Proposal for revised criteria for daylight provision for the European Daylight Standard EN 17037:2018+A1

With the focus on multifamily residential buildings

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Master thesis in Energy-efficient and Environmental Buildings
Faculty of Engineering | Lund University

Lund University

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Abstract

The European daylight standard EN 17037 was first introduced in 2018 with the aim of encouraging building designers to evaluate and ensure adequate daylight provision in buildings. However, experience has shown that the standard's criteria are generally perceived to be too challenging to achieve. Therefore, to suggest a more balanced threshold, this master's thesis aims to investigate compliance rate of existing buildings in Sweden for daylight provision criteria. In this study, 30 residential buildings in Sweden with a total of 3,570 rooms were selected based on Swedish building typical building forms and evaluated through Radiance-based daylight simulations using three different approaches: (1) Daylight Factor-based methods, (2) LM-83-12 method, and (3) a modified EN 17037 calculation method using illuminance level which is largely based on spatial Daylight Autonomy (sDA). In relation to the latter, compliance was checked for different combinations of illuminance thresholds and targeted area fractions. Then these compliance rates and the different combinations of the illuminance threshold as well as the targeted area fraction were compared to existing standards. Finally, a new criterion with three level of recommendations were proposed based on the new method. Results revealed that a large proportion of the examined individual rooms were able to meet various criteria for daylight provision. However, when looking at the buildings as a whole, only a few of them were able to fully meet these criteria. This is because many of the buildings have critical rooms that have limited access to the daylight, which makes it difficult to achieve the desired level of daylight provision at the building level. Furthermore, the finding of the study indicates that employing an illuminance threshold of 300 lux may not be beneficial in the context of the new criteria. Rather, a lower threshold coupled with a higher targeted area fraction would increase compliance and could be proposed as an alternative, but it needs to be backed up by further research.

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Abbreviation

DF_p	Point Daylight Factor
DF_{med}	Median Daylight Factor
sDA	Spatial Daylight Autonomy
ASE	Annual Sunlight Exposure
UDI	Useful Daylight Illuminance
BBR	Swedish Building Regulation
SBUF	Development Fund of Swedish Construction Industry
EN	European Standard
LEED	Certification system. Abbreviated from *Leadership in Energy and Environmental Design*
BREEAM	Certification system. Abbreviated from *Building Research Establishment Environmental Assessment Method*

1 Introduction

The urban population has been increasing over the past few decades and this trend is expected to continue (United Nations, 2018). Accommodating this growing population has resulted and results in increasing urban density. To increase profitability and to provide more housing, taller buildings, deeper floor plates and lower window-to-floor ratios have become more common. As a result, daylight accessibility indoors is jeopardized in urban areas (Grimm et al., 2008; Lee et al., 2022; Tregenza & Wilson, 2011).

Daylight in buildings has long been central for architectural design and building performance. Daylight has traditionally acted as a formgiver, but it also affects energy use of buildings and occupants' health. As long as energy and visual comfort issues are addressed, buildings with abundant daylight would always be preferred, as the physical and psychological benefits of natural daylight cannot be replaced by electric lighting (Knoop et al., 2019; Tregenza & Wilson, 2011). Recent research also showed the economic benefit of good daylight in buildings, as spaces with high daylight availability could attract 5-6% higher rent (Turan et al., 2020). Therefore, building designers should prioritize daylight availability in buildings.

In 2018, the first European Standard EN17037 "Daylight in Buildings" was issued. The scope was to encourage better daylight design in buildings, as well as to set ambitious targets for designers and developers (European Commission, 2018). However, several studies highlighted that the targets are too ambitious, as most existing and new buildings would fail to meet the requirements. It has also been pointed out that the ambitious requirements would require a large increase in window size, which would negatively affect the energy performance of buildings. The technical committee revising the standard - the European Committee for Standardization (CEN) Technical Committee (TC) 169 Working Group (WG) 11 'Daylight' - have expressed the desire to review the current standard towards more balanced requirements, where the ambition for better daylighting meets the needs of building designers and contractors.

Given this context, this thesis is part of a collective effort to identify alternative and more balanced requirements for daylight provision in buildings, which could reflect the current challenges faced by the building industry, while still ensuring adequate daylight in residential buildings.

1.1 Objective

The thesis aims to investigate the effect of different illuminance and room area targets on the compliance rate for daylight provision in a set of existing Swedish residential building stocks.

The study is based on the definition of spatial daylight autonomy (sDA). The tested illuminance and room area targets arose from brainstorming among experts in the CEN/TC169/WG11 Daylight, which are currently discussing the revision of the standard. Thirty buildings were selected from a dataset created in the context of the project 13209 'Moderniserad dagsljusstandard' (Rogers et al., 2018b) of the Development Fund of the Swedish Construction Industry. The results are compared with the current recommendation of daylight provision in European Daylight Standard EN 17037, as well as the sDA calculation method defined by the North American Approved Method from the Illuminating Engineering Society (IES) Lighting Measurements (LM) 83-12 (Illuminating Engineering Society, 2012a).

Finally, recommendations for potential illuminance and room area targets and their implications are discussed.

1.2 Research questions

According to the objectives, the research questions of this paper could be summarised as followed,

- How do illuminance levels and area targets affect compliance in existing residential buildings?
- Is there a set or sets of illuminance and area targets that could keep an acceptable compliance rate, whilst providing adequate daylight in residential buildings?
- What are the advantages and disadvantages of each set or sets of criteria, and how could they be suggested for future work?

1.3 Limitations

The selection of buildings from SBUF 13029 strived to include all building typologies according to different construction periods. However, subject to the accessibility of building models, the selection approximates the exact distribution of building typologies on the market.

The study focuses on the Swedish context, although the EN17037 standard applies to the whole Europe. It should be noted that other European groups are working on similar studies for their national contexts in parallel.

In order to facilitate comparison between building typologies in different countries, an identical Copenhagen weather file is selected for the purpose of the analysis. As such, the use of the Copenhagen weather file is not fully representative for the actual performance of the selected buildings, which are instead located at higher latitudes (Stockholm, Gothenburg, Örebro).

2 Background

Urbanization is happening at an unprecedented pace, with cities all around the world experiencing expansion due to rapidly growing urban populations. According to the United Nations, from 1950 to 2018, the world's urban population has grown from 25 per cent to 55 per cent, and it is expected to reach approximately 68 per cent by the mid-end of the 21st century. Europe is one of the most urbanized geographic regions, its urban population is expected to rise further, from 81 per cent in 2018 to 88 per cent in 2050 (United Nations, 2018). In this regard, the compactness of a built environment has been widely accepted to address the growing housing demand and promote urban development, which causes a significant increase in urban density (Yosef, 2006). Despite the many benefits of urban densification, like improvement in the energy efficiency of space heating and the reduction of transportation, it nonetheless has a significant impact on daylight accessibility (Šprah & Košir, 2019).

Several studies have indicated that sufficient daylight in buildings not only has a positive impact on decreasing the building's energy use of electric lighting (Bodart & De Herde, 2002) but also on human physiology and well-being such as mood and stress (Ticleanu, 2021). Exposure to daylight can help regulate the circadian rhythms, which can lead to improvements in the quantity and quality of sleep (Figueiro & Rea, 2016), as well as enhancing mood (Kaida et al., 2007) and reducing feelings of sleepiness during the day (Phipps-Nelson et al., 2003). To ensure buildings are provided with sufficient daylight and create a healthy indoor environment, it is important to prioritize daylighting design during the initial phase of building design.

From such perspective, in 2018 the CEN adopted the first ever European daylight standard EN 17037, *Daylight in buildings*, which overwent a minor update in 2021 (CEN, 2021). The standard covers four aspects of daylighting in buildings: 1) daylight provision, 2) sunlight access, 3) views out, and 4) glare. Although the standard was much welcome, requirements for daylight provisions have been proven to be relatively strict for both new and the existing buildings. Research has shown that many rooms in existing residential buildings fail to achieve the recommended daylight provision in EN17037:2021+A1, despite being able to comply with local building codes. For instance, in Sweden, approximately 69% of rooms in residential buildings comply with the Swedish building regulation (Bournas, 2020). However, when it comes to recommended daylight provision criteria based on calculation method one (DF method) and two (Illuminance based method) from the European daylight standard, only 16% and 45% of the rooms would be able to comply with these criteria, respectively (Bournas, 2020). In other words, the current recommendations for daylight provision in EN 17037 may not be suitable for the existing building stocks, and the mismatch between the European Standard and the market norm could make it difficult for the standard to be widely adopted.

When re-examining the requirements for daylight provision, it is crucial to consider that they would be used across Europe. Setting an overly ambitious daylight metric could lead to low compliance rate in northern Europe, which could discourage a wide application of the standard. Furthermore, if requirements are set too high, a larger window-to-floor ratio may be required, potentially leading to overheating. While overheating can be seen as an issue for all European countries, it is a particular issue in southern Europe. Therefore, finding a compromise between the daylight availability and compliance rate is essential for wider application of the standard at the European level.

2.1 History of daylighting design in buildings

As one of the fundamental elements of building design, daylighting design has been conveyed in different ways to represent its significance throughout various historical periods. From the Roman to the Victorian architecture period, there were no effective secondary sources to supplement natural light, and artificial lighting was both inadequate and costly. Consequently, buildings of these eras underwent significant structural changes to maximize the amount of light they could bring into the building (Lechner & Andrasik, 2021). This emphasis on daylighting design in buildings had as a central focus during this period (Bell, 1973). However, during the latter half of the 20th century, daylighting gradually became of reduced concern in architecture because of the widespread use of efficient electric lighting sources, and the abundance of cheap electricity. The energy crisis of the mid-1970s triggered by the petroleum shortages and new knowledge about the benefits of daylight, led to a reconsideration of the potential energy savings and benefits that could be achieved through daylighting. These historical milestones could be also recognized in the development of the Swedish residential building typologies over the years.

2.2 History of Swedish residential building typology

The dominant form of Swedish housing is multi-dwelling buildings, namely residential buildings containing three or more apartments, which makes up 52% of the national housing stock (SCB, 2022).

The following Swedish residential typologies (Figure 1) were categorised by Björk et al. (2021), and they were also used to categorise the building selection of this paper:

- *Large courtyard blocks* ("Storgårdskvarter")

This typology consists of buildings surrounding a courtyard and therefore forming a block. They are usually three to five storeys high. Since the new Town Planning Act (1907) was published, buildings were no longer allowed in the courtyard (Björk et al., 2021, p. 14).

- *Low-rise multi-apartments building* ("Lamellhus")

The dominant typology between the 1930s and 1970s is the rectangular shape detached apartment block "Lamellhus". It usually consists of two to four staircases and is three storeys high. Its emergence came with the development of modernist urban planning in the 1930s, and the preferences for sufficient daylight and balconies (Björk et al., 2021, p. 15).

- *Point tower* ("Punkthus")

From the 1930s until now, due to the fast expansion of urban areas in most cities, new multi-dwelling building constructions have often taken place on natural land adjacent to the existing urban development where there is hilly terrain (Björk et al., 2021, p. 16). Because of this condition, low-rise detached flats could not be built. Instead, a new type of apartment building point tower was introduced. A common feature of this building is a single staircase with four to six apartments on each floor, and it is usually constructed in groups.

- *Semi-closed courtyard blocks* ("Lamellhus halvslutna gårdar")

In the 1940s and 50s, many people moved to the big cities, especially after the Second World War which caused a serious housing shortage. To accommodate new residents, this type of building was built mostly on the edge of the city, and typically with a height of three storeys (Björk et al., 2021, p. 76). This building typology was the result of the reinterpretation of the low-rise detached apartment building, which connects and creates a semi-closed courtyard (Bournas & Dubois, 2019).

- *High-rise multi-apartment building* ("Skivhus")

This type of apartment building was common in the 1960s and 70s and it has rectangular shape apartments within the building. Unlike the low-rise detached apartment building, this type of building typically has eight to nine storeys. The building is usually constructed in parallel with a similar appearance. In addition, the location of the building and the spacing between each building were regulated by the incidence angle of sunlight as well as building height, which could ensure sufficient daylight in apartments (Björk et al., 2021, p. 16).

- *Postmodern blocks*

During the period between 1975 and 1995, this type of building emerged on the housing market after the Million Programme was phased out. It was usually constructed inside cities, arranged on a grid pattern to imitate the traditional urban layout of the old neighbourhood (Björk et al., 2021, p. 108). Unlike the large courtyard blocks, it typically has varying heights, and smaller windows due to the new energy legislation introduced after the energy crisis of 1973, and the room height was limited to 2,4 meters due to financial constraints (ArkDes, 2017, p. 220).

- *Dense city blocks*

Starting from 1995, the housing shortage resurfaced in the larger cities, primarily due to a significant decline in the construction of new housing development resulting from the economic crisis experienced in the early 90s.

With the help of new urban planning strategies, new projects were mainly placed on land that was previously used for other purposes, such as port, industrial, or hospital areas (Björk et al., 2021, p. 116). These new developments typically have higher building heights compared to the existing neighbourhoods as well as various appearances achieved by the different building materials.

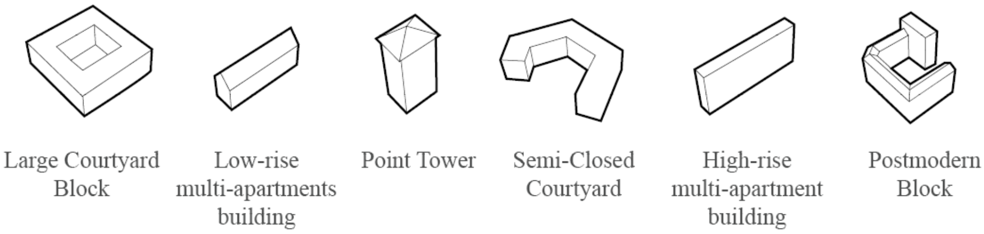

Figure 1 Building Typologies

2.3 Current standards

Since daylighting in buildings became legally binding for the first time in a number of countries, daylight criteria were first adopted in the Swedish building code in 1976 (STATENS PLANVERK, 1975), Denmark introduced the first mandatory daylight requirements in its building regulations in 2008 (Bolig- og Planstyrelsen, 2008), and later, in 2017, the Norwegian Building Regulation required a minimum average daylight factor of 2% for regularly occupied rooms (Direktoratet for byggkvalitet, 2017). Numerous research projects have been carried out, yielding valuable insights that accelerate the development of new metrics, while supporting the ongoing refinement of standards.

2.3.1 IES approved method for daylight metrics LM-83-12

The IES approved method for daylight metrics LM-83-12 was developed by the Illuminance Engineering Society, and it is currently adopted by voluntary certification schemes like LEED (Leadership in Energy and Environmental Design). The LM-83-12 approved method relies on the climate-based daylight metric Spatial Daylight Autonomy (sDA) (Illuminating Engineering Society, 2012b).

The sDA indicates the space (floor) area receiving sufficient daylight over a given analysis period. Therefore, sDA requires a definition of a) an illuminance threshold measured on a reference plane, b) an analysis area and c) a temporal threshold. Also, sDA obviously requires knowledge of the weather information for the location, typically provided by a climate file. In LM-83-12, the sensor grid should be offset 12 inches to 24 inches from walls (30,48 cm to 60,96 cm), and 30 inches (0,76 cm) above the finished floor (Illuminating Engineering Society, 2012b).

LM-83-12 suggests two levels of recommendation to evaluate the daylight provision by using the sDA with illuminance threshold 300 lx and temporal threshold of 50% of the analysis period ($sDA_{300/50\%}$). To meet preferred and nominally accepted daylight sufficiency, 75% and 55% of the analysed area must meet or exceed, respectively. In the assessment of LM-83-12, the use of dynamic blinds should be considered with the exceptions of,

1. Blinds are not installed as specified by the design, and
2. Annual Sunlight Exposure has been analysed and achieved 'nominally acceptable' occupant comfort (Illuminating Engineering Society, 2012a).

Table 1 — Recommended sDA performance criteria in LM-83-12

Level of recommendation	**Target illuminance**	**Fraction of space for the target level**	**Minimum target illuminance**	**Fraction of space for the minimum target level**	**Fraction of analysis period for the minimum threshold**
	E_T lx	F_{plane}, %	E_{TM} lx	F_{plane}, %	F_{time}, %
Nominally Accepted	300	55%	300	50%	50%
Preferred	300	75%	300	50%	50%

2.3.2 European standard CEN 17037:2018+A1 Daylight in building

Developed by the European Committee, EN 17037 has three levels of recommendations depending on target illuminance (European Comission, 2018). The standard provides two pathways, one based on sDA and the other based on target daylight factors. Target daylight factors depend on geographical locations, and they should ensure similar design compared to the sDA method. EN 17037 requires the sensor grid to be 0,85 m above the finished floor, and 0,5 m from the wall unless otherwise specified.

The current EN17037 suggests three levels of recommendation, see Table 2.

Table 2 — Recommendations of daylight provision by daylight openings in vertical and inclined surfaces

Level of recommendation	**Target illuminance**	**Fraction of space for the target level**	**Minimum target illuminance**	**Fraction of space for the minimum target level**	**Fraction of daylight hours**
	E_T lx	F_{plane}, %	E_{TM} lx	F_{plane}, %	F_{time}, %
Minimum	300	50%	100	95%	50%
Medium	500	50%	300	95%	50%
High	750	50%	500	95%	50%

2.3.3 Swedish building regulation BBR 29

In the latest national building regulation of Sweden (BBR29), it is recommended to have a window-to-floor ratio of at least 10% for each occupied room. This means a point daylight factor of approximately 1% could be achieve if the conditions of the standard are met. (Boverket, 2020).

2.4 Daylight recommendation of voluntary certification systems

The green architecture movement certainly contributed to the emergence of environmental certification systems regarding minimum daylight levels in rooms that are regularly occupied (Dubois et al., 2019, p. 74). And these systems encourage the building industry to achieve better daylight in buildings. Several voluntary certification schemes for building environmental performance include daylight requirements. These are based on current standards and methodologies to assess daylight.

2.4.1 LEED

There are three options for verifying daylight availability in LEED v4.1, which are,

1. Simulation of sDA according to LM-83-12 and ASE, and for spaces with ASE ≥ 10% glare protection should be specified.
2. Point-in-time illuminance simulation at 9 a.m. and 3 p.m. under clear sky conditions on the equinox day, and verify that the lux level is between 300 lux and 3,000 lux at both times,
3. Measuring illuminance in the regularly occupied space at approximate work plan height during any hour between 9 a.m. and 3 p.m. and demonstrating the illuminance level is between 300 lux and 3,000 lux.

Credits are provided based on the achieved results. For the first option, which is of interest in this thesis, credits and requirements are provided in Table 3 (USGBC, 2022).

Table 3 LEED v4.1 Daylight Credit for Option 1

Credit	**Compliance Area**	**Requirement**
1 point	40%	The average value of $sDA_{300/50\%}$ should reach at least the compliance area fraction of the regularly occupied floor area
2 points	55%	
3 points	75%	

In LEED certification system, the sensor grid should be set as per LM-83-12 (USGBC, 2022).

2.4.2 BREEAM-SE

Recently, Building Research Establishment Environmental Assessment Method (BREEAM) published the Swedish adaptation for new construction certification (Version 6.0) (Sweden Green Building Council, 2023). In this latest version, the daylight requirement in residential buildings is dependent on spatial functions and it is assessed either via median Daylight Factor or sDA (see Table 4). In BREEAM-SE certification process, the calculation grid should be set up as per EN 17037.

Table 4 BREEAM-SE for New Construction v6.0 2023 Daylight Credits

Area type	**Requirement**	**Minimum area (m^2) to comply**	
		2 Credits	3 Credits
Kitchen, Living rooms, dining rooms, studies, single-room apartment	**EITHER** D_T [a]=1.5% in 50% of the room **OR** E_T [b]= 200 lux in 50% of the room For at least 50% of the annual daylight hours	60%	80%
Bedrooms	**EITHER** D_T=0.8% in 50% of the room **OR** E_T=100 lux in 50% of the room For at least 50% of the annual daylight hours		

[a] **D_T is the target daylight factor** as measured according to EN 17037,
[b] **E_T is the target illuminance** as determined according to EN 17037

3 Methodology

3.1 Selection of buildings and models

Thirty buildings were selected from the collection included in the project SBUF 13209 (Rogers et al., 2018a). The buildings were selected according to building typologies and construction year (see Table 5), and they are meant to represent the existing Swedish building stock. However, due to the availability of building models, the selection has some differences with the distribution of the existing building typologies.

Building geometry is based on original permit drawings. It should be noted that in some cases, buildings may have undergone changes in interior wall partitioning, balconies and/or wall thickness (due to energy retrofitting). A fixed frame width of 10 cm and thickness of 6 cm were assumed in all simulation.

Table 5 List of selected buildings

ID	Cadastral Reference	City	Address	Year	Floors	Rooms
Large courtyard block ("storgårdskvarter")						
1	Kungsladugård 18:6	Gothenburg	Mariagatan 25	1923	3	37
2	Johanneberg 2:6	Gothenburg	Terrassgatan 3	1928	6	70
3	Pahl 8	Stockholm	Åsögatan 168	1875	7	75
4	Karlsvik 42	Stockholm	Sankt Eriksgatan 13	1910	6	85
5	Bikupan 20	Stockholm	Falugatan 23	1924	3	24
Multi-apartments building "Lamellhuskvarter"						
6	Dynamiten 2	Stockholm	Glimmerbacken 8-10	1938	4	45
7	Holaveden 3	Stockholm	Hallebergsvägen 34-36	1937	4	45
8	Mösseberg 9	Stockholm	Tranebergsvägen 36	1935	4	24
9	Tändhatten 1	Stockholm	Margretelundsvägen 36-38	1938	4	39
10	Postiljonen 15	Stockholm	Wollmar Yxkullsgatan 53	1934	6	110
11	Luxlampan 6	Stockholm	Disponentgatan 1	1935	7	201
Point Tower "punkthus"						
12	Rud 8:10	Gothenburg	Tamburingatan 9	1960	10	200
13	Kärnröret 2	Stockholm	Tranebergsvägen 10	1938	4	41
14	Signallyktan 1	Stockholm	Rålambsvägen 21	1943	7	144
15	Stjärnsången 1	Stockholm	Stagneliusvägen 35	1936	7	119
16	Fegen 1	Stockholm	Ymsenvägen 9	1946	8	92
17	Soldatgossen 1	Stockholm	Stagneliusvägen 51	1936	7	144
Semi-closed courtyard "Lamellhus halvslutna gårdar"						
18	Skärkarlen 9	Stockholm	Wergelandsgatan 26	1950	4	173
Panel Building "skivhusgrupper"						
19	Vårfrugillet 1	Stockholm	Ålgrytebacken 10	1962	4	128
20	Harholmen 1:8	Stockholm	Ekholmsvägen 345 - 363	1965	7	129
21	Branthomen 1:2	Stockholm	Brantholmsgränd 40-72	1965	7	173
22	Baronbackarna B:5	Örebro	Hjalmar Bergmans väg 54	1952	10	126
23	Gula Knapparna 2:16	Stockholm	Stora Sällskapets väg 28-30	1963	9	261
24	Drakenberg 14	Stockholm	Drakenbergsgatan 20-22	1973	9	230
Postmodern blocks "Postmoderna reformkvarter"						
25	Vasastaden 64:13	Gothenburg	Erik Dahlbergsgatan 12	1987	4	42
26	Minneberg 4	Stockholm	Svartviksslingan 73-79	1983	6	140
27	Gondolen 1	Stockholm	Pilotgatan 42	1981	5	173
28	Flygplanet 1	Stockholm	Horisontvägen 31-39	1982	5	229
29	Carmfronten 1:21-22	Stockholm	Varmfrontsgatan 2-74	1983	6	203
After 90s						
30	Lindholmen 37:1	Gothenburg	Ceresplatsen 1-5	2013	11	68

3.2 Simulations

The overall simulation workflow is presented in Figure 2. The building models were remodelled in Rhinoceros 3D for simulations. The daylight simulations were set up and performed in Grasshopper, by using the Radiance-based (Lawrence Berkeley National Laboratory, 2020) plugins from Ladybug tools.

There were three types of daylight simulations performed in this study:

- **Daylight factor method**. A simulation under CIE standard overcast sky (CIE, 2004) was performed to obtain the compliance rate of median daylight factor higher than 2,1%, which is the target daylight factor to achieve 300 lux suggested by EN 17037 for Copenhagen. Then the correlation between the median daylight factor and the sDA performance of each room under the new method was analysed;

- **EN 17037 modified method**. A climate-based simulation using Copenhagen weather file provided by TC169/WG11 committee members. The EN 17037 daylight hour schedule was adopted as analysis period (see 3.2.1.2), and the illuminance thresholds were set to 100 lux, 150 lux, 200 lux and 300 lux;

- **LM-83-12 modified method.** This modified method closely aligns with the LM-83-12 method, but it does not incorporate blinds or shades. The Copenhagen weather file was also used.

Subsequently, the simulation results obtained from the *proposed method* are expressed as sDA values with various illuminance thresholds. Then the compliance rate is calculated by studying various combinations of illuminance thresholds and compliance area fractions. Finally, the compliance rates of different thresholds and area fractions, along with those combinations used in the existing standards and certification systems are compared and discussed.

