Adaptive reuse assessment of an industrial warehouse building

Case study of different building programs on daylighting and thermal comfort performance

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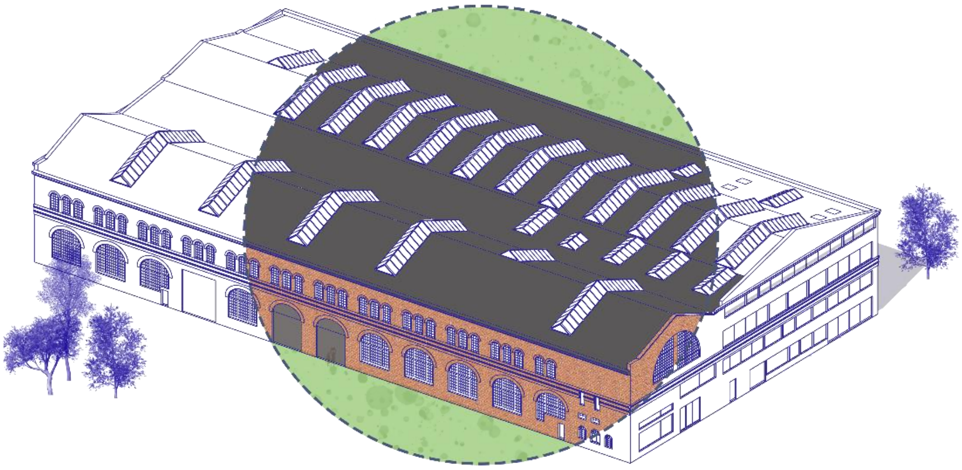

Lund University

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The degree project is the final part of the master programme leading to a Master of Science (120 credits) in Energy-efficient and Environmental Buildings.

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Abstract

The built environment includes many historic buildings that are not used to their full potential. Their lifespan can be extended with adaptive reuse strategies, repurposing constructions and introducing new building programs instead of demolishing and rebuilding them. This approach supports sustainability while also preserving heritage buildings. One common strategy is to retain the original building envelope. This project aims to adapt this strategy and introduce a building within a building construction, where the original façade is kept and a new structure is designed inside to accommodate the proposed programs. However, meeting current standards for indoor environmental quality, such as those for daylighting and thermal comfort, remains a challenge, especially when assigning new uses. Ensuring sufficient daylight is particularly difficult in adaptive reuse projects. Existing daylight standards are largely developed for new constructions and often apply uniform requirements regardless of building context or function. In historic buildings where façade alterations may be limited, these standards can restrict adaptable solutions. This project presents a case study where an industrial warehouse in southern Sweden is being adapted for new building programs. The existing envelope is kept preserved as a shell, while a new interior layout is assessed for three potential uses: office, educational and residential. These programs are evaluated and show how the building can remain relevant for future needs. Daylight performance is assessed with daylight factor, target illuminance and minimum target illuminance, vertical illuminance at eye level (as a proxy for circadian potential) and view out. Thermal comfort is evaluated through overheating hours in occupied zones. For the office and educational programs, the open spaces are examined, while in the residential program a few selected apartments are simulated, which were chosen based on their daylight performance. The study assumes that daylight requirements vary depending on the building program, and that a universal assessment approach may be insufficient. It proposes a context-sensitive evaluation of daylight in adaptive reuse projects. While some scenarios may not meet current standards due to spatial constraints, the results suggest that daylight and thermal comfort conditions can still be adequate for certain uses, even when current thresholds are not necessarily achieved.

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1 Introduction

1.1 Literature review

The European Union (EU) proposed climate targets in 2023, which include tackling greenhouse gas emissions. Compared to levels measured in 1990, the aim is to reduce them with 55 % by 2030 (2030 climate targets, n.d.). The construction industry contributes largely to the issues that the environment is currently facing. In the EU approximately a third of the waste materials come from this sector (Hamida et al., 2025). In Denmark, for example, 5 million tonnes of waste was produced by the building industry and infrastructure in 2020 (Recycle!, 2025). Therefore, it is important to apply techniques such as the R-strategies (reduce, reuse, recycle) in this sector as well (Hamida et al., 2025). As architecture is a resource-intensive and costly process, reusing existing buildings can be more practical than constructing new ones. It is crucial to preserve and protect old architectural heritage (Penića et al., 2015). Heritage buildings should be preserved rather than demolished. Conserving and reusing heritage buildings supports future generations' understanding of their historical origins as they constitute primary material records of historical lifeways and cultural practices (Mısırlısoy & Günçe, 2016).

1.1.1 Adaptive reuse

To keep the heritage of historic buildings, the architectural practice of transforming pre-existing buildings, known as adaptive reuse has emerged (Lanz & Pendlebury, 2022). Adaptive reuse is a distinct field of study and practice, originating from traditional building conservation, and it has been established for approximately half a century. Today, adaptive reuse is widely recognized as a key strategic intervention in urban environments, addressing pressing cultural and economic challenges related to the increasing stock of unused buildings (Lanz & Pendlebury, 2022). The existing building stock contains a substantial amount of embodied energy that should not be lost through demolition. Demolition followed by new construction, even when it is energy-efficient, requires several decades to compensate for the energy savings achieved through rehabilitating and reusing existing buildings reduction (Conejos, 2013). Adaptive reuse can support the objectives of the Kyoto Protocol for climate protection and emissions reduction (Conejos, 2013). In addition, adaptive reuse reduces environmental impact, resource consumption, and construction and demolition waste generated by the building industry (Conejos, 2013). Furthermore, Stone (2019) notes, the concept of "re-use" reflects a cultural attitude characteristic of the present era "Reduce, Reuse, Recycle," Stone argues, "is a slogan that encapsulates the twenty-first-century post-industrial society's demand for usefulness, purpose, and authenticity." The protection and maintenance of existing buildings, particularly historic monuments, are promoted through conservation, preservation, and adaptation practices. It is recognized that repurposing existing buildings are necessary, in order to save resources (Casamonti, 2017). According to Mısırlısoy & Günçe (2016) adaptive reuse is regarded as one of the most effective forms of sustainable design, which embodies these practises as it is a conservation-oriented approach. Adaptive reuse can transform heritage buildings into accessible and functional spaces while enabling their sustainable use.

Despite the advantages of adaptive reuse and the applications of the approach, there is a lack of the term and guideline on what adaptive reuse is and how to apply such practices into building projects. There is no clear boundary on what can be considered as an adaptive reuse project. Additionally, there are no current regulations specifying its building performance, more specifically suitable daylight conditions. Particularly in the adaptive reuse of historic buildings, the facade of the building should be retained. It is important to preserve the external façade of heritage buildings to protect their historical significance and present it for the future generations (Yazdani Mehr, 2019). This implies that the existing windows cannot be replaced. This can lead to compromising the visual comfort experience of the future inhabitants of the building after it was adaptively reused (Marzouk et al., 2022). Another issue is the applicability of existing regulations, which are tailored to new constructions, to be applied for existing buildings or buildings that undergo adaptive reuse. The regulatory framework are often limiting or impossible to achieve (Ikiz Kaya et al., 2021).

However, adaptive reuse presents significant challenges for building designers. Changing a building's function introduces new regulatory requirements. Determining an appropriate new use for a heritage building is a complex decision-making process involving multiple factors (Mısırlısoy & Günçe, 2016). The functionalities chosen for the buildings should be appropriate for the future needs of the residents, the urban area and the time period. Identifying the most suitable function within its context is essential to preserving the cultural significance of the heritage building. Otherwise, social and economic challenges may lead to disuse over time, or the new function may compromise the authenticity of the heritage building.

In adaptively reused projects, it can be difficult to achieve good indoor environment as historic buildings constitute an obstacle due to the lack of flexibility for changes on windows and facades (Neall, 2024). Moreover, in heritage buildings that are converted with adaptive reuse, different direction of exposure to natural light might cause damage in more delicate materials or objects. Different directions of exposure can happen after the change in the floorplans. It is an extra concern that needs to be taken care of during the design process (Balocco et al., 2019).

1.1.2 Concept of building within a building

One way of preservation is to use the existing construction as a shell, with buildings within the building. The idea of a building within a building is already practiced in contemporary architecture. It is a great way of treating a site by integrating an initial project into an existing building, developing it from the inside, so the historical district can be preserved (Switkowski, 2020). Even though the concept of a building inside a built environment or existing structure is acknowledged - for instance the Austrian company called STRABAG is advertising it as one of their main profiles - research is still focusing on traditional building envelopes regarding energy-efficiency (STRABAG, n.d.). Also, today's requirements still focus on operational energy, however, especially in the case of existing structures embodied energy is equally important (Mirabella et al., 2018). An adaptively reused building has lower embodied energy during the construction phase than a completely new building, since it produces less carbon emissions (STRABAG, n.d.). Geometry and building envelope parameters are also highly influential to the buildings energy performance (Kheiri, 2018). From an adaptively reused case in India, it was discovered that adaptive reuse of historic buildings plays a crucial role in revitalizing them while enhancing their social, economic, and environmental sustainability (Othman & Elsaay, 2018). The transformation of Kolkata Town Hall demonstrates a sustainable approach that preserved the building's significance within its local context and community. By choosing preservation over destruction, the initiative safeguarded the historical and cultural values embedded within the building. This outcome was further reinforced by the introduction of supportive laws aimed at protecting heritage properties and streamlining the conservation process (Othman & Elsaay, 2018).

1.1.3 Daylighting in buildings

Daylighting is a vital aspect of the built environment as it influences the perception of an interior space and regulates thermal comfort as it affects the indoor temperature depending on the solar gains (Vaisi & Kharvari, 2019). If it is done appropriately, daylighting in buildings can reduce energy use and improve humans well-being (Bálint Palmgren et al., 2024). Using strategies to utilize daylight indoors could increase the thermal and visual comfort and help achieve more sustainable buildings. The indoor daylight is an important aspect of building performance, hence, there are standards and legislations regulating the sufficient daylight performance by providing acceptable threshold values for daylight performance metrics. Since daylighting has such an important role in energy performance, sustainability and occupant well-being, another critical point is to not lose the identity of the building meanwhile upgrading daylighting conditions. This can be especially challenging in adaptive reuse, when built environment needs to be preserved (Piraei et al., 2022). Additionally, there are inconsistencies of the daylight standards and regulations as the differ in the metrics they use, some standards require daylight factor, other illuminance values, also some of them ignore the climate of the site (Tregenza & Mardaljevic, 2018).

Adequate daylighting conditions in the Scandinavian countries can be difficult to achieve: low solar angles and the dominance of overcast sky in winter contrast with abundance of daylighting during summer months (Piraei et al., 2022). For example, in Nordic countries the adoption of the EN 17037:2018 can be not only too hard to achieve, but also can cause additional costs and delays in permits (Rogers et al., 2025). Reaching these standards can be even more demanding in historic buildings where comfortable daylight performance is a challenging task, as many historical buildings do not meet the current daylight standards (Prihatmanti & Susan, 2017a). For example, in a case study of a high school buildings in Indonesia, build by Dutch architects, located in the city Surabaya, the classrooms had daylight factor (*DF)* below the required values. Resizing the windows would help improve the daylight performance; however, this is not possible with heritage buildings. Therefore, electrical fixtures were installed to improve the visual comfort (Prihatmanti & Susan, 2017a). In a recent case study on a historically listed warehouse in Trondheim, Norway, it was examined how daylighting can be upgraded by preserving the original façade. Through several scenarios, skylights and atriums were placed inside the building, which even though reduced the internal useful area for activities, improved multiple daylighting parameters in the building, such as spatial daylight autonomy (*sDA*), daylight factor, annual sunlight exposure (*ASE*), reduced glare and increased view out. Since the interference only happened on the roof and the interior of the building, the improvements were successful without damaging the exterior envelope under heritage protection (Piraei et al., 2022).

1.1.4 Importance of thermal comfort

Since the main purpose of a building is to provide a comfortable healthy indoor space for its occupants (De Dear, 2004), not only daylight but also other domains of indoor environmental qualities must be taken care of. Thermal comfort, in particular, is an essential component regarding building performance. It is defined by American Society of Heating, Refighting and Air-Conditioning Engineers (ASHRAE) defined as "the condition of mind in which satisfaction is expressed with thermal environment" (Alwetaishi, 2016; Bálint Palmgren et al., 2024). Thermal comfort is a "state of mind" and it is difficult to be depicted by specific values and parameters as it reflects a feeling (Hoof et al., 2010). A case study in Hefei, China indicated that after implementing adaptive reuse strategies on an industrial warehouse, the thermal comfort, in most of the assessed metrics, improves. In this study the thermal comfort was calculated based on voting values for indoor cold and hot feelings, expected temperature, humidity sensation, expected humidity, wind sensation, expected wind speed, and indoor comfort level (Li et al., 2025). Another indicator of thermal comfort is overheating. Overheating is a problem in building which negatively impacts thermal comfort (Ozarisoy & Elsharkawy, 2019). In a case study of a historical industrial facility in Austria, the overheating was successfully reduced through optimization measures combined into seven scenarios. All scenarios reduced the overheating compared to the base case (Gourlis & Kovacic, 2017).

1.2 Aim of the project

The aim of the project is to evaluate interior daylight conditions and thermal comfort in an adapted industrial warehouse building where the original envelope is kept as a shell in order to assess the quality of the indoor spaces. The performance of different programs is tested via simulations to determine which is the most suitable use for the building. The ability of the proposed layout to meet the required daylight and thermal comfort standards is assessed. This will be used to evaluate the suitability of the proposed daylight measurements from current standards to assess unconventional building typology such as the building within a building. The results from the performed simulations are critically analysed in terms of indoor daylight and thermal quality.

The specific research questions are the following:

How can an industrial building envelope be used as a shell for adaptive reuse to assess suitability for different functionalities from a daylighting standards and thermal aspect, based on the case study building in Varvsstaden?

Sub Q1: Can satisfactory daylight conditions, as defined in current Swedish legislation and international standards, be achieved for different building programs and in that case with what conditions?

Sub Q2: Can satisfactory thermal comfort conditions, as defined in current Swedish legislation, be achieved for different building programs?

Sub Q3: How do the assessed daylight performance outcomes of the case study compare with current standards and regulations, and to what extent do these findings suggest opportunities to extend daylight performance?

1.3 Standards and certifications

To answer the research questions, the current daylight and thermal comfort standards are explored. For the daylight performance, international, European and Swedish standards are investigated, whereas the thermal comfort is assessed through a Swedish voluntary standard. Multiple standards are further investigated and presented on Table *1*. However, not all target values and requirements are considered in this study. They are added to present the current state of the standards and give an overview of the practices for daylight assessments.

The main standard used for the daylight performance assessment in this study is the European standard EN 17037. The standard specifies methods for achieving comfortable indoor daylight performance through the effective utilization of natural light in occupied areas. This document provides guidance on the use of daylighting to ensure adequate interior illumination while limiting glare. Furthermore, it defines the metrics used for evaluating daylighting conditions and outlines the principles for their calculation and verification (Svenska institutet för standarder, 2021). The minimum daylight provision (E_{TM}) and target illuminance (E_T), the view out and glare are evaluated based on EN 17037 thresholds and calculation methods. Daylight provision and target illuminance describes how natural light is used in a building to meet lighting needs. A space is considered adequately daylit when target illuminance levels are achieved over a defined area for at least half of daylight hours, with an additional minimum level required for certain opening types. View out refers to the visual connection between indoor occupants and the external environment, providing information about weather, time of day, and surroundings, which can help reduce visual fatigue. It is assessed from occupant reference points and is considered to consist of three layers: sky, landscape, and ground. Glare is a visual discomfort caused by excessive luminance differences or bright areas that exceed the eye's adaptation level, leading to annoyance, reduced visual performance, or impaired visibility (Svenska institutet för standarder, 2021).

The Swedish National Board of Housing, Building and Planning (Boverket) is in charge of mandatory provisions and general recommendations (BBR) used in Sweden as planning, building, and housing regulations. The daylight metric assessed from this standard is daylight factor (DF) median. Regularly occupied rooms or room parts should be designed to ensure adequate access to daylight where possible, typically corresponding to a daylight factor of 1% (*Boverket´s Mandatory Provisions and General Recommendations, BBR*, 2018).

The melanopic equivalent daylight illuminance (*mEDI*) thresholds that would be followed in this study are based on Brown et al., (2022), which is widely used as guideline for circadian daylight design.

According to Brown et al., (2022) a minimum melanopic equivalent daylight illuminance of below 1 lux at eye level at 06:00 and below 10 lux at 19:00 is recommended for indoor residential and daytime environments to support circadian health. Additionally, WELL Building Standard V2 assesses mEDI and equivalent melanotic lux (EML). This is a way to measure the biological effect of light on human beings (*Circadian Lighting Design | WELL Standard*, n.d.). WELL V2 provides a collection of science-based strategies that support human health and well-being through design, operational practices, and policy measures, while encouraging a culture focused on health and wellness (WELL Certified, 2025). WELL V2 is internationally recognized standard for designing spaces for human well-being.

Leadership in Energy and Environmental Design (LEED) provides a framework for designing and certifying green buildings that are healthy, resource-efficient, and cost-effective, while also delivering environmental and social benefits (*LEED Rating System | U.S. Green Building Council*, n.d.). The daylight metric from LEED, introduced in Table *1*, is spatial daylight autonomy (sDA), however, it is not used in this study. The sDA is similar to the E_{TM} and E_T metrics from EN 17037. It is a metric that describes the annual availability of daylight in indoor environments. It is expressed as the percentage of an analysis area that achieves a specified minimum illuminance level for a defined portion of the annual operating hours (*Spatial Daylight Autonomy | HB-Radiance Primer*, 2022).

BREEAM is a UK-based building certification system developed by the Building Research Establishment (BRE) and widely used across Europe to assess environmental performance in buildings (*About BREEAM SE - Sweden Green Building Council*, n.d.). The Swedish adaptation, BREEAM SE, is used on the Swedish market. It aims to certify new buildings by evaluating and scoring areas such as energy use, indoor climate, water, and waste management, with results combined into an overall rating level (*About BREEAM SE - Sweden Green Building Council*, n.d.).

The regulation used for the thermal comfort threshold is Forum for Energy Efficient Buildings (FEBY12), which is a voluntary document in Sweden (Swedish Centre for zero energy, 2012). It refers to thermal comfort thresholds from Beställargruppen Lokaler (BELOK), which indicate setpoints to be applied for the indoor ventilation systems, to overcome overheating (Swedish Centre for zero energy, 2012). According to the document, the thermal comfort is measured in overheating hours percentage during the months between April and September. The overheating hours percentage should not exceed 10% (Swedish Centre for zero energy, 2012).

Table 1 Target measurements and their threshold values from daylight standards

Standards	**Measurements**	**Requirements**					
EN 17037	**Target illuminance**	**Level of recommendation for vertical inclined daylight openings**	**Target illuminance E_T (lx)**	**Fraction of space for target level F_{plane} (%)**	**Minimum target illuminance E_{TM} (lx)**	**Fraction of space for minimum target levels (%)**	**Fraction of daylight hours F_{time} (%)**
		Minimum	300	50	100	95	50
		Medium	500	50	300	95	50
		Maximum	750	50	500	95	50
LEED v4.1	**Spatial Daylight Autonomy**	*For New Construction, Core and Shell, Schools, Retail, Data Centres, Warehouses and Distribution Centres, Hospitality:*					
		The average sDA300/50% value for the regularly occupied floor area is at least 40%					
		The average sDA300/50% value for the regularly occupied floor area is at least 55%					
		The average sDA300/50% value for the regularly occupied floor area is at least 75%					
		Each regularly occupied space achieves sDA300/50% value of at least 55%					
		OR					
		Demonstrate illuminance levels are between 300 lux and 3,000 lux at both 9 a.m. and 3 p.m. Spaces with view-preserving automatic (with manual override) glare-control devices may demonstrate compliance for only the minimum 300 lux illuminance level.					
		New Construction, Core and Shell, Schools, Retail, Data Centres, Warehouses and Distribution Centres, Hospitality					
		Percentage of regularly occupied floor area					
		55%					
		75%					
		90%					

BBR	**Daylight factor**	DF *median* ≥ 1%			
EN 17037	**View out**	**View out**	**Horizontal sight angles**	**Outside distance of the view**	**Number of layers to be seen from at least 75% of utilized area: sky, landscape (urban and/or nature), ground**
		Minimum	≥ 14°	≥ 6,0 m	At least landscape layer is included
		Medium	≥ 28°	≥ 20,0 m	Landscape layer and one additional layer is included in the same view OPENING
		High ≥ 54° all layers are included in the same	≥ 54°	≥ 50,0 m	all layers are included in the same VIEW OPENING
BREEAM-SE		Where 75% of the occupied space in relevant areas of the building must meet the criteria (according to EN 17037) for the minimum level.			
LEED v.41		Provide occupants in the building with a view to the outdoor natural or urban environment for 75% of all regularly occupied floor area. Auditoriums, conference rooms dedicated to video conferencing, and gymnasiums may be excluded. Views into interior atria may be used to meet up to 30% of the required area.			
EN 17037 and BREEAM-SE	**Glare**	**Criterion disturbing glare probability (DGP)**			
		Glare is mostly not perceived		DGP ≤ 0,35	
		Glare is perceived but mostly not disturbing		0,35 < DGP ≤ 0,40	
		Glare is perceived and often disturbing		0,4 < DGP ≤ 0,45	
		Glare is perceived and mostly intolerable		DGP ≥ 0,45	
		Level of recommendation for glare protection	**DGP<5%**	The daylight glare probability DGP is an approach to consider both the illuminance at eye level and individual glare sources of high luminance to estimate the fraction of dissatisfied persons.	
		Minimum	0,45		

		Medium	0,4	
		High	0,35	
WELL V2	**Melanopic exposure [mEDI]**	**Threshold**		**Threshold for Projects with Enhanced Daylight**
		Not for dwellings and guest rooms *(The following light levels are achieved for at least four hours (beginning by noon at the latest) at a height of 18 in above the work-plane for all workstations in regularly occupied spaces)*		
		At least 150 EML [136 melanopic EDI]	OR	At least 120 EML [109 melanopic EDI]
		At least 275 EML [250 melanopic EDI]	OR	At least 180 EML [163 melanopic EDI]
		For dwellings and guest rooms		
		At least 150 EML [136 melanopic EDI]	OR	At least 120 EML [109 melanopic EDI]
		At least 275 EML [250 melanopic EDI]	OR	At least 180 EML [136 melanopic EDI]

2 Methodology

The project focuses on evaluating interior daylight conditions and thermal comfort in an adapted industrial building where the original envelope is kept as an exterior shell (see Figure *1*).

