Master's thesis

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Norwegian University of Science and Technology
Faculty of Architecture and Design
Department of Architecture and Technology

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Balcony Design in Norwegian Multi-story Residential Buildings: How the Size and Shape of the Balcony Affects Daylighting and Visual Qualities

Master's thesis in Sustainable Architeturce
Supervisor: Barbara Matusiak
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Abstract

The provision of a balcony to a residential unit offers several impacts on the well-being of occupants, including improved view enjoyment, and enhanced ventilation, as well as architectural values such as providing a private outdoor space. On the other hand, a balcony can act as an overhang, reducing daylight and sunlight through solar shading, and contributing to energy loss by increasing the heating load in cold climates.

In this thesis, different design proposals for balconies, are created with changes in size (in depth and width), typology (recessed/cantilevered), adjacent room function (kitchen/living room) of the balcony, and the placement of the balcony in connection to the building layout, are considered pursuing optimization of balcony design with a focus on daylight utilization. In addition, a separate case looking at a demographically densified future scenario of the residential development is investigated. View studies are done on design variations of balconies in the current and future scenarios.

This study provides a methodology for optimizing a range of balcony design variables for the objectives of daylighting and view. Accordingly, the daylighting indicators used are Spatial Daylight Autonomy (sDA), Annual Sunlight Exposure (ASE), and Mean Illuminance (Avg Lux). The view indicator is the number of layers of the view. The daylight performance is investigated with the use of the typical weather data set of a Continental Subarctic Climate city (Dfc), Trondheim, in Norway.

All the partly recessed balconies were eliminated. This means that the current situation model has the best daylighting indicator values, while also providing flexibility in use (partly sheltered, partly exposed to climatic conditions, providing visual and audible privacy). An interesting aspect of Proposal 4 is that, while it is better for most apartments, for the lower end apartment it is worse than the current situation model, due to lower direct sunlight access and annual mean illuminance. All daylighting indicator values are highest when the balcony is attached to the living room. The scenarios where the balcony is attached to the kitchen for the end apartment is only Proposal 2, which is in the minimum recommended depth of balcony. View studies showed

that staggering the placement of balconies between levels gives significant improvements to view compared to placement of balconies directly above or below each other.

Acknowledgment

I want to thank my supervisor, Barbara Matusiak for her support through this work, her patience, and her expertise. I am very grateful for the time she has spent on directing me.

I would also like to thank Sondre N. Andvik from Rojo Arkitekter for his help answering my questions and sharing the information needed for this thesis work. I want to thank my family and friends who have supported me throughout my studies and have provided good advice along the way. My parents Elfide and Raif Özgür as well as my brother Deniz for their great support. Lastly, my gratitude goes to Dr. Ve for giving me the time to work on this work and turning the pandemic into one-of-the-best times in my life.

Sammendrag

Å inkludere en balkong i en bolig gir flere forbedringer til velværet for beboerne, som for eksempel økt utsiktutnyttelse og forbedret ventilasjon, i tillegg til arkitektoniske verdier slik som å gi et privat uterom. På den andre siden kan en balkong fungere som et overheng som reduserer dagslys og sollys gjennom solskygging, og bidra til økt energibruk ved å øke varmetapet i kalde klimaer.

I denne avhandlingen har forskjellige design for balkonger, der variasjoner i størrelsen (bredde og dybde), type balkong (innfelt/utkraget), og funksjonen til nærliggende rom (kjøkken/stue) til balkongen, og plasseringen av balkongen på bygget, blir optimert for et balkongdesign med fokus dagslysutnyttelse. I tillegg blir det sett på en separat case som innebærer demografisk fortetning i det undersøkte boligområdet. Utsiktsstudier har blitt utført på designvariasjoner i både et scenario for dagens situasjon og det fremtidige fortetningsscenarioet.

Scenarioene ble evaluert basert på effekten av balkongdesignene og nærliggende rom i en etterkrigstidsleilighetsblokk i Trondheim. Denne typen eksperimentering med å redesigne balkonger kan være nyttig i beslutningsprosesser når det gjelder oppussing/renovering av denne typen bygg, som det finnes en signifikant andel av i Norge, og kan også være nyttig i fremtidige fortettingsscenarioer. Til slutt blir innvirkningen av type og størrelse til balkongen på praktisk bruk (skjerming av privatliv og mot elementene) og utsikt diskutert.

All delvis innebygde balkonger ble eliminert. Dette betyr at modellen av dagens situasjon har bedre dagslysindikatorer, og gir også mer fleksibilitet i bruk (beskyttelse mot elementene, visuelt og hørbart privatliv). Et forslag med større, men ikke innebygd, balkong gav bedre daglysindikatorer for alle simulerte leiligheter bortsett fra en endeleilighet på nederste nivå. De beste resultatene kom for versjoner der balkongen var tilknyttet stuen – kun ett forslag der balkongen var tilknyttet kjøkken gav godt resultat i dagslysindikatorer. Utsiktsstudier viste at et sikk-sakk-mønster for plasseringen av balkongene gav forbedringer til utsikten sammenlignet med dersom balkongene var plassert direkte over hverandre.

Nomenclature and Abbreviations

APD	Apartment Per Decare
ASE	Annual Sunlight Exposure
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
BPS	Building Performance Simulation
CBDM	Climate-Based Daylight Modeling
DA	Daylight Autonomy
DD	Demographic Density
DF	Daylight Factor
EPW	EnergyPlus Weather files
sDA	spatial Daylight Autonomy
SHGC	Solar Heat Gain Coefficient
Tvis	Visible Transmittance
UDI	Useful Daylight Illuminance (Annual)
WWR	Window-to-Wall Ratio

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The greenest building is the one that is already built.

Architect Carl Elefante

1. Introduction

1.1. Background

Densification of cities and adaptation of existing buildings are two strategies to promote sustainable development that have been focused on in the last decades.

In general, denser cities will generate less traffic than sparsely populated cities meaning shorter travel distances and thus less need for transport. Moreover, the denser the cities are built, the easier it is to operate the city by public transport and supply the other public services. But as the cities get denser some new challenges have emerged in urban life such as providing sufficient outdoor space for residents both in public and private forms. Quality and accessibility of open spaces are identified as one of the most important elements of the built environment and inner-city dwellings, and is considered important for improving compact-city livability for various groups throughout their lives. (Kotulla et al., 2019) The continued need for direct access to private outdoor spaces from housing units is essential, independent of whether the housing unit is in the suburbs or in dense city spaces, and is still necessary in higher latitudes and cold climates such as Norway.

Adaptation of existing buildings is another common strategy, meaning interventions done to existing building stock to keep up to today's needs and extend their life cycle. Both this strategy, and the densification strategy mentioned above, are commonly promoted in Norway. The existing building stock goes through renovations and rehabilitations for a variety of reasons such as taking advantage of developments in material and construction technology or extensions of the existing spaces to meet the specific needs of modern life. A common example in existing residential buildings is the extension and refurbishing of balconies, which can often be observed in post-war residential developments in Norway.

The following literature review is focused on the importance of balconies as a private open space in urban structures in the first part. The second part considers the use of balconies in residential buildings since their emergence as an architectural element in Norwegian culture looking at the recent history of Norway. The last part goes through balcony typologies and their impact on indoor comfort.

1.1.1. Densification in Norway

Densification of cities was historically done in a Nordic context mainly as a result of energy shortage, but in the last decades has also been regarded as a common strategy with the purposes of sustainable development and to reduce the impact of humanity on the environment. (Kotulla et al., 2019)

In the municipalities with constant population growth in Norway, such as in the regions of Oslo, Bergen and Trondheim, there is a desire for increased housing construction is realized in the form of densification within the established built environment, to prevent the demolition of agricultural areas, shared outdoor spaces, and other green infrastructure. (*Veileder i Bokvalitet [Guide for quality of living]*, 2012), (*Boligfortetting i Trondheim - status og muligheter [Housing densification in Trondheim - status and opportunities]*, 2019), (Leknes, 2021)

It is common to distinguish between physical densification and demographical densification. Physical densification involves that the floor area increases regardless of the number of occupants, while demographic densification is about gathering more citizens in smaller areas, often referred to as housing densification. Of these two, the latter type contributes to sustainable development goals. (Anna Lindholm, 2013)

Leknes et al. note that the urban area of Stavanger / Sandnes has increased by as much as 10 km^2 in the last 20 years, while the Bergen metropolitan area has increased by 1.5 km^2, and the Trondheim urban area has only increased by 0.1 km^2. At the same time, the number of residents per km^2 of the urban area has increased by 830 (34%) in Trondheim, 577 (24%) in Bergen, and 542 (23%) in Stavanger / Sandnes. (Source: Statistisk Sentralbyrå [Statistics Norway], table 04859). They conclude that the settlement of Stavanger / Sandnes that has increased by far the most in scope, while the population density has increased most in Trondheim. This shows that the densification of the Trondheim urban area is significantly higher than the other cities, showing that this strategy is the most prevalent in the development of this city.

The way demographic densification is implemented can be found when looking at the statistical distribution between types of dwellings over time. Table 1 shows a percentage comparison between types of dwellings in Norway in 2006 and 2022. As can be seen in the table the amount of detached houses has decreased the most, while the percentage of multi-dwelling buildings has increased the most. This indicates that densification is achieved mostly by replacing detached houses with multi-dwelling buildings. In addition, even though detached houses in 2022 are still the most common type of dwelling in Norway, the big cities have a proportionally lower amount of detached houses, e.g. in Oslo the percentage is only 8 %. Conversely, the proportion of multi-dwelling buildings are much higher in the big cities, with Oslo having 72 % of flats, Bergen has 46 % and Trondheim 43 % (source: Statistisk Sentralbyrå [Statistics Norway]).

Comparing the three cities, it is easily observed that Bergen and Trondheim most likely have opportunities for additional demographic densification in the form of replacing detached houses with multi-dwelling buildings.

Table 1: Comparison of percentage of types of dwelling in Norway between 2006 and 2022 (Source: Statistisk Sentralbyrå [Statistics Norway]).

	Dwellings (occupied and vacant)					
	Detached house	House with 2 dwellings	Row house, linked house and house with 3 dwellings or more	Multi-dwelling building	Residence for communities	Other building
2006	54.22	9.15	11.31	20.91	1.69	2.71
2022	48.38	8.98	11.99	25.17	2.63	2.86

However, a difference between a detached house and a multi-dwelling building is the ease-of-access to a private outdoor space.

1.1.2. Balconies as an architectural element in Nordic culture

Due to the climatic conditions, it is initially easy to suppose that private outdoor spaces would be less important when designing multi-dwelling buildings for Norwegian residents. This is evident in that Norwegians in modern times have spent most of their time indoors, especially before the arrival of high-tech climatic clothing – up to 90% according to Gunnar Berge, the minister of Local Government and Labor in Norway in 1992-1996 (Johan-Ditlef, 1993). However, Norwegians have historically had a close connection to nature and spending time outdoors. This has been in part to cope with the negative impacts of drastic changes in seasonal daylight availability which can have severe effects on their physical and psychological health (Andersen et al., 2012) (Viola et al., 2008) (Dogan & Park, 2019; Glickman et al., 2006).

Even though it is obvious today, the necessity of providing private outdoor spaces has not always been a priority for urban developers.

1.1.2.1. Early modern historical background of multi-residential buildings in Norway

The influences of the industrial revolution in Norway started to be seen in the 1840s (Dørum). Dørum states that it was not until the first decades of the 1900s, according to most historians, that Norway experienced the great breakthrough when hydraulic power and electricity came into general use in industry. These inventions resulted at the beginning of the actual large-scale industrialization of the country. In these years, employment in the sector reached a considerable extent, and the cities gained a sufficiently large population and thus a large group of consumers. This large population began gathering in denser living environments around the industrial areas. Housing shortages had developed in the big cities, a problem later exacerbated by the German occupation during WWII. Very many lived in poor conditions and did not have their own homes. In the 1930s, even new dwellings were unsatisfactory for families (Brockmann, 1948). Even so, access to clean and warm water, sanitary facilities, garbage disposal, refrigerators, central heating, and electric lights brought more people to these city apartment buildings. Their popularity led to women and children joining the labor market to help afford these tiny dwellings. Here, children often lived with their parents until their mid-twenties, and the whole household slept in the living rooms (Brockmann, 1948).

Even though city residency and living in denser built environments became more common among Norwegians, their bond to nature remained. Even low-income families found ways to escape from the densely built areas on holidays, such as self-built cabins out in the woods as shown with the “Ruud” family interviewed in the first professional housing survey in Norway (Brockmann, 1948). This survey, done during occupation years subjecting 200 families provided a basis for the post-war housing developments, is often considered the professional basis for understanding a good home, the development of which started during the reconstruction after the war and went on until the 1980s (Moe & Martens, 2021). The post-war reconstruction required a comprehensive and unified societal effort to solve the housing problems. The state, the municipalities, the housing cooperative, and private developers formed a closed cooperation with a common goal of building as many and good as possible. Housing planning became an important field for architects, engineers, and other professionals. Based on the housing sector, significant measures were taken to define lowest and highest limits of housing standards through the building permit scheme to even out the class differences (Moe & Martens, 2021). The reconstruction in 1950s went quickly, focused on quantity rather than quality. As a result, stereotypical block areas emerged, and satellite towns were built as part of a social housing policy with the ambition of removing housing shortages (Hansen, 2006).

Figure 1.1 The big housing demonstration due to housing shortages in front of Oslo city hall on September 20, 1951. Photo: Ungdommens Selvbyggerlag (USBL), 25 år I byggende arbeid [25 years in construction work], 1973. (left) The satellite town Lambertseter, 1952-61. 3311 apartment units in 1.8 square kilometer. Photo: NTB scanpix/arkiv. (right)

The rapid expansion of housing in the 1950s remedied the urgent need, and by the onset of the 1960s, housing construction slowed down (Moe & Martens, 2021). Regulations were being removed and people gradually received better advice and more free time. As such, the demands for good houses increased. In the 1970s, the apartments became larger, the balconies grew, and the cars could fit under the apartment blocks. Criticism of stereotypical block areas increased. Housing quality and living environment gradually became more important than the goal of as many homes as possible**.** The result of these changing priorities was that, in general, new developments started replacing high-rise buildings with a high density of low-rise buildings to achieve demographic densification. (Moe & Martens, 2021).

Since the 1970s, the offshore oil industry has played a dominant role in the Norwegian economy. (*Building and Urban Development in Norway*, 2004) That also affected the way cities are developed and dwellings are built. Building dense and modest was not a priority anymore. But these principles became important again in the last decades, this time with the purposes of sustainable development and reducing the impact of humanity on environment. (Kotulla et al., 2019)

In Marchenko's thesis, balconies were found to contribute a higher quality of compact living by providing a private outdoor space to apartments (Marchenko, 2021). In addition, The Association of Consulting Engineers in Norway (RIF) found that a balcony also is desirable for home buyers and therefore lead to larger deeper balconies being specified by developers (Daglys i Bygninger [Daylight in Buildings], 2020) This is apparently also reflected in the apartment property prices in Norway; according to real estate agents, an apartment with a balcony would sell for 2-3 hundred thousand kroner higher than one without in one area of Oslo (Drageset, 2017).

1.2. State-of-the-Art

1.2.1. Balconies as an open private space in urban life

Balconies are increasingly considered relevant in multi-family buildings in high-density cities. In fact, a recent review paper found that 69% of the included studies were published during the last decade (Ribeiro et al., 2020). In addition, awareness of the potential positive impacts of balconies has been rising during the COVID-19 pandemic. (Peters & Halleran, 2020)

The impact of balconies on the adjacent spaces' indoor environmental quality depends on their design, on the characteristic of the buildings, and the surroundings. (Černý et al., 2019) The increased challenge of providing satisfactory outdoor spaces in densely built urban areas combined with the higher awareness of their positive impacts makes this an important field to study. However, very few studies of this have been found in the literature – for Norway only a single study was found. (Marchenko, 2021)

1.3. Scope of Thesis

The case study is a minimal apartment in social housing with only one balcony. To ensure the access to the balcony, it is supposed to be adjacent to more public functions. Therefore, program of this study is limited to optimization of daylight in the living room and kitchen rooms. The current situation model will be kept as a benchmark and variations that do not satisfy the improve the daylighting qualities will be eliminated. In result, multiple optimal proposals will be presented.

1.4. Objective of Thesis

Objectives: Daylighting and view

Research questions:

1- Which ways can balcony design can contribute to "good dwelling" phenomenon?

2- To what extend balcony design affects visual qualities in residential buildings?

3- To what extend balcony design affects daylighting in residential buildings?

2. Methodology

This section first introduces the case study. Then variables selected based on the specifics of the case study are presented, from which different scenarios are created. Finally, appropriate methods are selected and described for each objective.

2.1. Case study

2.1.1. Location and Climate

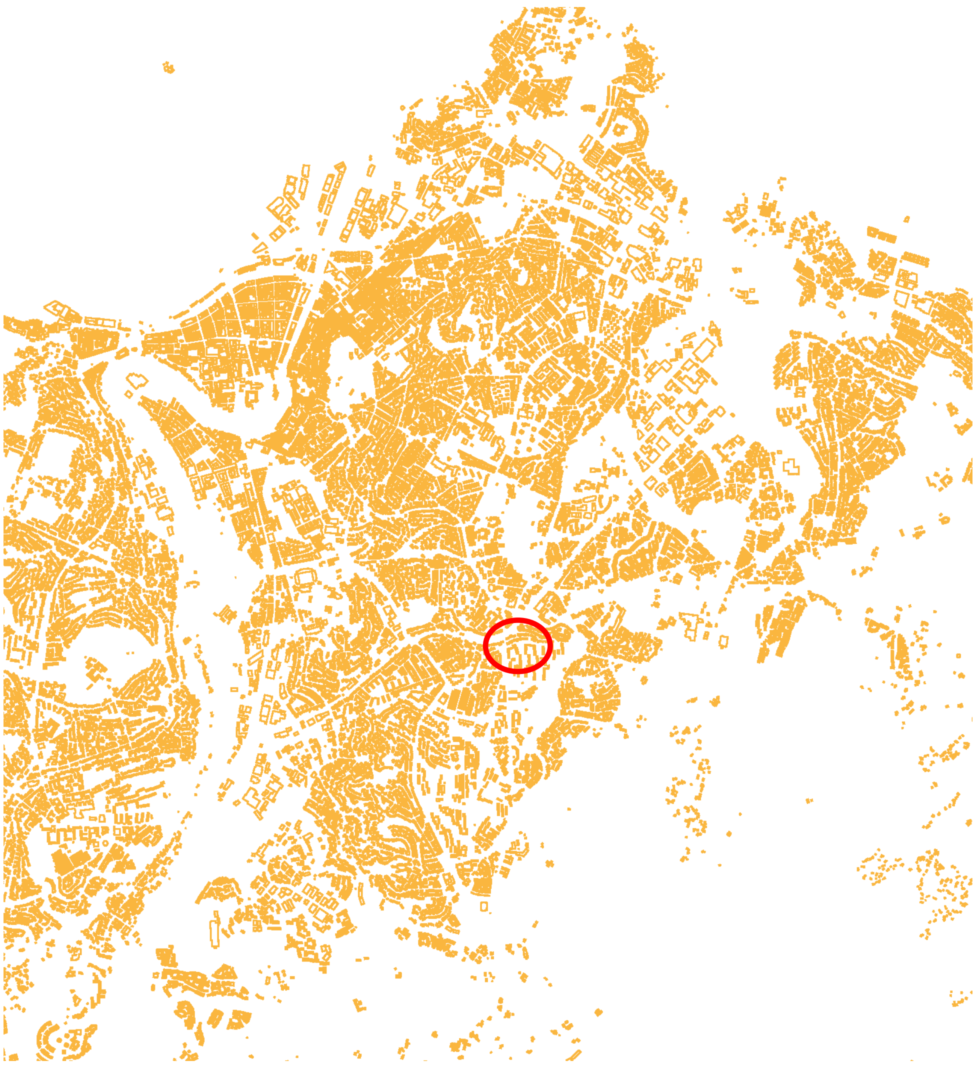


Figure 2.1 Figure-ground study of the buildings in the city of Trondheim. (Source: Tetthet i Trondheim, 2018) Othilienborg Borettslag is circled on the figure.