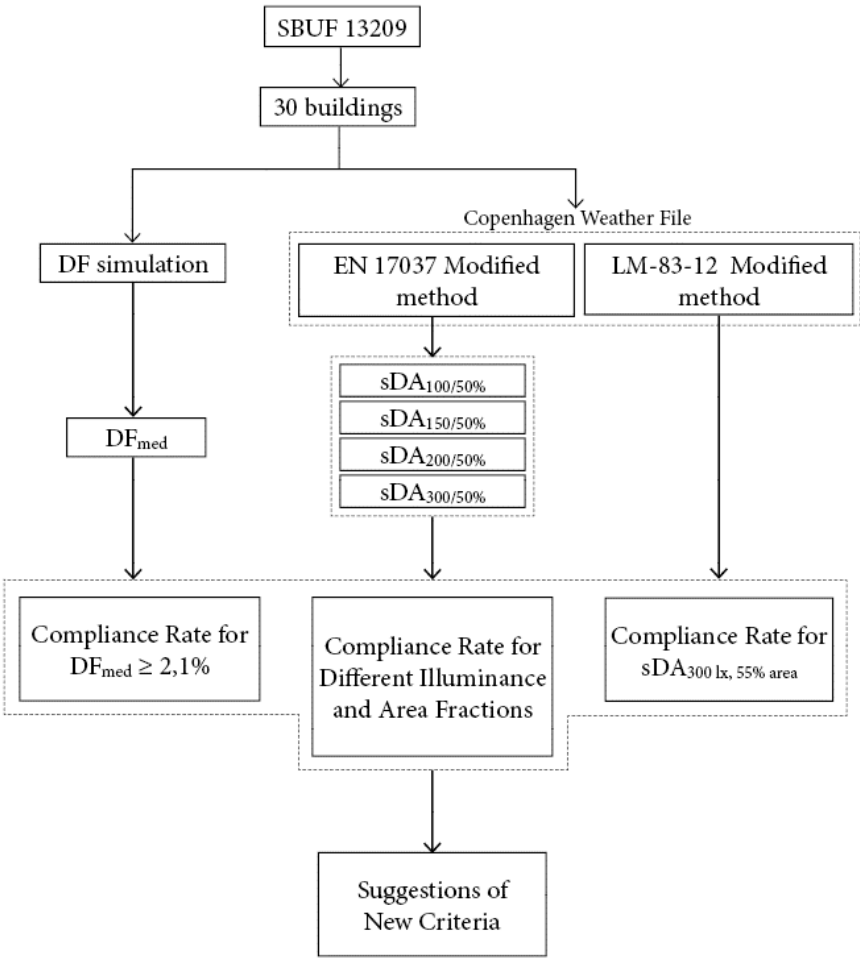

Figure 2 Illustration of Workflow

3.2.1 Simulation inputs

3.2.1.1 External surroudings

The surrounding 3D models were obtained from the SBUF 13209 database, and they were originally retrieved from the 3D model of the corresponding city.

3.2.1.2 Analysis period

There are two schedules used in this study, as illuminance simulations were performed according to two methods, the EN 17037 method and the LM-83-12 method. The daylight hour schedule described in EN 17037 (CEN, 2018) was used for the EN 17037 based simulations. It is defined as,

The rank-ordering (i.e., from highest to lowest) of the 8 760 values for diffuse horizontal illuminance and then extracting the first (i.e. the highest) 4 380 hourly values.

The values of diffuse horizontal illuminance were extracted from the weather file and processed in Excel to obtain the highest 4 380 values, then the list was made into the daylight hour schedule.

The occupant schedule defined in LM-83-12 (Illuminating Engineering Society, 2012b) was used for the LM-83-12 simulation. This schedule is defined as 8 a.m. to 6 p.m. (10 hours) local time per day.

3.2.1.3 Calculation grids

The calculation grid was set to 0,75 meter above floor to align with LM-83-12 (Illuminating Engineering Society, 2012a), and 0.5 meters offset from the wall. This study used the existing calculation grid in SBUF 13209, with a distance between each calculation point of 0,3 meters.

3.2.1.4 Surface and glazing properties

The reflectance and glazing transmittance used in the simulation could be seen in Table 6 below, the values were recommended by the European daylight standard EN 17037 :2018+A1. For materials that are not specified below, their reflectance was obtained from each SBUF 13209 model respectively.

Table 6 Surface Properties

Reflectance						**Transmittance**
Floor	Wall	Ceiling	Ground	Surrounding	Frame	Glazing
0,2	0,5	0,7	0,2	0,2	As per building	70%

3.2.1.5 Solar shading

The effect of interior shading devices such as roller blinds, venetian blinds, and curtains were not considered in the simulations. In the Nordic region, automated shading is rarely used in residential applications and the deployment of user-controlled shading in housing is in general notoriously difficult to predict, as it is significantly influenced by human preference. In the European context, it is well understood that issues of privacy commonly take priority over daylight access. Furthermore, in the Nordic region the presence of direct sunlight is normally appreciated during the winter. Given the above, it is logical for this study to adopt a modified version of the LM-83-12, which excludes the effects of dynamic shading on daylight provision.

3.3 Selection of metrics according to the new method

In order to suggest a set of revised thresholds, different combinations of illuminance thresholds and compliance areas were studied.

The tested illuminance thresholds were 100 lux, 150 lux, 200 lux and 300 lux, as advised by European Standard Committee members. Simulations were run for these thresholds and sDA was obtained. The simulation results were later processed in Excel and Python.

Then, the targeted compliance rate of different thresholds was generated in Excel for sDA of 30% to 95% of the floor area, at a 5%-steps increment. The compliance rate results of different thresholds and area fractions were plotted to study the trend of compliances. Lastly, the combinations of illuminance thresholds and corresponding area fractions were compared to existing standards and certification systems.

4 Results

4.1 Compliance rate according to current methods per building

4.1.1 EN 17037 Modified Method

This section displays the overall result of the 3,570 rooms, as well as building level results for the 30 selected buildings. The specific numbers of compliance would be presented in Table 7, Chapter 4.2.These buildings are grouped based on their construction year and building typology. The results are categorised according to illuminance thresholds of 100 lux, 150 lux, 200 lux, and 300 lux and shown in different boxplots and the detailed results of each building can be seen in the appendix.

Figure 3 shows that most rooms (88% of the 3,570 rooms as shown in Table 7) could achieve $sDA_{100/50\%}$ over 50% of their analysed area, and more than half of the rooms (56% of the analysed rooms as shown in Table 7) could achieve $sDA_{100/50\%}$ over 95% in their analysed area. However, at the building level, the average daylight performance of large courtyard blocks (building ID 1 to 5) and postmodern blocks (building ID 25 to 29) are lower compared to other buildings. This is primarily due to the rooms facing the courtyard being self-shaded. In addition, location of these typologies in densely built areas, which are more subjected to shading from surrounding buildings. By contrast, multi-apartment building (building ID 6 to 11), point tower (building ID 12 to 17), and panel building (building ID 19 to 24) have overall better daylight performance. Although a few buildings within these building typologies show different patterns of compliance area distribution. The main reason is that they are situated within a denser area, and the adjacent buildings are relatively tall, which creates more shading, especially for rooms on the lower level.

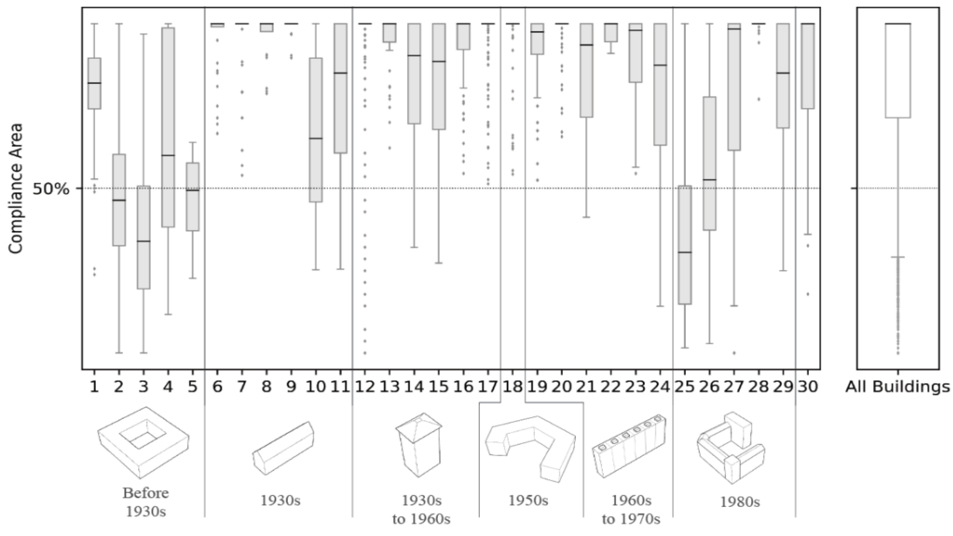

Figure 3 $sDA_{100/50\%}$ in each building with sensor grid height of 0,75 meter

Figure 5 shows the sDA results of illuminance threshold of 150 lux. The result shows that majority (76% as shown in Table 7) of the analysed rooms could achieve $sDA_{150/50\%}$ of 50%. And only less than half (34% as shown in Table 7) of the rooms could achieve $sDA_{150/50\%}$ of 95%. Moreover, the daylight condition within two buildings (ID 18 and 20) surpasses the others in this study. Typically, one building (ID 18, see Figure 4) compared with the large courtyard block, because of its unique semi-closed building typology, which dramatically reduces self-shading and provides more daylight to rooms facing the courtyard. Building 20 and 21 (see Figure 4) have similar surrounding contexts as well as orientation. However, the results of these two buildings differ from each other. It is primarily due to the differences of window-to-floor area ratio (see Figure 6). Since the daylight diminishes rapidly from the window to the deeper parts of the space, and the window-to-floor area ratio could play an important role in daylight penetration into the space, the difference of such a ratio leads to the different daylight performance.

Figure 4 Aerial view of building 18 (left), 20 (middle), and 21(right)

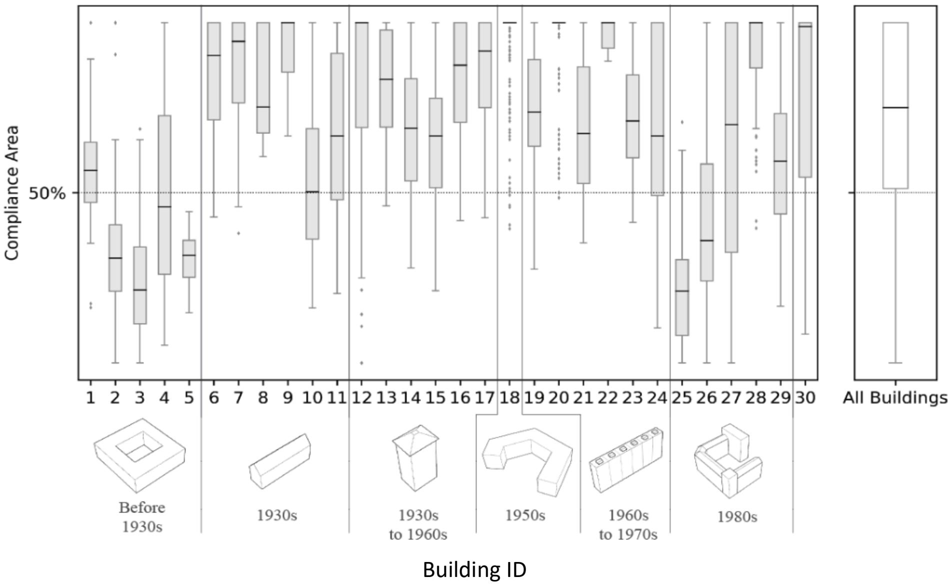

Figure 5 sDA150/50% in each building with sensor grid height of 0,75 meter

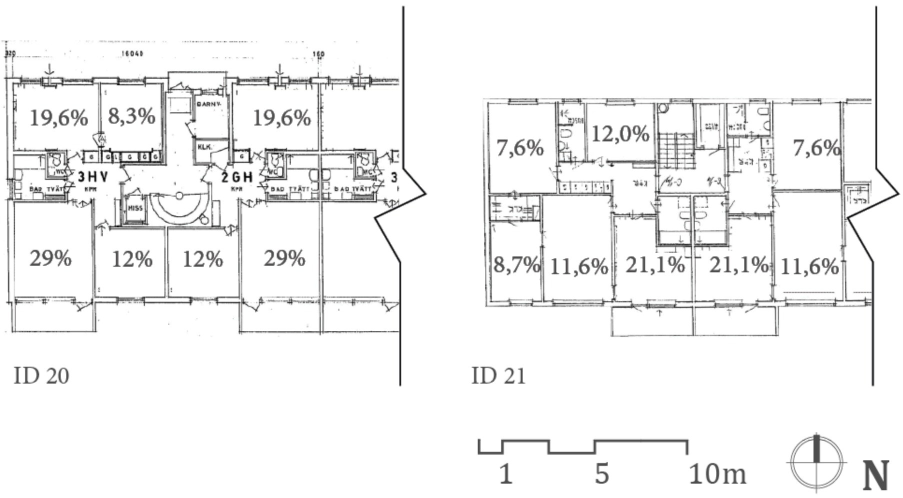

Figure 6 Window to Floor Ratio Comparison between Building ID 20 (left) and 21 (right)

Despite the variation in building typologies, when the illuminance threshold was increased to 200 lux, it was observed that as the illuminance threshold increased, the compliance rate of sDA in most evaluated rooms decreased. In addition, more than half (62% as shown in Table 7) of the evaluated rooms in the 30 selected buildings could comply with sDA200/50% of 50% in their analysed areas. However, less than a quarter (20% as shown in Table 7) of simulated rooms in those buildings were able to meet the same criteria for 95% of their analysed areas.

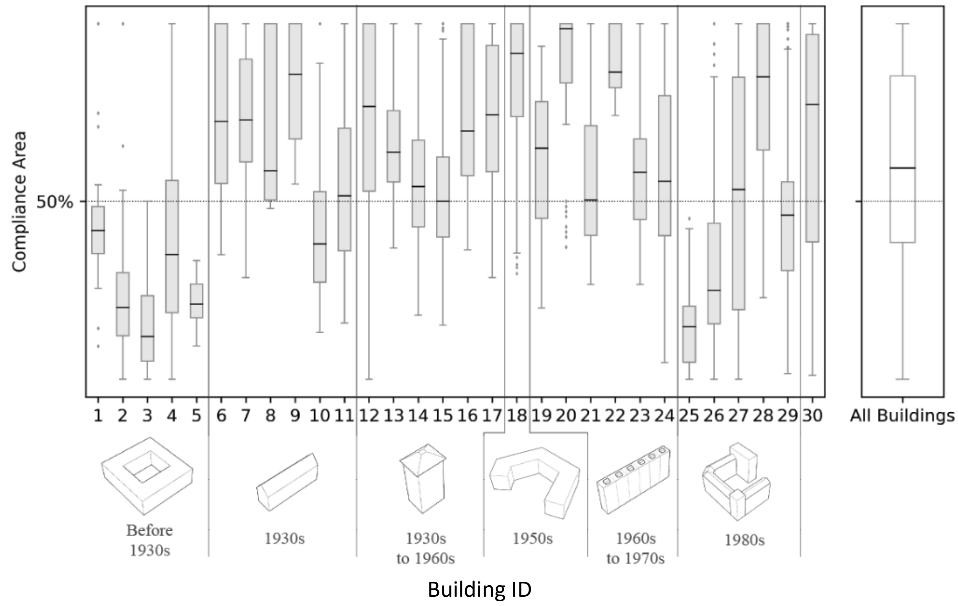

Figure 7 $sDA_{200/50\%}$ in each building with sensor grid height of 0,75 meter

Finally, when the illuminance threshold was set to 300 lux, only a tiny fraction (4% as shown in Table 7) of the analysed rooms could comply with $sDA_{300/50\%}$ of 95% and 34% could comply with $sDA_{300/50\%}$ of 50%. In other words, around more than half of analysed rooms would fail the minimum level of daylight provision recommendation for daylighting openings in vertical and inclined surfaces in EN 17037, as $sDA_{300/50\%}$ of 50% is required for the regularly occupied area. However, there is one building (ID 22, Figure 9) in which all rooms could achieve $sDA_{300/50\%}$ of 50%; this means only one building among the thirty selected buildings could fully comply with the current EN 17037 minimum criteria. This building has the advantage of a greater height than its neighbouring buildings. This advantage is obviously not possible for all buildings. This advantage contributes to this building becoming one of the best performing buildings. When it comes to different building typologies, $sDA_{300/50\%}$ results of most rooms fall within the range of 30% to 70% of compliance area, with the exception of large courtyard blocks and postmodern blocks which have a lower level of daylight performance. Rooms in these building typologies are more likely to experience a greater contrast in daylight distribution within the space, and it could possibly lead to visual discomfort for the occupants.

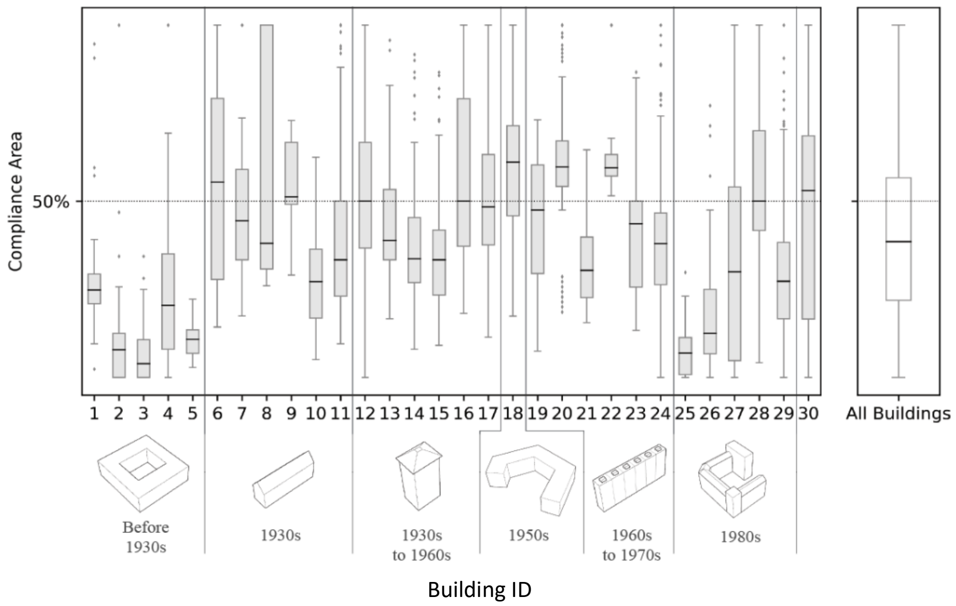

Figure 8 $sDA_{300/50\%}$ in each building with sensor grid height of 0,75 meter

Figure 9 Aerial View of Building 22 (Baronbackarna B:5)

4.1.2 Results of the LM-83-12 method

The overall compliance rate of LM-83-12 'nominally accepted' daylight provision in all rooms regardless of which building they belong to is 33%. The breakdown of results by each building could be seen in Figure 10. The darker grey bars above the zero axis indicate the percentage of rooms in the building that passed $sDA_{300/55\%}$ of LM-83-12, and vice versa for the light grey bars below the zero axis. When the whole bar is above zero axis, the building could pass LM-83-12. It shows that none of the 30 selected buildings was compliant with LM-83-12 on the level of whole building. Three buildings (ID 3, 5, and 25) performed rather poorly, having no compliant rooms. The first two are large courtyard block, and the third is a postmodern block. The common characteristics of these three buildings are,

- located in densely built areas
- a courtyard in the centre where self-shading occurs at corners
- relatively deep floor plans that reduce daylight penetration
- most windows are north facing, and the east, west facing windows were shaded by surrounding buildings.

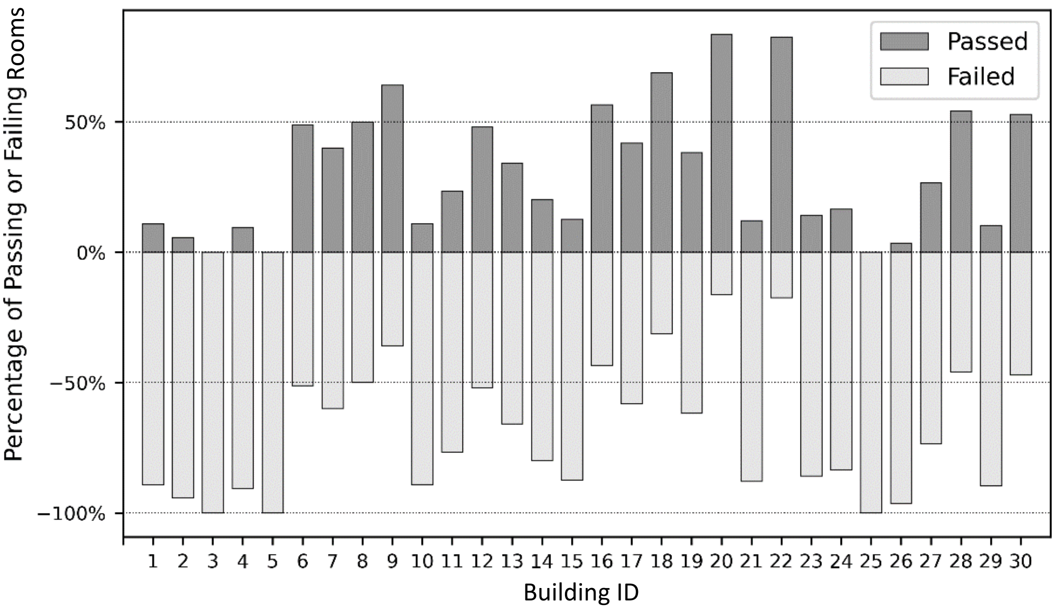

Figure 10 LM-83-12 Compliance rate for nominally accepted daylight provision

4.1.3 Results of Daylight factor method

A total of 66% of rooms could comply with the requirement. DF_{med} of 2,1% was the target daylight factor set in EN 17037 to achieve 300 lux for Copenhagen. In the 3,570 examined rooms, 684 rooms complied with DF greater than 2.1%, which corresponds to 19% of all rooms. However, this requirement could not be met by the whole building in any of the selected buildings. Only two buildings (9 and 18) had more than half of the rooms achieving the requirement due to the low-density area they situated. Therefore, it confirms that the current metrics in EN 17037 could be regarded as difficult to meet among the existing building stock, especially in densely built areas.

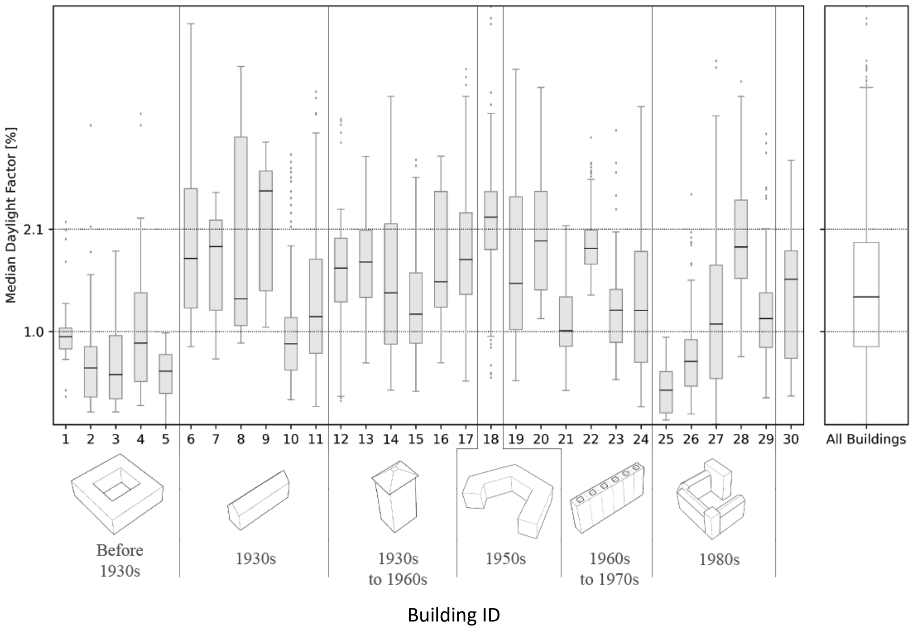

Figure 11 Results of median daylight factor

4.2 Compliance rate per room according to different illuminance thresholds and area fractions

The summary of compliance rates under different combinations of illuminance thresholds and area fractions can be seen below (Table 7 and Table 8). A red-green colour scale is used to visualise the distribution of compliance rate. Green denotes a high compliance rate, whereas red indicates a low compliance rate. Table 7 and Figure 12 show the overarching results for all 3,570 rooms, regardless which building they belong to. The results provide a general overview of daylight availability in the Swedish residential buildings. Table 8 and Figure 13 show the compliance rate on the level of building. Only when all rooms in the building comply with the corresponding metric would the building be considered as compliant. Despite the much higher compliance rate at room level, when all rooms in a building were required to comply with the same metrics, the compliance rate decreases significantly. For example, $sDA_{300/50\%}$ of 30% area is met by 64% of all rooms, but on building level, it is only complied by one single building out of the thirty selected buildings (ID 22), which corresponds to 3% of the selected building. It is also the only building that could still be able to comply when the illuminance was set to 300 lux. As mentioned previously, building 22 has the exceptional advantage of being the tallest building in the proximity and therefore not shaded by any surrounding building.

The contrast of compliance rate between room level and building level implies the difficulty of having all rooms in the building being compliant. If all the rooms in the building should achieve a criterion for the whole building to be considered as compliant, some rooms could be over lit, especially in the building typologies that daylight availability varies significantly within the building. The consequence could be that some rooms would have unnecessary large windows, which could potentially lead to overheating and therefore energy performance could be compromised. Consequently, room level compliance should be used to inform the design.