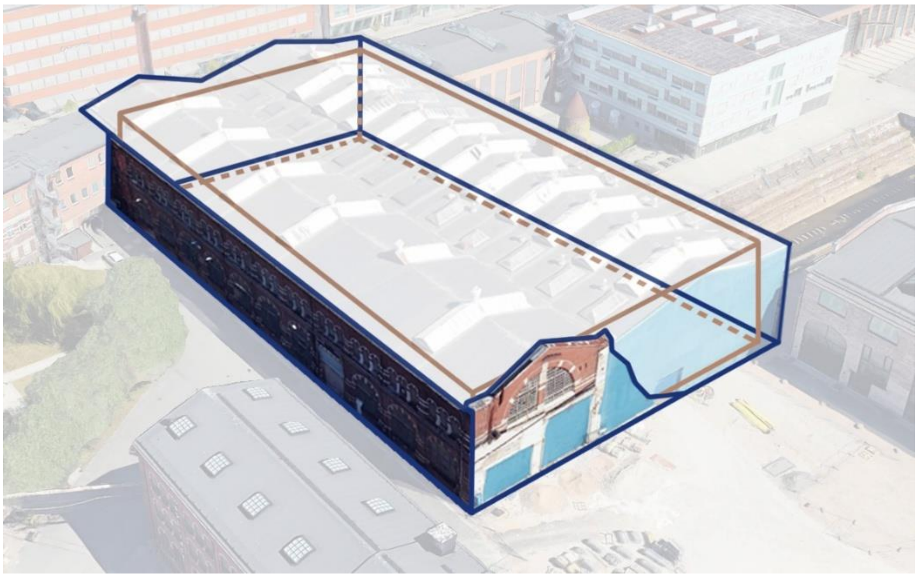


Figure 1 Conceptual 3D visualization of the proposed case study

The site is located in 55°36'43.7"N 12°59'25.2"E Malmö, Varvsstaden area, Southern Sweden (see Figure *2*) and the building is currently under deconstruction. The following adaptive reuse strategies are integrated: preserving the existing envelope and critical structural elements while introducing a new interior building with a flexible floorplan. The layouts are designed to accommodate different building programs, such as office, educational and residential to provide further versatility to future needs. The daylight conditions are evaluated through daylight factor, view out, EN 17037 illuminance-based method (E_T and E_{TM}) and vertical illuminance at eye-level. The latter used as a proxy for circadian potential. The thermal comfort assessment is based on overheating hours, which means that the operative temperature of the room during occupied hours are not exceeding more than 80 hours per year above 24°C or 26°C (Swedish Centre for zero energy, 2012). This is assumed to be equivalent to 10% of the period between April and September (Swedish Centre for zero energy, 2012). Each function and layout is assessed through these values to see if they meet the requirements. A digital model was built in Rhinoceros® 8 by Robert McNeel & Associates® based on building documentation and architectural plans with a precision of 5 cm. Thermal comfort is assessed through simulations using the Radiance rendering engine via Honeybee (HB) by Ladybug Tools® within the Grasshopper environment in Rhino and daylighting is evaluated through ClimateStudio (CS).

Figure 2 Site map of the Varvsstaden area in Malmö, Sweden

2.1 Thesis flowchart

The process of conducting this research is visualized in Figure *3*. The tasks listed for each stage for all four areas of work listed performed simultaneously.

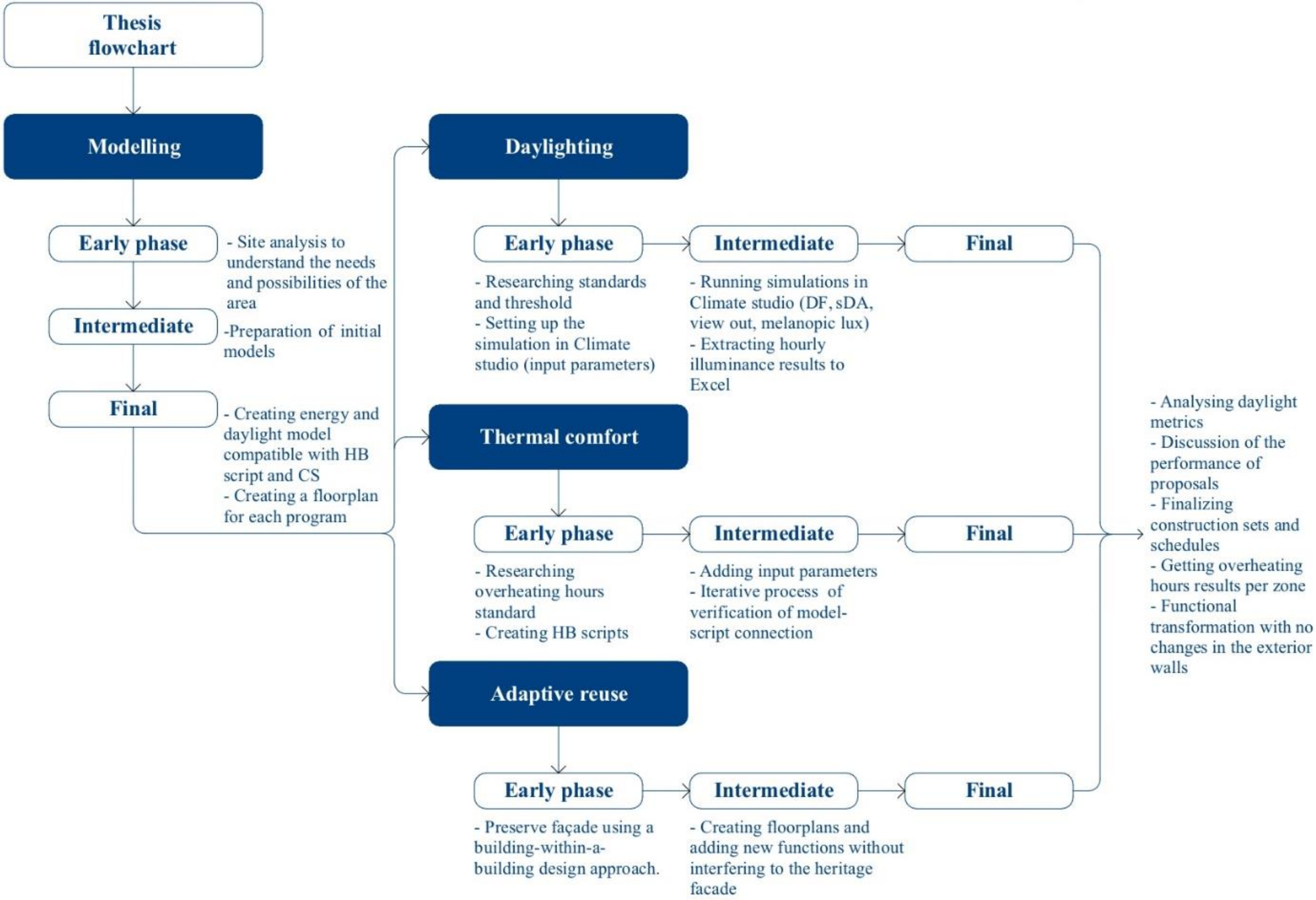


Figure 3 The thesis flowchart

2.2 Site analysis

The site analysis was performed by acquiring documents from the real estate developer of the area, Varvsstaden AB, having a site visit to this industrial district and to the case study building and assessing the weather data in Malmö with Grasshopper.

A climate analysis on Malmö city was performed to assess the outdoor temperatures and solar exposure of the building. The weather data is considered when performing the thermal comfort analysis and daylight availability. The average temperature in Malmö is 9,04°C, the minimum is -7,3°C and maximum is 29,4°C. The graphs showing the total radiation, horizontal global radiation, dry bulb temperature and solar radiation map of the site are presented in Figure *A 1*, Figure *A 2* and Figure *A 3* in Appendix A Site analysis. Figure *4* presents the solar exposure on the building from each façade and the roof based on the simulation. It shows the solar radiation in kWh/m^2. On Figure *A 4* in Appendix A Site analysis the radiation map of the site is presented.

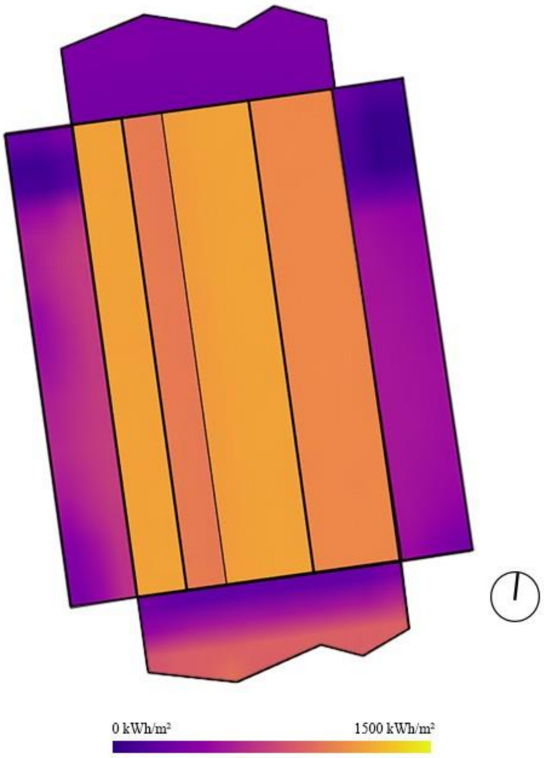


Figure 4 Exploded solar radiation map of the case study building

The analysed building is the old Machine and Assembly Hall in Varvsstaden area, Malmö. It is approximately 14 meter high, 53 meters wide and 95 meters long, therefore it is about 5000 m^2. Historically, Varvsstaden's land was first developed during the second half of the 19th century. Kockums Mekaniska Verkstad AB, a Swedish ship manufacturer company moved partly their operations here. In 1910, Swedish architect Axel Stenberg designed a series of red brick industrial buildings to this area, where the production of manufacturing continued. In 1995, the last submarine was manufactured here. Since then, Varvsstaden is undergoing a transformation into a mixed city. The goal of Malmö city's municipality is for Varvsstaden to become an attractive area with high environmental quality for education, research, businesses, housing, culture and recreation. The heritage of this area is an important link between the central city and Västra Hamnen. The area concerns one of Malmö's oldest and best-preserved industrial environments. The industrial activity of Kockums Mekaniska Verkstad AB has had enormous significance for the city's development. Its history is closely linked to Malmö's history, and the old harbour area is a unique environment in the city. Today, it is an industrial environment where history is tangible and present with very high conservation values.

The buildings within this area, including the case study building of this project, have been inventoried and assessed for cultural and historical value by Malmö city's municipality (see Figure 5) (*Detaljplan För Fastigheten Hamnen 2 1 : 149 (Varvshallarna) i Hamnen i Malmö*, 2017).

Figure 5 Air-photo of the Kockums area in the 1970s, the case study building can be seen on the left side of the picture (Kockums mekaniska verkstad / Malmö city archive) (Startsida Malmö stad, n.d.)

The original construction of the Machine and Assembly Hall was designed by Axel Stenberg too in 1912. Back then the building was completely free-standing and had the shape of a basilica, consisting of a higher, completely open nave on the inside and two somewhat lower side naves with galleries. To the west, the machine shop was built in 1923 together with the Assembly Hall. In 1937, the building was extended to the south. Then the original south façade disappeared, which was monumental with a large arched window, similar to the preserved north side (see Figure 6) (*Detaljplan För Fastigheten Hamnen 2 1 : 149 (Varvshallarna) i Hamnen i Malmö*, 2017).

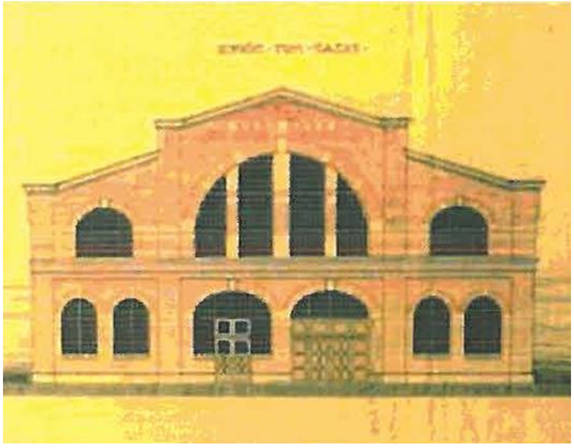


Figure 6 The original elevation layout of the south façade from 1911 (Detaljplan För Fastigheten Hamnen 2 1 : 149 (Varvshallarna) i Hamnen i Malmö, 2017)

The documents provided by the land developer were used to assess the surroundings around the analysed building, their proximity to it and their use. Additionally, as the researched building is currently an ongoing adaptive renovation project, suggestions about its possible use, based on the needs of the area and the developer's perspective, are proposed in the given documents. The suggested building programs based on the received documents are the following: retail, offices, hotels, educational functions, healthcare and residential use (see Figure 7).

Figure 7 The suggested building programs per area in Varvsstaden, Malmö (Detaljplan För Fastigheten Hamnen 2 1 : 149 (Varvshallarna) i Hamnen i Malmö, 2017)

The main concept of this case study is to use the original façade of the Machine and Assembly Hall as a shell and build a building within a building. The original façade remains the same, with red brick with abundant patterned masonry in white lime sandstone. The round-arched window openings are equipped with small-barred iron windows, as are the later square window openings to the east (Figure *6*) (*Detaljplan För Fastigheten Hamnen 2 1 : 149 (Varvshallarna) i Hamnen i Malmö*, 2017). The north façade, facing Stora Varvsgatan Street, is dominated by a large, semi-circular window, while the southern, extended façade has a more modern opening design, but at the time of the site visit it was also undergoing deconstruction (see Figure *8* and Figure *9*). On the roof there are long skylights. The interior of the building has been preserved with a completely open space, which offers flexibility for adaptive reuse. The site visit also helped to get familiar with the space and reassure that the volume is big enough to handle the hypothesized building within the building.

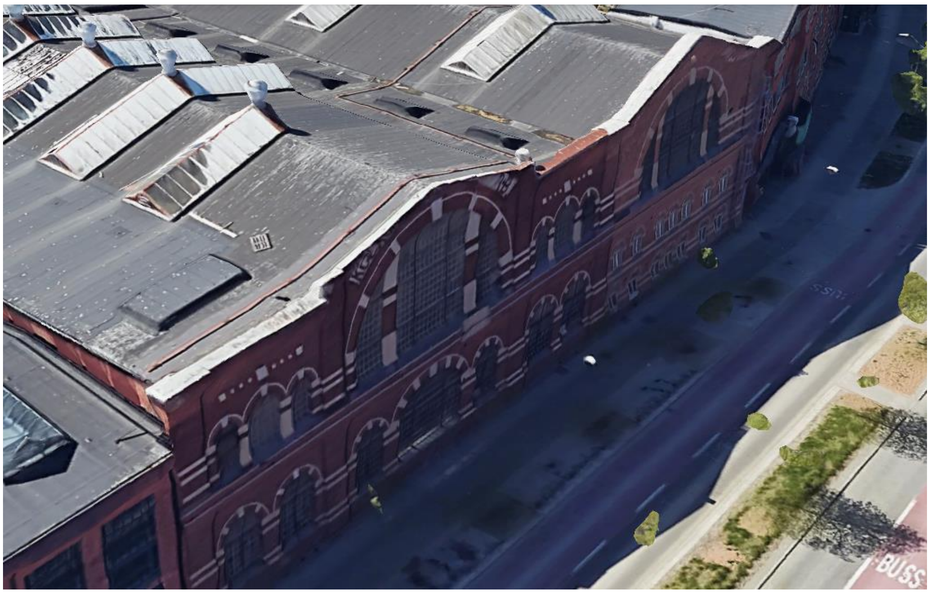


Figure 8 Air-photo of the north façade of the case study building (source: Google Earth)

Figure 9 The state of the south façade during the site visit

(a) (b)

Figure 10 (a), (b) The state of the interior of the warehouse during the site visit

The site visit was conducted on 2025 December 4th. Figure *10 (a), (b)* show the state of the building at the day of the visit. During the site visit, measurements of the materials reflectance and indoor illuminance of the building were done between 12:30 and 14:00 o'clock under overcast sky conditions. As the building was under deconstruction, only the first floor of the east façade of the building was possible to be measured. Due to the condition of the ground floor's east façade, which was highly affected by a previous fire incident, no measurements were made. Most of the windows on this part of the building were highly damaged or boarded-up. The reflectance of main surfaces was measured with a calibrated spectrophotometer Konica Minolta CM-26dG, while daylight illuminance was measured with calibrated Hagner EC-1 luxmeters. Resulting from the years of abandonment and the current construction work, the windows and skylights were in bad condition, which most likely affected the value of the assessment.

2.3 Definition of programs

Three different programs for suggested usage were envisaged for the building: office, educational, and residential (see Figure *11*). The main possible usage of the building was provided by Varvsstaden AB. Based on the suggested programs; the main choice was an office program. Additionally, the building was previously planned to facilitate an educational institution, that is why was educational program was also chosen. Close to this industrial area, Malmö University has multiple buildings. The municipality's vision is clear to expand educational use under the development of this area as well.

To test different schedules of occupancy and how that would affect the thermal comfort performance, residential program was chosen. This would test the ability of the building to accommodate apartments and simulate its performance for more extensive occupancy schedule, compared to the educational and office program which have similar occupancy schedules. In the public functions, office and educational, the occupied hours start at 07:00. The educational occupancy schedule ends at 18:00 where the educational occupancy ends at 17:00. The residential program has a 24-hour schedule. The occupancy schedules can be seen in Appendix B Program schedule inputs. The input parameters for each building program can be seen in 2.5.1 Energy simulation in Table *4*. Moreover, this fast-expanding area has accommodated multiple offices, so housing is an important part of the district too to be solved. Also, as the former two programs focus on the daylight provision during working hours during the day, the residential program shifts the focus from daylight availability to circadian rhythm measurements.

(a) (b) (c)

Figure 11 (a), (b), (c) First floor layout of the three different building programs: office, educational and residential

2.4 Modelling

Both energy and daylight models were created based on the documents received from the developer of the ongoing renovation of the case study building. This gave the starting point for 3D modelling, in both models the exterior facade, the "shell" was made based on these drawings. It followed the original outline and construction of the Assembly Hall.

The here suggested interior building within the building was based on the received architectural plans. Since on the floorplans a part of the first floor was offset from the exterior wall, this distance was followed for the whole interior building. The interior walls are therefore placed 0,5 meters away from the original facade on every side. One of the advantages of this cavity space between the exterior shell and the interior walls provides an extra air-layer to the building. Air is a poor conductor of heat, so it functions as a thermal break between the shell and the interior wall (M. Almansour, 2018). In case of overheating, it can also help to cool down the building naturally with the help of the stack effect (Lim et al., 2020). It was important to not design the cavity space too deep, since that would have made the building within the building more away from the window, which therefore would have reduced the daylight availability of the occupied spaces. The interior walls were designed to be made of a cross-laminated timber (CLT) construction. An axonometric view of the building with a building is presented on Figure *12*.

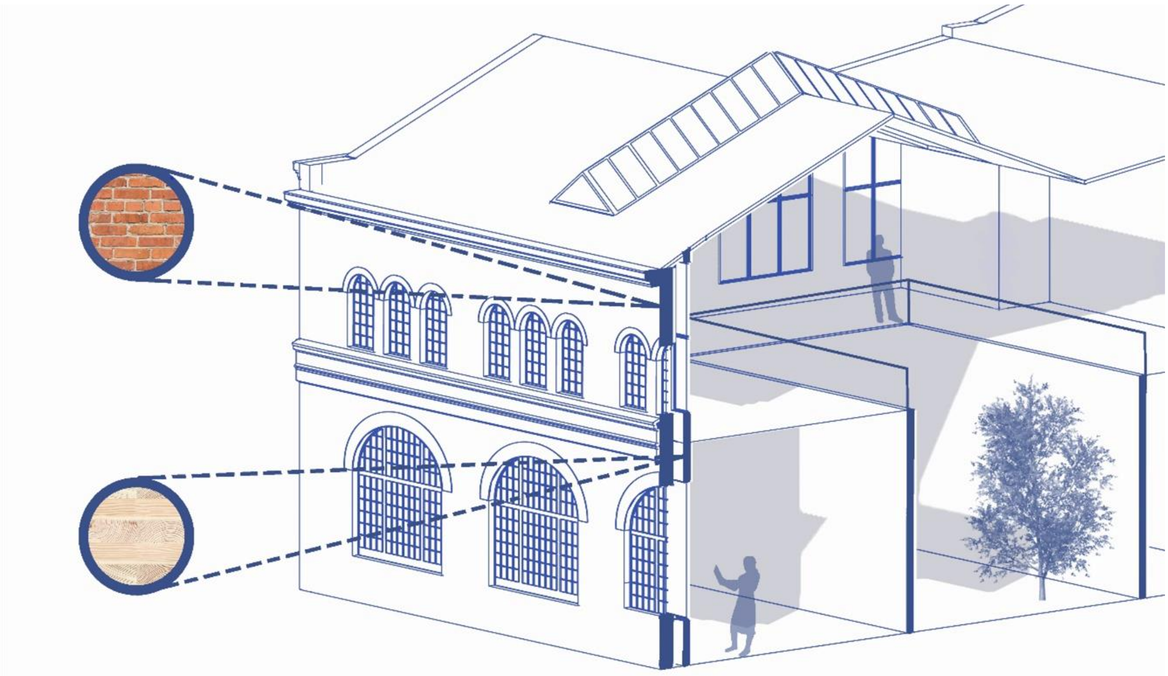


Figure 12 Axonometric visualization of the case study that shows the exterior wall as a shell and the new construction inside

2.4.1 Energy model

The energy model in Rhino was created in a way, so the Honeybee script correctly recognises the hierarchy between exterior and interior walls, ceiling and floors and the rest of the building elements. This model was also a simplification of the original building; however, the construction remains the same, therefore the thermal mass stays consistent. The first step was to model the exterior facade. Four vertical surfaces were connected; these surfaces represented the outer side of the exterior wall. The windows were simplified to single, larger openings on each building façade, since the window-to-wall ratio is of importance for Energy Plus simulations, rather than detailed shapes. The same process was followed when creating the skylights. The original shape of the roof was also simplified to a flat roof. Modelling the interior building within the shell was more challenging for Honeybee to recognise them as walls inside the building. Therefore, the occupied spaces were modelled alongside with the unoccupied spaces, following the same strategy of connecting the surfaces. So, every surface, every interior wall, ceiling and floor was doubled, and later in the script separated. Each room was modelled as a separate zone, even the cavities, such as the space between exterior and interior wall, the open spaces and the atriums. In the illustration, the zone between the exterior and interior wall, the occupied and unoccupied zones are shown with different colours. The energy zones are shown on Figure *13*.