(*Tetthet i Trondheim [Density in Trondheim]*, 2018)

The case study is a residential development, Othilienborg Borettslag (see Figure 2.1), located in Trondheim city in the center of Trøndelag (63° 26’ 48.5772” N and 10° 25’ 18.8616” E).

Trondheim, as most regions in Norway – 11 out of 18, lie in the Subarctic climate zone (Dfc) according to the Köppen-Geiger climatic classification, with severe winters, no dry season, and cool summers. (The Global Historical Weather and Climate Data, 2022)


Figure 2.2 Othilienborg housing project, 1965-67, Trondheim is an example to high utilization of daylight and view in housing projects at high altitudes by means of approximately 60 meters distance between buildings.

Othilienborg housing project, constructed between 1965-67, consists of 409 apartments, a common building for social gatherings and gym, an open-air playground, trash sorting facilities, private garage units, parking lots and many outdoor seating areas. Figure 2.2 and Figure 2.3 shows historical and more current images of the housing project. There are green walking and disk golf routes passing through the housing development, and a football field next to it. The distance between the rows of apartment blocks is approximately 60 meters, more than what is typical for a housing development in the area. This means the apartments can get the daylight with lower angles compared to housing developments that are built denser. Each apartment block is four floors, including the entrance floor with storage spaces and three floors of apartments. There are two types of apartments in each floor: apartments with two bedrooms (72 m²) and apartments with three bedrooms (80 m²).


Figure 2.3 Othilienborg BL photographs; before extension of the balconies (left), after the extension of balconies (right).

2.1.2. Design and Layout

As mentioned, the placement of the apartment blocks in Othilienborg is beneficial for daylight access. Daylight access is prioritized in architecture design, and for example Neufert Architects' Data and the guide on Lighting for Communal Residential Buildings specifies that the movement of the sun should impact the layout and orientation of a residential unit. (Neufert & Neufert, 2012) (Chartered Institution of Building Services Engineers, 2013) Already in 1936, Neufert suggested room types, and activities commonly associated with the rooms, should dictate where in the residential unit a room was placed, so that access to natural light is beneficial during most of the time a room or other space is used. For example, stimulation from being exposed to morning daylight between 6 AM and 10 AM is important for the circadian rhythm (Konis, 2017), meaning that bed-rooms ideally should have windows oriented at least partly towards east. The recent COVID-19 pandemic lockdowns once more showed the importance of the flexibility in use of apartments. For personal reasons or general reasons like the COVID-19 pandemic, homes may need to be used as workspaces, kindergartens, patient, or elderly care rooms etc. which shows the importance of adequate daylighting in homes. (Amorim et al., 2022)

Looking at the orientation of the sun path around a typical apartment block unit in Othilienborg Borettslag in Figure 2.4, as well as the floor plan shown in Figure 2.5, it is seen that the design follows the guidelines mentioned in the previous paragraph. The daylight access in relation to function of spaces in Othilienborg apartment units is shown as a diagram in Table 2.

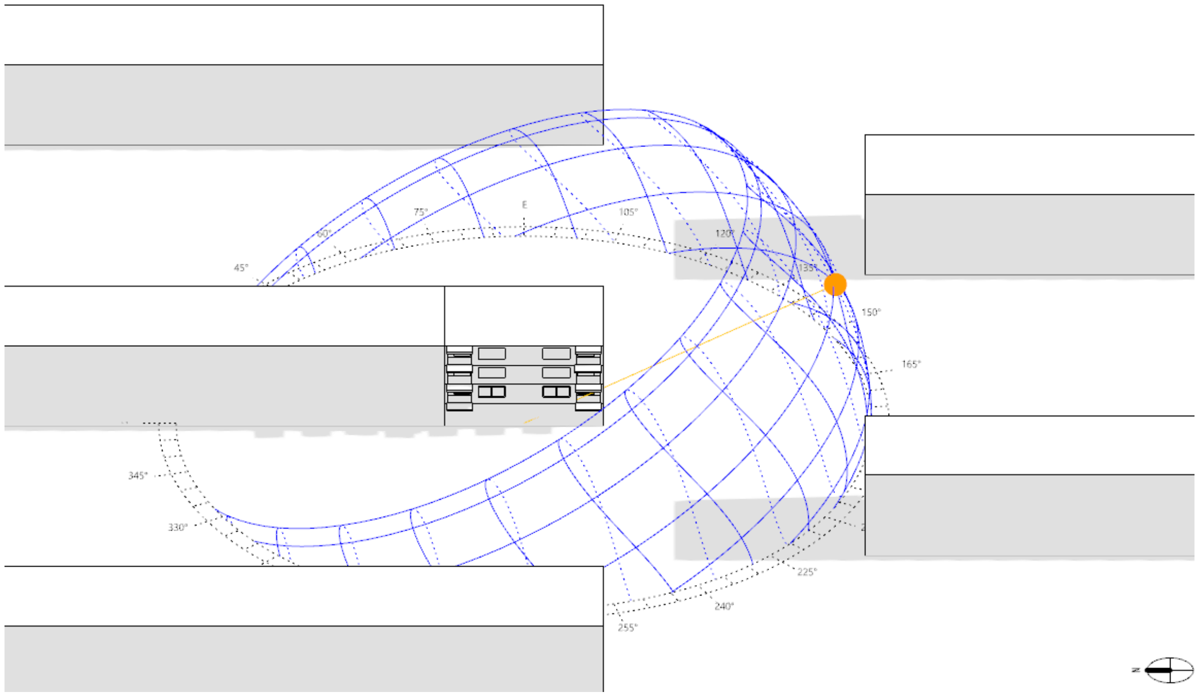


Figure 2.4 Isometric view of the sun path diagram of the apartment in Othilienborg BL (sun position at 12:00 at the Autumnal Equinox).

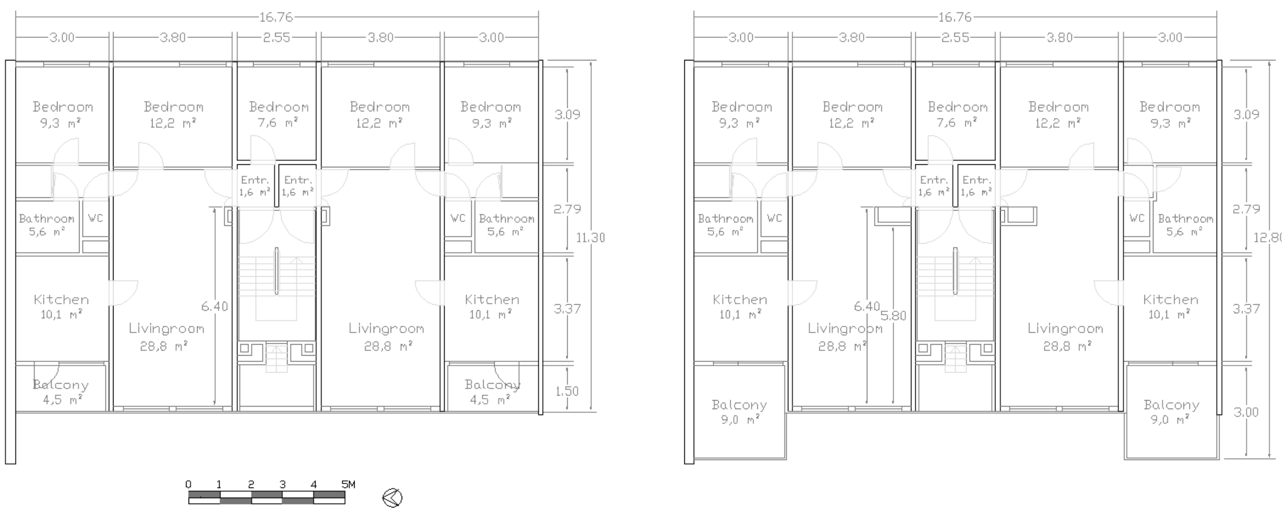


Figure 2.5 Othilienborg BL plan drawing; before the extension of the balconies (left), current situation (right).

Table 2: Daylight access in relation to function of spaces

Othilienborg BL – A layout design following and letting in the daylight
Private – bedrooms – east facing – gets the morning sun to wake up or work
Services – bathroom, toilet, entrance, and circulation areas – no daylight
Public – living room, kitchen, and balcony – west facing – afternoon sun to enjoy

The apartments in the development were built with only recessed balconies 1.5 meters in depth and 3 meters in width, as shown on the left in Figure 2.5. These were in accordance with what was found historically to be the requirements of residents. (Brockmann, 1948) Also when looking at the trends for balcony size in more recent years, the original design was within minimum recommended specifications. (Edvardsen et al., 2022) However, the balconies were extended as approximately 1.5-meter cantilever structure, shown on the right in Figure 2.5, based on the voting results from the residents, showing that even though the original balconies were within modern minimum recommendation, the requirements and desires of the residents were for larger balconies. The current situation balcony has some flexibility in use, since it is partly shielded from weather conditions. As for the orientation with regards to sunlight access, a west-facing balcony is found to be well suited with regards to its desired use. (Brockmann, 1948)

Connection of the apartments in the current situation can be seen in Figure 2.6. For privacy reasons, residents generally want to be well isolated from their neighbors. (Brockmann, 1948) None of the connections are completely optimized for privacy, as one side always has no spatial separation from a neighboring balcony. Connection (1) and (3) provides more privacy against neighbors than connection (2). The solutions of connection (1) and (3) give considerably more audible privacy than just a screen in between, as seen in connection (2). Comparing the balconies of the recessed blocks in connection (1) and (3), the recessed block in connection (1) has more advantages concerning sunlight access. This is due to that in connection (3), the recessed block is on the northern side, and therefore losing sunlight access from the south.

(1)

(2)

(3)

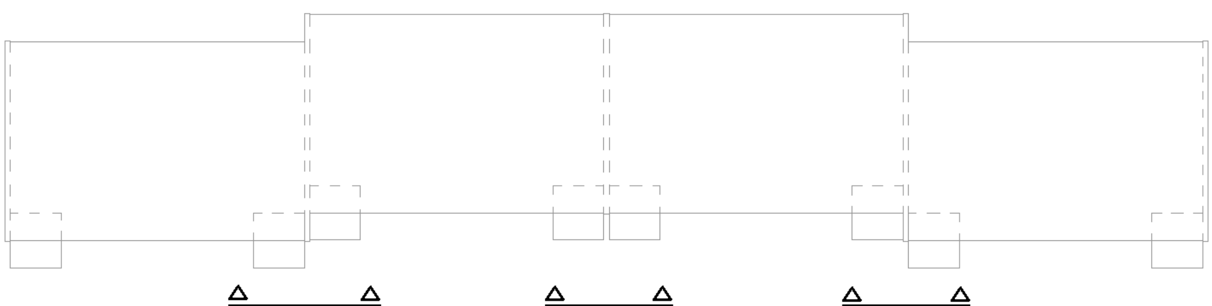


Figure 2.6 Connections of apartments in the current situation

During the visit of the apartment in Figure 2.7 and Figure 2.8, the current resident was shown the plan of the balcony prior to the extension renovation. He asked, “What’s the point to have such a balcony?”. When he was asked for clarification, he explained as given the small size and being fully recessed, the balcony wouldn’t satisfy his expectations from a private outdoor space. (Resident of Othilienborg BL, personal communication, May 12, 2022)

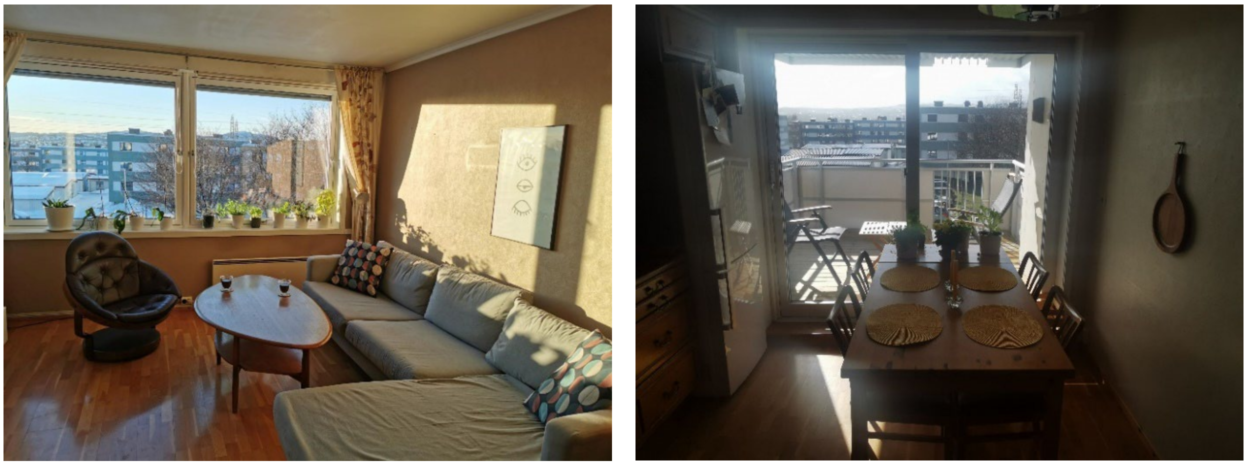


Figure 2.7 Interior images of a second-floor end apartment at Othilienborg BL; in the living room (on the left, February 20, 2022, by the author), in the kitchen (on the right, 12 PM, March 29,2022).

Figure 2.8 Interior image of a second-floor end apartment at Othilienborg BL; in the kitchen (3 PM, February 14,2022).

2.2. Parameters, Scenarios, and Indicators

This study provides a methodology for optimizing a range of balcony design variables for the objectives of daylighting and view. Accordingly, the daylighting indicators used are Spatial Daylight Autonomy (sDA), Annual Sunlight Exposure (ASE), and Mean Illuminance (Avg Lux). The view indicator is the number of layers of the view. The parameters used to create different scenarios include size (in depth and width), typology (recessed/cantilevered), adjacent room function (kitchen/living room) of the balcony, and the placement of the balcony in connection to the building layout. In addition, a separate case looking at a demographically densified future scenario of the residential development is investigated by a shadow study and daylighting simulations.

2.2.1. Parameters

The parameters used in the scenarios are shown in Table 3.

Table 3 Parameters used in the scenarios

Design elements	Name	Type
Balcony type	Recessed/Overhang	Variable
Balcony size	Depth	Variable (1,5m or 3m)
	Width	Variable (3m – 7,1m)
Adjacent rooms of balcony	Kitchen/Living room	Variable
Layout of the apartment block	Mirrored/repetitive	Variable
Density of apartment blocks	Height	Constant (4 floors)
	Distance in-between	Variable (current = 60m, future scenario = 25m)

2.2.2. Scenarios

2.2.2.1. Core scenarios

Plan drawings of the core scenarios are shown in Figure 2.9 to Figure 2.12, while 3D models of the core scenarios can be found in Figure 2.13 to Figure 2.16.

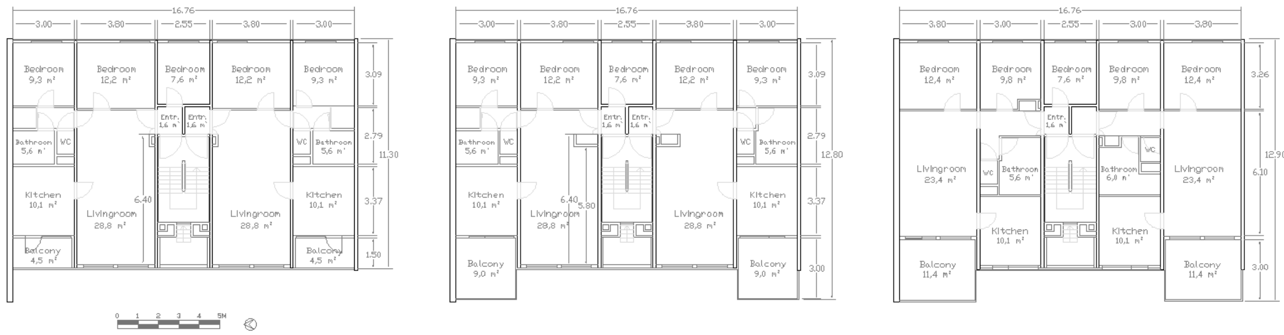


Figure 2.9 Plan drawings of before renovation (left), current situation (center), proposal 1 (right).

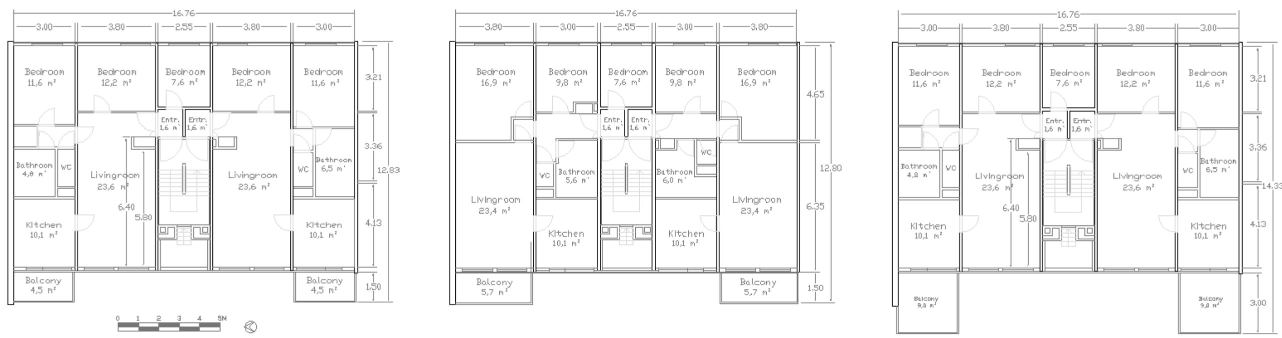


Figure 2.10 Plan drawings of proposal 2 (left), proposal 3 (center), and proposal 4(right).

