice and future work

In the short term, results shows the importance of installation of solar shadings in office buildings to guarantee user's comfort during working hours. The research provides a multi-criteria and user-centered control algorithm for solar shadings that could be reused and adapted in furthers studies on more complicated adaptive façades.

In the long term, the work:

- will contribute to the development of a new and cost-efficient solar shading
- will provide to façade designers new solutions that could contribute to deliver more efficient and comfortable office buildings
- will help to formulate recommendations to facility managers for the adoption of more user-accepted and people centric control strategies for dynamic solar shadings in offices
- will contribute to solve the European energy and climate crisis, providing a people-centric and smart solution for building renovation.

This research raised some points to be tackled in future research.

Firstly, this study is focused on a specific case study and climate zone. In order to generalise the results here discussed, it is suggested to make a similar study in other climate zones.

In addition, durability of the system has not been taken into account. It is suggested in the future to include this parameter in the study, being it a parameter that could influence the possibility to produce and industrialise this solution in large scale. In the same optics, it is suggested to perform a cost benefit analysis, so to have another criteria to choose the parameters it is worth to control and include in the control algorithm.

We can also remark that results are sensitive to the illuminance and glare evaluation in the room. Hence, it is suggested to use more accurate instruments to evaluate those parameters (e.g., Radiance).

Finally, to combine the complementary advantages of VB45 and VB0, we suggest carrying out a study on VB with a variable slat angle.

6 Conclusions

In this section, the conclusions of the research are driven. The research's reasons and context are recalled to remind the relevance of the work. Research questions are answered.

This work will be the terrain of further investigation for the hosting lab, myself, and the scientific community.

6.1 Drawing Conclusions

As described in chapter 2, most of the studies present in the literature are conducted in cold climates. They are focused on daylight performance, leaving in the background view of the outside, and user preferences (Al-Masrani & Al-Obaidi, 2019; Tabadkani, Roetzel, et al., 2020). In addition, most implemented control algorithms are designed to minimise or artificial lighting needs or heating and cooling energy needs. None investigated daylight, view, glare, lighting, and energy savings altogether (Tabadkani, Roetzel, et al., 2020), even if a compromise between human comfort and energy savings would be the best solution.

This is what has been done in this research: discomfort glare, light quantity, room occupancy, solar irradiance, and human preferences have been integrated into the control algorithm so to optimise the energy needs and the comfort and satisfaction of a worker in a single office in a temperate climate.

Two shading technologies have been compared: VB and RB. A control algorithm combining DGI, horizontal illuminance, room occupancy, indoor operative temperature and vertical solar irradiance on the window has been designed.

Despite the increased office energy needs, visual comfort was significantly increased.

Therefore, it has been concluded that installing solar shadings is also worthwhile in offices positioned in temperate climate areas.

6.2 Next steps and future research

The modelling and simulation work can be considered as concluded. The outcomes of this research will be the object of a paper that will be published in the following months.

New questions to be tackled in future works have been raised:

- How to generalise the results obtained for this specific case study and climate zone to develop a standard control algorithm?
- How is shading durability affected by the shading control algorithm?
- How could results change using a more sophisticated instrument to evaluate horizontal illuminance and glare?
- Could be a VB with a variable slat angle another good technology to be considered?
- Is the cost of shading compatible with the diffusion of such technology on a large scale?

7 References

Al-Masrani, S. M., & Al-Obaidi, K. M. (2019). Dynamic shading systems: A review of design parameters, platforms and evaluation strategies. *Automation in Construction*, *102*, 195–216. https://doi.org/10.1016/j.autcon.2019.01.014

Attia, S., Bilir, S., Safy, T., Struck, C., Loonen, R., & Goia, F. (2018). Current trends and future challenges in the performance assessment of adaptive façade systems. *Energy and Buildings*, *179*, 165–182. https://doi.org/10.1016/j.enbuild.2018.09.017

Choi, S.-J., Lee, D.-S., & Jo, J.-H. (2017). Lighting and cooling energy assessment of multi-purpose control strategies for external movable shading devices by using shaded fraction. *Energy and Buildings*, *150*, 328–338. https://doi.org/10.1016/j.enbuild.2017.06.030

Day, J. K., Futrell, B., Cox, R., Ruiz, S. N., Amirazar, A., Zarrabi, A. H., & Azarbayjani, M. (2019). Blinded by the light: Occupant perceptions and visual comfort assessments of three dynamic daylight control systems and shading strategies. *Building and Environment*, *154*, 107–121. https://doi.org/10.1016/j.buildenv.2019.02.037

Karlsen, L., Heiselberg, P., Bryn, I., & Johra, H. (2016). Solar shading control strategy for office buildings in cold climate. *Energy and Buildings*, *118*, 316–328. https://doi.org/10.1016/j.enbuild.2016.03.014

Kwon, M., Remøy, H., van den Dobbelsteen, A., & Knaack, U. (2019). Personal control and environmental user satisfaction in office buildings: Results of case studies in the Netherlands. *Building and Environment*, *149*, 428–435. https://doi.org/10.1016/j.buildenv.2018.12.021

Light and lighting. Lighting of work places. Part 1 Indoor work places. (2021). British Standards Institution.

Luna-Navarro, A., Loonen, R., Juaristi, M., Monge-Barrio, A., Attia, S., & Overend, M. (2020). Occupant-Facade interaction: A review and classification scheme. *Building and Environment*, *177*, 106880. https://doi.org/10.1016/j.buildenv.2020.106880

Nabil, A., & Mardaljevic, J. (2006). Useful daylight illuminances: A replacement for daylight factors. *Energy and Buildings*, *38*(7), 905–913. https://doi.org/10.1016/j.enbuild.2006.03.013

Peel, M. C., Finlayson, B. L., & McMahon, T. A. (2007). Updated world map of the Ko¨ppen-Geiger climate classification. *Hydrol. Earth Syst. Sci.*

Piccolo, A., & Simone, F. (2009). Effect of switchable glazing on discomfort glare from windows. *Building and Environment*, 10.

Tabadkani, A., Roetzel, A., Li, H. X., & Tsangrassoulis, A. (2020). A review of automatic control strategies based on simulations for adaptive facades. *Building and Environment*, *175*, 106801. https://doi.org/10.1016/j.buildenv.2020.106801

Tabadkani, A., Tsangrassoulis, A., Roetzel, A., & Li, H. X. (2020). Innovative control approaches to assess energy implications of adaptive facades based on simulation using EnergyPlus. *Solar Energy*, *206*, 256–268. https://doi.org/10.1016/j.solener.2020.05.087

Thalfeldt, M., & Kurnitski, J. (2015). External shading optimal control macros for 1- and 2-piece automated blinds in European climates. *Building Simulation*, *8*(1), 13–25. https://doi.org/10.1007/s12273-014-0194-3

Xiong, J., Tzempelikos, A., Bilionis, I., & Karava, P. (2019). A personalized daylighting control approach to dynamically optimize visual satisfaction and lighting energy use. *Energy and Buildings*, *193*, 111–126. https://doi.org/10.1016/j.enbuild.2019.03.046

Annex 1: Organisational chart

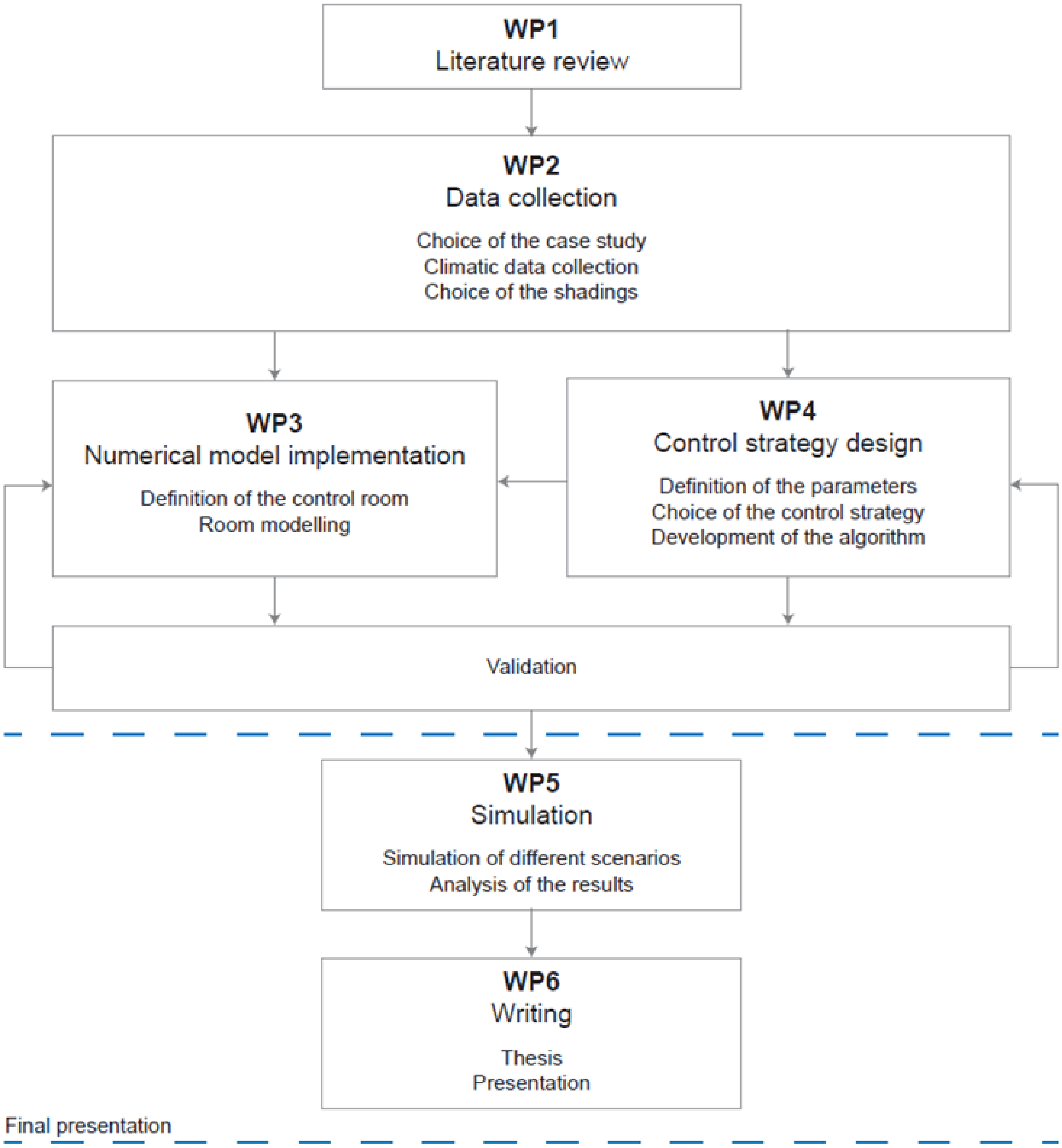


Figure A.0.1 Organisational chart

Annex 2: Literature Review Matrix

Aurora Bertini, 2022

Universite de Liege, Faculty of Applied Sciences, Belgium
Sustainable Buildings Design Lab (SBD)

RESOURCES SCREENING LIST

No.	Source	Link	Address
1	Google Scholar	https://scholar.google.be/	-
2	Web of Science	https://www.webofscience.com/wos/woscc/basic-search	-
3	IEEE Xplore	https://ieeexplore.ieee.org/Xplore/home.jsp	-

Aurora Bertini, 2022

Universite de Liege, Faculty of Applied Sciences, Belgium
Sustainable Buildings Design Lab (SBD)

LITERATURE SURVEY LIST

No.	Publication	Citations	Observation
0	**"External shading", office, control**	-	-
1	Thalfeldt, M., & Kurnitski, J. (2015, February). External shading optimal control macros for 1-and 2-piece automated blinds in European climates. In *Building Simulation* (Vol. 8, No. 1, pp. 13-25). Tsinghua University Press.	6	2015
2	Choi, S. J., Lee, D. S., & Jo, J. H. (2017). Lighting and cooling energy assessment of multi-purpose control strategies for external movable shading devices by using shaded fraction. *Energy and Buildings*, *160*, 328-338.	28	2017
3	Tabadkani, A., Tsangrassoulis, A., Roetzel, A., & Li, H. X. (2020). Innovative control approaches to assess energy implications of adaptive facades based on simulation using EnergyPlus. *Solar energy*, *206*, 256-268.	14	2020
4	Freewan, A. A., & Shqra, L. W. (2017). Analysis of energy and daylight performance of adjustable shading devices in region with hot summer and cold winter. *Advances in Energy Research*, *5* (4), 289.	5	2017
5	Lee, B. (2019). Heating, Cooling, and Lighting Energy Demand Simulation Analysis of Kinetic Shading Devices with Automatic Dimming Control for Asian Countries. *Sustainability*, *11* (5), 1253. https://doi.org/10.3390/su11051253	5	2019
0	**"kinetic shading", office, control, occupant**	-	-
6	Lee, D., Cho, Y. H., & Jo, J. H. (2021). Assessment of control strategy of adaptive facades for heating, cooling, lighting energy conservation and glare prevention. *Energy and Buildings*, *236*, 110739.	3	2021
7	Samadi, S., Noorzai, E., Beltrán, L. O., & Abbasi, S. (2020). A computational approach for achieving optimum daylight inside buildings through automated kinetic shading systems. *Frontiers of Architectural Research*, *9* (2), 335-349.	29	2020
8	Hosseini, S. M., Mohammadi, M., Rosemann, A., Schröder, T., & Lichtenberg, J. (2019). A morphological approach for kinetic façade design process to improve visual and thermal comfort. *Building and Environment*, *153*, 186-204.	69	2018
0	**Shading control strategies user problems**		
9	Luna-Navarro, A., Loonen, R., Juaristi, M., Monge-Barrio, A., Attia, S., & Overend, M. (2020). Occupant-Facade interaction: a review and classification scheme. *Building and Environment*, *177*, 106880.	32	2020
10	Al-Masrani, S. M., & Al-Obaidi, K. M. (2019). Dynamic shading systems: A review of design parameters, platforms and evaluation strategies. *Automation in construction*, *102*, 195-216.	45	2019
11	Xiong, J., Tzempelikos, A., Bilionis, I., & Karava, P. (2019). A personalized daylighting control approach to dynamically optimize visual satisfaction and lighting energy use. *Energy and Buildings*, *193*, 111-126.	28	2019

12	Day, J. K., Futrell, B., Cox, R., Ruiz, S. N., Amirazar, A., Zarrabi, A. H., & Azarbayjani, M. (2019). Blinded by the light: Occupant perceptions and visual comfort assessments of three dynamic daylight control systems and shading strategies. *Building and Environment*, *154*, 107-121.	51	2019
13	Attia, S., Bilir, S., Safy, T., Struck, C., Loonen, R., & Goia, F. (2018). Current trends and future challenges in the performance assessment of adaptive façade systems. *Energy and Buildings*, *179*, 165-182.	90	2018
14	Kwon, M., Remøy, H., van den Dobbelsteen, A., & Knaack, U. (2019). Personal control and environmental user satisfaction in office buildings: Results of case studies in the Netherlands. *Building and Environment*, *149*, 428-435.	55	2019
15	Tabadkani, A., Roetzel, A., Li, H. X., Tsangrassoulis, A., & Attia, S. (2021). Analysis of the impact of automatic shading control scenarios on occupant's comfort and energy load. *Applied energy*, *294*, 116904.	6	2021
16	Grobman, Y. J., Austern, G., Hatiel, Y., & Capeluto, I. G. (2020). Evaluating the Influence of Varied External Shading Elements on Internal Daylight Illuminances. *Buildings*, *10*(2), 22.	3	2020
17	Valitabar, M., Mahdavinejad, M., Skates, H., & Pilechiha, P. (2021). A dynamic vertical shading optimisation to improve view, visual comfort and operational energy. *Open House International*.	8	2021
18	Shi, X., Abel, T., & Wang, L. (2020). Influence of two motion types on solar transmittance and daylight performance of dynamic façades. *Solar Energy*, *201*, 561-580.	15	2020
19	Al-Masrani, S. M., Al-Obaidi, K. M., Zalin, N. A., & Isma, M. A. (2018). Design optimisation of solar shading systems for tropical office buildings: Challenges and future trends. *Solar Energy*, *170*, 849-872.	76	2018
20	Nicoletti, F., Carpino, C., Cucumo, M. A., & Arcuri, N. (2020). The Control of Venetian Blinds: A Solution for Reduction of Energy Consumption Preserving Visual Comfort. *Energies*, *13*(7), 1731.	10	2020
21	Mangkuto, R. A., Koerniawan, M. D., Apriliyanthi, S. R., Lubis, I. H., Hensen, J. L., & Paramita, B. (2021). Design Optimisation of Fixed and Adaptive Shading Devices on Four Façade Orientations of a High-Rise Office Building in the Tropics. *Buildings*, *12*(1), 25.	1	2021
22	Charpentier, V., Meggers, F., Adriaenssens, S., & Baverel, O. (2020). Occupant-centered optimization framework to evaluate and design new dynamic shading typologies. *PloS one*, *15*(4), e0231554.	1	2020
23	Queiroz, N., Westphal, F. S., & Pereira, F. O. R. (2020). A performance-based design validation study on EnergyPlus for daylighting analysis. *Building and Environment*, *183*, 107088.	12	2020
24	Li, S., Liu, L., & Peng, C. (2020). A review of performance-oriented architectural design and optimization in the context of sustainability: Dividends and challenges. *Sustainability*, *12*(4), 1427.	25	2020
25	Taveres-Cachat, E., Grynning, S., Thomsen, J., & Selkowitz, S. (2019). Responsive building envelope concepts in zero emission neighborhoods and smart cities-A roadmap to implementation. *Building and Environment*, *149*, 446-457.	46	2019
26	Koohsari, A. M., & Heidari, S. (2022). Subdivided venetian blind control strategies considering visual satisfaction of occupants, daylight metrics, and energy analyses. *Energy and Buildings*, *257*, 111767.	0	2022
27	Sun, Z., Cao, Y., Wang, X., & Yu, J. (2021). Multi-objective optimization design for windows and shading configuration: considering energy consumption, thermal environment, visual performance and sound insulation effect. *International Journal of Energy and Environmental Engineering*, *12*(4), 805-836.	2	2021
28	Phuong, N. T. K., & Solovyev, A. K. (2020). Assessment of building daylight systems considering sunscreens under real conditions of the sky. *Vestnik MGSU*, *2*, 180-200.	1	2020
29	Koç, S. G., & Kalfa, S. M. (2021). The effects of shading devices on office building energy performance in Mediterranean climate regions. *Journal of Building Engineering*, *44*, 102653.	4	2021