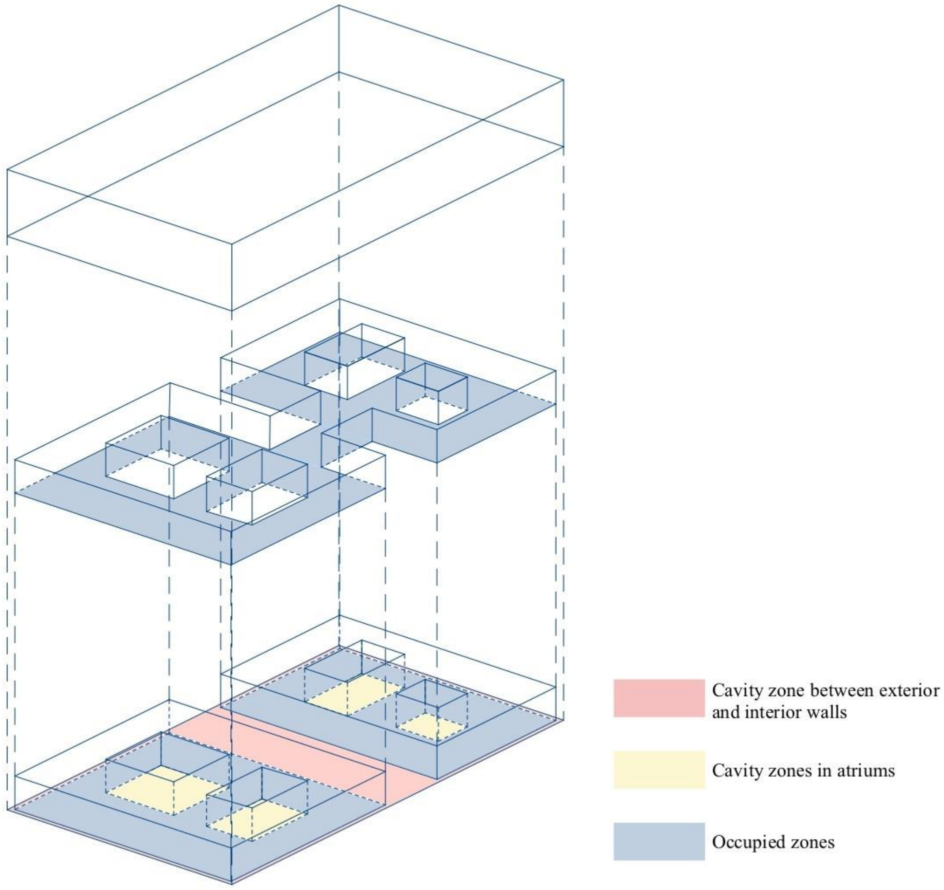


Figure 13 3D visualization of the energy model per floor, which shows the thermal zones in open spaces

2.4.2 Daylight model

Following best practice, the daylight model is more detailed than the energy model, see Figure *14*. The windows, the window frames, the wall thicknesses and 3D facade detail all influence on the daylight simulation results, this is why an accurate and comprehensive model was made. These details might cast shadows, reflectance or act as surfaces where light can bounce from, which could affect the daylight performance (Dubois et al., 2025). The exterior facade details were based on the received architectural drawings.

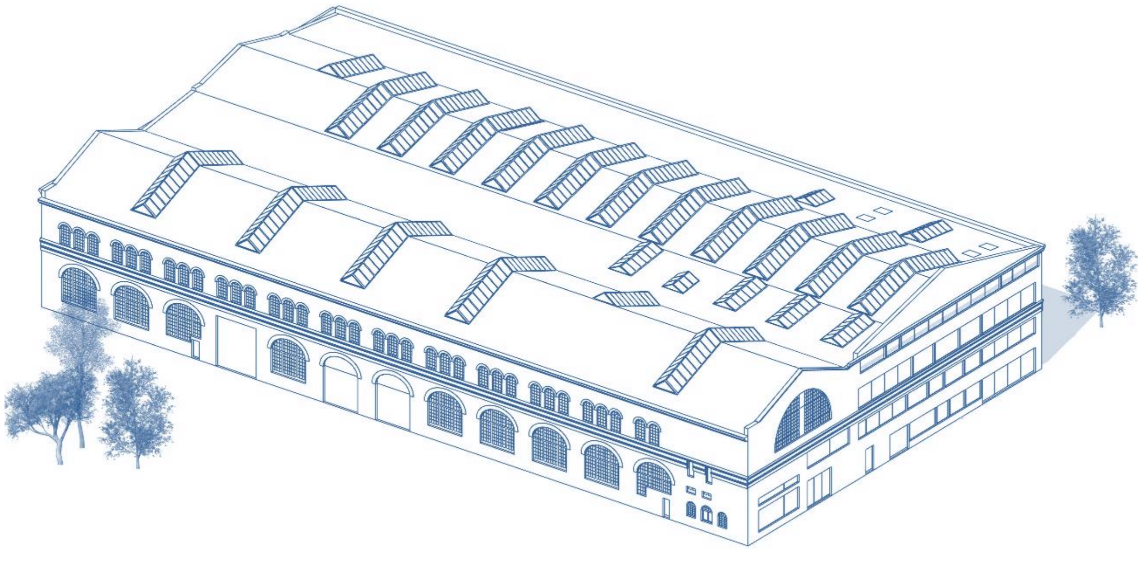


Figure 14 Axonometric 3D view of the daylight model

2.5 Creating scripts

To perform the thermal comfort and daylight simulations, the data simulation programs Grasshopper and ClimateStudio were used. Grasshopper is the visual programming environment used within Rhinoceros 8, in Grasshopper the plug-ins Honeybee and Ladybug tools were used. ClimateStudio is used for environmental performance analysis, specifically daylight simulations. ClimateStudio is a plugin for Rhinoceros 3D (*ClimateStudio*, n.d.).

2.5.1 Energy simulation

A script in HB was created to perform the thermal comfort analysis. First, each layer of the building envelope was connected to sperate HB Face components, which are connected to HB Room. The model has 8 energy zones for the office and educational program, which are separated by the HB Room components. They are divided by the use of the spaces; exterior shell, 4 atriums, ground floor with north orientation, ground floor with south orientation and first floor. The first floor is considered 1 energy zone since both parts of the building are connected by a bridge. In the case of residential program, 4 additional zones are added, which are the selected apartments based on their daylight performances. The corridors were not assessed for thermal comfort in the residential program. Each construction layer was connected to the respective building material. The construction layers and windows were custom made or chosen from the HB library as it can be seen on Table *2*, Figure 15, Figure 16 and Table *3*. The construction sets taken from the HB Library are chosen based on the appropriate total U-value. The layers in these constructions are assumed based on the detailed drawings from (Föreningen Sveriges Skogsindustrier, 2026). The three different programs for usage, educational, office and residential, were chosen from the HB Search Programs component. The program inputs can be seen on Table *4* below. Internal loads were set to zero for the spaces which are unoccupied, such as the atriums and the exterior shell. The setting is called Plenum and all the loads such as people, electric lightning and equipment, hot water, gas equipment, ventilation, set point are set to zero. The schedules that were used can be seen on Table *B 1*, Table *B 2* and Table *B 3* in Appendix B Program schedule inputsAs they are taken from the HB library, they are based on the ASHRAE 90.1 standard (*ASHRAE-90.1-2022-.Pdf*, n.d.).

Table 2 Construction inputs of the energy script

Construction	**Thickness /m**	**Materials**	**Total U-value /(W/(m^{2}K))**	**Source**	**Reference**
Exterior wall	0,5	Brick	1,95	Custom	(Svenska institutet för standarder, 2007)
	0,02	Plaster			
Ground floor	0,02	Flooring	2,42	Custom	(Svenska institutet för standarder, 2007)
	0,2	Concrete			
	0,2	Gravel			
Interior wall	0,15	Generic wood	0,7	HB library	-
Roof	0,25	Metal roofing	0,97	HB library	-
Floor/ Ceiling	0,02	Flooring	0,41	Custom	(Svenska institutet för standarder, 2015)
	0,08	Mineral wool			
	0,12	Concrete			

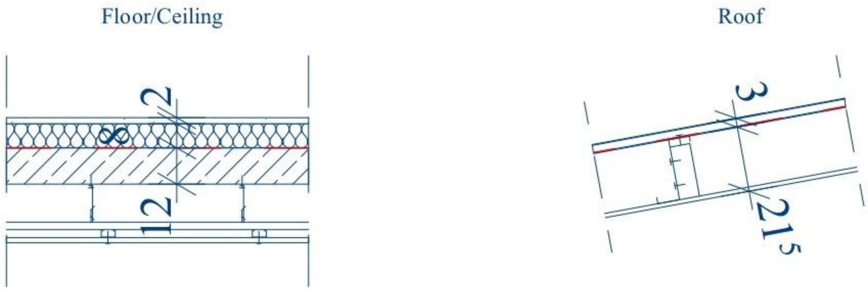


Figure 15 Sections of the construction inputs (Ceiling and Roof)

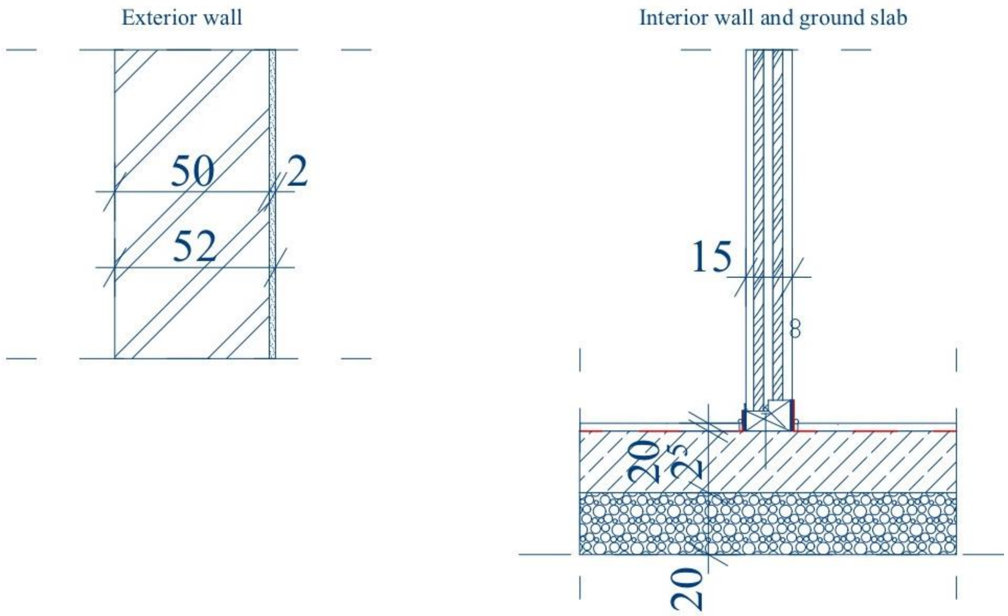


Figure 16 Sections of the construction inputs (Exterior wall, Interior wall and Ground slab)

Table 3 Construction inputs of the windows in the energy script

Construction	**Total U-value $/(W/(m^2K))$**	**Solar Heat Gain Coefficient (g-value)**	**Visible transmittance (T_{vis})**	**Source**
Exterior original windows, skylights	5,4	0,75	0,8	(Double Glazing Windows Installer, 2025)
Interior windows	1,4	0,75	0,8	(Eurac Research, 2026)

Table 4 Input parameters per building programs of the energy script

Input parameters	**Office program**	**Educational program**	**Residential program**
Program type from HB	Large office: Open office	College: Lecture Hall	Midrise apartment: Apartment
Simulation period	The simulation period for overheating hours is the same for all the programs, in a year from April 1st to September 30th		
People density / (people/m^2)	0,06	0,7	0,03

Input parameters	Office program	Educational program	Residential program
Lighting density / (W/m^2)	6,6	6,6	9,4
Equipment density / (W/m^2)	7,6	10	6,7
Infiltration rate / (l/s-m^2)	0,227	1,024	0,596
Heating setpoint / °C	21	21	22
Cooling setpoint / °C	24	24	24
Ventilation rate per person / (l/s-person)	2,4	0	0
Ventilation / ACH	0	0	0,35

The energy simulation was performed for a one-year period. A weather file data for Malmö was taken from the EPW map from Ladybug Tools (*EPW Map*, n.d.). Based on the simulated results, the operative temperature on the ground floor north and south orientation and the first floor was considered. The overheating hours were calculated based on the temperatures between April and September and additionally as a sensitivity analysis between July and August too. The months for sensitivity analysis were chosen based on the results of the climatic site analysis in 2.2 Site analysis, where the months with the highest dry bulb temperature and total radiance are July and August. For the sensitivity analysis, the same threshold was considered, 10 %, as from the assessment based on the standard (Swedish Centre for zero energy, 2012). The results were extracted for each program.

The thermal comfort was measured based on overheated hours, which means that the operative temperature of the zone during occupied hours are not more than 80 hours per year above 26 °C. The threshold is 10 % of the period between April 1st and September 30th. Additionally, as a sensitivity analysis, another period was assessed: from July 1st until August 31st, and it was not only tested at 26°C but 24°C as well.

2.5.2 Daylight simulation

The daylight simulations were done in CS in Rhino8. This was done due to the size and detail level of the building model. To perform the simulations, the layers from the Rhino model were assigned to a building material that represents the real-life's reflectance performance, which was measured on site. For the windows a single-pane window with high transmittance, 77 %, was taken (see Table *6*). A table with the materials and their reflectance values is presented in
Table *5* and Table *6*.

Layer	Material	VLR Total / %	VLR Specular / %
Roof	New Black Asphalt	4,2	0
Ground slab	Exterior Concrete floor	22 (Swedish Centre for zero energy, 2012)	0,6
Exterior façade and surrounding buildings	Historic Brick Wall	24,4	0
Doors	Painted metal door	17,5	2,4
Window frames	Mullion grey	23,6	2,8
Interior wall	Off-white Plaster Wall	84,1	0,4
Interior floor	Laminate floor	23,3	0,9

Table 5 Construction inputs of the daylight simulation

Layer	**Material**	**VLR Total / %**	**VLR Specular / %**
Roof	New Black Asphalt	4,2	0
Ground slab	Exterior Concrete floor	22 (Swedish Centre for zero energy, 2012)	0,6
Exterior façade and surrounding buildings	Historic Brick Wall	24,4	0
Doors	Painted metal door	17,5	2,4
Window frames	Mullion grey	23,6	2,8
Interior wall	Off-white Plaster Wall	84,1	0,4
Interior floor	Laminate floor	23,3	0,9

Table 6 Construction inputs of the windows in the daylight simulation

Layer	**Material**	**VLT / %**	**VLR front / %**	**VLR back / %**	**Solar Heat Gain Coefficient (g-value)**
Skylights, exterior and interior windows	Solexia, single pane	76,8	7,5	7,6	0,62

The daylight analysis was performed on each room or open space for the three building interior layouts, which are based on the use of the space for office, educational or residential purposes. Five daylight performance indicators were tested. The *DF*, target and minimum target illuminance (E_T and E_{TM}) according to EN17037, view out and vertical illuminance from daylight were simulated for all building programs. Glare was tested for the educational and office programs. The daylight factor is tested on a uniform diffuse sky. The target illuminance (E_T and E_{TM}) was tested using the Malmö weather data taken from the CS library. The hourly illuminance was extracted in a csv-file in order to calculate the target illuminance based on the EN 17037 daylight standard which are presented in **Error! Reference source not found.**. This was calculated by extracting the hourly illuminance values for each point of the grid for all daylit hours. The glare was tested based on the daylight glare probability (*DGP*), which was simulated on CS. The view out was simulated with CS and the values based on the EN 17037 standard were considered for this research. Lastly, the melanopic exposure was simulated through spectral point-in-time illuminance workflow with an analysis mode vertical eye illuminance. This simulation gives as an output the equivalent melanopic lux (*EML*). In this analysis the melanopic equivalent daylight illuminance (*mEDI*) is assessed so the *EML* values were converted to *mEDI* by multiplication by 0,9063 (Huang et al., 2024). For the office and educational programs, measurements were performed during the autumn equinox at 09:00, 12:00 and 15:00 o'clock. For the residential program, the apartments, which fulfilled the target illuminance and *DF* requirements, were chosen. Additionally, apartments with low daylight performance and medium daylight performance were added to compare and assess their melanopic lux. For the residential program the summer solstice and autumn equinox were selected following common practice. It is because these dates represent the extremes of daylight duration and solar angles. The times for measurement are 06:00 and 19:00 o'clock. The simulations for all building programs was done for CIE overcast and CIE clear sky conditions. Different times were chosen based on the threshold values and required *mEDI*. All daylight metrics were set to have 12 ambient bounces and 0,01 weight limit. For the daylight availability metrics the grids were placed 0,6 meters away from each other and the work plane offset was 0,85 meters.

During the *DGP* and *EML* assessment the grids were 2,4 meters away. The *EML* sensors were offset at eye level, 1,2 meters. The view division was 8 and the view rotation was at 0°.

3 Results

In this section the results from the site analysis, daylight simulations and thermal comfort performance in terms of overheating hours percentage for the three functions are presented.

3.1 Daylight performance

For all programs their relevant daylight metrics are presented. The compliance of the results with the thresholds defined from the current standards is visualized and presented in graphs and tables.

3.1.1 Office program

For the office program the daylight factor *median*, target illuminance (E_T) and minimum target illuminance (E_{TM}), glare, view out and *mEDI* were tested. The layout of the office space for the ground and first floor can be seen on Figure *17*.

(a) (b)

Figure 17 (a), (b) Office program layout in 1:500 (left: ground floor, right: first floor)

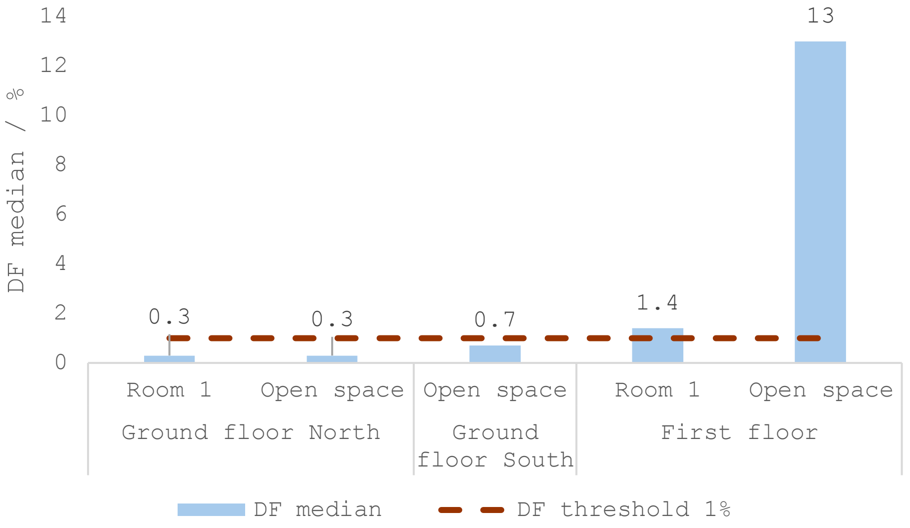


Figure 18 Daylight factor median percentage for the office program

Figure *18*Figure *18* shows the daylight factor results for each space, included the required daylight availability, from the office layout. Room 1, on ground floor north, is located on the north façade of the building and does not receive enough daylight to meet the *DF median* threshold of 1%. The open spaces on the ground floor perform poorly as the space is deep and there is not enough daylight provision from the windows. Additionally, the atriums do not contribute significantly to daylight penetration, as they are enclosed and the modelled skylights are not positioned directly above them, resulting in poorly illuminated spaces. The first-floor open space and room 1 meet the *DF median* requirement, making it suitable area in terms of *DF* performance. The first floor has high *DF median* because of the skylight and windows, making the space very well-lit and uniform, therefore it reaches 13% *DF median*. The daylight distribution of the *DF* can be seen on Figure *C 1* (a), (b) Daylight factor distribution in office layout (left: ground floor, right: first floor)in Appendix C Layouts and Daylight performance on building layout, where the high daylight factor percentage distribution can be seen on the first floor.

