Efficient renewable sufficiency

A dense office transformation for resilient affordable housing

Lina Eriksson - Master thesis 2024

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Architecture and Planning Beyond Sustainability

Abstract

Sustainability is discussed within almost every sector today, including architecture. It is widely known that there needs to be a change in how we live and consume resources, and plenty of ongoing efforts reflect this. Renewable energy and increased efficiency to reach net zero carbon or energy are repeatedly mentioned. However, there is rarely talk about change in habits or decreased consumption, even though the first studies on the subject came out over 50 years ago.

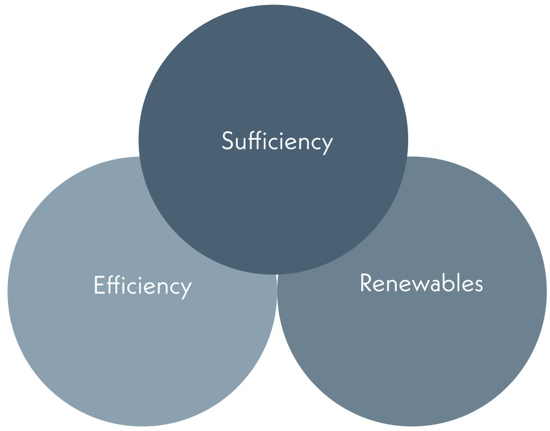
Human emissions are, despite ongoing efforts, growing rapidly. Even with the technological development and green solutions emerging in many sectors, the improvements are devoured by the growing consumption. Buildings are a huge contributor to this situation, being a large polluter throughout their lifespan.

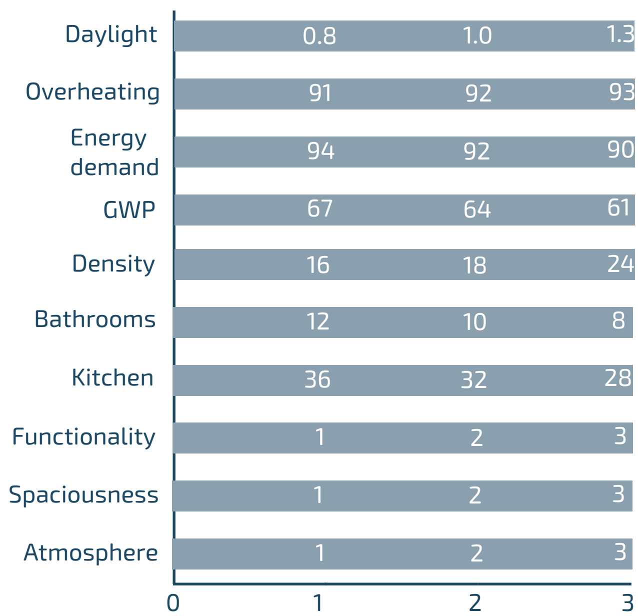
Efficiency and renewables through technology and sustainable resources can only partly meet the need for reduced demand. With rebounds, limits and the need for complete net-zero, sufficiency in consumption is crucial for lowering the impact of the use of goods and services. For buildings, sufficiency means density, flexibility in design, co-use of spaces and appliances, and repurposing old buildings, combined with efficiency in ventilation, conditioning and lighting, all achieved with sustainable materials and renewable energy.

This project transforms an office building in Gothenburg to accessible, affordable housing with a low environmental footprint through the implementation of these interventions. This is achieved through case studies, an iterative design process with testing and evaluation, and finally optimising a design regarding construction, efficiency, and renewables. This results in a low-impact co-living solution emphasising sufficiency in shared design, achieved in combination with efficient technology and renewable solutions.

The project shows that through adaptive reuse of empty offices, dense affordable housing while maintaining design quality is possible by combining the three concepts. Furthermore, the thesis explores and reflects upon challenges within transformation, and the different ways to implement sufficiency in design.

Keywords: sufficiency, efficiency, renewables, transformation, housing





Student background

Sustainability is crucial in every aspect of life to minimise climate change, including architecture. Sustainability is a big topic in society today, but in my opinion, there is a lot of greenwashing and cherry-picking. There needs to be a holistic view of sustainability, not only working with the convenient parts. It has been known for a long time that we must change how we live; we can't keep treating resources as never-ending. Instead, we need to work with what already exists, making transformation an essential part of architecture.

Housing has a growing impact due to more area per capita, while at the same time, there is an ongoing housing crisis, and inequalities within economy and housing are only growing. Therefore, I explore how to bring together multiple aspects of sustainability to improve the overall footprint, while transforming offices into inclusive housing.

For a building to be truly sustainable, we need to include all aspects of sustainability.

Architecture and Engineering, Chalmers, Bachelor degree in 2020

Architecture and Planning Beyond Sustainability, MPDSD, Chalmers Master's program (2021- 2024)

- Master's thesis preparation:
  Academic approaches and general structure
- Master's thesis preparation:
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- Sustainable transformation of a derelict industrial building

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- Green Building Design A
- Restoration and integrated conservation A
- Knowledge and heritage active preservation
- Parametric and algorithmic modelling
- Energy transition & Low-carbon architecture
- Environmental History of Architecture

Industrial ecology, MPTSE, Chalmers Master Program (2022-2024)

Internship
Year in Industry intern, Sustainability & Building Physics, Buro Happold, London (2020-2021)

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And finally, my family for all the unconditional love and support I always get from home.

Content

Introduction

Problem statement

Climate change is one of the biggest issues in human history, with a monumental impact on the planet. Currently, Earth's mean temperature has risen by 1,1°C compared to the 1800s (United Nations [UN], n.d.-a). To change this, world leaders have formed multiple climate agreements. The goal of the latest one, the 2015 Paris Agreement, is to keep global warming at a maximum of 1,5°C. This target requires a 45 % emission reduction by 2030 and net-zero emissions by 2050. Many commitments are made, however, with the current pace, global emissions will increase by 11% by 2030 based on national plans (UN, n.d.-a).

The building and construction sector are extensive contributors to energy demand and emissions from resource and energy consumption. Globally, according to the Intergovernmental Panel on Climate Change [IPCC](Cabeza et al., 2022), in 2019, buildings were responsible for 31% of energy use, 21% of GHG emissions, and 31% of CO2 emissions. Out of this, residential energy use contributed 50%, energy use in non-residential buildings 32%, and embodied emissions 18%. Since 1990, building CO_2- emissions have grown by 50%, with indirect emissions rising by 92%. Hence, a big part of climate change can be attributed to buildings (Cabeza et al., 2022).

A recent development in cities in general and Gothenburg in particular is the addition of luxury condos, skyscrapers, and high-rise office buildings. There is increasing wealth in construction directed towards exploiters, resulting in expensive housing, less green spaces, and denser cities. At the same time as Gothenburg is building new high-rise office buildings, around 10% of the existing offices are empty (Bahlenberg, 2023).

Therefore, a reasonable action for Gothenburg as a city would be transforming a share of the empty offices into low-cost housing. Changing the building functions could help everyone, partly because the offices would no longer be a vacant waste of resources, while simultaneously helping develop the city when more people can have a stable life and stay in Gothenburg. A transformation benefits city development and would decrease the environmental footprint of the city overall, helping us all reach our climate goals in an environmentally, economically, and socially sustainable way.

Purpose

The main focus of this thesis is the use of and interaction between sufficiency, efficiency, and renewables and to explore how these can be combined to achieve a low carbon footprint and more inclusive housing market. Cutting consumption first and later meeting remaining needs most efficiently reduces impacts and costs in the best way.

The thesis addresses sustainable development socially, economically, and environmentally by dealing with reduced carbon footprint and affordable housing. Lowering the energy consumption and resource use during the whole lifetime of the building is both economically and ecologically sustainable. Meeting the remaining energy demand using renewables will further strengthen this, while accessibility and affordable housing will help create a more inclusive housing market, also addressing social sustainability.

This is mainly done on a building and apartment scale, combining space design with technology, using density, flexibility, bioclimatic, passive & net-zero design strategies, efficiency in systems and appliances, and recyclable, sustainable materials and energy. These subconcepts of sufficiency, efficiency, and renewables are applied during a transformation of an office building to achieve green affordable housing for the people needing it the most. Incorporating these concepts and transforming the building to low impact requires careful design of spaces and functionality.

Applying the concepts during the transformation of a building can create an example of how to transform buildings to handle urgent issues on a larger scale, enabling new life for unused spaces. If they can be preserved and even turned affordable, there is no reason to leave them empty or tear them down.

Aim and research questions

This project aims to reduce both the operational and embodied carbon of a residential building through the use of design and reduced consumption (sufficiency), technology (efficiency), and sustainable materials and energy (renewables) to achieve resilient affordable housing. The goal is to show that low-footprint housing can be for everyone, achieved through the adaptive reuse of an existing office building into housing for people with challenging economic circumstances.

Simultaneously, the thesis investigates the difficulties in transforming offices into high-quality housing through theory and design.
Furthermore, using the concept of density and designing smaller spaces, this project aims to explore small space design and various ways of implementing sufficiency in design.

The ambition is to show that there are multiple ways to improve the environmental footprint of buildings, but efficiency and renewables cannot solve the situation alone.

The thesis aims to answer the following research question and subquestions:

How can the concepts of sufficiency, efficiency and renewables be applied in transformation of an existing office building to achieve resilient affordable housing?

Subquestions

What are the main challenges with transforming existing offices into housing?

How can sufficiency in buildings be achieved in a Swedish context in relation to the Swedish Standard?

Method

The methods for this thesis include research on design, research for design, and research by design. Research for design was performed through literature studies of concepts and criteria, site and building analysis, and project references for inspiration. Research on design included case studies and testing designs using various evaluation criteria from the literature study. Research by design occurred mainly through iterations of drawings, 3D modelling, and evaluation testing.

First, literature studies were performed to position the thesis in the current debate and define the link between research and design by defining concepts for project application and criteria to use for design evaluation. Following the literature research, site and building analysis was performed to analyse the local context, the physical qualities of the building, and the feeling of the area. Lastly, to conclude the research for design, project references, case studies, and examples were used to find inspiration for solutions in design and for possible design elements to include.

During the design phase, the concepts defined from the literature were implemented through research by design. Each floorplan option processed different ways to implement the design concepts extracted from research. These were later assessed using the evaluation criteria, combining research by design and research for design to choose the best design option. Furthermore, research by design has also been used during the analysis of the existing building as a 3D model has been created in ArchiCAD and used to concatenate and understand the design and construction. Finally, research for design has been applied through optimisation of construction and shading for the final design proposal.

Several Grasshopper (Rhinoceros) plugins have been used to evaluate the design, specifically CAALA, Honeybee, Radiance, EnergyPlus, and Ladybug. These are described further under the evaluation criteria in the Background chapter of this thesis. The framework used for qualitative design evaluation is called MAB, Manual for Analysis of Housing Qualities.

Delimitations

Several limitations are applied to make this project feasible. Firstly, the concepts apply to the chosen building, not society or the housing sector as a whole. Political and planning processes, such as changes in development plans, are excluded, as the project focuses more on application on the building itself.

The concepts are applied to a transformation project, where only the building before transformation and not the current, newly renovated design is considered. Only interventions applicable to the specific building are included. Furthermore, the passive solutions applied are chosen for the Swedish temperate climate.

The project implementation will focus on the building only, not surrounding spaces, although a context analysis is made for possible uses of the bottom floor and transport, services, etcetera. This thesis also only includes work with the outdoor spaces within the building, for example balconies. Furthermore, the focus lies on the transformation from offices to housing, which means that building elements not affected by the change will remain untouched outside of necessary construction changes, such as extra insulation. This includes the roof, ground, and load-bearing pillars.

Sufficiency is considered mainly within housing, but also, as the target audience of this project is people who are likely in need of public transportation, mobility is included. The project does not consider sufficiency in food, self-sufficiency, or sufficiency on a political level. The focus lies more on the current debate, the relationships between the concepts, and how these can be applied to architecture.

Affordable housing is considered through economic aspects of transformation and design choices impacting the cost, not calculating numbers or cost per sqm. Measuring costs within a transformation project is challenging, and furthermore, it would make the scope of this thesis too big. Instead, the economic aspects of this report focus on design and transformation choices impacting the project economy.

Reading instructions

This thesis is divided into seven main chapters.

First, a background chapter explains the concepts, how they are viewed within the industry, and the combination between them. This is followed by a part about why and how the design evaluation is performed. The chapter ends with a summary of the terms and concepts extracted from the theory. This is followed by the Existing building chapter, giving a context to the site and analysing the existing building and its construction. Drawings and pictures highlight the main characteristics of each building part. This chapter is followed by Case studies, where references serving as inspiration for the project are presented.

The design study in this project starts in the chapter Early Design Process. This chapter presents the design concepts and strategies that have been explored through floorplan design. The design evaluation is presented using a comparison matrix for each option. The chapter ends with a reflection of the results and the choice of a design for further refining. This chosen design is further processed with regard to shading and daylight in the chapter Design Optimisation. The construction is tested and optimised regarding insulation and materials. The design chapters are finished with the Technology applications, where efficiency and renewables concepts are applied to the chosen and optimised design.

The final design proposal chapter presents the resulting design and shows the final evaluation results. The report is finished with a discussion and conclusion, where several aspects of the theory, concepts, and design project are discussed, the process is reflected on, and the research questions are answered.

Background

Theory

Within the sustainable development community, there are three main strategies; efficiency, sufficiency, and consistency, although consistency is also often called renewables. These concepts aim to reduce consumption and the resulting footprint, although they are generally described and applied differently, with disagreements on how to reduce the environmental footprint of societies (Fischer et al., 2023). There is a common understanding that these are the only three ways forward, but how to use and combine them is widely debated (Jungell-Michelsson & Heikkurinen, 2022).

Efficiency is broadly established in society today, generally defined as reducing the energy and material needed to produce or use a good or service. This means improving impact through technology, focusing on reducing the energy and resource amount used per unit of product or service, such as less fuel consumption per driven km for a vehicle or less kWh use per sqm. Efficiency does not require lifestyle changes and has the potential to cut plenty of costs, both economic and ecological (Hedenus et al., 2018).

However, there are disagreements about limits and rebound effects. With increasing efficiency, consumption tends to rise. For example, if you own a car requiring less fuel, driving the vehicle is cheaper, and you will likely use it more. Efficiency improvements lead to lower energy use and costs, but a large share is lost due to increased expenditure, causing the total savings to be comparatively small (Hedenus et al., 2018). Furthermore, critics claim that efficiency cannot meet the 1.5°C target alone, as the goal is net-zero, and efficiency reductions can only partly decrease demand (Lorek & Spangenberg, 2019a).

Sufficiency is a less established concept, lacking clear consensus and definition in the sustainable development community (Jungell-Michelsson & Heikkurinen, 2022, Fischer & Grießhammer, 2013). Generally, it refers to reducing consumption through changing consumption habits and decreasing demand for energy and resources (Fischer & Grießhammer, 2013). Sufficiency means concentrating on changes in lifestyle and behaviour necessary to reduce the need for a service or good. For instance, measures can be lowered indoor temperature, less living area, and shorter distance driven (Hedenus et al., 2018).

Sufficiency is a transdisciplinary concept, with possible application on various societal levels and sectors and multiple possible ways of execution. Sufficiency is heavily debated and discussed on several societal levels and from numerous perspectives (Jungell-Michelsson & Heikkurinen, 2022). Official reports rarely mention sufficiency, however, there are a growing number of scientific publications regarding this concept. Overall sufficiency is considered a successful concept, essential to turn the situation around and tackle growing demand.

However, sufficiency also has possible rebound effects and limits. Sufficiency will limit growth and impact people's lifestyles. Critics mean that you cannot decide the consumption level of others and that patterns will only shift (Hedenus et al., 2018). Sufficiency currently mainly occurs through individual actions. Hence, rebounds may come from people spending the saved money or time on other consumption or more resource-intensive activities, goods, or services (Sorell et al., 2020). Due to this, savings can be smaller than anticipated. Furthermore, the sufficiency limit is the 1.5°C target (Cabeza et al., 2022).

When considering consumption, it is crucial to remember that huge discrepancies remain in society. Social gaps are growing, while at the same time, consumption is strongly associated with social status. Therefore, sufficiency and efficiency have a social component affecting consumption and behaviour in both directions.

Renewables (called consistency in some sources, although sharing the definition) is a less commonly discussed concept, focusing on meeting demand with renewable, recyclable resources and energy. This means lower impact from the whole lifecycle of a product or service. For example, for wind power, materials and resources for the windmill should also be renewable. Hence, embodied carbon is a vital part of this concept. Recycling is crucial; resources should not be downcycled into a nonreusable state (Fischer et al., 2023).

This concept also has limits and rebounds. Consumption of renewable energy and resources tends to be higher, as people think use is without impact (Galvin et al., 2021). However, considering embodied emissions from production and transport, higher consumption will still impact the carbon footprint. Furthermore, transitioning to renewable materials requires resources (Safarzynska et al., 2023).

Another possible rebound effect is a lower recycling rate due to decreased recycling incentives. Finally, and most importantly, renewables are not scalable to meet the required demand for green energy. Biofuels require production land and material, while solar and wind power are weather-dependent (Lorek & Spangenberg, 2019a).

Combination of the concepts

With this in mind, combining the three concepts is a good solution for sustainable development (Fischer et al., 2023). Most literature focuses on sufficiency and efficiency and how to mix them to achieve the best result. The consensus seems to be that sufficiency should come before efficiency (Sachs & Santarius, 2013), (Bierwirth & Thomas, 2015), (Lorek & Spangenberg, 2019a).

"It takes sufficiency to make efficiency effective" (Lorek & Spangenberg, 2019a, p.1070)

The rebounds of efficiency mainly come from increased consumption, while the rebounds of sufficiency and renewables come from a shift in consumption instead of overall reduction (Lorek & Spangenberg, 2019a), (Sorell et al., 2020) (Galvin et al., 2021). Therefore, by first applying sufficiency to reduce consumption, followed by efficiency to lower demand for remaining needs, and lastly, renewables to meet the demand with the lowest impact, the consumption footprint is reduced the most. However, more focus tends to be on efficiency, as it does not require substantial individual changes. Strategy combinations are seldom applied in reality.

A clear example of lacking combination is the energy sector. The debate is centred around efficiency while reducing consumption through a change of habits or lifestyle is less frequently mentioned. For example, the Swedish electricity support scheme was consumption-based and applied to everyone (Regeringskansliet n.d.). The support covered 80% of all consumers' use for a certain period, regardless of income, quantity, or purpose of electricity use. The use of renewables focuses on meeting the growing energy demand. However, the Swedish government also concentrates on nuclear energy, a non-renewable energy source. Furthermore, sufficiency is rarely mentioned (Öbrink, 2021). The growing demand is an example of the outcome when only one or partly two strategies are applied.