30	Heidari Matin, N., & Eydgahi, A. (2020). Factors affecting the design and development of responsive facades: a historical evolution. *Intelligent buildings International*, *12* (4), 257-270.	9	2020
31	O'Donovan, A., Murphy, M. D., & O'Sullivan, P. D. (2021). Passive control strategies for cooling a non-residential nearly zero energy office: Simulated comfort resilience now and in the future. *Energy and Buildings*, *231*, 110607.	15	2021
32	Fallahi, Z., & Henze, G. P. (2019). Interactive buildings: A review. *Sustainability*, *11* (14), 3988.	18	2019
33	Moghtadernejad, S., Chouinard, L. E., & Mirza, M. S. (2020). Design strategies using multi-criteria decision-making tools to enhance the performance of building façades. *Journal of Building Engineering*, *30*, 101274.	23	2020

34	Karlsen, L., Heiselberg, P., Bryn, I., & Johra, H. (2016). Solar shading control strategy for office buildings in cold climate. *Energy and buildings*, *118*, 316-328.	70	2016
35	Tabadkani, A., Roetzel, A., Li, H. X., & Tsangrassoulis, A. (2020). A review of automatic control strategies based on simulations for adaptive facades. *Building and Environment*, *175*, 106801.	34	2020
36	Beck, W., Dolmans, D., Dutoo, G., Hall, A., & Seppanen, O. (2010). Solar Shading: How to Integrate Solar Shading in Sustainable Buildings, REHVA Guidebook 12.	3	2010
37	International Organization for Standardization. (2022). Energy performance of buildings – Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads – Part 3: Calculation procedures regarding adaptive building envelope elements (ISO/DIS 52016-3:2022).		2022

Aurora Bertini, 2022

Universite de Liege, Faculty of Applied Sciences, Belgium
Sustainable Buildings Design Lab (SBD)

LITERATURE REVIEW MATRIX

No.	REFERENCE	STUDY PARAMETERS	FOCUS	GAP	FINDINGS
1	Thalfeldt, M., & Kurnitski, J. (2015, February). External shading optimal control macros for 1-and 2-piece automated blinds in European climates. In Building Simulation (Vol. 8, No. 1, pp. 13-25). Tsinghua University Press.	Choice of the control strategy mainly according to energy use, but also duration of unobstracted view and simplicity of the system Effect of shadings on sizing of cooling units Effects of shadings on energy demand according to the variation of the glazed surface, g-value, number of panes, insulation thickness Difference between 1- and 2-piece blinds	Optimal control principle for external shadings in Tallin, Paris and Athens Minimsation of the energy demand	Focus on the best strategy to minimise the energy consumption, without considering the users' comfort In the control strategy, shadings can be drawn in the case of high temperatures, if there is no need of artificial light It does not consider the angle to determine if the view to the outside is possible or not	External blinds are more energy-effective with respect to internal blinds In cold climates: external blinds are more effective with larger glazing areas and higher g-values; 2-piece blinds slightly increase the energy use; high illuminance is the main cause for the use of shadings In warm climates: high temperatures are the main cause of use of shadings Total irradiance on façades is not sufficient to implement an effective control strategy Shading control based on indoor conditions is the most energy-effective PI controllers are more energy-efficient than slat angle control, but is more expensive
9	Luna-Navarro, A., Loonen, R., Juaristi, M., Monge-Barrio, A., Attia, S., & Overend, M. (2020). Occupant-Facade interaction: a review and classification scheme. Building and Environment, 177, 106880.	Occupant-façade interaction Types of interactions Disciplines involved in the design of an interaction strategy	Multi-disciplinary approach on occupant-façade interaction Classification of the types of interactions Indications about the design of a good interaction strategy for users satisfaction	Recommandations to effectively manage the interfaces among different disciplines Effects of types of interaction on energy efficiency	No general and universal design solutions for satisfactory interaction strategies Holistic effects of interactive scenarios on user's satisfaction is still missing Interfaces are fundamental to ensure occupants' satisfaction Interactive strategies have to deal with ethics and privacy
2	Choi, S. J., Lee, D. S., & Jo, J. H. (2017). Lighting and cooling energy assessment of multi-purpose control strategies for external movable shading devices by using shaded fraction. Energy and Buildings, 150, 328-338.	Energy conservation, illuminance satisfaction, glare protection Shaded fraction to combine solar and physical characteristics of the shading Profile angle to prevent glare	Algorithm for external shadings Balance between energy and visual comfort Algorithm designed so to be applied to different shapes of shadings Different time periods in summer to verify the performance of the strategy Real-scale mock-up test	Energy savings is always the first criteria to control the movement. This is true in the short-term, but different choices could be compensated on a longer term User preference is considered in term of choice of the control strategy, but at the end energy savings prevail in each control strategy It is not clear how to control the switch between the three control modes The control does not consider user's preferences: some glare could be accepted in order to have a better view to the outside, considering also the results of the study	When the amount of solar radiation is high, shadings mostly remain in a fully closed state Shading material must be considered in the design of the control strategy

3	Tabadkani, A., Tsangrassoulis, A., Roetzel, A., & Li, H. X. (2020). Innovative control approaches to assess energy implications of adaptive facades based on simulation using EnergyPlus. Solar energy, 206, 256-268.	Shading modelling on EnergyPlus Control strategy for non-conventional shadings (due to the limitations of the software, simulations are done with conventional shadings)	Pros and cons of the parameters used in control strategy design in EnergyPlus Limitations of EnergyPlus modelling How to overcome those limitations Parameters at the basis of EnergyPlus calculations	The methodology cannot be applied if the control strattegy includes also thermal comfort (thermal comfort = continuous; visual comfort = discrete) Shade factor control strategy applicable only with opaque shadings	When the weather is rainy, the external surface is considered wet and the convection coefficient is very high (1000) The convection factor is higher for venetian blinds than for roller blades
13	Attia, S., Bilir, S., Safy, T., Struck, C., Loonen, R., & Goia, F. (2018). Current trends and future challenges in the performance assessment of adaptive façade systems. Energy and Buildings, 179, 165-182.	Current trends of adaptive façades Performance assessment of adaptive façades Literature review	Gaps in performance assessment Future challenges Object-based façade characterisation and classification	No consideration of the economic aspects	Lack of an assessment of the façade interaction with building services and occupant personal control Literature is focused on single performance parameters of façade, mainly during the design phase and using simulations or lab measurements. No consideration of the performance in the post-construction phase Soft-landing process for AF: control and program the façade actions depending on the occupants' needs Undermining of façade users. AF should cater for occupant comfort and wellbeing. Also important for the penetration and market uptake of AF Definition of KPIs (importance of considering users in AF design)
12	Day, J. K., Futrell, B., Cox, R., Ruiz, S. N., Amirazar, A., Zarrabi, A. H., & Azarbayjani, M. (2019). Blinded by the light: Occupant perceptions and visual comfort assessments of three dynamic daylight control systems and shading strategies. Building and Environment, 154, 107-121.	Occupant perception Visual comfort Productivity Workplace satisfaction	Subjective visual comfort perception How daylight performance and automation affect the user experience Benefits of daylighting control Automation vs autonomy Relationship daylight-productivity	No consideration of thermal comfort and energy efficiency How to maximise views and benefits from daylighting while maintaining occupant control and building energy performance	Higher access to daylight –> higher perceived level of productivity, higher satisfaction With venetian blinds, occupants closer to the perimeter are more satisfied than the occupants further from windows. The opposite for fabric shadings Statistically significant but weak relationship between perceived productivity and ability to alter electric light With venetian blinds, occupants closer to the perimeter are more satisfied in terms of daylight acces than the occupants further from windows. Strong impact of access to daylight on satisfaction Strong interest of users in having a greater control Where occupants can control shadings, a higher productivity is percieved when there is access to daylight and the ability to control the lighting conditions (natural and electric)

					buildings should be designed with occupants in mind (and not solely for energy efficiency); it is crucial that designers understand daylighting strategies, shading, and corresponding human perceptions of comfort. Main complaints: shading automation, glare, cold temperature
14	Kwon, M., Remoy, H., van den Dobbelsteen, A., & Knaack, U. (2019). Personal control and environmental user satisfaction in office buildings: Results of case studies in the Netherlands. Building and Environment, 149, 428-435.	Visual comfort Thermal comfort Occupant's satisfaction	Relationship personal control on indoor enviromental conditions and user satisfaction with thermal and visual comfort Psychological impact of personal control Actual use of person control Office buildings in Netherlands Analysis in different seasons	Thermal comfort is related to building services control but not to shading systems No consideration of energy use No monitoring of indoor temperature before and after occupant's control of heating, cooling, ventilation and sunshading	Higher controllability leads to more thermal and visual satisfaction Personal control of ventilation is the most significant factor influencing the thermal satisfaction Heating control is strongly related to users' satisfaction in mid-season and winter. In summer this is for cooling Controllability of sunshades is important for the overall visual comfort Significant correlation between lighting control and daylight satisfaction Occupants working without control of sunshading and lighting were the least satisfied with light quality and view to the outside. Complete control = the most satisfied --> occupants should have control over the office environment
11	Xiong, J., Tzempelikos, A., Bilionis, I., & Karava, P. (2019). A personalized daylighting control approach to dynamically optimize visual satisfaction and lighting energy use. Energy and Buildings, 193, 111-126.	Preference profiles Occupant sensitivity Exterior conditions Daylight control	Multi-objective optimisation where satisfaction utility and predicted lighting energy consumption are used in parallel Single-objective optimisation where satisfaction utility is converted into a constraint when minimising lighting energy Personalised shading control to minimise lighting demand and maximise occupant's satisfaction	Extension of the method to thermal preferences Difficult to be implemented	According to the sensibility of occupants, it is possible to admit more or less daylight and, then, to reduce more or less the lighting energy demand Different preference profiles lead to different Pareto optimal patterns under various weather conditions during the year
		Architectural, mechanical (=kinetics), operational (=power to run the system) and automation components Sun position Peak temperature and humidity Natural light Sky model	Potentials and limitations of dynamic shading systems (DSS) Design elements and platforms for DSS Strategies to examine system performance Literature review	Cost, maintenance and installation are not considered	The majority of literature adopted computer simulations as main tool Simulations are time-saving and effective, but can be inaccurate in terms of daylight. Emperical validation is suggested, but on the long-term Arduino and parametric software tools found to be promising Literature is mostly focused on offices Kinetic applications are mostly evaluated based on daylight performance. Thermal performance consideration is limited. Energy generation, ventilation and view are rarely addressed

10	day, J. K., Futrell, B., Cox, R., Ruiz, S. N., Amirazar, A., Zarrabi, A. H., & Azarbayjani, M. (2019). Blinded by the light: Occupant perceptions and visual comfort assessments of three dynamic daylight control systems and shading strategies. Building and				All dynamic systems and proposed control strategies improve daylight performance and visual comfort In cold and temperate climates, in offices shadings have a negative impact on heating demand, because visual comfort is the primary factor throughout the year Incorporating lighting control, sharing data about HVAC and occupancy remarkably improve the overall performance of different systems and help bridging gaps of dynamic shadings Dynamic shading is not an ideal solution for passive heating in offices in cold and moderate climates, but is useful to improve visual condition, reduce overheating in summer and the annual energy demand Few studies employed a multivariable control strategy, triggered by two setpoints through a hybrid control strategy defined by values of continuous variables and discrete mode Dynamic shadings are considered as a technological trend rather than an architectural element that has been frequently neglected Automation and control aspects must be considered at the early stages of the design The overall energy can serve as a key indicator to assess the shading performance, but attention should be given to daylight efficiency in functional spaces, like offices. Multicriteria methodology is needed to successfully design shadings. It should consider a hierarchy amongst multiple factors (e.g., indoor space activity, climatic zone and user requirements)
34	Karlsen, L., Heiselberg, P., Bryn, I., & Johra, H. (2016). Solar shading control strategy for office buildings in cold climate. Energy and buildings, 118, 316-328.	Glare Daylight sufficiency View Energy savings Overheating	Internal+external shadings Energy use and indoor environmental performance Full-scale experiment Simulations During working hours, avoid glare and overheating, while ensuring satisfactory daylight and view Outside working hours, energy savings	User interaction is not considered	The benefit of the combination internal-external shading is more evident in heating-dominated climates The combination visual-thermal comfort with internal-external shadings or only external shadings are the best compromise between energy use and indoor environment: lowest energy demand, thermal comfort, daylight sufficiency The slat angle is less than 45° during significant part of the time: view to the outside For moderate cold climates, only external shadings are preferred in terms of cost User should have the opportunity to overrule the automatic glare control

35	Tabadkani, A., Roetzel, A., Li, H. X., & Tsangrassoulis, A. (2020). A review of automatic control strategies based on simulations for adaptive facades. Building and Environment, 175, 106801.	Automatic control strategies	Literature review	No clear definition of results according to the climatic conditions	Existing studies only investigate automatic shading controls for typical AF (roller shades or venetian blinds), that cannot deliver multi-objective control over different human comfort perspectives and energy consumption simultaneously
				How user preferences are considered in the control strategies in existing studies	Higher priority to daylihgting and glare as main control inputs for shadings
					Lack of comprehensive review of automatic controls including visual and thermal comfort + energy savings
					The most common type of open-loop control is the cut-off angle, but it is not sufficient to control glare. Therefore, several studies integrated other strategies like glare control or occupant's information
					Controlling the thermal environment usually is based on global irradiance and temperature
					Different controls according to occupancy schedule in some studies
					Model based controller balanced better daylight and glare, reduces energy demand up to 10%, but not in terms of window occlusion height. View to the outside remains a complex metrics to satisfy
					Experimental results showed open and closed loop control improve both energy savings. Open loop guarantees more daylight, closed loop glare-free environment.
					Most of literature on automatic control is focused on daylight to reduce or electrical demand or heating/cooling
					A compromise human comfort-energy savings is the best solution, but few studies focus on thermal comfort and none investigate thermal comfort, daylight, view, glare, lighting/energy savings altogether
					There is no standard room for conducting simulations
					Only one study proposed a methodology to reduce the number of shading movements
					Cold climate is the mostly investigated
					None of the studies adopting a closed-loop control considered user preferences as an input. Two studies proved the potential of adding user prefence factors into open-loop control
					Occupant's preference is the most important factor to determine the level of automatic control efficiency
					Several studies confirm that occupants can endure short periods of glare discomfort if view is available

					View is neglected in 2/3 of studies due to its quantification difficulties An integrated automatic control to cover human comfort objectives and energy altogether is needed Studies remark that the limitations of automatic shadings are: they are more accepted if users can overrule it; users are satisfied if automatic control satisfies their preferences. Therefore, there is a need to make control strategies based on user demands and preferences
36	Beck, W., Dolmans, D., Dutoo, G., Hall, A., & Seppanen, O. (2010). Solar Shading: How to Integrate Solar Shading in Sustainable Buildings, REHVA Guidebook 12.	Solar shading integration	Choice of solar shadings Energy effects of solar shadings Solar shading integration Maintenance of solar shadings Standards for shutters and blinds		The choice of the type of shading depends on multiple factors: climate, orientation of the building, prevailing wind conditions, height of the building, character of the building, regional preferences, building's construction details, user's expectation and behaviour.
37	International Organization for Standardization. (2022). Energy performance of buildings – Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads – Part 3: Calculation procedures regarding adaptive building envelope elements (ISO/DIS 52016-3:2022).	Energy needs for heating and cooling Internal temperatures Sensible and latent heat loads	Calculation procedures Adaptive building envelope elements	Simplified approach for the user's behaviour model	Identification of input data Distinction between simplified and detailed adaptive building element modelling Definition of control types, scenarios and conditions Definition of sensors Modelling of the user behaviour Post-processing outputs
	Norouziasas, A., Rahif, R., Tabadkani, A., Van Dijk, D., & Attia, S. (). Implementation and sensitivity analysis of ISO 52016-3 for adaptive façades: A case study of office buildings.	Multi-objective optimisation Heating, cooling, lighting, internal air temperature	Simplified approach multi-objective optimisation: Multi-Objective Parametric Analysis (MOPA) Reccomendations to select an automated control strategy in the office building Assessment of the most effective control strategy on heating, cooling, lighting loads using a global sensitivity analysis Application of ISO 52016-3	No occupant interaction Interconnection of multiple softwares	There is no standardised way to assess control strategies for adaptive façades, and mostly for dynamic shadings Roller blinds are better than venetian blinds in decreasing the energy consumption Simple fixed shading perform better than automated venetian blinds in some cases. In this case, cooling consumtion is 10,62% higher comparing with fixed shadings The lowest mean temperature value was with roller blinds, the highest without shadings Recommendation to select roller blinds or venetian blinds to reduce energy consumption in oceanic temperate climates Automatic control to avoid dissipating operative temperature inside the office room