Table 7 Target illuminance performance for office program

Floor/ orientation	**Room number**	**Minimum**	**Medium**	**Maximum**
Ground floor North	Room 1	*Fail*	*Fail*	*Fail*
	Open space	*Fail*	*Fail*	*Fail*
Ground floor South	Open space	*Fail*	*Fail*	*Fail*
Floor/ orientation	**Room number**	**Minimum**	**Medium**	**Maximum**
First floor	Room 1	*Fail*	*Fail*	*Fail*
	Open space	*Pass*	*Pass*	*Pass*

The target illuminance has similar performance between the ground and first floors as the *DF*. The target illuminance is presented based on the pass-fail criteria for minimum, medium and maximum requirements from the EN 17037 standard. The ability of the spaces to meet or fail the target and minimum target illuminance requirements is presented in Table *7*. Table *D 1* in Appendix D Resultspresents the results for each illuminance threshold: 100 lux, 300 lux, 500 lux, and 750 lux, achieved for at least 50% of the evaluated time. These results were used to determine whether each space met the pass or fail criteria. The values that pass the minimum criteria (E_{TM}) are highlighted in lighter blue color. The values passing the higher criteria (medium and maximum) for target illuminance are colored with darker blue to visualize the ability of the building to surpass the minimal requirements. The ground floor does not meet the requirements for both the standard and beyond minimum standard values. The standard threshold is met on the first floor, and the open space meets the requirements due to the availability of skylights which increase the uniform daylight distribution across space.

On Table *D 1* in Appendix D Results, the simulated glare performance for the office layout is presented. On the ground floor north, both the open space and room 1, do not have any perceived glare as the *DGP* is 0,3 % and 0% respectively. On the ground floor south, the glare is perceived as disturbing, *DGP* 2,6%. Despite the poor daylight availability performance of the area with south orientation of the ground floor, there is high contrast between the windows and the interior space. On the first floor, room 1, as it has north orientation, the *DGP* is 0%. The open space presents a major difficulty as the glare perceived is intolerable. The *DGP* is 40,5%, which is caused by the large area of windows and skylight on this floor. The glare distribution on the office layout can be seen on Figure *C 10*Figure C 10 (a), (b) Glare distribution in office layout (left: ground floor, right: first floor) in Appendix C Layouts and Daylight performance on building layout

Table 8 View out performance for office program

Floor/ orientation	**Room number**	**View out / % (EN 17037)**			
		Fail	**Minimum**	**Medium**	**High**

Ground floor North	Room 1	100	0	0	0
	Open space	26	74	0	0
Ground floor South	Open space	49	51	0	0
First floor	Room 1	99,5	0,5	0	0
	Open space	7	43	50	0

Table *8* visualizes the view out from the office floor plan. The four categories: fail, minimum, medium and high, add up to a 100%, which is the area of the studied space. Based on this, 75% of the area that covers requirements is determined. When the fail category is less than 35%, then the space analyzed is considered to have sufficient view out. The view out requirements is fulfilled only by the open space on the first floor. The rest of the area does not cover the requirements.

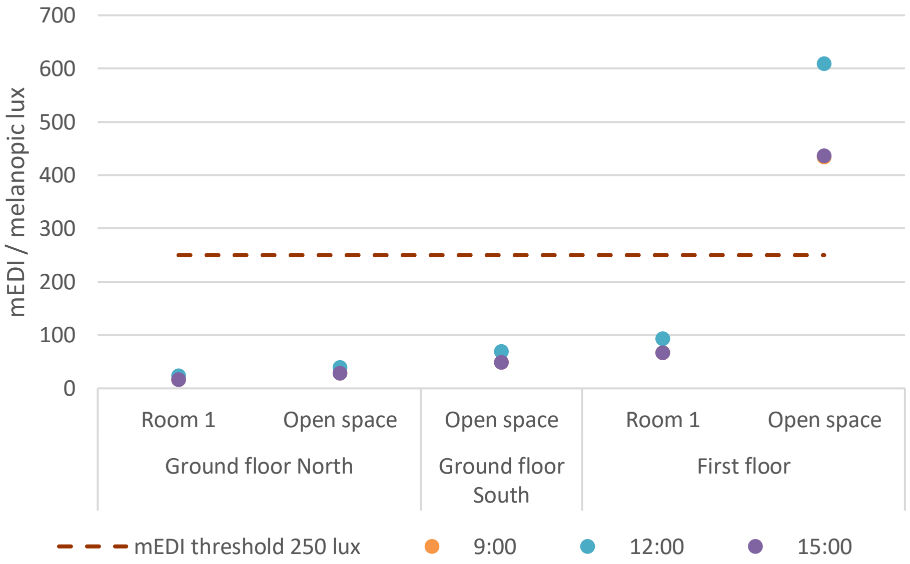


Figure 19 Melanopic equivalent daylight illuminance for office program with overcast sky

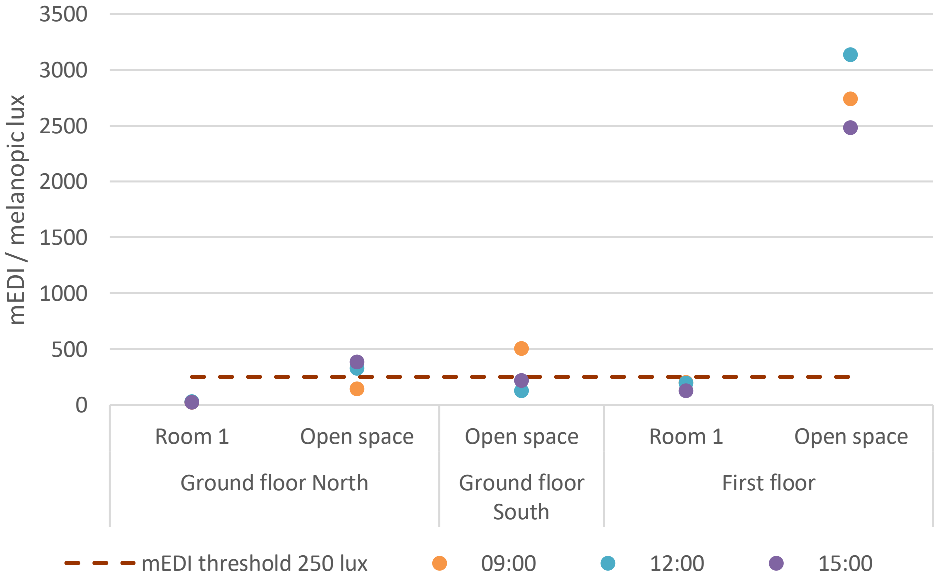


Figure 20 Melanopic equivalent daylight illuminance for office program with clear sky

The melanopic equivalent daylight illuminance was simulated during September 22nd for clear and overcast sky (see Figure *20* and Figure *20*). This is done to verify whether there is sufficient light exposure to support the circadian rhythm of the body. Both for the clear sky and overcast sky, the *mEDI* threshold, 250 melanopic lux, is surpassed on the open space on the first floor. In the north open space on the ground floor the threshold is reached during the 12:00 and 15:00 o'clock measurements and on the south side open space, the melanopic exposure exceeded the threshold at 09:00 o'clock. On Figure *19*, which presents the *mEDI* results for overcast sky, the 09:00 and 15:00 o'clock simulated values are overlapping. This can be justified by the similarity of the sun angle in Sweden at 09:00 and 15:00 o'clock and the total diffuse of sunlight, which results in identical values for these hours.

3.1.2 Educational program

The same daylight metrics as in the office program were investigated for the educational program. The layout of the educational program can be seen on Figure *21*.

(a) (b)

Figure 21 (a), (b) Educational program layout in 1:500 (left: ground floor, right: first floor)

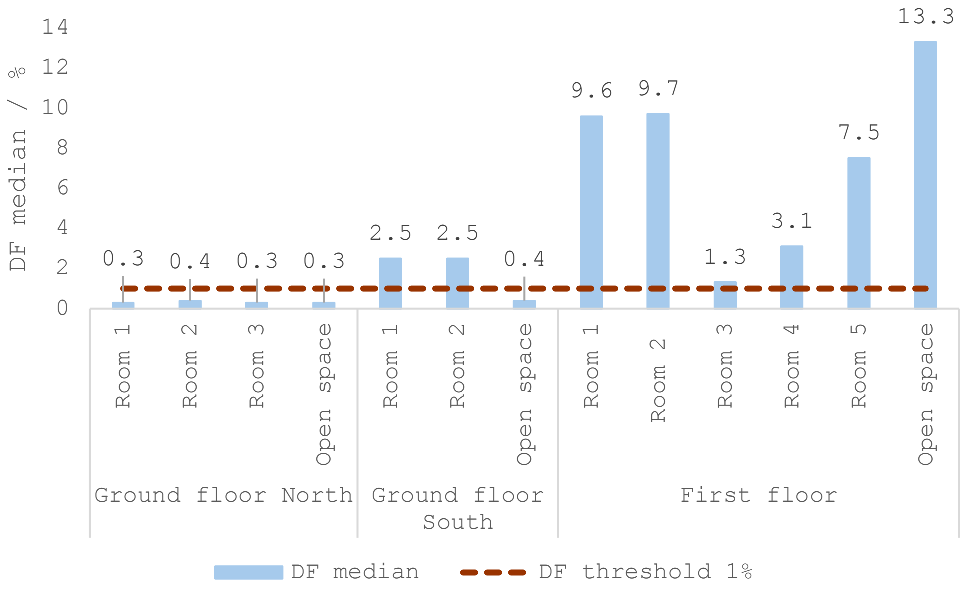


Figure 22 Daylight factor median percentage for the educational program

Figure *22* presents the daylight factor simulated values in the educational layout. The *DF* on the north orientation on the ground floor performs poorly and does not reach the threshold value as there is no sufficient daylight availability. Room 1 and 2 on ground floor south, which face west and east, exceed the minimum threshold, providing satisfying *DF median* percentage. The east and west rooms do not face any obstructions. Also, they are not deep rooms, therefore the illuminance can reach through the whole room and due to their orientation, they receive high illuminance values. All the spaces on the first floor reach the *DF* threshold. This is due to the high window-to-wall ratio and skylights as well as the absence of obstructions in front of the facades.

Table 9 Target illuminance performance for educational program

Floor/ orientation	**Room number**	**Minimum**	**Medium**	**Maximum**
Ground floor North	Room 1	*Fail*	*Fail*	*Fail*
	Room 2	*Fail*	*Fail*	*Fail*
	Room 3	*Fail*	*Fail*	*Fail*
	Open space	*Fail*	*Fail*	*Fail*
Ground floor South	Room 1	*Pass*	*Fail*	*Fail*
	Room 2	*Pass*	*Fail*	*Fail*
	Open space	*Fail*	*Fail*	*Fail*
First floor	Room 1	*Pass*	*Pass*	*Pass*
	Room 2	*Pass*	*Pass*	*Pass*
	Room 3	*Fail*	*Fail*	*Fail*
	Room 4	*Pass*	*Pass*	*Fail*
	Room 5	*Pass*	*Pass*	*Pass*
	Open space	*Pass*	*Pass*	*Pass*

The north oriented part of the ground floor does not reach any of the standard, minimum target illuminance, or beyond values for target illuminance. However, the rooms on the ground floor and all the spaces on the first floor reach the standard threshold for E_{TM}. The open space on the ground floor south fails the requirements as the space is deep and the windows do not provide sufficient lightning. On the first floor every room except room 3, which is north facing, cover beyond the minimum standard thresholds E_T (see Table *9*). Figure C *8* in Appendix C Layouts and Daylight performance on building layoutpresent the lux distribution across the ground and first floors. The table with results for each lux value used by EN 17037 is presented on Table *D 1* in Appendix D Results

The daylight glare probability on the educational layout has similar performance compared to the office layout. All of the areas on the ground floor north do not exhibit any perceivable glare as the *DGP* is 0% for every room. On the ground floor south, every space has *DGP* exceeding the tolerable glare values, which results in uncomfortable glare conditions. On the first floor, only room 3 and room 4, which are north and west oriented have *DGP* of 0%, which makes them comfortable in terms of glare performance. The open space on the first floor presents the highest visually disturbing glare percentage, as the DGP is 45,7%, which significantly exceeds the acceptable threshold. The simulated DGP performance can be seen on Table *D 1* in Appendix D Resultsand the distribution across the educational layout is presented on Figure C *11* Figure C 11in Appendix C Layouts and Daylight performance on building layout

Table 10 View out performance for educational program

		View out / % (EN 17037)

Floor/ orientation	**Room number**				
		Fail	**Minimum**	**Medium**	**High**
Ground floor North	Room 1	11	89	0	0
	Room 2	100	0	0	0
	Room 3	100	0	0	0
	Open space	25	75	0	0
Ground floor South	Room 1	99,7	0,3	0	0
	Room 2	99	1	0	0
	Open space	44	56	0	0
First floor	Room 1	6	94	0	0
	Room 2	98,4	0,4	1,1	0
	Room 3	99,5	0,5	0	0
	Room 4	72	1	27	0
	Room 5	68	6	26	0
	Open space	9	38	53	0

The view out, presented on Table *10*, for the educational program does not meet the 75% threshold for every are except room 1 on the ground floor north and the open space on the first floor.

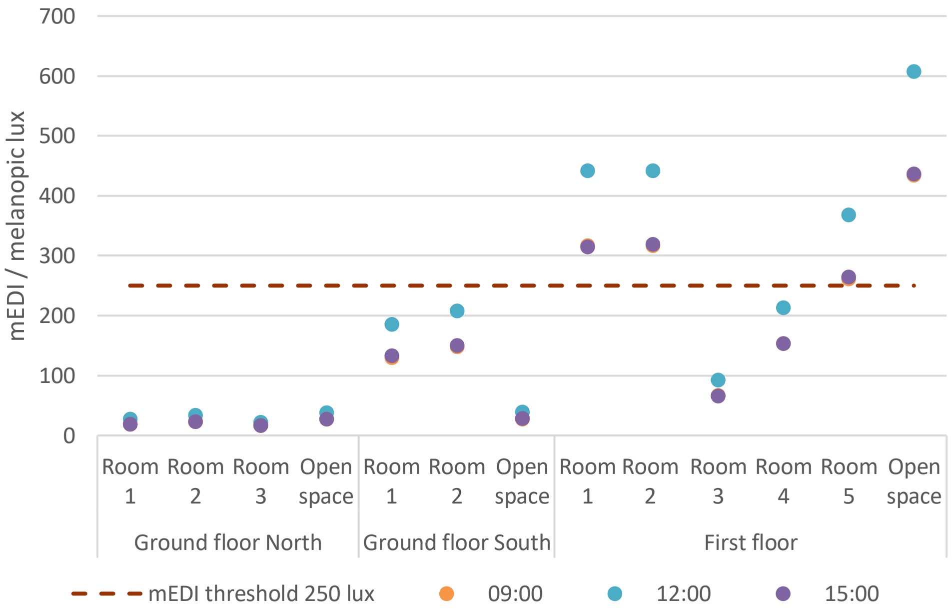


Figure 23 Melanopic equivalent daylight illuminance for educational program with overcast sky

During overcast sky, none of the spaces on the ground floor meet the 250 melanopic lux threshold for either of the simulated times (see Figure *23*). On the first floor during the three simulation times, rooms 1, 2, 5 and the open space exceed the required value. As room 3 and room 4 have north and west orientation, during overcast sky they do not meet the threshold. The simulated values at 09:00 and 15:00 overlap for the same reasons as described in Section 3.1.1, when describing the *mEDI* figures of the office program.

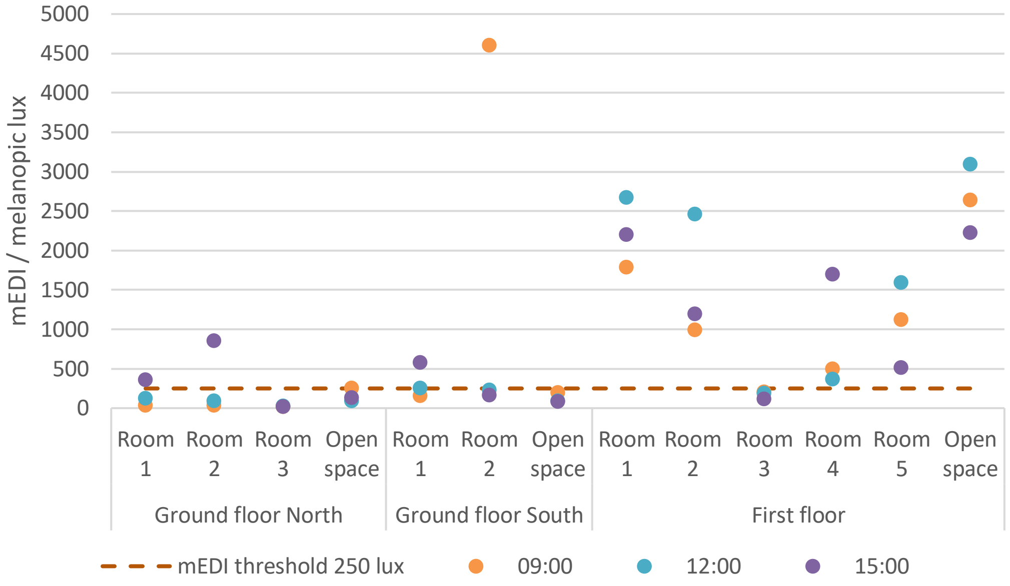
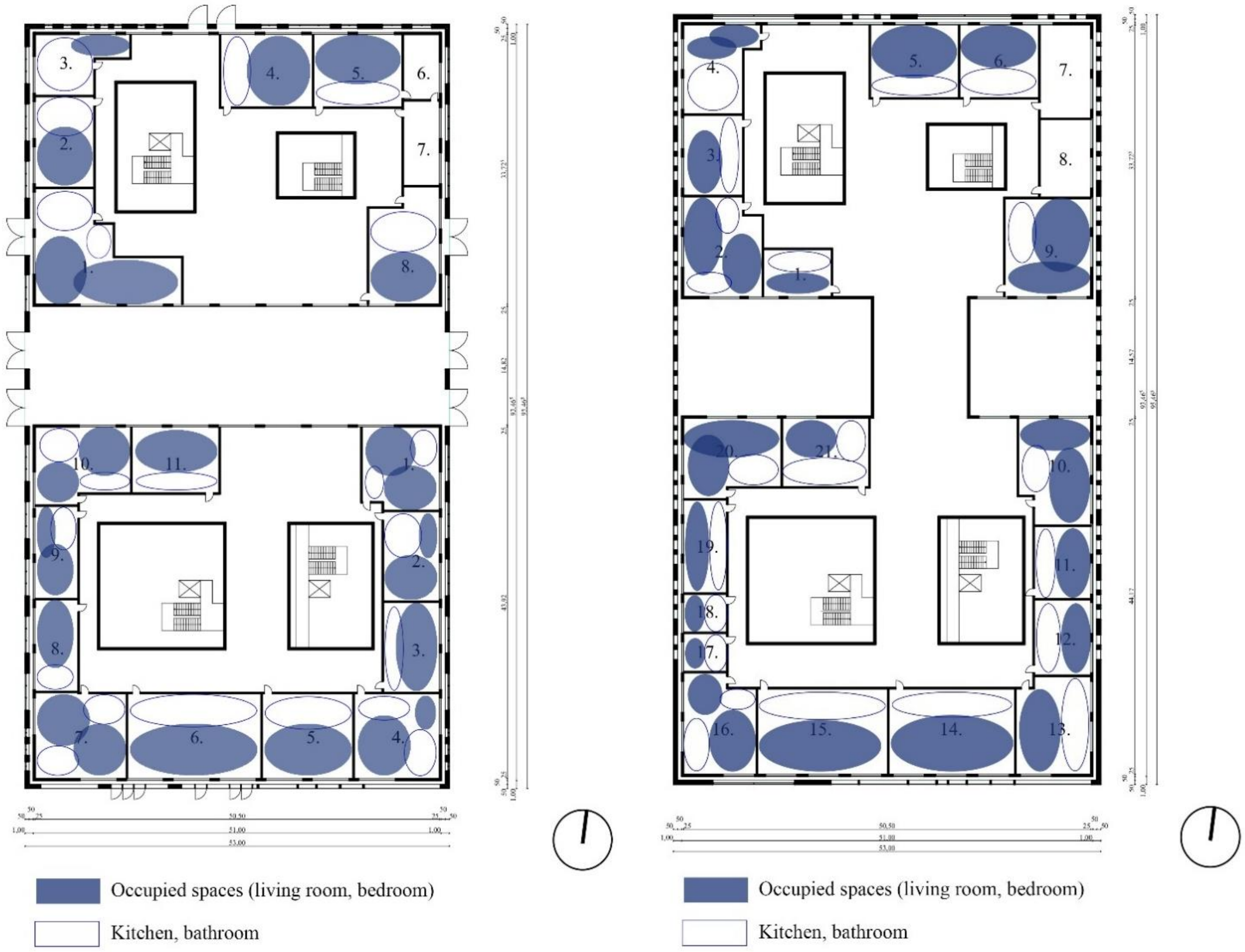


Figure 24 Melanopic equivalent daylight illuminance for educational program with clear sky

For clear sky measurements, the north orientation on the ground floor fulfils the threshold at 15:00 in rooms 1 and 2. There is a sharp peak in the values measured at 09:00 in room 2 on the south ground floor. This is because the room is facing east. During the early morning hours, the sun is shining directly in the space and as there are no obstructions in front of the windows of the room, this results in peak melanopic lux value. The rooms on the first floor, besides room 3, perform well as they fulfil the melanopic lux threshold. The 09:00 and 15:00 measurements are overlapping, similar to the beforementioned *mEDI* figures. The clear sky simulated values can be seen on Figure *24*.

3.1.3 Residential program

As the residential program consists of apartments, the open space is from the previous floor plans is hallway. Therefore, there are no daylight performance requirements that need to be followed as the space has no regular occupancy. Only the apartments will be further investigated. The *DF median*, target illuminance (E_{TM} and E_{T}), view out and melanopic equivalent daylight illuminance are measured. The residential layout can be seen on Figure *25*.