Building context

These three strategies can also be applied to the building sector. The SER (sufficiency, efficiency, renewables) framework is used by the IPCC to assess and suggest measures to reduce the impact of GHG emissions from the building sector (Cabeza et al., 2022). The framework was originally created for the energy sector in France to reduce environmental impact. Figure 1 shows how the framework is applied to the building sector, defining the concepts within a building context (Saheb, 2021).

Sufficiency focuses on tackling the causes of human environmental impact by avoiding the demand for energy and materials over the lifecycle of buildings and goods. It is about long-term actions driven by non-technological solutions.
Efficiency focuses on the symptoms of human impact by improving energy and materials intensities. It is about continuous short-term marginal technological improvements.

Lastly, renewables focus on the consequences of human activity by reducing environmental impacts from energy and material demand. The hierarchical framework stipulates that sufficiency should come before efficiency and renewables (Cabeza et al., 2022).

In a building context, sufficiency interventions “do not consume energy during the use phase of buildings and do not require maintenance nor replacement over the lifetime of buildings.” For example, density, bioclimatic design, nature-based solutions, multi-functionality through shared spaces, flexibility in size, circular use of materials, optimisation of building use through lifestyle changes, and repurposing unused existing buildings are mentioned. Efficient applications in buildings are usually labelled as crucial to achieving net zero. This includes LED lighting, smart appliances, heat pumps, ventilation, and FTX systems for heat circulation. Renewable applications in buildings are sustainable materials and renewable energy (Cabeza et al., 2022).

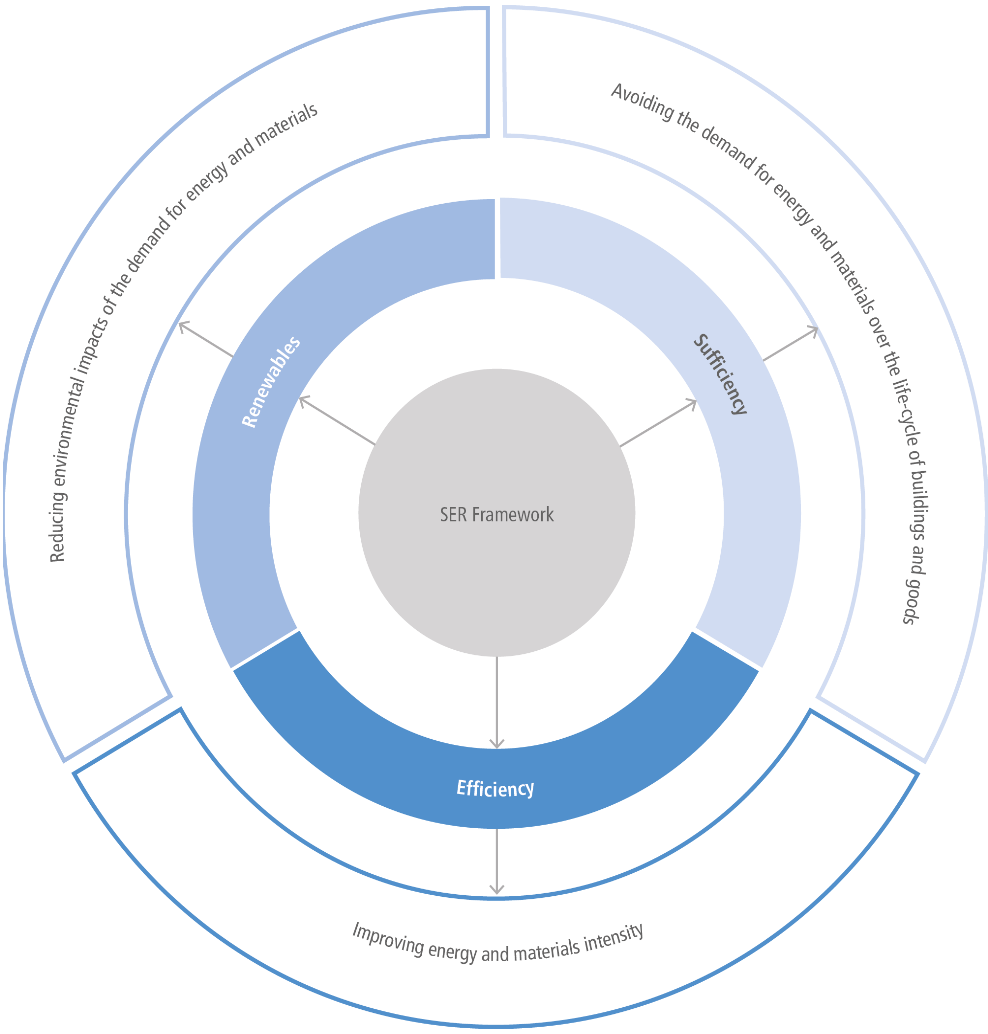


Figure 1. SER framework application to buildings. (Saheb, 2021)

According to the IPCC (Cabeza et al., 2022), most of the GHG emissions from buildings come from population growth, increasing floor area per capita, inefficiency of new buildings, low renovation rates, increased use, number and sizes of appliances and use of carbon-intensive energy. The three top impacts from the residential sector are food, housing, and mobility, making them target areas for sufficiency (Akanji et al., 2021), (Cabeza et al., 2022).

Over the past century, the trend has been increased space per person, causing increased energy and resource demand unmet by efficiency. The energy use per square meter has been reduced along with a slight decrease in total energy use for heating, although there is a significant gap between the energy savings per sqm and the total energy savings. This shows that efficiency can substantially lower the energy demand in buildings, although most of the savings vanish due to rebound effects (Bierwirth & Thomas, 2015).

Hence, not only energy can be considered for sustainable housing, as increased spacing counteracts energy efficiency. Sustainable homes require a holistic approach, starting with reduced consumption. Therefore, the three strategies should be combined into a space-effective, low-demand building driven by renewable energy through the application of selected subconcepts. First, minimalism, flexibility, and co-living are applied as sufficiency concepts to reduce living area per person and reduce the impact of resource use. Passive design can reduce the need for heating, cooling, and lighting through envelope design, orientation, shading, and daylight optimization.

Efficiency technology such as FTX systems, efficient lighting, and low-energy appliances can further reduce demand.

Lastly, sustainable materials, solar panels, and batteries can reduce the lifecycle footprint and generate green energy for the building, reducing operational and embodied carbon even further.

Affordable housing

In addition to the global situation of growing energy demand and increased living space, the UN has identified affordable housing as a core issue for global sustainability, establishing that the world will need to build 96,000 new affordable homes daily to house the estimated 3 billion needing housing in 2030. Affordable housing refers to housing where a household does not spend more than 30% of the income on housing-related expenses, including mortgage payments, rent payments and direct operational costs such as taxes and services like water and energy (United Nations Economic Commission for Europe [UN], 2021).

SDG goal number 11, sustainable cities and communities, monitors the progress, with target 11.1 tracking affordable housing specifically. It is also mentioned as crucial for goal 1, poverty eradication. This shows that affordable housing is crucial for the development of societies and cities and should be a part of the planning of green cities for the future (UN, 2021).

The need for affordable housing can also be put into a Swedish context. According to the report Boende till rimlig kostnad (Boverket, 2016), translating to housing for a reasonable cost, published by the Swedish National Board of Housing, Building and Planning (Boverket), around 15% of the study basis spent more than 30% of their income on living expenses. 42 % of the 40 % with the lowest disposable income spend more than 30% of their income on living expenses, around 1,3 million people (Boverket, 2016).

The groups where the margins are the lowest are families with many children, seniors, people living in big cities and people renting their apartments second-hand (Boverket, 2016).

However, this report is from 2016, and this has likely changed since, with the current inflation situation and growing living costs. It is reasonable to assume that these numbers have increased today and that the margins between people who own accommodation and those who rent are decreasing. While the report numbers clearly show the need for affordable living in Sweden, it is likely even higher today.

Transformation of buildings

Reviving and reusing empty or unused buildings is a big part of sufficiency, optimising the use of existing constructions. However, it is not always easy to transform a building.

According to Boverket's study determining the preset for transforming a public locale to housing (Boverket, 2021), determining which requirements apply to changing a building can be complicated, depending on the extent of the interventions. A complete renovation from office to housing likely falls under the transformation category, meaning new building requirements regarding thermal comfort, energy use, and fire safety generally apply. Furthermore, this means that the existing structure might not be completely reusable (Boverket, 2021).

Within the transformation itself, bigger challenges than expected can possibly occur. Regarding transformation of entire office buildings, the load-bearing construction is often possible to reuse, although other existing elements can prove more difficult. There is often a need to tear down the existing floor plans due to daylight, the frequent placement of one central staircase or elevator group, limitations from window placement (often placed in ties), or the typical placement of toilets in central groups. As housing has severely different needs than offices regarding these aspects, many existing walls, shafts, and bathrooms need replacing. However, preserving the construction is usually possible due to the regularly occurring classical pillar deck system (Boverket, 2021).

A transformation often requires changes in installations due to the changes in floor plan, as the necessary division of bathrooms results in plumbing and water fixtures being difficult or impossible to reuse. Furthermore, office ventilation is generally placed in large central units, while housing requires smaller units for each apartment. Placing new installations in the ceiling is preferable and usually aided by the high internal height in office buildings (Boverket, 2021).

The rules for rent negotiation are the same as for non-transformed housing and are not regarded as an issue. As in every project, the long-term economy needs to add up. However, budget calculation can be challenging in transformation projects. The uncertainty of a transformation project regarding the quality and characteristics of existing components, possibly in combination with older or missing documentation, provides higher economic risk. The budget includes maintenance costs, rent income, transformation costs, investment yield, and taxes (Boverket, 2021).

Regarding transformation cost, all the required changes mentioned affect the building economy. The changes to meet the different needs of housing compared to locales can severely crank up the cost of the transformation. For example, a requirement to add or alter the staircases or elevators results in a significantly higher transformation cost. The same goes for changing the existing building envelope or the building load-bearing construction. Other considerable costs are kitchens, bathrooms, and installations (Boverket, 2021).

Furthermore, there are other economic aspects of transformation within the system that cannot be impacted by design. For example, tax & VAT rules differ between locales and housing. New housing has fewer fees than transformation, although taxes are generally lower for housing than locales. Another significant factor is that the general income from locales is higher per sqm than for housing. Therefore, renting only parts of the building with the rest vacant might prove more economical than transforming vacant buildings into housing. Transforming a building into housing might result in income loss, depending on the building size and number of tenants. Another intriguing aspect mentioned in the report is that the economic calculation is more advantageous with communally-owned housing than rental apartments, where income is limited. (Boverket, 2021).

In conclusion, numerous economic aspects impact the possibility of transforming locales into housing, although several are influenceable through design choices. For example, maintenance cost, transformation cost, and number of tenants partly depend on choices made during the renovation. (Boverket, 2021).

Terms and Concepts

Sufficiency

Reducing consumption through changing consumption habits, decreasing demand for energy and resources. Concentrating on changes in lifestyle and behaviour to reduce the need for a service or good. Sufficiency is a debated concept that should be implemented first according to theory.

In a building context, sufficiency interventions require no energy or maintenance during the use phase. Examples include density, bioclimatic design, multi-functionality through shared spaces, flexibility in size, circularity, optimization of building use, and repurposing unused buildings.

Efficiency

Reducing energy and material needed to produce or use a good or service. Improving impact through technology, and does not require lifestyle changes. Efficiency improvements lower energy use and costs, although total savings are relatively small due to increased consumption. Efficiency reductions can only partly decrease demand. For buildings, efficiency measures include LED lighting, smart appliances, HVAC and FTX systems for heat circulation.

Renewables

Meeting demand with renewable, recyclable resources and energy, lowering impact from the whole service or product lifecycle. Materials and resources for a product should also be renewable. Embodied carbon is a vital part of this concept, as higher consumption will still impact the carbon footprint, and transitioning to renewable materials requires resources. Renewables should be applied last in a project and include sustainable materials and energy.

Affordable housing

Affordable housing refers to housing where a household does not spend more than 30% of their income on housing-related expenses. The UN has identified that the world will need 96,000 new affordable homes daily to meet 2030 housing demand. In a Swedish context, 42% of the 40% with the lowest disposable income spend more than 30% of their income on housing. In total, around 15% spend more than 30% of their income on housing

Daylight

Daylight is important in housing, all rooms where humans spend more permanent time should have a direct connection to daylight. Daylight is measured in Daylight Factor, the ratio of light outside and inside. The median daylight factor should be above 0,8% to pass requirements.

Thermal comfort

Thermal comfort is essential for wellbeing, and measures how humans experience indoor temperature. Operative temperature is used, meaning the mean value of temperature and radiation from surrounding surfaces. Thermal comfort is measured in Thermal Comfort Percent (TCP), which indicates the predicted ratio of people satisfied for a certain operative temperature.

Primary energy demand

Primary energy is energy that can be directly extracted from natural energy sources, Primary energy includes raw energy before converted to other forms. Hence, primary energy demand indicates how much energy the building consumes directly from energy sources. The primary energy demand is measured in kWh/m^2.

GWP

Greenhouse gases (GHGs) are a common name for gases absorbing energy and keeping it in the atmosphere. The Global Warming Potential (GWP) is a measurement comparing the impact from different gases to the impact of CO2 over a certain time. Global Warming Potential is measured in kg CO_2-eq/m^2 in a building context. GWP essentially measures the carbon footprint of a building.

MAB

MAB stands for Manual for analysis of housing qualities, and is a framework for ensuring high-quality design while improving project economy. Framework is split in categories, this project focuses on accommodation qualities. MAB is used as a qualitative tool in this thesis to measure soft values of design. The framework has been simplified with the application to transformation and a comparative evaluation.

Subconcepts

The concepts presented in Figure 2 are extracted from the theory of this thesis. They are sorted into the main categories that this thesis concerns. Several concepts fall under multiple categories and are therefore repeated. Figure 3 and Figure 4 on the following page show how they are applied and their relation to the evaluation criteria presented in the next section.