If either the illuminance threshold or required compliance area increases, the compliance rate decreases. However, a given compliance rate can be met with more than a combination of target area fraction and illuminance threshold. For instance, in Table 7, 55% of the rooms studied were able to comply with $sDA_{300/50\%}$ of 35%. To maintain a similar compliance rate, the illuminance threshold could be lowered while increasing the targeted area fractions, such as a combination of $sDA_{200/50\%}$ of 55%, $sDA_{150/50\%}$ of 70%, and $sDA_{100/50\%}$ of 95%. This could exemplify the flexibility and approach to be considered when suggesting a set or sets of new metrics, as the compliance rate could be addressed either through retaining illuminance thresholds constant but varying area fraction, and vice versa. Such a change would provide a certain degree of flexibility in design, for example allows for marginally deeper rooms.

Table 7 Summary of Compliance Rate for Different Illuminance Thresholds and Area Fractions by Rooms

Threshold / Area	**100 lx**	**150 lx**	**200 lx**	**300 lx**
30%	95%	90%	83%	64%
35%	93%	87%	79%	55%
40%	92%	84%	74%	48%
45%	90%	80%	68%	40%
50%	88%	76%	62%	34%
55%	85%	71%	55%	26%
60%	82%	67%	49%	21%
65%	79%	61%	43%	15%
70%	76%	55%	38%	12%
75%	72%	51%	34%	10%
80%	68%	46%	30%	8%
85%	65%	41%	25%	6%
90%	61%	38%	22%	5%
95%	56%	34%	19%	4%

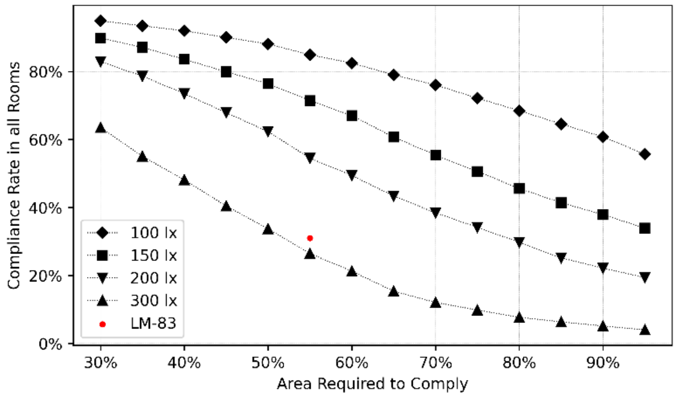

Figure 12 Trend of Compliance Rate per room

It should be noted that the high compliance rate at 30% area fraction could be misleading. At this area threshold, regularly occupied rooms in residential buildings tend to be relatively small, and after the 0,5-metre grid offset from wall, 30% of the remaining calculation grid is considerably small compared to the size of the room. For example, 30% of the calculation grid area of a 3 by 3 meters room is only 1,2 m^2 (a rather small occupiable area). Therefore, it is advisable to use a targeted area fraction which ensures that the occupiable area which is daylit is of a reasonable absolute size.

Table 8 Summary of Compliance Rate in Different Thresholds and Area Fractions in the 30 selected buildings

Threshold / Area	**100 lx**	**150 lx**	**200 lx**	**300 lx**
30%	57%	43%	33%	3%
35%	50%	43%	27%	3%
40%	47%	37%	10%	3%
45%	43%	20%	10%	3%
50%	43%	17%	7%	3%
55%	30%	13%	3%	0%
60%	23%	10%	3%	0%
65%	20%	7%	3%	0%
70%	13%	3%	3%	0%
75%	13%	3%	0%	0%
80%	10%	3%	0%	0%
85%	10%	3%	0%	0%
90%	7%	0%	0%	0%
95%	0%	0%	0%	0%

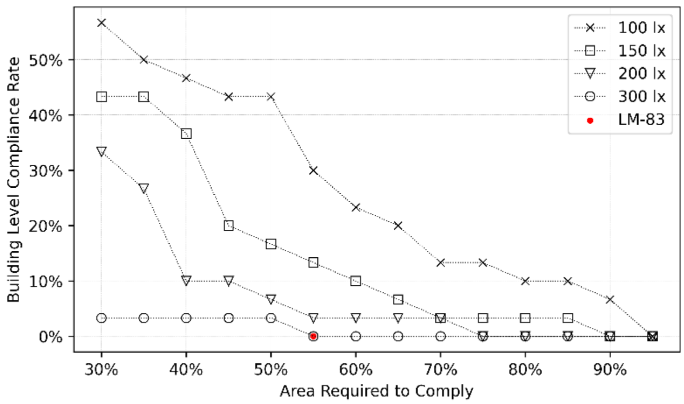

Figure 13 Trend of Building Compliance Rate

5 Proposal for new recommendations

Based on the aforementioned results, proposals for new recommendations for daylight provision in residential buildings are presented here. In particular, the results showed that:

- 19% of the rooms, and none of the thirty buildings complied with DF_{med} of 2.1%, which is the current EN17037:2018+A1 target daylight factor in Copenhagen

- 33% of the rooms, and none of the thirty buildings complied with LM-83-12

- 66% of the rooms, and three of the thirty buildings (10%) complied with Swedish building regulation (BBR), with DF_{med} of at least 1%.

These numbers provide an overview of the Swedish residential building stock's daylight availability and compliance with the current standards. These results could be used to guide the proposals, cross referencing the criteria and area requirements in the current certification systems.

The following proposals keep the existing structure of three levels of performance similar to the current EN1703:2018+A1. The three levels are "Level I" with the lowest ambition – or minimum requirement, to "Level III" being the one with highest ambition with regards to daylight provision. Considering that daylight provision criteria of the Swedish national building code have been recommended as baseline criteria, its compliance rate (66%) is used to set the target compliance rate for the "Level I" recommendation. The target of the proposal is to provide a daylight availability that could ensure a reasonable compliance rate; therefore, the compliance rate of LM-83-12 (33%) is used to set the target compliance rate for "Level III" recommendation. Subsequently, the compliance rate "Level II" recommendation would be targeted to the mid-point between "Level I" and "Level III", which is around 50% compliance.

Because of the correlation between illuminance and area fraction under the same compliance rate mentioned in 4.2, the new proposals potentially offer two alternative approaches. The first of these approaches would be to fix the target illuminance and vary the area fraction. And the second alternative is to have a fixed target area fraction, and then vary the illuminance threshold with the ambition being to approximately match the three levels of target compliance rates stated above. The advantage of having only one threshold in the metric is that it simplifies the simulation process and reduces the amount of data to process. However, keeping the same area fraction but varying the illuminance thresholds may more accurately match different levels of expectation for a daylit space. This approach with fixed area fractions, returns only the illuminance of the space. The mixing of different illuminance thresholds and area fractions in the proposed metric at the same time was also considered, but later rejected as it was deemed to be over complicated and illogical with risk that it could shift the designers and engineers' attention away from the intention of providing good daylighting.

5.1 Fixed illuminance with varying compliance areas

The following proposals (Table 9) of combinations with the fixed illuminance and varying areas of compliance is examined below. The advantage of having the same illuminance but varying compliance areas for different level is the simplicity of simulation process, and the less amount of data to post-process. Therefore, having the same illuminance could potentially be more time-efficient in the future assessing process. As mentioned before, when recommending illuminance and area for each level, the target compliances are 66% for level I, 50% for level II and 33% for level III.

Table 9 Proposals with same illuminance threshold and different compliance area

Level of Recommendation	Proposal 1 ($sDA_{200/50\%}$)	Proposal 2 ($sDA_{300/50\%}$)
I	45% Area	30% Area
II	60% Area	40% Area
III	75% Area	50% Area

Proposal 1 uses 200 lux as the target illuminance, and the sDA thresholds are 45%, 60% and 75% of the area for the three levels of recommendation. According to the simulation results, "Level I" compliance is found to

be 68%, 49% for "Level II", and 34% for "Level III". The advantage of using a lower illuminance (compared to Proposal 2) is, with the same target compliance rate, it allows a larger fraction of room area to be assessed. By doing so, daylight uniformity in the room could be addressed and therefore ensuring better visual comfort.

Proposal 2 uses 300 lux as the target illuminance, and the area fractions are 30%, 40% and 50% for "Level I" to "Level III" respectively. The advantage of having 300 lux as the target illuminance is that it aligns with the recommended illuminance of the current EN 17037. It is also the lower bound of useful daylight illuminance (UDI) – Autonomous. When daylight reaches 300 lux, users could perform task completely relying on daylight, and therefore autonomous from the supplement of electric lighting (Mardaljevic, 2015) . Between 100 lux to 300 lux, it is believed that electric lighting would be turned on to supplement daylight (Mardaljevic, 2015), therefore, 300 lux might be a more meaningful illuminance when setting criteria for daylight availability in buildings. However, using 300 lux as the target illuminance comes with a critical disadvantage that, keeping the same compliance rate, the area fraction required to comply would be significantly smaller. In "Level I", the required area fraction has been reduced to 30%. As discussed before, in the context of residential building, 30% compliance of the room area could become a small patch near the window and could not signify an overall good daylight in the room.

Compliance Area	100 lx	150 lx	200 lx	300 lx
30%	95%	90%	83%	64%
35%	93%	87%	79%	55%
40%	92%	84%	74%	48%
45%	90%	80%	68%	40%
50%	88%	76%	62%	34%
55%	85%	71%	55%	26%
60%	82%	67%	49%	21%
65%	79%	61%	43%	15%
70%	76%	55%	38%	12%
75%	72%	51%	34%	10%
80%	68%	46%	30%	8%
85%	65%	41%	25%	6%
90%	61%	38%	22%	5%
95%	56%	34%	19%	4%

Compliance Area	100 lx	150 lx	200 lx	300 lx
30%	95%	90%	83%	64%
35%	93%	87%	79%	55%
40%	92%	84%	74%	48%
45%	90%	80%	68%	40%
50%	88%	76%	62%	34%
55%	85%	71%	55%	26%
60%	82%	67%	49%	21%
65%	79%	61%	43%	15%
70%	76%	55%	38%	12%
75%	72%	51%	34%	10%
80%	68%	46%	30%	8%
85%	65%	41%	25%	6%
90%	61%	38%	22%	5%
95%	56%	34%	19%	4%

Figure 14 Illuminance, Area Fraction and Compliance Rate of Proposal 1 (left) and Proposal 2 (right)

5.2 Fixed compliance area with varying illuminance thresholds

Two proposals of same targeted compliance areas with varying illuminance thresholds are presented in Table 10. These proposals start with the same targeted area fraction of the regularly occupied space and set different target illuminance according to the different level of recommendation and utilisation of the space.

Table 10 Proposals for the same compliance area with different illuminance thresholds

Level of Recommendation	Proposal 3 (50% Area)	Proposal 4 (80% Area)
I	$sDA_{150/50\%}$	$sDA_{100/50\%}$
II	$sDA_{200/50\%}$	$sDA_{150/50\%}$
III	$sDA_{300/50\%}$	$sDA_{200/50\%}$

Proposal 3 uses an area fraction of 50% with three illuminances (150 lux, 200 lux, and 300 lux) according to different level of recommendations. This metric could be achieved by 76% of the rooms for level I, 62% for level II and 34% for level III. The compliance rates of Proposal 3 are slightly higher than the target compliance rate set before and makes it easier to achieve. The advantage of Proposal 3 is setting the area fraction as 50%. It is a straightforward indication of the daylight performance in half of the room area; therefore, it could be easily understood by any users. The "Level III" of recommendation ($sDA_{300,\ 50\%}$ = 50% area) also aligns with the current EN 17037.

Proposal 4 aims to cover a larger examined area by targeting 80% of the space, while recommending lower illuminance thresholds of 100 lux, 150 lux, and 200 lux for each level of recommendation. Compared to proposal 3, additional 30% of the area could be evaluated which has a potential to achieves a more evenly distributed daylight within a given space. However, the need for compromise arises due to lower compliance rate at each level (68%, 46%, and 30%), which suggests that achieving the requirements may be more challenging.

Compliance Area	100 lx	150 lx	200 lx	300 lx
30%	95%	90%	83%	64%
35%	93%	87%	79%	55%
40%	92%	84%	74%	48%
45%	90%	80%	68%	40%
50%	88%	76%	62%	34%
55%	85%	71%	55%	26%
60%	82%	67%	49%	21%
65%	79%	61%	43%	15%
70%	76%	55%	38%	12%
75%	72%	51%	34%	10%
80%	68%	46%	30%	8%
85%	65%	41%	25%	6%
90%	61%	38%	22%	5%
95%	56%	34%	19%	4%

Compliance Area	100 lx	150 lx	200 lx	300 lx
30%	95%	90%	83%	64%
35%	93%	87%	79%	55%
40%	92%	84%	74%	48%
45%	90%	80%	68%	40%
50%	88%	76%	62%	34%
55%	85%	71%	55%	26%
60%	82%	67%	49%	21%
65%	79%	61%	43%	15%
70%	76%	55%	38%	12%
75%	72%	51%	34%	10%
80%	68%	46%	30%	8%
85%	65%	41%	25%	6%
90%	61%	38%	22%	5%
95%	56%	34%	19%	4%

Figure 15 Illuminance, Area Fraction and Compliance Rate of Proposal 3 (left) and Proposal 4 (right)

6 Conclusion

The study assessed the effect of varying illuminance thresholds and targeted area fractions with ambition of establishing a new daylight provision criteria with focus on compliance of residential buildings. To achieve this, a radiance-based simulation was used to evaluate a total of 30 buildings in Sweden. The simulation results were expressed through DF and sDA. Subsequently, the compliance rates were calculated and compared with the compliance rates of existing standards as well as Swedish building regulations (BBR). Furthermore, the illuminance thresholds and targeted area fractions specified in the standards and the building certification systems were discussed. Finally, new criteria were suggested that include three levels of recommendations and aims to provide a more balanced approach while taking into consideration daylight availability in the context of historical levels of daylight access in residential buildings. Overall, the outcome of this study could be concluded as follows:

- Compliance rate of daylight availability in current Swedish residential buildings

Despite the Swedish building regulations for daylight provision being considered a less strict criterion compared to other standards, achieving compliance with the recommended standard of DF ≥ 1 % was found to be difficult to achieve, especially at the building level. This is mainly due to the conditions within the building that cause limited access to daylight, such as rooms on the ground floor shaded by the surrounding or deep rooms (when compared to head height ratio). The mismatch between the expectations set by the standards and the daylight availability in existing residential buildings is hindering the wide adoption of the European daylight standard within the construction industry. In addition, in order to meet the criteria of current standards, a general increase in window area would be needed. Such a change could potentially increase the consumption of operating energy due to additional heat gains during the cooling season and heat loss during the heating season. Consequently, the cost of development could be adversely affected as mechanical equipment would need to be sized to accommodate these additional thermal loads. In addition, it should be noted that glass is a relatively expensive building material when compared with others normally used for construction of Swedish multi-family dwelling. It was also found that compliance rates were significantly affected by various factors, including building typology, orientation, surrounding context, urban density, and floor plan. Therefore, in order to ensure a good level of daylight provision in buildings, it is very important to integrate daylighting design into the initial stages of building design and urban planning.

- Proposal of the new criteria

To ensure the new criteria maintain three levels of recommendation or performance, three separate degrees of compliance were targeted. The idea behind this is to keep the new guidelines approximately in line with the historic level of daylight access already established in the existing building stock. In other to identify the optimal combination of illuminance threshold and targeted area fraction which is in line with current target rates of compliance, two approaches were used. The first approach emphasised achieving uniform daylighting conditions rather than a specific illuminance level, which could potentially provide better visual comfort to building occupants. This was achieved by using a specific illuminance threshold while varying the targeted area fractions. The second approach took the opposite approach and varied illuminance thresholds while maintaining a constant targeted area fraction. However, to avoid the potential visual discomfort caused by the poor daylight uniformity, it is likely advantageous to retain a higher area fraction. Therefore, proposal 1 and proposal 4 are of greater interest when compared to the other proposals examined here and both represent potential for a wider application of the European daylight standard in residential buildings than the current criteria of the EN 17037:2018+A1.

7 Reflection and future work

To have a comprehensive understanding of daylight availability in the existing building stock in Sweden, additional building assessments are necessary, as only 30 residential buildings were evaluated in this study. Furthermore, as the European daylight standard applies to all types of buildings, it is essential to include buildings other than residential, such as schools, hospitals, and commercial buildings, in the research. Lastly, generating and comparing data from various European countries would also be beneficial. This is because factors such as geography, climate, historical background, and local policy could have significant impacts on the results. These results could shed light on the potential variations in the overall results across different contexts, which could potentially benefit the future development of the new metric.

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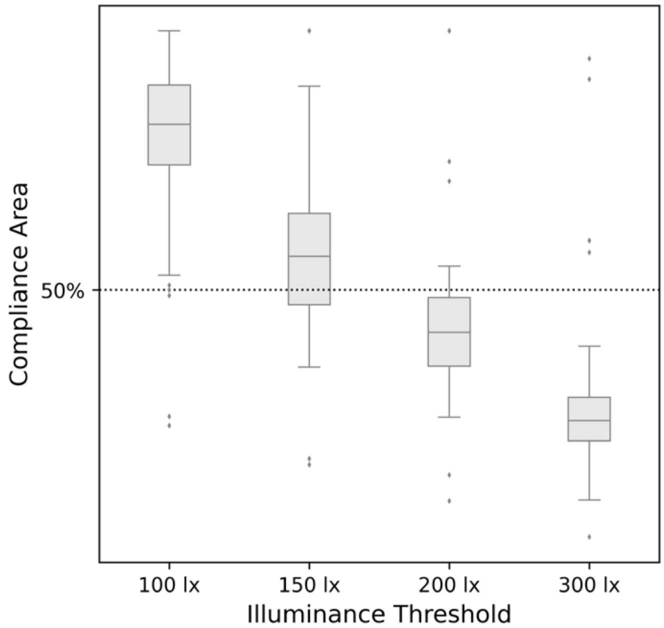
Appendix

1. Kungsladugård 18:6 Mariagatan 25, Kungsladugård, Göteborg

Fig B1.1

Fig B1.2



Year: 1923
Typology: Courtyard Block "storgårdskvarter"
Architect: unknown
Analyzed Rooms: 37

Table B1. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	92%	68%	22%	11%
55% Area	84%	54%	11%	11%
75% Area	68%	11%	5%	5%
85% Area	35%	8%	5%	5%
95% Area	16%	5%	5%	0%

LM-83 55% Area
11%

Room $DF_{med} \geq 2,1\%$
3%

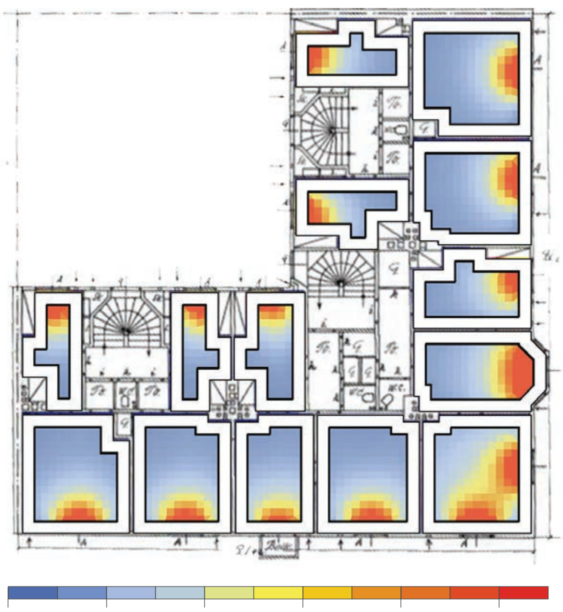


Fig B1.3

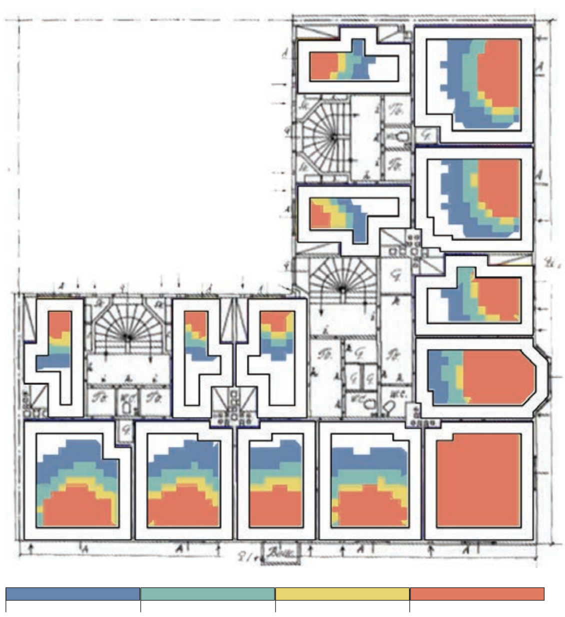
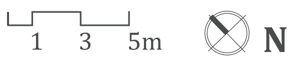


Fig B1.4



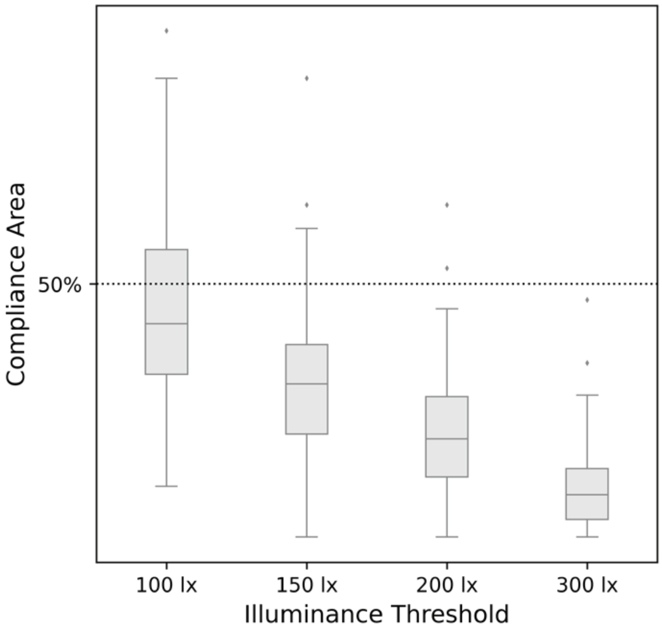
(Figure B1.1) Aerial View of the Building (Source: earth.google.com)
(Figure B1.2) Compliance Area Distribution according to Different Illuminance
(Figure B1.3) Daylight Factor of 1st Floor
(Figure B1.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

2. *Johanneberg 2:6*

Terrassgatan 3, Johanneberg, Göteborg

Fig B2.1

Fig B2.2



Year: 1928
Typology: Courtyard Block “storgårdskvarter”
Architect: unknown
Analyzed Rooms: 70

Table B2. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	36%	7%	3%	0%
55% Area	29%	7%	1%	0%
75% Area	6%	1%	0%	0%
85% Area	4%	1%	0%	0%
95% Area	1%	0%	0%	0%

LM-83 55% Area
1%

Room DF_{med} ≥ 2,1%
0%

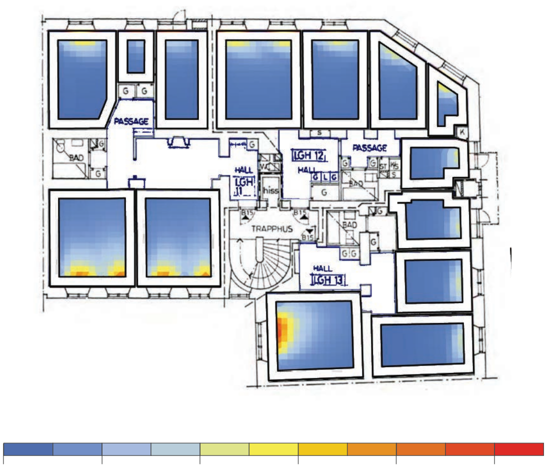


Fig B2.3

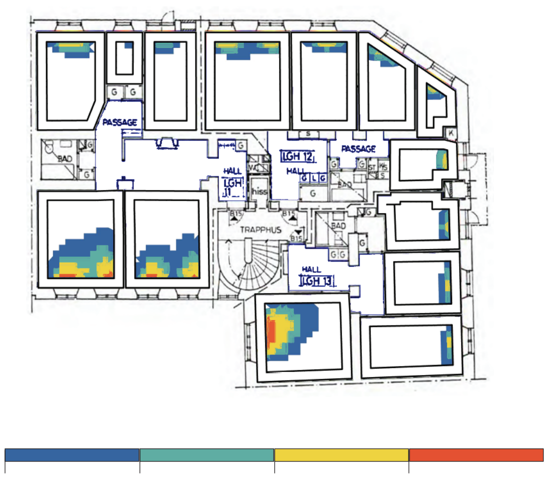


Fig B2.4

1 5 10m N

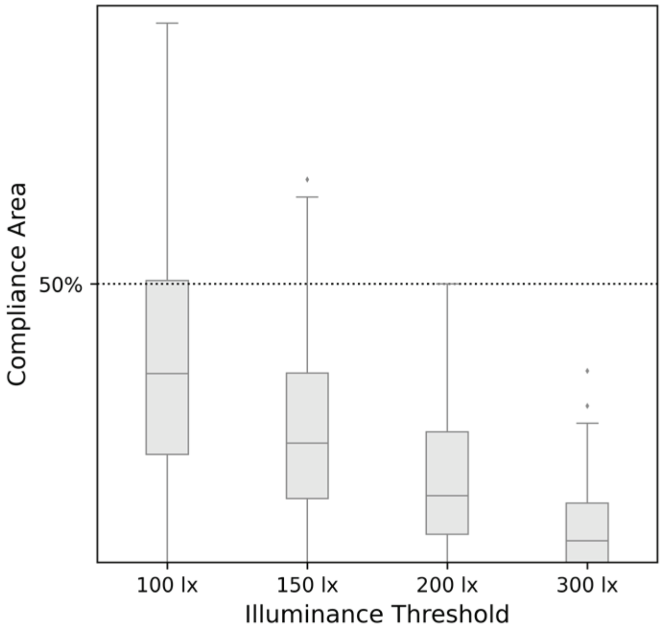
(Figure B2.1) Aerial View of the Building (Source: earth.google.com)
(Figure B2.2) Compliance Area Distribution according to Different Illuminance
(Figure B2.3) Daylight Factor of 1st Floor
(Figure B2.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