Annex 3: Plans, Elevations and Sections of the building

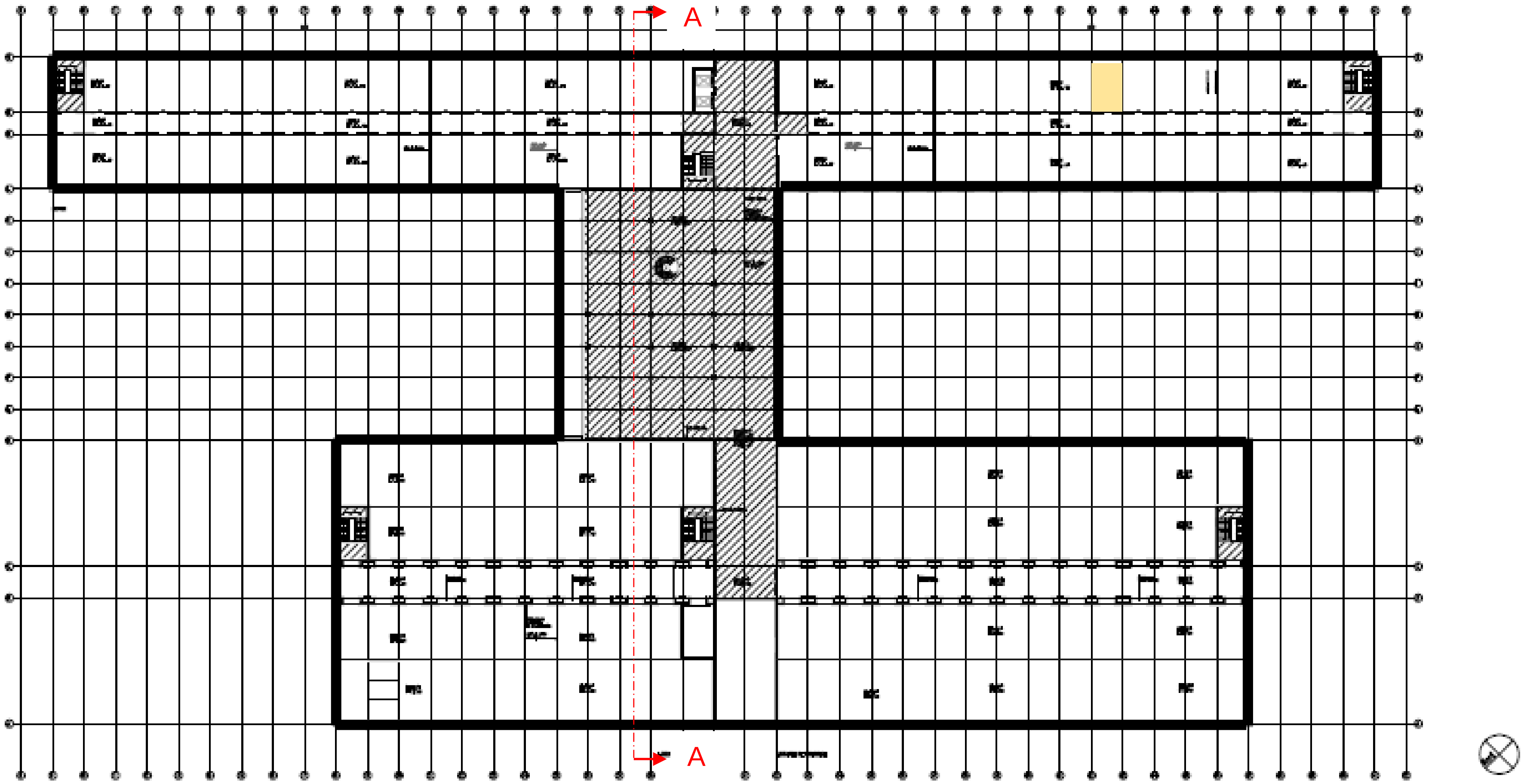


Figure A.3.1 Plan of the building B52 - Level 0

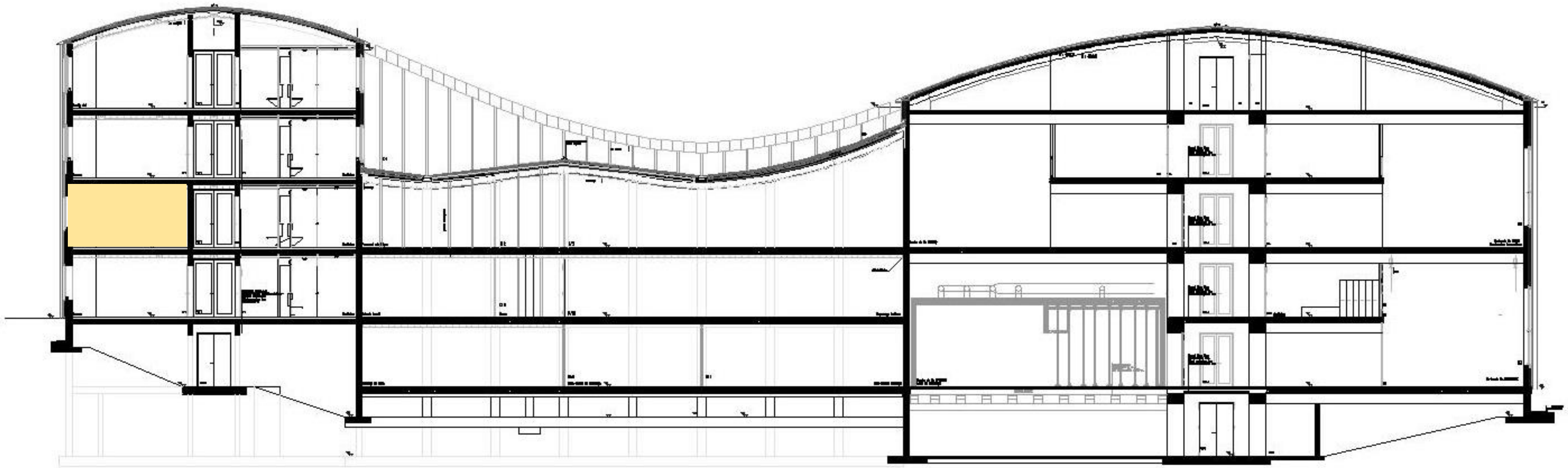


Figure A.3.2 Section A-A

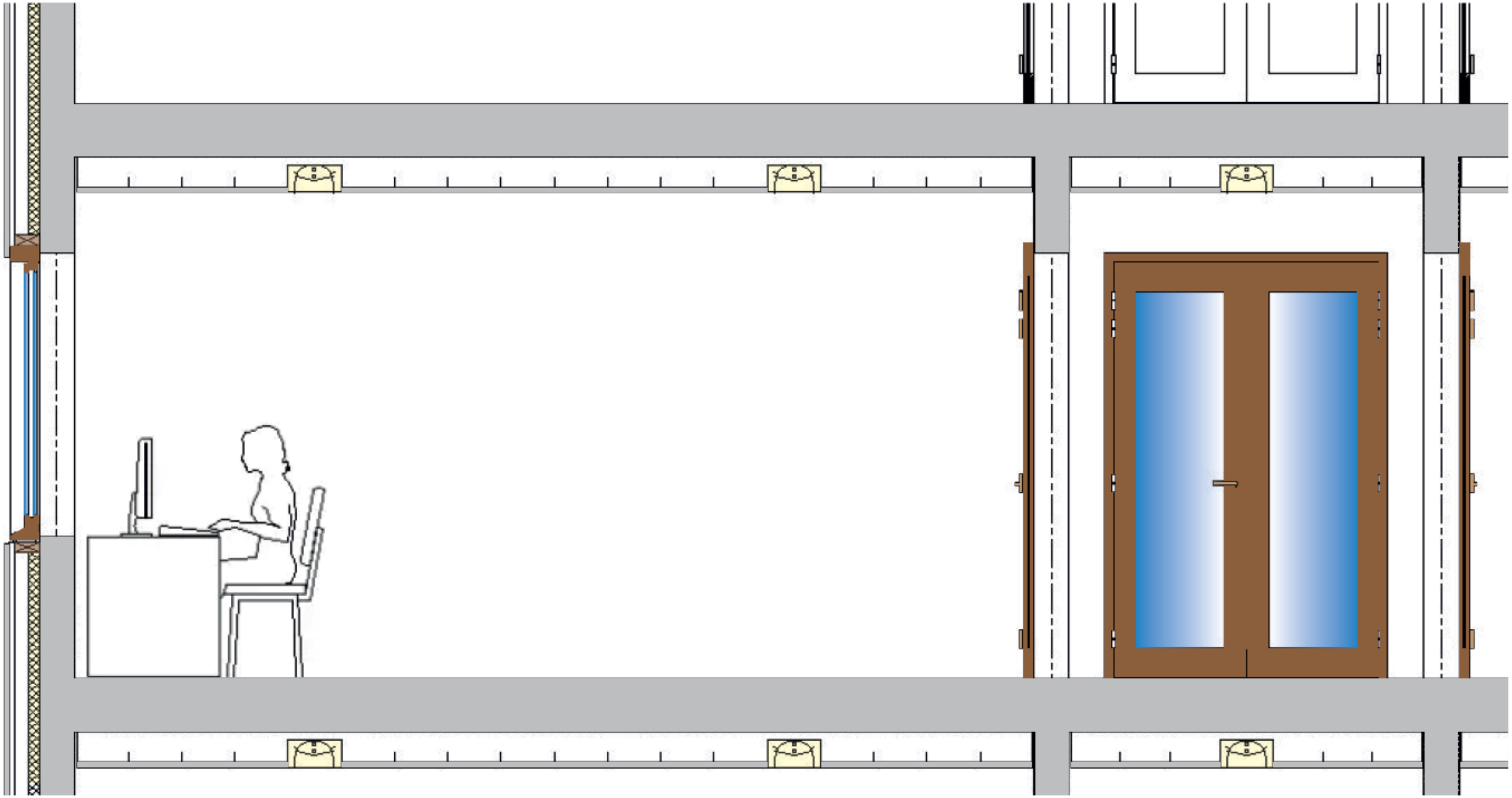


Figure A. 1.3 Section of the office

Annex 4: Climatic analysis of the site – Liège (Belgium)

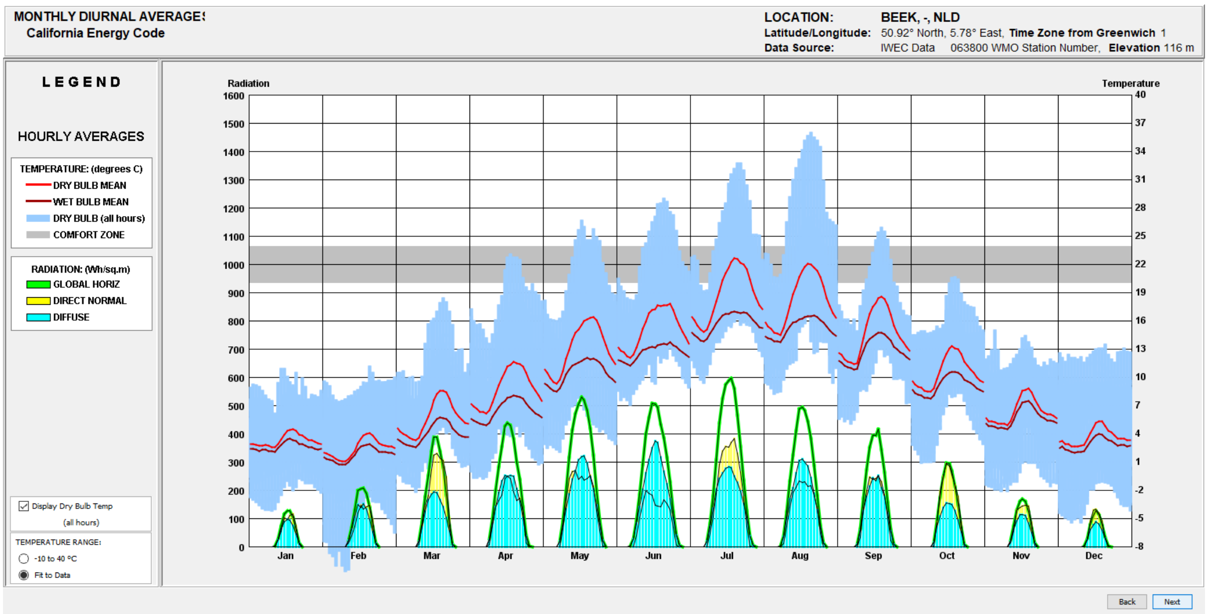


Figure A.4.1 Yearly progression of external air temperature and of solar radiation

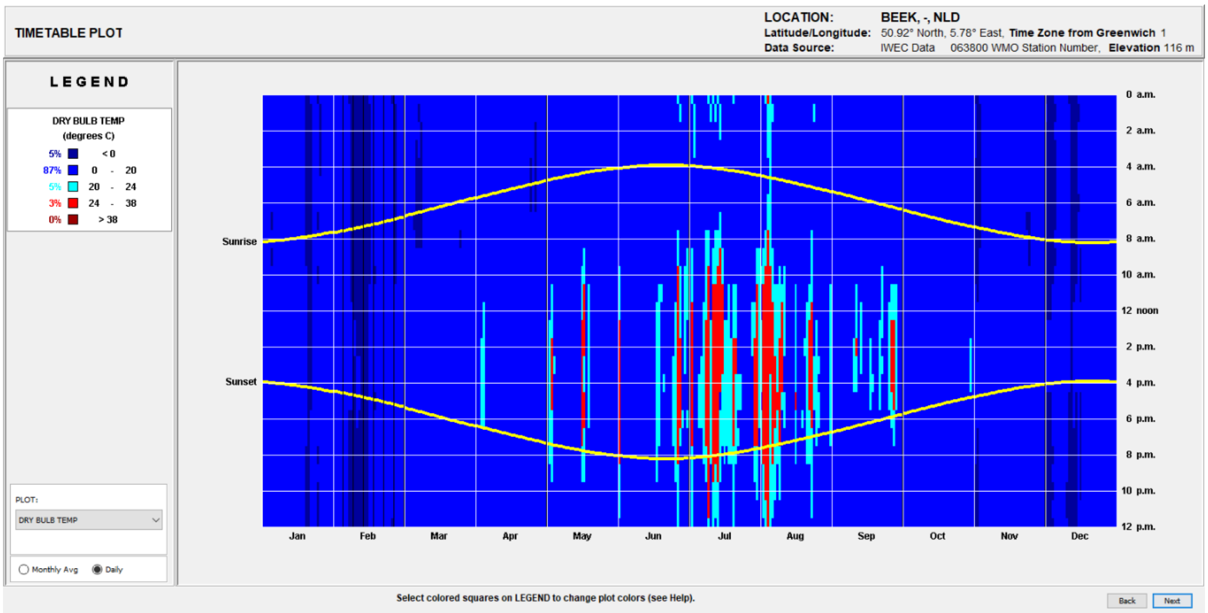


Figure A.4.2 Yearly and hourly progression of dry bulb external air temperature

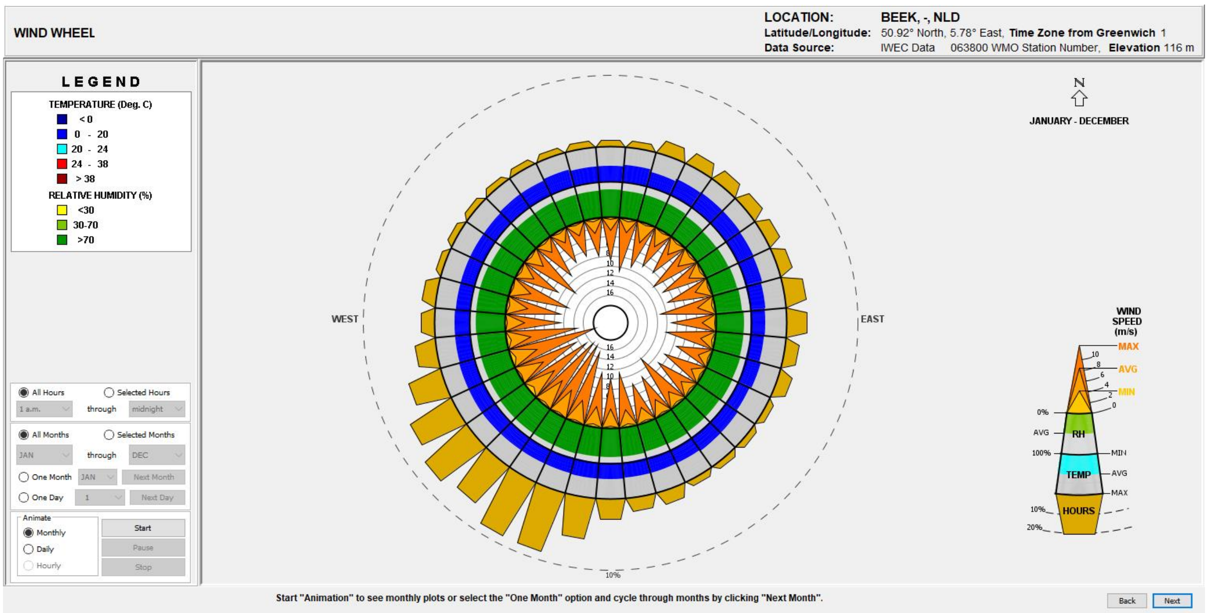


Figure A.4.3 Wind wheel with the representation of the yearly cumulative number of hours per each wind direction