(a) (b)

Figure 25 (a), (b) Residential program layout with recommended apartment division in 1:500 (left: ground floor, right: first floor)

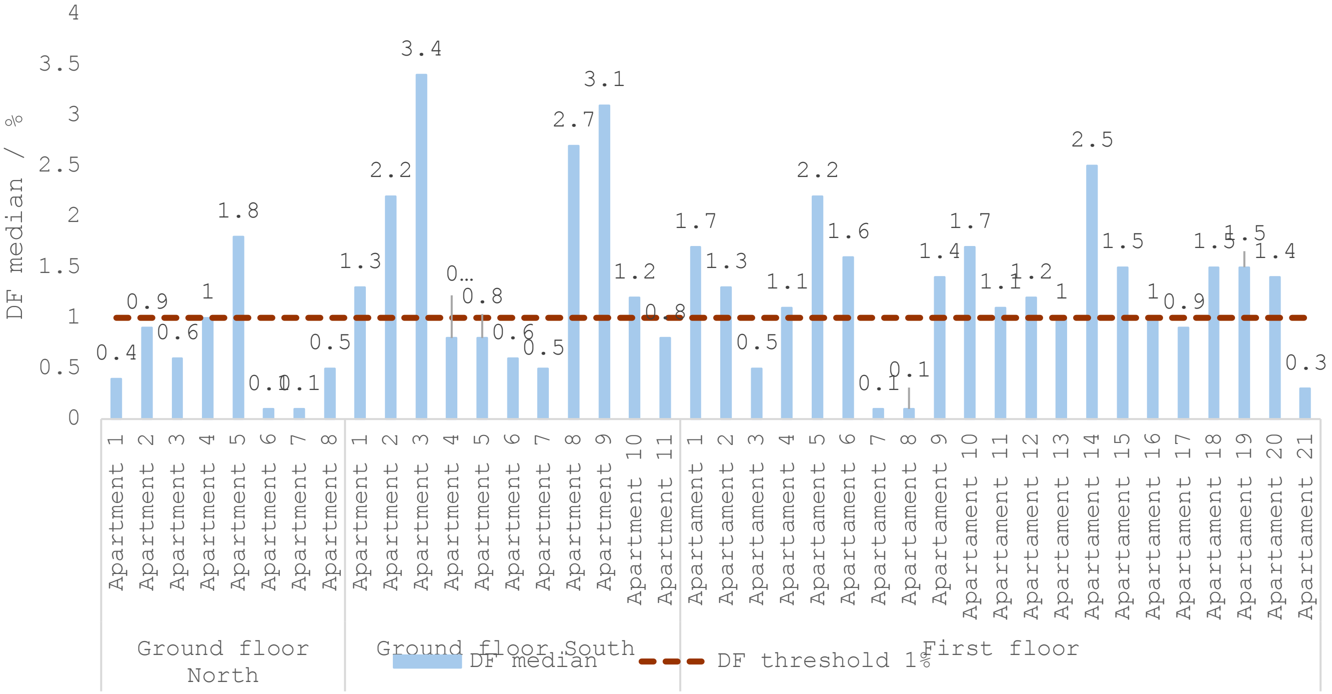


Figure 26 Daylight factor median percentage for residential program

Figure *26* shows the *DF median* simulated percentages for every apartment from the residential layout. On the ground floor, only apartments 4 and 5 meet the threshold requirements. Both apartments face north, however, because of the size of the windows and the dept of the spaces it can be concluded why the apartments meet the requirement. On the ground floor south, the apartments facing east and west meet the requirement. On the first floor, majority of the apartments fulfil the threshold value. This is because there are no obstructions on the west, east and north facades. As they are higher the sun can directly shine through the windows without having reflection from the ground. The apartments that perform the worst on both ground and first floor are located on the north-east façade. They underperform due to the size of the windows and the alignment between the inner and exterior windows.

Table 11 Target illuminance for residential program

Floor	**Apartment number**	**Target Illuminance**		
		Minimum	**Medium**	**Maximum**
Ground floor North	Apartment 1	*Fail*	*Fail*	*Fail*
	Apartment 2	*Fail*	*Fail*	*Fail*
	Apartment 3	*Fail*	*Fail*	*Fail*
	Apartment 4	*Fail*	*Fail*	*Fail*
	Apartment 5	*Pass*	*Fail*	*Fail*
	Apartment 6	*Fail*	*Fail*	*Fail*
	Apartment 7	*Fail*	*Fail*	*Fail*
	Apartment 8	*Fail*	*Fail*	*Fail*
Ground floor South	Apartment 1	*Fail*	*Fail*	*Fail*
	Apartment 2	*Fail*	*Fail*	*Fail*
	Apartment 3	*Pass*	*Fail*	*Fail*
	Apartment 4	*Fail*	*Fail*	*Fail*
	Apartment 5	*Fail*	*Fail*	*Fail*
	Apartment 6	*Fail*	*Fail*	*Fail*
	Apartment 7	*Fail*	*Fail*	*Fail*
	Apartment 8	*Pass*	*Fail*	*Fail*

	Apartment 9	*Pass*	*Fail*	*Fail*
	Apartment 10	*Fail*	*Fail*	*Fail*
	Apartment 11	*Fail*	*Fail*	*Fail*
First floor	Apartment 1	*Fail*	*Fail*	*Fail*
	Apartment 2	*Fail*	*Fail*	*Fail*
	Apartment s3	*Fail*	*Fail*	*Fail*
	Apartment 4	*Fail*	*Fail*	*Fail*
	Apartment 5	*Pass*	*Fail*	*Fail*
	Apartment 6	*Pass*	*Fail*	*Fail*
	Apartment 7	*Fail*	*Fail*	*Fail*
	Apartment 8	*Fail*	*Fail*	*Fail*
	Apartment 9	*Fail*	*Fail*	*Fail*
	Apartment 10	*Pass*	*Fail*	*Fail*
	Apartment 11	*Fail*	*Fail*	*Fail*
	Apartment 12	*Fail*	*Fail*	*Fail*
	Apartment 13	*Fail*	*Fail*	*Fail*
	Apartment 14	*Fail*	*Fail*	*Fail*
	Apartment 15	*Fail*	*Fail*	*Fail*
	Apartment 16	*Fail*	*Fail*	*Fail*
	Apartment 17	*Fail*	*Fail*	*Fail*
	Apartment 18	*Fail*	*Fail*	*Fail*
	Apartment 19	*Fail*	*Fail*	*Fail*
	Apartment 20	*Fail*	*Fail*	*Fail*
	Apartment 21	*Fail*	*Fail*	*Fail*

The residential program overall underperforms in terms of target illuminance and minimum target illuminance (see Table *11*). Only 7 out of the 40 apartments meet the minimum target illuminance (E_{TM}) requirements. None of the spaces meet the beyond standard values E_T.

Table 12 View out performance for residential program

Floor	**Apartment number**	**View out / % (EN 17037)**			
		Fail	***Min***	***Medium***	***High***
Ground floor North	Apartment 1	3	97	0	0
	Apartment 2	100	0	0	0
	Apartment 3	99,5	0,5	0	0
	Apartment 4	100	0	0	0
	Apartment 5	99,6	0,4	0	0
	Apartment 6	100	0	0	0
	Apartment 7	100	0	0	0
	Apartment 8	5	95	0	0
Ground floor South	Apartment 1	3	97	0	0
	Apartment 2	99,6	0,4	0	0
	Apartment 3	100	0	0	0
	Apartment 4	100	0	0	0
	Apartment 5	100	0	0	0
	Apartment 6	100	0	0	0
	Apartment 7	100	0	0	0
	Apartment 8	100	0	0	0

	Apartment 9	100	0	0	0
	Apartment 10	5	95	0	0
	Apartment 11	0	100	0	0
First floor	Apartment 1	0	100	0	0
	Apartment 2	5	95	0	0
	Apartment 3	100	0	0	0
	Apartment 4	100	0	0	0
	Apartment 5	100	0	0	0
	Apartment 6	100	0	0	0
	Apartment 7	100	0	0	0
	Apartment 8	100	0	0	0
	Apartment 9	100	0	0	0
	Apartment 10	100	0	0	0
	Apartment 11	100	0	0	0
	Apartment 12	100	0	0	0
	Apartment 13	100	0	0	0
	Apartment 14	100	0	0	0
	Apartment 15	100	0	0	0
	Apartment 16	100	0	0	0
	Apartment 17	100	0	0	0
	Apartment 18	100	0	0	0
	Apartment 19	100	0	0	0
	Apartment 20	0,7	99,3	0	0
	Apartment 21	16	84	0	0

On Table *12*, the view out performance of the residential spaces is presented. The apartments perform poorly in terms of view out as they do not reach the requirements for 75% of the area. However, the apartments facing north and south cover the minimum criteria as they are facing other buildings.

Table 13 Melanopic equivalent daylight illuminance for the chosen apartments of the residential program

Floor	**Apartment number**	**mEDI / melanopic lux**							
		June 21st				**September 22nd**			
		Overcast sky		**Clear sky**		**Overcast sky**		**Clear sky**	
		06:00	**19:00**	**06:00**	**19:00**	**06:00**	**19:00**	**06:00**	**19:00**
Ground floor North	Apartment 1	18	13	49	63	1	0	8	0
Ground floor South	Apartment 3	130	94	8036	131	9	0	1091	0
	Apartment 8	100	71	140	1198	6	0	46	0
	Apartment 9	111	81	133	969	7	0	53	0
First floor	Apartment 2	51	36	100	188	4	0	33	0
	Apartment 5	102	73	219	413	6	0	72	0
	Apartment 6	74	53	150	538	5	0	53	0
	Apartment 10	74	53	2289	113	5	0	1575	0

None of the measured apartments met the melanopic lux requirement for 06:00 or 19:00 o'clock during the equinox and solstice overcast and clear sky (see Table *13*). On September 22nd at 19:00 o'clock during overcast and clear sky all the apartments meet the requirements. Apartment 1 on ground floor north meets the requirements for all measured times during September 22nd. This is because the apartment performed poorly on the daylight availability metrics, and there is not enough penetration of daylight.

3.2 Overheating hours

The thermal comfort was assessed based on overheated hours, measured in zones of each building program, which are presented in separate tables. The values that fulfil the standard are highlighted with blue.

Table 14 Overheating percentage sensitivity analysis for office program

Zones	**Overheating / %**			
	April – Sepember		**July – August**	
	Above 24°C	**Above 26°C**	**Above 24°C**	**Above 26°C**
First floor, open space	14,8	5,6	35,5	15,1
Ground floor, northern open space	0	0	0	0
Ground floor, southern open space	0	0	0	0

The overheating hours for the office space are presented on Table *14*. In the office program, overheating only occurred on the first-floor open space, which is justified by the hight daylight availability coming from the skylights and windows present. For all measured times and temperatures, the overheating is 0% on the ground floor. On the first floor the open space is below the threshold only at 26°C during April and September, where the overheating is 5,6%. The 24°C measurement during April and September exceeds the 10% on the first floor, which can be explained by the number of skylights on the roof and large window openings on the façade. For both temperature thresholds measured in July and August the overheating percentage is surpassing the acceptable range.

Table 15 Overheating percentage sensitivity analysis for educational program

Zones	**Overheating / %**			
	April - Sepember		**July - August**	
	Above 24°C	**Above 26°C**	**Above 24°C**	**Above 26°C**
First floor, open space	26,1	12,7	48,3	27,7
Ground floor, northern open space	8,8	0	18,2	0
Ground floor, southern open space	9	0	18,3	0

The educational program shows higher overheated hours in multiple zones, especially on the first floor (Table *15*), which can be explained by the amount of skylight on the roof and high exposure of daylight. Every measured period exceeds the 10% acceptable overheating percentage. Also, the educational program has a higher people density, which means more internal gains and therefore more overheating is present. The highest value is 48,3 % overheated hours above 24 °C during July and August, which indicates extremely high overheating present in the summer months. There is uniform overheating between 18,2-18,3 % on the ground floor above 24°C during the July-August period. No significant overheating issues were identified in the remaining spaces.

Table 16 Overheating percentage sensitivity analysis for the selected apartments of the residential program

Zones	**Overheating / %**			
	April - Sepember		**July - August**	
	Above 24°C	**Above 26°C**	**Above 24°C**	**Above 26°C**
First floor, Apartment 5	12,8	3,1	35,1	9,2
First floor, Apartment 10	11,2	2,4	31	7,2
Ground floor, northern side, Apartment 5	0	0	0	0
Ground floor, southern side, Apartment 3	0	0	0	0

As for the residential program, a few apartments with the highest daylight performance on each part of the building were selected to be assessed for thermal comfort (see Table *16*). Issues with overheating were identified when measuring overheating above 24°C for both measurement periods on the first floor. Apartment 5 on the first floor, which is facing north, has the highest overheating percentage from the measured apartments, reaching 35,1%. The 26°C threshold measurements have acceptable overheating percentage. The apartments on the ground floor do not have any overheating.

4 Discussion

The discussion of results is divided into four sections: per program, per daylight metric and per building typology and discussion about the thermal comfort performance. Additionally, previous research and case studies are reviewed to identify similarities and differences with the findings of the thesis. Lastly, the setback which occurred during the process of this study are discussed.

The results from the daylight simulations reflect on the suitability of the spaces, based on the proposed layouts, to accommodate the specified programs. As the office and educational programs have similar floor plans, their performance in terms of daylight availability and view out is similar. The north-facing spaces on the ground floor generally receive the lowest daylight availability (*DF median* and target illuminance), though the reduced exposure means glare is not a significant issue. On the first floor, these programs meet the required daylight thresholds, however, glare becomes disturbing in these areas. For all programs, spaces exceeding standard target illuminance fail to meet requirements, largely due to a lack of uniformity caused by room depth and ceiling height. However, in the educational program on the first floor all spaces besides one room, pass the minimum, medium and maximum requirements for target illuminance. This is due to the availability of skylights, distributed along the whole roof, that ensure sufficient uniform daylight. The rooms which fulfil the requirements are west and east facing. The room which does not meet the standard values is north facing, therefore there is no sufficient daylight penetration through that façade. Under clear sky conditions, east-facing rooms in both office and educational settings achieve the target of 250 melanopic lux at 09:00 o'clock, while west-facing rooms meet this target at 12:00 and 15:00 o'clock, primarily due to sun angle and unobstructed façade exposure. Similarly, open spaces on the first floor meet this threshold, whereas north-facing rooms on the same level do not, due to their orientation. The combination of unobstructed light and sun angle also leads to peaks in melanopic lux in these areas. Despite these factors, the quality of outward views remains insufficient in most designed spaces across both public functions.

In the residential program, the daylight factor requirements are fulfilled in most of the apartments. The apartments that do not meet the *DF median* requirement on the ground floor north are located on the north façade. The apartments that do not meet the *DF* requirements on the ground floor south are located on the south façade. As there is a building in close proximity in front of the researched building, it is seen as an obstruction that causes shading and reduces the daylight availability on the apartments facing south. The apartments with the lowest *DF* percentage on the first floor are located on the north-east façade and the low performance is due to the location of the external and internal windows and their orientation. The target illuminance is the worst performing metric for this program. Only 7 out of 40 apartments reach minimum target illuminance requirements. The melanopic exposure requirements are different as it is important for the melanopic lux to be low to ensure appropriate function of the circadian rhythm. In all rooms tested, the melanopic exposure exceeds the acceptable values, except at 19:00 o'clock on September 22nd for overcast and clear sky. This is due to the earlier sunset time compared to the summer equinox. However, based on these results it can be concluded that residential program is not suitable for this building typology and floor plans based on the assess metrics.

Across all cases, view out requirements are generally not met, which can largely be attributed to the constraints of adaptive reuse. The daylight factor median is the easiest metric to be fulfilled due to the low required minimum value. An adequate amount of daylight is entering the interior space as high window-to-wall ratio is designed in the interior building and there are big windows on the exterior façade.

The target illuminance is difficult to achieve since the requirements for this metric indicate high daylight uniformity and availability which is not present in this building. This metric presents a combination of required lux values for 50% or 95% of the space, which fail to be accomplished in closed rooms with high ceilings, deep spaces or north orientation.

The view out is the most challenging metric to meet the standard requirements. Unlike new constructions, existing buildings cannot have their location or surroundings altered, inherently limiting opportunities to improve outward views. As a result, view out becomes a challenging criterion to satisfy in renovation and adaptive reuse projects. The only spaces that meet the minimum view out requirements are the open areas within public functions. This is due to their larger floor areas and exposure to multiple façades, which allow them to achieve at least the landscape layer along with an additional visual layer.

Lastly, glare performance is inconsistent, with compliance occurring in approximately half of the evaluated cases. In smaller, enclosed rooms where daylight penetration is limited, disturbing glare is generally not observed due to the absence of strong direct sunlight. In contrast, open-plan spaces exhibit higher glare levels, particularly on the first floor, where the presence of skylights and reduced external obstructions increases direct light exposure and, consequently, the likelihood of discomfort glare.

It is challenging to establish adequate comfortable daylight performance in an adaptively reused building, which exterior façade is used as a shell to an interior building. The question of what constitutes good daylight performance becomes particularly relevant when established metrics or thresholds are not fully met. Rather than relying solely on pass-fail criteria and threshold values for daylight metrics, this provides a broader academic discussion about the qualitative and contextual dimensions of daylighting. For example, how visual comfort, spatial experience, and user needs might redefine acceptable performance. Closely related to this is the need to determine which daylight metrics are important based on building function, where different uses may demand different balances between illuminance, glare control, and view out. This introduces an ongoing debate about how such trade-offs should be evaluated, what parameters should be prioritized in specific contexts, and how shortcomings in one aspect of daylight performance might be compensated. This study suggest that adequate daylight performance of an adaptively reused building is not achieved based on the current daylight standards thresholds. Already existing buildings which are seen as cultural and historical heritage have “inherited” daylight availability which is difficult to be modified in order to reach sufficient indoor daylight comfort for new defined programs.

The findings of the thermal comfort analysis can be discussed according to several key aspects. Overheating occurs only on the first floor. This is due to the presents of skylights and windows. The window-to-wall ratio on the external façade is 30%, the interior façade is 40% and there is 20% skylights-to-roof ratio. As the first floor has higher solar exposure and sun penetration from the skylights, a higher degree of overheating occurs and exceeds the assessed standard threshold. The ground floor for any of the analysed programs does not have any overheating hours percentage that exceed the acceptable values. This is due to the absence of skylights, which is also reflected in the poor daylight performance. Additionally, big open spaces, with high ceiling, cause the air to warm up slower, which reduces the chance of overheating due to the surface-to-volume ratio of the spaces. However, on the open space on the first floor for the office and educational programs, the overheating is highest despite the big volume, due to the skylights, which let solar energy inside the building, warming up the air more as there is also lower amount of thermal mass. The simulation period has a significant influence on the calculated overheating percentage. When the analysis is conducted over an extended period from April to September, the results indicate that indoor temperatures exceeding the overheating threshold remain below 10%. This suggests that over a broader timeframe, periods of lower temperatures moderate the overall assessment of thermal discomfort. However, as part of a sensitivity analysis, the evaluation period was restricted to the peak summer months of July and August, during which the highest temperatures typically occur (see Figure A *1* and Figure A *2* in Appendix A Site analysis Under these conditions, the proportion of overheating increased substantially, rising to approximately 12%. This is almost three times higher than the longer simulation period and exceeds the acceptable limit. These findings demonstrate that the selection of the simulation period can strongly affect thermal comfort outcomes and highlight the importance of carefully defining assessment boundaries when interpreting overheating risks.

The results demonstrate a strong relationship between daylight availability and thermal comfort, indicating that the two factors are closely interconnected. High daylight availability, which is present is spaces that comply with the standard daylight performance metrics, was found to correspond with an increased number of overheating hours. Conversely, spaces with insufficient daylight exposure showed little to no occurrence of overheating. These findings highlight the need to achieve a balanced design approach in order to ensure optimal indoor comfort in terms of both daylight performance and thermal comfort.

In comparison with similar case studies, the findings of the Machine and Assembly Hall show comparable trends. For example, an Indonesian high school building's classrooms had *DF* below the required values. Since it was a heritage building, the windows could not be replaced or altered. In this case, daylight performance and visual comfort was also partially achieved by alternative strategies, instead of fulfilling regulations (Prihatmanti & Susan, 2017). A similar project to this thesis was a historically listed warehouse in Trondheim, Norway. Here the only way to fulfil current legislations was by introducing skylights to the roof. This way the daylight performance was improved, and the original façade was still preserved. Here, the daylight standards were solely achieved by altering the roof (Piraei et al., 2022). A case study of an Austrian historic industrial facility demonstrated that overheating can be reduced by introducing optimisation measures through seven scenarios. It shows that even if thermal comfort is not necessarily achieved for current legislations, implementing further optimisation can reduce overheating (Gourlis & Kovacic, 2017). This is similar to the findings of the assessment in the Machine and Assembly Hall.

During the course of this study, technical issues were encountered. The biggest setback was the incompatibility between the HB script and the Rhino8 daylight model. As the model is very heavy (291 KB) due to the details and round window shapes, it was not possible to be connected to the HB scripts. A HB script was prepared to assess the daylight performance of the building, prior to the use of CS. The benefits of using a HB script are the ability to run multiple simulations for different areas simultaneously. The time for running the daylight simulations would have drastically decreased compared to using CS. Also, if the HB script was used to conduct the daylight analysis, the research results could have deepened by the variation of input parameters modified such as the ambient bounces of light and the limit weight.

Difficulty occurred between creating the building model in a way that was correctly recognized by the HB thermal comfort script. As the model has an external wall with cavity space, internal walls and atriums, which are all different energy zones, it was challenging to correctly build the script, so they are properly recognized. This required iterative adjustments between the HB energy script and the energy model, which was resolved over the course of a few weeks. Lastly, the program schedule and loads and construction layers created issues and produced unreliable results. Adjustments and tests between the custom programs and constructions were done in order to achieve adequate inputs, similar to real-life, while achieving valid output. Additionally, combinations between the custom inputs and the HB library programs and constructions were tested. This process was time demanding which slowed down the production of results for the thermal comfort part of the research.