3. Pahl 8

Åsögatan 168, Södermalm, Stockholm

Fig B3.1

Fig B3.2



Year: 1875
Typology: Courtyard Block “storgårdskvarter”
Architect: unknown
Analyzed Rooms: 75

Table B3. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	27%	9%	1%	0%
55% Area	23%	5%	0%	0%
75% Area	8%	0%	0%	0%
85% Area	3%	0%	0%	0%
95% Area	3%	0%	0%	0%

LM-83 55% Area
0%

Room DF_{med} ≥ 2,1%
0%

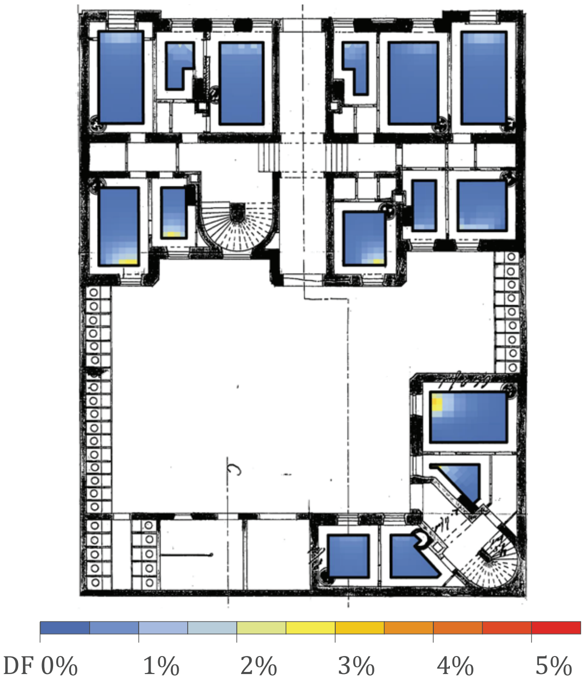


Fig B3.3

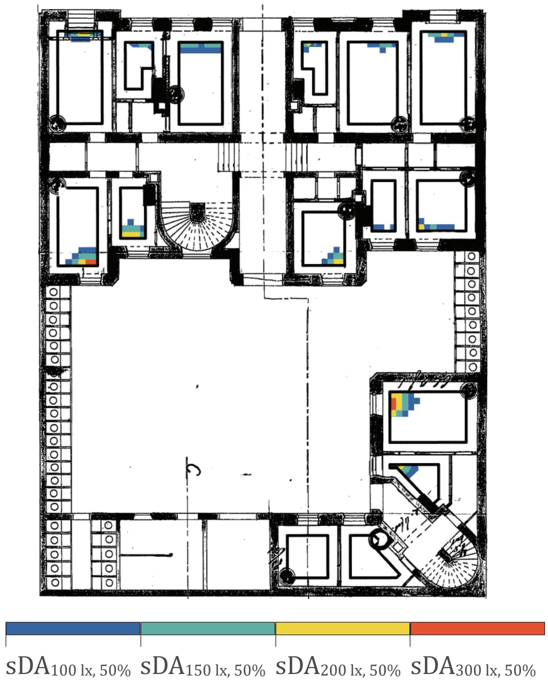
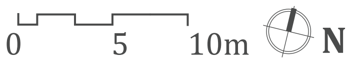


Fig B3.4



(Figure B3.1) Aerial View of the Building (Source: earth.google.com)
(Figure B3.2) Compliance Area Distribution according to Different Illuminance
(Figure B3.3) Daylight Factor of 1st Floor
(Figure B3.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

4. Karlsvik 42

Sankt Eriksgatan 13, Kungsholmen, Stockholm

Fig B4.1

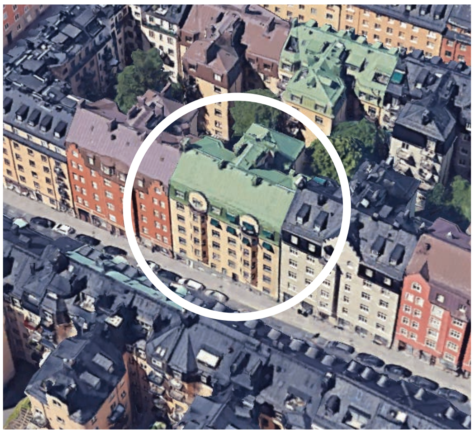
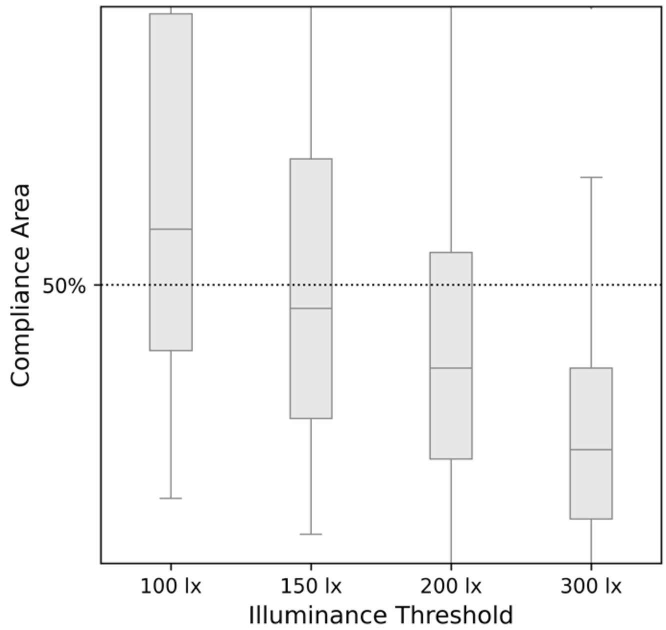


Fig B4.2



Year: 1910
Typology: Courtyard Block "storgårdskvarter"
Architect: unknown
Analyzed Rooms: 85

Table B4. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	60%	46%	32%	11%
55% Area	55%	40%	26%	7%
75% Area	38%	22%	12%	2%
85% Area	32%	16%	7%	2%
95% Area	29%	14%	14%	2%

LM-83 55% Area
9%

Room DF_{med} ≥ 2,1%
6%

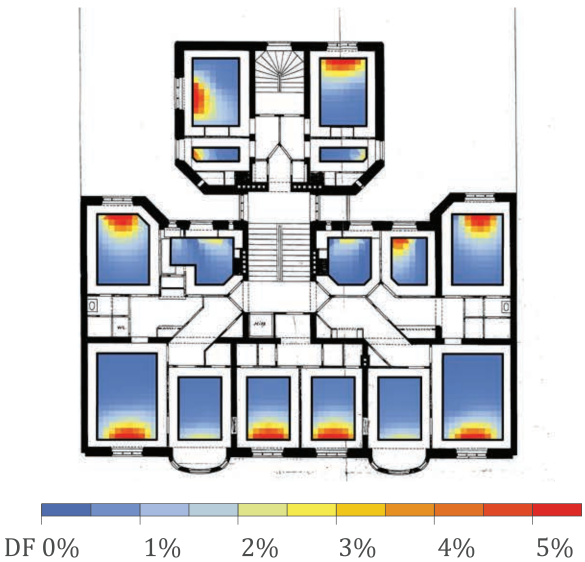


Fig B4.3

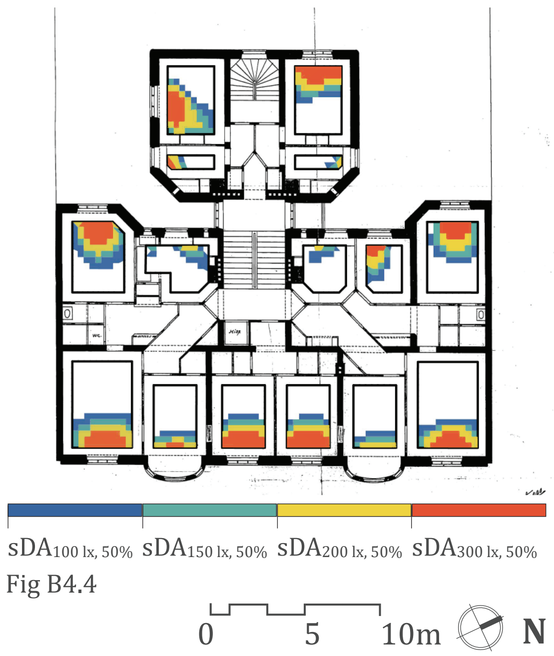


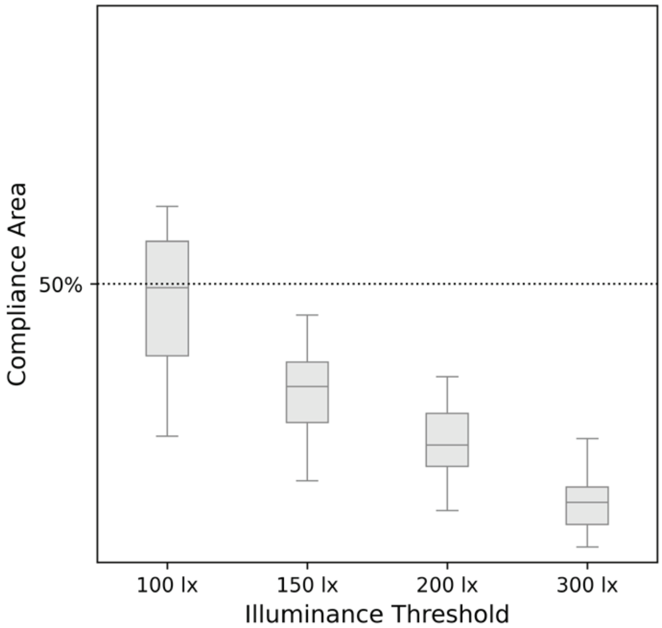
Fig B4.4

(Figure B4.1) Aerial View of the Building (Source: earth.google.com)
(Figure B4.2) Compliance Area Distribution according to Different Illuminance
(Figure B4.3) Daylight Factor of 1st Floor
(Figure B4.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

5. Bikupan 20 Falugatan 23 Rödaberget, Stockholm

Fig B5.1

Fig B5.2



Year: 1924
Typology: Courtyard Block “storgårdskvarter”
Architect: Carl Åkerblad
Analyzed Rooms: 24

Table B5. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	50%	0%	0%	0%
55% Area	33%	0%	0%	0%
75% Area	0%	0%	0%	0%
85% Area	0%	0%	0%	0%
95% Area	0%	0%	0%	0%

LM-83 55% Area
0%

Room $DF_{med} \geq 2{,}1\%$
0%

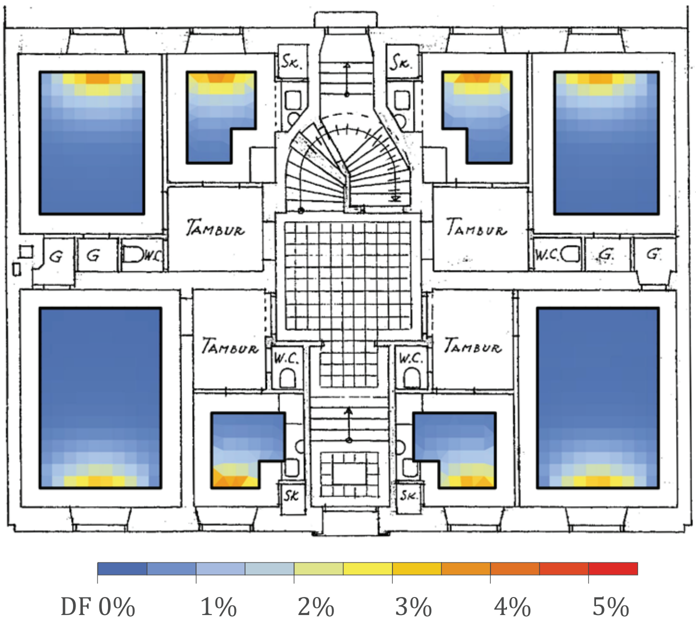


Fig B5.3

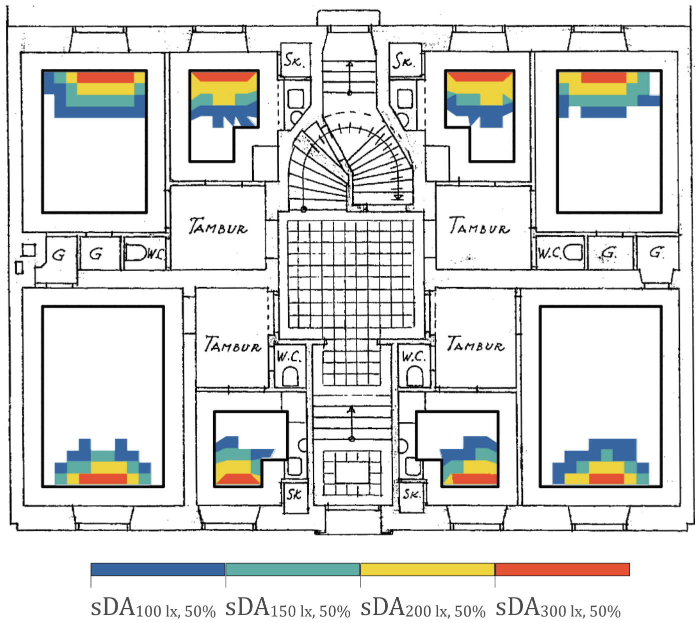


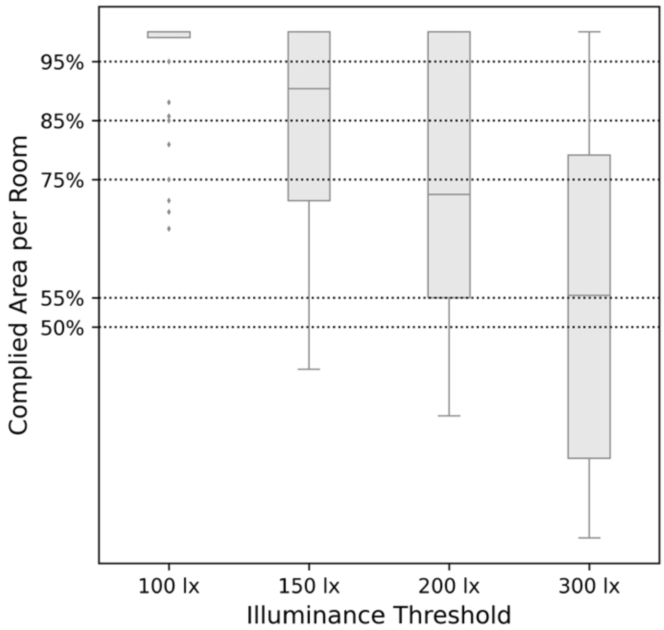
Fig B5.4

(Figure B5.1) Aerial View of the Building (Source: earth.google.com)
(Figure B5.2) Compliance Area Distribution according to Different Illuminance
(Figure B5.3) Daylight Factor of 1st Floor
(Figure B5.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

6. *Dynamiten 2* Glimmerbacken 8-10, Traneberg, Stockholm

Fig B6.1

Fig B6.2



Year: 1938
Typology: Detached Flats “Lamellhuskvarter”
Architect: Bernt Lundahl
Analyzed Rooms: 45

Table B6. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	100%	98%	80%	53%
55% Area	100%	93%	76%	51%
75% Area	91%	67%	49%	27%
85% Area	87%	53%	42%	22%
95% Area	78%	47%	47%	16%

LM-83 55% Area
49%

Room DF_{med} ≥ 2,1%
36%

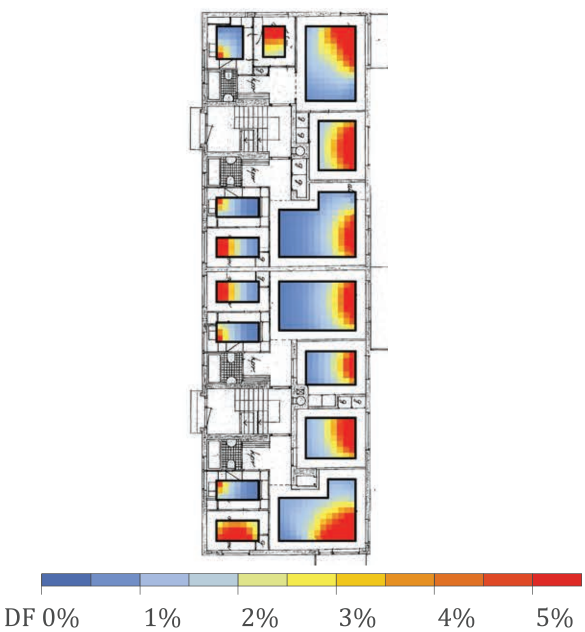


Fig B6.3

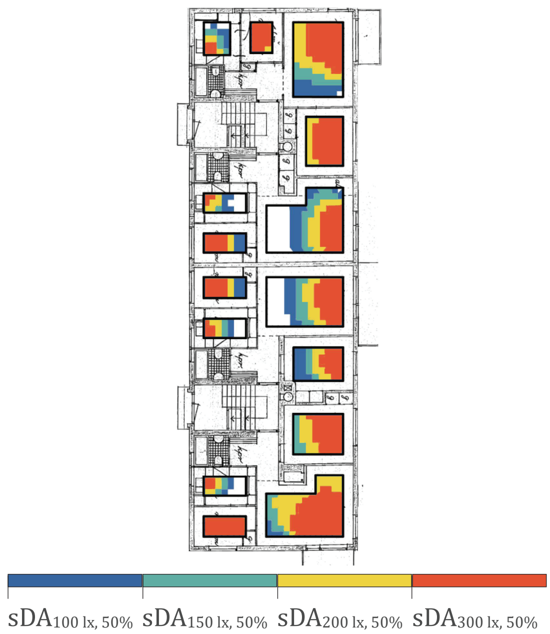
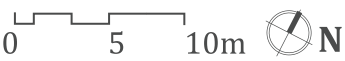


Fig B6.4



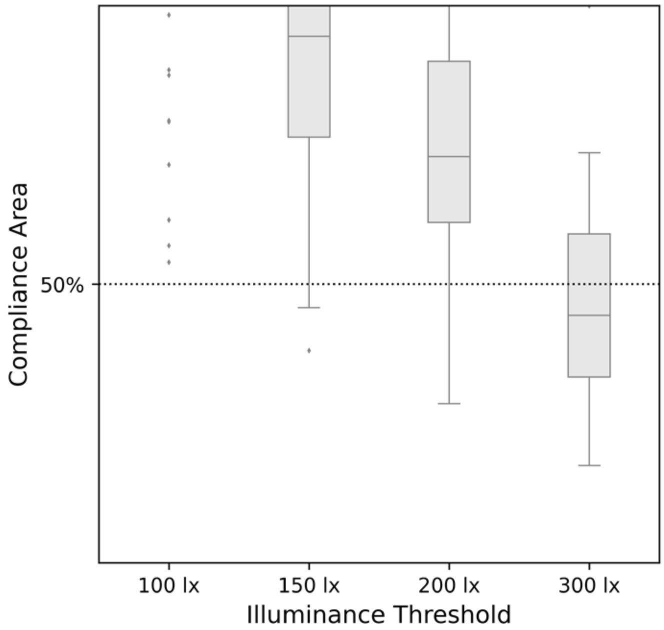
(Figure B6.1) Aerial View of the Building (Source: earth.google.com)
(Figure B6.2) Compliance Area Distribution according to Different Illuminance
(Figure B6.3) Daylight Factor of 1st Floor
(Figure B6.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

7. Holaveden 3

Hallebergsvägen 34-36, Traneberg, Stockholm

Fig B7.1

Fig B7.2



Year: 1937
Typology: Detached Flats “Lamellhuskvarter”
Architect: unknown
Analyzed Rooms: 45

Table B7. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	100%	91%	82%	38%
55% Area	98%	91%	82%	31%
75% Area	87%	76%	49%	13%
85% Area	82%	62%	33%	13%
95% Area	78%	49%	22%	13%

LM-83 55% Area
40%

Room $DF_{med} \geq 2{,}1\%$
38%

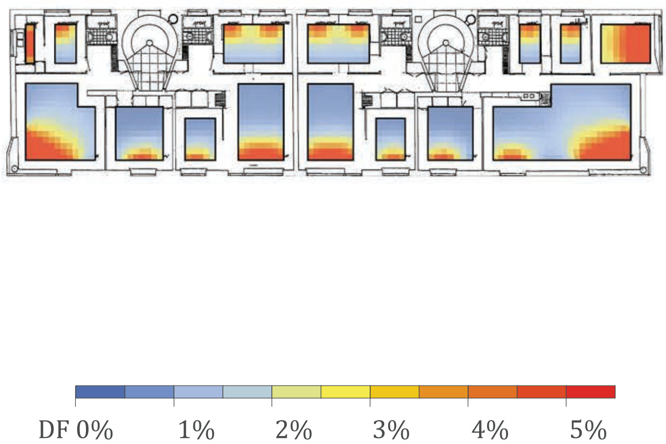


Fig B7.3

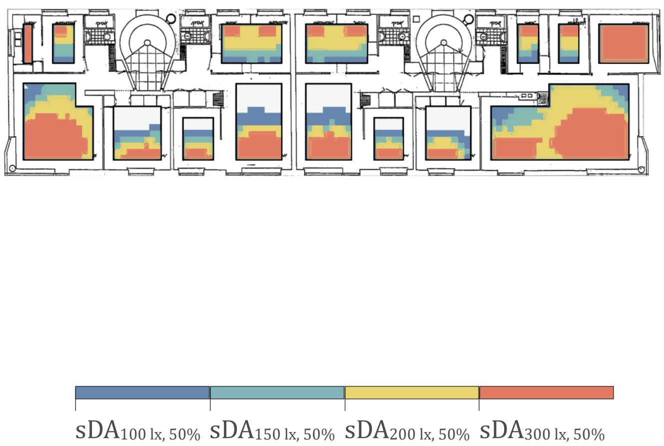
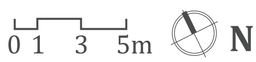


Fig B7.4

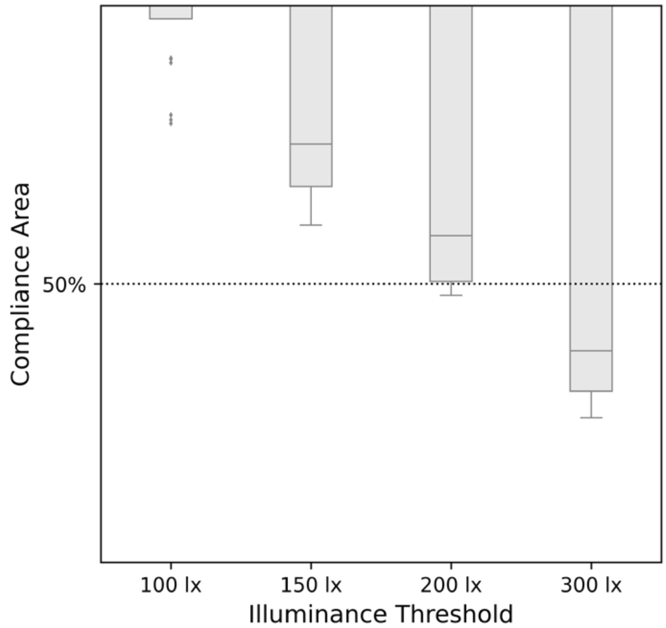


(Figure B7.1) Aerial View of the Building (Source: earth.google.com)
(Figure B7.2) Compliance Area Distribution according to Different Illuminance
(Figure B7.3) Daylight Factor of 1st Floor
(Figure B7.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

8. *Mösseberg 9* Tranebergsvägen 36, Traneberg, Stockholm

Fig B8.1

Fig B8.2



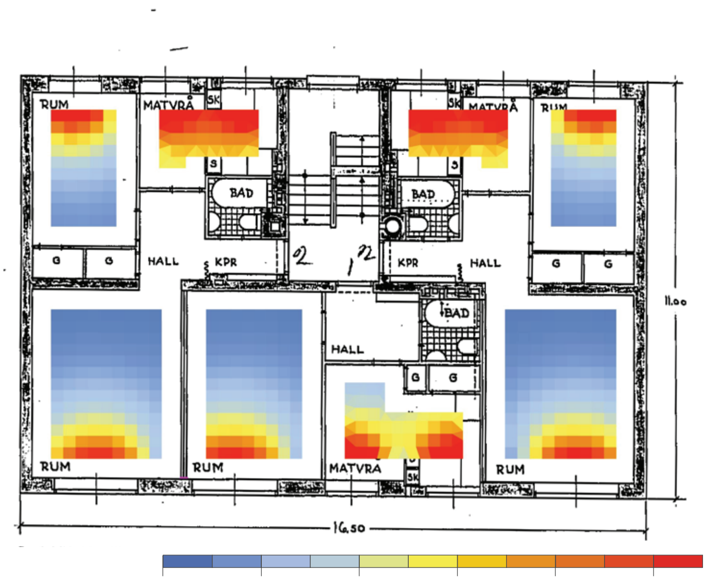
Year: 1924
Typology: Courtyard Block “storgårdskvarter”
Architect: Carl Åkerblad
Analyzed Rooms: 24