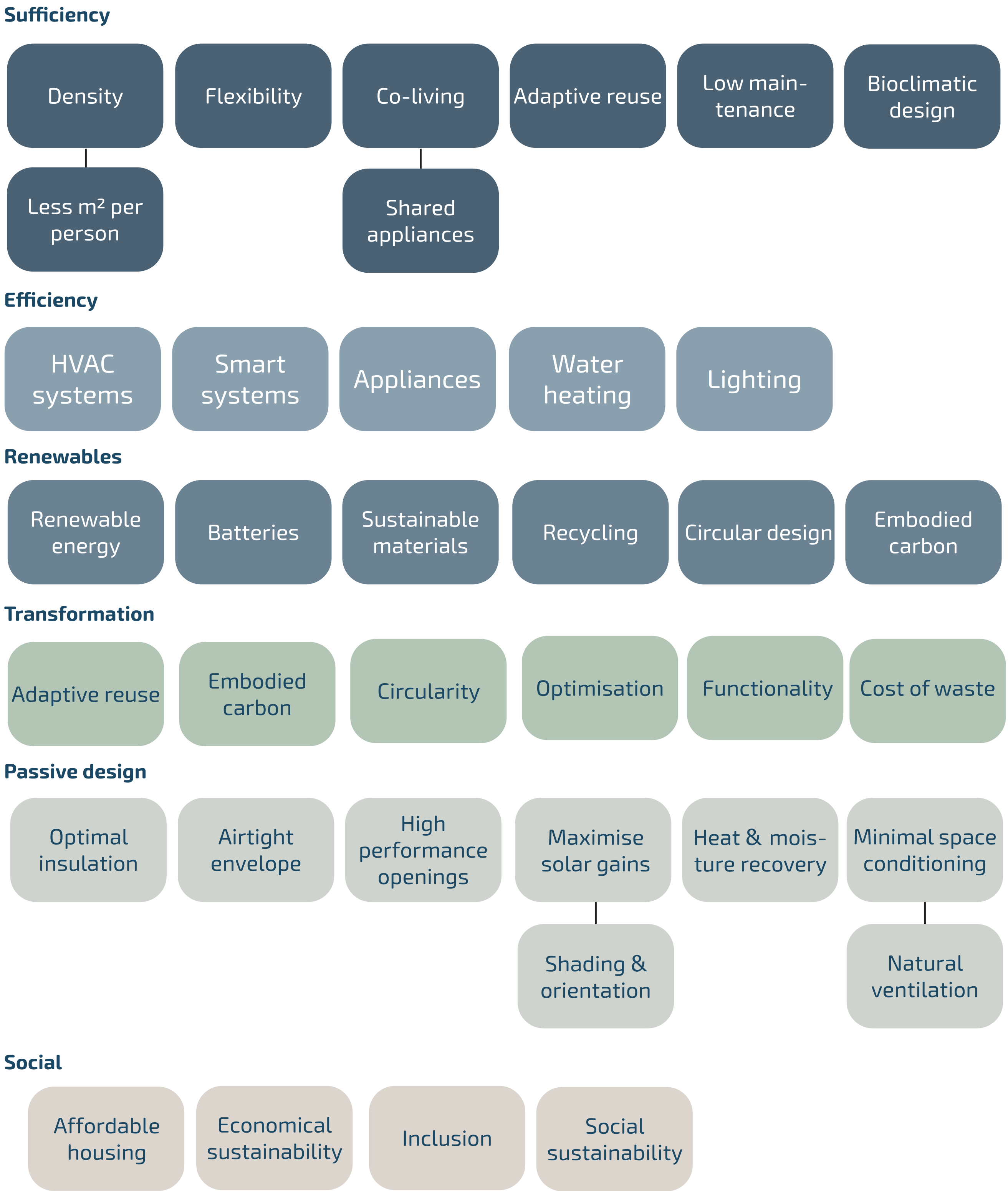


Figure 2. Important terms with subconcepts

Application of concepts in design stages

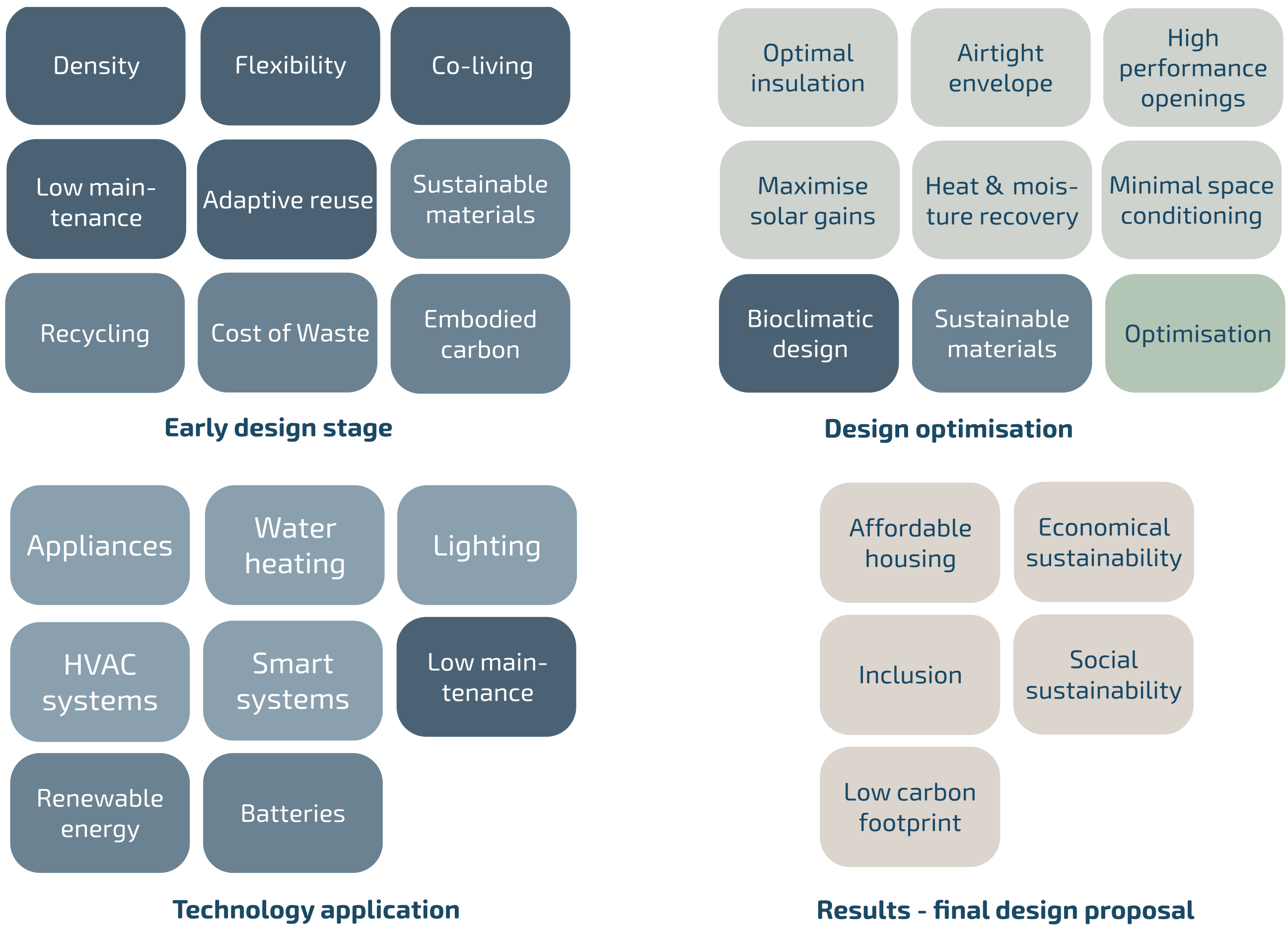


Figure 3. Concepts divided into project stages

Link between concepts and evaluation criteria

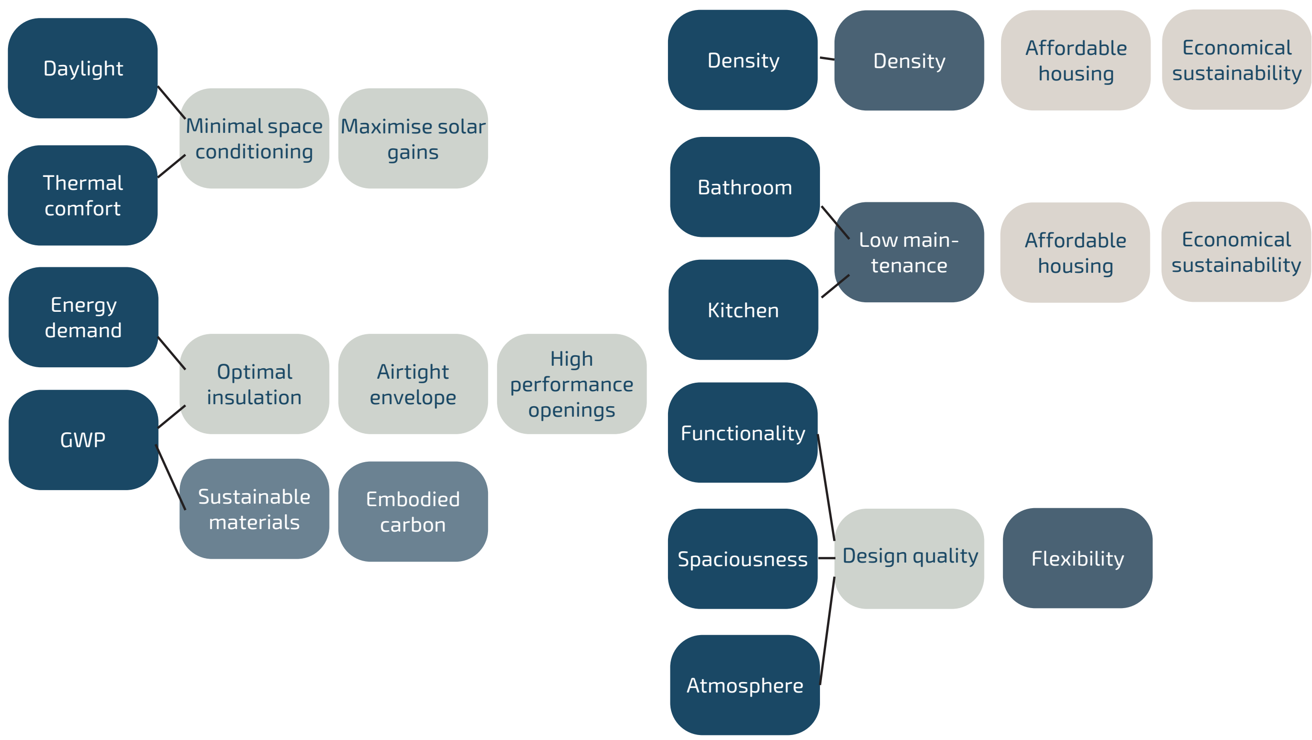


Figure 4. Application of evaluation criteria to concepts

Design evaluation criteria

Daylight

Daylight is a key factor for the quality and experience of an apartment. The Swedish building rules state that rooms where humans spend the most time should have a direct connection to daylight (Boverket, 2020).

Daylight is measured using daylight factor (DF), defined as the ratio of illumination indoors compared to outdoors with a grey overcast sky (Swedish Green Building Council [SGBC], 2020).

There are no longer any specific requirements in the Swedish building rules, although in Miljöbyggnad 3.1 (the framework used in the renovation), the minimum requirement of the average daylight factor is 0.8 %, while the silver requirement is 1.0 % and the gold requirement is 1.3 % (SGBC, 2020).

There are four different ways to measure the daylight factor. The median daylight factor is used in this thesis, simulating daylight factor as a median for the room in a grid of points 0,8 m above the floor and between 0.1 and 0.5 m from the walls. The maximum distance between points should be 0.5 m (SGBC, 2020).

The daylight is simulated using the Radiance tool from the Honeybee plugin in Grasshopper.

The daylight measuring scale for the matrix is
0: DF <0.8
1: 0.8 ≤ DF ≤ 1.0
2: 1.0 ≤ DF ≤ 1.3
3: 1.3 ≤ DF

Thermal comfort

Thermal comfort is an important concept both for human well-being and the environment. Thermal comfort is a measurement of how humans experience indoor temperature. The experience of the temperature in a room depends on both air temperature and the radiation from the surrounding surfaces. Therefore, the operative temperature is generally used to measure thermal comfort. Operative temperature is the mean value of the temperature and the radiation and is viewed as a better way to measure human experience. Therefore, operative temperature is used in this project to measure thermal comfort (Folkhälsomyndigheten, [FHM] 2022a).

The Public Health Organisation of Sweden has developed guidelines for operative temperature in buildings. In the summer, the temperature should be between 18 and 26 degrees, while it should stay between 18 and 24 degrees in the winter (FHM, 2022b).

Thermal comfort is commonly measured using the indicator Predicted Percentage Dissatisfied (PPD), indicating the percentage of people likely to be uncomfortable with the thermal climate. PPD is measured using the operative temperature and the guidelines for operative temperature limits (SGBC, 2020).

In this project, the numbers have been slightly modified. Instead, this project is looking at thermal comfort percent (TCP), which is the opposite of PPD, essentially stating how many percent of people are comfortable.

Since overheating is likely to be an issue in this building, the period used is the summer, and the analysis shows a mean value of the percentage of people predicted to be comfortable during the summer.

The simulation is performed using the tool EnergyPlus within the plugin Honeybee in Grasshopper.

As the analysis is comparative, the scale is based on the simulation results to show a difference between options. The simulation values range from just above 90 to between 93 and 94.

This means the scale for thermal comfort is:
0: TCI <91%
1: 91 % ≤ TCP < 92%
2: 92 % ≤ TCP < 93%
3: 93 % ≤ TCP

Primary energy demand

The primary energy is the amount of energy that can be extracted from naturally occurring energy sources, meaning before the raw energy source is converted to other forms. Primary energy includes all raw energy, both renewables and fossil fuels, however it does not mean the directly usable energy. Hence, the primary energy demand indicates how much energy that the building consumes directly from energy sources, and it is different from the final energy consumption.

The primary energy demand will be measured using the program CAALA in this project. CAALA is a tool where users can estimate the climate impact of a project and where it is possible to change or test different parameters of the design, such as building construction, location climate or energy system. The primary energy demand is expressed in the unit kWh/m^2 (CAALA, n.d.)

In the appendix, a breakdown of the primary energy demand for each option is shown.

According to the Swedish building rules, the primary energy demand (E_{pet}) for apartment buildings should not exceed 75 kWh/m^2. Important to note is that for the design evaluation matrix, the scale described below is used. For the final design calculation of the energy demand, the values are compared to the requirement in the Swedish building rules (Boverket, 2020)

In the simulation results of the options, the results vary between 95 and 90 kWh/m^2.

Therefore, to measure differences, the scale for primary energy demand is:
0: $94 < E_{pet}$
1: $92 \leq E_{pet} \leq 94$
2: $90 \leq E_{pet} \leq 92$
3: $E_{pet} \leq 90$

0 1 2 3
94 92 90

Carbon footprint - global warming potential

Greenhouse gases (GHGs) are a general name for substances that impact our climate by absorbing energy and keeping it from leaving the earth's atmosphere. The two most important aspects when talking about GHGs are the absorbable energy amount and the time the gas stays in the atmosphere, which is very different for different gases (United States Environmental Protection Agency [EPA], 2023)

Therefore, Global Warming Potential (GWP) has been developed for comparing different gases over a certain time frame. GWP measures how much energy a ton of the material will absorb over the next 20, 50 or 100 years, depending on the chosen timeframe.

The most common measurement is GWP-100, measuring the impact of a ton of the gas over the next 100 years. When measuring the GWP, the gases are compared to the impact from CO_2, the most common greenhouse gas, over the chosen time period. Hence, Global Warming Potential is measured in kg CO_2-eq/m^2 in a building context (EPA, 2023).

In this project, the GWP will be calculated using CAALA. The tool measures the GWP over the lifetime of a project using life cycle analysis. The life cycle stages included, models and program setup can be found in the appendix.

The evaluation scale for the GWP is based on the variety in results between the tested options.
The results from this simulation varies between 68 and 61 kg CO_2-eq/m^2.

Therefore, the scale used for GWP is
0: $67 < GWP$
1: $64 < GWP \leq 67$
2: $61 < GWP \leq 64$
3: $GWP \leq 61$

0 1 2 3
67 64 61

MAB - housing analysis

MAB stands for "Manual för analys av bostadskvaliteter", translating to Manual for analysis of housing qualities, which is a framework developed by CBA, Centrum for Boendets Arkitektur (Centre for Living Architecture) at Chalmers University of Technology
The framework is a tool for ensuring high-quality housing while simultaneously keeping costs down and improving the project economy. The framework analyses 28 qualities divided into three categories: accommodation, yard, and building. As the design evaluation focuses on the apartments, the accommodation qualities have been selected and applied. MAB is used as a qualitative tool in this thesis to measure the soft values of design, complementing the quantitative characteristics of the other criteria (Granath & Nylander, 2023)

The accommodation qualities are further split into three sections: functionality, spaciousness and atmosphere. For the sake of comparison and application to this project, the MBA evaluation system has been simplified. Each category is a separate criterion, with the number of qualities fulfilled as the indicator. A floor plan option is considered a pass if 70% of the apartments fulfil the quality criteria. Each quality passed is awarded a point in the matrix category. (Granath & Nylander, 2023).

Functionality

1. Space efficiency
Apartment area is <95% of the country average.

2. Technical rationality
Apartment should have max three shafts: one for drain, one for supply and one for exhaust air.

3. Furnishable space
Furnishable space should be ≥ 50% of total area.

4. Potential for remained living
2 of 3 following 3 subqualities should be fulfilled:
- Ample bedroom size: 3*3,1 m
- Bedroom can be entered without disturbing other functions
- < 6 m between bed, entrance, bath and storage

As shafts are separately added later, the technical rationality quality will not be used. The measuring scale is therefore based on qualities 1, 3 and 4.

Spaciousness

5. Axiality
There should be at least two axes in an apartment.

6. Interior circular flow and movement
There should be at least one instance of interior circular flow in an apartment.

7. Room shape
Rooms should be representable with one square.

8. Flexibility
MAB has 5 demands, of which 3 should be fulfilled.
- There should be at least two general rooms of at least 13 sqm in an apartment
- An apartment should be usable even if the living room is removed
- The number of rooms in the apartment should be flexible
- At least one room outside of the kitchen and living room should have two connections to other rooms
- There should be at least one autonomous room in an apartment. An autonomous room is located within 4 meters from the entrance, reached from a neutral space, and with a furnishable area of at least 3*3.1 m.

As interior circular flow is not possible in any apartment in any option, and this is a comparative analysis, only quality 5, 7 and 8 will be considered.

Atmosphere

9. Facade directions
An apartment should have openings in at least two directions.

10. Balconies
An apartment should connect to a balcony, terrace, or outdoor space.

11. Designed daylight
There should be at least one element of designed daylight, such as French doors, corner windows, niches, etc.

12. Dark area.
There should be <15% dark area in an apartment.

As designed daylight requires designing with specific qualities that might be limited in a transformation project, and a daylight analysis is performed, designed daylight is not considered.

Economy criteria

The economic evaluation will not be made by calculating actual rent cost, as this is a little specific and complicated for this thesis. For the same reason, the building cost will not be evaluated. Instead, three indexes of design choices with a significant impact on the building, maintenance, and rent costs, thus impacting the final economy of the project, are applied. These are density, number of bathrooms, and kitchen length.

Density

Density is a prominent concept for sufficiency and a great measurement of living area per person, besides having an extensive impact on the building economy. The indicator used is the number of inhabitants per floor. As this number ranges from 16 to 24, the measuring scale is:

1 pt: 16 people
2 pts: 18 people
3 pts: 24 people

Bathrooms

A bathroom is a source of energy and water use. Furthermore, the construction cost, partly due to water and sewage connections, is a big part of building costs.

The index is based on the number of bathrooms, including preserved ones. This number ranges from 12-8 per floor, and hence the matrix scale is:

1 pt: 12 bathrooms
2 pts: 10 bathrooms
3 pts: 8 bathrooms

Kitchen

Kitchens are another source of energy use and construction cost. With both individual and shared kitchens in this project, the length of the kitchen and appliances in meters are used as an index. The values range from 28-45 m, leading the measuring scale to be:

0 pt >36
1 pt: 36-32
2 pt: 32-28
3 pts: 28 or above

Resulting matrix

The presented evaluation criteria and indices result in a matrix where each measured quality is gradable on a scale from 0-3.

The matrix provides a basis for comparing various design options using qualitative and quantitative indices.

This matrix is used to evaluate the design options in the early design process and for input and testing during the design optimization phase. This method is used to test design implications and to optimize the final design.

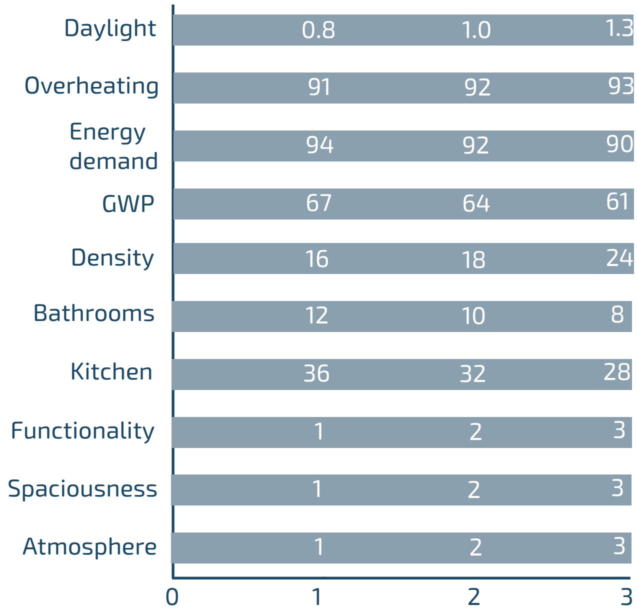


Figure 5. Design evaluation matrix

Reference buildings

BRF Viva

BRF Viva is a housing project with communally owned apartments completed in Gothenburg in 2019. The project goal is to be the most innovative project in Sweden. Although the three ecology concepts are not explicitly stated, several solutions are categorizable within them. Sufficiency is applied through smaller apartments and a carpool, removing individual parking. There are also community areas with office spots, community rooms, guest rooms, laundry rooms, workshops, etc. Efficiency solutions such as heating, ventilation, and FTX systems are implemented. Renewable measures are solar panels, reused batteries from buses, and low-impact concrete (Riksbyggen, n.d.).

An evaluation of BRF Viva made by CBA published in 2021 showed that overall, the project is appreciated and well-working. The apartments are considered relatively dense, however residents are generally positive.

The common spaces are appreciated, although many residents don't use them that much. Specific reasons mentioned are lack of maintenance and a lack of possibility to track bookings. One resident commented that office spaces would have been more practical had they been individual.

A majority of the tenants also appreciate the sharing of tools and the decreased need to own stuff, although half the residents do not use them.