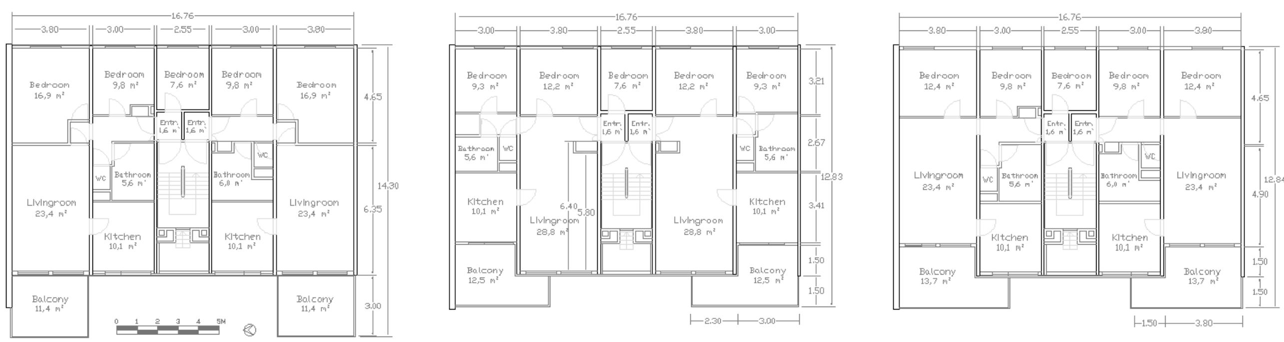


Figure 2.11 Plan drawings of proposal 5 (left), proposal 6 (center), and proposal 7 (right).

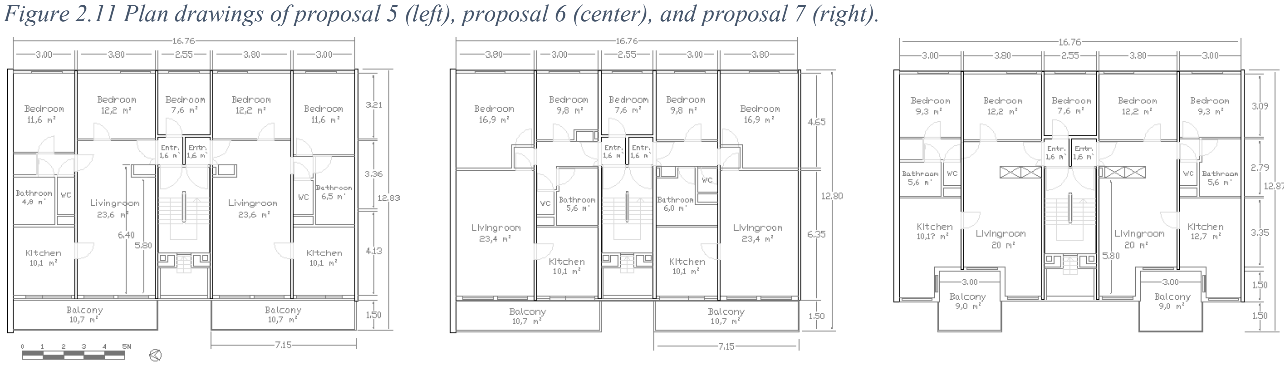


Figure 2.12 Plan drawings of proposal 8 (left), proposal 9 (center), and proposal 10 (right).

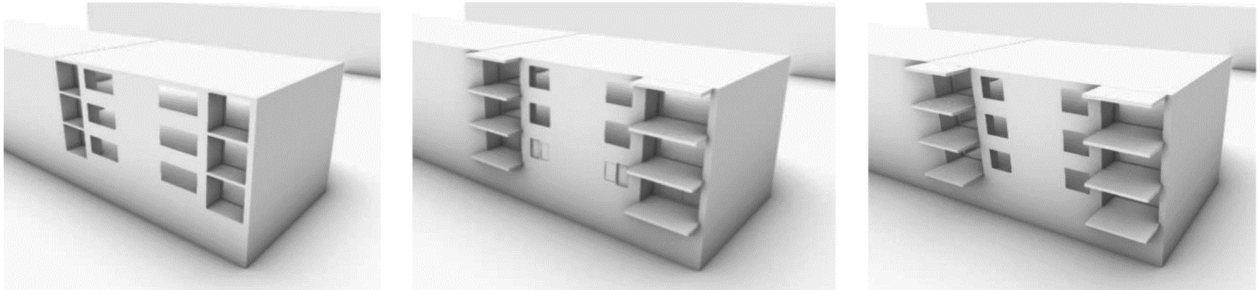


Figure 2.13 Perspective views of models of before renovation (left), current situation (center), proposal 1 (right).

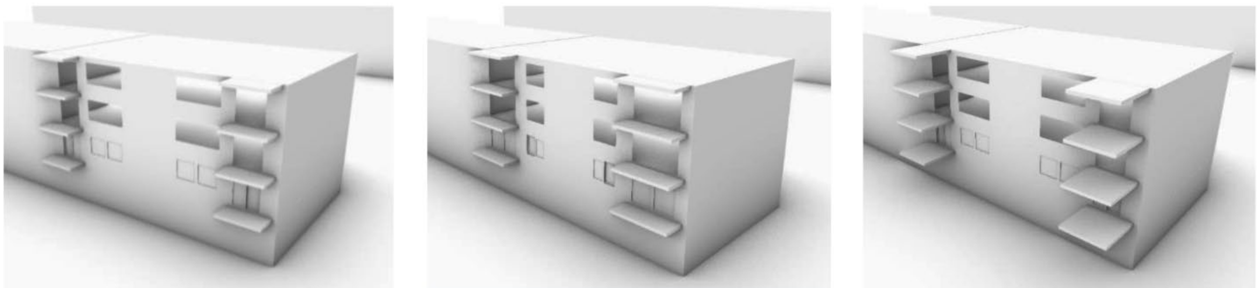


Figure 2.14 Perspective views of models of proposal 2 (left), proposal 3 (center), proposal 4 (right).

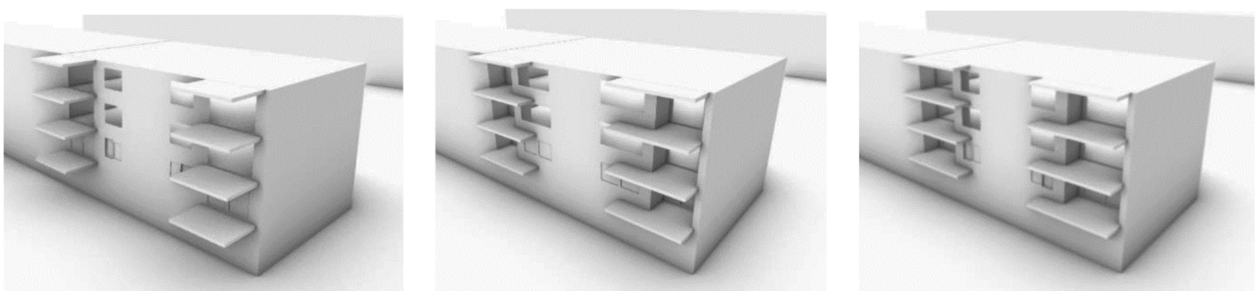


Figure 2.15 Perspective views of models of proposal 5 (left), proposal 6 (center), proposal 7 (right).

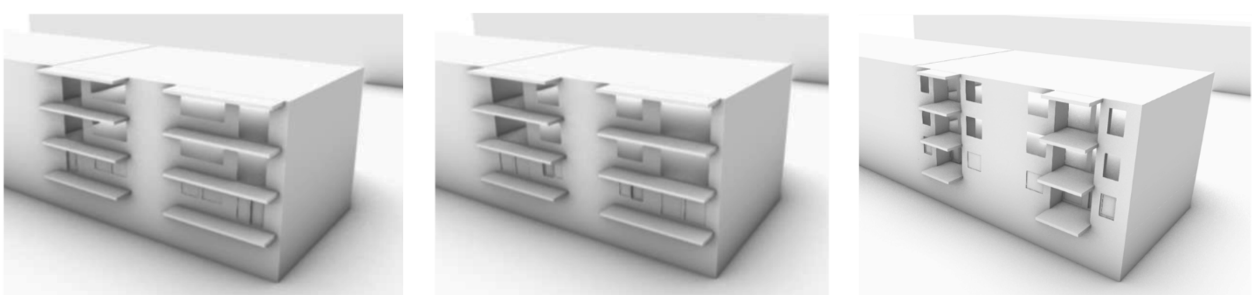


Figure 2.16 Perspective views of models of proposal 8 (left), proposal 9 (center), and proposal 10 (right).

2.2.2.2. Extended scenarios

These scenarios are combinations of core scenarios showing variation between different levels and can be seen in Figure 2.17 and Figure 2.17.

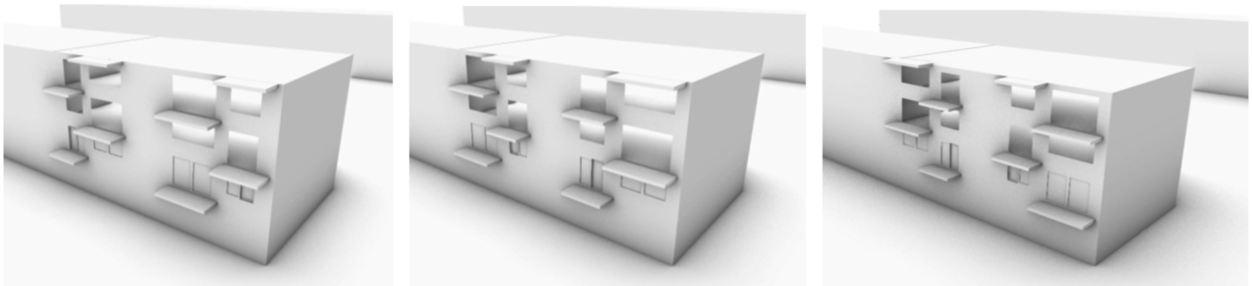


Figure 2.17 Perspective views of model of proposal 11 (left) proposal 13 (center), and proposal 14 (right).

2.2.2.3. Multi-level simulation scenarios

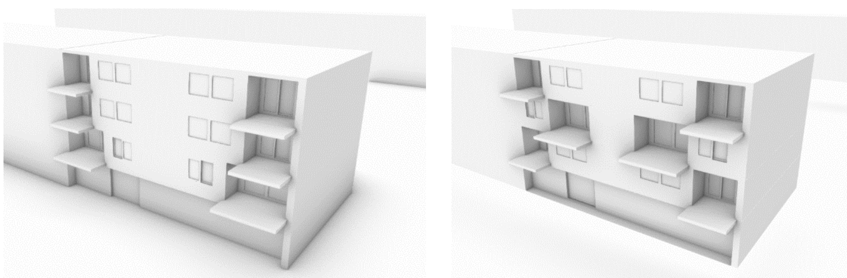


Figure 2.18: Perspective views of models of proposal 15 (left) and proposal 16 (right)

2.2.2.4. Future Scenario

As mentioned in the introduction, increasing demographical densification contributes to increased sustainability through e.g., less land area used per person and more opportunities for public transport. To compare demographic density (referred to as DD going forward) in different areas in city of Trondheim, the number of residential units per area will be used in this thesis, as it is commonly used in literature and gives an acceptable representation of the density of persons in housing development areas. This way of calculating demographic density can be misleading to a certain degree, as plot size and location of residential units can give a poor area usage even if the experienced density is high. In addition, the number of residences per land area says little about how many people are living in each residential unit. (Anna Lindholm, 2013) Nevertheless, as this part of the thesis mostly focuses on densification in housing developments, using residential units per area gives a good comparison between cases.

Figure 2.19 Othilienborg Borettslag, constructed 1967-68, 409 apartment units, 95.22 decare.

A satellite image of Othilenborg Borettlag and the surrounding area can be seen in Figure 2.19. It is seen that the ratio of the green areas to the built area is high compared to the immediately surrounding area. Calculated demographical density in Othilienborg Borettslag is 4.3 apartments per decare (apd). This is low compared to centrally located housing developments, which, according to a density study in Trondheim Kommune have significantly higher DDs (Ilsvika 10.2

apd, Dyre Halses Gate 26.6 apd, Lademoen 14.4 apd, Lade Allé 7.3 apd, Elgeseter Gate 17.3 apd) than Othilienborg Borettslag. (*Tetthet i Trondheim [Density in Trondheim]*, 2018) In fact, similar housing developments having around the same DD as Othilienborg Borettslag are in general located less central compared to Othilienborg (see e.g., Selsbakkhøgda Borettslag, DD 4.5 apd). The low DD combined with the central location shows a potential for densification in Othilienborg with possible infill development, which started in part in 2017 by the construction of Alfred Trønsdals Veg 2 (Figure 2.20).

Figure 2.20 New developments around Othilienborg Borettslag: Alfred Trønsdals Veg 2, Norgeshus, 2017. (left), Steinanvegen housing project, Voll Arkitekter, 2017. (right) (source: http://vollark.no/portfolio_page/steinanvegen/*)*

A possible infill project would be expected to affect the daylighting in, and the view from, the apartments in Othilienborg Borettslag, as external obstruction has been found to be the major physical factor affecting luminous comfort. (Xue et al., 2014) Therefore, a case showing a potential future scenario with an infill project in the area of Othilienborg Borettslag, as shown in Figure 2.21, has been included in the scope of the thesis. Comparing the estimated DD in the future scenario, around 8 apd, to other centrally located housing developments, the infill project can be seen to have increased the DD to central location levels and can be considered to be a realistic future scenario.

Figure 2.21 Site plan of the current scenario (left), and a future scenario of an infill development case of Othilienborg Borettslag (left). The case study apartment block module is marked on the site plans.

In addition to daylighting simulations, a shadow study has also been performed for the infill development case. The site model is modelled in Rhinoceros 7 as a flat terrain (the same as in daylight analysis). The shadow studies are conducted in Climate Studio under the site analysis workflow, yielding the results as shown in Figure 2.22. As can be seen, additional blocks in-between the ones present in the current situation may impact daylighting quality, but the exact effect is dependent on specific terrain slope in addition, which is considered outside the scope of this thesis.

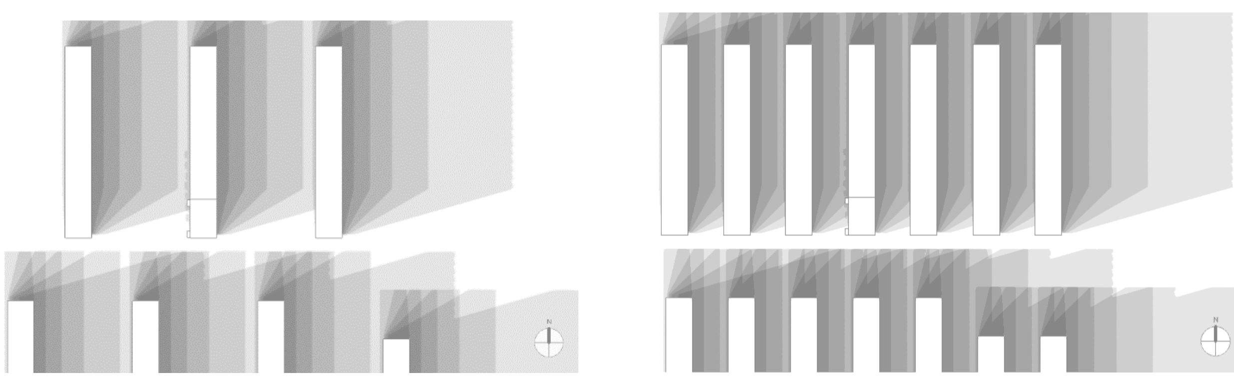


Figure 2.22 Shadow study of the site in current situation (left), shadow study of the site in the future scenario(right). Both are conducted by superposing the shadows in Autumn Equinox at 12 PM, 1 PM, 2 PM, 3 PM, 4 PM, 5 PM.

2.2.3. Indicators

Climate-based annual daylight evaluation metrics are used as indicators to evaluate the daylighting quality of subjected spaces. One of those metrics is Spatial Daylight Autonomy (sDA) which represent the percentage of the regularly occupied floor area that is meeting target illuminance levels (300 lux) using daylight alone for at least 50% of occupied hours during the year. (ClimateStudio Solemma) In this thesis, occupied hours refer to 8 AM – 6 PM with daylight saving time (DST), Monday- Sunday for all the daylighting metrics. Even though the time limits for occupied hours in residential buildings are not as defined like office buildings, its use is considered as necessary for this study, since the desirability of daylight outside of those hours and with that low angle are controversial. The second metric used is Annual Sunlight Exposure (ASE), which is generally used to detect glare probabilities, but in this study referred as direct sunlight exposure and is considered a positive factor on occupants' well-being. It is defined as the percentage of the regularly occupied area that receives direct sunlight, more than 1000 lux directly from the solar disc, for more than 250 occupied hours. (ClimateStudio Solemma). The third metric used is mean illuminance, which ClimateStudio defines as "the average illuminance over the regularly occupied floor area over all occupied hours". (ClimateStudio Solemma)

2.2.4. Daylighting Simulations

Modelling for all the simulations is done in Rhinoceros 7 in this thesis work. The weather file of Trondheim is sourced from Meteonorm Global Climate Database. All the daylighting simulations are conducted in Climate Studio under the Daylight Availability workflow. In the daylighting model of the work plane dimensions consist of 0.5 m offset from walls and its height is set to 0.8 meter. Sensor spacing is approximately 0.6 meter.

In the first stage, the current situation is modelled and Figure 2.23 shows the current situation model, with mirrored apartments building layout. This has been set up from the architectural drawings of the existing project in Othilienborg Borettslag.