Table B8. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	100%	100%	88%	38%
55% Area	100%	100%	54%	38%
75% Area	100%	50%	38%	38%
85% Area	88%	38%	38%	38%
95% Area	75%	38%	38%	33%

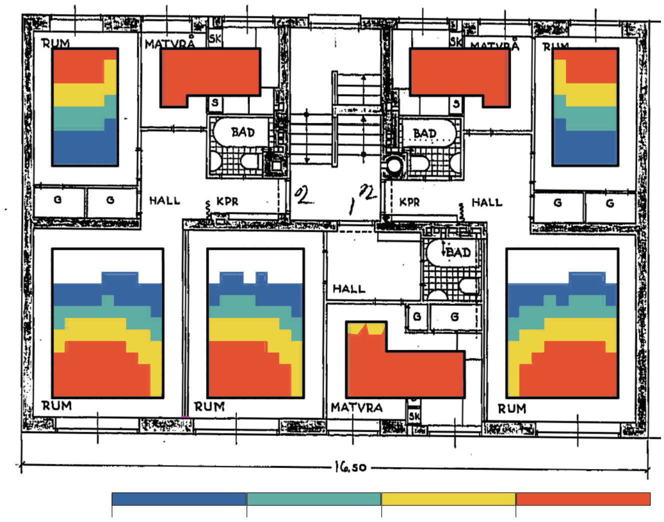
LM-83 55% Area
50%

Room $DF_{med} \geq 2,1\%$
38%



DF 0% 1% 2% 3% 4% 5%

Fig B8.3



$sDA_{100\ lx,\ 50\%}$ $sDA_{150\ lx,\ 50\%}$ $sDA_{200\ lx,\ 50\%}$ $sDA_{300\ lx,\ 50\%}$

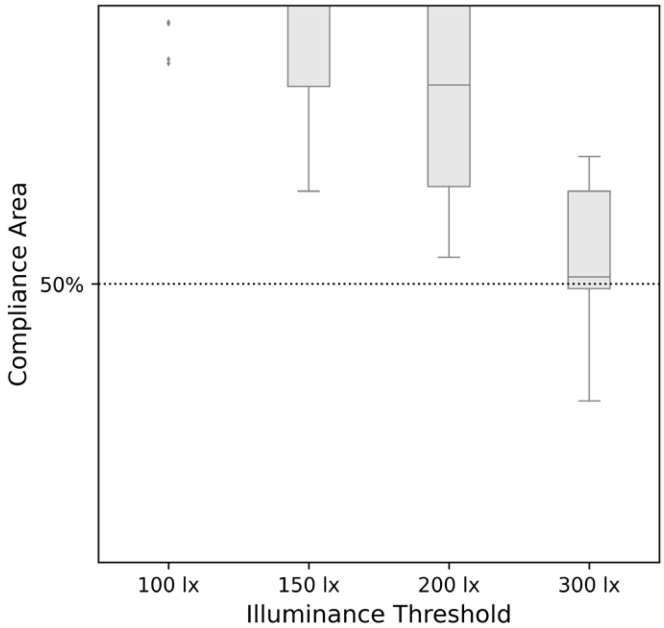
Fig B8.4

(Figure B8.1) Aerial View of the Building (Source: earth.google.com)
(Figure B8.2) Compliance Area Distribution according to Different Illuminance
(Figure B8.3) Daylight Factor of 1st Floor
(Figure B8.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

9. *Tändhatten 1* Margretelundsvägen 36-38, Stockholm

Fig B9.1

Fig B9.2



Year: 1938
Typology: Detached Flats “Lamellhuskvarter”
Architect: Cyril Marcus
Analyzed Rooms: 39

Table B9. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	100%	100%	100%	74%
55% Area	100%	100%	92%	49%
75% Area	100%	87%	62%	0%
85% Area	100%	77%	54%	0%
95% Area	95%	62%	62%	0%

LM-83 55% Area
64%

Room $DF_{med} \geq 2,1\%$
62%

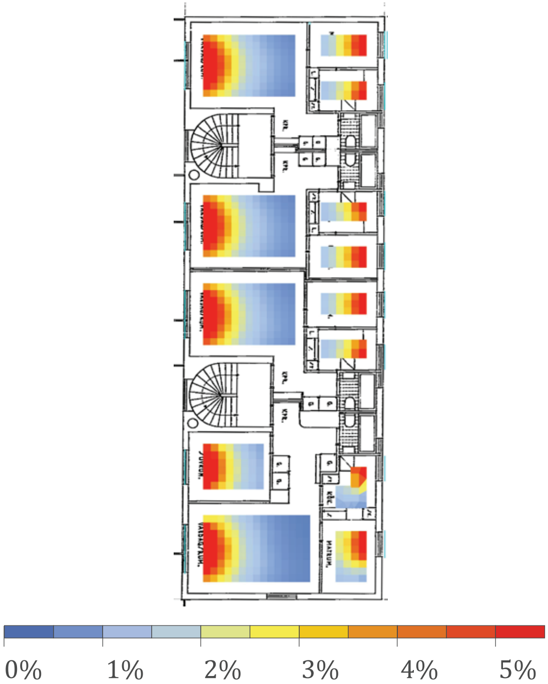


Fig B9.3

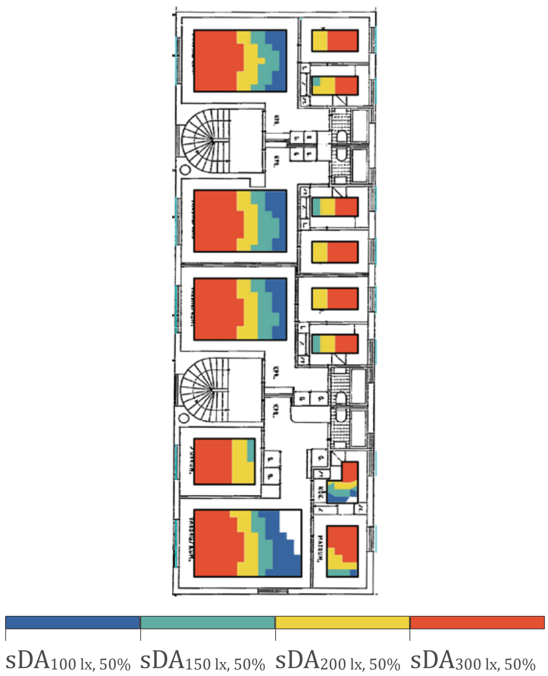
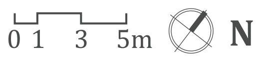


Fig B9.4



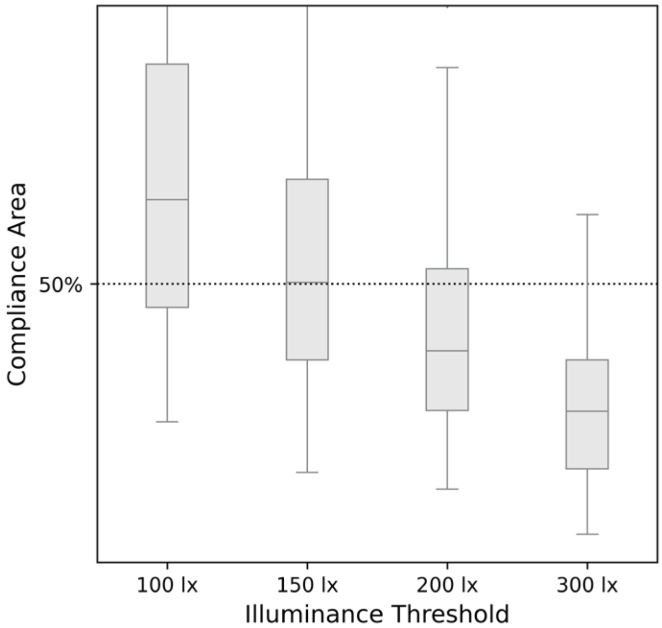
(Figure B9.1) Aerial View of the Building (Source: earth.google.com)
(Figure B9.2) Compliance Area Distribution according to Different Illuminance
(Figure B9.3) Daylight Factor of 1st Floor
(Figure B9.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

10. Postiljonen 15

Wollmar Yxkullsgatan 53, Södermalm, Stockholm

Fig B10.1

Fig B10.2



Year: 1934
Typology: Detached Flats “Lamellhuskvarter”
Architect: J. Hebert
Analyzed Rooms: 110

Table B10. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	72%	53%	29%	8%
55% Area	63%	40%	23%	5%
75% Area	40%	20%	7%	0%
85% Area	30%	13%	2%	0%
95% Area	20%	8%	8%	0%

LM-83 55% Area
11%

Room $DF_{med} \geq 2{,}1\%$
11%

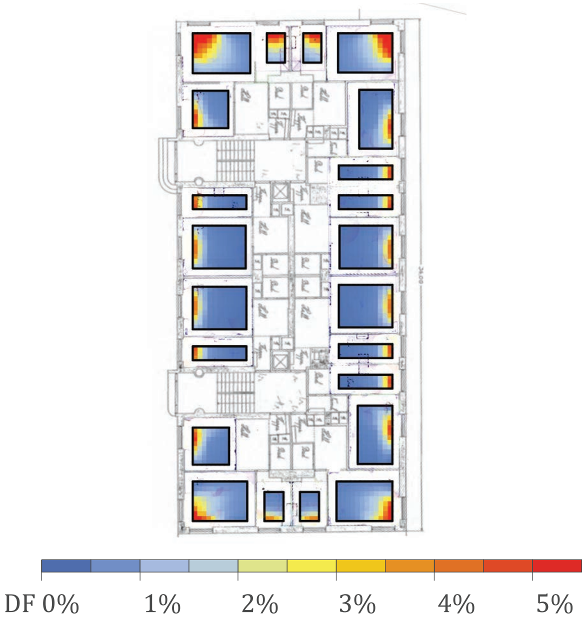


Fig B10.3

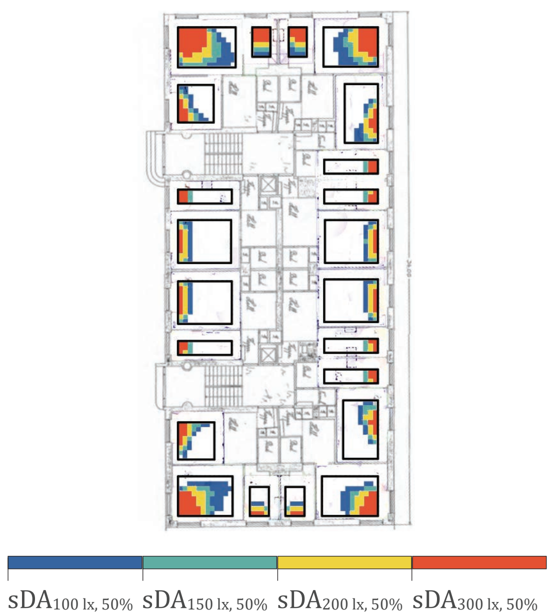
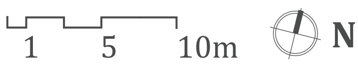


Fig B10.4



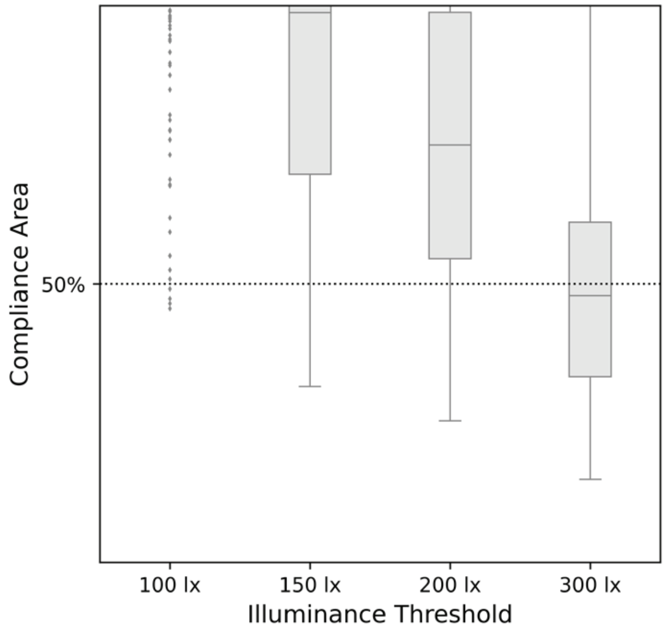
(Figure B10.1) Aerial View of the Building (Source: earth.google.com)
(Figure B10.2) Compliance Area Distribution according to Different Illuminance
(Figure B10.3) Daylight Factor of 1st Floor
(Figure B.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

11. *Luxlampan 6*

Disponentgatan 1, Lilla Essingen, Stockholm

Fig B11.1

Fig B11.2



Year: 1935
Typology: Detached Flats “Lamellhuskvarter”
Architect: unknown
Analyzed Rooms: 201

Table B11. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	85%	73%	53%	26%
55% Area	79%	63%	44%	18%
75% Area	60%	39%	22%	8%
85% Area	50%	28%	14%	6%
95% Area	40%	22%	11%	3%

LM-83 55% Area
23%

Room $DF_{med} \geq 2{,}1\%$
18%

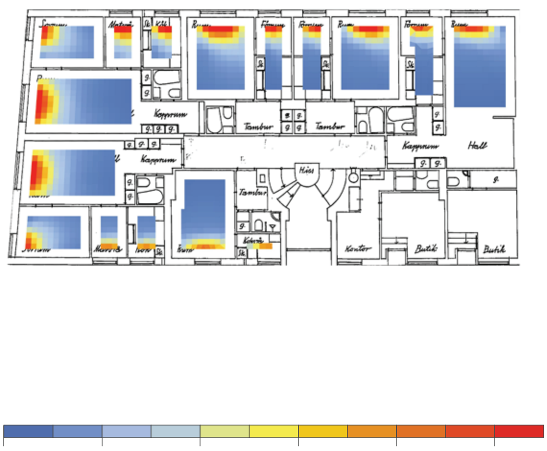


Fig B11.3

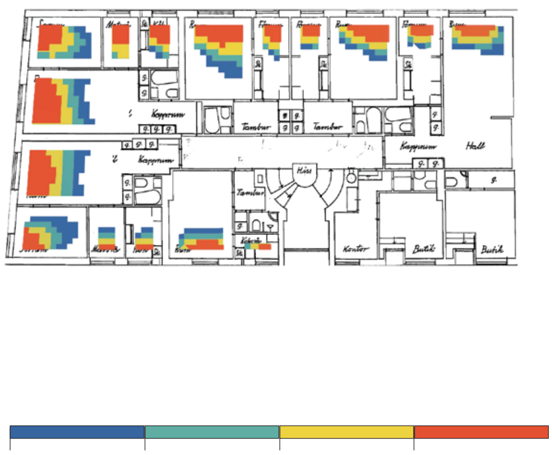
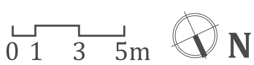


Fig B11.4



(Figure B11.1) Aerial View of the Building (Source: earth.google.com)
(Figure B11.2) Compliance Area Distribution according to Different Illuminance
(Figure B11.3) Daylight Factor of 1st Floor
(Figure B11.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

12. Rud 8:10

Tamburingatan 9, Frölunda, Göteborg

Fig B12.1

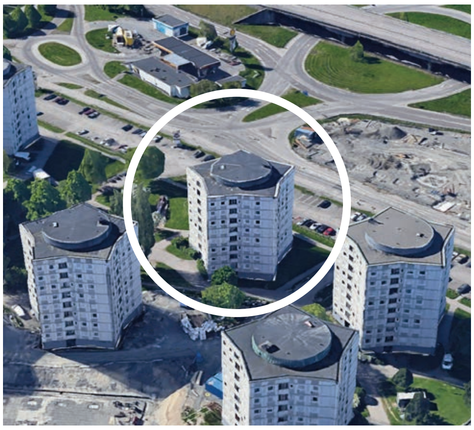
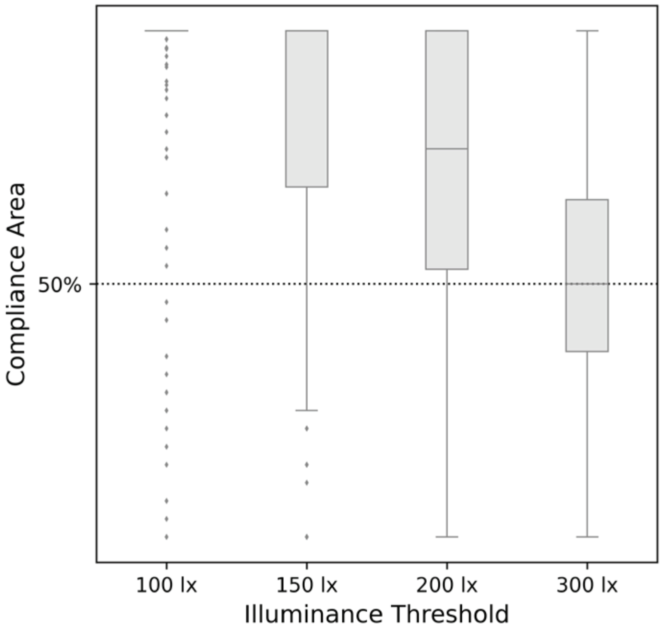


Fig B12.2



Year: 1960
Typology: Point Tower “punkthus”
Architect: unknown
Analyzed Rooms: 200

Table B12. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	93%	81%	79%	54%
55% Area	93%	81%	74%	42%
75% Area	91%	71%	53%	21%
85% Area	88%	63%	44%	18%
95% Area	83%	60%	33%	15%

LM-83 55% Area
48%

Room $DF_{med} \geq 2{,}1\%$
18%

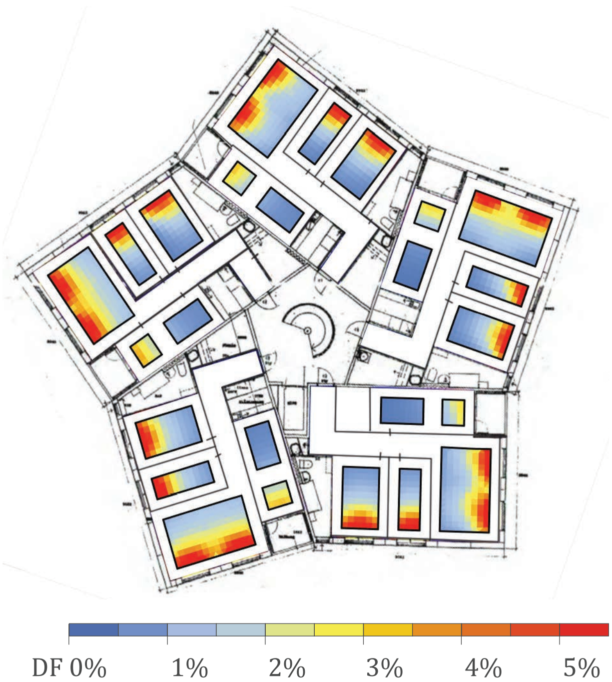


Fig B12.3

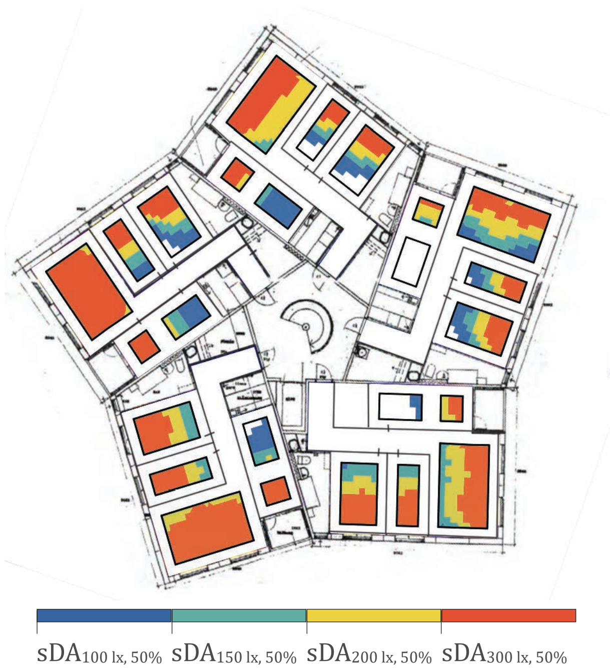


Fig B12.4

(Figure B12.1) Aerial View of the Building (Source: earth.google.com)
(Figure B12.2) Compliance Area Distribution according to Different Illuminance
(Figure B12.3) Daylight Factor of 1st Floor
(Figure B12.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

13. *Kärnröret 2*

Tranebergsvägen 10, Traneberg, Stockholm

Fig B13.1

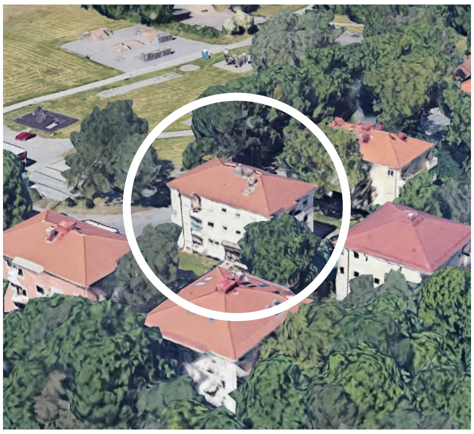
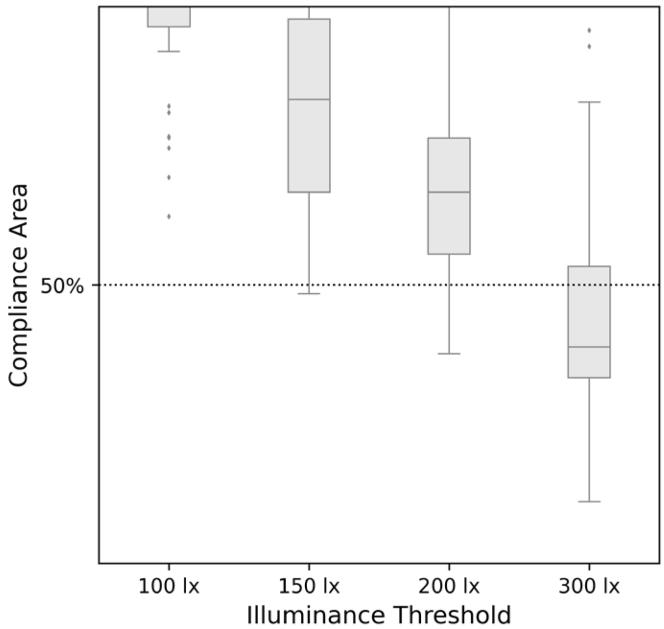


Fig B13.2



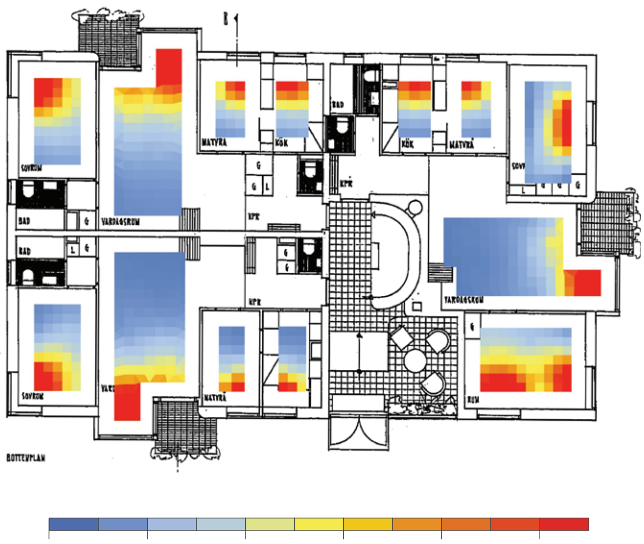
Year: 1938
Typology: Point Tower “punkthus”
Architect: unknown
Analyzed Rooms: 41

Table B13. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	100%	98%	88%	27%
55% Area	100%	98%	76%	20%
75% Area	93%	68%	34%	7%
85% Area	83%	46%	15%	5%
95% Area	73%	32%	7%	2%

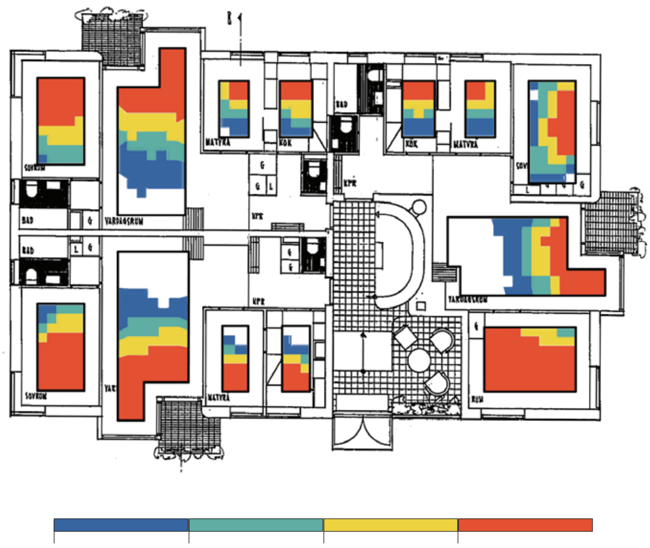
LM-83 55% Area
34%

Room DF_{med} ≥ 2,1%
24%



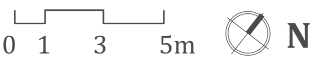
DF 0% 1% 2% 3% 4% 5%

Fig B13.3



$sDA_{100\,lx,\,50\%}$ $sDA_{150\,lx,\,50\%}$ $sDA_{200\,lx,\,50\%}$ $sDA_{300\,lx,\,50\%}$