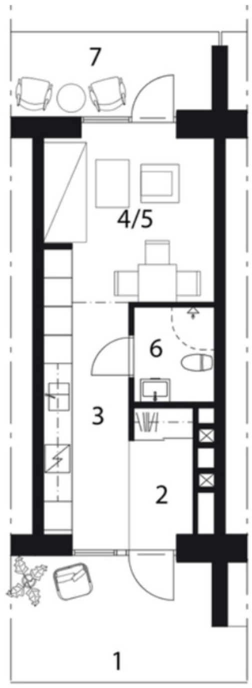


Figure 6. 1-bed unit 30.5 sqm (ArchDaily, 2021)

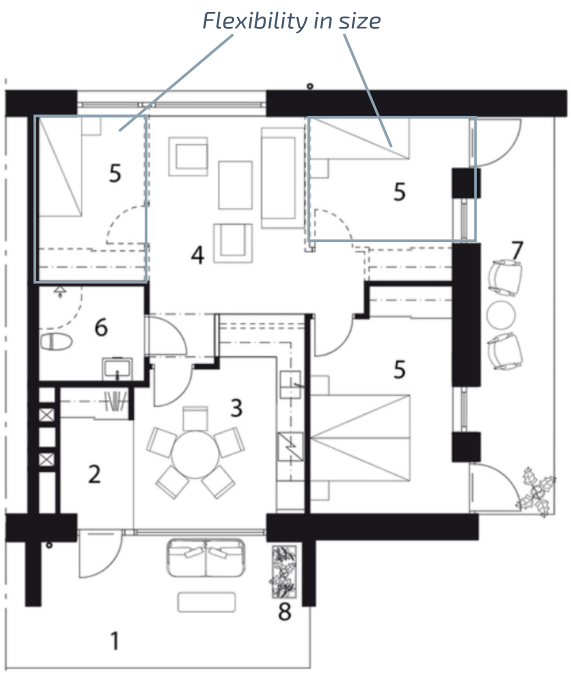


Figure 7. 1-3-bed unit 72 sqm (ArchDaily, 2021)

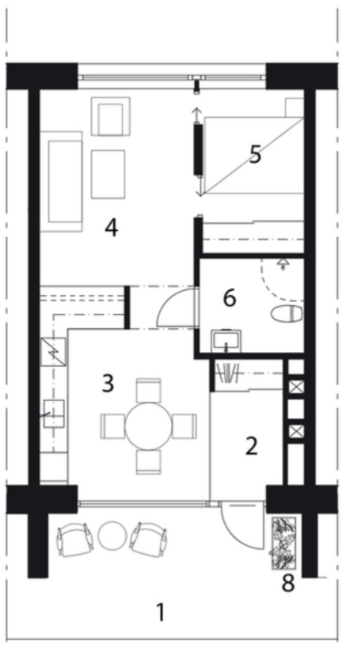


Figure 8. 1-bed unit 47.1 sqm (ArchDaily, 2021)

Figure 9. Office space (Riksbyggen, n.d.)

Figure 10. Inside BRF Viva (Ulf Celander, 2021)

Reflection

BRF Viva is an interesting example that, although not clear as a spoken strategy, combines sufficiency, efficiency, and renewables.

The project combines various apartment sizes and types, with dense, narrow units, and bigger, flexible units. However, the flexible units show a clash between density and flexibility. While the 3-bed setup is space-effective, the 1-bed setup requires a larger apartment with unused space. Plenty of communal spaces exist, with valuable resident input for the design of shared spaces.

Never too small

Never Too Small is an Australian media company producing YouTube series and books highlighting examples of small-space living and footprint design. Projects from around the world are showcased in video documentaries and pictures, focusing on solutions for comfortable living using less (Never Too Small, n.d.)

Pictures presented below are chosen from the book *Never Too Small - Reimagining Small Space Living* (Beath & Price, 2021), showing examples of interior solutions for smaller living areas. These are used as inspiration for how design can be performed outside the Swedish context, where regulations might be less strict.

Figure 11 & 12. Piano apartment, Taipei, (Hey!Cheese, 2019)

Figure 13. Boneca, Sydney (Tom Ferguson, 2020)

Figure 14. Cairo Flat, Fitzroy (Tom Ross, 2020)

Figure 15. Urban Cabin, Bergamo (Francesca Perani, 2019)

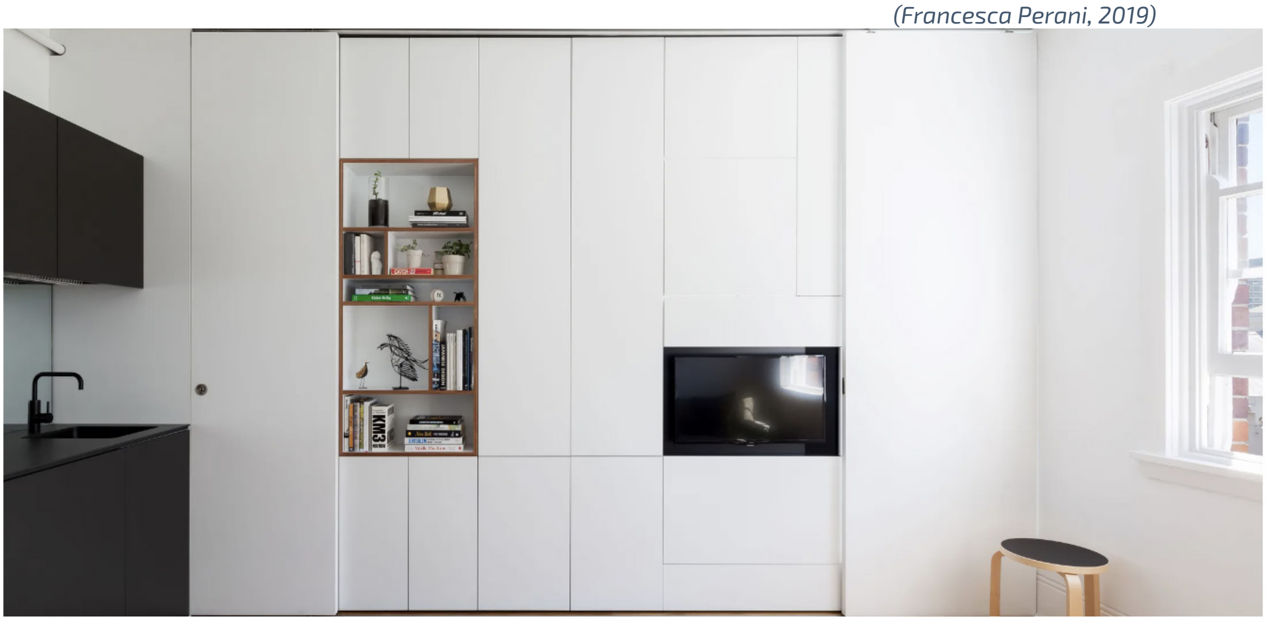


Figure 16. Darlinghurst apartment, Sydney (Katherine Lu, 2020)

Figure 17. Type Street Apartment (Tess Kelly, 2020)

Reflection

These projects are about making the most of a space, with canny storage and maximised functionality. There are many different uses of one room, and these are just a few examples of different possibilities. Most applications require a bit of room height, which makes them difficult to apply in this project. The ideas chosen above would be implementable in my design. A significant difference is the storage flexibility, in these examples full-size wardrobes are rare, and instead, built-in storage with flexibility in sizes and space is utilised.

Zollhaus Coliving

Zollhaus Coliving in Zurich, Switzerland, is part of the Kalkbreite collective and was finished in 2021. This collective contains multiple types of co-living, such as hall-living, senior co-living, and spaces in apartments.

There are plenty of shared spaces, both general rooms and rooms for rent. Common spaces include cafeteria, reception, and laundry rooms. Rentable services include guesthouse, seminar space, meeting rooms, sauna, garden kitchens, and bicycle parking (Kalkbreite, n.d.)

Figure 18. Zollhaus building (Martina Meier, n.d.)

Figure 19. Co-living floor plan

Figure 20. Flex meeting rooms (Saloon, n.d.)

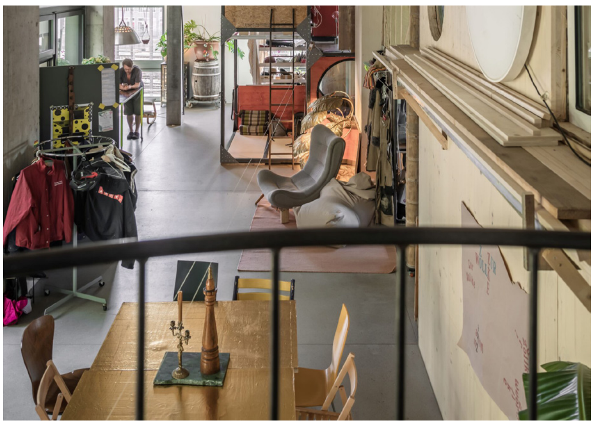


Figure 21. Hall Living (Annette Landsmann, n.d.)

Reflection

There is a combination of apartment sizes and types. I have looked at the apartment co-living, as this shows an example of how flexibility in size can be achieved in shared apartments. There are fixed rooms, but the space can be expanded by renting more rooms or even the whole apartment. Within the apartment, everything is shared except beds and storage. The co-living areas are relatively small, with little kitchens. Three people share a bathroom, while six people share a kitchen.

Charenton-Le Pont transformation

This transformation from offices to 90 apartments was completed in 2016 by MOATTI-RIVERE in Charenton Le-Pont, France. The project started with a repetitive facade and focused the transformation on providing individuality and flexibility to the apartments.

The project works with orientation, shading, and vegetation to optimize the solar gains. Therefore, the apartments can still have large windows. The project houses various apartment sizes, using the same concepts but with adaptation for different placement in the building and flexibility. The units are compact and often with only one facade (ArchDaily, 2016).

Figure 22. Original facade (Moatti-Riviere, n.d.)

Figure 23 & 24. Floor plan (ArchDaily, 2016)

Figure 25 & 26. Transformed facade (Michel Denancé, n.d.)

Reflection

The project shows a valuable example of how to work with an existing facade with plenty of openings. There is a variety in size and placement of windows. Furthermore, the project works with shading in various ways.

There are many examples here of apartments with only one facade, and multiple narrow units that can serve as inspiration for my design. For example, unit T2 shows an insightful way to design a 1-bedroom apartment in 40 sqm. Unit T1 provides an example of a dense studio apartment.

Building context

Introduction

The specific building transformed in this project was found and selected through a search of empty offices in Gothenburg. The selection was based on location, overall size, building depth, opening sizes and placement, entrance areas, and availability of drawings.

This building has recently been renovated, with the addition of three floors and more offices in the new and previously existing spaces. However, as mentioned, there are currently plenty of empty offices in Gothenburg, so the addition of offices is not crucial at this time. Furthermore, the owner is Göteborgslokaler, owned by Göteborgs Stad and hence a municipality company. Therefore, it should be possible and also more beneficial for the owner and municipality overall to transform the building into housing instead. With this background, the starting point for this project is the building before this renovation, to explore an adaptive reuse option instead.

The nine-story building has two connected parts, equally sized floors and entrances towards the street. The building sits at street level, with parking outside and public functions at the entrance floor. There are green spaces behind the building and no balconies, only marquees. The building is relatively narrow, making daylight and thermal comfort design easier in small apartments. Windows are numerous, good-sized and placed in ties, enabling flexibility with their placement in the design.

Figure 27. Karlatornet (Saleh Abdul-Rahman, 2023)

Figure 28. The planned Central Station area (Göteborgs Stad, 2024)

Figure 29. Engelbrektsgatan 69-71 (Sofia Larsson, 2015)

Location

The location of the building is in central Gothenburg, perfectly situated for housing. It is within short walking distance of Scandinavium and Berzeliigatan tram stations, close to Korsvägen, and has plenty of bus stops nearby.

There are grocery stores, restaurants, cinemas, and other services nearby, and the heart of Gothenburg is within walking distance. Therefore, residents are unlikely to be car-dependent, making the site perfect for affordable housing.

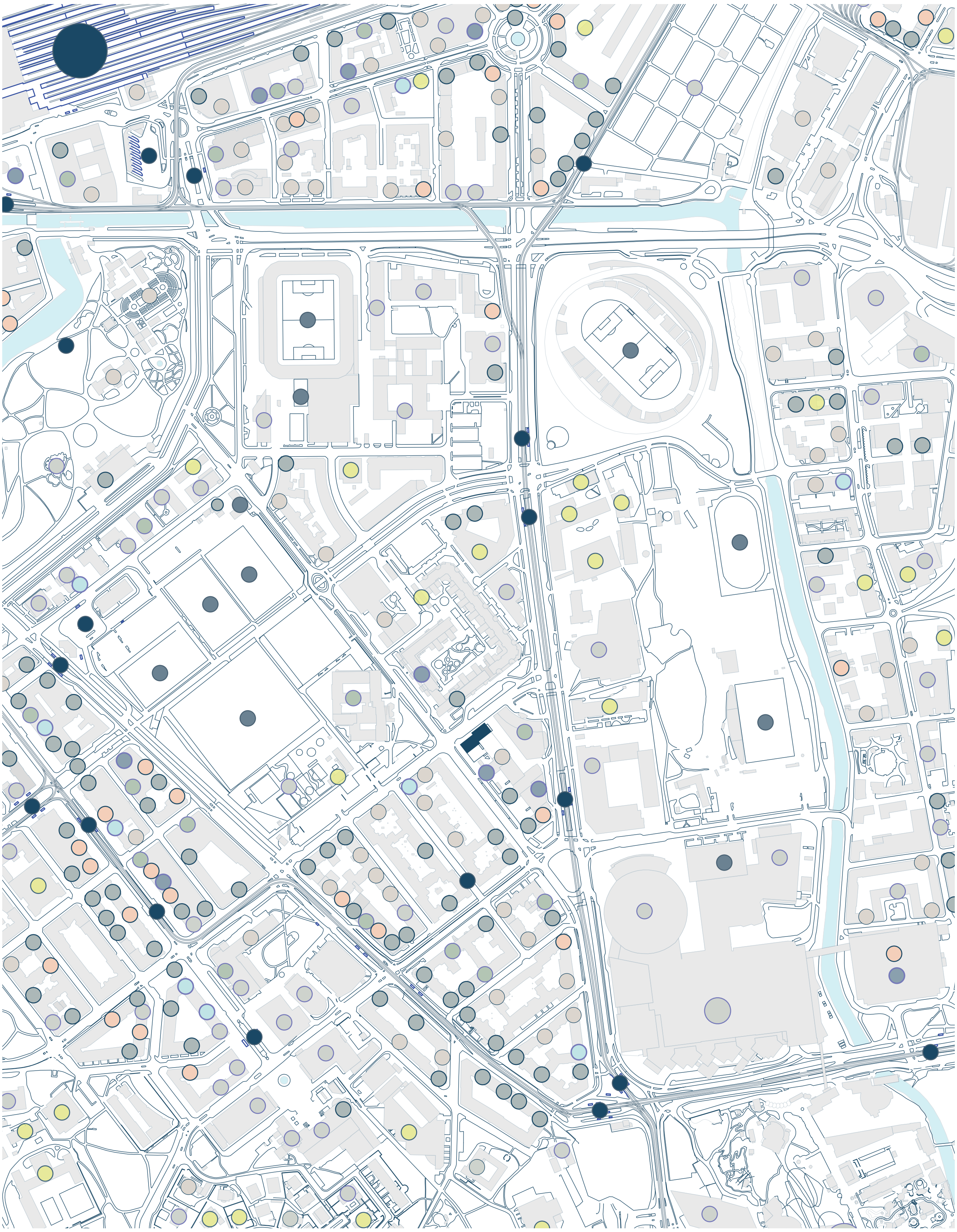


Figure 30. Context map of the area, 1:7500

GROCERY STORE
RESTAURANT
HOTEL
SPORTS FIELD/ARENA
FUNCTIONS
CINEMA/MUSEUM
SERVICES
PUBLIC TRANSPORT
OTHER STORES
EDUCATION

The existing building

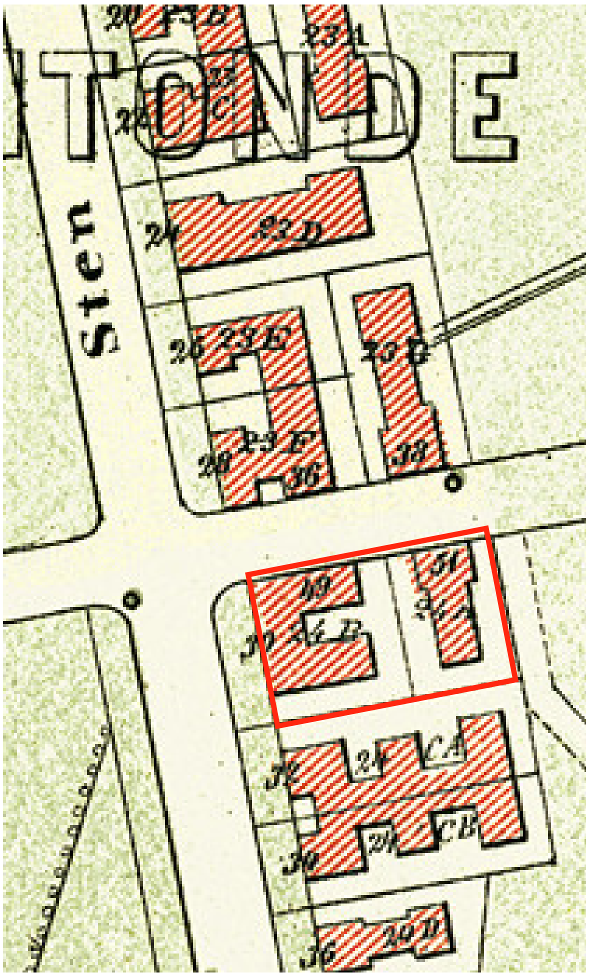


Figure 31. Kv. Opalen, 1888, (Riksarkivet, Landsarkivet i Göteborg),

Figure 32. Characteristic buildings in the area, early 1900s (Göteborg Stadsmuseum)

Figure 33. Kv. Opalen, 1960 (Lantmäteriet)

Building timeline

1880s – "Landhövdingehus and wooden houses are constructed in Kv. Opalen

1960s – The houses are demolished

1962 – Planning of four skivhus in Kv. Opalen begins

1965 – The office building in the corner of Sten Sturegatan and Engelbrektsgatan is constructed, projected by Lennart Kvarnström

1983 – The building is renovated. The recycling room is constructed.

1990 – The office building is remodelled

The original buildings on the site were constructed in the 1880s and can be seen in Figures 31 and 32. These wooden houses lasted until the early 1960s when they were replaced by the current development.

The nine-story building in focus for this project was constructed in 1965 and has two connected parts, slightly offset to each other. The building is part of the historical neighbourhood Opalen (hence Kv. Opalen) and was constructed together with three neighbour houses, although their style and materials are slightly different.

The building was first renovated in 1893, and since then, several remodellings and additions have been performed. Significant additions and changes to highlight are the multiple changes to the entrances, the addition of several canopies, accessibility modifications, and various remodellings of the entrance floor. The latest changes before the renovation started in 2020 was the temporary remodelling to house the English school in Gothenburg during the school renovation.