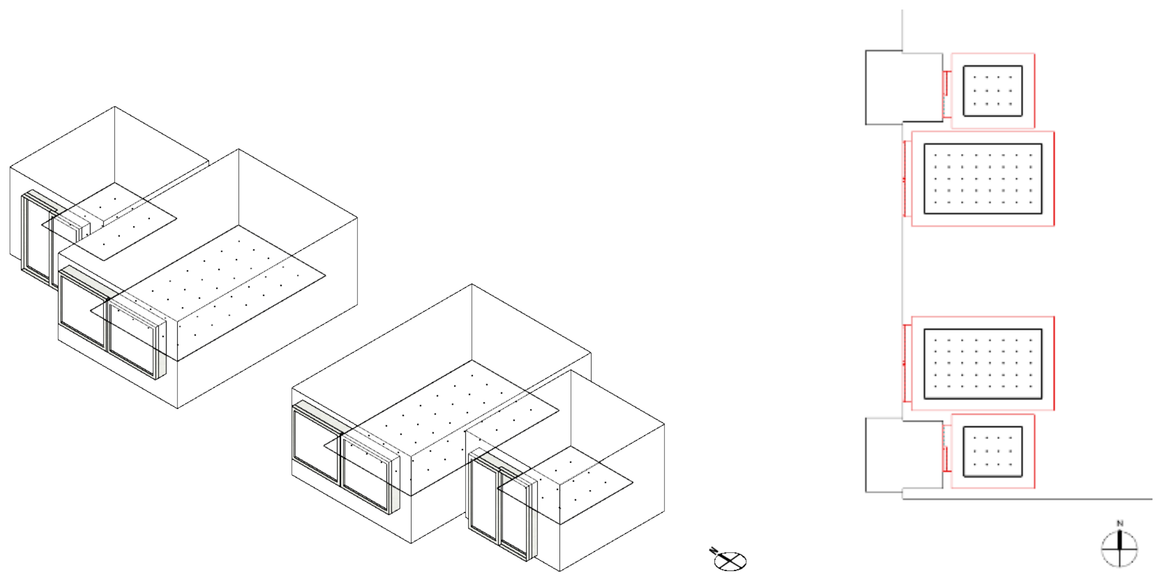


Figure 2.23 Model used in daylighting simulations, representing the current situation

Figure 2.24 shows the two different types of apartment; middle type and end type, included in the simulations. Simulations in the first stage were performed only at the lower level, i.e. the first floor as indicated in Figure 2.24, as this is the most critical level for daylighting. The evaluation of objectives in the first stage is also discussed only for the lower level.

Table 4 and Table 5 shows the input parameters to the simulations.

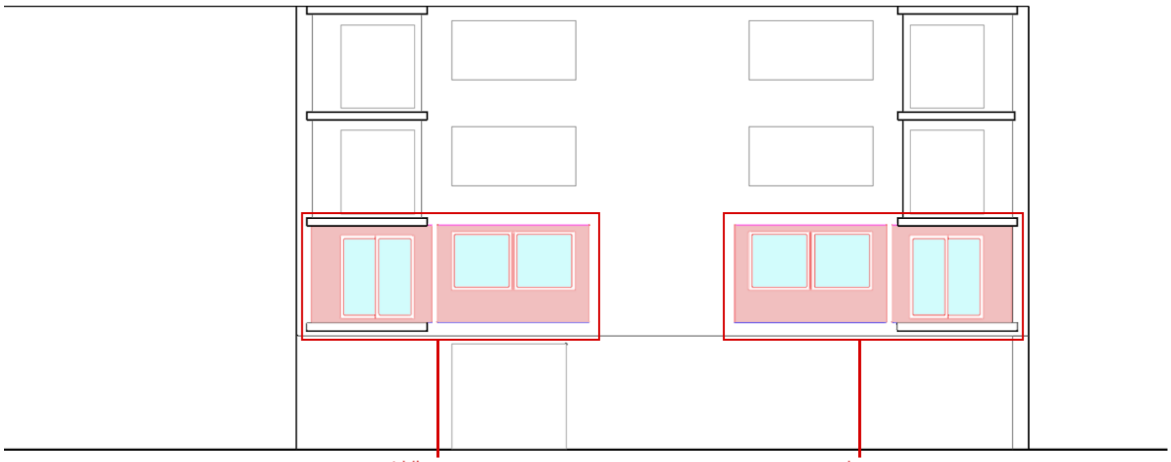


Figure 2.24: Facade schematic showing the difference between the middle and end apartments included in the simulations. Simulations at the first stage were performed for the lower level only, as indicated in the figure.

Table 4 Features and dimensions of the study model of the current situation for daylighting simulations.

Parameters		Unit	Value
Balcony	orientation	Degree	0° N
Balcony extension	depth	m	1.5
Balcony recession	depth	m	1.5
Floor Plate in LR	depth	m	5.8
	width	m	3.8
Floor Plate in kitchen	depth	m	3.37
	width	m	3
Ceiling	height	m	2.4
Glazing in the LR	height	m	1.3
	width	m	2 x 1.37
Glazing in the kitchen	height	m	1.84
	width	m	2 x 0.80
Plinth of glazing in LR	height	m	0.85
Plinth of glazing in kitchen	height	m	0.20
Outer walls	Thickness	m	0.35
WWR	LR	%	64
	kitchen	%	69

Table 5 Material characteristics used of the study model of the current situation for daylighting simulations.

Surfaces	Material	Value	Feature
Ceilings	White Painted Room Ceiling	82.20%	Reflectance
Walls and window frames	Beige Painted wall	68.10%	Reflectance
Floors	Wooden Parquet floor	19.78%	Reflectance
Exteriors (Incl. balconies)	Dirty Exterior Concrete	28.07%	Reflectance
Glazing	Solarban 60 (2) Clear	0.31	SHGC

2.2.5. View Studies

The view out is the other main feature of a window, in addition to daylighting. The view from a window has been found important for people inside when focusing on a task, since it provides visual information about location, time and weather conditions, as well as information about activities and events outside the building. (Lam & Ripman, 1977) Moreover, a view has been found to be desirable due to being aesthetically pleasing, and to ensure psychological restoration and health while indoors. (Matusiak & Klöckner, 2016)

The view preferences of residents can be affected by several factors, often referring to the information contained in the view. While the amount and complexity of information, e.g. a wide view with long sight-lines, has been found to be preferred, preference has also been related to the specific information contained in the view. (Kaplan & Kaplan, 1989; Tuaycharoen, 2006) In the literature, dividing the information in the view into layers has been found to be a useful discretization of the information; the most common way is to divide a view into a sky layer, a landscape layer, and a ground layer, with each layer providing different information. (Markus 1967) This theory finds its place as a recommendation in the building codes such as the European standard EN-17037 (2018) and as a view criteria in certification systems for sustainable built environment such as BREEAM-NOR.

In NS-EN 17037: 2018 Daylight in buildings at least two layers are recommended to be in the view from window. The three layers of view is defined as sky, landscape (urban or nature) and ground (water) (top, middle, bottom).

In this thesis, these recommendations are adopted to evaluate the quality of view, with a focus on the sky layer as that layer has been found to be most important in recently published literature (Kim et al., 2022; Wang et al., 2021)

The method uses the horizontal and vertical viewing angles given by the window glass from a given point of view.

The point of view is from an observer's eye, at a height of 1.65 m, standing at the center point of the kitchen, and standing at the same line in-depth as for the kitchen but at the middle point of the width of the living room, as illustrated in Figure 2.25. Example images of the points of view can be found in Figure 4.2.

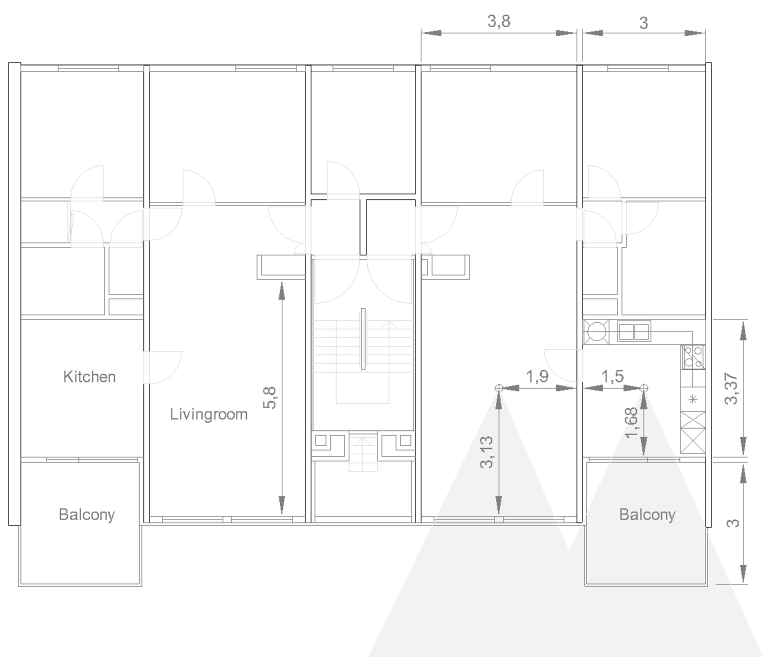


Figure 2.25 Illustration of the points of view and window viewing angles used in the view study

To detect visibility of e.g., the sky layer, a line on the vertical section of a building and the nearest neighborhood from the highest point of the opposite building to the observer's eye can be drawn. It is worth noting that in the view study, the real terrain instead of a flat landscape was used in order to include the landscape slope, as this can significantly impact the view.

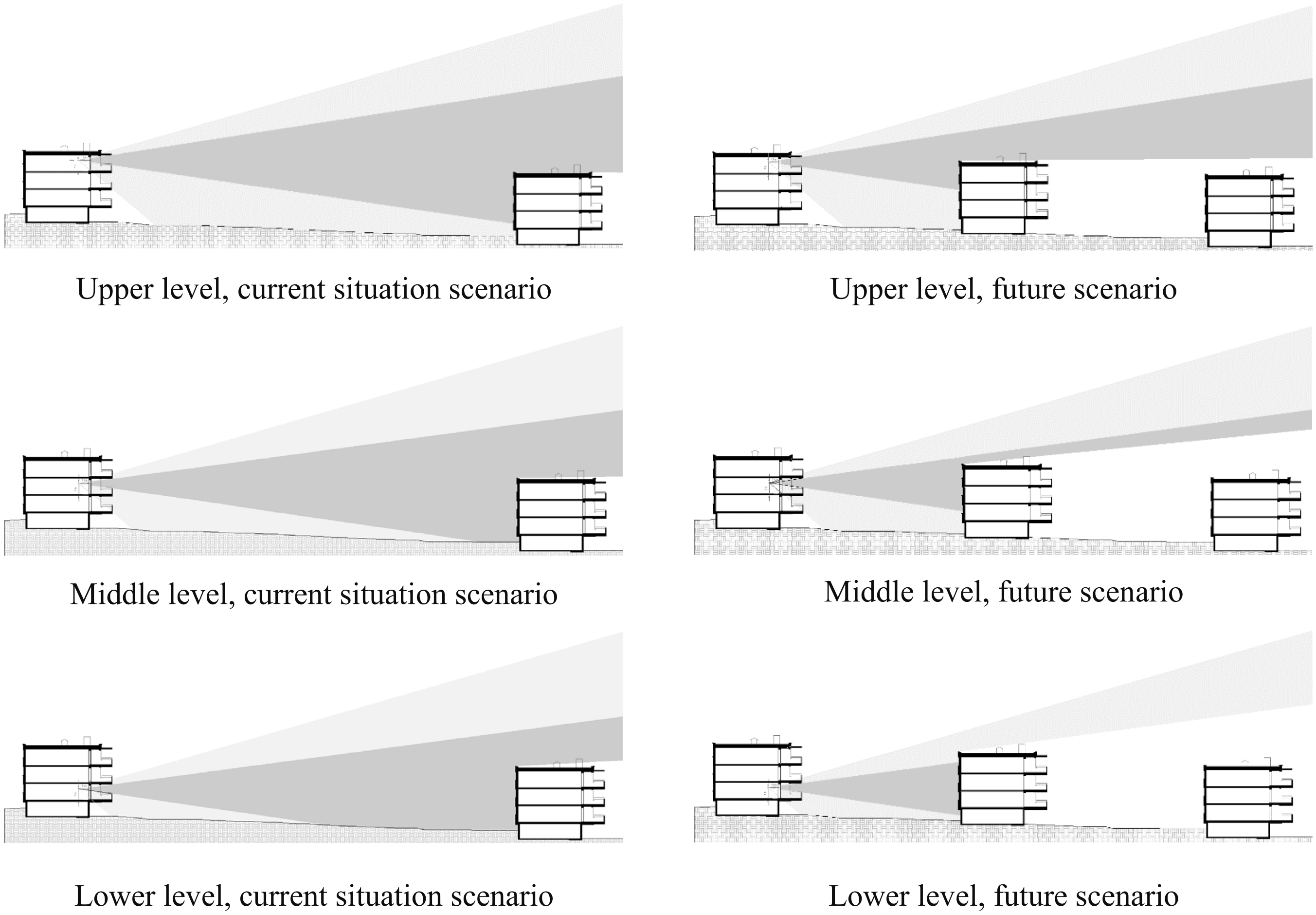


Figure 2.26: Results from view study. Current situation model (left) and future scenario model (right). Top row shows the view from the upper level, middle row shows the view from middle level, and bottom row shows the view from the lower level. The darkest cone shows the view of the scenario, while the brighter cone shows what the view would be without a balcony.

Figure 2.27 Key plan of the sections used in the view study

3. Results

3.1. Daylighting Simulations

A summary of the results from the daylighting simulations for the lower level can be found in Table 6, and for the middle level in Table 7. The numbers in the results tables represents the weighted-by-area average of the respective daylighting indicators for the two areas (living room and kitchen) for each apartment. Detailed results are included in the APPENDIX.

The results are sorted according to whether the daylighting indicators are better or worse than the current situation case. Proposals marked with orange highlights show lower values of daylighting indicators than the current situation model, and were eliminated. Proposals marked with yellow highlights are the best of the second stage daylighting simulations process.

Table 6 Results from daylighting simulations at the lower level. Proposals marked with orange highlights show lower values of daylighting indicators than the current situation model, and were eliminated. Proposals marked with yellow highlights are the best of the second stage daylighting simulations process.

Level	Apt. type	Attached to	balcony type	balcony dimensions width (m)	depth (m)	sDA	direct sunlight access	Avg Lux	case
LOWER	end apt.	kitchen	recessed	3	1.5	40.60%	5.50%	605	current situation
			cantilevered	3	1.5				
			recessed	-	-	64.90%	5.50%	689	proposal 2
			cantilevered	3	1.5				
			recessed	-	-	54.00%	3.70%	603	proposal 4
			cantilevered	3	3				
			recessed	3	1.5	36.90%	0.00%	438	proposal 6
			cantilevered	5.3	1.5				
			recessed	-	-				
			cantilevered	3	1.5				
			recessed	-	-	53.80%	0.00%	561	proposal 13
			cantilevered	3	1.5				
			recessed	3	1.5	37.90%	0.00%	441	Proposal 16
			cantilevered	3	1.5				
			recessed	3	1.5				
			cantilevered	3	1.5				
		K and LR	recessed	-	-	51.60%	0.00%	461	proposal 8
			cantilevered	6.8	1.5				
			recessed	-	-	56.50%	0.00%	507	proposal 9
			cantilevered	6.8	1.5				
			recessed	3	1.5	11.70%	0.00%	322	proposal 10
			cantilevered	3	1.5				
		living room	recessed	3.8	1.5	31.30%	0.00%	406	proposal 1
			cantilevered	3.8	1.5				
			recessed	-	-	81.50%	7.40%	884	proposal 3
			cantilevered	3.8	1.5				
			recessed	-	-	42.10%	0.00%	466	proposal 5
			cantilevered	3.8	3				
			recessed	3.8	1.5	42.10%	0.00%	466	proposal 7
			cantilevered	5.3	1.5				
			recessed	-	-	83.40%	7.40%	883	proposal 11
			cantilevered	3.8	1.5				
			recessed	-	-	87.10%	9.60%	901	proposal 14
			cantilevered	3.8	1.5				
			recessed	3.8	1.5	35.30%	0.00%	420	proposal 15
			cantilevered	3.8	1.5				
	middle apt	kitchen	recessed	3	1.5	40.60%	7.40%	615	current situation
			cantilevered	3	1.5				
			recessed	-	-	62.70%	7.40%	712	proposal 2
			cantilevered	3	1.5				
			recessed	-	-	50.00%	7.40%	667	proposal 4
			cantilevered	3	3				
			recessed	3	1.5	33.30%	7.40%	543	proposal 6
			cantilevered	5.3	1.5				
			recessed	-	-	70.40%	9.60%	844	proposal 11
			cantilevered	3	1.5				
			recessed	-	-	70.40%	7.40%	823	proposal 14
			cantilevered	3	1.5				
			recessed	3	1.5	32.10%	0.00%	415	Proposal 16
			cantilevered	3	1.5				
			recessed	3	1.5				
			cantilevered	3	1.5				
		K and LR	recessed	-	-	47.30%	0.00%	474	proposal 8
			cantilevered	6.8	1.5				
			recessed	-	-	52.80%	0.00%	510	proposal 9
			cantilevered	6.8	1.5				
			recessed	3	1.5	7.00%	0.00%	321	proposal 10
			cantilevered	3	1.5				
		living room	recessed	3.8	1.5	33.50%	2.20%	418	proposal 1
			cantilevered	3.8	1.5				
			recessed	-	-	81.50%	9.60%	897	proposal 3
			cantilevered	3.8	1.5				
			recessed	-	-	42.40%	2.20%	496	proposal 5
			cantilevered	3.8	3				
			recessed	3.8	1.5	42.40%	2.20%	496	proposal 7
			cantilevered	5.3	1.5				
			recessed	-	-				
			cantilevered	3.8	1.5				
			recessed	-	-	67.30%	7.40%	764	proposal 13
			cantilevered	3.8	1.5				
			recessed	3.8	1.5	39.00%	2.20%	453	proposal 15
			cantilevered	3.8	1.5				

Table 7 Results from daylighting simulations at the middle level. Proposals marked with orange highlights show lower values of daylighting indicators than the current situation model, and were eliminated. Proposals marked with yellow highlights are the best of the second stage daylighting simulations process.