Fig B13.4



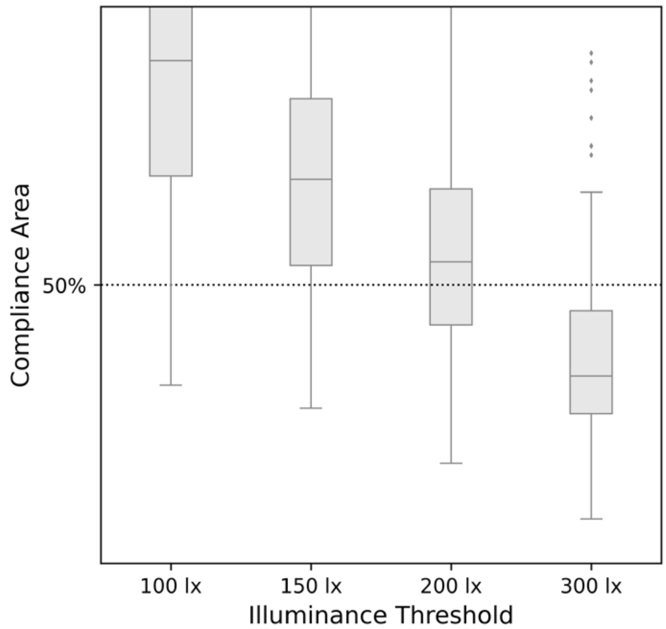
(Figure B13.1) Aerial View of the Building (Source: earth.google.com)
(Figure B13.2) Compliance Area Distribution according to Different Illuminance
(Figure B13.3) Daylight Factor of 1st Floor
(Figure B13.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

14. *Signallyktan 1*

Rålambsvägen 21, Fredhäll, Stockholm

Fig B14.1

Fig B14.2



Year: 1943
Typology: Point Tower “punkthus”
Architect: J.A.S. Stark
Analyzed Rooms: 144

Table B14. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	92%	82%	63%	19%
55% Area	88%	72%	48%	12%
75% Area	69%	42%	19%	7%
85% Area	60%	24%	15%	3%
95% Area	45%	16%	10%	0%

LM-83 55% Area
20%

Room DF_{med} ≥ 2,1%
29%

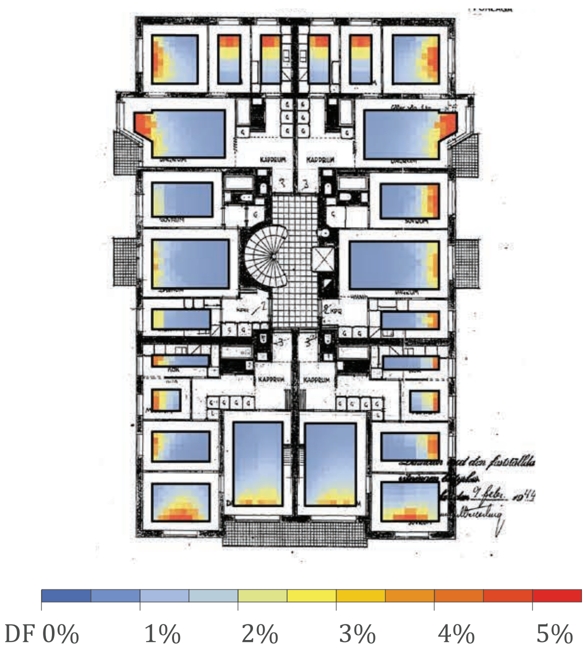


Fig B14.3

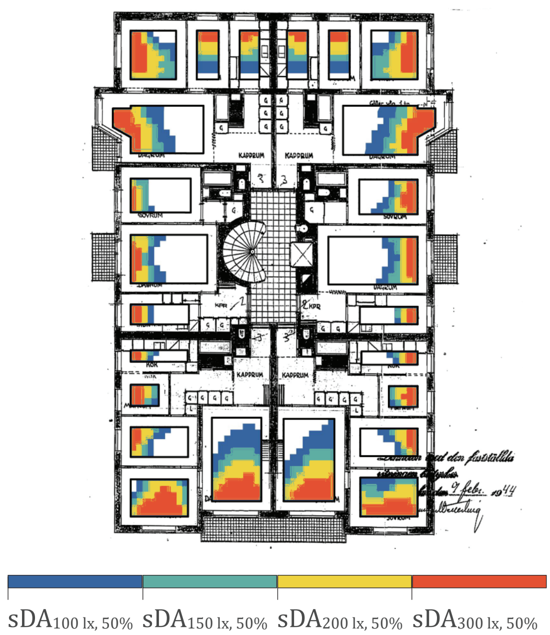


Fig B14.4

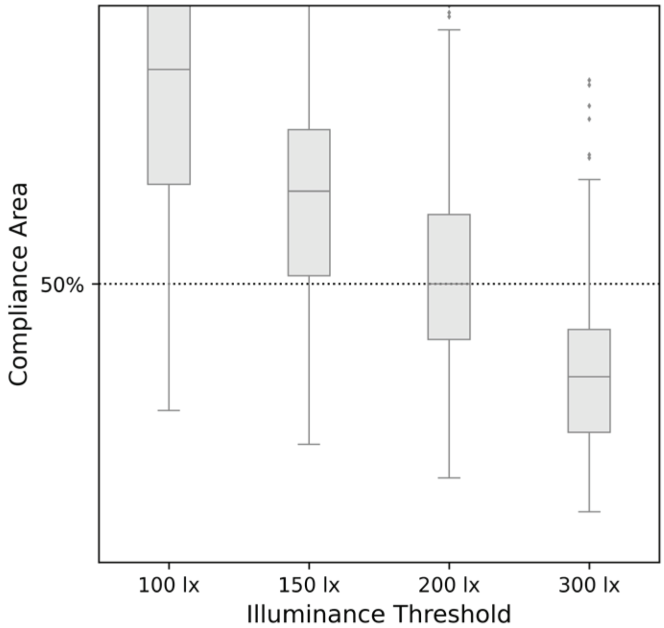
(Figure B14.1) Aerial View of the Building (Source: earth.google.com)
(Figure B14.2) Compliance Area Distribution according to Different Illuminance
(Figure B14.3) Daylight Factor of 1st Floor
(Figure B14.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

15. Stjärnsången 1

Stagneliusvägen 35, Fredhäll, Stockholm

Fig B15.1

Fig B15.2



Year: 1936
Typology: Point Tower "punkthus"
Architect: Wald Conradson
Analyzed Rooms: 119

Table B15. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	94%	80%	54%	14%
55% Area	91%	68%	40%	10%
75% Area	66%	34%	13%	3%
85% Area	53%	21%	8%	2%
95% Area	37%	11%	11%	0%

LM-83 55% Area
13%

Room DF_{med} ≥ 2,1%
9%

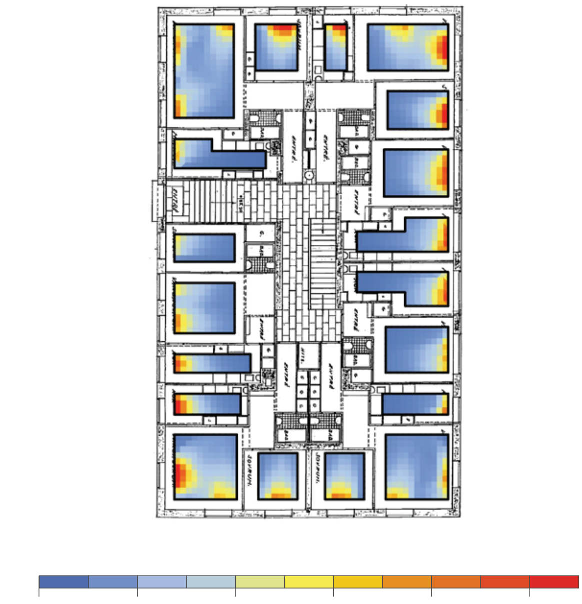


Fig B15.3

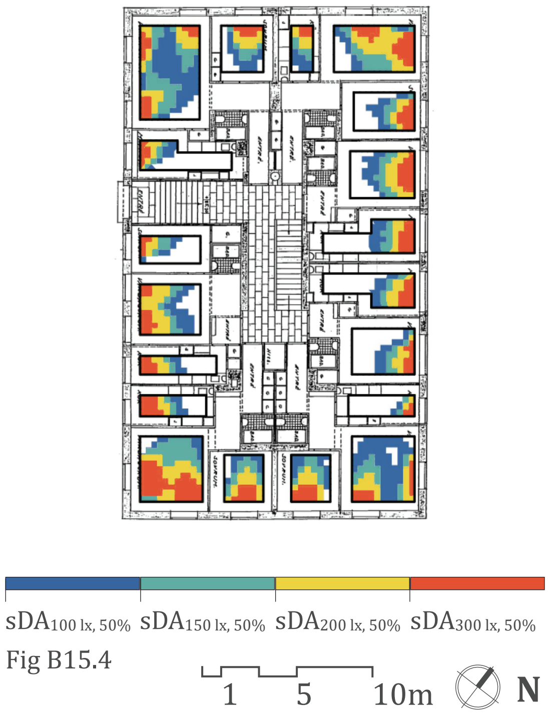


Fig B15.4

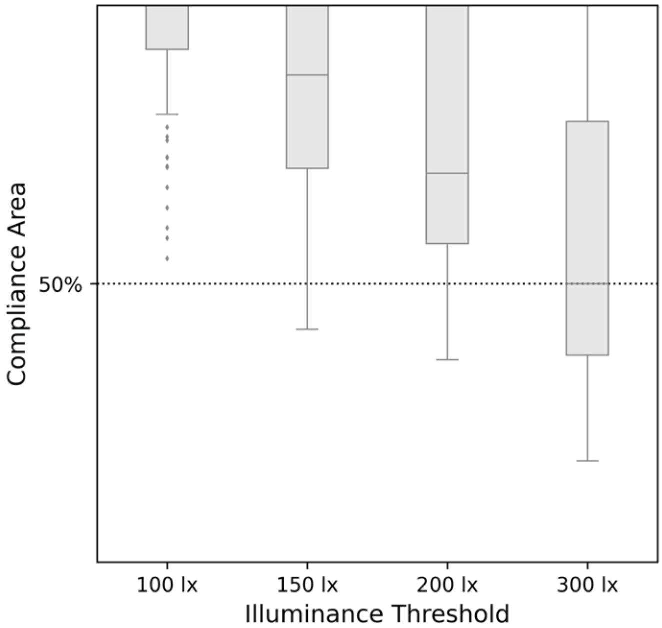
(Figure B15.1) Aerial View of the Building (Source: earth.google.com)
(Figure B15.2) Compliance Area Distribution according to Different Illuminance
(Figure B15.3) Daylight Factor of 1st Floor
(Figure B15.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

16. Fegen 1

Rindögatan 28, Gärdet, Stockholm

Fig B16.1

Fig B16.2



Year: 1938
Typology: Point Tower “punkthus”
Architect: M. Larsson
Analyzed Rooms: 66

Table B16. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	100%	96%	86%	51%
55% Area	99%	92%	77%	41%
75% Area	90%	68%	45%	36%
85% Area	82%	51%	42%	20%
95% Area	72%	45%	40%	7%

LM-83 55% Area
57%

Room DF_{med} ≥ 2,1%
40%

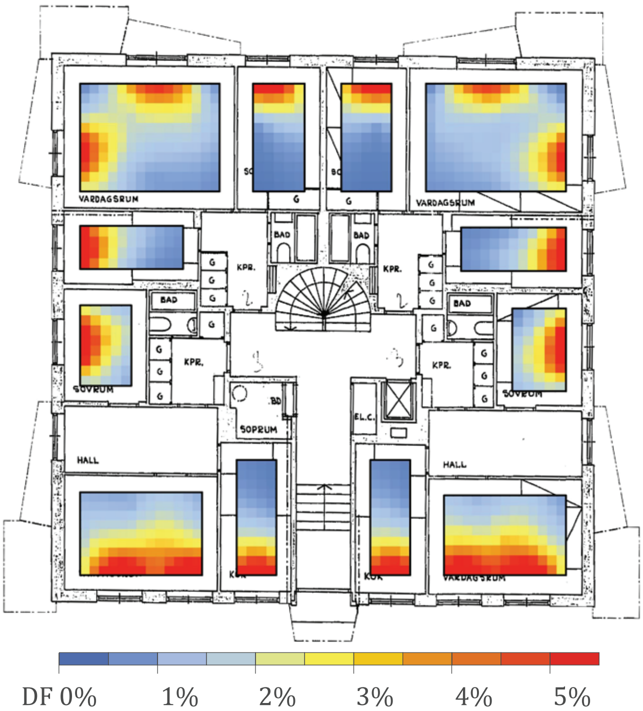


Fig B16.3

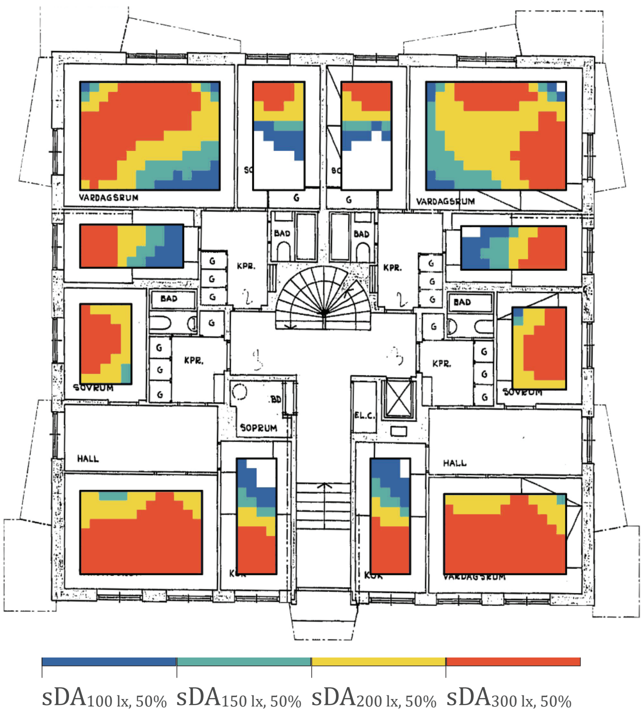
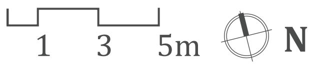


Fig B16.4



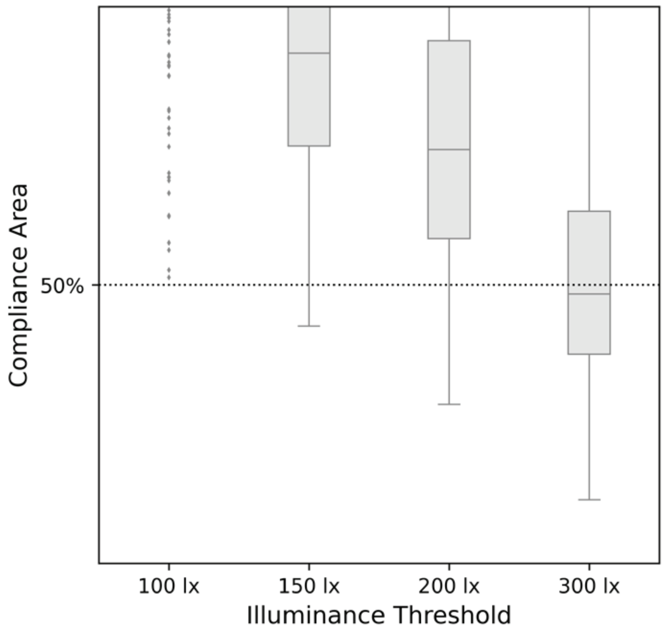
(Figure B16.1) Aerial View of the Building (Source: earth.google.com)
(Figure B16.2) Compliance Area Distribution according to Different Illuminance
(Figure B16.3) Daylight Factor of 1st Floor
(Figure B16.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

17. Akterspegeln 20:4

Sjöbjörnsvägen 22, Gröndal, Stockholm

Fig B17.1

Fig B17.2



Year: 1945
Typology: Point Tower “punkthus”
Architect: Sven Backström, Leif Reinius
Analyzed Rooms: 33

Table B17. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	100%	95%	85%	47%
55% Area	99%	92%	80%	37%
75% Area	92%	76%	50%	17%
85% Area	88%	64%	35%	15%
95% Area	83%	41%	25%	12%

LM-83 55% Area
42%

Room DF_{med} ≥ 2,1%
34%

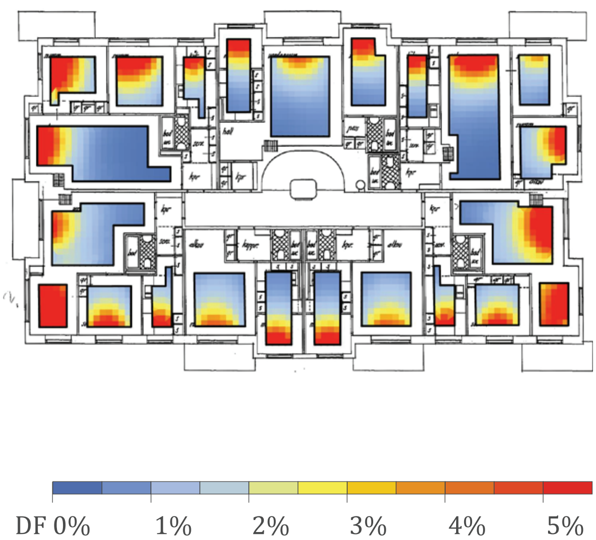


Fig B17.3

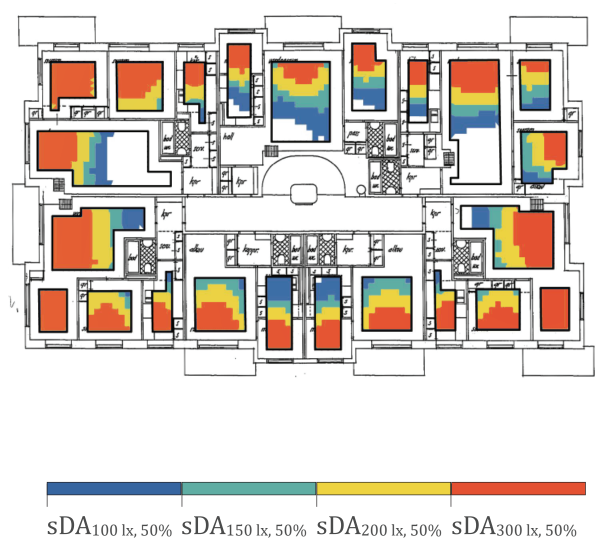
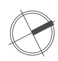


Fig B17.4



N

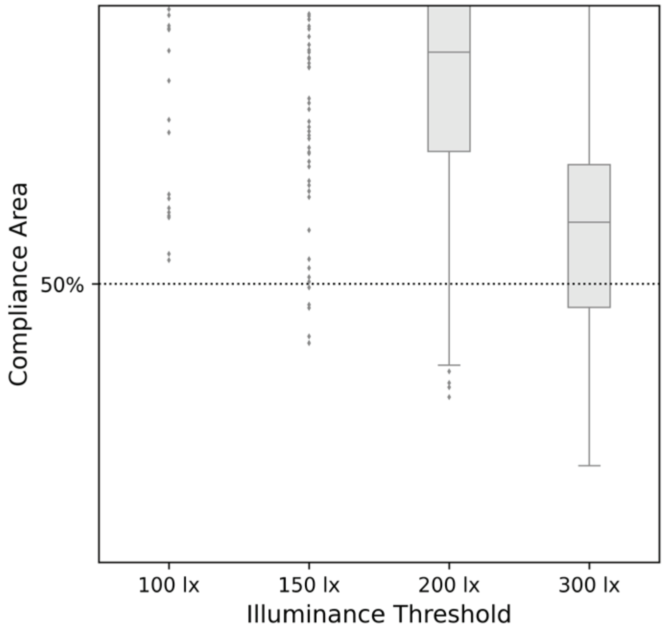
(Figure B17.1) Aerial View of the Building (Source: earth.google.com)
(Figure B17.2) Compliance Area Distribution according to Different Illuminance
(Figure B17.3) Daylight Factor of 1st Floor
(Figure B17.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

18. Skärkarlen 9

Wergelandsgatan 26, Skarpnäck, Stockholm

Fig B18.1

Fig B18.2



Year: 1950
Typology: Semi-closed courtyard "halvslutna gårdar"
Architect: HSB Riksförbund
Analyzed Rooms: 173

Table B18. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	100%	97%	94%	68%
55% Area	99%	95%	91%	60%
75% Area	95%	89%	75%	18%
85% Area	94%	84%	58%	9%
95% Area	93%	79%	46%	7%

LM-83 55% Area
69%

Room $DF_{med} \geq 2{,}1\%$
54%

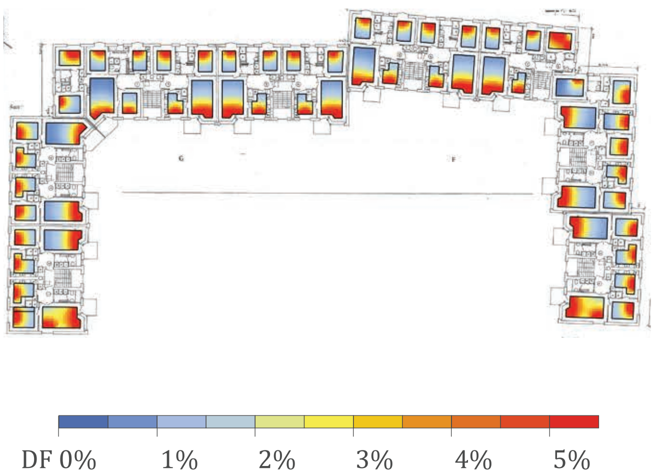


Fig B18.3

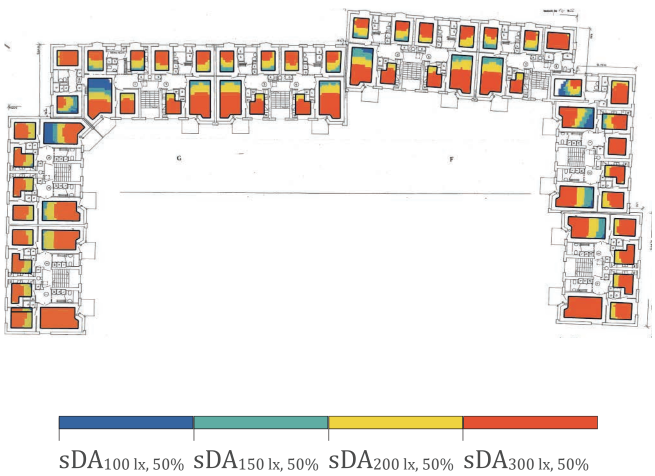
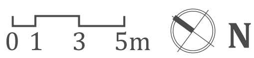


Fig B18.4



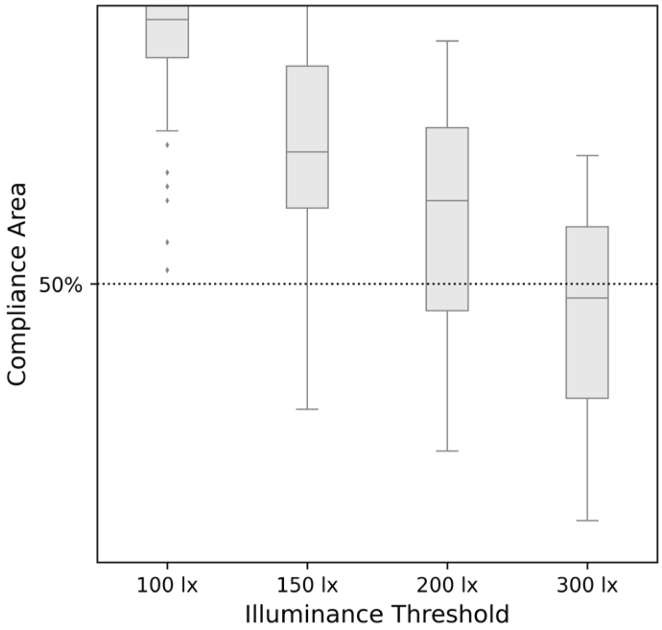
(Figure B18.1) Aerial View of the Building (Source: earth.google.com)
(Figure B18.2) Compliance Area Distribution according to Different Illuminance
(Figure B18.3) Daylight Factor of 1st Floor
(Figure B18.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

19. Vårfrugillet 1

Ålgrytebacken 13, Gärdet, Stockholm

Fig B19.1

Fig B19.2



Year: 1962
Typology: Panel Building "skivhusgrupper"
Architect: unknown
Analyzed Rooms: 128

Table B19. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	100%	91%	73%	42%
55% Area	98%	84%	55%	30%
75% Area	92%	49%	36%	0%
85% Area	83%	37%	5%	0%
95% Area	63%	19%	0%	0%