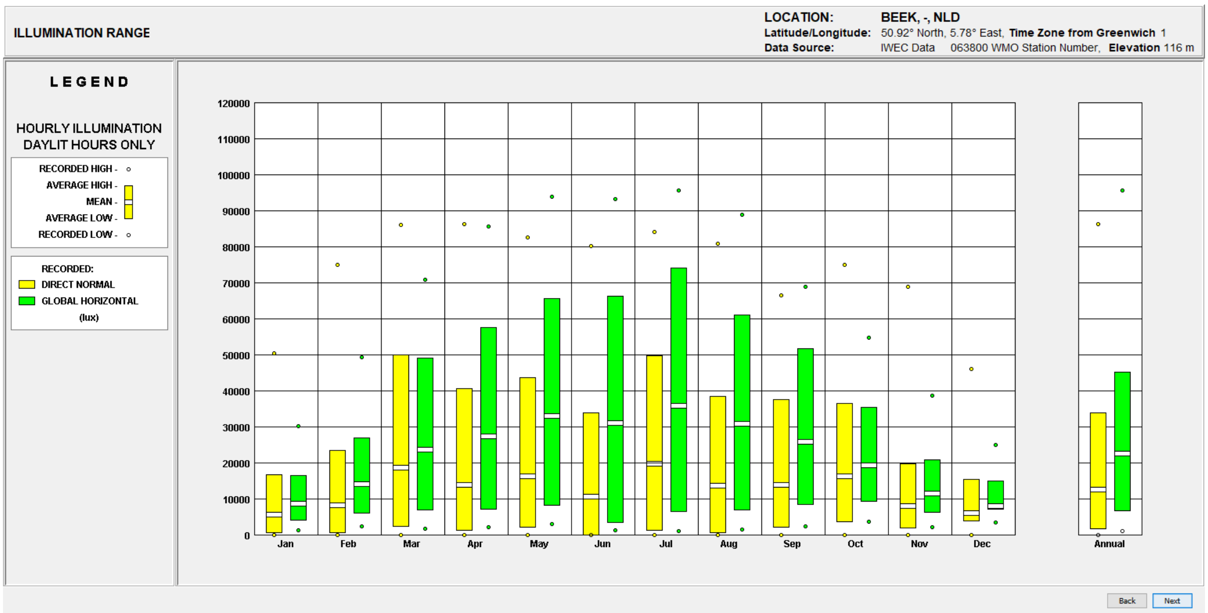


Figure A.4.4 Illuminance progression

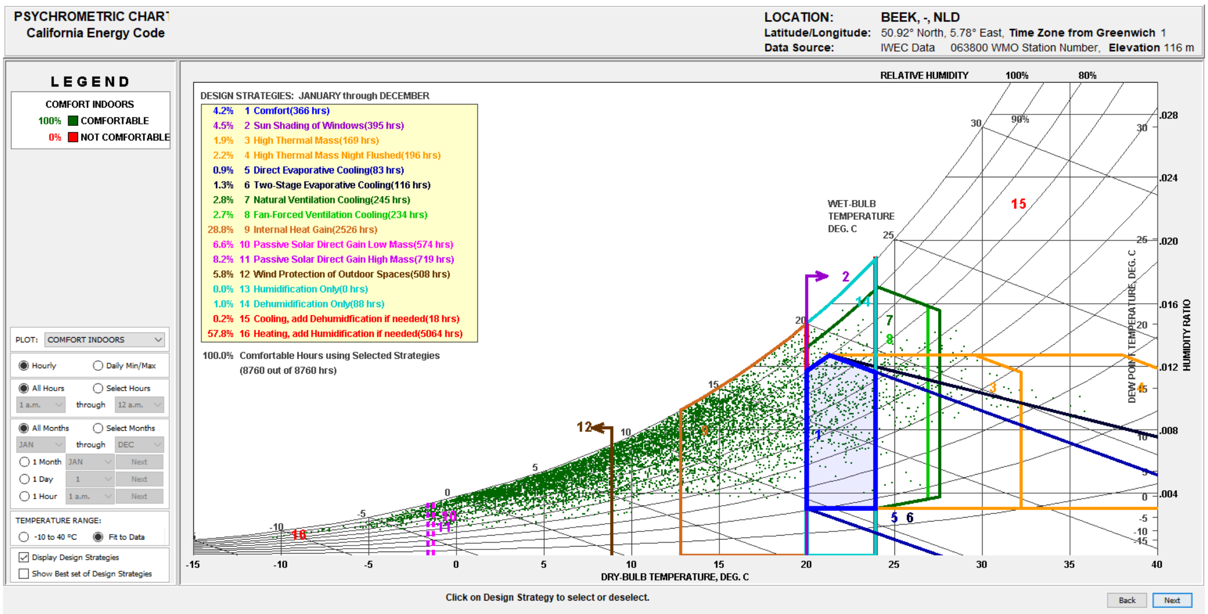


Figure A.4.5 Givoni diagram with the most effective strategies to guarantee indoor thermal comfort

Annex 5: Climatic analysis of the site – Milan (Italy)

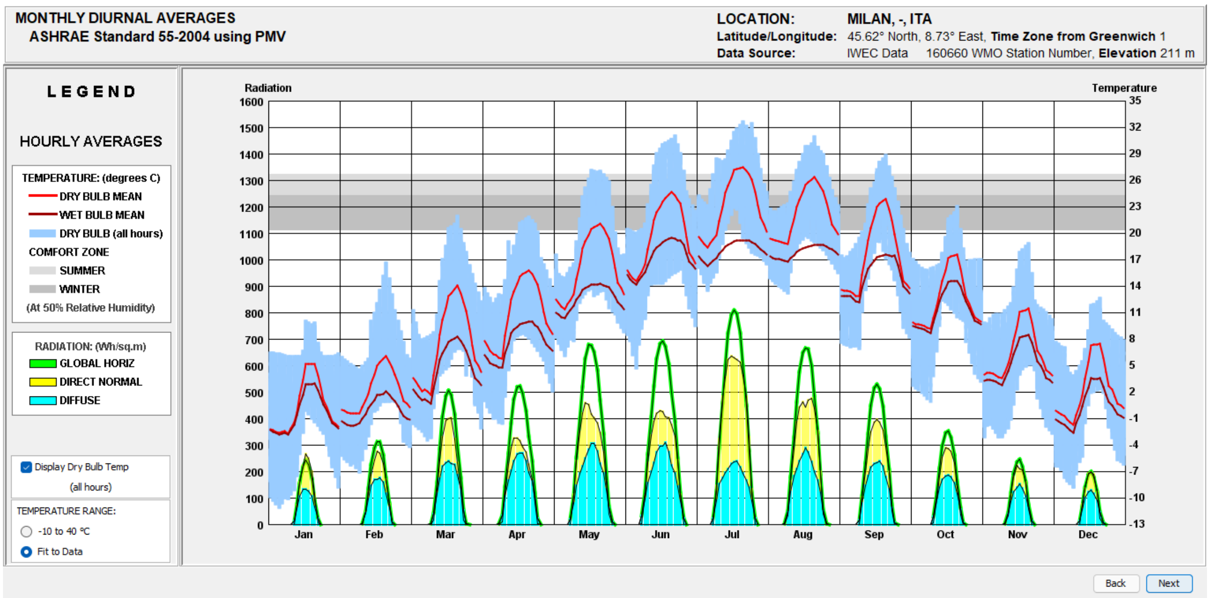


Figure A.5.1 Yearly progression of external air temperature and of solar radiation

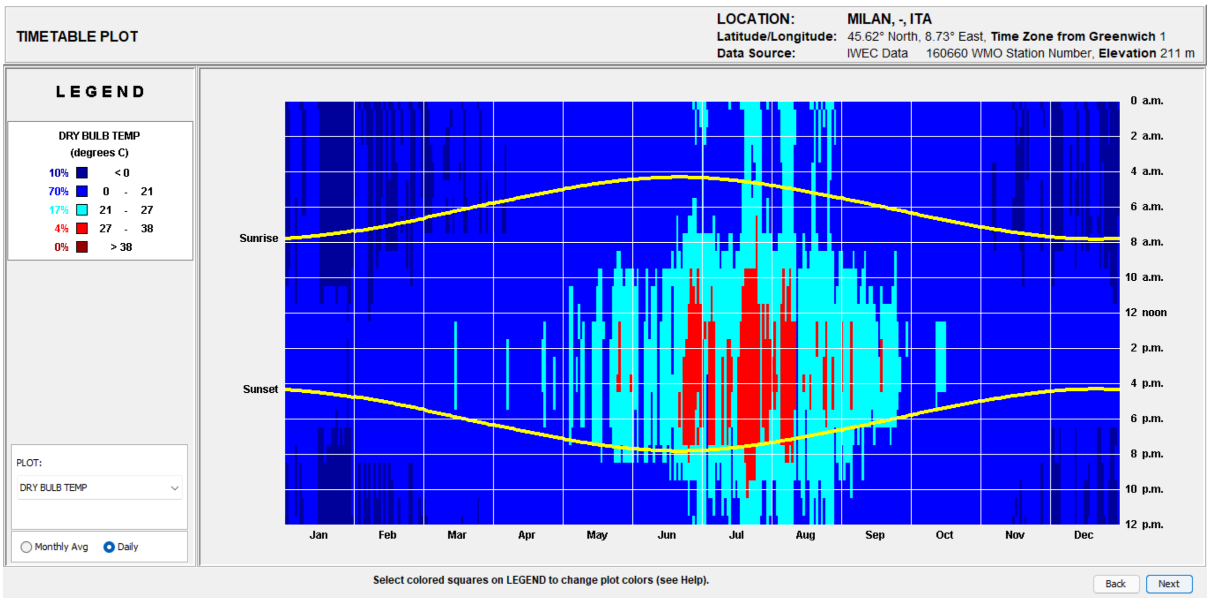


Figure A.5.2 Yearly and hourly progression of dry bulb external air temperature

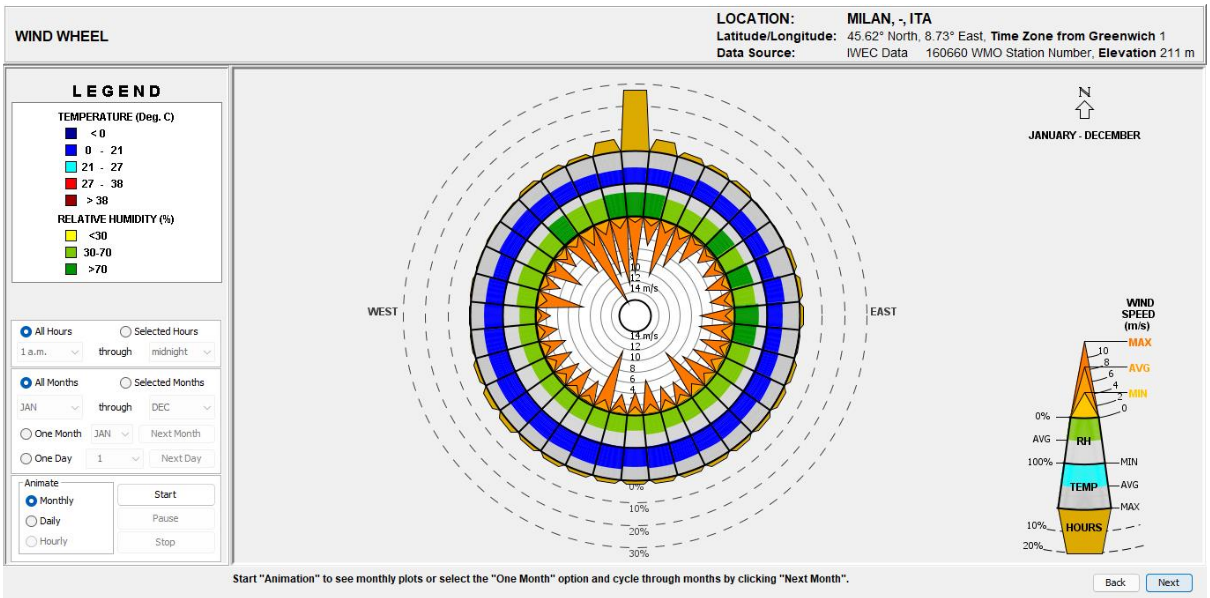


Figure A.5.3 Wind wheel with the representation of the yearly cumulative number of hours per each wind direction

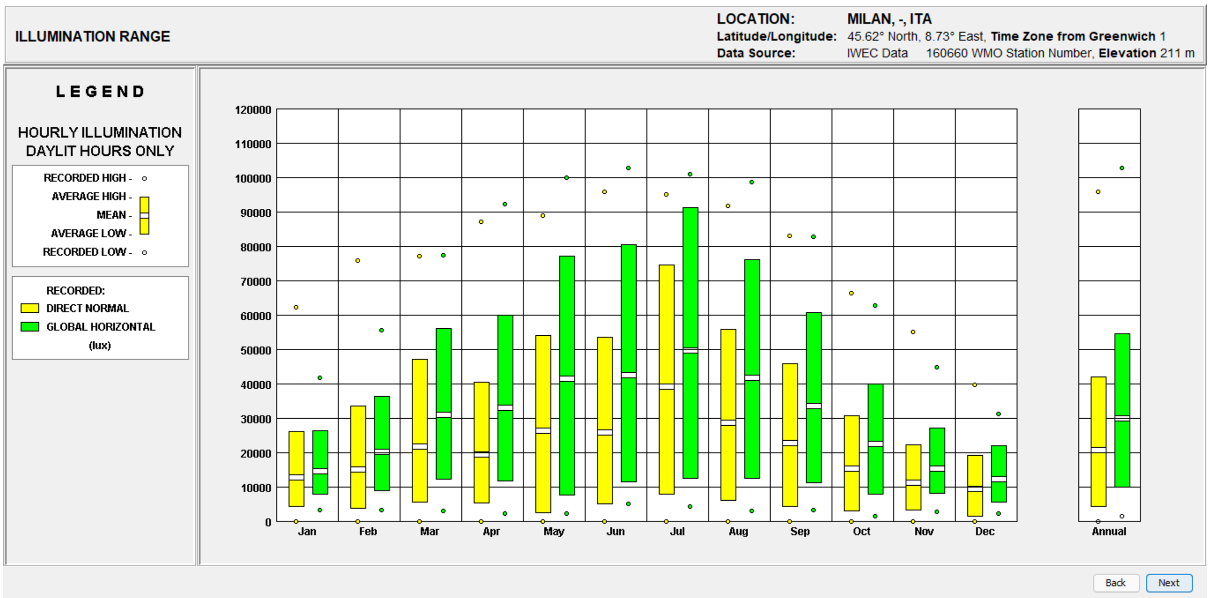


Figure A.4.4 Illuminance progression

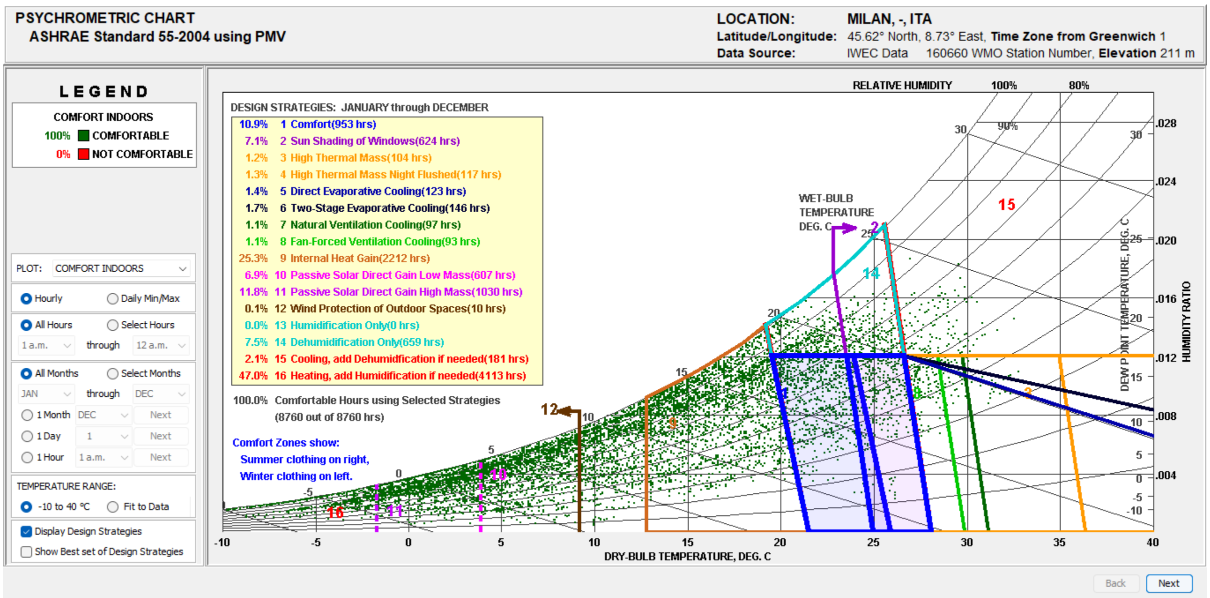


Figure A.5.5 Givoni diagram with the most effective strategies to guarantee indoor thermal comfort

Annex 6: Envelope properties calculation

External wall

Layer	Thermal conductivity (W/mK)	Thermal Resistance (m^2K/W)	Thickness (cm)
Interior		0,13	
Concrete	1,13	0,18	20
Glass wool	0,036	1,67	6
Ventilated air cavity	0,45	0,18	8,1
Batten	0,13	0,19	2,5
Non-ventilated air cavity	0,025	0,02	0,05
Stainless steel	17	2,94e-5	0,05
Exterior		0,04	
TOTAL		**2,406 (0,416W/m2K)**	**36.7**

Internal wall Office

Layer	Thermal conductivity (W/mK)	Thermal Resistance (m^2K/W)	Thickness (cm)
Interior		0,13	
Concrete	1,13		10
Interior		0,13	
TOTAL		**0,348 (2,869W/m2K)**	**10**

Internal wall Corridor

Layer	Thermal conductivity (W/mK)	Thermal Resistance (m^2K/W)	Thickness (cm)
Interior		0,13	
Concrete	1,13		20
Interior		0,13	
TOTAL		**0,437 (2,288W/m2K)**	**20**

Floor

Layer	Thermal conductivity (W/mK)	Thermal Resistance (m^2K/W)	Thickness (cm)
Interior		0,1	
Ceramic tiles	0,8	0,01	1
Rhin sand	1,40	0,09	9
Soft membrane	0,1	0,01	0,1
Concrete	1,13	0,2	20
Interior		0,1	
TOTAL		**0,534 (U=1,873)**	**30,1**

ubakus

All statements without guarantee

ExternalWall

Exterior wall
created on 27.6.2022

Thermal protection

U = 0,45 W/(m²K)