Figure 34. Overview of Kv. Opalen (Sofia Larsson, 2015)

Figure 35.The current building (Wikimedia Commons, 2017)

1995
Addition of veranda on entrance floor

1996
Changes in offices, canopies, entrance, loading bays and emergency exits. Addition of fan units on roof.

2009
The entrance is renovated, the ground is prepared for accessibility

2010
Change from restaurant to conference

2018
Parts of the building are temporary transformed to house Engelska Skolan.

2020
Renovation and extension of the building is started

Site

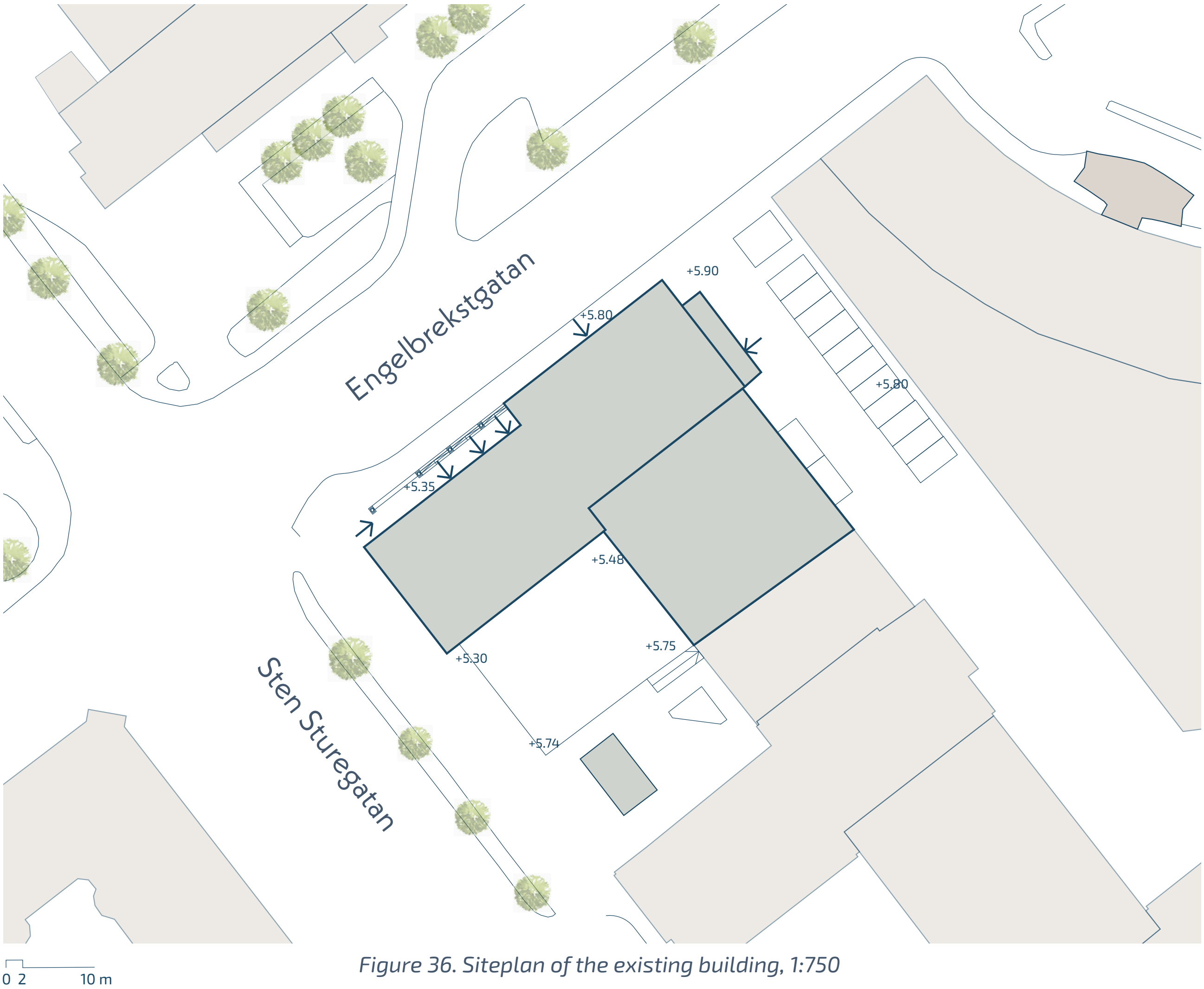


Figure 36. Siteplan of the existing building, 1:750

The site is, as mentioned previously, located at the corner of Sten Sturegatan and Engelbrektsgatan. The building and its entrances are situated on the street level, accessible both via stairs and from the pavement. There are also additional entrances towards the northwest and northeast, among them a loading bay at street level.

Paid parking usable by guests exists northeast of the building, towards the hotel. The entrance to the underground parking garage is situated here as well, although not within the property limit. The neighbouring property connects to the building on the basement and entrance levels. Furthermore, the building is located right at the end of the property limit to the northwest and the southwest, where the public pavement starts at the edge of the perimeter.

A garden is located to the southwest of the building. A possibility to work with the roof of the entrance floor, towards the southeast, also exists.

Figure 37. The public entrance towards Sten Sturegatan (Wikimedia Commons, 2017)

Building analysis

Entrance floor

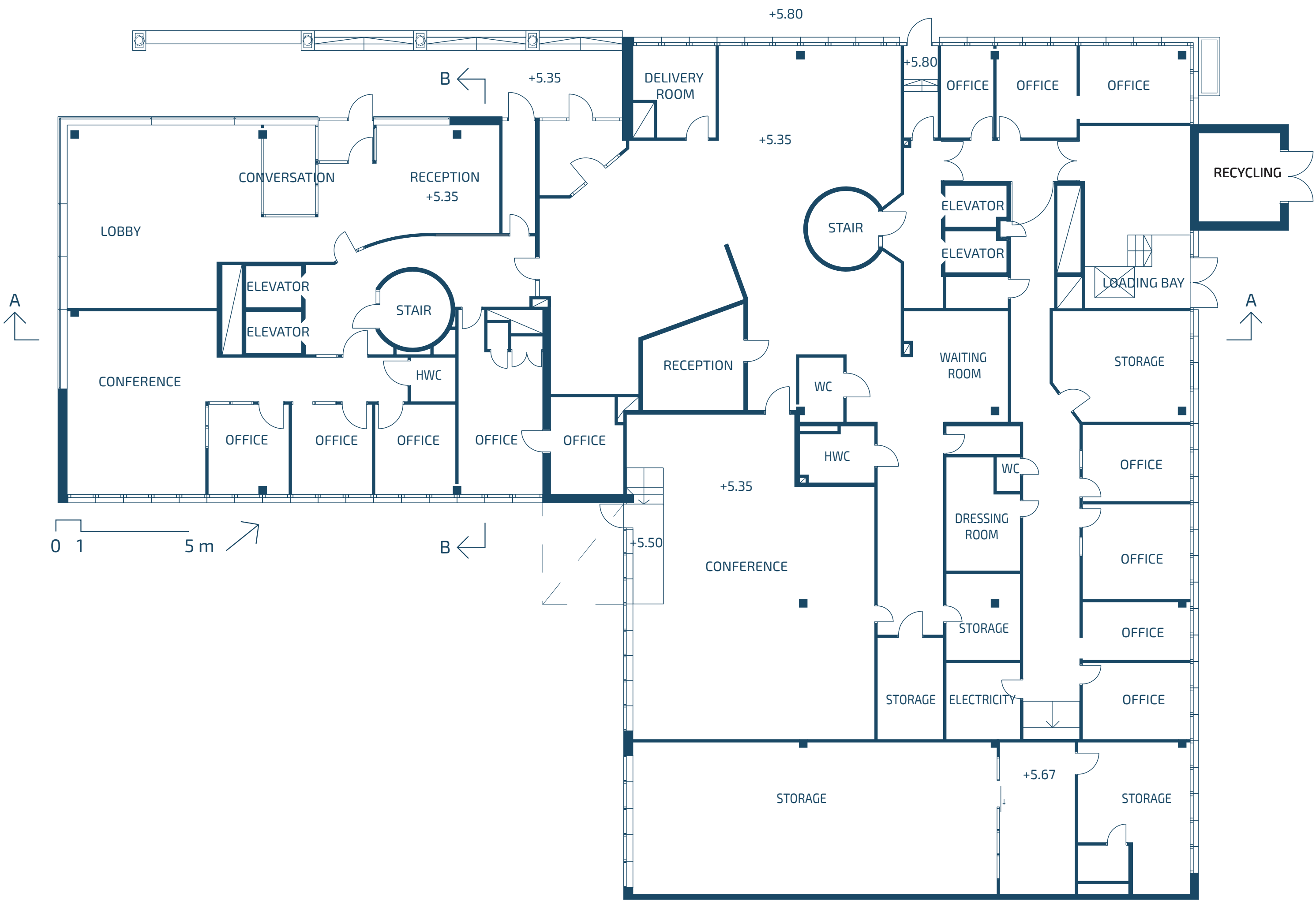


Figure 38. Existing entrance floor plan, 1:250

On the entrance floor, there are multiple street-level entrances usable by both public and private visitors. However, there are slight height differences both indoors & outdoors, resulting in stairs and ramps. There is a connection between the staircases with the possibility of connecting the entire floor, however, there are pillars scattered in the middle of spaces. There are four elevators and two staircases, all surpassing the accessibility limits of the Swedish standard. The accessible WCs (HWCs) also pass the standard requirements, although they are modest in size. There is an accessible recycling room within the Swedish Standard 50-meter distance limit of the entrances.

Overall, the majority of the entrance floor is preservable. The situation with multiple entrances enables a division between private and public entrances, providing the possibility to keep the core private.

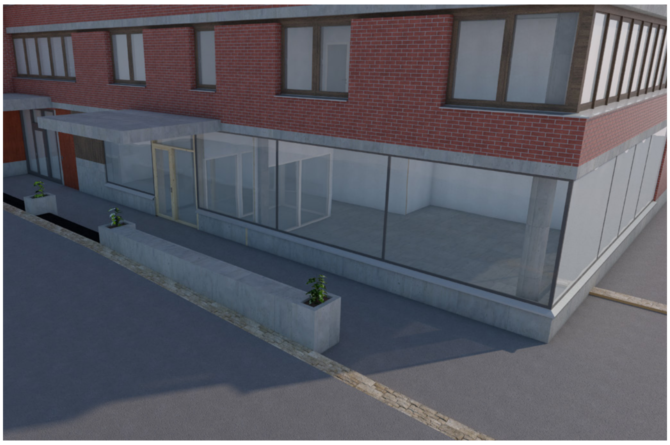


Figure 39. Public entrance

Basement

The basement is mainly used for technology, storage and parking. There is plenty of parking, however slightly obstructed by the pillar system. There is a staircase connection from the parking garage to street level, but no direct elevator connection.
There is also a sauna, changing rooms and showers that could be kept and used by residents. There are storage rooms that could be turned into storage units for the residents. There could also be space for residential bike parking.

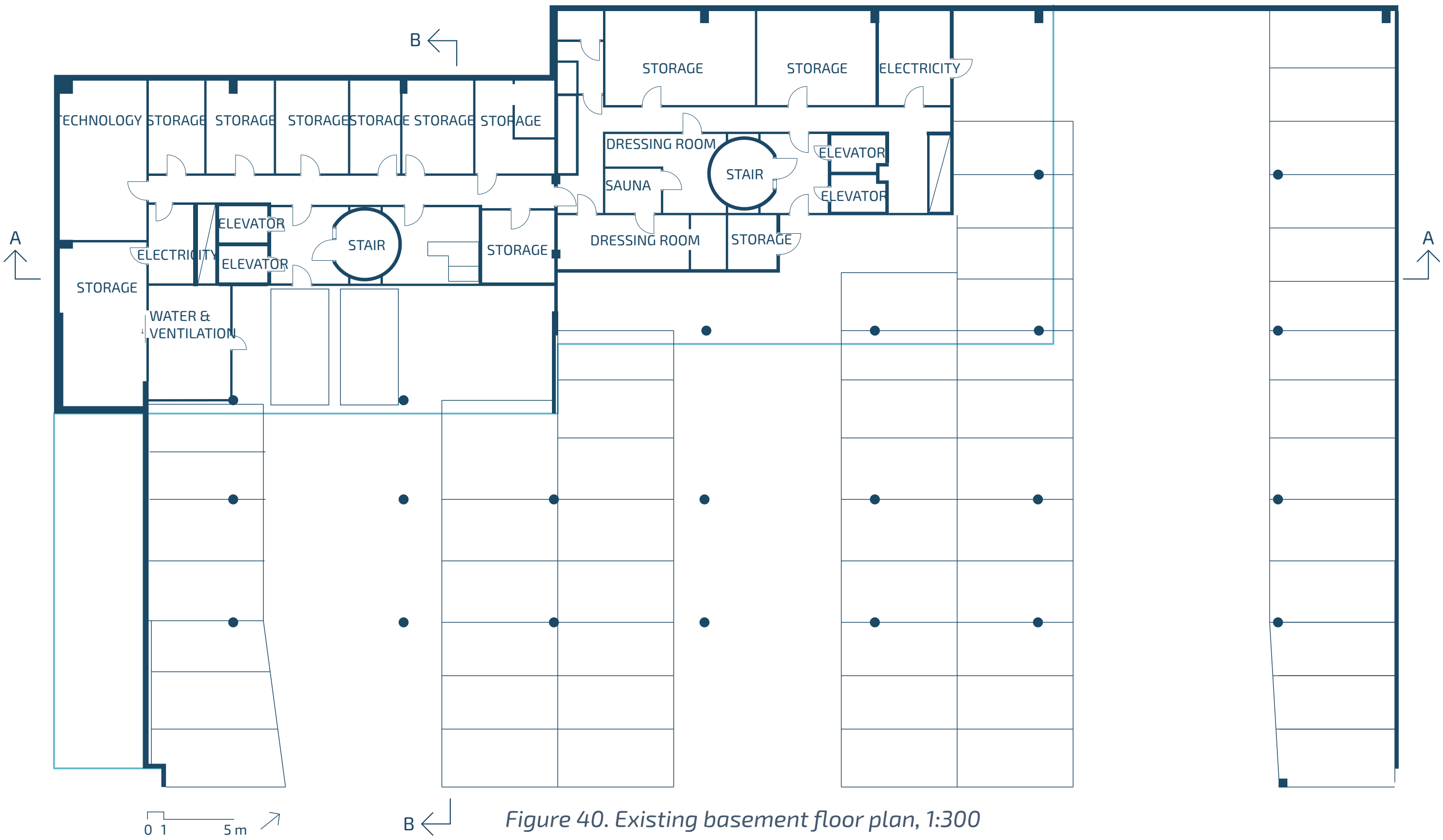


Figure 40. Existing basement floor plan, 1:300

Typical floor plans

The concrete core with shafts, elevators and staircases goes all the way through the building. There are less pillars than the basement and entrance floor, which makes it highly likely that the core elements are loadbearing.
The other central elements, housing bathrooms, shafts and storage, are not concrete, but are also generally the same for each floor.
A comparison of two floors shows that the internal walls outside of the core and central elements are different for each floor. It can also be noted that some of the staircases have been extended, likely to fit a stretcher.