LM-83 55% Area
38%

Room DF_{med} ≥ 2,1%
33%

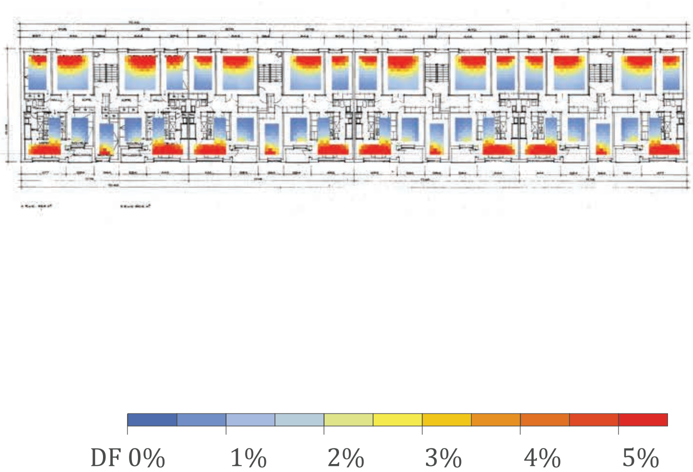


Fig B19.3

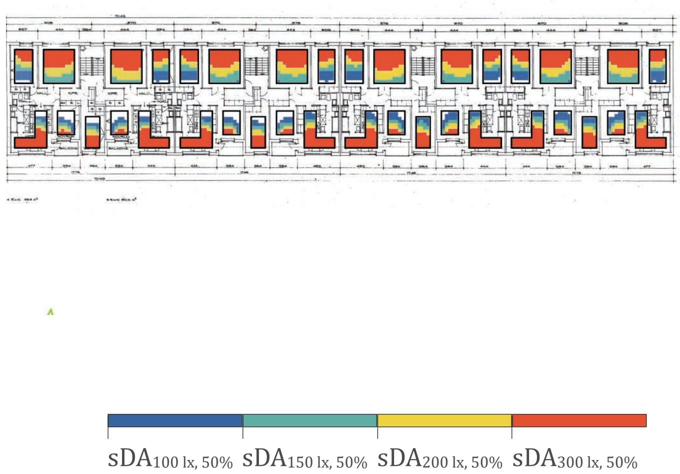
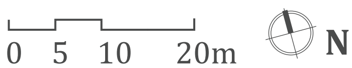


Fig B19.4



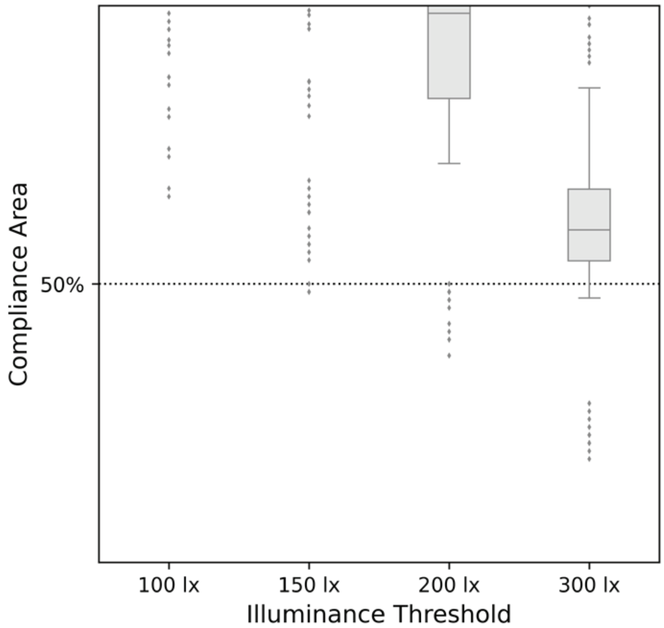
(Figure B19.1) Aerial View of the Building (Source: earth.google.com)
(Figure B19.2) Compliance Area Distribution according to Different Illuminance
(Figure B19.3) Daylight Factor of 1st Floor
(Figure B19.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

20. *Harholmen 1:8*

Ekholmsvägen 345-363, Skärholmen, Stockholm

Fig B20.1

Fig B20.2



Year: 1965
Typology: Panel Building “skivhusgrupper”
Architect: Ernst Grönwall
Analyzed Rooms: 129

Table B20. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	100%	99%	90%	84%
55% Area	100%	98%	88%	71%
75% Area	96%	88%	82%	20%
85% Area	94%	85%	73%	14%
95% Area	89%	84%	65%	7%

LM-83 55% Area
84%

Room $DF_{med} \geq 2{,}1\%$
36%

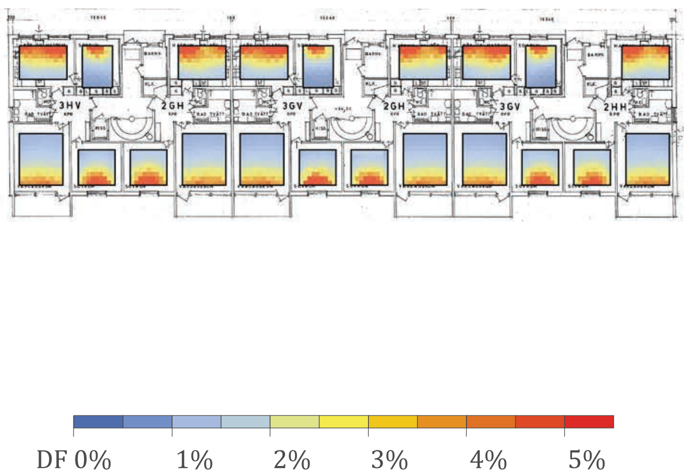


Fig B20.3

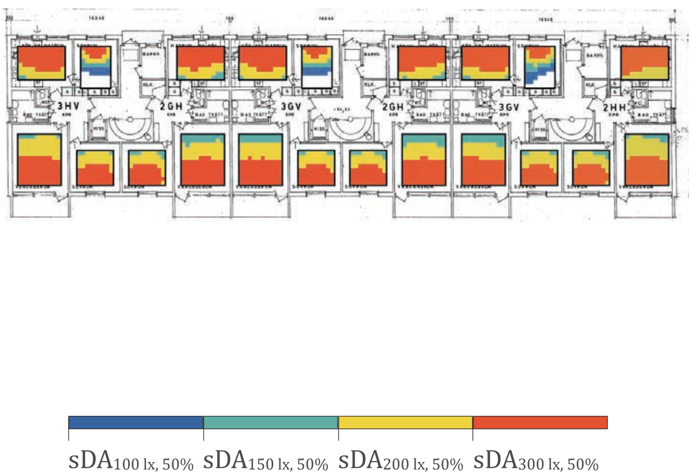
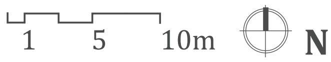


Fig B20.4



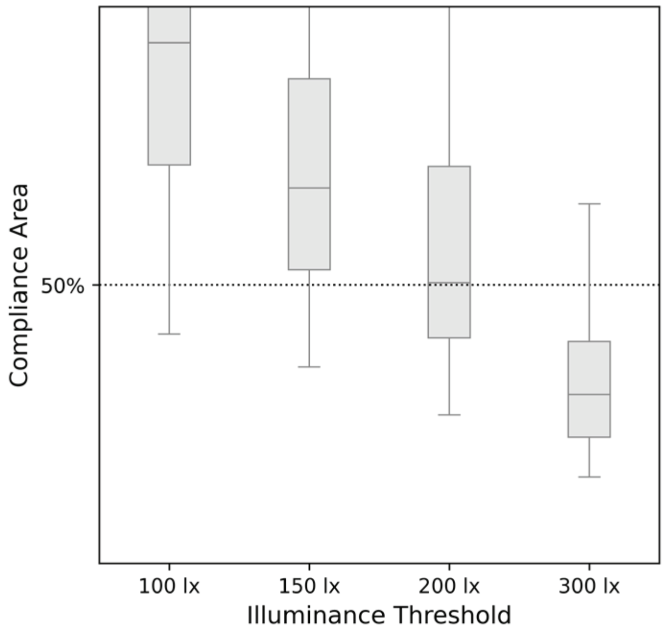
(Figure B20.1) Aerial View of the Building (Source: earth.google.com)
(Figure B20.2) Compliance Area Distribution according to Different Illuminance
(Figure B20.3) Daylight Factor of 1st Floor
(Figure B20.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

21. Branthomen 1:2

Brantholmsgränd 40-72, Skärholmen, Stockholm

Fig B21.1

Fig B21.2



Year: 1965
Typology: Panel Building "skivhusgrupper"
Architect: Svenska Riksbyggen
Analyzed Rooms: 173

Table B21. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	99%	79%	53%	16%
55% Area	97%	72%	43%	12%
75% Area	71%	39%	18%	0%
85% Area	59%	28%	13%	0%
95% Area	46%	18%	8%	0%

LM-83 55% Area
12%

Room DF_{med} ≥ 2,1%
1%

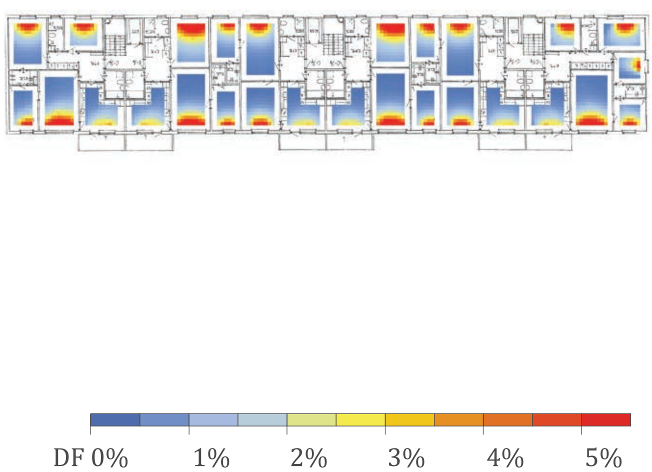


Fig B21.3

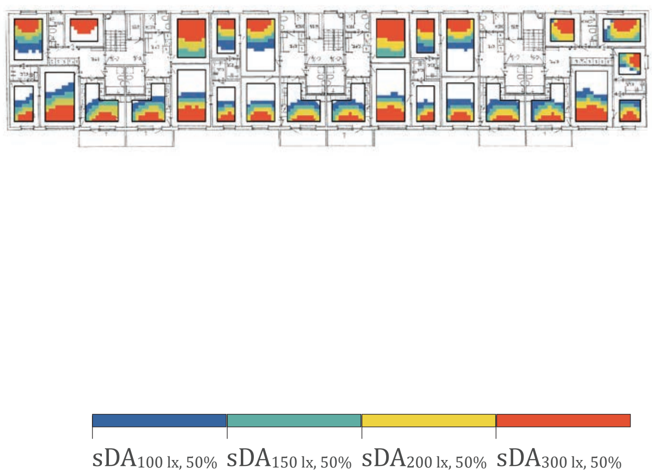


Fig B21.4

1 5 10m N

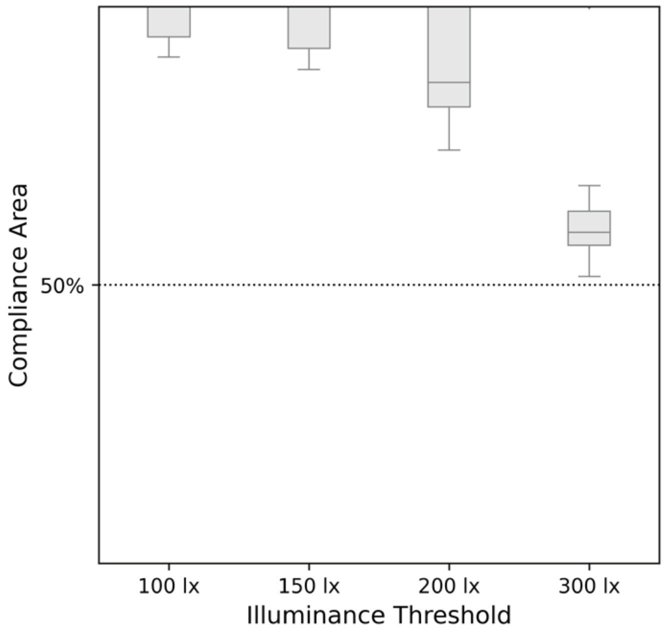
(Figure B21.1) Aerial View of the Building (Source: earth.google.com)
(Figure B21.2) Compliance Area Distribution according to Different Illuminance
(Figure B21.3) Daylight Factor of 1st Floor
(Figure B21.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

22. Baronbackarna B:5

Hjalmar Bergmans väg 54, Örebro

Fig B22.1

Fig B22.2



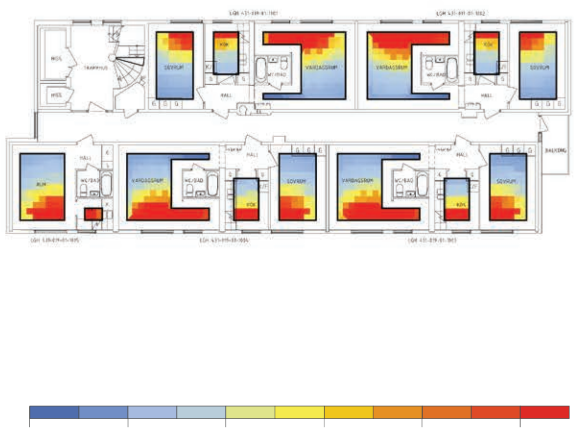
Year: 1952
Typology: Panel Building “skivhusgrupper”
Architect: unknown
Analyzed Rooms: 112

Table B22. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	100%	100%	100%	100%
55% Area	100%	100%	100%	83%
75% Area	100%	100%	98%	7%
85% Area	100%	100%	59%	7%
95% Area	71%	71%	40%	7%

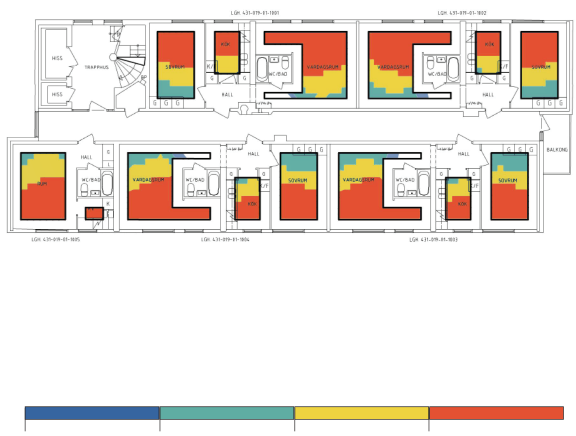
LM-83 55% Area
83%

Room $DF_{med} \geq 2{,}1\%$
22%



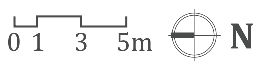
DF 0% 1% 2% 3% 4% 5%

Fig B22.3



$sDA_{100\,lx,\,50\%}$ $sDA_{150\,lx,\,50\%}$ $sDA_{200\,lx,\,50\%}$ $sDA_{300\,lx,\,50\%}$

Fig B22.4



(Figure B22.1) Aerial View of the Building (Source: earth.google.com)
(Figure B22.2) Compliance Area Distribution according to Different Illuminance
(Figure B22.3) Daylight Factor of 1st Floor
(Figure B22.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

23. Drakenberg 0:16

Drakenbergsgatan 14-18, Södermalm, Stockholm

Fig B23.1

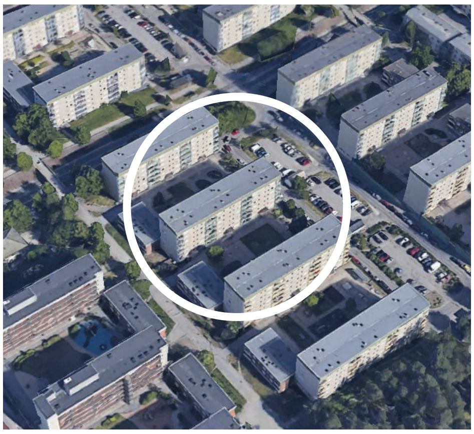
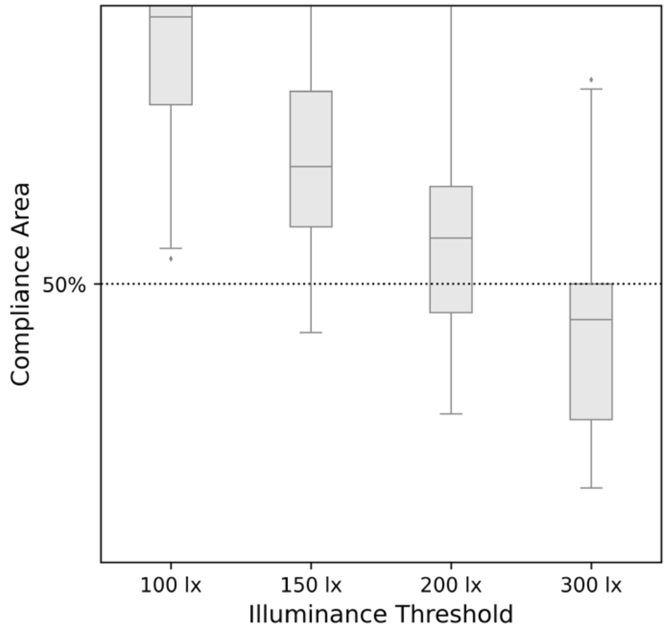


Fig B23 ?



Year: 1971
Typology: Panel Building "skivhusgrupper"
Architect: Lars Bryde
Analyzed Rooms: 277

Table B23. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	100%	94%	64%	28%
55% Area	100%	87%	55%	11%
75% Area	87%	40%	15%	7%
85% Area	71%	25%	9%	2%
95% Area	56%	19%	7%	0%

LM-83 55% Area
14%

Room $DF_{med} \geq 2{,}1\%$
2%

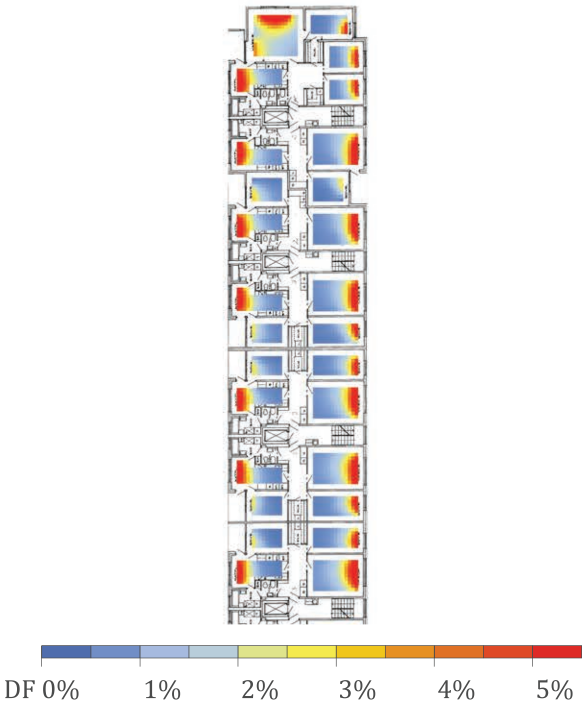


Fig B23.3

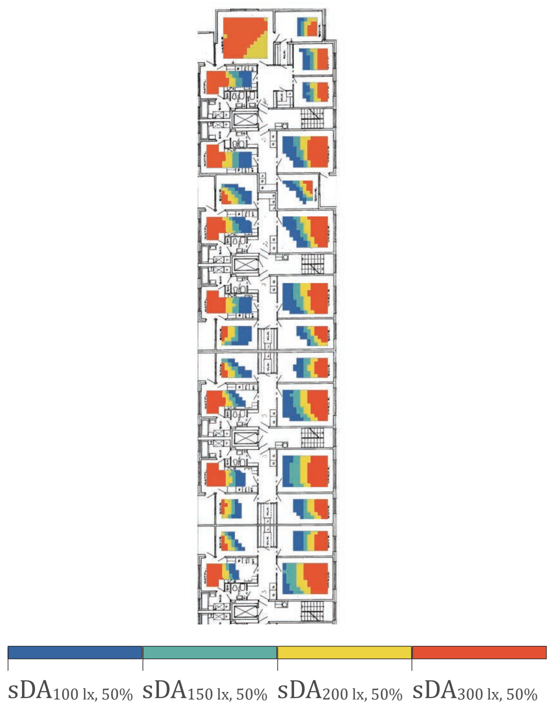
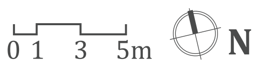


Fig B23.4



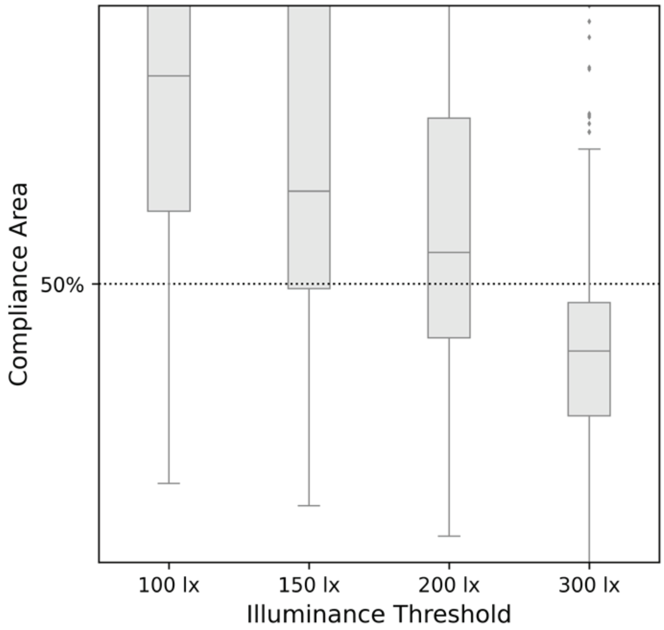
(Figure B23.1) Aerial View of the Building (Source: earth.google.com)
(Figure B23.2) Compliance Area Distribution according to Different Illuminance
(Figure B23.3) Daylight Factor of 1st Floor
(Figure B23.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

24. Risinge 0:1

Risingeplan 12-24, Tensta, Stockholm

Fig B24.1

Fig B24.2



Year: 1968
Typology: Panel Building “skivhusgrupper”
Architect: Svenska Riksbyggen
Analyzed Rooms: 174

Table B24. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	88%	74%	61%	22%
55% Area	81%	66%	50%	17%
75% Area	62%	44%	31%	7%
85% Area	51%	35%	21%	3%
95% Area	47%	32%	16%	2%

LM-83 55% Area
17%

Room DF_{med} ≥ 2,1%
10%

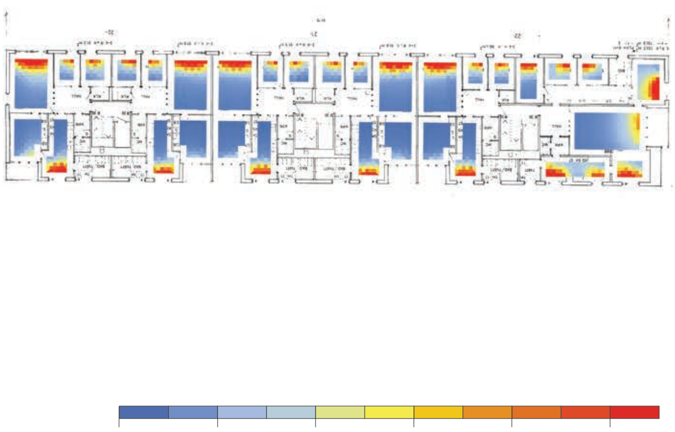


Fig B24.3

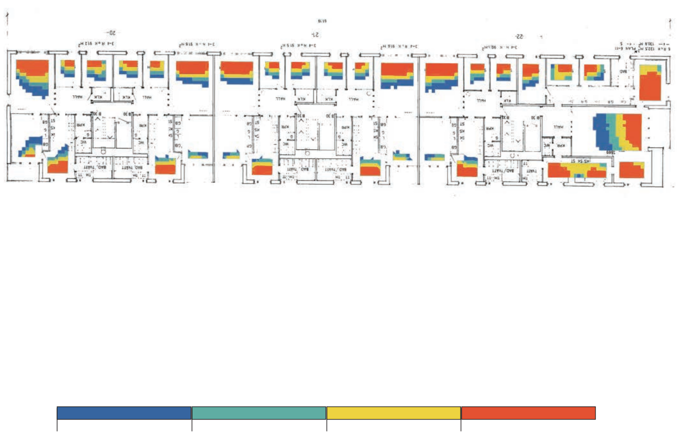
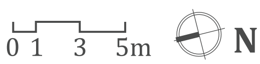


Fig B24.4



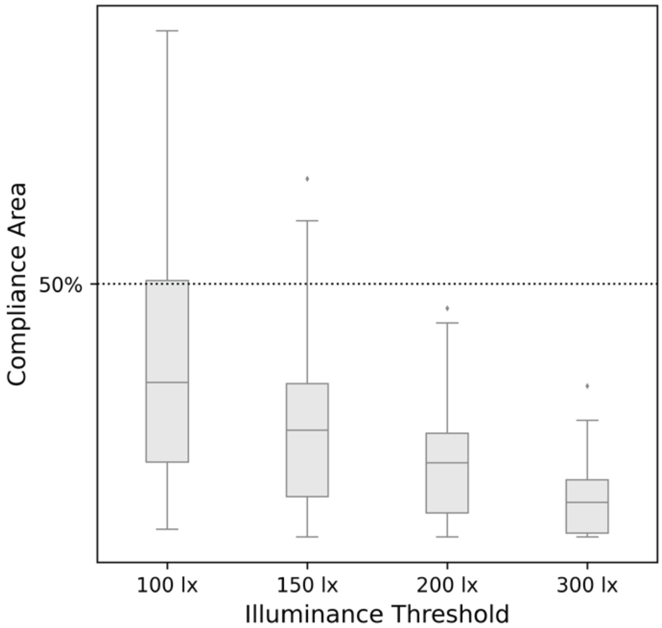
(Figure B24.1) Aerial View of the Building (Source: earth.google.com)
(Figure B24.2) Compliance Area Distribution according to Different Illuminance
(Figure B24.3) Daylight Factor of 1st Floor
(Figure B24.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