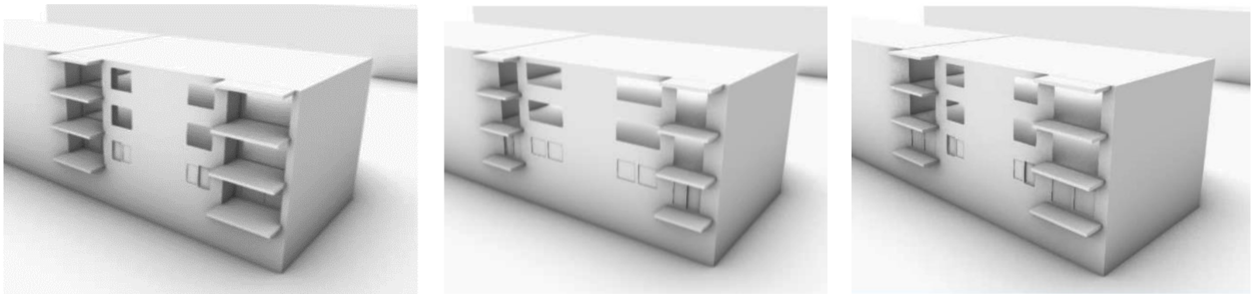
MIDDLE	end apt.	kitchen	recessed	3	1.5	42.50%	5.50%	623	current situation
			cantilevered	3	1.5				
			recessed	3	1.5	44.30%	5.50%	626	proposal 15
			cantilevered	3	1.5				
		living room	recessed	3	1.5	41.70%	0.00%	409	Proposal 16
			cantilevered	3	1.5				
			recessed	3	1.5				
			cantilevered	3	1.5				
			recessed	3	1.5	39.00%	0.00%	418	Proposal 1
			cantilevered	3	1.5				
	middle apt	kitchen	recessed	3	1.5	40.60%	7.40%	634	current situation
			cantilevered	3	1.5				
			recessed	3	1.5	44.30%	7.40%	634	proposal 15
			cantilevered	3	1.5				
		living room	recessed	3	1.5	43.40%	0.00%	427	Proposal 16
			cantilevered	3	1.5				
			recessed	3	1.5	37.20%	2.20%	431	Proposal 1
			cantilevered	3	1.5				

3.2. View

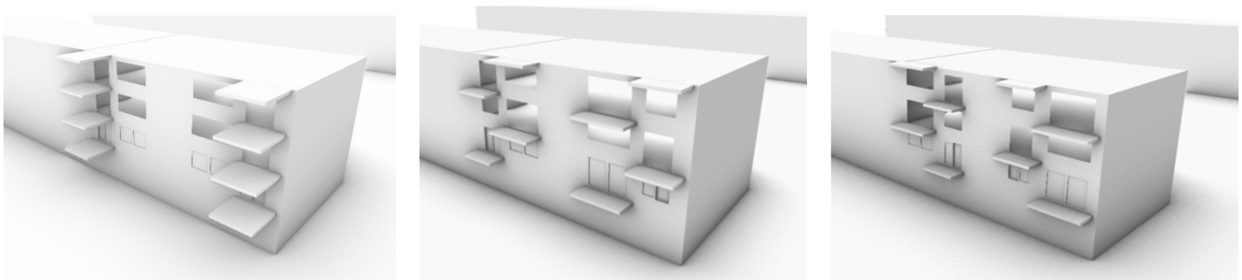
The evaluation of the quality of the view is conducted for only a selection of scenarios which have very similar levels of daylighting and architectural qualities, as a complimentary study

4. Discussion

After running the daylight simulations process, the scenarios with lower values of sDA, ASE, and Avg Lux compared to the current situation were eliminated. The scenarios left after the first elimination are shown in Figure 4.1.



Current situation (left), proposal 2 (center), proposal 3 (right)



proposal 4 (left), proposal 11 (center), proposal 14 (right)

Figure 4.1 Daylighting scenarios left after the first elimination

All the partly recessed balconies were eliminated. This means that the current situation model has the best daylighting indicator values, while also providing flexibility in use (partly sheltered, partly exposed to climatic conditions, providing visual and audible privacy). An interesting aspect of Proposal 4 is that, while it is better for most apartments, for the lower end apartment it is worse than the current situation model, due to lower direct sunlight access and annual mean illuminance. All daylighting indicator values are highest when the balcony is attached to the living room. The scenarios where the balcony is attached to the kitchen for the end apartment is only Proposal 2, which is in the minimum recommended depth of balcony. (Edvardsen et al., 2022) Proposal 4 is kept for architectural reasons, as it is the best of the large-size balconies. The staggered balconies were found to perform better in the view study.

Landscape slope was not included in the daylighting simulations. This may be expected to have some effect on the results, but due to increased computation time and the increased complexity of geometry required to implement it, it was considered to be outside the scope of the thesis.

WWR in the spaces of apartments changes between different scenarios since the glazing attached to the balcony continues down until the floor and the adjacent spaces to the balcony changes between scenarios. However, the closer the glazing surface to the floor the less impact it has on the average illuminance of the space. (Dogan & Park, 2019)

In this thesis, occupied hours refer to 8 AM – 6 PM with daylight saving time (DST), Monday-Sunday for all the daylighting metrics. Even though the time limits for occupied hours in residential buildings are not as defined like office buildings, its use is considered as necessary for this study, since the desirability of daylight outside of those hours and with that low angle are controversial. The second metric used is Annual Sunlight Exposure (ASE), which is generally used to detect glare probabilities, but in this study referred as direct sunlight exposure and is considered a positive factor on occupants' well-being.

Figure 4.2 Images from a current situation middle level end apartment, taken from the points of view described in the methodology

In the case seen in Figure 4.2 the quality of the view would be categorized as high level according to European standard EN-17037 (2018) not only because of the observed number of view layers, 3, but also due to the natural objects in the context. In this example, since it is an end apartment, and aligned with the nearest block in the surrounding, the view is stretching to the horizon which is a feature observed often in high quality views. (Matusiak & Klöckner, 2016) However, the evaluation of the quality of the view in this study does not consider these features since they will differ according to each unit in each scenario.

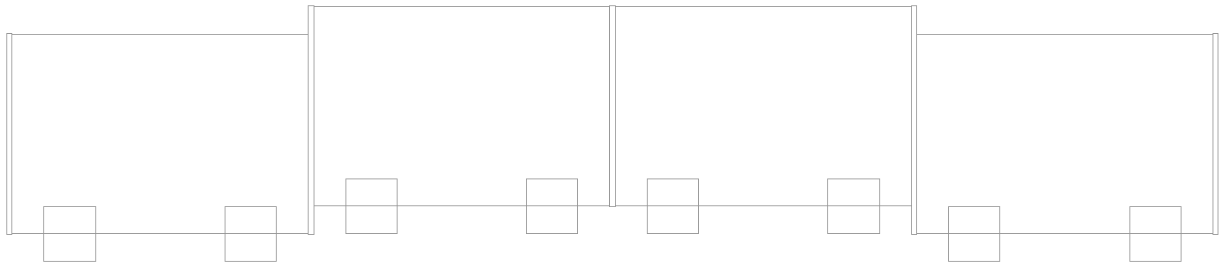


Figure 4.3 Apartment connections in Proposal 10

Proposal 10 tends to propose better connections between apartments, but it failed due to daylighting indicator values, even though it performed good in view studies. It is possible that this proposal could have worked in regard to values of daylighting indicators, if the width of the spaces in the apartments (total facade area of the apartment units) were variable.

5. Conclusion

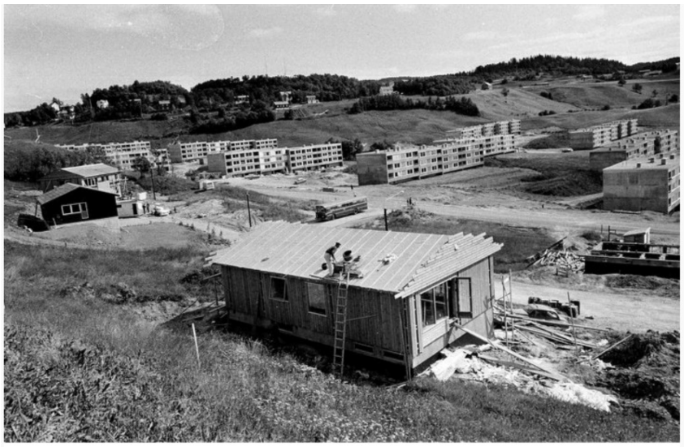
All the partly recessed balconies were eliminated. This means that the current situation model has the best daylighting indicator values, while also providing flexibility in use (partly sheltered, partly exposed to climatic conditions, providing visual and audible privacy). An interesting aspect of Proposal 4 is that, while it is better for most apartments, for the lower end apartment it is worse than the current situation model, due to lower direct sunlight access and annual mean illuminance. All daylighting indicator values are highest when the balcony is attached to the living room. The scenarios where the balcony is attached to the kitchen for the end apartment is only Proposal 2, which is in the minimum recommended depth of balcony

A comparison between the daylighting simulation results of the current situation and several proposed changes eliminated all suggested recessed balconies and most large balconies. Of non-eliminated proposals, balconies attached to the living room performed better than balconies attached to the kitchen. View studies showed that staggering the placement of balconies between levels gives significant improvements to view compared to placement of balconies directly above or below each other.

6. Future work

Since the staggered balconies performed better in the view studies and were among the better ones in the daylighting simulations, larger variants of these types of balconies can be interesting to study further.

In future work, it would be prudent to perform daylighting simulation with landscape slope for comparative purposes.



TRONDHEIM I VEKST 1968: Blokkene på Othilienborg skulle inneholde omtrent 450 leiligheter. Småhusbebyggelsen er også godt i gang, ser vi. Bildet er tatt fra Moholtlia. FOTO: ADRESSAVISENS FOTOARKIV

TRE ETASJERS BLOKKER VAR MER AKSEPTERTE BOLIGER ENN HØYBLOKKER PÅ 1970-TALLET: Det var mulig å følge med smårollingene fra leiligheten. Den første lekeplassen på Othilienborg (bildet) var veldig populær. En stor mangel var imidlertid gjerde mot Omkjøringsveien 20 meter bortenfor, men borettslaget sa nei: Det var ikke moderne med gjerde! Bildet er tatt i 1971.

Figure 6.1 Photos of Othilienborg Borettslag in 1960s. (source: Adresseavisen, adressa.no)

References

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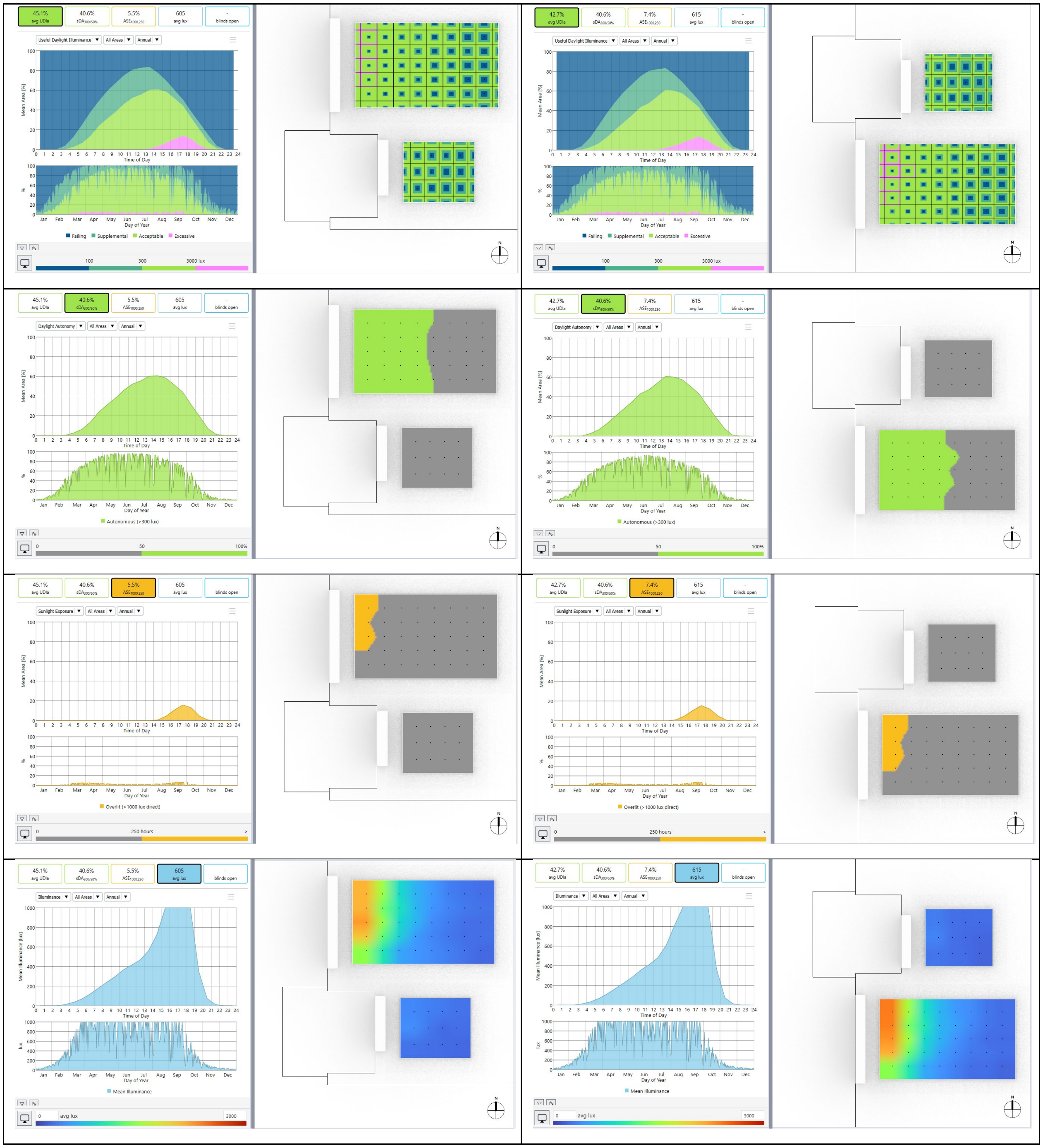
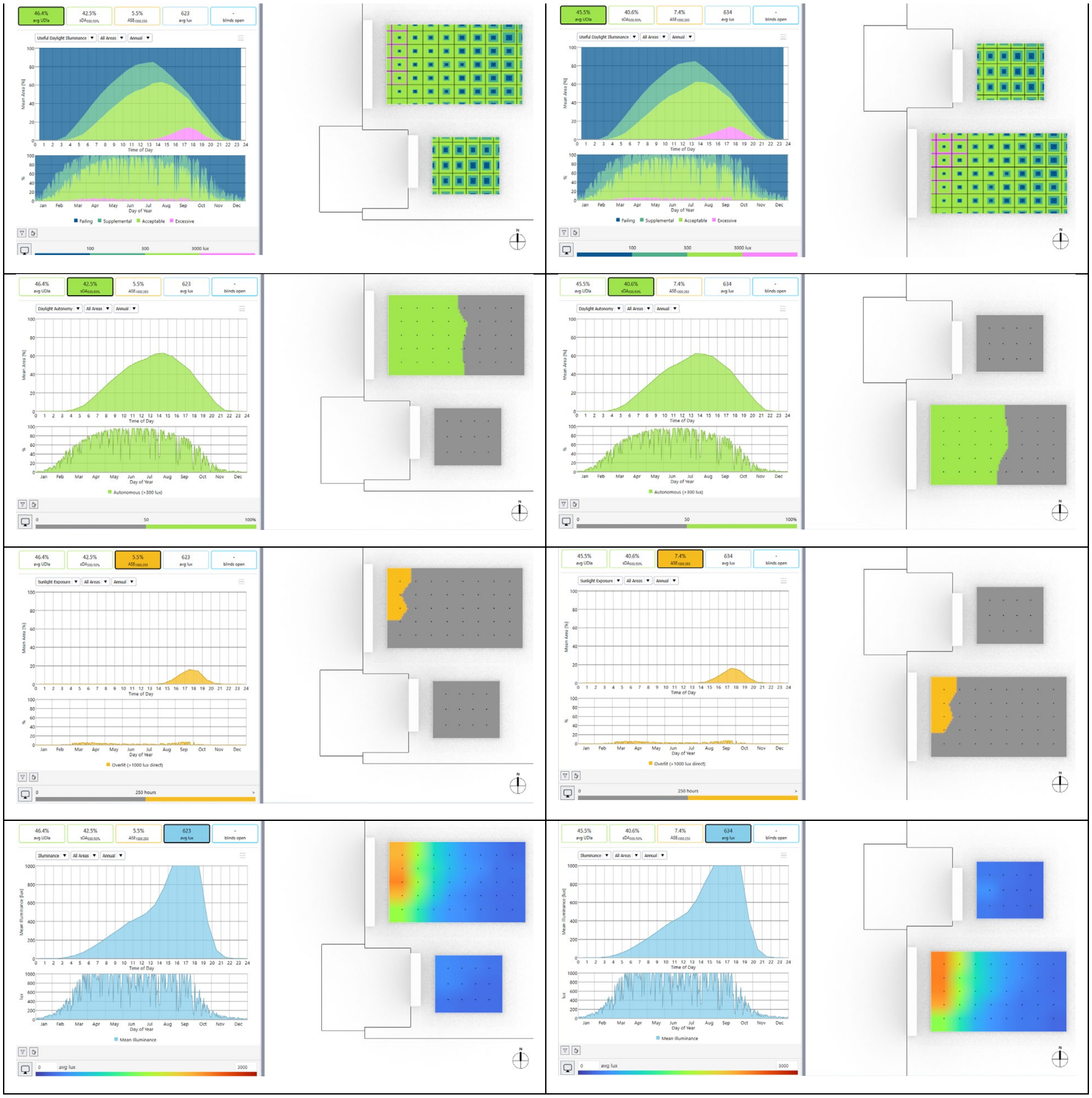
APPENDIX



End apt. (location on the building layout)   Middle apt. (location on the building layout)

Current situation (building layout: mirrored apartments)

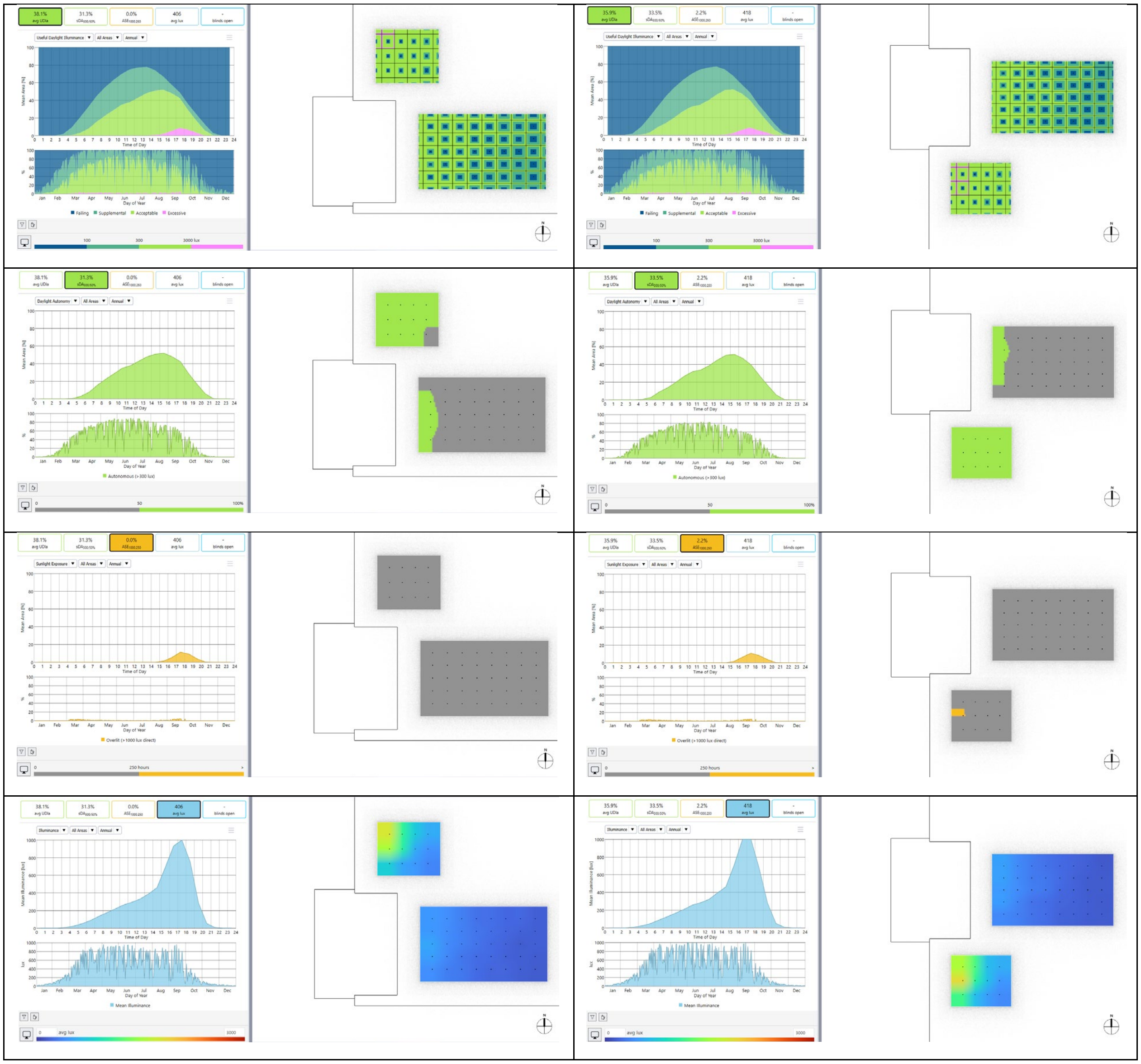
(Lower level)