5 Conclusion

This study evaluates interior daylight conditions and thermal comfort in an adaptively reused industrial building, where the original envelope is retained as an external shell. The project integrates a building within a building strategy that preserves the façade while introducing building programs for office, educational, and residential uses. The results demonstrate how an adaptive reused building, whose original façade is preserved and used as a shell for new interior building, is evaluated based on its daylight and thermal comfort performance according to current standard thresholds.

Across all building programs, the study highlights the limitations of applying standardized daylight metrics to adaptive reuse projects. The results show that satisfactory daylight conditions can only be partially achieved. Adequate daylight penetration is possible through large windows and skylights, particularly on the first floor and in open spaces. The *DF median* performance of the educational and office layouts both reached exceptionally high percentage, which exceeded the minimum threshold of 1%. For both layouts the open space on the first floor reached 13% *DF median.* The room on the first floor of the office space, reached 1,4% *DF median*, despite the north orientation. The rooms on the first floor from the educational layout the *DF median* performance varies between reached between 1,3%, north oriented, and 9,7%, west oriented. On the residential layout, where the apartments are closed and there is no additional daylight supply besides from the windows, the *DF median* threshold is still achieved for majority of the spaces. However, compliance with stricter daylight criteria, including target and minimum target illuminance, glare, and view out requirements, is rarely achieved. The minimum target illuminance and target illuminance are challenging to achieve as the building is deep and it there is no sufficient daylight penetration and uniformity to cover the requirement of 95% of the area. The E_{TM} is achieved only on the ground floor south from the office layout and in the rooms on the ground floor south from the educational layout. The educational layout has the best performance in terms of E_T as all rooms, besides room 3 which is north oriented, on the first floor pass the medium and maximum E_T criteria. This indicates that the skylights, windows and room size are sufficient to receive 300 lux, 500 lux and 750 lux for 50% of the time. The residential layout fails to achieve any E_T threshold, however, a few apartments passed the E_{TM} thresholds. View out requirements are the most challenging to satisfy, reflecting constraints due to the existing urban context and preserved envelope. Daylight performance is especially limited in north-oriented spaces and in the enclosed residential layouts. The results suggest that the proposed building typology is more suitable for public functions than residential use under current design conditions. Also, achieving acceptable daylight conditions in historic buildings often involves compromising certain daylight performance metrics, rather than fully complying with current daylight standards as not every designated space is able to fulfil these standards. The daylight performance can be seen on Table *17.*

Table 17 Daylight metrics performance overview

Daylight metrics	**Programs**			
	Public		**Private**	
	Ground floor	**First floor**	**Ground floor**	**First floor**
DF median	⊗	✓	⊗	✓
E_{TM}	⊗	✓	⊗	⊗
E_T	⊗	✓	⊗	⊗
View out	⊗	✓	⊗	⊗
Glare	✓	⊗	-	-
mEDI	⊗	✓	⊗	⊗

Overheating was observed only on the first floor due to the presence of skylights and larger window areas, which increase solar exposure and indoor heat gains. The results on the first floor for all the proposed layouts exceeds 10%. The highest reached value is 45,8% for 24°C on the first floor in the educational layout, however, this value was measured during the hottest summer months, July and August. The highest overheating percentage measured based on the FEBY12 standard, is 26,1% for 24°C measurement setting, which is also on the first floor from the educational layout. The ground floor for all building programs remained within acceptable overheating limits. The findings also reveal a strong dependency on the selected simulation period and people density, with overheating risk increasing during peak summer months.

To conclude, the study demonstrates the extend of suitability of current daylight and thermal comfort standards to be used as assessment metrics for unconventional building types, such as the building within a building construction. The case study shows that an industrial building envelope can be reused as a shell for new interior functions. The suitability of different programs depends strongly on daylight performance and thermal comfort, as these parameters are mutually dependent. While thermal comfort can be achieved on the ground floor, daylight performance is constrained.

To expand the findings from the building proposition from this study, future research topics are suggested. First, based on the daylight analysis performed in this research, it was discovered that majority of the spaces in the building do not fulfil the target illuminance, view out and melanopic exposure requirements. A problem-solution analysis where critical evaluation on the proposed layout and discovered results can be done. Solutions resolving the mentioned issues in this analysis can be further explored to strengthen the findings in this study.

Second, different architectural layouts which would be designed specifically for each function can be proposed. The daylight performance and thermal comfort can be assessed and compared to the proposed layouts here to assess whether more spaces fulfil or do not fulfil the requirements.

Third, constructing a building within an existing structure is likely to result in lower environmental impacts compared to new-build construction from the ground up. However, this approach may entail greater environmental impacts than interventions limited to the addition of new floors or the reconfiguration of internal layouts within the existing building. To comprehensively evaluate environmental performance, a life cycle assessment (LCA) can be undertaken to estimate the project’s total impact and to identify the life cycle stage with the greatest contribution.

Lastly, proposing a ventilation strategy and assessing the energy impact could be possible future research. As the building will be mechanically ventilated, an appropriate ventilation system and AHU unit that fits the requirements for each specific program can be further explored. The effect on the energy consumption to fully mechanically ventilated building with no natural ventilation can be assessed.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT to improve readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Appendix

Appendix A Site analysis

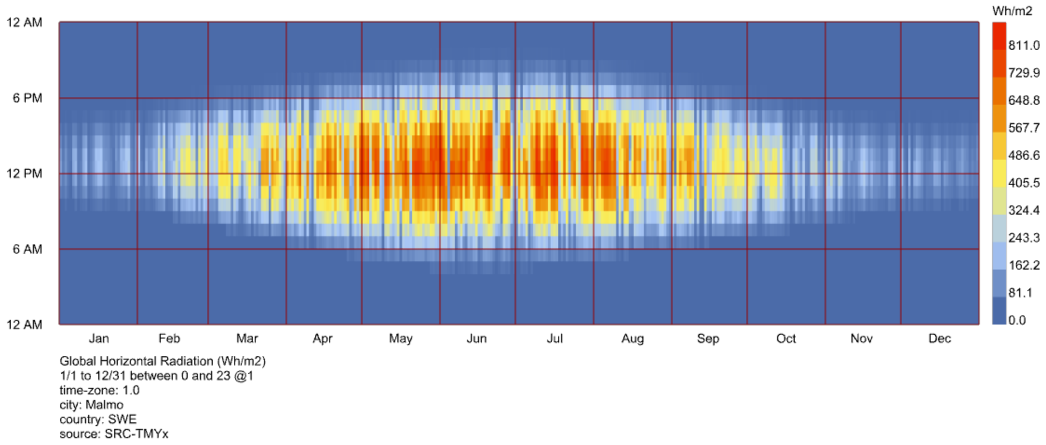


Figure A 1 Global horizontal radiation graph in Malmö, Sweden

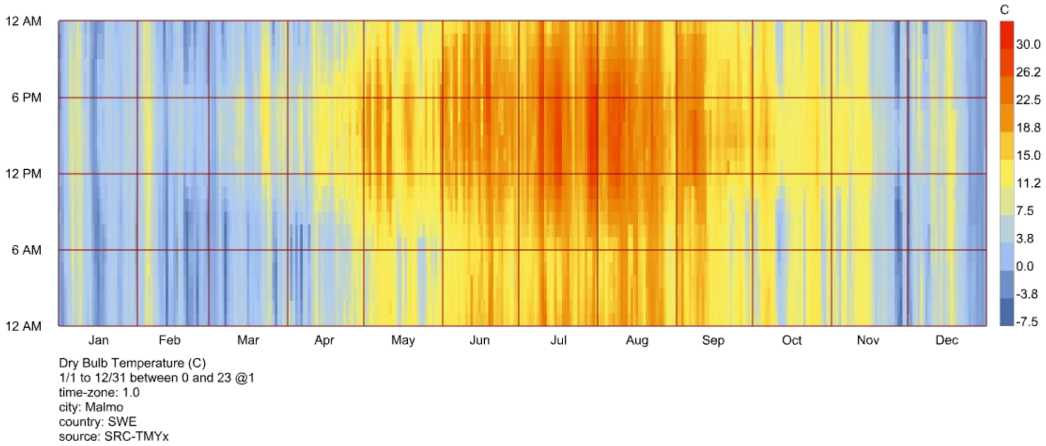


Figure A 2 Dry bulb temperature graph in Malmö, Sweden

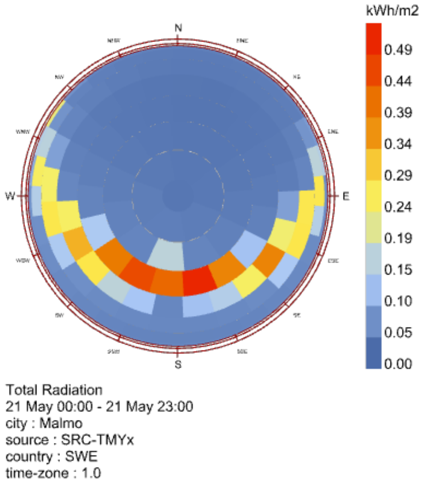


Figure A 3 Total radiation chart in Malmö, Sweden

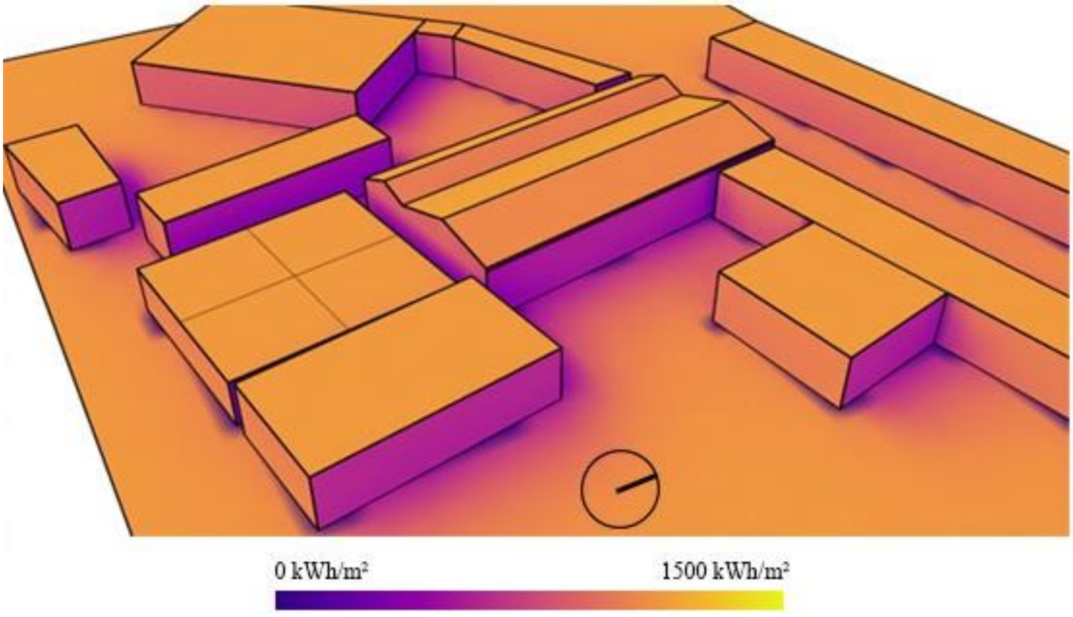


Figure A 4 Solar radiation map

Appendix B Program schedule inputs

Table B 1 Occupancy schedule in each building program

Hour	**Program**					
	Office		**Educational**		**Residential**	
	Weekday	**Weekend**	**Weekday**	**Weekend**	**Weekday**	**Weekend**
00:00	0	0	0	0	1	1
01:00	0	0	0	0	1	1
02:00	0	0	0	0	1	1
03:00	0	0	0	0	1	1
04:00	0	0	0	0	1	1
05:00	0	0	0	0	1	1
06:00	0	0	0	0	1	1
07:00	0,1	0	0,3	0	0,85	0,85
08:00	0,2	0	0,3	0	0,4	0,4
09:00	0,95	0	0,4	0	0,25	0,25
10:00	0,95	0	0,4	0	0,25	0,25
11:00	0,95	0	0,4	0	0,25	0,25
12:00	0,95	0	0,4	0	0,25	0,25
13:00	0,5	0	0,3	0	0,25	0,25
14:00	0,95	0	0,3	0	0,25	0,25
15:00	0,95	0	0,3	0	0,25	0,25
16:00	0,95	0	0,3	0	0,25	0,25
17:00	0,2	0	0,3	0	0,3	0,3
18:00	0,2	0	0	0	0,55	0,55
19:00	0	0	0	0	0,85	0,85
20:00	0	0	0	0	0,85	0,85
21:00	0	0	0	0	0,85	0,85
22:00	0	0	0	0	1	1
23:00	0	0	0	0	1	1

Table B 2 Lighting schedule in each building program

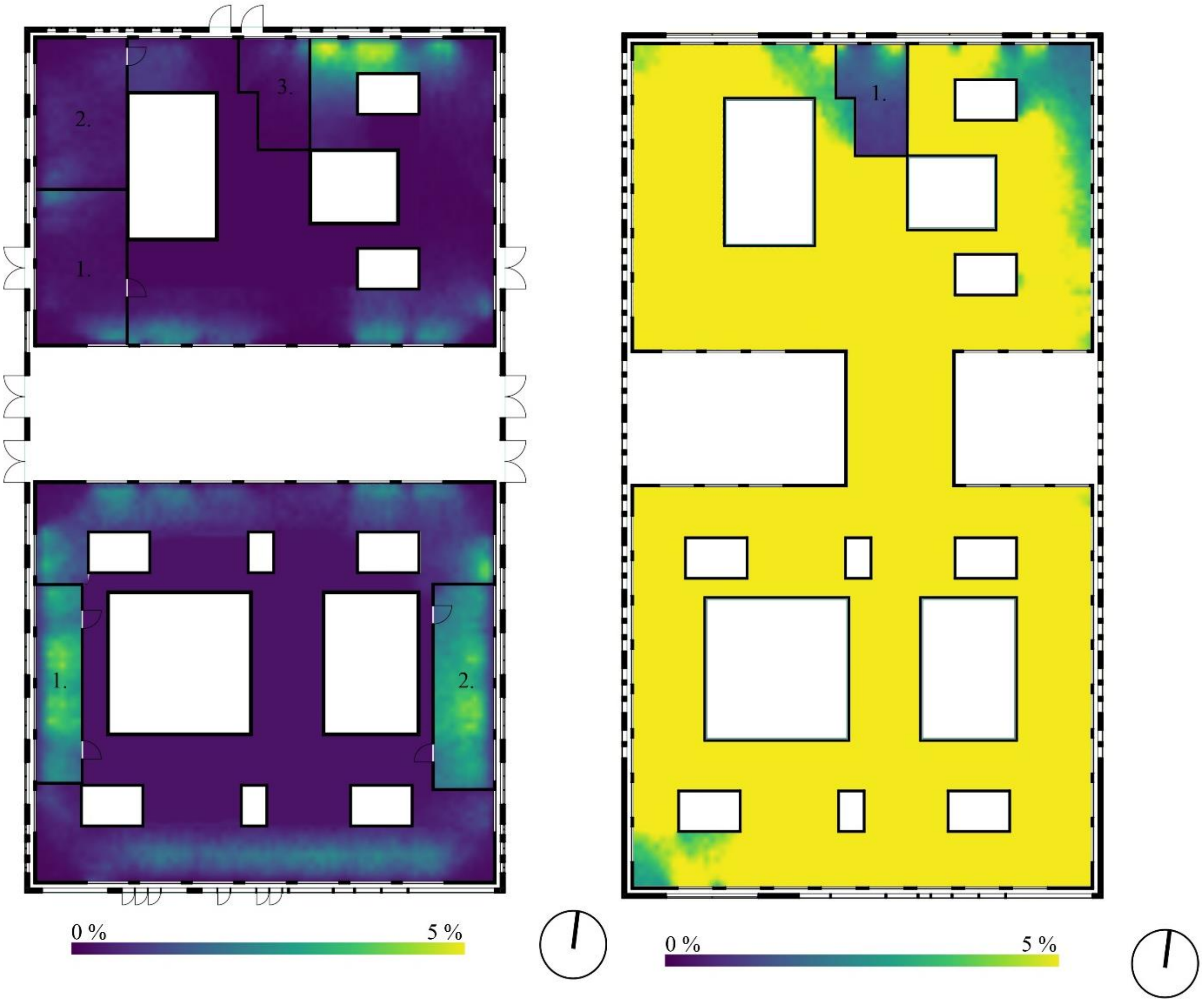
Hour	Program					
	Office		Educational		Residential	
	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
00:00	0	0	0	0	0,07	0,07
01:00	0	0	0	0	0,07	0,07
02:00	0	0	0	0	0,07	0,07
03:00	0	0	0	0	0,07	0,07
04:00	0	0	0	0	0,07	0,07
05:00	0	0	0	0	0,16	0,16
06:00	0,14	0	0	0	0,25	0,25
07:00	0,3	0	0,9	0	0,44	0,44
08:00	0,9	0	0,9	0	0,35	0,35
09:00	0,9	0	0,9	0	0,16	0,16
10:00	0,9	0	0,9	0	0,07	0,07
11:00	0,9	0	0,9	0	0,07	0,07
12:00	0,9	0	0,9	0	0,07	0,07
13:00	0,9	0	0,9	0	0,07	0,07
14:00	0,9	0	0,9	0	0,07	0,07
15:00	0,9	0	0,9	0	0,07	0,07
16:00	0,9	0	0,9	0	0,07	0,07
17:00	0,9	0	0,9	0	0,16	0,16
18:00	0,5	0	0,9	0	0,44	0,44
19:00	0,3	0	0,9	0	0,63	0,63
20:00	0,3	0	0,9	0	0,81	0,81
21:00	0,2	0	0,9	0	1	1
22:00	0,2	0	0	0	1	1
23:00	0	0	0	0	0,72	0,72

Table B 3 Equipment schedule in each building program

Hour	Program					
	Office		Educational		Residential	
	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
00:00	0,4	0,3	0,4	0,4	0,44	0,44
01:00	0,4	0,3	0,4	0,4	0,44	0,44
02:00	0,4	0,3	0,4	0,4	0,44	0,44
03:00	0,4	0,3	0,4	0,4	0,38	0,38
04:00	0,4	0,3	0,4	0,4	0,38	0,38
05:00	0,4	0,3	0,4	0,4	0,44	0,44
06:00	0,4	0,3	0,4	0,4	0,57	0,57
07:00	0,4	0,3	0,4	0,4	0,7	0,7
08:00	0,9	0,3	1	0,4	0,7	0,7
09:00	0,9	0,3	1	0,4	0,7	0,7
10:00	0,9	0,3	1	0,4	0,7	0,7
11:00	0,9	0,3	1	0,4	0,7	0,7
12:00	0,9	0,3	1	0,4	0,7	0,7

Hour	Program					
	Office		Educational		Residential	
	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
13:00	0,7	0,3	1	0,4	0,7	0,7
14:00	0,9	0,3	1	0,4	0,7	0,7
15:00	0,9	0,3	1	0,4	0,7	0,7
16:00	0,9	0,3	1	0,4	0,7	0,7
17:00	0,9	0,3	1	0,4	0,81	0,81
18:00	0,45	0,3	0,4	0,4	1	1
19:00	0,4	0,3	0,4	0,4	1	1
20:00	0,4	0,3	0,4	0,4	0,94	0,94
21:00	0,4	0,3	0,4	0,4	0,94	0,94
22:00	0,4	0,3	0,4	0,4	0,88	0,88
23:00	0,4	0,3	0,4	0,4	0,7	0,7

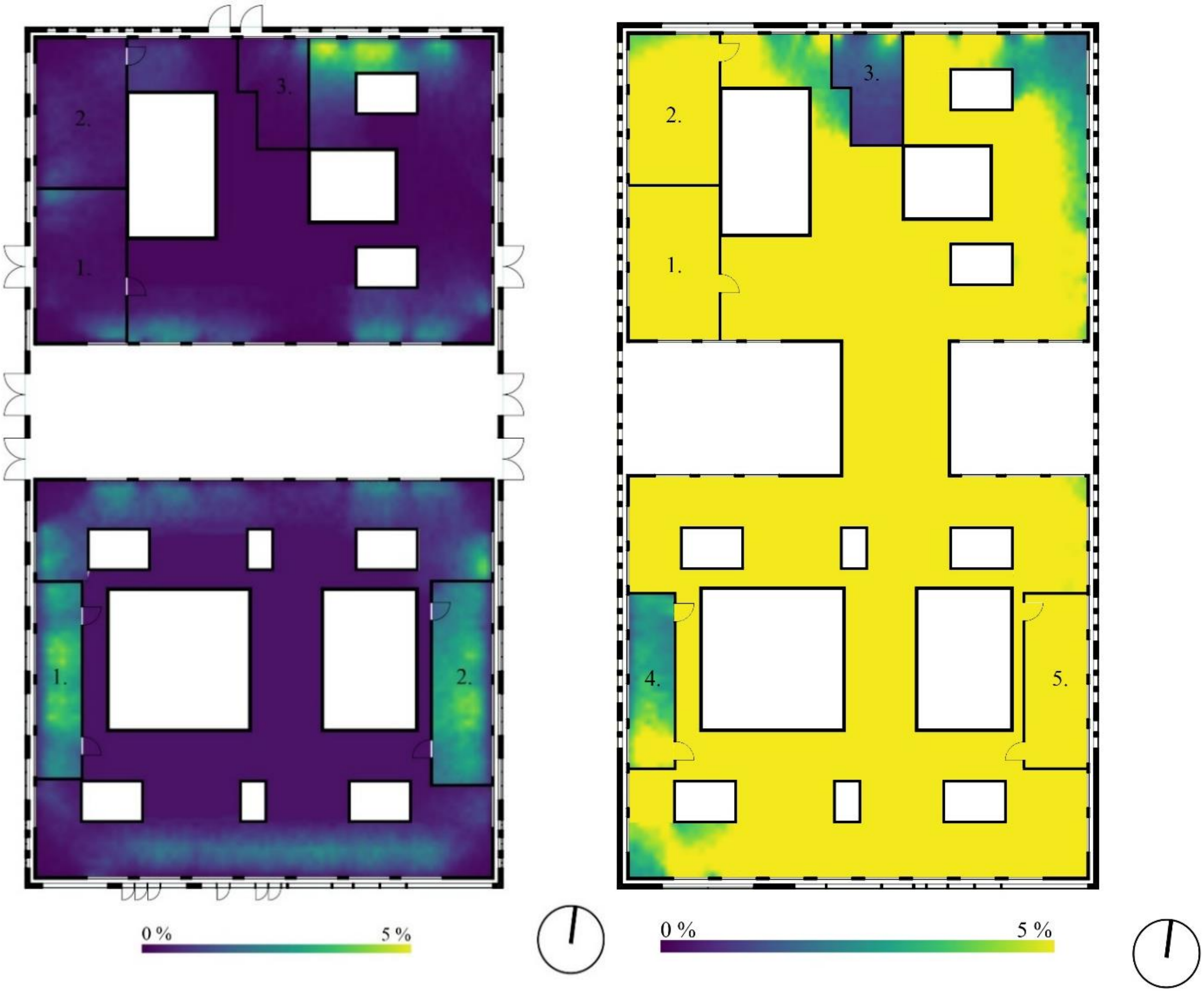
Appendix C Layouts and Daylight performance on building layout