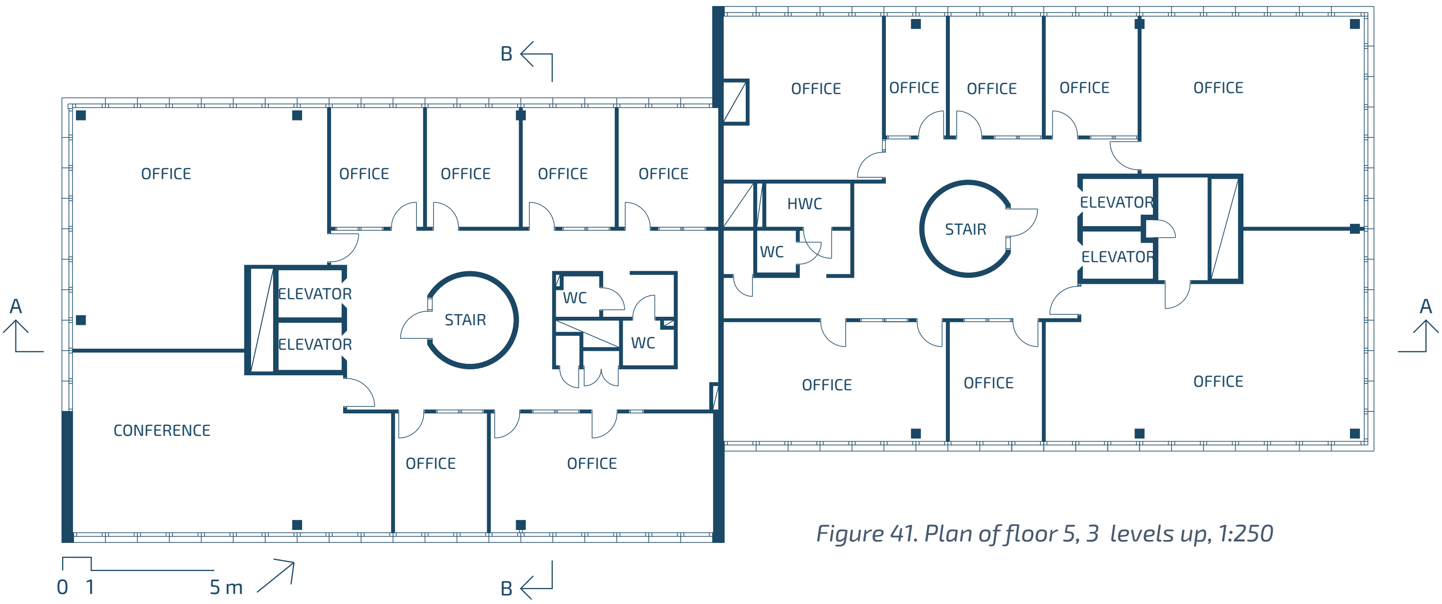


Figure 41. Plan of floor 5, 3 levels up, 1:250

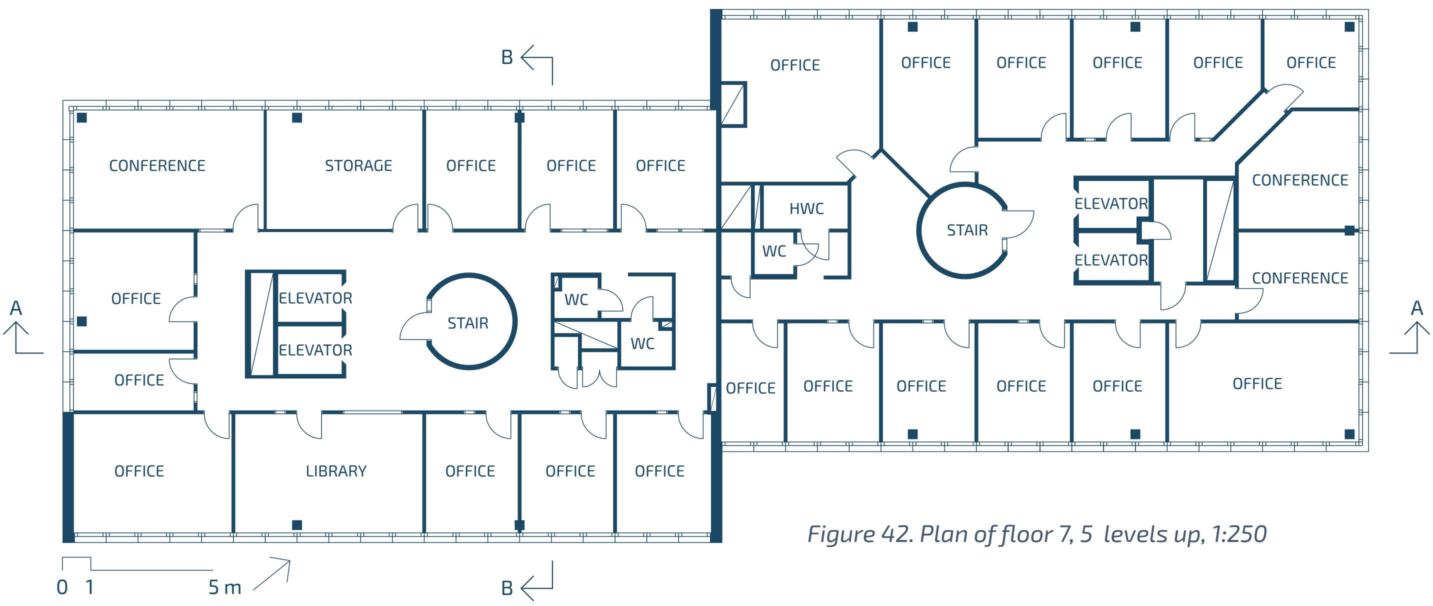


Figure 42. Plan of floor 7, 5 levels up, 1:250

Elevations

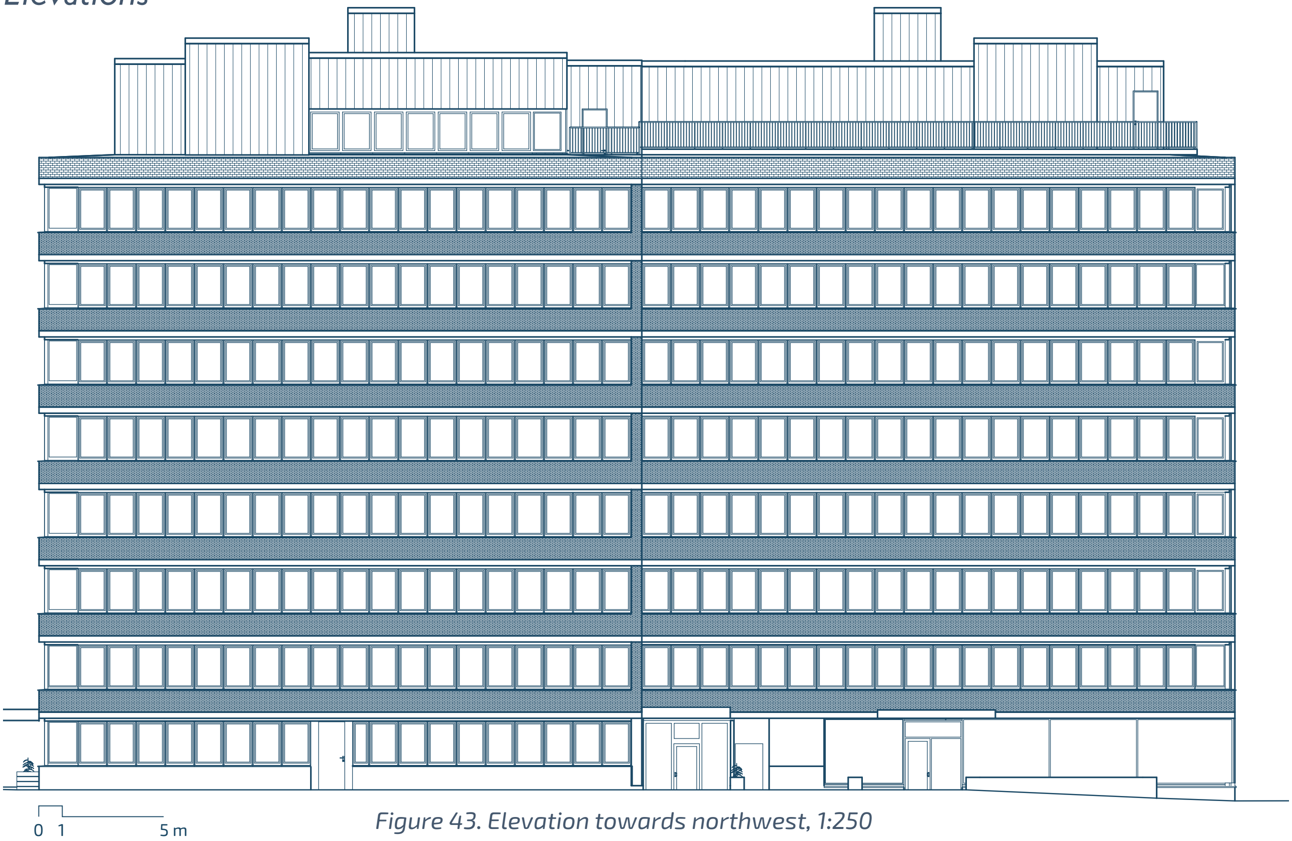


Figure 43. Elevation towards northwest, 1:250

Windows are placed in a module system with the pillars and are placed the same on all floors except the roof and entrance floor. Brick parts are placed under the windows, while painted cement fibre boards are placed between the windows and the slabs. Corner windows also have cement fibre in the intersection between them.

In the middle of both the north and south facades, there is a break between the two ties where the two building parts are offset. In the south facade, the window tiers go over one of the corners, while the other one ends in a wall. In the north facade, the windows go over both corners.

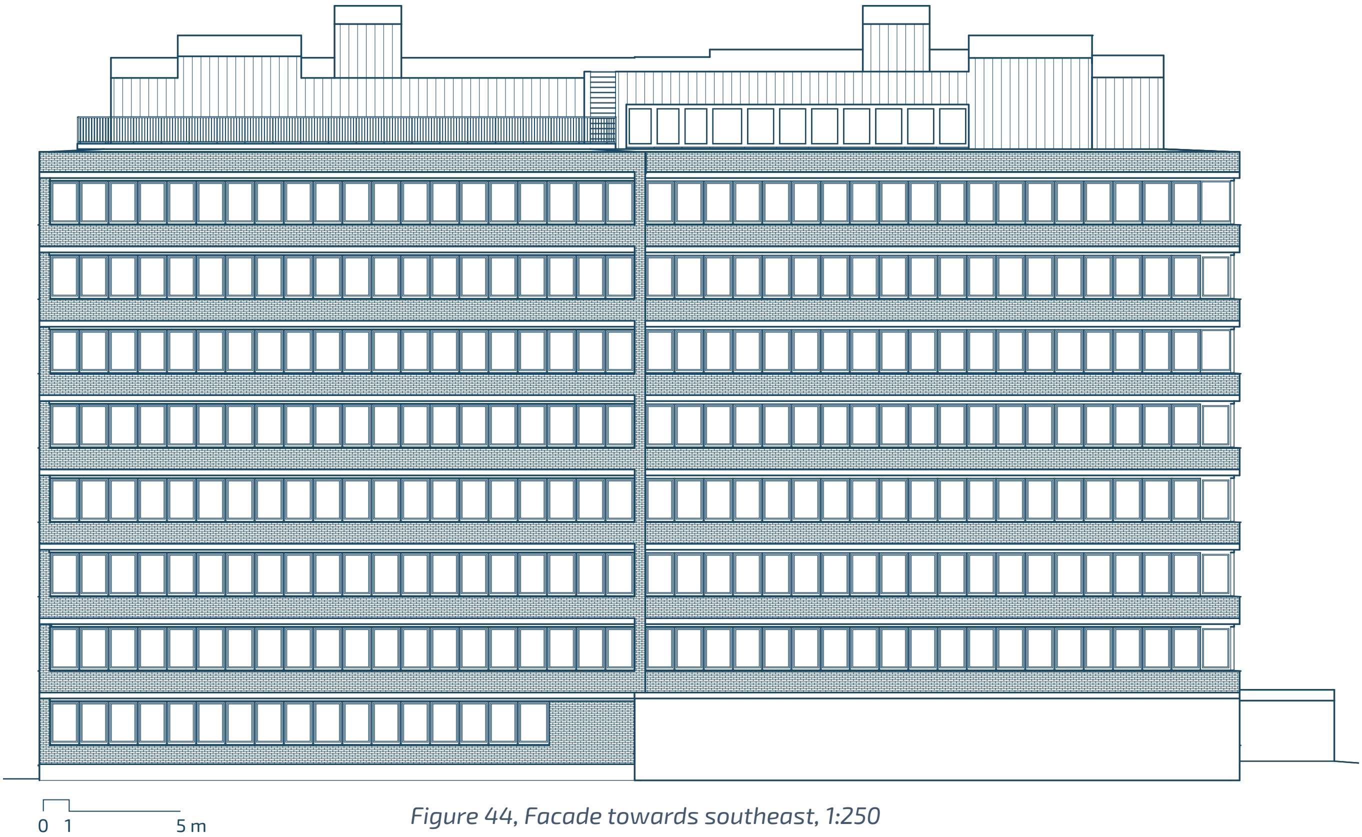


Figure 44, Facade towards southeast, 1:250

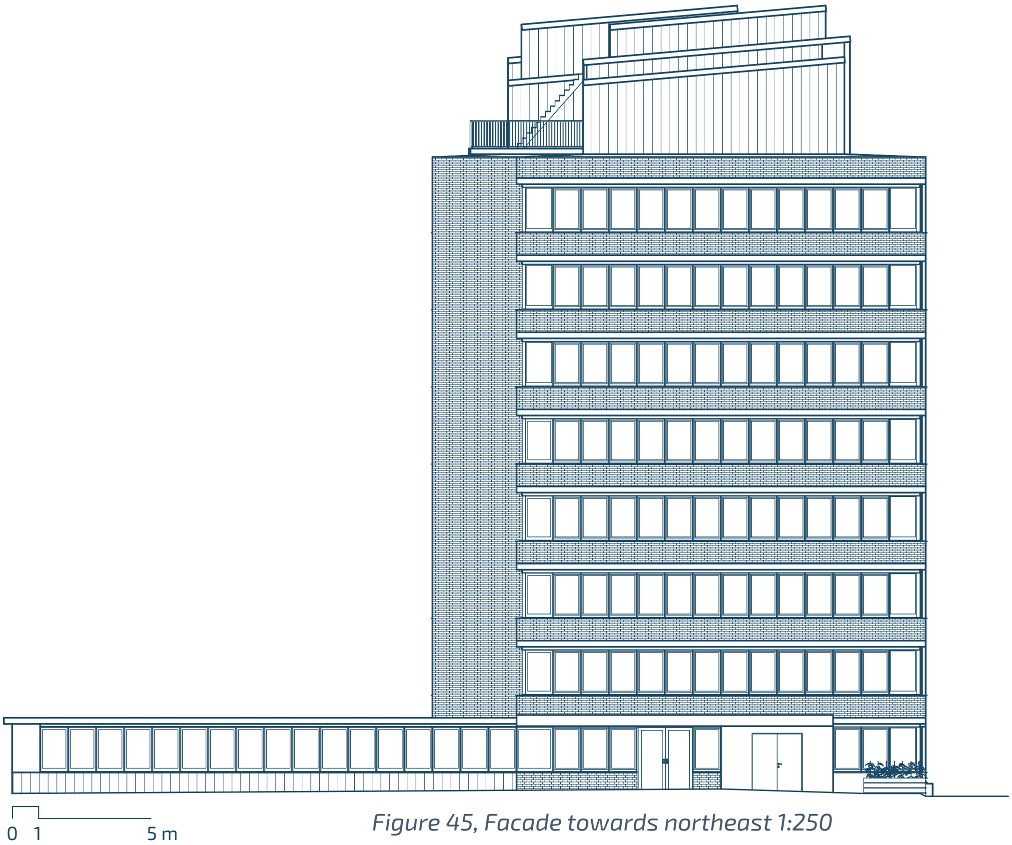


Figure 45, Facade towards northeast 1:250

Towards the southwest, there is a section of the wall without openings. Here, the slabs also don't go all the way through, giving an uninterrupted wall structure from ground to roof.

Towards the northeast, the windows go over the entire wall and both corners. On the ground floor, the openings go all the way to the plot boundary. There is no shading on this facade. There are also no windows or slabs on the offset parts.

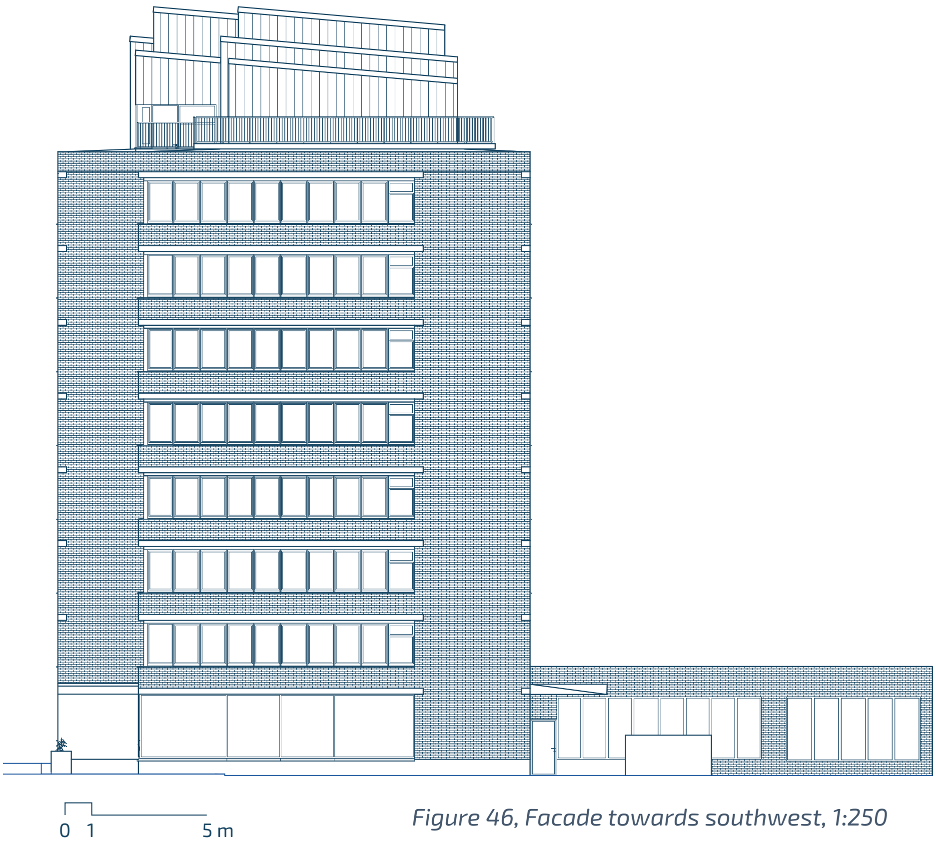
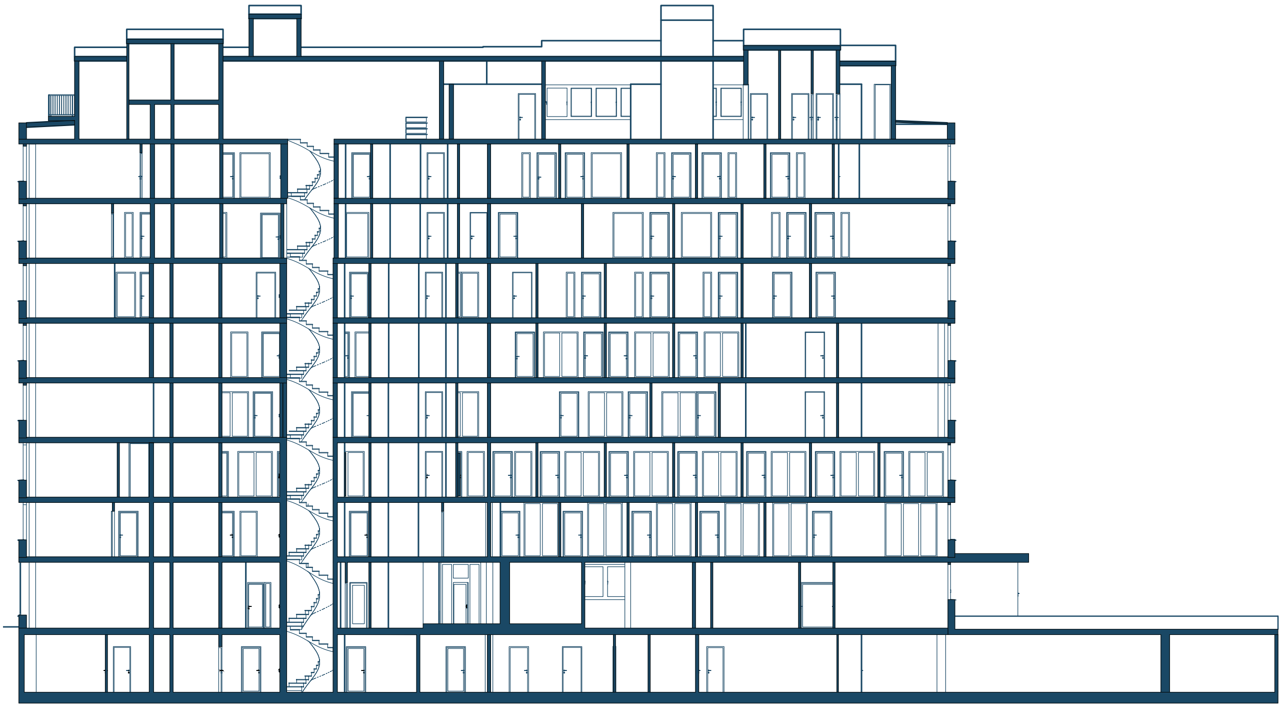


Figure 46, Facade towards southwest, 1:250

Sections

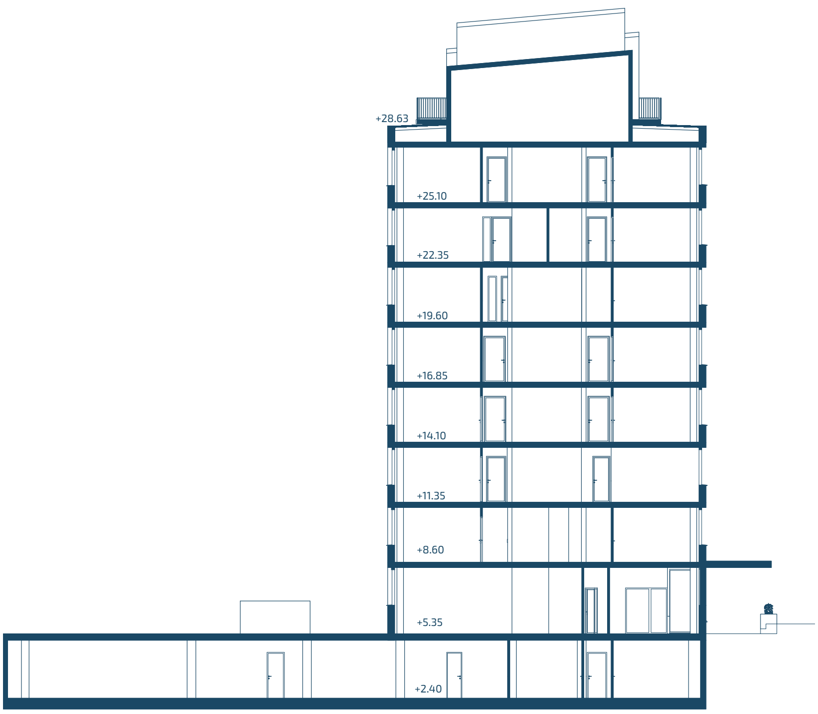


0 1 5 m

Figure 47. Section A-A, 1:250

The heights of the typical floors are all equal, at 2.75 each, including the slab. The height of the entrance floor is 3.25 m, and the height of the basement is 2.95 m. The sections clearly show differences between the floors regarding wall placement, doors, windows, and functions of the rooms.