End apt. (location on the building layout) Middle apt. (location on the building layout)

Current situation (building layout: mirrored apartments)

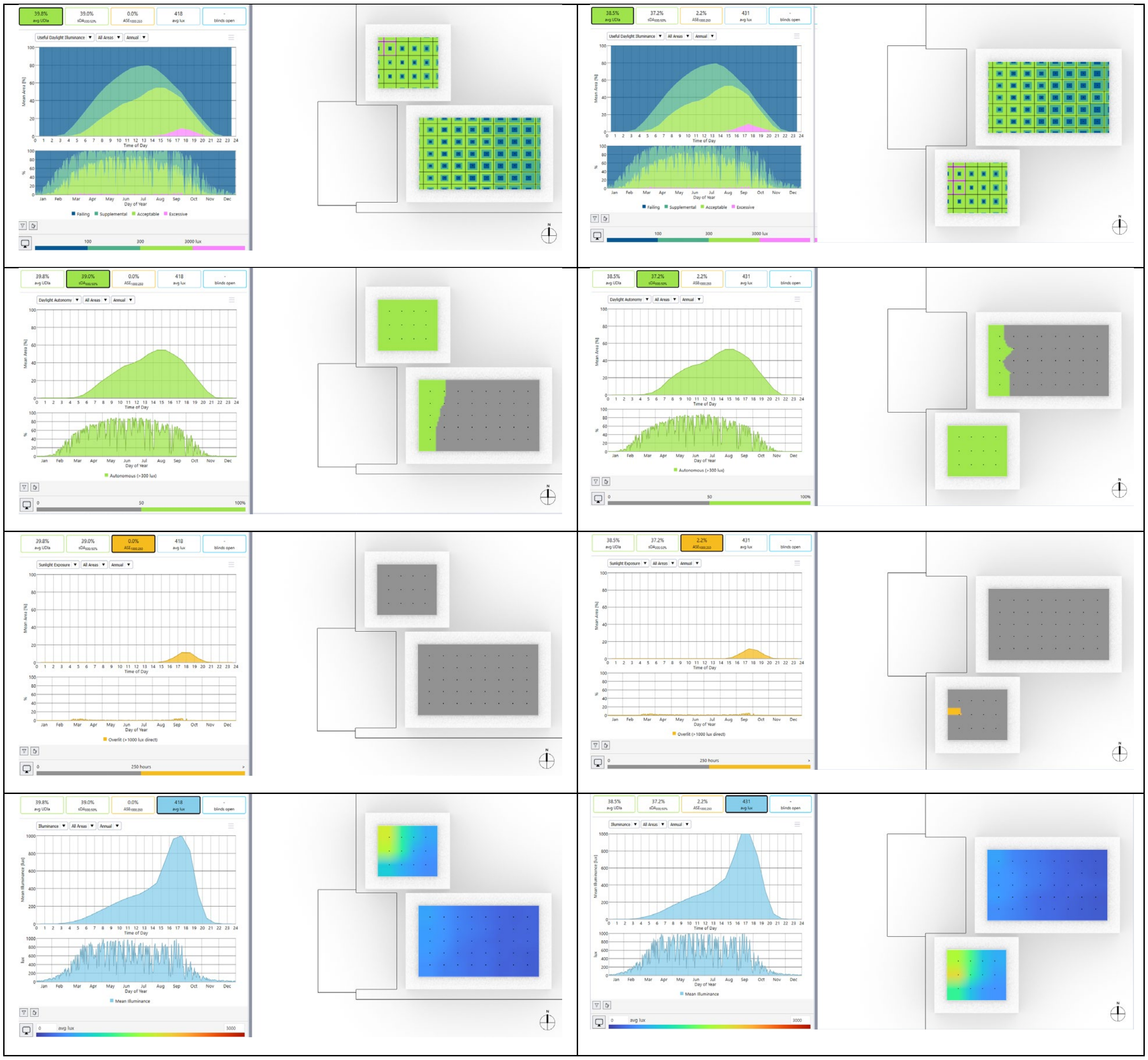
(Middle level)



End apt. (location on the building layout) Middle apt. (location on the building layout)

Proposal 1 (building layout: mirrored apartments)

(Lower level)



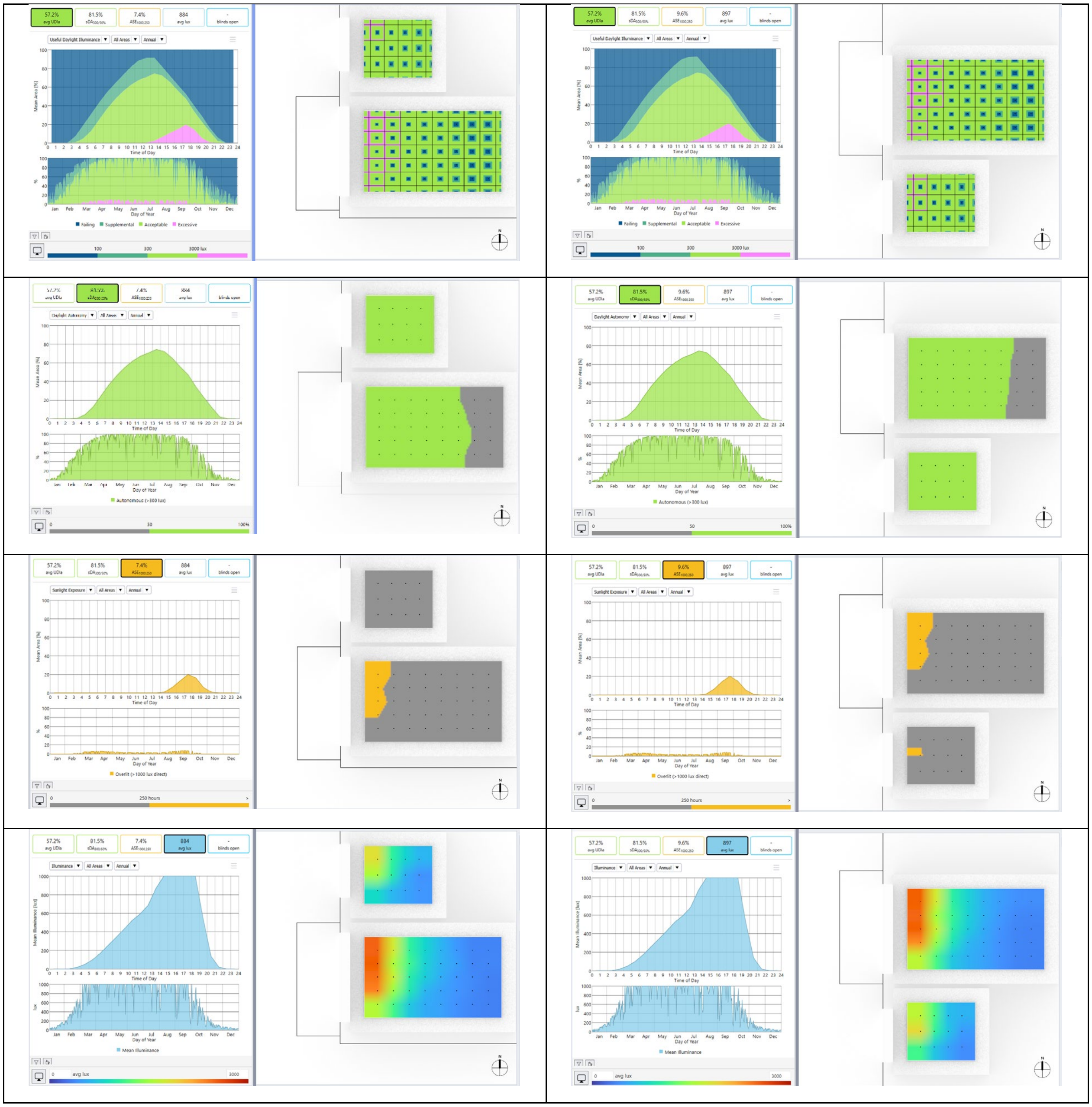
End apt. (location on the building layout)   Middle apt. (location on the building layout)

Proposal 1 (building layout: mirrored apartments)

(Middle level)

End apt. (location on the building layout) Middle apt. (location on the building layout)

Proposal 2 (building layout: mirrored apartments)

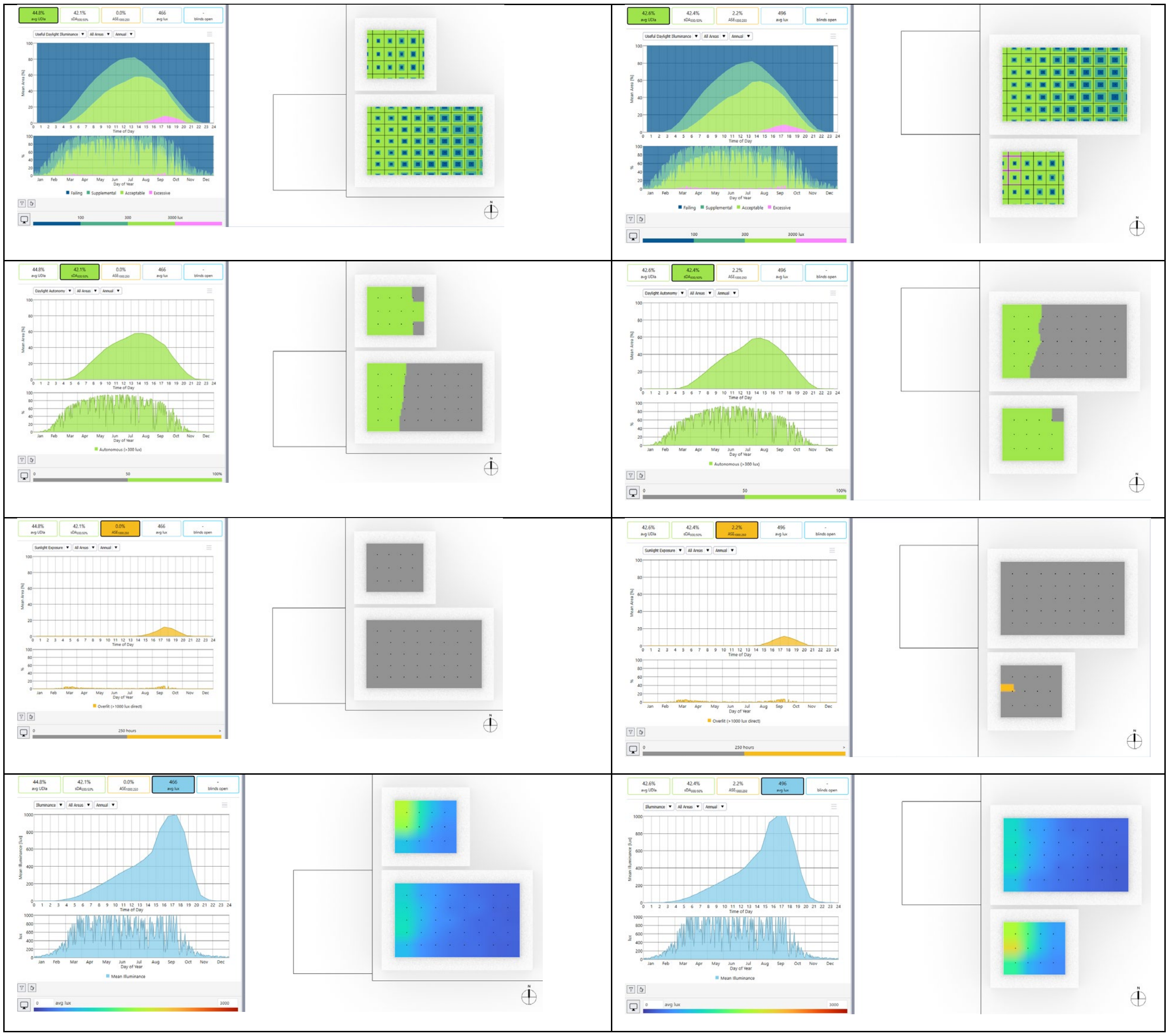


End apt. (location on the building layout)   Middle apt. (location on the building layout)

Proposal 3 (building layout: mirrored apartments)

End apt. (location on the building layout) Middle apt. (location on the building layout)

Proposal 4 (building layout: mirrored apartments)



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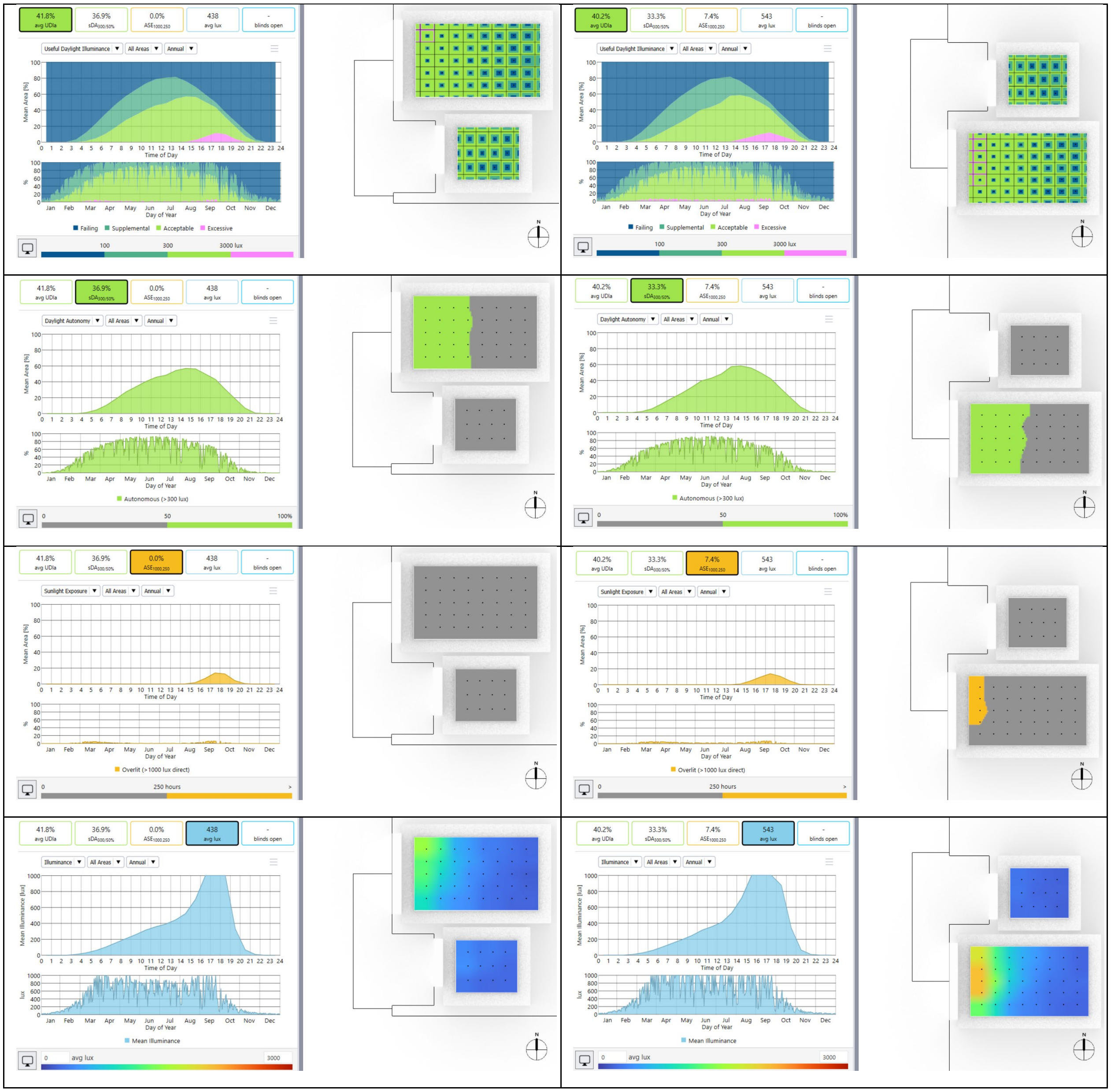
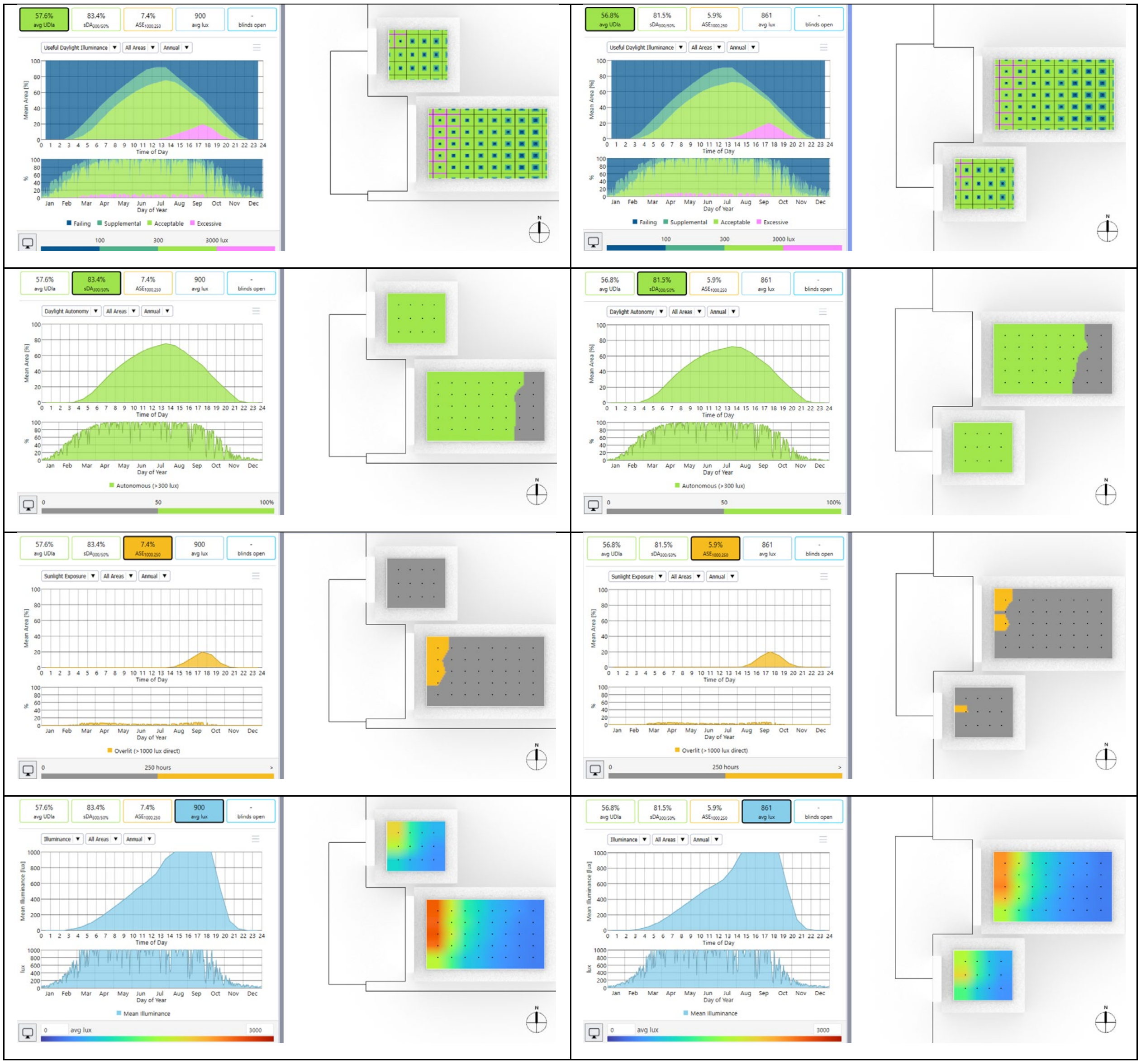
Proposal 5 (building layout: mirrored apartments)