GEG 2020 Bestand*: U<0,24 W/(m²K)

excellent insufficient

Moisture proofing

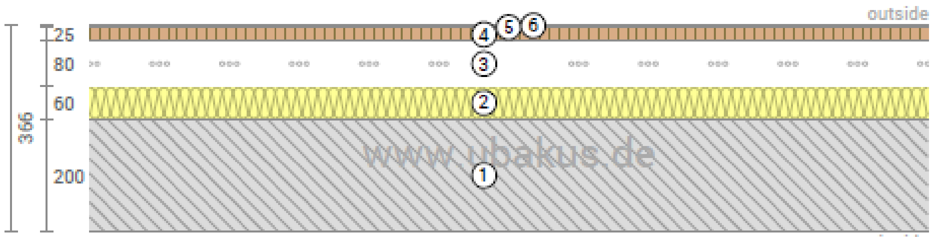
No condensate

excellent insufficient

Heat protection

Temperature amplitude damping: 66
phase shift: 8,0 h
Thermal capacity inside: 397 kJ/m²K

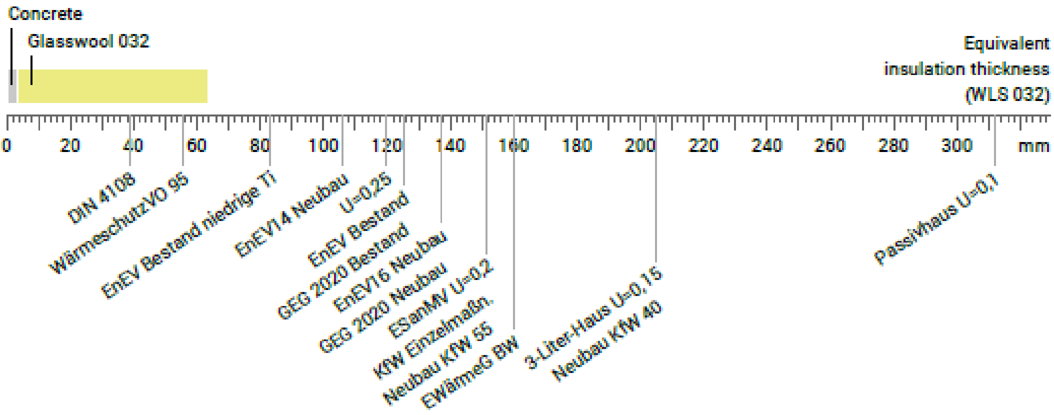
excellent insufficient



① Concrete (200 mm)
② Glasswool 032 (60 mm)
③ Rear ventilated level (80 mm)
④ OSB/3 (25 mm)
⑤ Stationary air (0,5 mm)
⑥ Stainless Steel

Impact of each layer and comparison to reference values

For the following figure, the thermal resistances of the individual layers were converted in millimeters insulation. The scale refers to an insulation of thermal conductivity 0,032 W/mK.



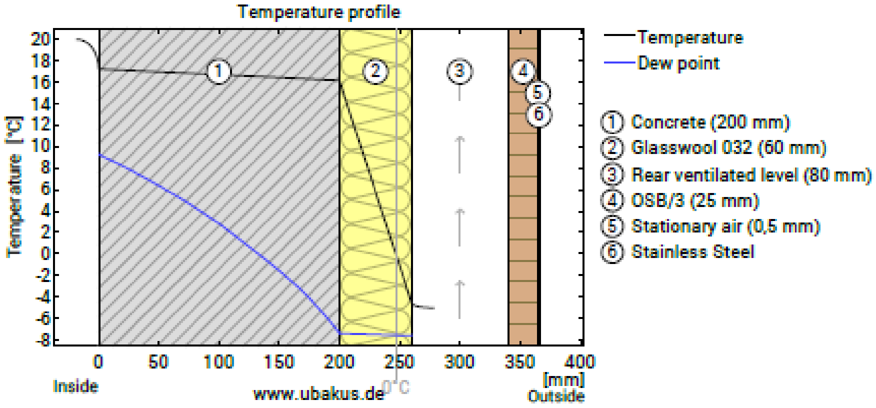
Inside air :	20,0°C / 50%		Thickness:	36,6 cm
Outside air:	-5,0°C / 80%	sd-value: 16,1 m	Weight:	501 kg/m²
Surface temperature.:	17,2°C / -4,6°C		Heat capacity:	457 kJ/m²K

*Vergleich mit dem Höchstwert gemäß GEG 2020 für erstmaligen Einbau, Ersatz oder Erneuerung von Außenwänden (Anlage 7, Zeile 1a,1b).

Page 1

ExternalWall, U=0,45 W/(m²K)

Temperature profile



Temperature and dew-point temperature in the component. The dew-point indicates the temperature, at which water vapour condensates. As long as the temperature of the component is everywhere above the dew-point temperature, no condensation occurs. If the curves have contact, condensation occurs at the corresponding position.

Layers (from inside to outside)

#		Material	λ [W/mK]	R [m²K/W]	Temperatur [°C] min	max	Weight [kg/m²]
		Thermal contact resistance*		0,130	17,2	20,0	
1	20 cm	Concrete	2,000	0,100	16,1	17,2	480,0
2	6 cm	Glasswool 032	0,032	1,875	-4,6	16,1	1,8
		Thermal contact resistance*		0,130	-5,0	-4,6	
3	8 cm	Rear ventilated level (outside air)			-5,0	-5,0	0,0
4	2,5 cm	OSB/3			-5,0	-5,0	15,5
5	0,05 cm	Stationary air (unventilated)			-5,0	-5,0	0,0
6	0,05 cm	Stainless Steel (austenitic)			-5,0	-5,0	4,0
	36,6 cm	Whole component		2,235			501,3

*Thermal contact resistances according to DIN 6946 for the U-value calculation. Rsi=0,25 and Rse=0,04 according to DIN 4108-3 were used for moisture proofing and temperature profile.

Surface temperature inside (min / average / max):	17,2°C	17,2°C	17,2°C
Surface temperature outside (min / average / max):	-4,6°C	-4,6°C	-4,6°C

ExternalWall, U=0,45 W/(m²K)

Moisture proofing

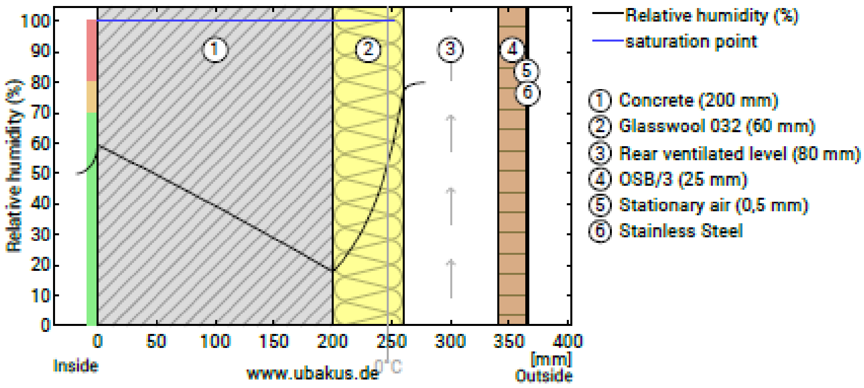
For the calculation of the amount of condensation water, the component was exposed to the following constant climate for 90 days: inside: 20°C und 50% Humidity; outside: -5°C und 80% Humidity. This climate complies with DIN 4108-3.

This component is free of condensate under the given climate conditions.

#		Material	sd-value [m]	Condensate [kg/m²]	[Gew.-%]	Weight [kg/m²]
1	20 cm	Concrete	16,00	-		480,0
2	6 cm	Glasswool 032	0,12	-		1,8
	36,6 cm	Whole component	16,12			501,3

Humidity

The temperature of the inside surface is 17,2 °C leading to a relative humidity on the surface of 60%.Mould formation is not expected under these conditions.
The following figure shows the relative humidity inside the component.

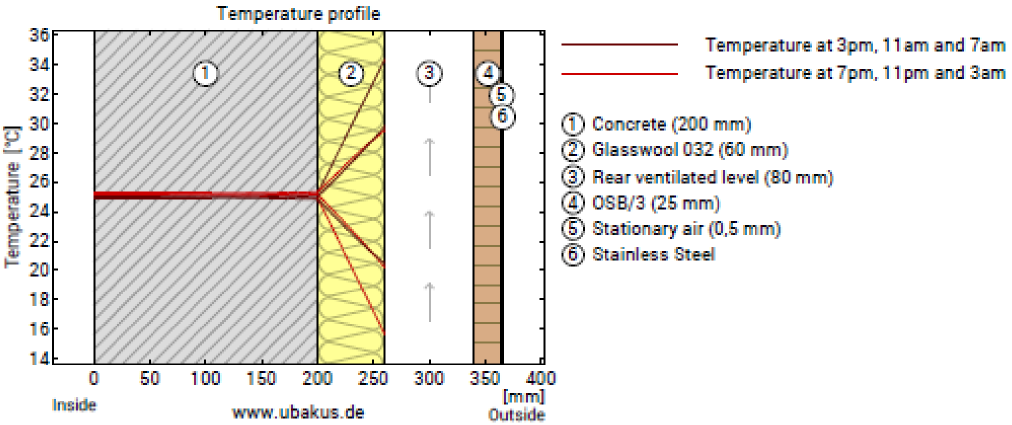


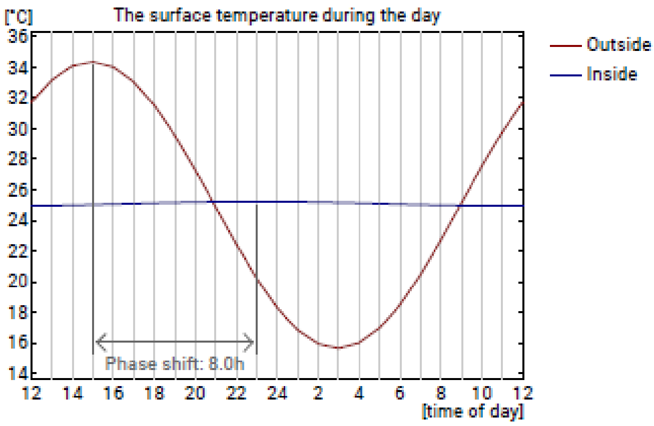
Notes: Calculation using the Ubakus 2D-FE method. Convection and the capillarity of the building materials were not considered. The drying time may take longer under unfavorable conditions (shading, damp / cool summers) than calculated here.

ExternalWall, U=0,45 W/(m²K)

Heat protection

The following results are properties of the tested component alone and do not make any statement about the heat protection of the entire room:





Top: Temperature profile within the component at different times. From top to bottom, brown lines: at 3 pm, 11 am and 7 am and red lines at 7 pm , 11 pm and 3 am.
Bottom: Temperature on the outer (red) and inner (blue) surface in the course of a day. The arrows indicate the location of the temperature maximum values . The maximum of the inner surface temperature should preferably occur during the second half of the night.

Phase shift*	8,0 h	Heat storage capacity (whole component):	457 kJ/m²K
Amplitude attenuation **	66,2	Thermal capacity of inner layers:	397 kJ/m²K
TAV ***	0,015		

* The phase shift is the time in hours after which the temperature peak of the afternoon reaches the component interior.
** The amplitude attenuation describes the attenuation of the temperature wave when passing through the component. A value of 10 means that the temperature on the outside varies 10x stronger than on the inside, e.g. outside 15-35 °C, inside 24-26 °C.
*** The temperature amplitude ratio TAV is the reciprocal of the attenuation: TAV = 1 / amplitude attenuation

Note: The heat protection of a room is influenced by several factors, but essentially by the direct solar radiation through windows and the total amount of heat storage capacity (including floor, interior walls and furniture). A single component usually has only a very small influence on the heat protection of the room.

All statements without guarantee

InternalWallRoom

internal wall
created on 23.6.2022

Thermal protection

U = 3,23 W/(m²K)

Heated on both sides: No requirement*

excellent — insufficient

Moisture proofing

No condensate

excellent — insufficient

Heat protection

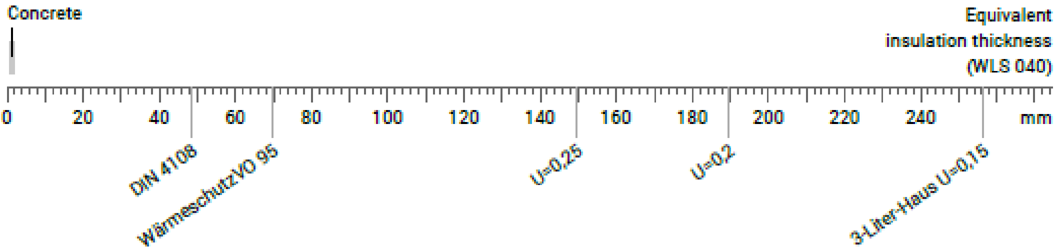
Temperature amplitude damping: 1,1
phase shift: 1,7 h
Thermal capacity inside: 45 kJ/m²K

excellent — insufficient

(1) Concrete (100 mm)

Impact of each layer and comparison to reference values

For the following figure, the thermal resistances of the individual layers were converted in millimeters insulation. The scale refers to an insulation of thermal conductivity 0,040 W/mK.



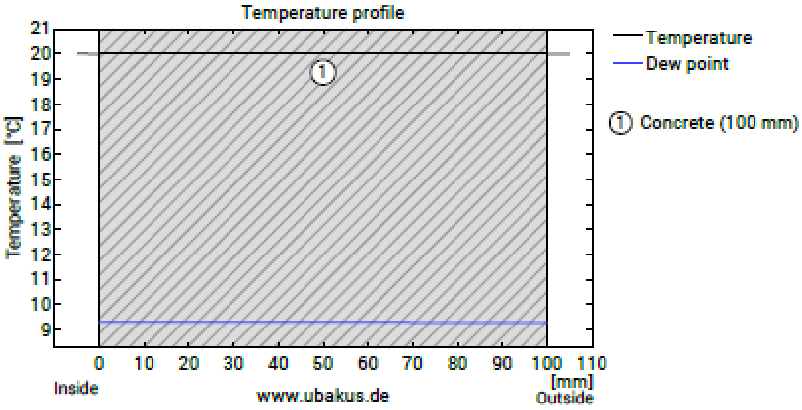
Inside air :	20,0°C / 50%		Thickness:	10,0 cm
Inside air 2:	20,0°C / 50%	sd-value: 13,0 m	Weight:	240 kg/m²
Surface temperature.:	20,0°C / 20,0°C		Heat capacity:	228 kJ/m²K

*Vergleich mit dem Höchstwert gemäß GEG 2020 für erstmaligen Einbau, Ersatz oder Erneuerung von Bauteilen zwischen beheizten Räumen (keine Anforderung).

Page 1

InternalWallRoom, U=3,23 W/(m²K)

Temperature profile



Temperature and dew-point temperature in the component. The dew-point indicates the temperature, at which water vapour condensates. As long as the temperature of the component is everywhere above the dew-point temperature, no condensation occurs. If the curves have contact, condensation occurs at the corresponding position.

Layers (from inside to outside)

#		Material	λ [W/mK]	R [m²K/W]	Temperatur [°C] min	max	Weight [kg/m²]
		Thermal contact resistance*		0,130	20,0	20,0	
1	10 cm	Concrete	2,000	0,050	20,0	20,0	240,0
		Thermal contact resistance*		0,130	20,0	20,0	
	10 cm	Whole component		0,312			240,0

*Thermal contact resistances according to DIN 6946 for the U-value calculation. Rsi=0,25 and Rse=0,04 according to DIN 4108-3 were used for moisture proofing and temperature profile.

Surface temperature inside (min / average / max):	20,0°C	20,0°C	20,0°C
Surface temperature outside (min / average / max):	20,0°C	20,0°C	20,0°C

Moisture proofing

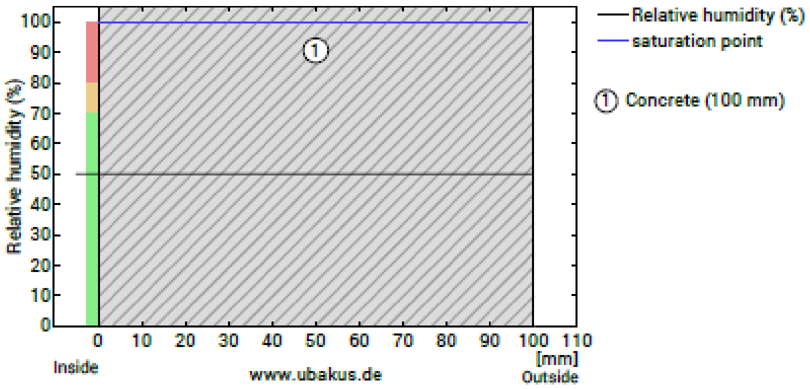
For the calculation of the amount of condensation water, the component was exposed to the following constant climate for 90 days: inside: 20.01°C und 50% Humidity; outside: 20°C und 50% Humidity (Climate according to user input).

This component is free of condensate under the given climate conditions.

#		Material	sd-value [m]	Condensate [kg/m²]	[Gew.-%]	Weight [kg/m²]
1	10 cm	Concrete	13,00	-		240,0
	10 cm	Whole component	13,00			240,0

Humidity

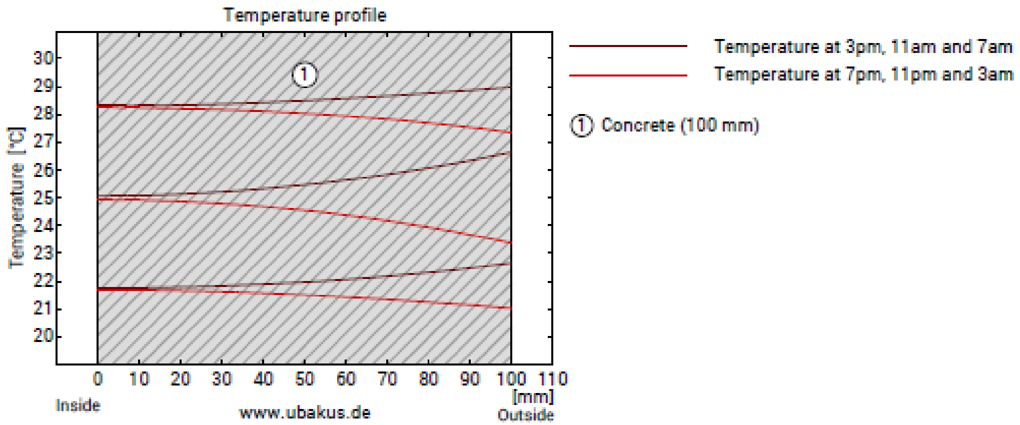
The temperature of the inside surface is 20,0 °C leading to a relative humidity on the surface of 50%.Mould formation is not expected under these conditions.
The following figure shows the relative humidity inside the component.