25. Vasastaden 14:2

Erik Dahlbergsgatan 12, Landala Vasastaden, Göteborg

Fig B25.1

Fig B25.2



Year: 1987
Typology: Post-Modern Reforms
Architect: Jaak Lohk
Analyzed Rooms: 42

Table B25. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	31%	10%	0%	0%
55% Area	24%	7%	0%	0%
75% Area	10%	0%	0%	0%
85% Area	10%	0%	0%	0%
95% Area	5%	0%	0%	0%

LM-83 55% Area
0%

Room DF_{med} ≥ 2,1%
0%

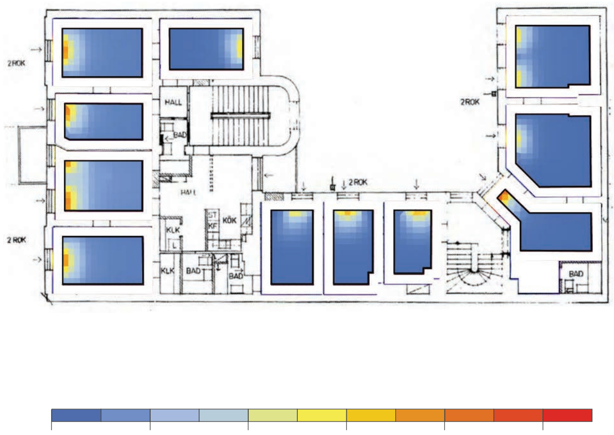


Fig B25.3

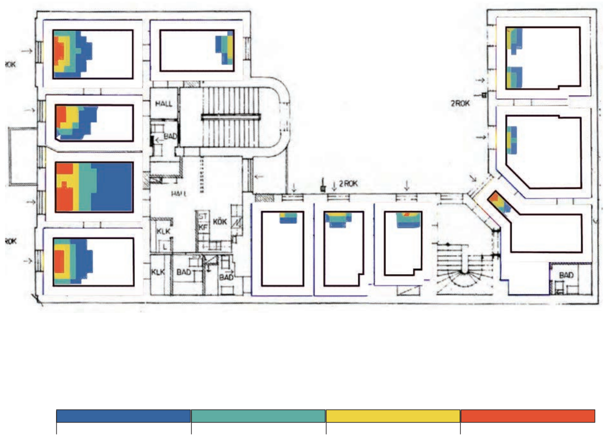
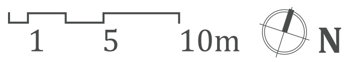


Fig B25.4



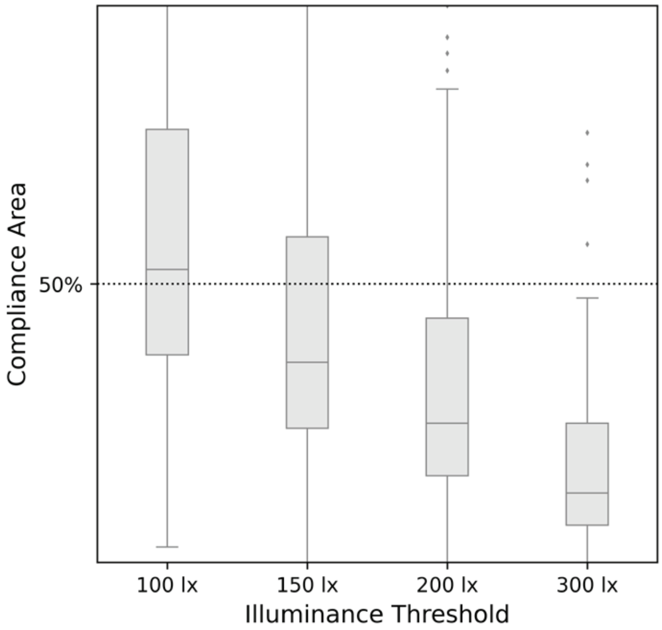
(Figure B25.1) Aerial View of the Building (Source: earth.google.com)
(Figure B25.2) Compliance Area Distribution according to Different Illuminance
(Figure B25.3) Daylight Factor of 1st Floor
(Figure B25.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

26. Minneberg 4

Svartviksslingan 73-79, Minneberg, Stockholm

Fig B26.1

Fig B26.2



Year: 1983
Typology: Post-modern Reforms
Architect: Brunnberggrupen
Analyzed Rooms: 140

Table B26. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	56%	33%	20%	4%
55% Area	48%	28%	17%	4%
75% Area	29%	15%	6%	1%
85% Area	20%	14%	4%	0%
95% Area	16%	10%	1%	0%

LM-83 55% Area
4%

Room DF_{med} ≥ 2,1%
1%

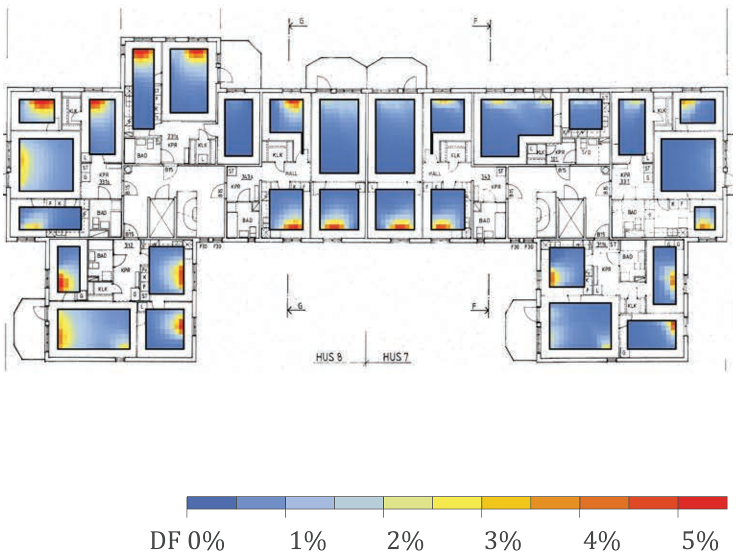


Fig B26.3

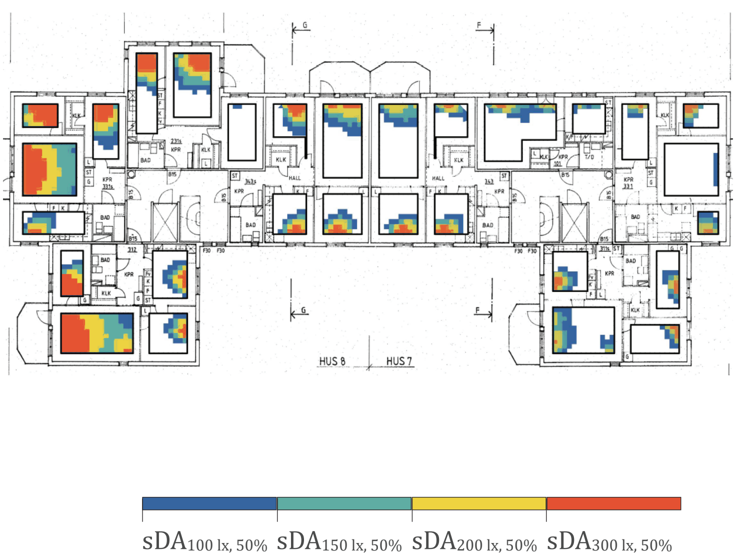
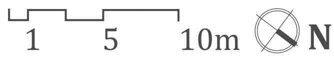


Fig B26.4



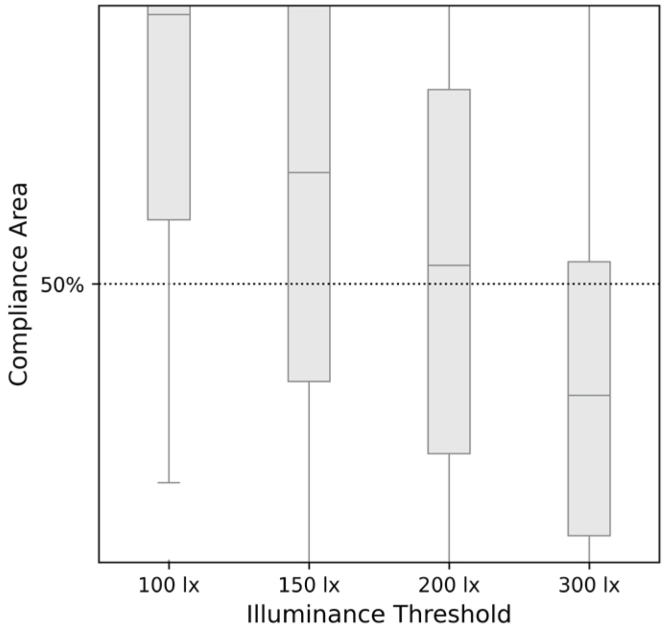
(Figure B26.1) Aerial View of the Building (Source: earth.google.com)
(Figure B26.2) Compliance Area Distribution according to Different Illuminance
(Figure B26.3) Daylight Factor of 1st Floor
(Figure B26.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

27. Gondolen 1

Pilotgatan 36-50, Skarpnäck, Stockholm

Fig B27.1

Fig B27.2



Year: 1981
Typology: Post-modern Reforms
Architect: Brunnberggrupen
Analyzed Rooms: 173

Table B27. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	82%	64%	55%	29%
55% Area	79%	62%	48%	25%
75% Area	65%	48%	31%	10%
85% Area	60%	41%	25%	8%
95% Area	54%	37%	21%	6%

LM-83 55% Area
27%

Room DF_{med} ≥ 2,1%
13%

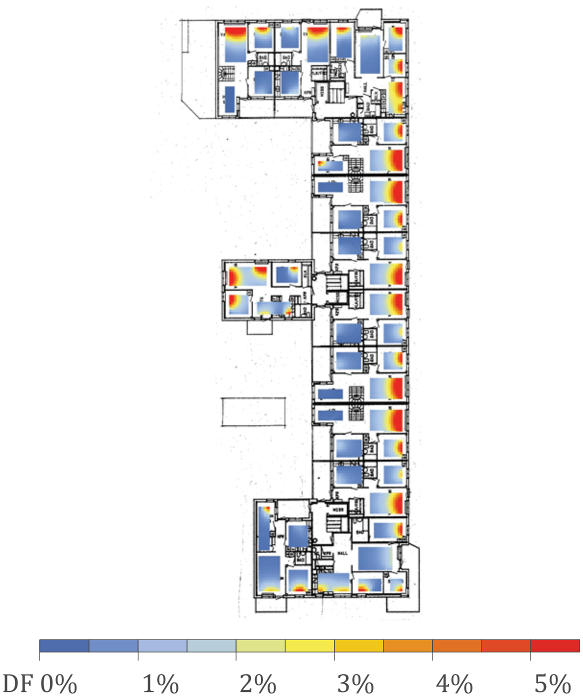


Fig B27.3

Fig B27.4

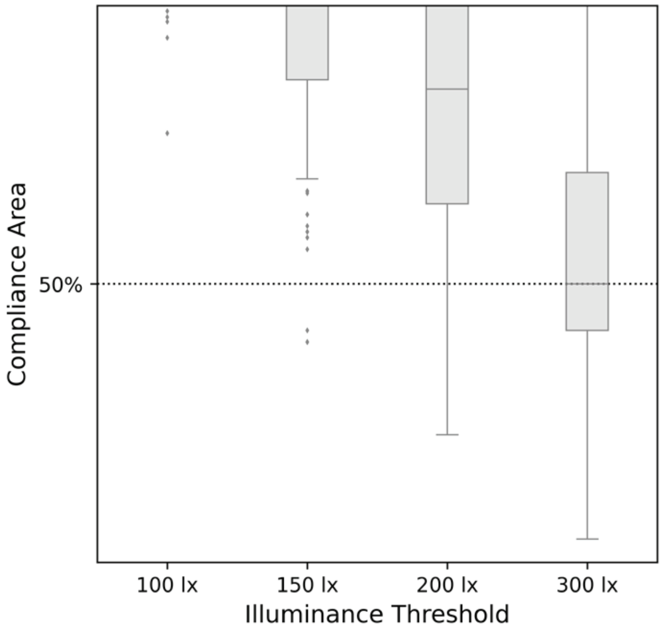
(Figure B27.1) Aerial View of the Building (Source: earth.google.com)
(Figure B27.2) Compliance Area Distribution according to Different Illuminance
(Figure B27.3) Daylight Factor of 1st Floor
(Figure B27.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

28. Starrbäcksängen 0:8

Starrängsringen 17, Ladugårdsgärdet, Stockholm

Fig B28.1

Fig B28.2



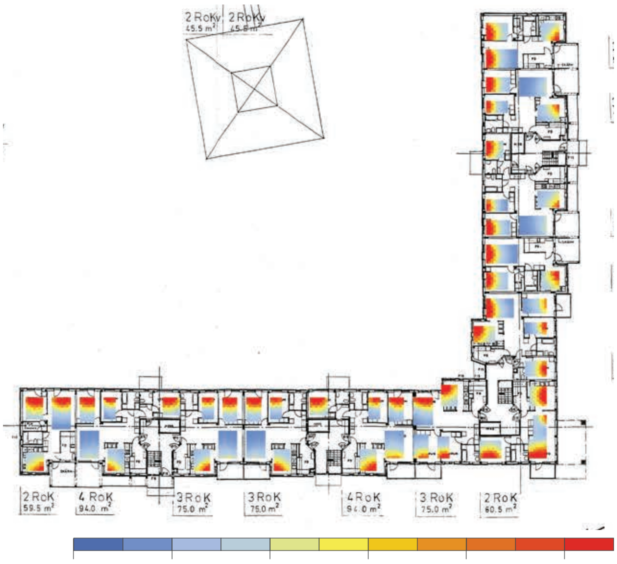
Year: 1991
Typology: Post-modern Reforms
Architect: Nyréns
Analyzed Rooms: 63

Table B28. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	100%	99%	95%	50%
55% Area	100%	99%	89%	44%
75% Area	100%	90%	60%	21%
85% Area	99%	76%	51%	9%
95% Area	99%	66%	43%	3%

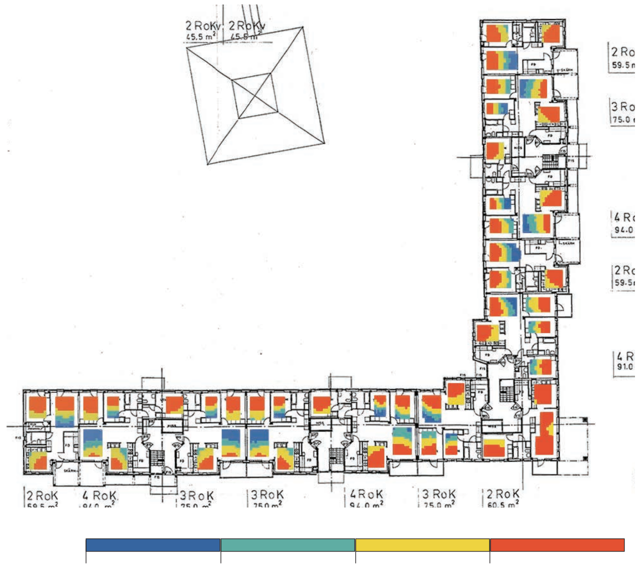
LM-83 55% Area
54%

Room DF$_{med}$ ≥ 2,1%
37%



DF 0% 1% 2% 3% 4% 5%

Fig B28.3



sDA$_{100\ lx,\ 50\%}$ sDA$_{150\ lx,\ 50\%}$ sDA$_{200\ lx,\ 50\%}$ sDA$_{300\ lx,\ 50\%}$

Fig B28.4

0 1 3 5m N

(Figure B28.1) Aerial View of the Building (Source: earth.google.com)
(Figure B28.2) Compliance Area Distribution according to Different Illuminance
(Figure B28.3) Daylight Factor of 1st Floor
(Figure B28.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

29. Starrbäcksängen 0:34

Starrängsringen 19, Ladugårdsgärdet, Stockholm

Fig B29.1

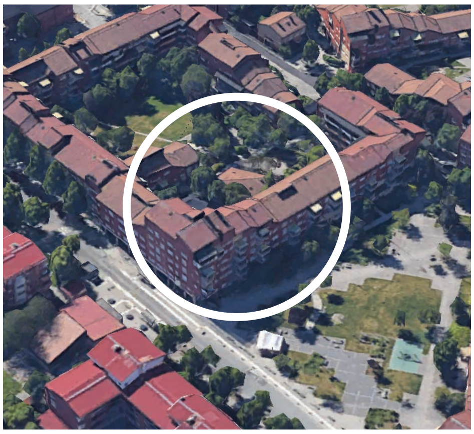
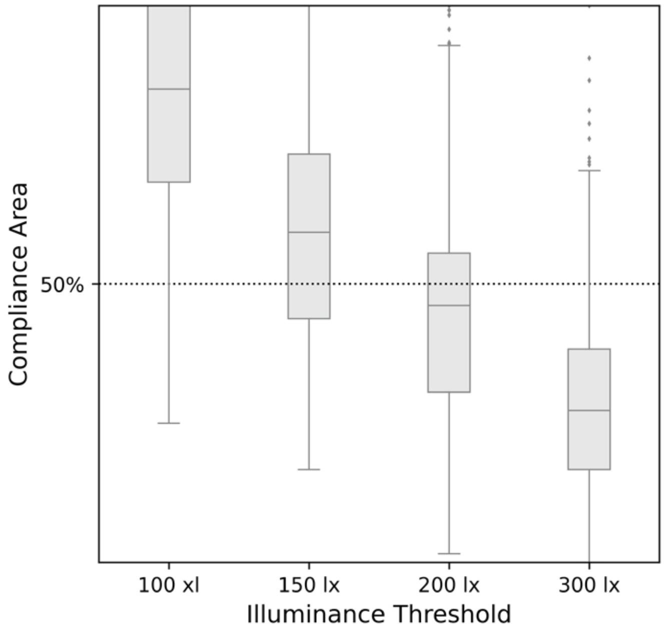


Fig B29.2



Year: 1991
Typology: Post-modern Reforms
Architect: Nyréns
Analyzed Rooms: 63

Table B29. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	92%	67%	43%	10%
55% Area	89%	60%	27%	8%
75% Area	66%	24%	12%	3%
85% Area	50%	15%	10%	1%
95% Area	34%	11%	6%	0%

LM-83 55% Area
10%

Room DF_{med} ≥ 2,1%
4%

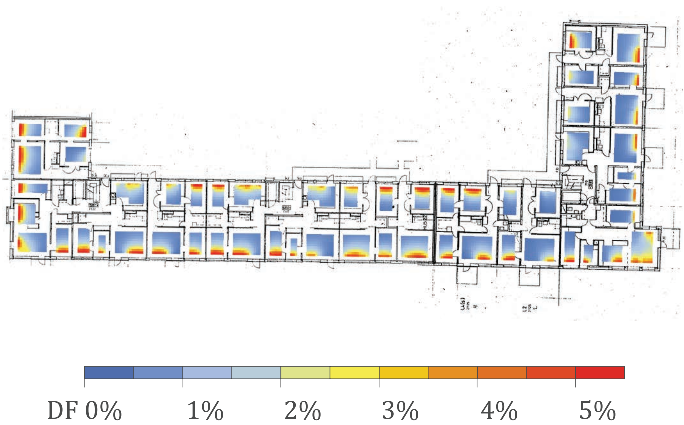


Fig B29.3

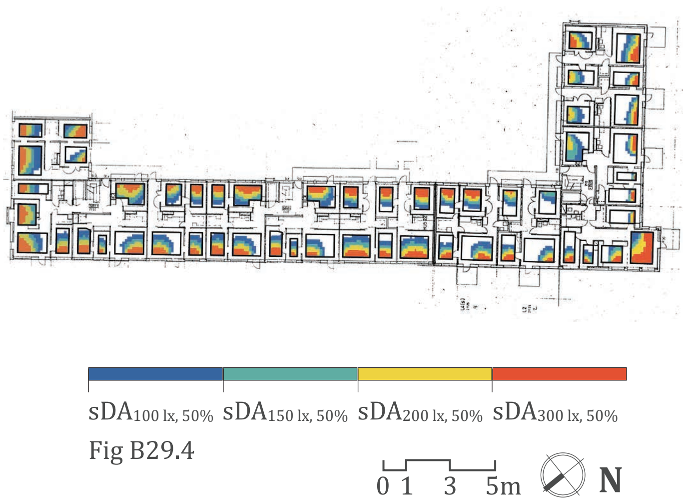


Fig B29.4

(Figure B29.1) Aerial View of the Building (Source: earth.google.com)
(Figure B29.2) Compliance Area Distribution according to Different Illuminance
(Figure B29.3) Daylight Factor of 1st Floor
(Figure B29.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

30. Lindholmen 37:1

Ceresplatsen 1-5, Lindholmen, Göteborg

Fig B30.1

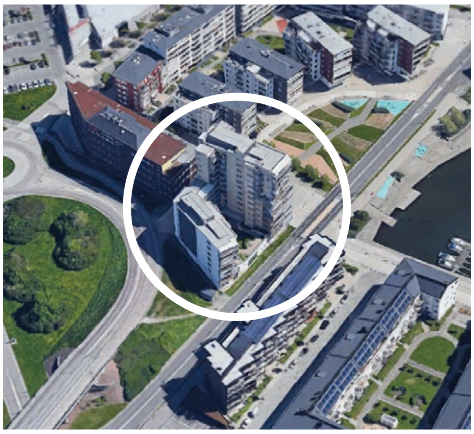
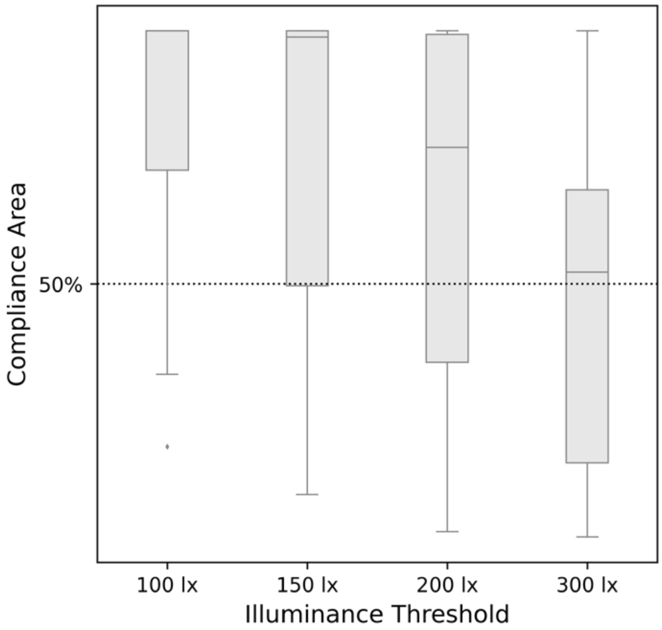


Fig B30.2



Year: 2013
Typology: Others
Architect: unknown
Analyzed Rooms: 68

Table B30. Ratio of Compliance with Different Metrics

	sDA(100 lx,50%)	sDA(150 lx,50%)	sDA(200 lx,50%)	sDA(300 lx,50%)
50% Area	88%	74%	65%	53%
55% Area	85%	71%	62%	43%
75% Area	72%	63%	53%	21%
85% Area	71%	59%	44%	16%
95% Area	68%	54%	34%	7%

LM-83 55% Area
53%

Room DF_{med} ≥ 2,1%
13%

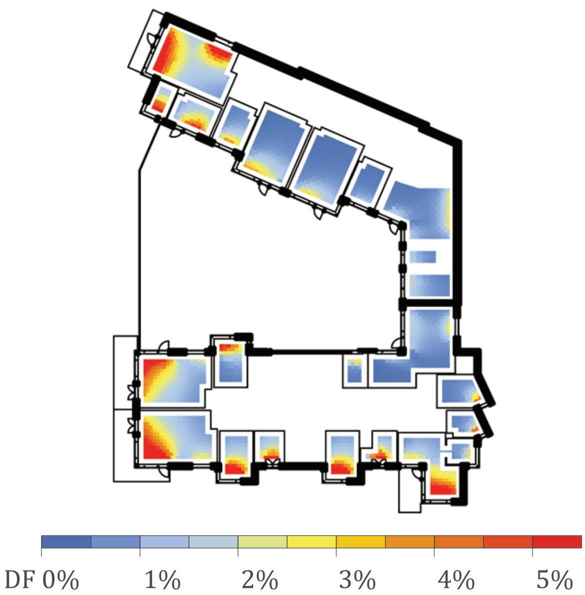


Fig B30.3

Fig B30.4

(Figure B30.1) Aerial View of the Building (Source: earth.google.com)
(Figure B30.2) Compliance Area Distribution according to Different Illuminance
(Figure B30.3) Daylight Factor of 1st Floor
(Figure B30.4) Spatial Daylight Autonomy Compliance of 1st Floor According to Different Threshold

LUND UNIVERSITY

Divisions of Energy and Building Design, Building Physics and Building Services
Department of Building and Environmental Technology