End apt. (location on the building layout)   Middle apt. (location on the building layout)

Proposal 6 (building layout: mirrored apartments)



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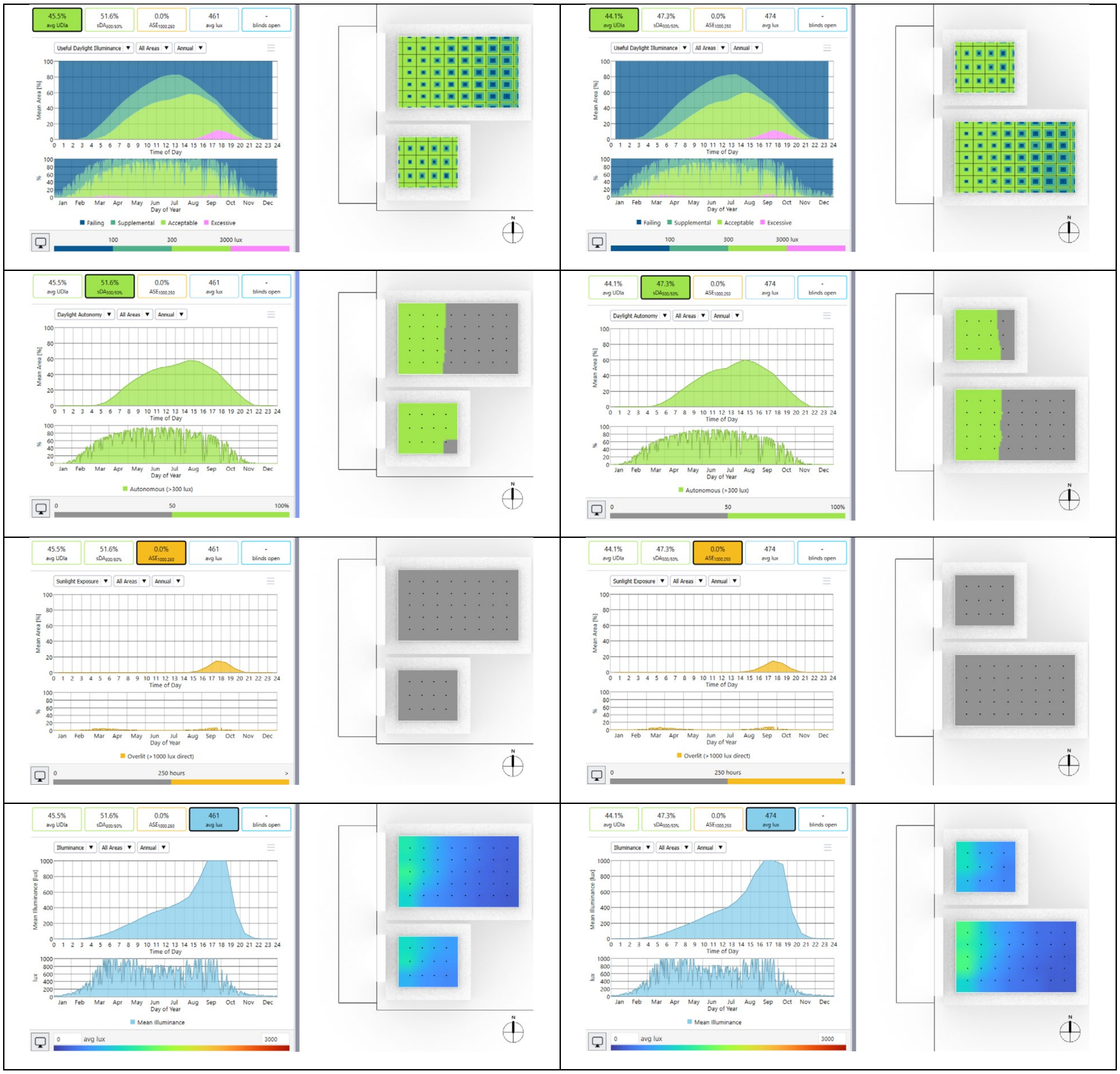
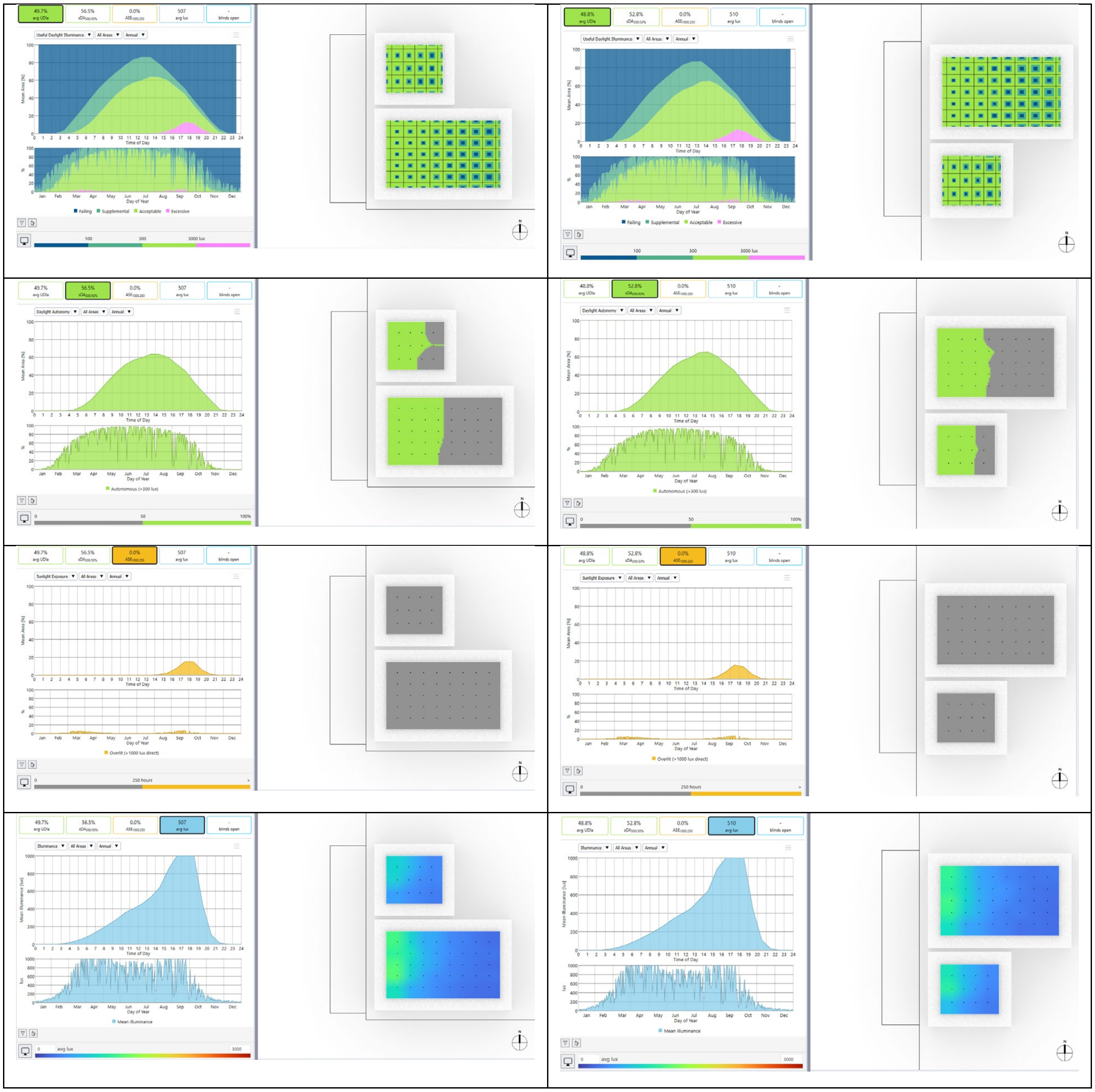
Proposal 7 (building layout: mirrored apartments)



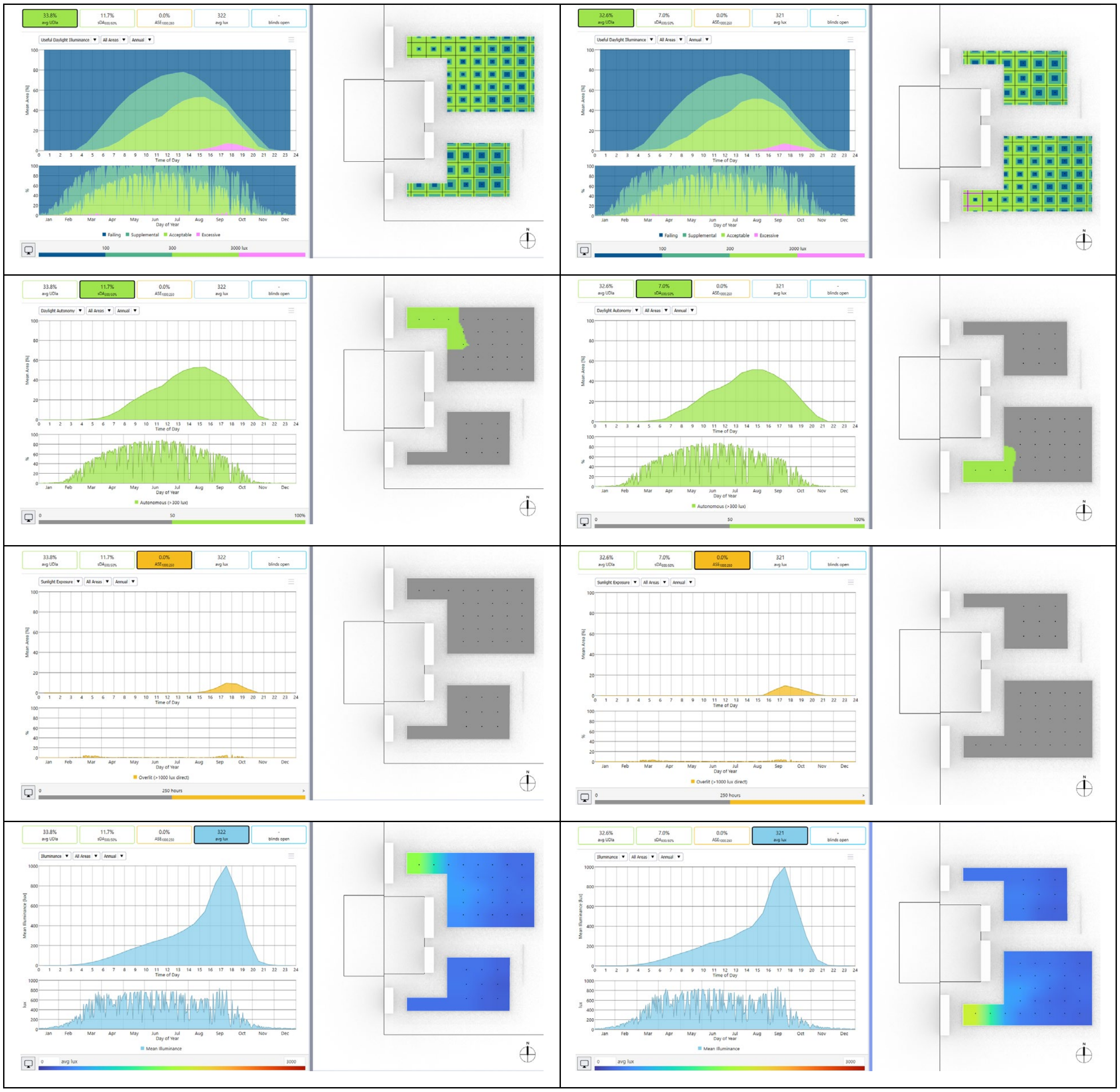
End apt. (location on the building layout) Middle apt. (location on the building layout)

Proposal 8 (building layout: mirrored apartments)



End apt. (location on the building layout) Middle apt. (location on the building layout)

Proposal 9 (building layout: mirrored apartments)



End apt. (location on the building layout) Middle apt. (location on the building layout)

Proposal 10 (building layout: mirrored apartments)

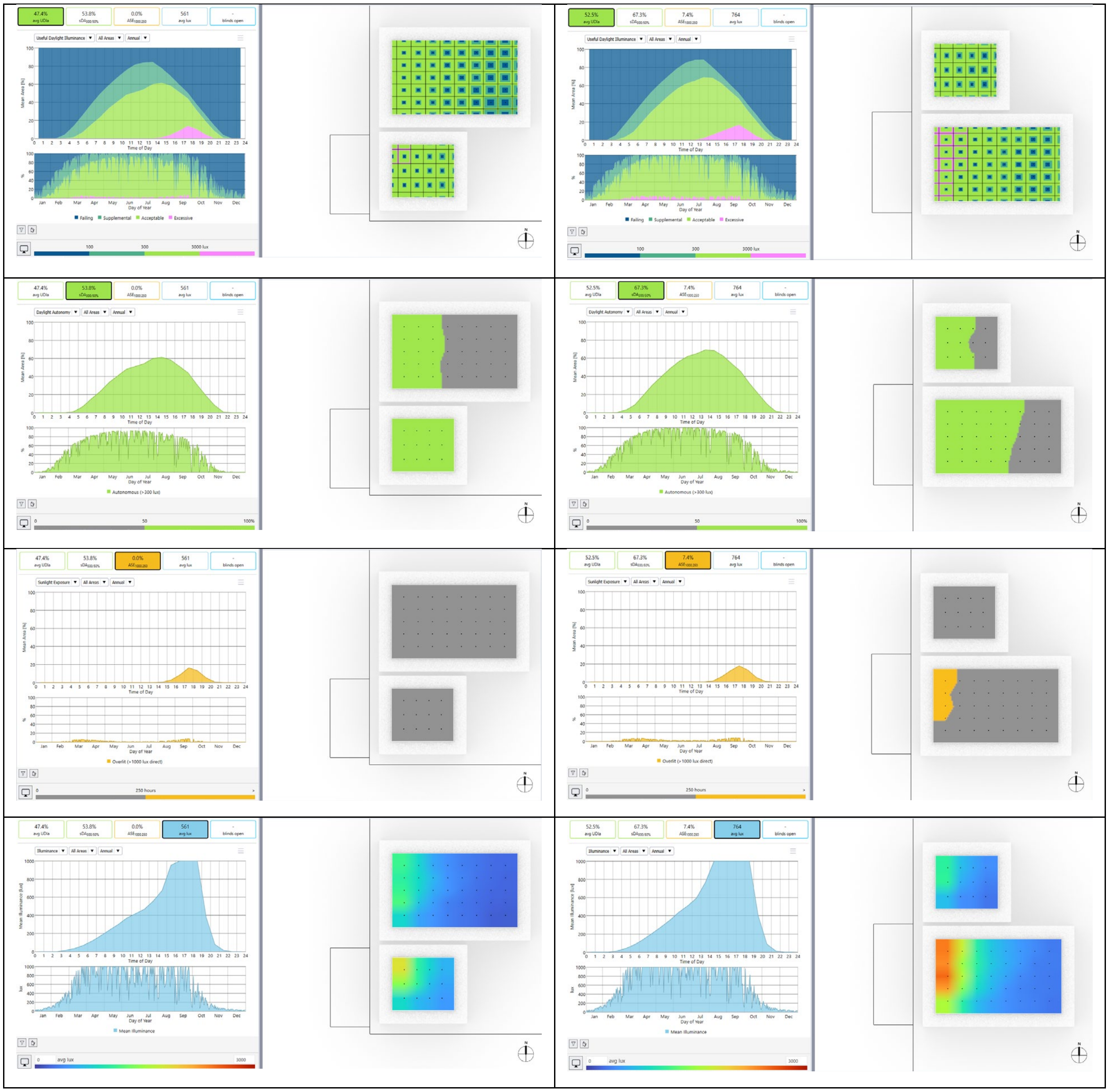
End apt. (location on the building layout)　　Middle apt. (location on the building layout)

Proposal 11 (building layout: mirrored apartments)

End apt. (location on the building layout)