The floor slabs run through the building, and on the inside the slab is raised, although there is no indication in the original drawings of any other floor construction or covering than the raw concrete, which makes it difficult to know what the material looks like in reality.



0 1 5 m

Figure 48. Section B-B, 1:250

Detail and construction analysis

The current construction consists of exterior walls with two thicknesses, 320 mm and 350 mm. Both of these are brick with concrete structure and insulation between. The main problem with the existing walls is that both of these lack airgap to ventilate the brick. This means that moisture can move through the construction and cause issues. The current U-value is 0.45 W/(m2*K).

The suggestion from the actual renovation is to insulate outwards & replace the brick, due to several reasons. Importantly, insulating inwards would mean that the thermal bridges remain, and the facade will need to be replaced anyway due to bad brick joints. This means that the outer walls will go beyond the plot boundary, but this was approved by the building permit council in Gothenburg. However, it is worth noting that it was protested by the neighbours for going against the detailed plan for the site.

Another issue is that the slabs go all the way through the construction, resulting in a thermal bridge throughout the building severely impacting the thermal performance of the building. Furthermore, according to a facade investigation made for the renovation, the concrete is damaged from carbonisation.

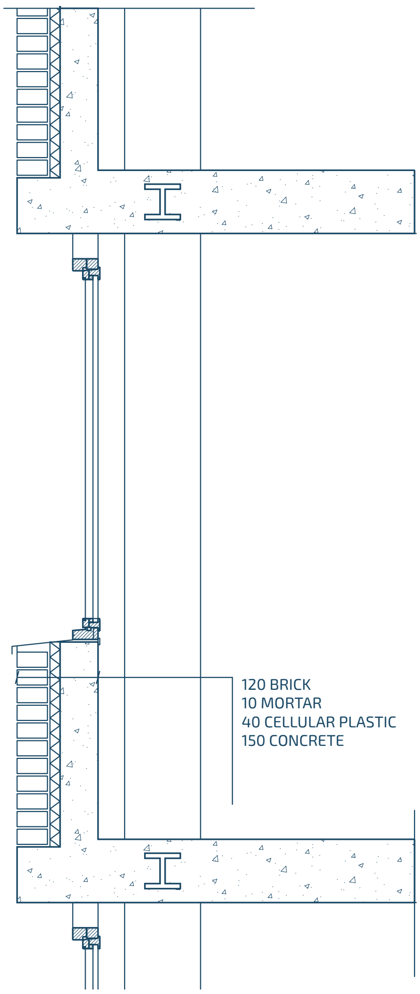


Figure 49. Existing detail

Pillar system

The pillars are thoroughly described in the original drawings, they are all constructed of reinforced concrete and placed throughout the whole building. The wall parts without windows are assumed to be load-bearing, as pillars are not placed here, differently from the rest of the system. As the pillars are from the original construction, they might require some maintenance.

Interior walls & core

The core is, as mentioned, loadbearing and specified as concrete on original drawings. The construction of the interior walls is not specified, and these are different on each floor, meaning these are not load-bearing and likely not concrete.

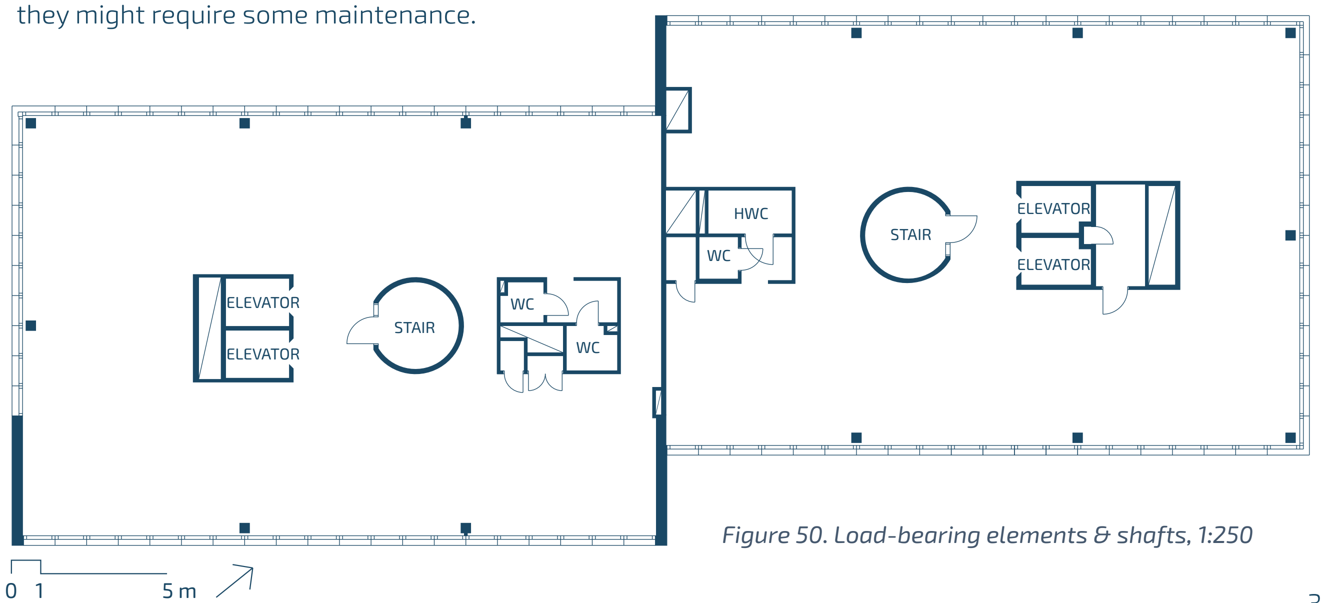
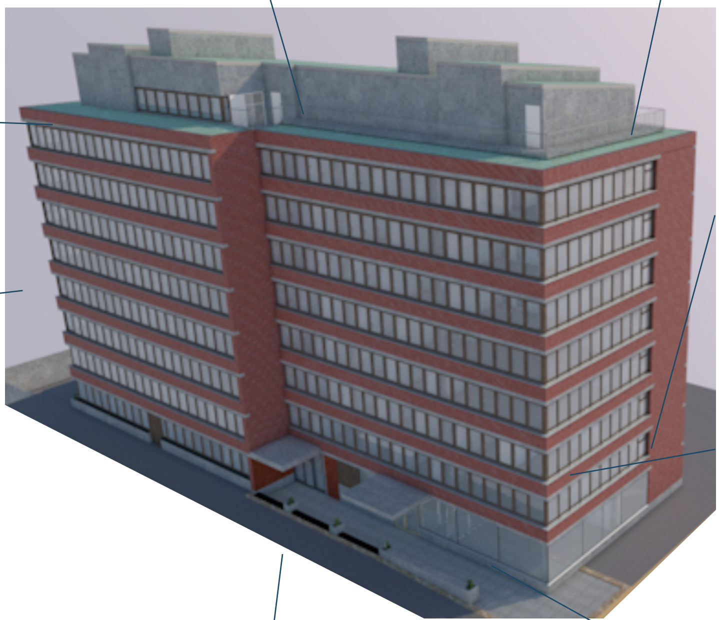


Figure 50. Load-bearing elements & shafts, 1:250

Material analysis



Daylight analysis

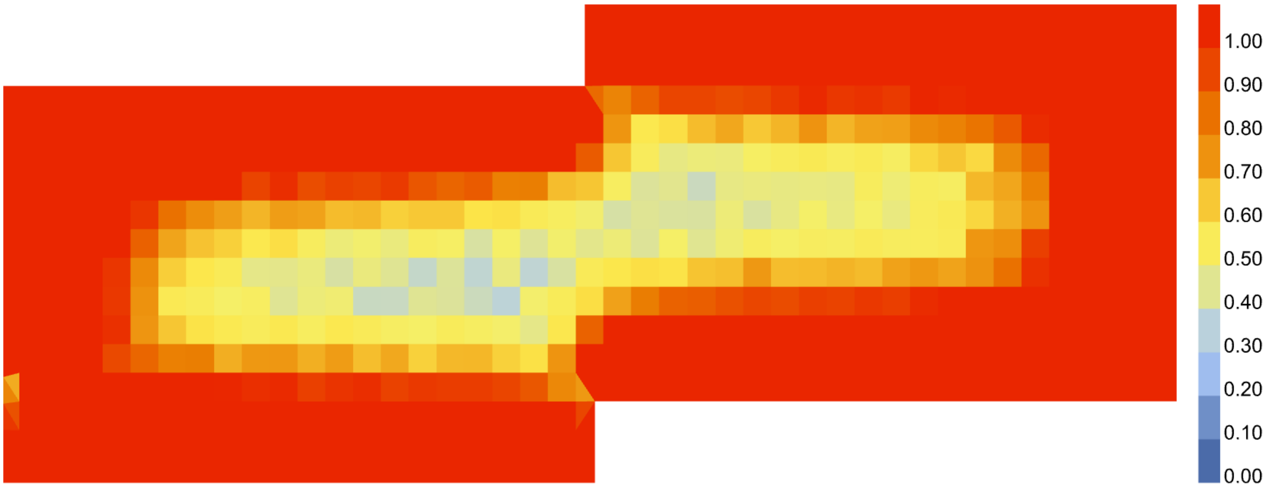


Figure 51. Daylight of the existing building

The daylight analysis of the core and external elements shows that there is ample daylight throughout the building. Based on this high daylight factor throughout the building, it is possible to close openings to be able to place walls, kitchens and other permanent elements.

Overheating analysis

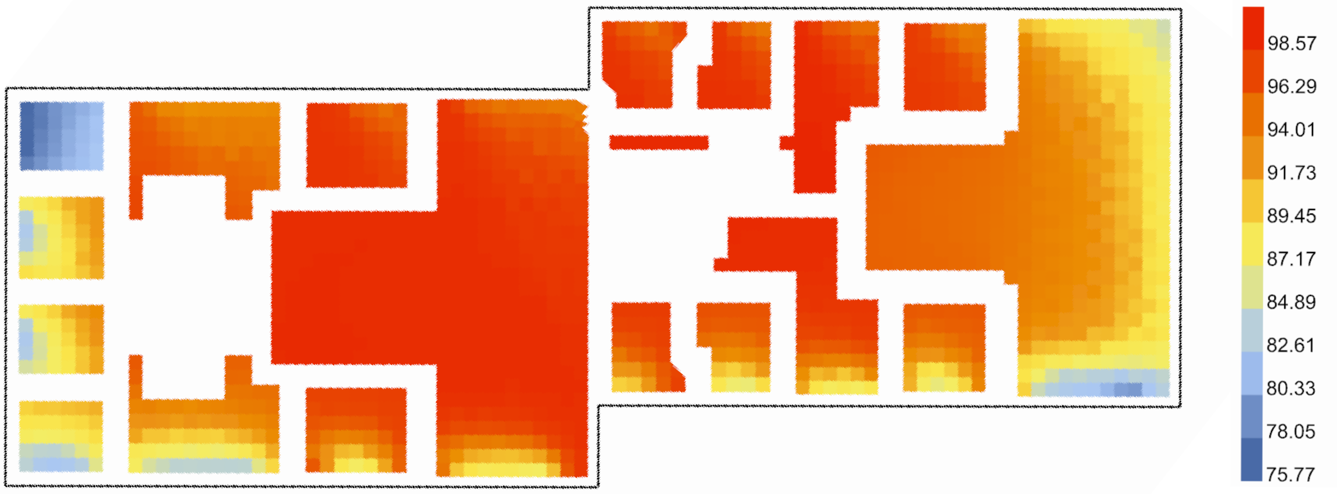


Figure 52. Thermal comfort of the existing building

The overheating analysis is performed using the same model and programs as the daylight analysis. This is based on thermal comfort and operative temperature.

This result shows that a lot of spaces are at risk of overheating. This is based currently on my experience of previous overheating analysis performed during internship.
There are plenty of windows placed in ties, with no balconies or other permanent shading elements. Furthermore, the project intention of small spaces makes overheating even more likely. This analysis is also strengthened by the fact that awnings for shading already exist in three directions.

Caala analysis

The program CAALA is used to analyse energy demand and carbon footprint through life cycle assessment. For this analysis, the same model as for the daylight and overheating is used.

These results indicate the performance of the existing building and show where the improvement possibilities lie. This kind of analysis of the existing elements gives the opportunity to compare different solutions, for example, different thicknesses or types of insulation.

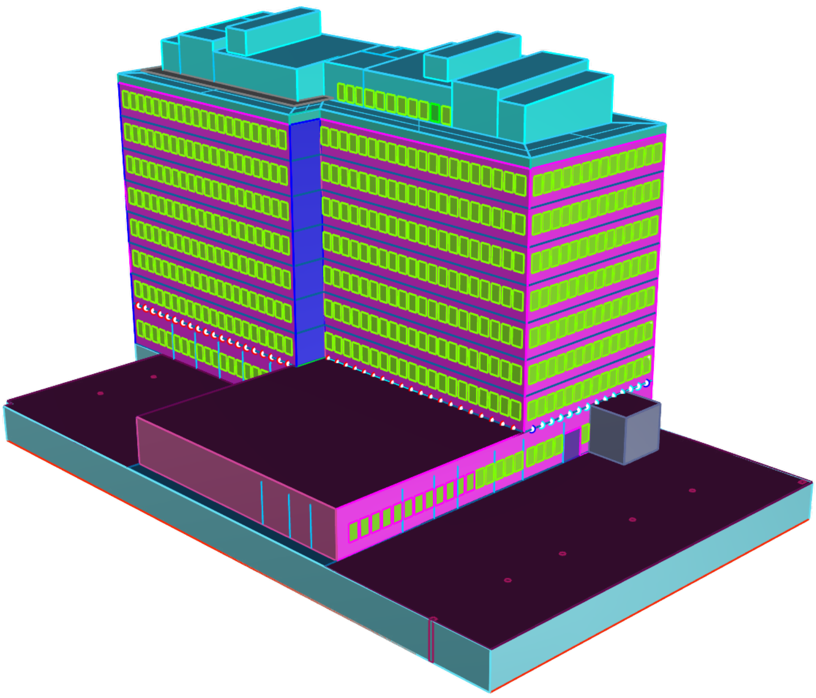


Figure 53. Existing CAALA model

Primary energy demand

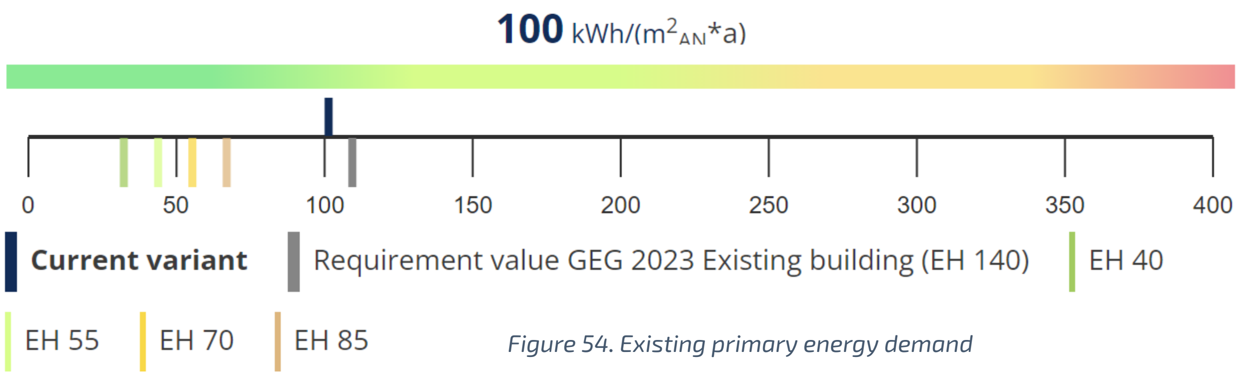


Figure 54. Existing primary energy demand

Life cycle assessment

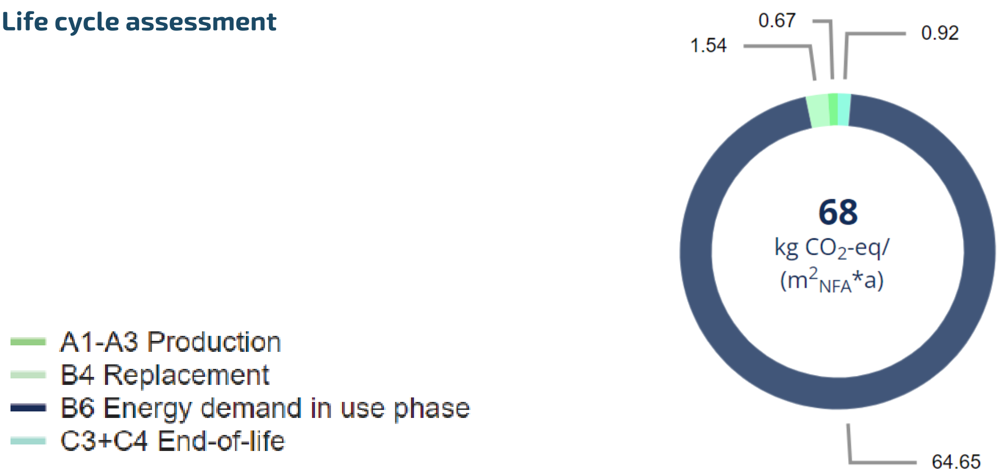


Figure 55. Existing GWP

Ventilation, MEP and technology analysis

In the existing building, there are several large shafts for ventilation, water, and other systems. These are connected to the elevators or the existing WCs. In addition to the larger shafts, there are smaller ones located right next to the WCs. Ideally, these shafts will be kept, as it would be both expensive and difficult to move or remove them completely. However, a few shafts are a little difficult to work with because of their placements.