(a)

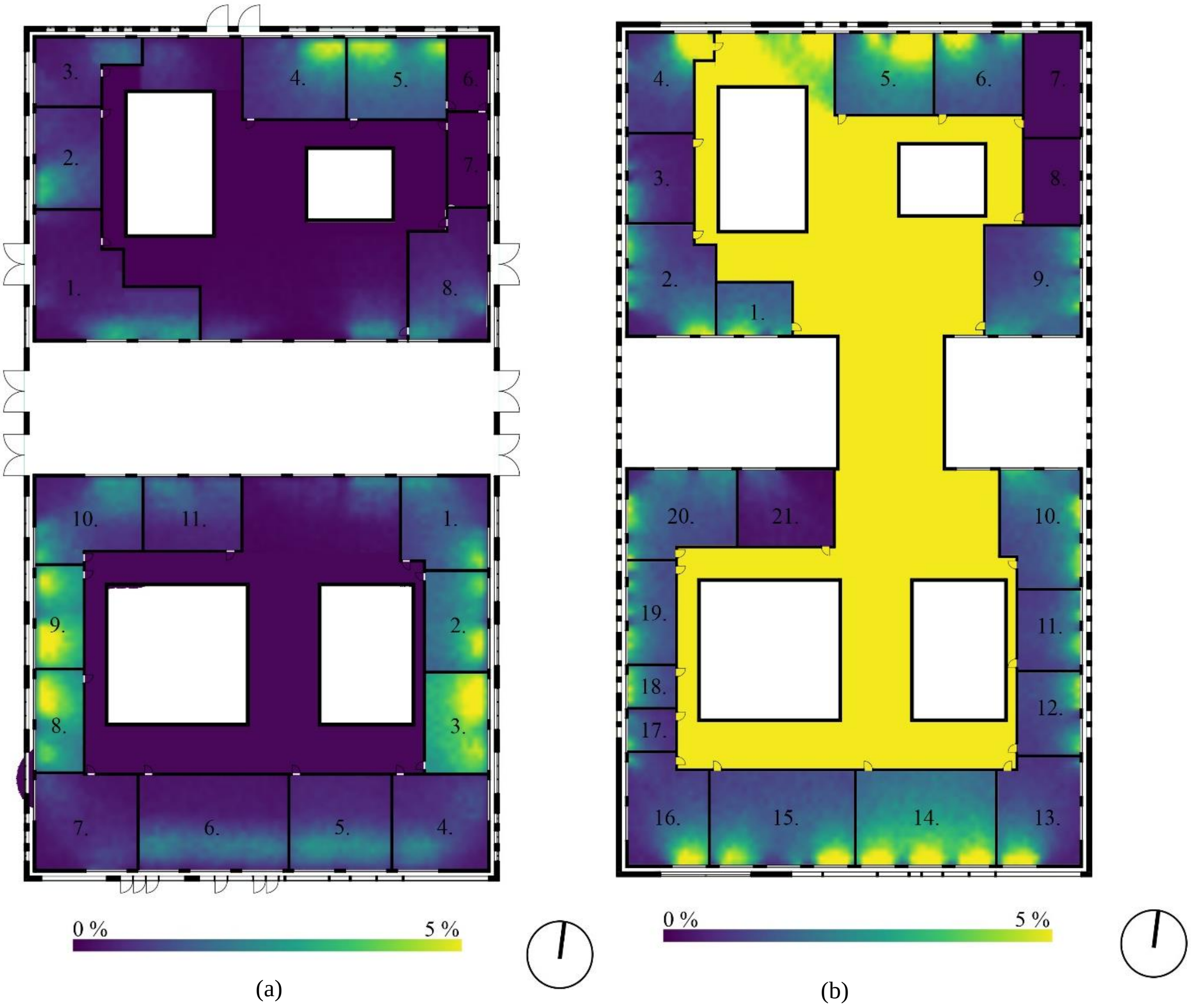
(b)

Figure C 1 (a), (b) Daylight factor distribution in office layout (left: ground floor, right: first floor)



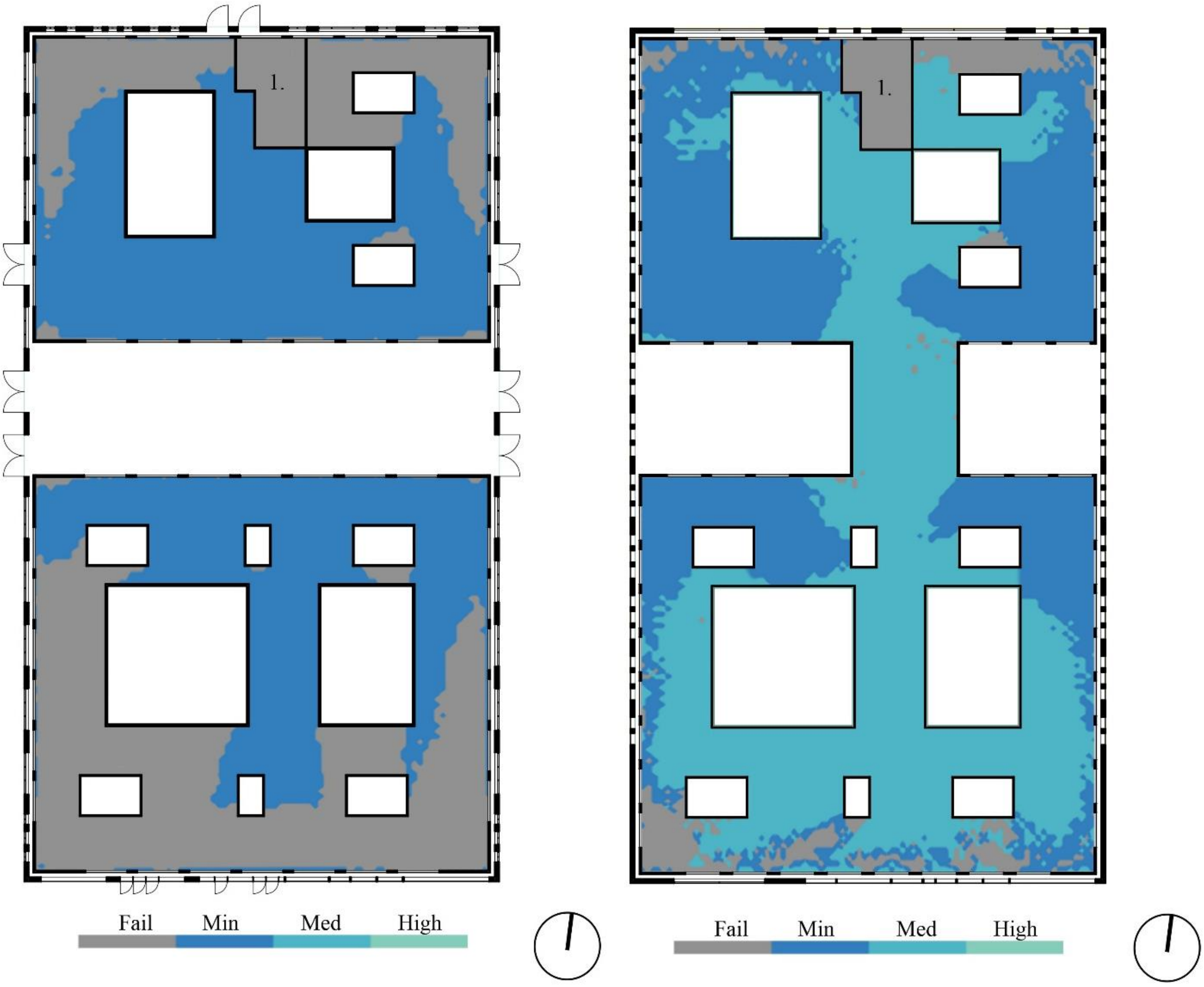
(a) (b)

Figure C *2* (a), (b) Daylight factor distribution in educational layout (left: ground floor, right: first floor)



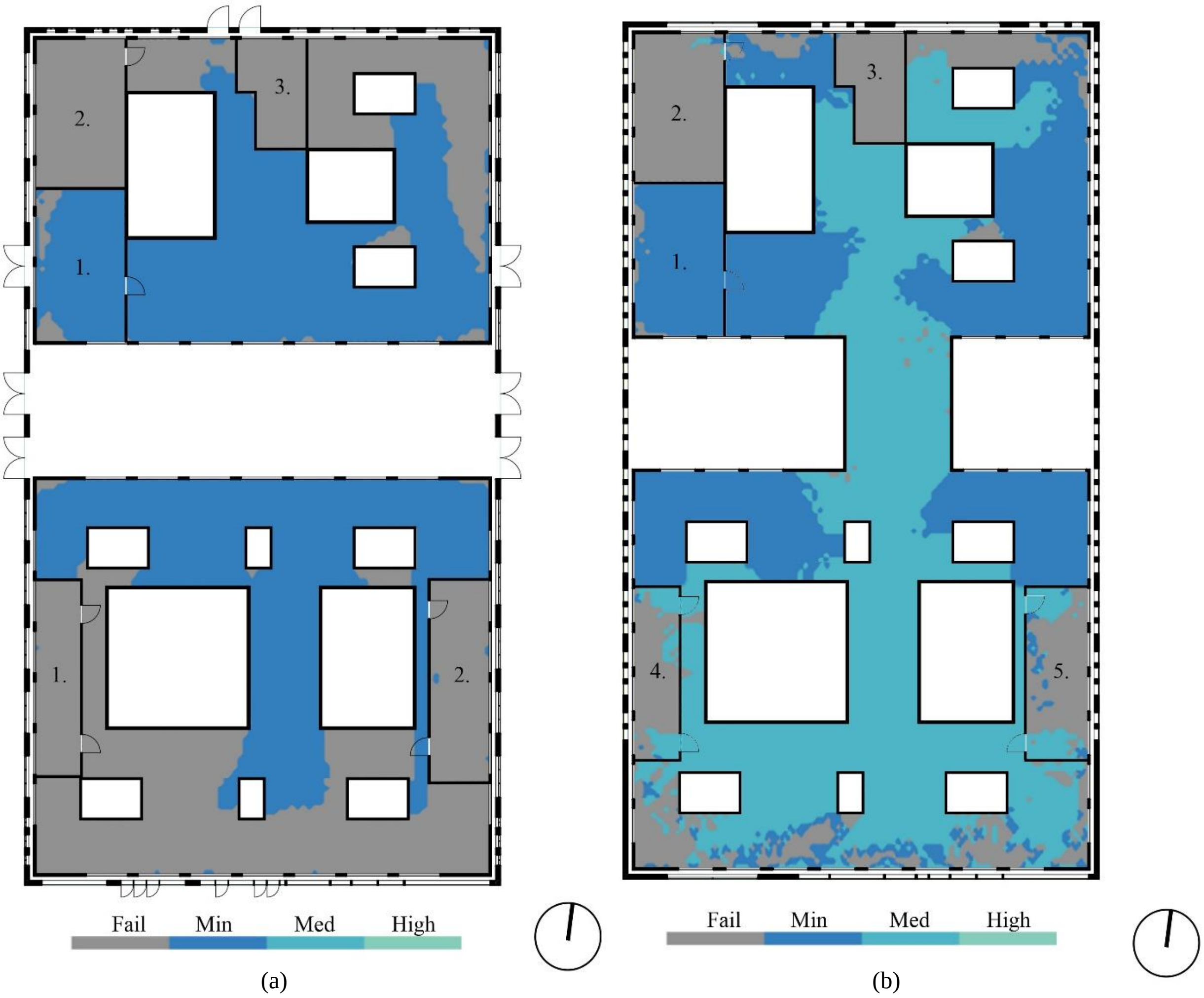
(a) (b)

Figure C *3* (a), (b) Daylight factor distribution in residential layout (left: ground floor, right: first floor)



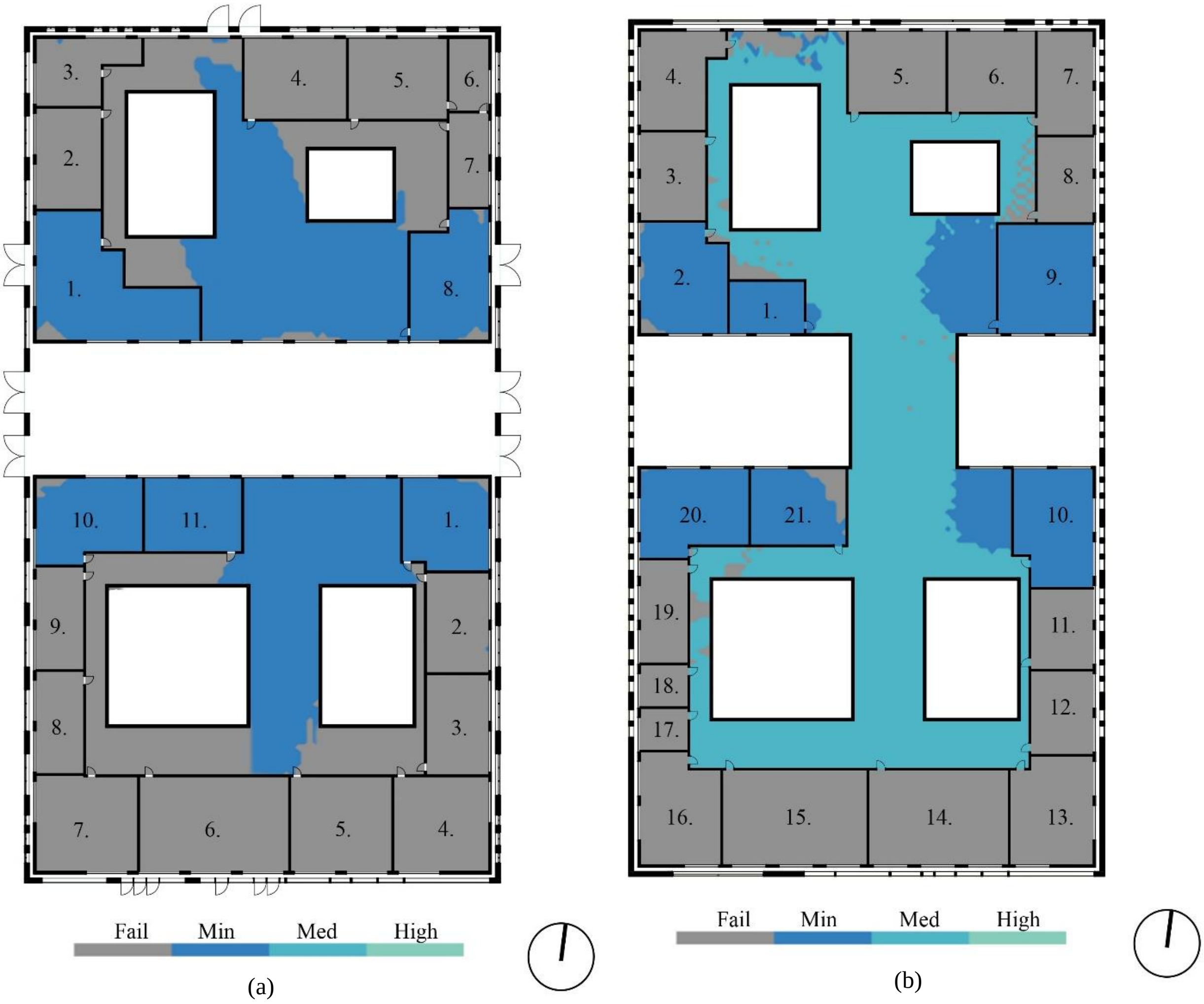
(a) (b)

Figure C *4* (a), (b) View out distribution in office layout (left: ground floor, right: first floor)



(a) (b)

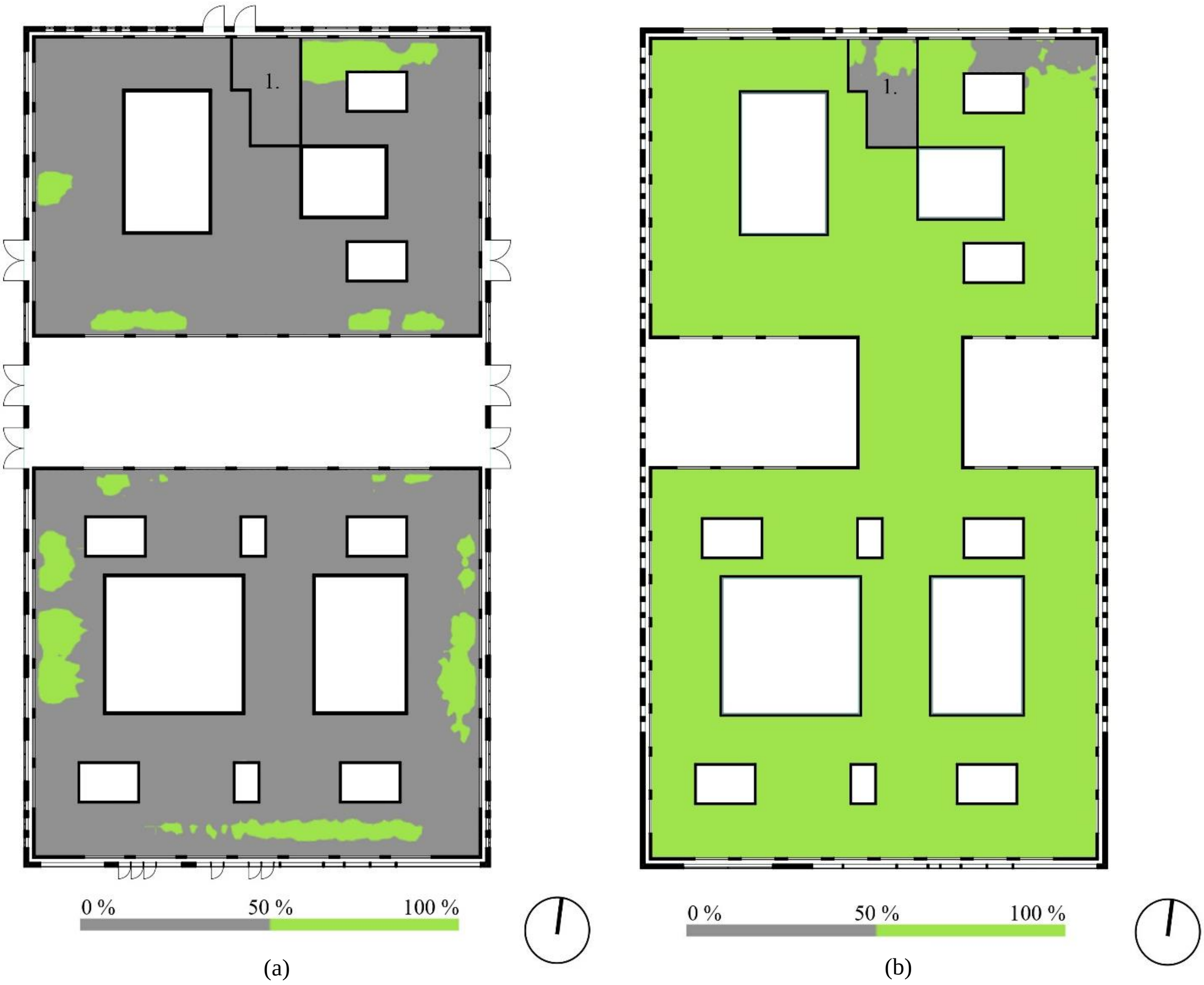
Figure C 5 (a), (b) View out distribution in educational layout (left: ground floor, right: first floor)



(a)

(b)