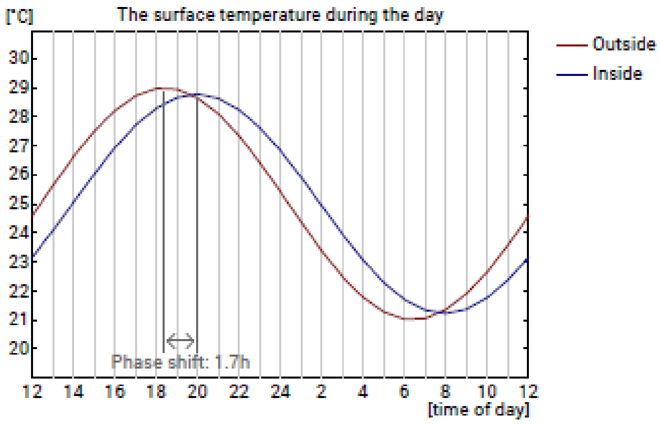


Notes: Calculation using the Ubakus 2D-FE method. Convection and the capillarity of the building materials were not considered. The drying time may take longer under unfavorable conditions (shading, damp / cool summers) than calculated here.

Heat protection

The following results are properties of the tested component alone and do not make any statement about the heat protection of the entire room:





Top: Temperature profile within the component at different times. From top to bottom, brown lines: at 3 pm, 11 am and 7 am and red lines at 7 pm , 11 pm and 3 am.
Bottom: Temperature on the outer (red) and inner (blue) surface in the course of a day. The arrows indicate the location of the temperature maximum values . The maximum of the inner surface temperature should preferably occur during the second half of the night.

Phase shift*	1,7 h	Heat storage capacity (whole component):	228 kJ/m²K
Amplitude attenuation **	1,1	Thermal capacity of inner layers:	45 kJ/m²K
TAV ***	0,947		

* The phase shift is the time in hours after which the temperature peak of the afternoon reaches the component interior.
** The amplitude attenuation describes the attenuation of the temperature wave when passing through the component. A value of 10 means that the temperature on the outside varies 10x stronger than on the inside, e.g. outside 15-35 °C, inside 24-26 °C.
*** The temperature amplitude ratio TAV is the reciprocal of the attenuation: TAV = 1 / amplitude attenuation

Note: The heat protection of a room is influenced by several factors, but essentially by the direct solar radiation through windows and the total amount of heat storage capacity (including floor, interior walls and furniture). A single component usually has only a very small influence on the heat protection of the room.

ubakus

InternalWallCorridor

internal wall
created on 23.6.2022

Thermal protection

U = 2,78 W/(m²K)

Heated on both sides: No requirement*

Moisture proofing

No condensate

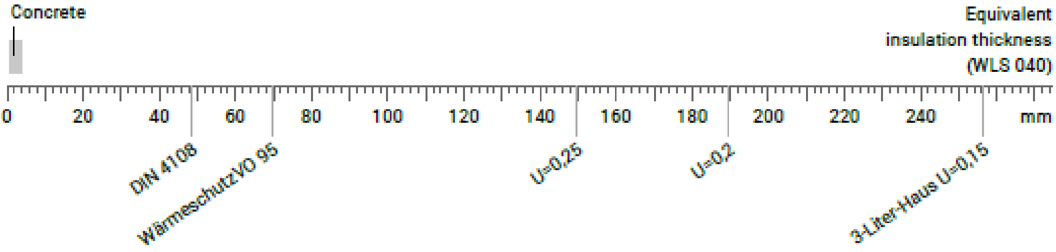
Heat protection

Temperature amplitude damping: 1,7
phase shift: 4,8 h
Thermal capacity inside: 109 kJ/m²K

① Concrete (200 mm)

Impact of each layer and comparison to reference values

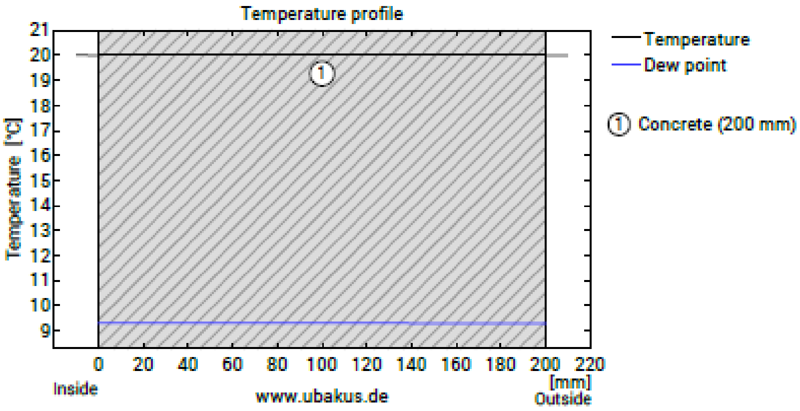
For the following figure, the thermal resistances of the individual layers were converted in millimeters insulation. The scale refers to an insulation of thermal conductivity 0,040 W/mK.



Inside air :	20,0°C / 50%		Thickness:	20,0 cm
Inside air 2:	20,0°C / 50%	sd-value: 26,0 m	Weight:	480 kg/m²
Surface temperature.:	20,0°C / 20,0°C		Heat capacity:	456 kJ/m²K

*Vergleich mit dem Höchstwert gemäß GEG 2020 für erstmaligen Einbau, Ersatz oder Erneuerung von Bauteilen zwischen beheizten Räumen (keine Anforderung).

Temperature profile



Temperature and dew-point temperature in the component. The dew-point indicates the temperature, at which water vapour condensates. As long as the temperature of the component is everywhere above the dew-point temperature, no condensation occurs. If the curves have contact, condensation occurs at the corresponding position.

Layers (from inside to outside)

#		Material	λ [W/mK]	R [m²K/W]	Temperatur [°C] min	max	Weight [kg/m²]
		Thermal contact resistance*		0,130	20,0	20,0	
1	20 cm	Concrete	2,000	0,100	20,0	20,0	480,0
		Thermal contact resistance*		0,130	20,0	20,0	
	20 cm	Whole component		0,360			480,0

*Thermal contact resistances according to DIN 6946 for the U-value calculation. Rsi=0,25 and Rse=0,04 according to DIN 4108-3 were used for moisture proofing and temperature profile.

Surface temperature inside (min / average / max):	20,0°C	20,0°C	20,0°C
Surface temperature outside (min / average / max):	20,0°C	20,0°C	20,0°C

Moisture proofing

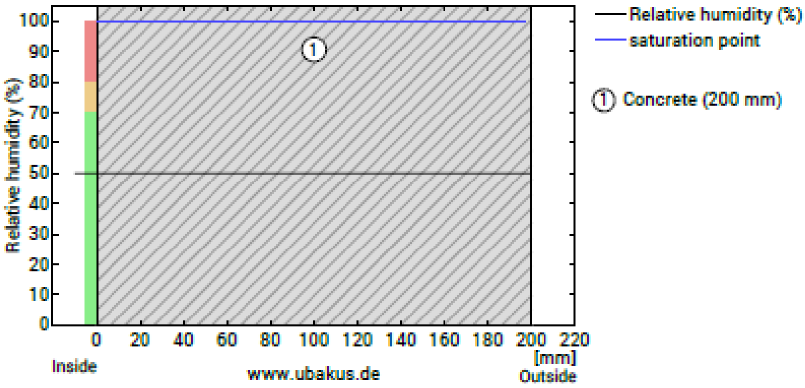
For the calculation of the amount of condensation water, the component was exposed to the following constant climate for 90 days: inside: 20.01°C und 50% Humidity; outside: 20°C und 50% Humidity (Climate according to user input).

This component is free of condensate under the given climate conditions.

#		Material	sd-value [m]	Condensate [kg/m²]	Condensate [Gew.-%]	Weight [kg/m²]
1	20 cm	Concrete	26,00	-		480,0
	20 cm	Whole component	26,00			480,0

Humidity

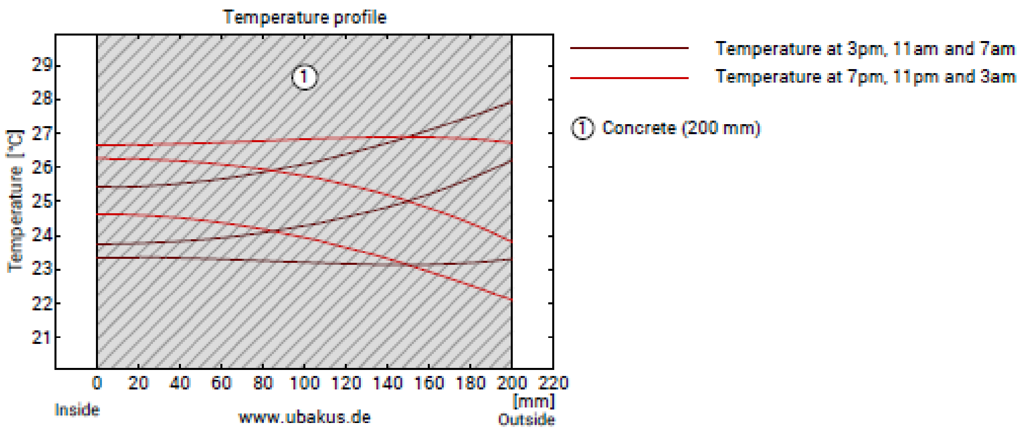
The temperature of the inside surface is 20,0 °C leading to a relative humidity on the surface of 50%.Mould formation is not expected under these conditions.
The following figure shows the relative humidity inside the component.

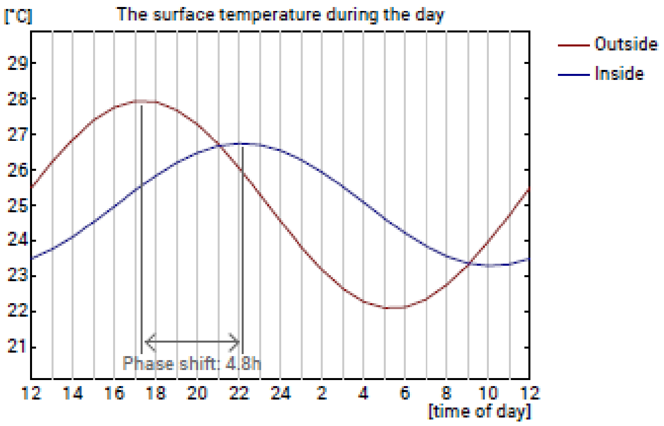


Notes: Calculation using the Ubakus 2D-FE method. Convection and the capillarity of the building materials were not considered. The drying time may take longer under unfavorable conditions (shading, damp / cool summers) than calculated here.

Heat protection

The following results are properties of the tested component alone and do not make any statement about the heat protection of the entire room:





Top: Temperature profile within the component at different times. From top to bottom, brown lines: at 3 pm, 11 am and 7 am and red lines at 7 pm , 11 pm and 3 am.
Bottom: Temperature on the outer (red) and inner (blue) surface in the course of a day. The arrows indicate the location of the temperature maximum values . The maximum of the inner surface temperature should preferably occur during the second half of the night.

Phase shift*	4,8 h	Heat storage capacity (whole component):	456 kJ/m²K
Amplitude attenuation **	1,7	Thermal capacity of inner layers:	109 kJ/m²K
TAV ***	0,589		

* The phase shift is the time in hours after which the temperature peak of the afternoon reaches the component interior.
** The amplitude attenuation describes the attenuation of the temperature wave when passing through the component. A value of 10 means that the temperature on the outside varies 10x stronger than on the inside, e.g. outside 15-35 °C, inside 24-26 °C.
***The temperature amplitude ratio TAV is the reciprocal of the attenuation: TAV = 1 / amplitude attenuation

Note: The heat protection of a room is influenced by several factors, but essentially by the direct solar radiation through windows and the total amount of heat storage capacity (including floor, interior walls and furniture). A single component usually has only a very small influence on the heat protection of the room.

Floor

Floor
created on 23.6.2022

Thermal protection

U = 1,72 W/(m²K)

Heated on both sides: No requirement*

excellent insufficient

Moisture proofing

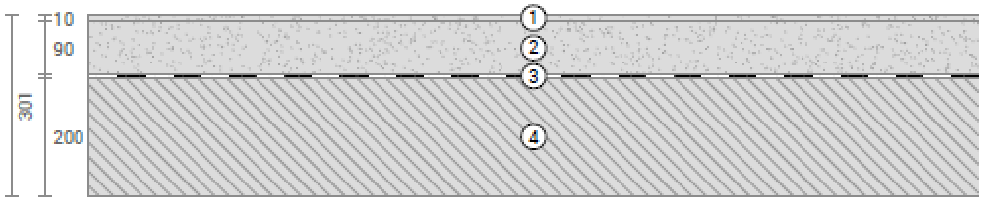
No condensate

excellent insufficient

Heat protection

Temperature amplitude damping: 2,9
phase shift: 7,8 h
Thermal capacity inside: 136 kJ/m²K

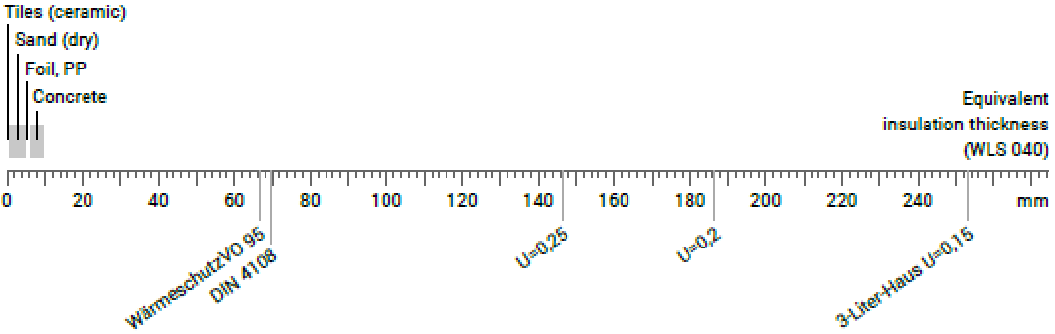
excellent insufficient



1. Tiles (10 mm)
2. Sand (90 mm)
3. Foil, PP
4. Concrete (200 mm)

Impact of each layer and comparison to reference values

For the following figure, the thermal resistances of the individual layers were converted in millimeters insulation. The scale refers to an insulation of thermal conductivity 0,040 W/mK.

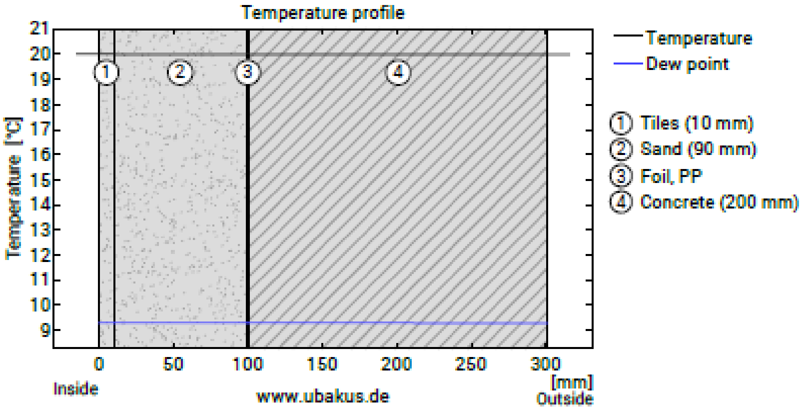


Inside air :	20,0°C / 50%		Thickness:	30,1 cm
Inside air 2:	20,0°C / 50%	sd-value: 37,8 m	Weight:	636 kg/m²
Surface temperature.:	20,0°C / 20,0°C		Heat capacity:	587 kJ/m²K

*Vergleich mit dem Höchstwert gemäß GEG 2020 für erstmaligen Einbau, Ersatz oder Erneuerung von Bauteilen zwischen beheizten Räumen (keine Anforderung).

Floor, U=1,72 W/(m²K)

Temperature profile



Temperature and dew-point temperature in the component. The dew-point indicates the temperature, at which water vapour condensates. As long as the temperature of the component is everywhere above the dew-point temperature, no condensation occurs. If the curves have contact, condensation occurs at the corresponding position.

Layers (from inside to outside)

#		Material	λ [W/mK]	R [m²K/W]	Temperatur [°C] min	max	Weight [kg/m²]
		Thermal contact resistance*		0,170	20,0	20,0	
1	1 cm	Tiles (ceramic)	1,200	0,008	20,0	20,0	20,0
2	9 cm	Sand (dry)	0,700	0,129	20,0	20,0	135,0
3	0,1 cm	Foil, PP	0,220	0,005	20,0	20,0	0,9
4	20 cm	Concrete	2,000	0,100	20,0	20,0	480,0
		Thermal contact resistance*		0,170	20,0	20,0	
	30,1 cm	Whole component		0,585			635,9

*Thermal contact resistances according to DIN 6946 for the U-value calculation. Rsi=0,25 and Rse=0,04 according to DIN 4108-3 were used for moisture proofing and temperature profile.