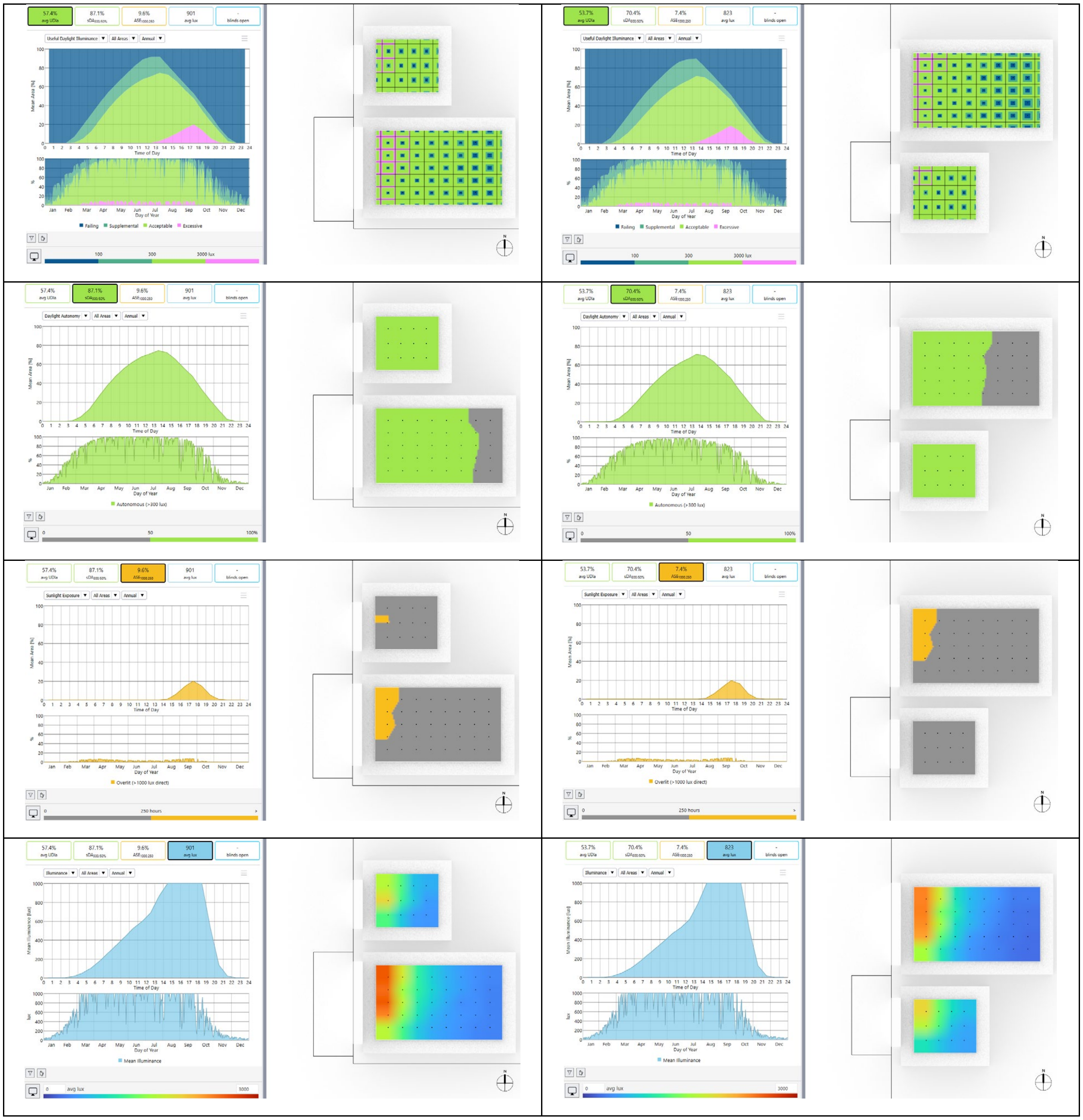
Middle apt. (location on the building layout)

Proposal 12 (building layout: mirrored apartments)



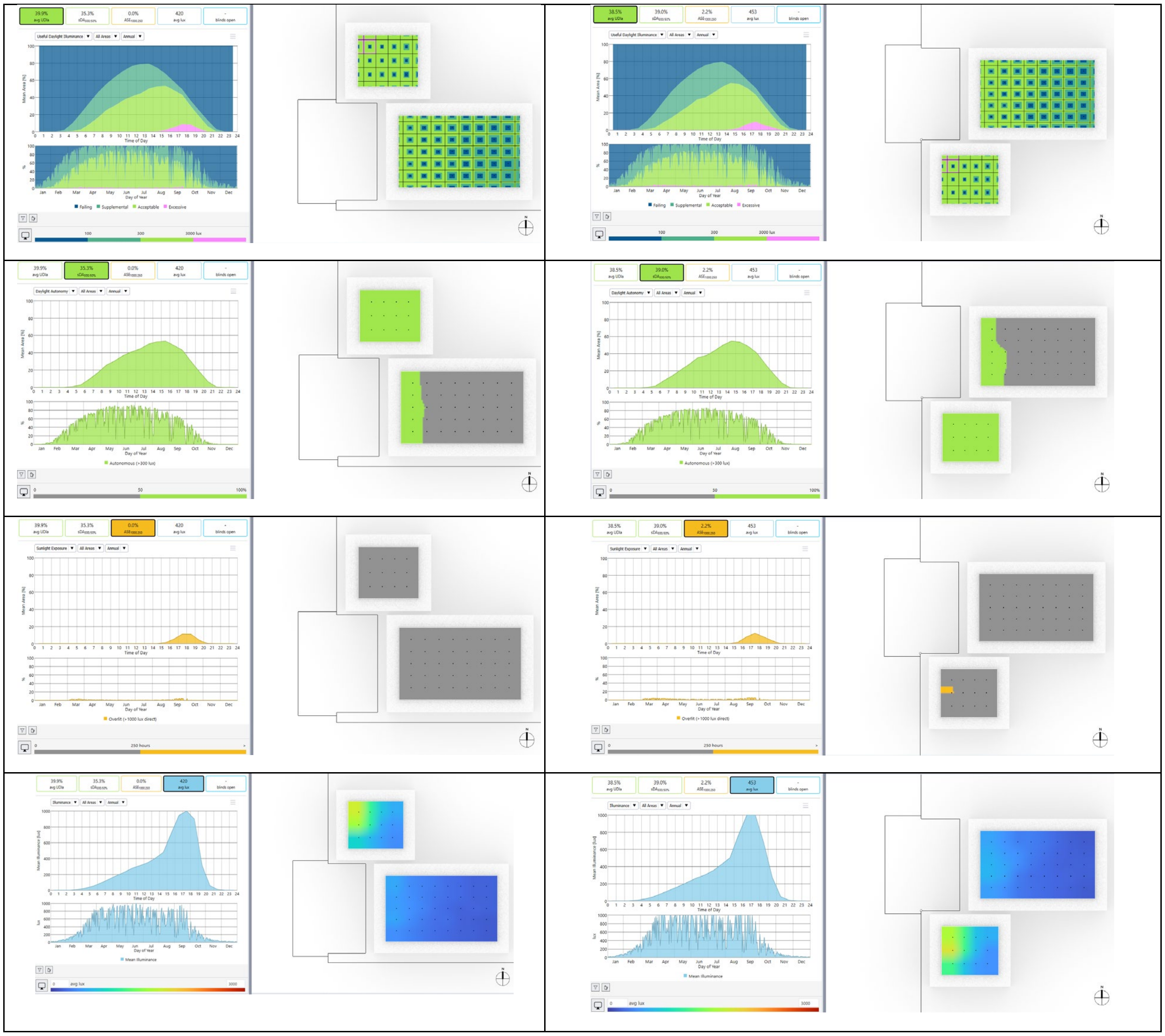
End apt. (location on the building layout)　　Middle apt. (location on the building layout)

Proposal 13 (building layout: mirrored apartments)



End apt. (location on the building layout)   Middle apt. (location on the building layout)

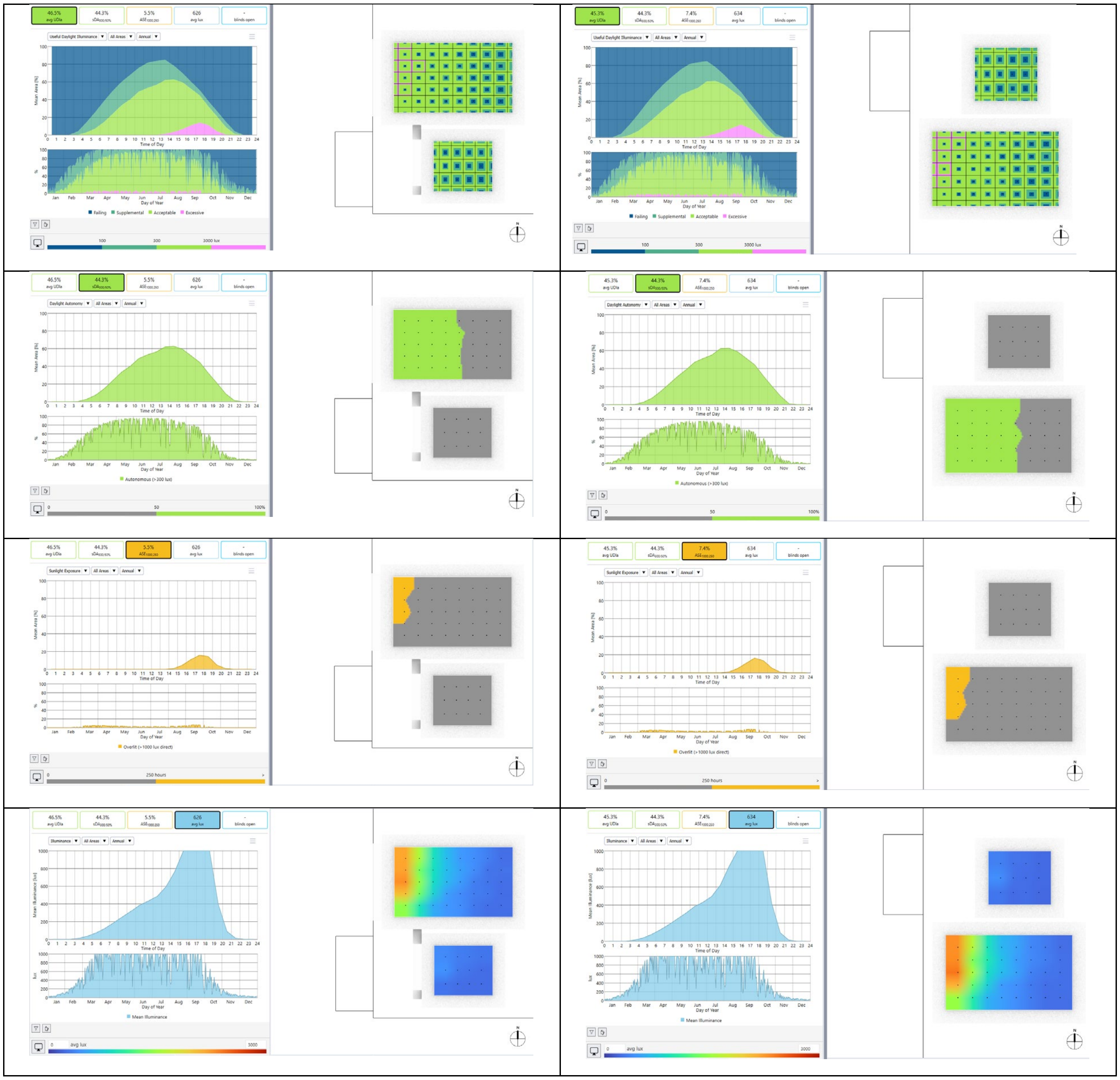
Proposal 14 (building layout: mirrored apartments)



End apt. (location on the building layout)   Middle apt. (location on the building layout)

Proposal 15 (building layout: mirrored apartments)

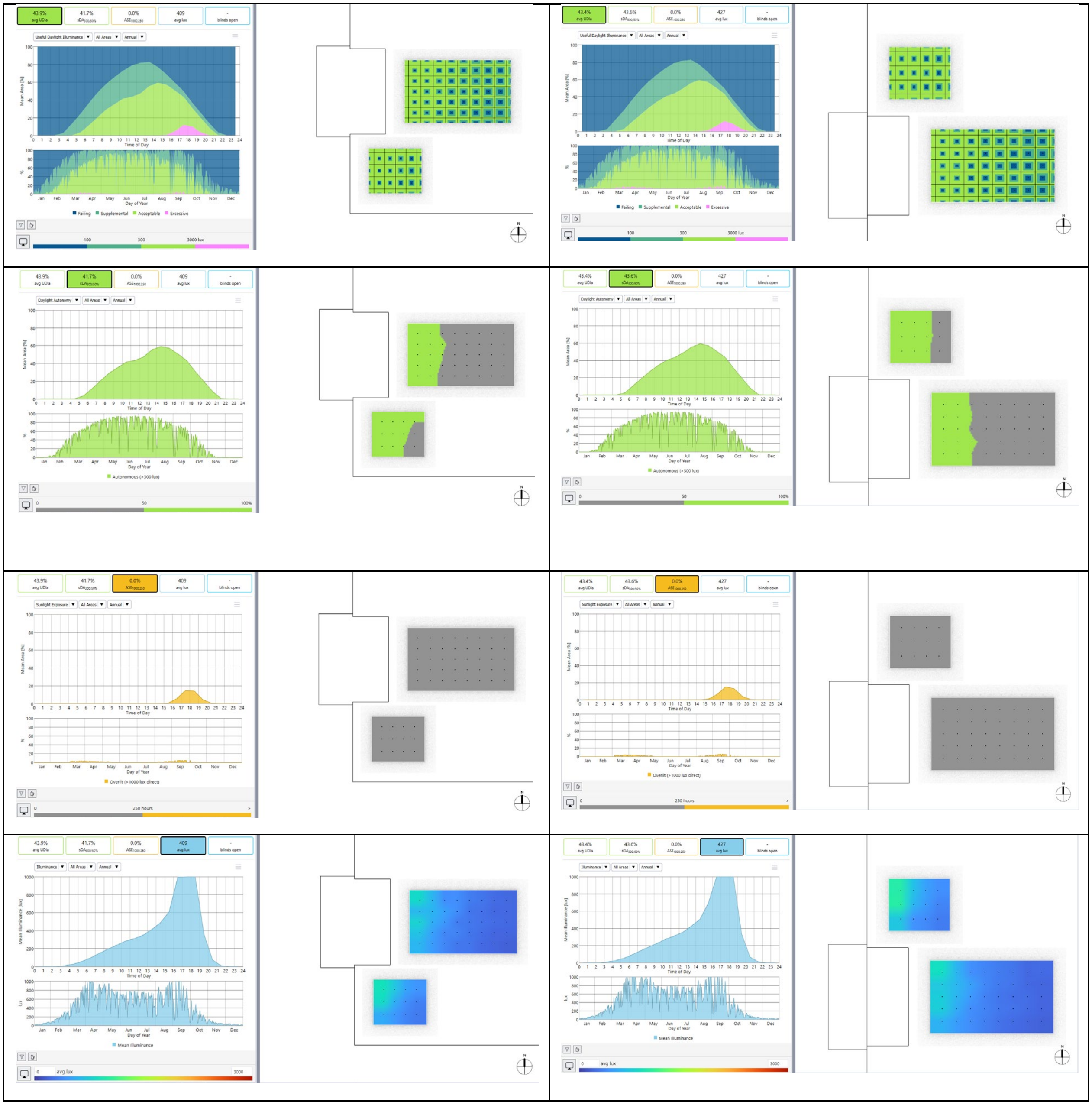
(Lower level)



End apt. (location on the building layout) Middle apt. (location on the building layout)

Proposal 15 (building layout: mirrored apartments)

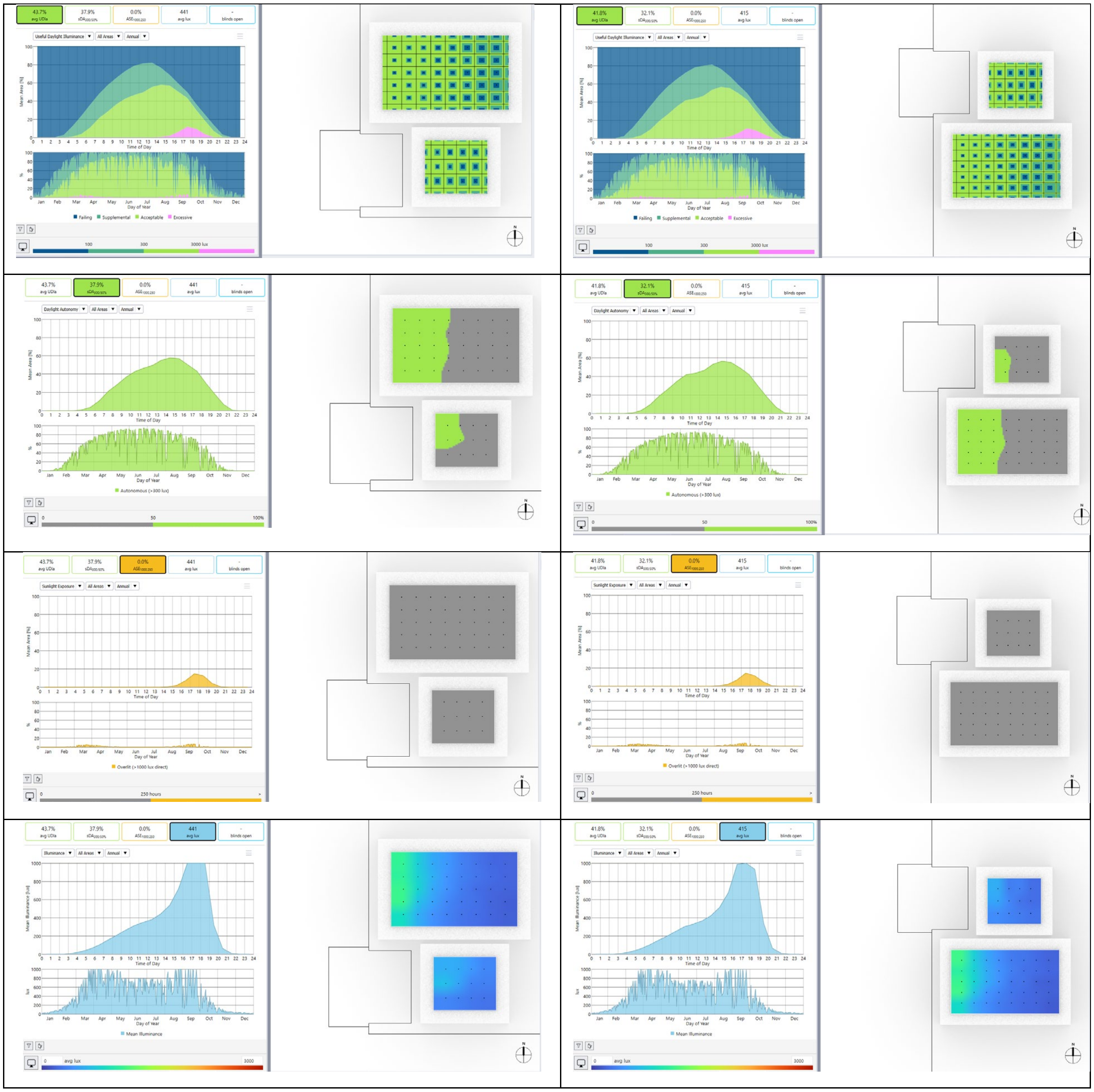
(Middle level)



End apt. (location on the building layout) Middle apt. (location on the building layout)

Proposal 16 (building layout: mirrored apartments)

(Middle level)



End apt. (location on the building layout) Middle apt. (location on the building layout)

Proposal 16 (building layout: mirrored apartments)

(Lower level)

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