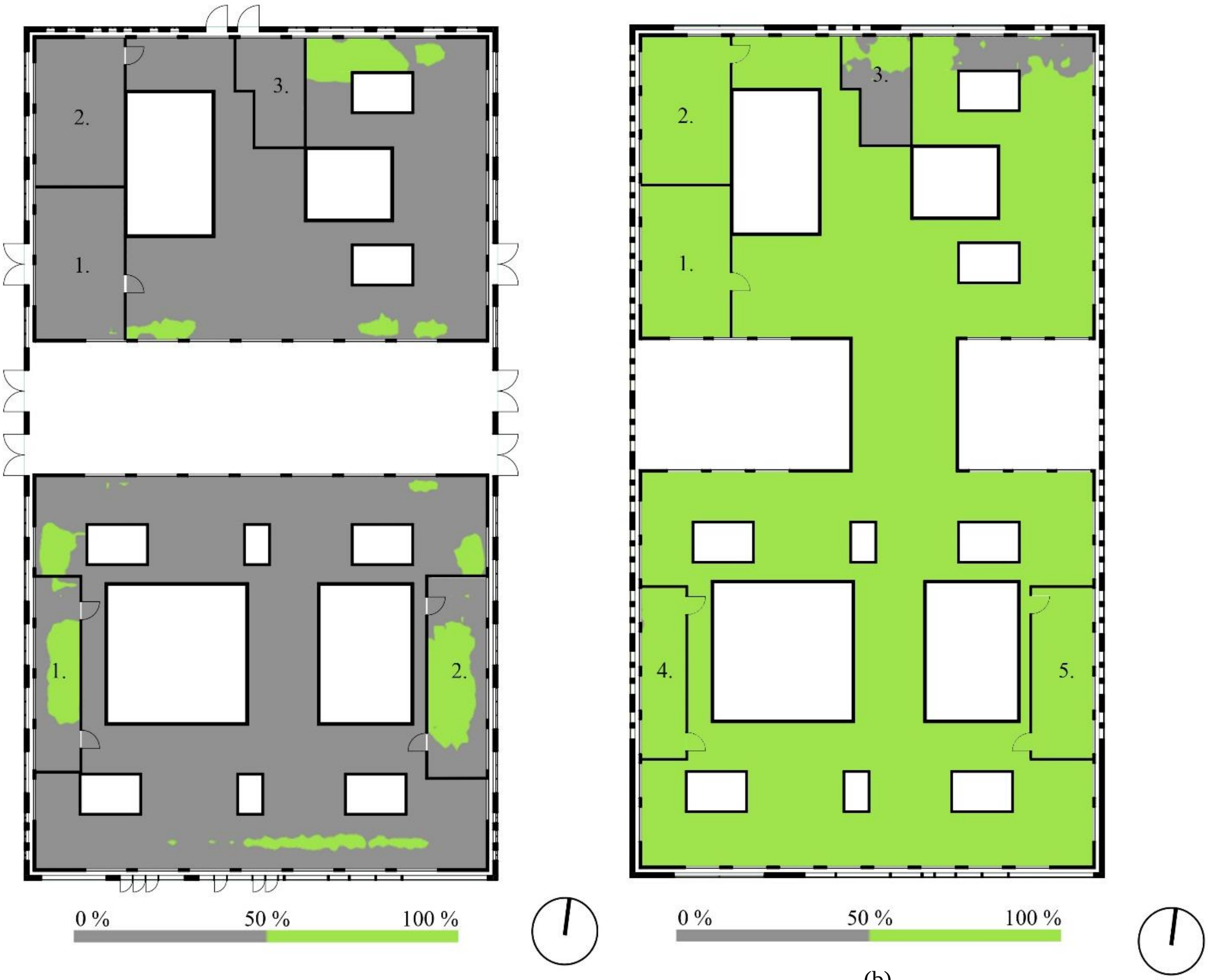
Figure C *6* (a), (b)View out distribution in residential layout (left: ground floor, right: first floor)



(a)

(b)

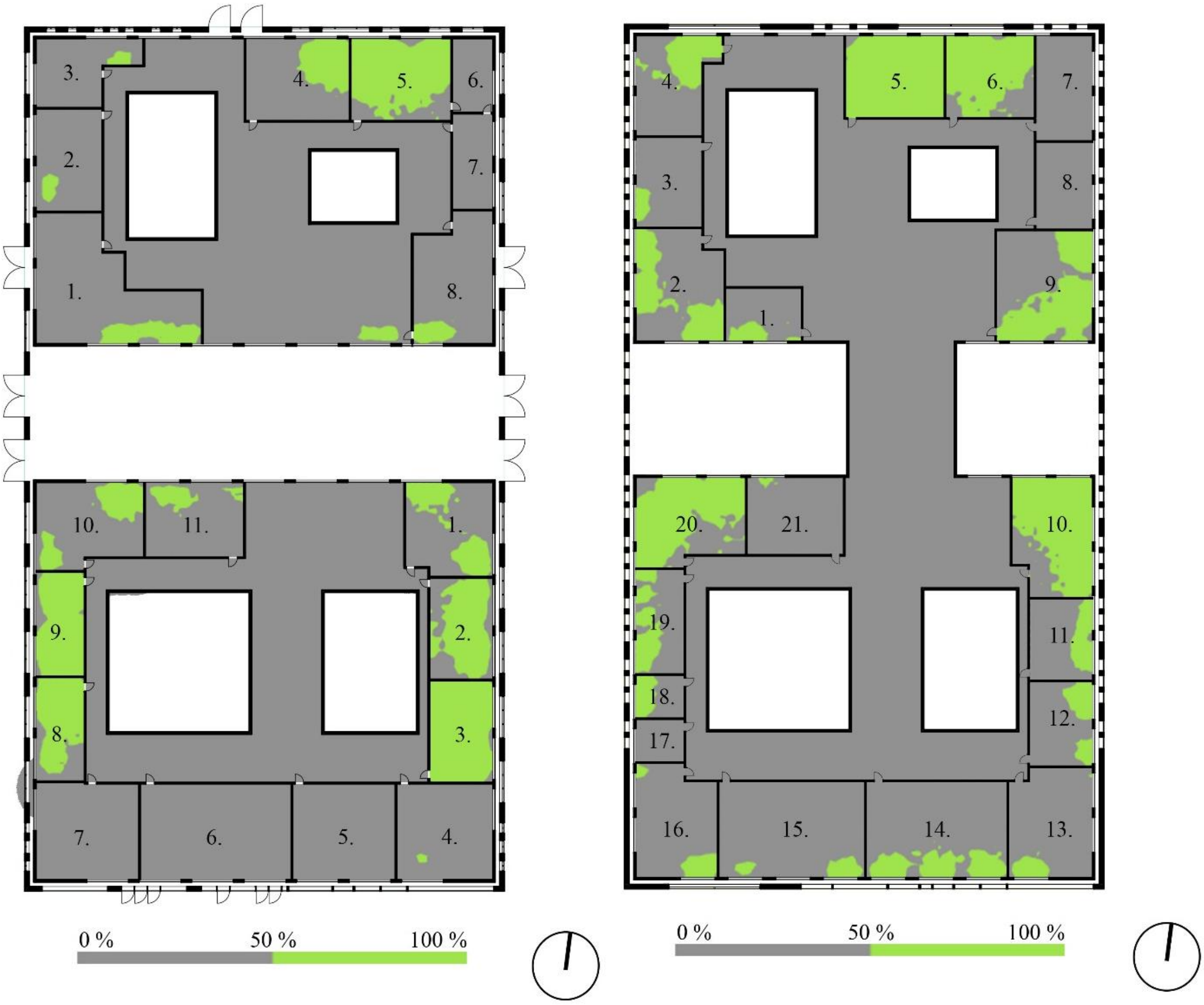
Figure C *7* (a), (b) Spatial daylight autonomy distribution in office layout (left: ground floor, right: first floor)



(a)

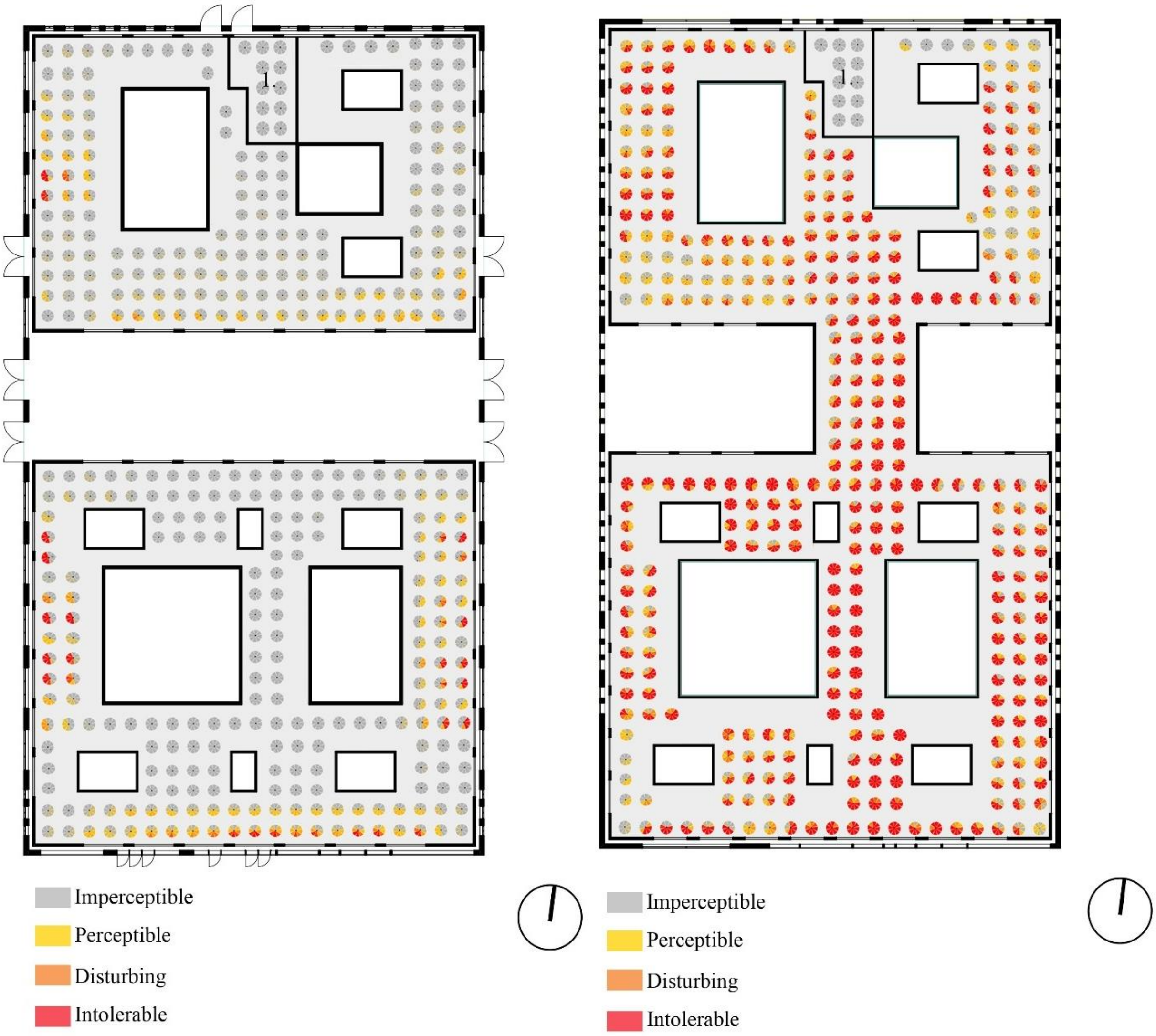
(b)

Figure C *8* (a), (b) Spatial daylight autonomy distribution in educational layout (left: ground floor, right: first floor)



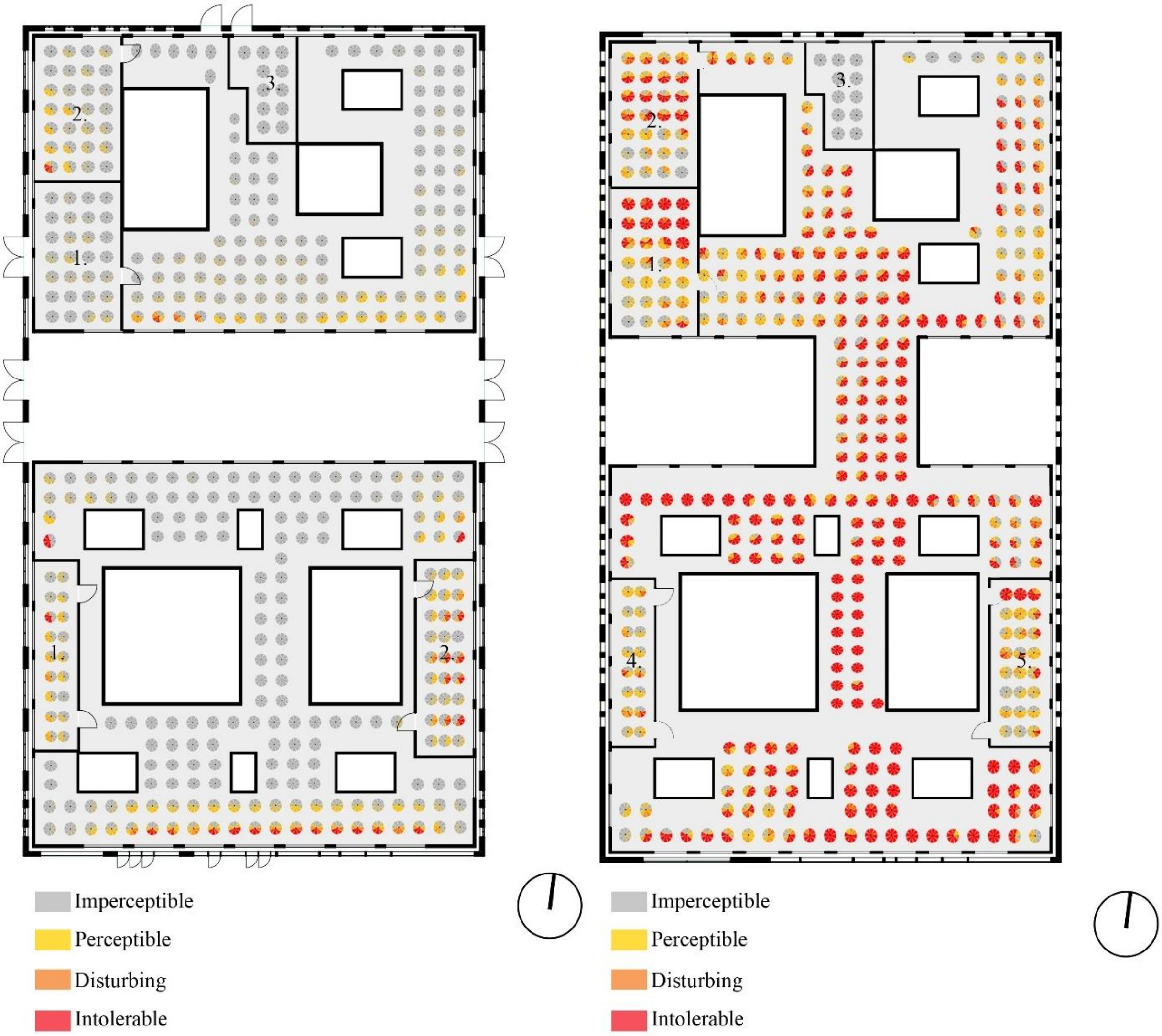
(a) (b)

Figure C *9* (a,), (b) Spatial daylight autonomy distribution in residential layout (left: ground floor, right: first floor)



(a) (b)

Figure C *10* (a), (b) Glare distribution in office layout (left: ground floor, right: first floor)



(a) (b)

Figure C 11 (a), (b) Glare distribution in the educational layout (left: ground floor, right: first floor)

Appendix D Results

Table D 1 Office and educational programs daylight performance results

Program	**Floor and orientation**	**Room number**	**DF** ***Median/ %***	**Target illuminance**							**Glare**	**View out (EN 17037) / %**				**mEDI / melanopic lux**					
																Overcast sky			**Clear sky**		
				100 lux	**300 lux**	**500 lux**	**750 lux**	**Minimum**	**Medium**	**Maximum**	**DGP / %**	**Fail**	**Min**	**Medium**	**High**	**09:00**	**12:00**	**15:00**	**09:00**	**12:00**	**15:00**
Office program	Ground floor North	Room 1	0,3	9,23	0	0	0	*Fail*	*Fail*	*Fail*	0	100	0	0	0	16	24	16	26	32	24
		Open space	0,3	33,2	6,02	1,27	0	*Fail*	*Fail*	*Fail*	0,3	26,3	73,7	0	0	28	39	28	147	331	386
	Ground floor South	Open space	0,7	54,8	11,57	1,09	0	*Fail*	*Fail*	*Fail*	2,6	48,8	51,2	0	0	49	69	49	508	130	223
	First floor	Room 1	1,4	100	42,93	6,52	0,54	*Fail*	*Fail*	*Fail*	0	99,5	0,5	0	0	67	93	67	204	199	130
		Open space	13	100	99,7	96,8	89,11	*Pass*	*Pass*	*Pass*	40,5	6,9	43,1	50	0	434	609	437	2740	3136	2487
Educational program	Ground floor North	Room 1	0,3	22,99	0,44	0	0	*Fail*	*Fail*	*Fail*	0	11,2	88,8	0	0	19	27	19	41	127	364
		Room 2	0,4	15,63	0	0	0	*Fail*	*Fail*	*Fail*	0	100	0	0	0	24	34	24	36	93	859
		Room 3	0,3	9,85	0	0	0	*Fail*	*Fail*	*Fail*	0	100	0	0	0	16	23	16	24	33	24
		Open space	0,3	30,53	6,3	2,06	0	*Fail*	*Fail*	*Fail*	0	25,2	74,8	0	0	27	38	27	257	98	139
	Ground floor South	Room 1	2,5	100	61,8	9,38	0	*Pass*	*Fail*	*Fail*	2,1	99,7	0,3	0	0	131	186	133	160	256	581
		Room 2	2,5	100	63,63	1,47	0	*Pass*	*Fail*	*Fail*	3,7	98,8	1,2	0	0	148	208	150	4603	236	167
		Open space	0,4	37,31	2,71	0	0	*Fail*	*Fail*	*Fail*	2,2	43,7	56,3	0	0	27	39	28	202	97	92
	First floor	Room 1	9,6	100	100	100	100	*Pass*	*Pass*	*Pass*	25,9	5,8	94,2	0	0	317	442	315	1795	2680	2206
		Room 2	9,7	100	100	100	99,33	*Pass*	*Pass*	*Pass*	17,9	98,4	0,4	1,1	0	317	442	319	1000	2467	1201
		Room 3	1,3	100	40,21	6,52	1,08	*Fail*	*Fail*	*Fail*	0	99,5	0,5	0	0	67	92	66	206	194	123
		Room 4	3,1	100	100	91,01	37,5	*Pass*	*Pass*	*Fail*	0	72,3	1,2	26,6	0	153	213	153	498	375	1702
		Room 5	7,5	100	100	100	99,71	*Pass*	*Pass*	*Pass*	13	67,6	6	26,4	0	261	368	265	1124	1596	515
		Open space	13,3	100	99,69	96,85	88,57	*Pass*	*Pass*	*Pass*	45,7	9,3	38,3	52,4	0	434	608	437	2647	3095	2229

Table D 2 Residential program daylight performance results

Floor	**Apartment number**	**DF** ***Median*** **/ %**	**Target illuminance**							**View out (EN 17037) / %**			
			100 lux	**300 lux**	**500 lux**	**750 lux**	**Minimum**	**Medium**	**Maximum**	**Fail**	**Min**	**Medium**	**High**
Ground floor North	Apartment 1	0,4	35,2	2,8	0	0	*Fail*	*Fail*	*Fail*	3,2	96,8	0	0
	Apartment 2	0,9	46,5	3,1	0	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 3	0,6	48,4	0	0	0	*Fail*	*Fail*	*Fail*	99,5	0,5	0	0
	Apartment 4	1	95,1	20,7	6	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 5	1,8	99,6	55	7,7	0	*Pass*	*Fail*	*Fail*	99,6	0,4	0	0
	Apartment 6	0,1	0	0	0	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 7	0,1	0	0	0	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 8	0,5	44,5	2,1	0	0	*Fail*	*Fail*	*Fail*	4,6	95,4	0	0
Ground floor South	Apartment 1	1,3	94,2	12,9	0	0	*Fail*	*Fail*	*Fail*	3,2	96,8	0	0
	Apartment 2	2,2	100	36	0,9	0	*Fail*	*Fail*	*Fail*	99,6	0,4	0	0
	Apartment 3	3,4	100	91,7	12,3	0	*Pass*	*Fail*	*Fail*	100	0	0	0
	Apartment 4	0,8	58,5	0	0	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 5	0,8	32,8	0	0	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 6	0,6	22,1	0	0	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 7	0,5	35,6	0	0	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 8	2,7	100	55,6	8,2	0	*Pass*	*Fail*	*Fail*	100	0	0	0
	Apartment 9	3,1	100	74,3	9,9	0	*Pass*	*Fail*	*Fail*	100	0	0	0
	Apartment 10	1,2	0,8	0,1	0	0	*Fail*	*Fail*	*Fail*	4,6	95,4	0	0
	Apartment 11	0,8	0,8	0	0	0	*Fail*	*Fail*	*Fail*	0	100	0	0
First floor	Apartment 1	1,7	0	0	0	0	*Fail*	*Fail*	*Fail*	0	100	0	0
	Apartment 2	1,3	95,7	26,6	4,3	0	*Fail*	*Fail*	*Fail*	4,9	95,1	0	0
	Apartment 3	0,5	47,1	5,9	0,0	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 4	1,1	99,6	25,4	15,1	10,3	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 5	2,2	100	89,3	33,7	11,1	*Pass*	*Fail*	*Fail*	100	0	0	0
	Apartment 6	1,6	100	50,6	13,3	2,0	*Pass*	*Fail*	*Fail*	100	0	0	0
	Apartment 7	0,1	0	0	0	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 8	0,1	0	0	0	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 9	1,4	100	24	1	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 10	1,7	100	53,5	7,4	0	*Pass*	*Fail*	*Fail*	100	0	0	0
	Apartment 11	1,1	100	13,9	0,6	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 12	1,2	99,5	16,1	1,6	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 13	1	62,3	6,8	0,3	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 14	2,5	100	16,7	0,2	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 15	1,5	75,6	7,1	0	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 16	1	76,5	9,2	0	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 17	0,9	98,6	20,8	1,4	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 18	1,5	100	34,7	2,8	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 19	1,5	100	23,4	2,9	0	*Fail*	*Fail*	*Fail*	100	0	0	0
	Apartment 20	1,4	99,3	47,7	4,6	0	*Fail*	*Fail*	*Fail*	0,7	99,3	0	0
	Apartment 21	0,3	25	0,4	0	0	*Fail*	*Fail*	*Fail*	15,9	84,1	0	0

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