Surface temperature inside (min / average / max): 20,0°C 20,0°C 20,0°C
Surface temperature outside (min / average / max): 20,0°C 20,0°C 20,0°C

Floor, U=1,72 W/(m²K)

Moisture proofing

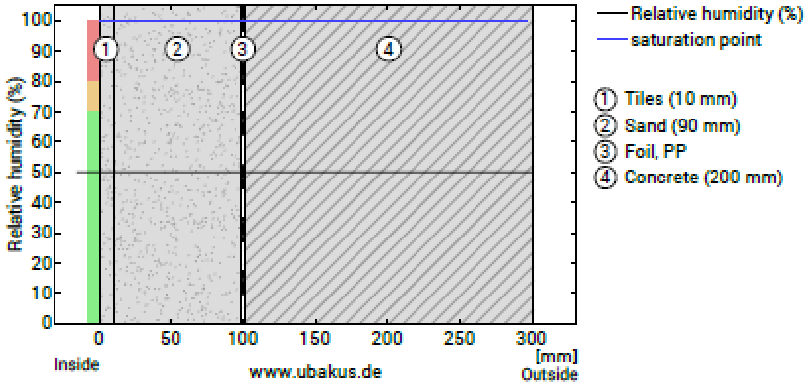
For the calculation of the amount of condensation water, the component was exposed to the following constant climate for 90 days: inside: 20.01°C und 50% Humidity; outside: 20°C und 50% Humidity (Climate according to user input).

This component is free of condensate under the given climate conditions.

#		Material	sd-value [m]	Condensate [kg/m²]	[Gew.-%]	Weight [kg/m²]
1	1 cm	Tiles (ceramic)	1,50	-		20,0
2	9 cm	Sand (dry)	0,27	-		135,0
3	0,1 cm	Foil, PP	10,00	-		0,9
4	20 cm	Concrete	26,00	-		480,0
	30,1 cm	Whole component	37,77			635,9

Humidity

The temperature of the inside surface is 20,0 °C leading to a relative humidity on the surface of 50%.Mould formation is not expected under these conditions.
The following figure shows the relative humidity inside the component.

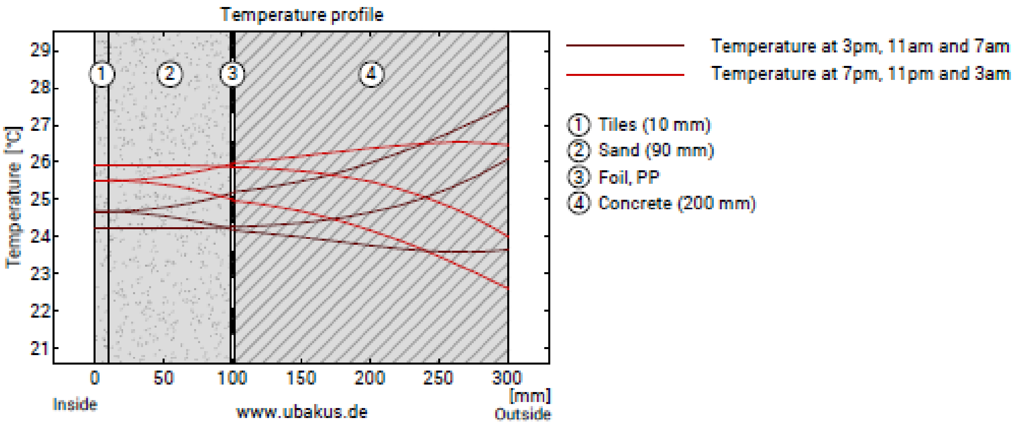


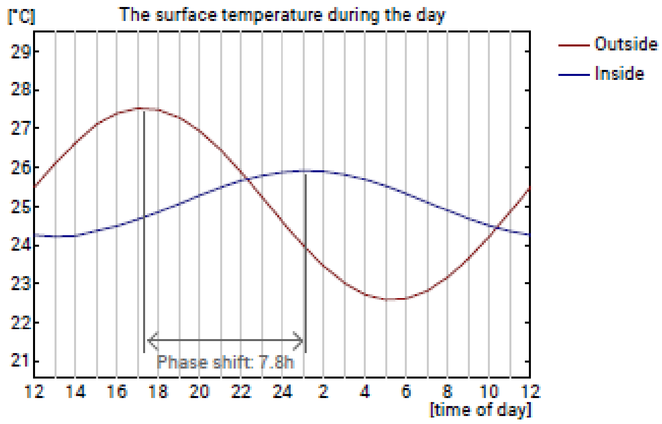
Notes: Calculation using the Ubakus 2D-FE method. Convection and the capillarity of the building materials were not considered. The drying time may take longer under unfavorable conditions (shading, damp / cool summers) than calculated here.

Floor, U=1,72 W/(m²K)

Heat protection

The following results are properties of the tested component alone and do not make any statement about the heat protection of the entire room:





Top: Temperature profile within the component at different times. From top to bottom, brown lines: at 3 pm, 11 am and 7 am and red lines at 7 pm , 11 pm and 3 am.
Bottom: Temperature on the outer (red) and inner (blue) surface in the course of a day. The arrows indicate the location of the temperature maximum values . The maximum of the inner surface temperature should preferably occur during the second half of the night.

Phase shift*	7,8 h	Heat storage capacity (whole component):	587 kJ/m²K
Amplitude attenuation **	2,9	Thermal capacity of inner layers:	136 kJ/m²K
TAV ***	0,343		

* The phase shift is the time in hours after which the temperature peak of the afternoon reaches the component interior.
** The amplitude attenuation describes the attenuation of the temperature wave when passing through the component. A value of 10 means that the temperature on the outside varies 10x stronger than on the inside, e.g. outside 15-35 °C, inside 24-26 °C.
***The temperature amplitude ratio TAV is the reciprocal of the attenuation: TAV = 1 / amplitude attenuation

Note: The heat protection of a room is influenced by several factors, but essentially by the direct solar radiation through windows and the total amount of heat storage capacity (including floor, interior walls and furniture). A single component usually has only a very small influence on the heat protection of the room.

Calculated by	Aurora Luigia Teresa Bertini	Calculated on	27/6/2022	Country	Belgium

Thermobel Stopray:
① 6 mm Stopray Vision-70 pos.2 Annealed ② 12 mm Air 100% ③ 4 mm Planibel Clearlite Annealed

Glass performance data simulation

Light properties - EN 410

Light transmittance : τv [%]	70
External light reflection : ρv [%]	14
Internal light reflection : ρvi [%]	15
Colour rendering index : Ra [%]	97

Energy properties - EN 410

Total solar energy transmittance : g [%]	36
External energy reflection : ρe [%]	41
Internal energy reflection : ρei [%]	46
Direct energy transmission : τe [%]	33
Energy absorption glass 1 : αe1 [%]	25
Energy absorption glass 2 : αe2 [%]	1
Total energy absorption : αe [%]	26
Shading coefficient : SC	0.41
UV transmission : τuv [%]	19
Selectivity	1.94

Thermal properties - EN 673

Thermal transmittance (vertical glazing) : U value [W/(m².K)]	1.5

Acoustic properties

Direct airborne sound reduction - Interpolated : Rw (C;Ctr) [dB] 1	35 (-1;-3)

Safety properties

Resistance to fire - EN 13501-2	NPD
Reaction to fire - EN 13501-1	NPD
Bullet resistance - EN 1063	NPD
Burglar resistance - EN 356	NPD
Pendulum body impact resistance - EN 12600	NPD / NPD
Explosion resistance - EN 13541	NPD

Thickness and weight

Nominal thickness : [mm]	22.0
Weight : [kg/m²]	25

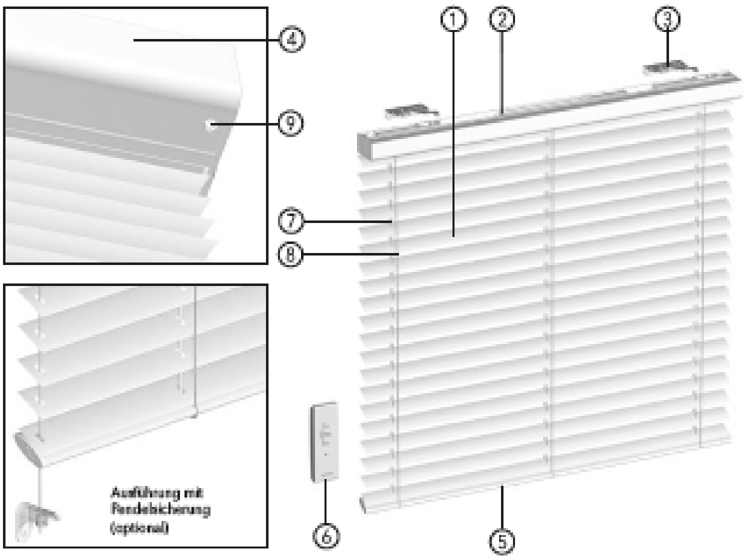
1. The sound reduction indexes are interpolated (no test available). They correspond to glazing with dimensions 1230 mm by 1480 mm according to EN ISO 10140-3. In-situ performances may vary according to the effective glazing dimensions, supporting system, installation, environment, noise sources etc. The accuracy of the given indexes is +/- 2 dB.

Glass Configurator
Calculation software verified by INISMa
EN 410 and EN 673
Report n° 2018B COU 35741

Annex 7: Shading datasheets

Modell 09-1085, 09-1185, 09-4485*, 09-1285

Akku-Funk-Antrieb 12 V

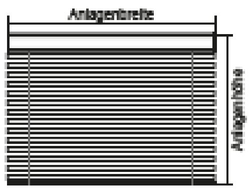


1. Lamellenbehang
2. Oberschiene
3. Spannhebelträger lang
4. Akku-Funk-Antrieb 12 V
5. Unterschiene
6. Funk-Handsender, 1-Kanal, im Lieferumfang enthalten
7. Aufzugsschnur
8. Leiterkordel
9. Ladebuchse

Technische Daten

Modell:

09-1085 Akku-Funk-Antrieb, Lamelle 16 mm
09-1185 Akku-Funk-Antrieb, Lamelle 25 mm
09-4485* Akku-Funk-Antrieb, Lamelle 25 mm mit nicht sichtbarer Lamellenstanzung
09-1285 Akku-Funk-Antrieb, Lamelle 35 mm

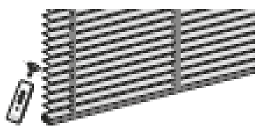


Beschreibung:

Akku-Funk-Antrieb 12 V mittig in der Oberschiene, mit integriertem Funk-Empfänger und automatischer Endlagenabschaltung. Akku vorgelagert. Nicht feuchtraumgeeignet. Oberschiene aus stranggepresstem Aluminium. Unterschiene aus stranggepresstem Aluminium. Lamellenfarben laut MHZ-Kollektion. Schnüre und Leiterkordeln farblich auf Lamellen abgestimmt.

Maße:

Modell	Min. Breite	Max. Breite	Max. Höhe	Max. Fläche
09-1085	ab 51 cm	bis 63 cm	180 cm	ca. 1 m²
	ab 61 cm	bis 270 cm	360 cm	5 m²
09-1185	ab 51 cm	bis 63 cm	180 cm	ca. 1 m²
	ab 61 cm	bis 380 cm	360 cm	5 m²
09-4485*	ab 51 cm	bis 63 cm	180 cm	ca. 1 m²
	ab 61 cm	bis 380 cm	360 cm	5 m²
09-1285	ab 51 cm	bis 63 cm	180 cm	ca. 1 m²
	ab 61 cm	bis 450 cm	360 cm	5 m²

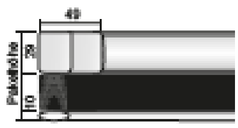


Technikfarben:

100 silberfarbig eloxiert — 257 schwarz eloxiert
171 weiß pulverbeschichtet — 650 anthrazit pulverbeschichtet

Pakethöhen:

Anlagenhöhe bis (cm)	50	100	150	200	250	300	350
09-1085	5,0	6,0	7,5	9,0	10,5	11,5	13,5
09-1185	5,0	6,5	7,5	8,5	9,5	11,0	12,0
09-1185 mit perforierten Lamellen	6,0	7,0	8,0	9,0	10,0	11,0	12,0
09-4485*	6,0	8,0	10,0	11,0	12,0	13,0	14,0
09-1285	5,0	6,0	8,5	8,5	9,5	10,5	11,5



Behang:

Breite 16, 25 und 35 mm, Aluminium 0,22 mm, elastisch, einbrennlackiert, Oberflächen und Farben siehe Kollektion. Detaillierte Informationen siehe Broschüre Materialeigenschaften.

Bedienung:

Heben und Senken mittels Funk-Antrieb 12 V, inkl. Akku und Funk-Handsender Situo RTS Pure (im Lieferumfang enthalten). Ladegerät nicht im Lieferumfang enthalten. Verschiedene Steuerungsmöglichkeiten durch Funk-Handsender. Preise für Elektro-Zubehör S. 17.

Sonderausstattung:

- Pendelsicherung, Stahldraht ø 1 mm, kunststoffummantelt
- mehrfarbiger Behang S. 12
- Aufpreise S. 10–11
- weiteres Zubehör S. 14–16
- * nicht sichtbare Lamellenstanzung S. 13

TOILE EN FIBRE DE VERRE

Toile en fils de fibre de verre tissés et enduits ou plus simplement toile en fibre de verre

Ces fils à noyau en fibre de verre sont revêtus individuellement d'une couche de plastisol. Ce processus de fabrication permet de produire des toiles souples. La toile a un poids propre élevé et est idéale pour les systèmes de protection solaire à enroulement vertical.

CARACTERISTIQUES TECHNIQUES

	Sergé	Natté	Métal	Privacy
				
Composition	Fil en fibres de verre [42 %] avec enduit PVC [58 %]			
Largeur disponible	De 1350 à 2700 mm Sélection limitée jusqu'à 3200 mm	2500 mm Sélection limitée jusqu'à 3200 mm	2850 mm	2700 mm
Classe de résistance au feu	M1 [FRR] - NF P 92-503 Euroclass C-s3.d0 [EU] - NF EN 13501-1	M1 [F] - NF P 92-503 B1 [DE] - DIN 4102-1 BS [GB] - 476 Pt 6 Class 0 Euroclass C-s3.d0 [EU] - NF EN 13501 - 1 mounted according to EN 13823 & EN 14716 F3 [F] - NF F16-101	M1 [FR] - NF P 92-503 B1 [DE] - DIN 4102-1 Euroclass C-s3.d0 [EU] - NF EN 13501 - 1 mounted according to EN 13823 & EN 14716 FR [US] - NFPA 701	M1 [FR] - NF P 92-503 B1 [DE] - DIN 4102-1 Class 1 - UNI 9177 C - BS 5867 FR - NFPA 701 [US]
Résistance à la lumière	Degré 7 - ISO105 B 02	Degré 7-8 - ISO105 B02	Degré 7-8 - ISO105 B02	Degré 7 - ISO105 B 02
Epaisseur	ca. 0,55 mm - EN ISO 5084	ca. 0,53 mm - EN ISO 2286 - 3	ca. 0,70 mm - EN ISO 2286 - 3	ca. 0,80 mm - ISO 5084
Poids	ca. 535 g/m² - NF 12127	ca. 560 g/m² - EN ISO 2286 - 2	ca. 520 g/m² - EN ISO 2286 - 2	ca. 620 g/m² - NF EN 12127
Résistance à la déchirure chaîne	8,5 daN - EN ISO 4674-1	≥ 10 daN - EN 1875 - 3	≥ 10 daN - EN 1875 - 3	5,90 daN - ISO 4674-1
Résistance à la déchirure trame	7,5 daN - EN ISO 4674-1	≥ 9 daN - EN 1875 - 3	≥ 8 daN - EN 1875 - 3	6,20 daN - ISO 4674-1
Résistance à la traction chaîne	> 260 daN/5 cm - EN ISO 1421	> 220 daN/5 cm - EN ISO 1421	> 200 daN/5 cm - EN ISO 1421	> 321 daN/5cm - EN ISO 1421
Résistance à la traction trame	> 225 daN/5 cm - EN ISO 1421	> 200 daN/5 cm - EN ISO 1421	> 170 daN/5 cm - EN ISO 1421	> 277 daN/5 cm - EN ISO 1421
Facteur d'ouverture	5%	3%	2%	1%

Réf.		AS	RS	TS	TV	g_{tot} ext. C	g_{tot} ext. D	Confort thermique C	Contact visuel avec l'extérieur	Utilisation de lumière naturelle	Eblouisse-ment	Intimité la nuit	Visualisation CF1
SC0202 [+]	CF1	13,2	65,9	21,0	21,2	0,15	0,10	2	0	2	1	2	
	CF2	12,7	66,3	21,0	21,2	0,15	0,10						
SCM36 [+]	CF1	27,7	59,8	12,4	11,6	0,11	0,08	3	1	1	1	2	
	CF2	23,4	64,2	12,4	11,6	0,10	0,07						
SC2002 [+]	CF1	26,4	58,2	15,5	13,7	0,13	0,09	3	1	2	1	2	
	CF2	28,1	56,4	15,5	13,7	0,13	0,09						
SC2020 [+]	CF1	32,5	52,5	14,9	12,9	0,13	0,09	3	3	2	0	1	
	CF2	32,4	52,7	14,9	12,9	0,13	0,09						
SCM45 [+]	CF1	48,7	42,6	8,7	7,8	0,10	0,08	3	3	1	1	1	
	CF2	52,4	38,9	8,7	7,8	0,10	0,08						
SC1002 [+]	CF1	39,1	49,2	11,7	10,2	0,11	0,08	3	1	1	1	2	
	CF2	43,6	44,6	11,7	10,2	0,12	0,09						
SC0110 [+]	CF1	68,8	26,5	4,7	4,5	0,09	0,08	4	2	1	3	2	
	CF2	73,8	21,5	4,7	4,5	0,10	0,08	3					
SC0102 [+]	CF1	56,2	37,2	6,7	6,6	0,09	0,08	4	2	1	3	2	
	CF2	66,4	26,9	6,7	6,6	0,10	0,08	3					
SCM31 [+]	CF1	63,0	33,2	3,9	3,6	0,08	0,07	4	2	1	3	1	
	CF2	70,9	25,2	3,9	3,6	0,09	0,08						
SC0207 [+]	CF1	37,4	50,9	11,7	9,9	0,11	0,08	3	1	1	1	2	
	CF2	41,4	46,9	11,7	9,9	0,11	0,08						
SC0707	CF1	51,7	38,3	10,1	8,4	0,11	0,09	3	3	1	1	1	
	CF2	50,5	39,4	10,1	8,4	0,11	0,09						
SC4949	CF1	53,0	37,0	10,0	9,0	0,11	0,09	3	1	1	1	2	
	CF2	53,0	37,0	10,0	9,0	0,11	0,09						
SC0606	CF1	88,0	8,1	3,9	3,8	0,10	0,09	3	2	1	3	2	
	CF2	87,7	8,4	3,9	3,8	0,10	0,09						
SC3030 [+]	CF1	91,4	5,0	3,6	3,6	0,10	0,09	3	2	1	3	2	
	CF2	91,6	4,8	3,6	3,6	0,10	0,09						
SC0130 [+]	CF1	86,5	9,9	3,6	3,6	0,10	0,09	3	2	1	3	2	
	CF2	83,8	12,6	3,6	3,6	0,10	0,08						
SC0101 [+]	CF1	81,3	15,1	3,5	3,6	0,10	0,08	3	2	1	3	2	
	CF2	81,3	15,1	3,5	3,6	0,10	0,08						
SC0109	CF1	65,6	27,7	6,8	5,7	0,10	0,08	3	2	1	3	2	
	CF2	71,5	21,7	6,8	5,7	0,11	0,09						
SC0816	CF1	63,4	26,1	10,5	8,4	0,13	0,10	3	1	1	1	2	
	CF2	54,3	35,3	10,5	8,4	0,12	0,09						
SC1006 [+]	CF1	73,2	21,1	5,7	5,0	0,10	0,09	3	2	1	3	2	
	CF2	66,3	28,0	5,7	5,0	0,10	0,08						
SC2050	CF1	70,6	21,1	8,3	7,8	0,12	0,09	3	1	1	1	2	
	CF2	59,7	32,0	8,3	7,8	0,11	0,09						
SCM33 [+]	CF1	73,4	23,0	3,6	3,0	0,09	0,08	4	2	1	3	2	
	CF2	76,5	19,8	3,6	3,0	0,09	0,08						
SC0140 [+]	CF1	76,0	18,4	5,6	4,7	0,10	0,09	3	2	1	3	2	
	CF2	77,6	16,8	5,6	4,7	0,11	0,09						
SCM17 [+]	CF1	67,8	29,2	3,0	2,7	0,08	0,07	4	2	1	3	2	
	CF2	74,4	22,6	3,0	2,7	0,09	0,07						

Sous réserve d'erreurs et de modifications techniques.

Les couleurs imprimées peuvent différer légèrement, consultez notre carnet d'échantillons pour la couleur exacte.

AS: Facteur d'énergie solaire absorbée en % • RS: Facteur d'énergie solaire reflétée en % • TS: Facteur d'énergie solaire transmise en % • TV: Facteur de transmission lumineuse visible en % • g_{tot} ext. avec vitrage de type C • g_{tot} ext. avec vitrage de type D • Classement de confort thermique et visuel selon la norme EN 14501

CF 1 = côté de confection 1, côté supérieur de l'échantillon dans le carnet • CF 2 = côté de confection inférieur de l'échantillon dans le carnet

[+]: Largeur supplémentaire de 3200 mm pour une sélection de couleurs.

Annex 8: EMS Code

The code here below can be used for VB. In order to apply it to RB, we just need to replace the expression “Shade_Status_Exterior_Blind_On” with “Shade_Status_Exterior_Shade_On”.

Instead, to apply this code to the control strategy without glare evaluation, we can replace the expression “Glare180_NoShading > 22” with “Glare180_NoShading > 100”.

```
Output:EnergyManagementSystem,
     Verbose,
     Verbose,
     Verbose;

EnergyManagementSystem:Sensor,
   Illuminance_NoShading,
   Blocco1:Office,
   Daylighting Reference Point 1 Illuminance;

EnergyManagementSystem:Sensor,
   Glare90_NoShading,
   Blocco2:Office,
   Daylighting Reference Point 1 Glare Index;

EnergyManagementSystem:Sensor,
   Glare135_NoShading,
   Blocco3:Office,
   Daylighting Reference Point 1 Glare Index;

EnergyManagementSystem:Sensor,
   Glare180_NoShading,
   Blocco4:Office,
   Daylighting Reference Point 1 Glare Index;

EnergyManagementSystem:Sensor,
   Illuminance_Shading,
   Blocco5:Office,
   Daylighting Reference Point 1 Illuminance;

EnergyManagementSystem:Sensor,
   Surface_Outside_Face_Incident_Solar_Radiation_Rate_per_Area,
   Blocco1:Office_Wall_2_0_0_0_0_0_Win,
   Surface Outside Face Incident Solar Radiation Rate per Area;

EnergyManagementSystem:Sensor,
   Zone_People_Occupant_Count,
```

```
   Blocco10:Office,
   Zone People Occupant Count;

EnergyManagementSystem:Sensor,
   Zone_Operative_Temperature,
   Blocco10:Office,
   Zone Operative Temperature;

EnergyManagementSystem:ProgramCallingManager,
   Window Shading Device EMS Controller,    ! Name
   BeginTimestepBeforePredictor , ! EnergyPlus Model Calling Point
   Set_Shade_Control_State ;         ! Program Name

EnergyManagementSystem:Actuator,
    Blocco10_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status,   !
Name
    Blocco10:Office_Wall_2_0_0_0_0_0_Win,    ! Component Name
Surface name with shade controls
    Window Shading Control, ! Component Type
    Control Status;    ! Control Type

EnergyManagementSystem:Actuator,
    Blocco12_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status,   !
Name
    Blocco12:Office_Wall_2_0_0_0_0_0_Win,    ! Component Name
Surface name with shade controls
    Window Shading Control, ! Component Type
    Control Status;    ! Control Type

EnergyManagementSystem:Actuator,
    Blocco13_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status,   !
Name
    Blocco13:Office_Wall_2_0_0_0_0_0_Win,    ! Component Name
Surface name with shade controls
    Window Shading Control, ! Component Type
    Control Status;    ! Control Type

EnergyManagementSystem:Actuator,
    Blocco14_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status,   !
Name
    Blocco14:Office_Wall_2_0_0_0_0_0_Win,    ! Component Name
Surface name with shade controls
    Window Shading Control, ! Component Type
    Control Status;    ! Control Type

EnergyManagementSystem:Program,
    Set_Shade_Control_State,     ! Name

    !SET OccupantOverriding = @RandomUniform 0 1,
```

```
    !SET OccupantOverridingRound = @Round OccupantOverriding,

     set a=0,
     set b=0,
     set c=0,
     set d=0,

     IF Glare180_NoShading > 22,
          SET a = 1,
     ENDIF,

     IF Glare135_NoShading > 22,
          SET b = 1,
     ENDIF,

     IF Glare90_NoShading > 22,
          SET c = 1,
     ENDIF,

     SET d = a+b+c,

     IF Zone_People_Occupant_Count > 0,
          IF d==2 || d==3,
               SET
Blocco10_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Exterior_Blind_On,
               SET
Blocco12_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Exterior_Blind_On,
               SET
Blocco13_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Exterior_Blind_On,
               SET
Blocco14_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Exterior_Blind_On,
          ELSE,
               IF
Surface_Outside_Face_Incident_Solar_Radiation_Rate_per_Area > 150 &&
Zone_Operative_Temperature >24,
                    IF Illuminance_Shading > 600 ,
                         SET
Blocco10_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Exterior_Blind_On,
                         SET
Blocco12_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Exterior_Blind_On,
                         SET
Blocco13_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Exterior_Blind_On,
```

```
                           SET
Blocco14_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Exterior_Blind_On,
                      ELSE,
                           SET
Blocco10_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Off,
                           SET
Blocco12_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Off,
                           SET
Blocco13_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Off,
                           SET
Blocco14_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Off,
                      ENDIF,
                 ELSE,
                      SET
Blocco10_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Off,
                      SET
Blocco12_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Off,
                      SET
Blocco13_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Off,
                      SET
Blocco14_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Off,
                 ENDIF,
           ENDIF,
      ELSE,
           IF
Surface_Outside_Face_Incident_Solar_Radiation_Rate_per_Area > 150 &&
Zone_Operative_Temperature >24,
                 SET
Blocco10_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Exterior_Blind_On,
                 SET
Blocco12_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Exterior_Blind_On,
                 SET
Blocco13_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Exterior_Blind_On,
                 SET
Blocco14_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Exterior_Blind_On,
           ELSE,
```

```
                SET
Blocco10_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Off,
                SET
Blocco12_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Off,
                SET
Blocco13_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Off,
                SET
Blocco14_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status =
Shade_Status_Off,
           ENDIF,
      ENDIF;

  EnergyManagementSystem:OutputVariable,
     Erl Shading Control Status, ! Name
     Blocco10_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status, !
EMS Variable Name
     Averaged, ! Type of Data in Variable
     ZoneTimeStep ; ! Update Frequency

  EnergyManagementSystem:OutputVariable,
     Erl Shading Control Status 2, ! Name
     Blocco12_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status, !
EMS Variable Name
     Averaged, ! Type of Data in Variable
     ZoneTimeStep ; ! Update Frequency

  EnergyManagementSystem:OutputVariable,
     Erl Shading Control Status 3, ! Name
     Blocco13_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status, !
EMS Variable Name
     Averaged, ! Type of Data in Variable
     ZoneTimeStep ; ! Update Frequency

  EnergyManagementSystem:OutputVariable,
     Erl Shading Control Status 4, ! Name
     Blocco14_Office_Wall_2_0_0_0_0_0_Win_Shading_Deploy_Status, !
EMS Variable Name
     Averaged, ! Type of Data in Variable
     ZoneTimeStep ; ! Update Frequency

EnergyManagementSystem:OutputVariable ,
Erl Blocco1:Office d, ! Name
d , ! EMS Variable Name
Averaged , ! Type of Data in Variable
ZoneTimeStep ; ! Update Frequency
```

```
EnergyManagementSystem:GlobalVariable , d;

Output:Variable, *, Daylighting Reference Point 1 Daylight
Illuminance Setpoint Exceeded Time, Timestep;
Output:Variable, *, Daylighting Reference Point 1 Daylight
Illuminance Setpoint Exceeded Time, Hourly;
Output:Variable, *, Daylighting Reference Point 1 Daylight
Illuminance Setpoint Exceeded Time, Monthly;
Output:Variable, *, Daylighting Reference Point 1 Daylight
Illuminance Setpoint Exceeded Time, RunPeriod;

Output:Variable, *, Surface Outside Face Incident Solar Radiation
Rate per Area, Timestep;
Output:Variable, *, Surface Outside Face Incident Solar Radiation
Rate per Area, Hourly;
Output:Variable, *, Surface Outside Face Incident Solar Radiation
Rate per Area, Monthly;
Output:Variable, *, Surface Outside Face Incident Solar Radiation
Rate per Area, RunPeriod;

Output:Variable, *, Daylighting Reference Point 1 Illuminance,
Timestep;
Output:Variable, *, Daylighting Reference Point 2 Illuminance,
Timestep;
Output:Variable, *, Zone People Occupant Count, Timestep;

Output:Variable, *, Zone Air Temperature, Timestep;
Output:Variable, *, Zone Operative Temperature, Timestep;
Output:Variable, *, Daylighting Reference Point 1 Glare Index,
Timestep;
Output:Variable, *, Daylighting Reference Point 2 Glare Index,
Timestep;


  Output:Variable,
    *,
    Erl Shading Control Status,
    Timestep;

Output:Variable, Environment, Site Outdoor Air Drybulb Temperature,
Timestep;
Output:Variable, Environment, Site Outdoor Air Drybulb Temperature,
Hourly;
Output:Variable, Environment, Site Outdoor Air Drybulb Temperature,
Monthly;
Output:Variable, Environment, Site Outdoor Air Drybulb Temperature,
RunPeriod;

Output:Variable, *, Lights Electricity Energy, Timestep;
```

```
Output:Variable, *, Lights Electricity Energy, Hourly;
Output:Variable, *, Lights Electricity Energy, Monthly;
Output:Variable, *, Lights Electricity Energy, RunPeriod;

Output:Variable, *, Lights Electricity Rate, Timestep;
Output:Variable, *, Lights Electricity Rate, Hourly;
Output:Variable, *, Lights Electricity Rate, Monthly;
Output:Variable, *, Lights Electricity Rate, RunPeriod;

Output:Variable, *, Zone Ideal Loads Zone Sensible Cooling Rate,
Timestep;
Output:Variable, *, Zone Ideal Loads Zone Sensible Cooling Rate,
Hourly;
Output:Variable, *, Zone Ideal Loads Zone Sensible Cooling Rate,
Monthly;
Output:Variable, *, Zone Ideal Loads Zone Sensible Cooling Rate,
RunPeriod;

Output:Variable, *, Zone Ideal Loads Zone Sensible Heating Rate,
Timestep;
Output:Variable, *, Zone Ideal Loads Zone Sensible Heating Rate,
Hourly;
Output:Variable, *, Zone Ideal Loads Zone Sensible Heating Rate,
Monthly;
Output:Variable, *, Zone Ideal Loads Zone Sensible Heating Rate,
RunPeriod;

Output:Variable, *, Zone Lights Electricity Rate, Timestep;
Output:Variable, *, Zone Lights Electricity Rate, Hourly;
Output:Variable, *, Zone Lights Electricity Rate, Monthly;
Output:Variable, *, Zone Lights Electricity Rate, RunPeriod;

Output:Variable, *, Zone Ventilation Mass Flow Rate, Timestep;
Output:Variable, *, Zone Ventilation Mass Flow Rate, Hourly;
Output:Variable, *, Zone Ventilation Mass Flow Rate, Monthly;
Output:Variable, *, Zone Ventilation Mass Flow Rate, RunPeriod;

EnergyManagementSystem:ProgramCallingManager,
    Init Window Shading Device Control Constants,    ! Name
    BeginNewEnvironment , ! EnergyPlus Model Calling Point
    InitializeShadeControlFlags ;         ! Program Name 1


   EnergyManagementSystem:GlobalVariable,    Shade_Status_None;
   EnergyManagementSystem:GlobalVariable,    Shade_Status_Off ;
   EnergyManagementSystem:GlobalVariable,
Shade_Status_Interior_Shade_On;
   EnergyManagementSystem:GlobalVariable,
Shade_Status_Switchable_Dark;
```

```
   EnergyManagementSystem:GlobalVariable,
Shade_Status_Exterior_Shade_On;
   EnergyManagementSystem:GlobalVariable,
Shade_Status_Interior_Blind_On;
   EnergyManagementSystem:GlobalVariable,
Shade_Status_Exterior_Blind_On;
   EnergyManagementSystem:GlobalVariable,
Shade_Status_Between_Glass_Shade_On;
   EnergyManagementSystem:GlobalVariable,
Shade_Status_Between_Glass_Blind_On;


   EnergyManagementSystem:Program,
      InitializeShadeControlFlags,
            ! these are control flag values used inside EnergyPlus
for window shades
            ! EMS control of window shading devices involves setting
the control values for shading control actuators with
            !  one of these values. The variable names can be used
or replaced, it is the whole number values that trigger
            !  changes in the modeling.
            !  Shades and Blinds are either fully on or fully off,
partial positions require multiple windows.
            ! the window shading control flag values follow
            !  -1: if window has no shading device
      Set Shade_Status_None = 0.0 - 1.0,  ! this is how to write a
negative number Erl does not have unary "minus," only binary
subtraction
            !   0: if shading device is off
      Set Shade_Status_Off = 0.0,
            !   1: if interior shade is on
      Set Shade_Status_Interior_Shade_On = 1.0,
            !   2: if glazing is switched to darker state
      Set Shade_Status_Switchable_Dark = 2.0,
            !   3: if exterior shade is on
      Set Shade_Status_Exterior_Shade_On = 3.0,
            !   6: if interior blind is on
      Set Shade_Status_Interior_Blind_On = 6.0,
            !   7: if exterior blind is on
      Set Shade_Status_Exterior_Blind_On = 7.0,
            !   8: if between-glass shade is on
      Set Shade_Status_Between_Glass_Shade_On = 8.0,
            !   9: if between-glass blind is on
      Set Shade_Status_Between_Glass_Blind_On = 9.0;
            !  10: window has interior shade that is off but may be
triggered on later
            !       to control daylight glare
            !  20: window has switchable glazing that is unswitched
but may be switched later
```

```
            !       to control daylight glare or daylight
illuminance
            !  30: window has exterior shade that is off but may be
triggered on later
            !       to control daylaight glare or daylight
illuminance
            !  60: window has interior blind that is off but may be
triggered on later
            !       to control daylaight glare or daylight
illuminance
            !  70: window has exterior blind that is off but may be
triggered on later
            !       to control daylaight glare or daylight
illuminance
            !  80: window has between-glass shade that is off but
may be triggered on later
            !       to control daylaight glare or daylight
illuminance
            !  90: window has between-glass blind that is off but
may be triggered on later
            !       to control daylaight glare or daylight
illuminance
            ! A "shading device" may be an exterior, interior or
between-glass shade or blind,
            ! or the lower-transmitting (dark) state of switchable
glazing (e.g., electrochromic).
            ! In all cases, the unshaded condition is represented
            ! by the construction given by window's
Surface()%Construction and
            ! the shaded condition is represented by the
construction given by
            ! the window's Surface()%ShadedConstruction
```