In addition to the shafts, there are technology rooms in the basement. These are a little spread out on the floor, often with rooms between them. There are rooms for all necessary equipment, including electricity, water, and elevator technology. There is also a possibility to expand these rooms if necessary, as they are all located next to storage rooms. As previously mentioned, there is no direct elevator connection to parts of the bottom floor, which might cause a need for more technology spaces. Ventilation and fans are located on the roof.

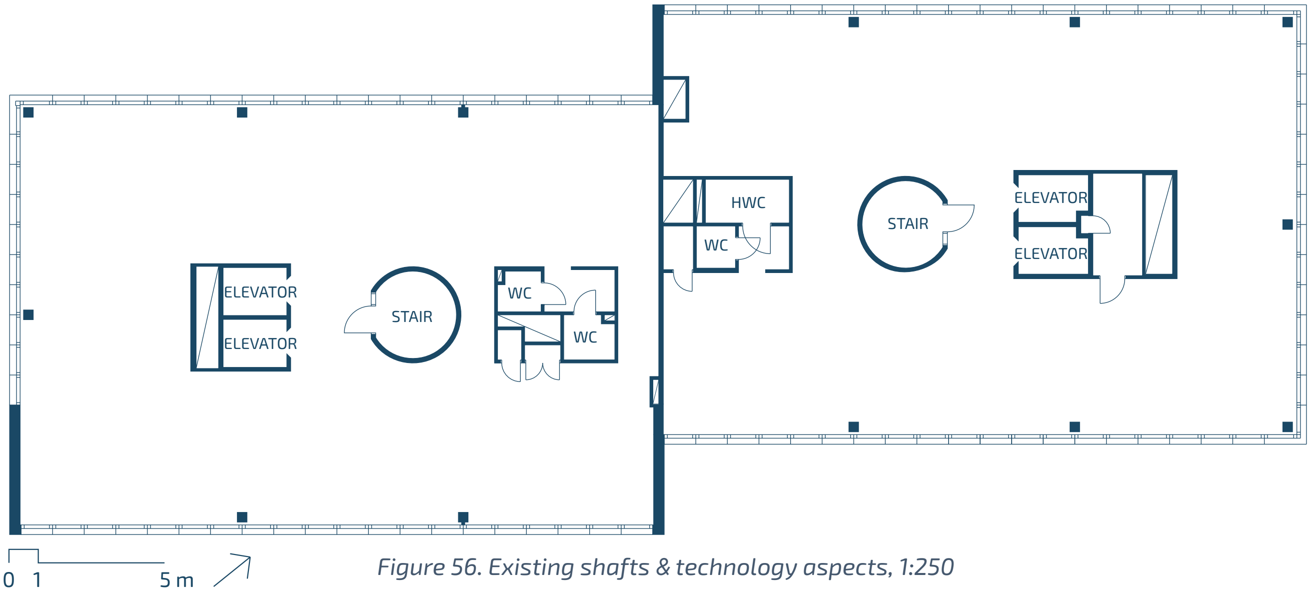


Figure 56. Existing shafts & technology aspects, 1:250

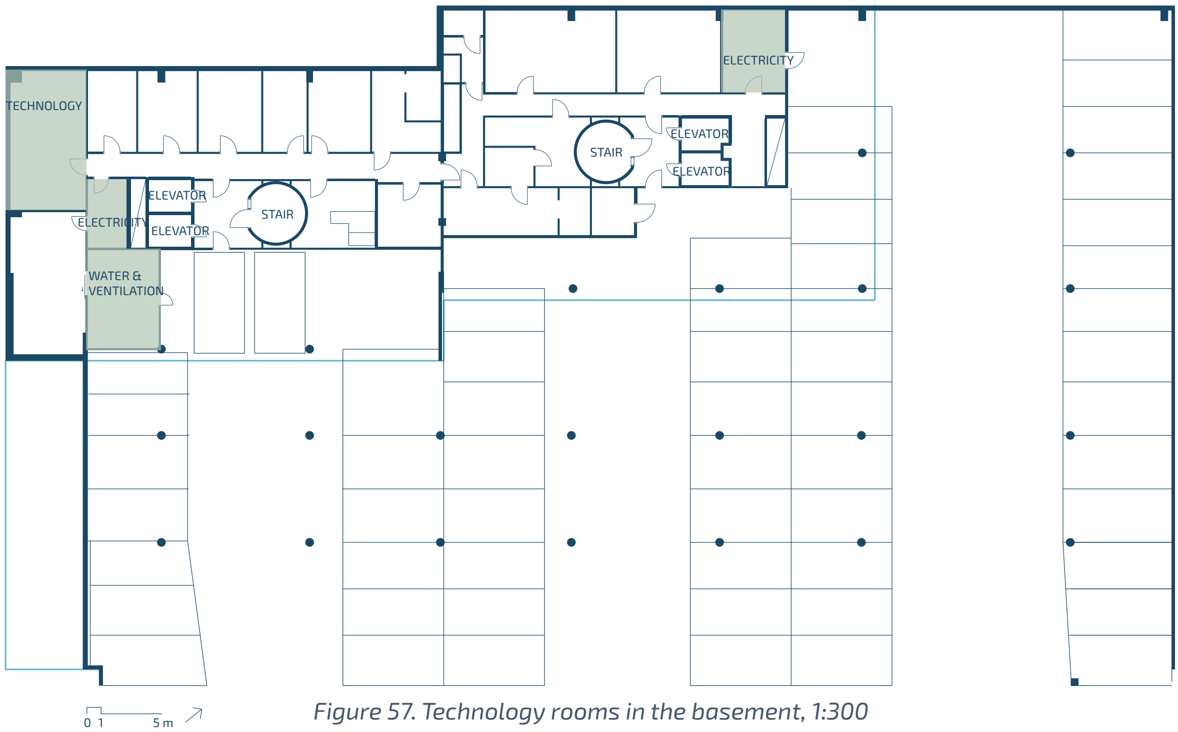


Figure 57. Technology rooms in the basement, 1:300

Early design process

Introduction

Several possible floor plans and space organisations have been explored based on various criteria, and they are all presented in this section.

Nine different options are presented along with their design idea and specific concepts. Furthermore, the evaluation matrix described in the background is used to compare designs.

Overarching concepts - early design stage

During the early design process, sufficiency concepts are explored through testing of different floor plan designs. Many other applications are kept in mind, such as ventilation requirements, water systems, renewable energy, etc., but are not the focus of the early design phase.

Users

The target audience for this project is people who might struggle with affording other housing for various reasons. This includes, but is not limited to, young adults, seniors, families with lower budgets and keyworkers with lower salaries.
This requires flexible, small but accessible spaces with thermal comfort and ample daylight.

Density

Density is crucial in sufficiency, and considered through design for lower living area per person

Flexibility

Flexibility is considered through flexibility in size within units and creating multi-purpose spaces

Co-living

Sufficiency in co-living is explored, enabling a comparison between private and public.

Low main-tenance

Maintenance is considered both in the early material choices and in the number of bathrooms and kitchens

Adaptive reuse

Adaptive reuse is considered by changing required spaces into housing while keeping other parts untouched

Sustainable materials

Required thicknesses for sustainable material constructions are decided and used in plan drafts

Recycling

Recycling is considered through reuse of the existing, and through design for tenant recycling

Cost of Waste

Keeping as much as possible is economical both for the environment and the project economy.

Embodied carbon

Embodied carbon is considered through reusing as much as possible of the existing

Design options and evaluation

Swedish standard - small

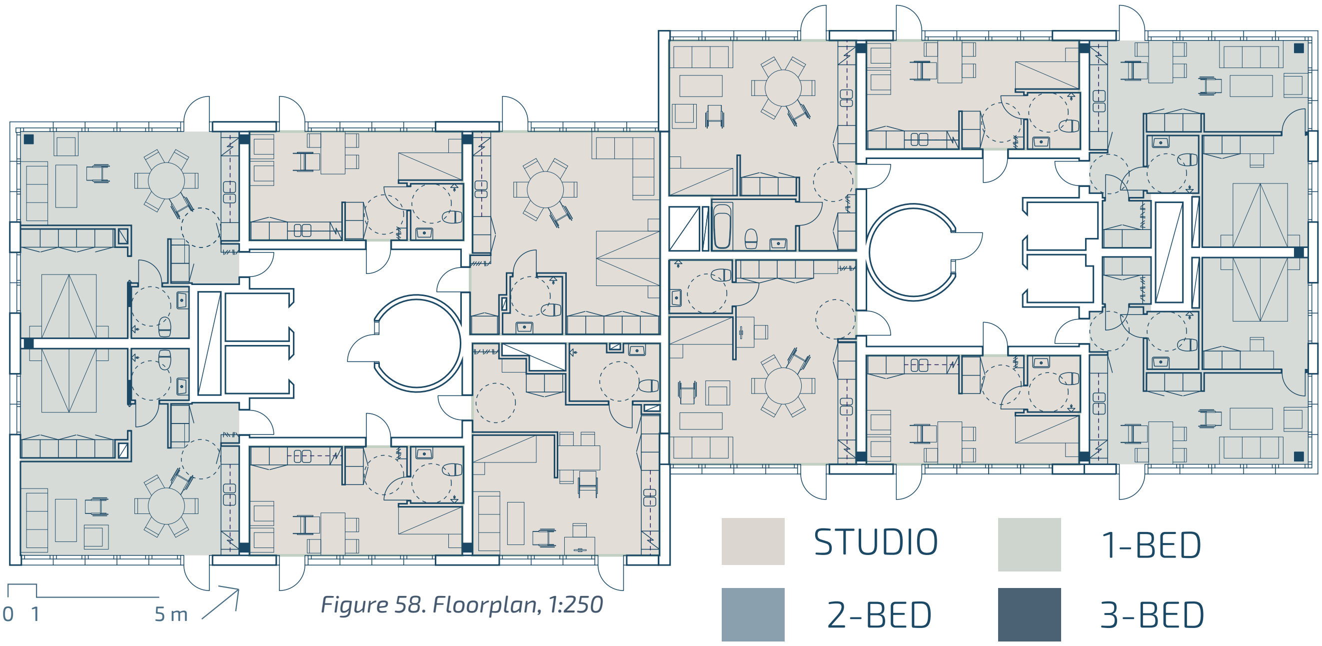


Figure 58. Floorplan, 1:250

Option concept

In this option, all the criteria for normal level accessibility according to the Swedish standard are fulfilled. The existing pillars are built into the walls not to interrupt the furnishable space in the apartments. Furthermore, the existing shafts are kept and rebuilt into new bathrooms. Furthermore, this floorplan attempts to create small, space-effective units with full accessibility. This option serves as a test of small, one-sided apartments. Within the apartments, a division of space is attempted, keeping the bed separate from the everyday functions and providing the possibility to partition the room.

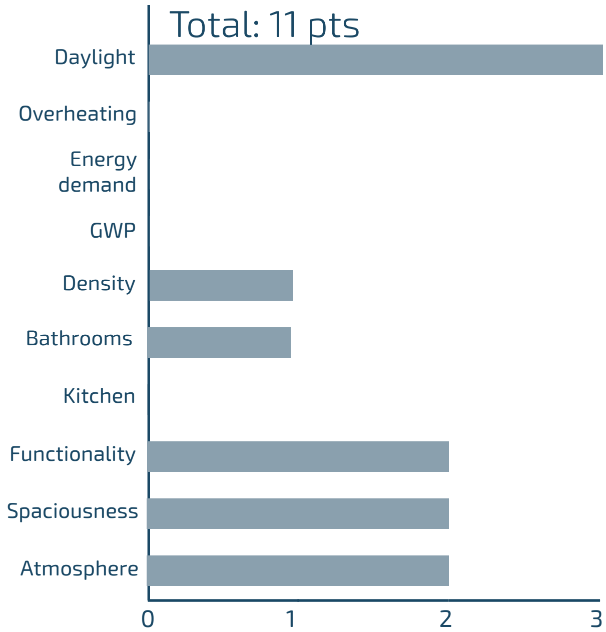


Figure 59. Design evaluation result

Reflection around design

Putting the pillars inside the wall creates very strict apartment sizes, deciding the layout and distribution of apartments. This means that creativity within the apartments is necessary but limited.

Within the apartments, each function has its separate space, however, with this strict division of space furnishing possibilities and flexibility in the use of space are constrained. This option results in many small apartments, lacking variety in size and with limited possibility to house the intended users of this project.

It can also be concluded that working with small apartments, limiting aspects are kitchen size and storage requirements.

Reflection of result

This option presents each unit with an individual kitchen and bath, resulting in a low index on these criteria. Furthermore, narrow apartments with plenty of windows tend to overheat a lot, further impacting the primary energy demand. The GWP is affected by the closure of numerous windows, and a large number of new walls. The apartments themselves are space-effective, although this results in a lack of flexibility in size within the apartments.

Swedish standard - large

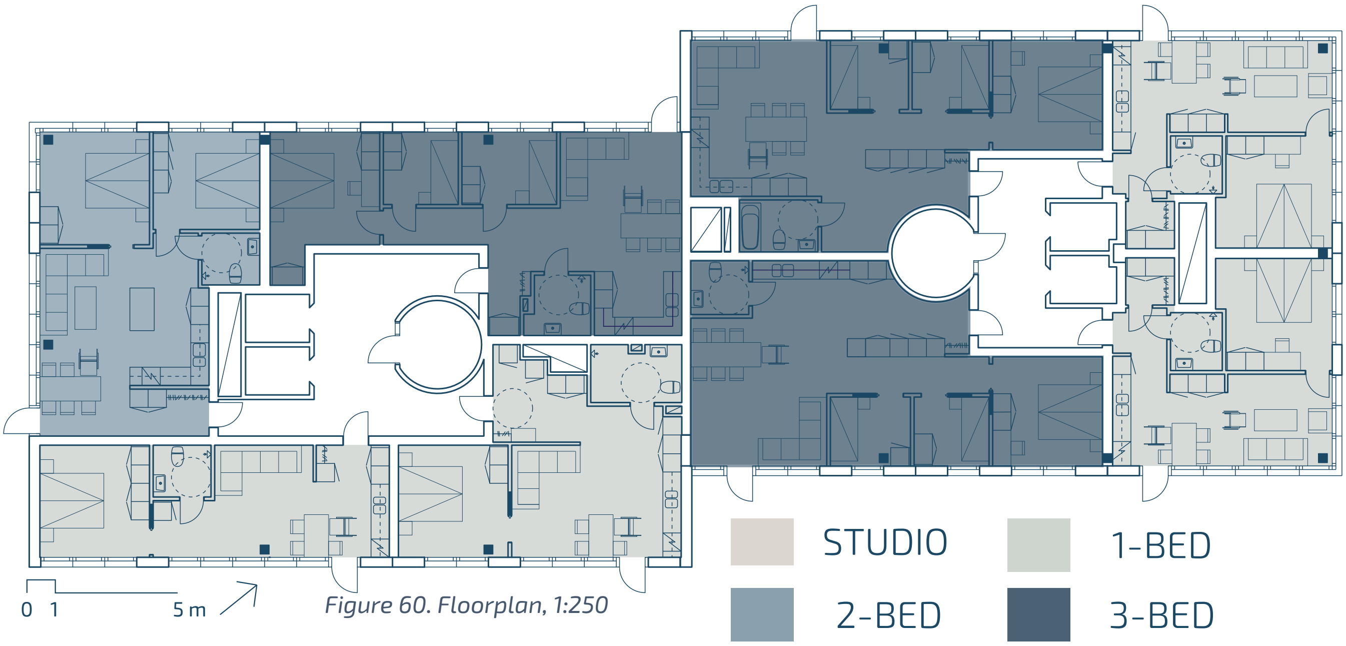


Figure 60. Floorplan, 1:250

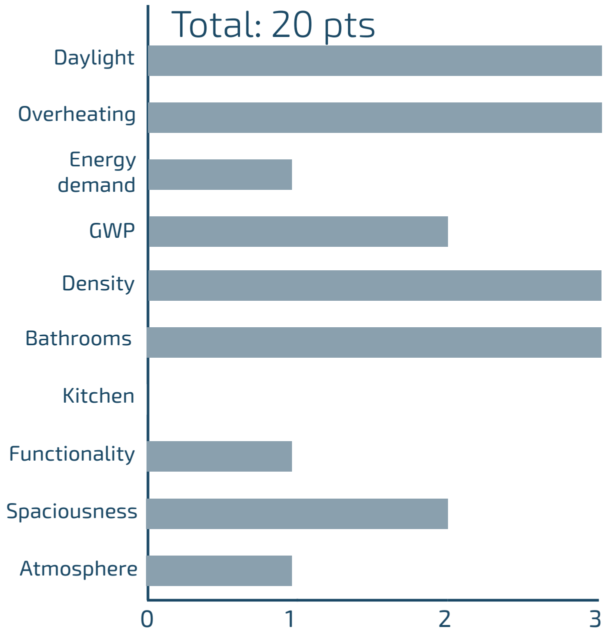


Figure 61. Design evaluation result

Option concept

As in the previous option, this floorplan layout fulfills the normal level criteria of accessibility. However, pillars are partly placed within the units, with a few placed within the walls. In this option, more variety between units is attempted, and the layout consists more of larger apartments with multiple bedrooms. The bedrooms vary in size within the units, but at least one bedroom per apartment can house an accessible double bed.

Furthermore, this option explores how the staircase can be optimised and utilised, working with a more narrow stairwell and engaging the round staircase in design.

Reflection around design

This option provides a better balance of unit types, with multiple sizes and options for various users. However, bigger units provide a larger share of dark areas due to multiple bedrooms with daylight requirements using the limited number of openings.

The free placement of pillars gives more flexibility in apartment sizes and placement, however, it also provides challenges with functionality and the furnishability of a room. Building the circular staircase shape into an apartment results in narrow corners and an unusable wall in the hallway. However, it does result in a more harmonical shape of the stairwell.

Reflection of result

The energy demand is lower per sqm with more openings, with fewer walls resulting in lower GWP. Larger apartments house many inhabitants with few bathrooms. Kitchens are fewer, but still relatively large. The functionality is limited due to the long distance between the bedroom and entrance for daylight reasons. This option results in many apartments with only one facade and with plenty of dark areas, strongly affecting the atmosphere. It can be concluded that larger apartments are better from a technical view, however with decreased design quality.

Lowered standard - small

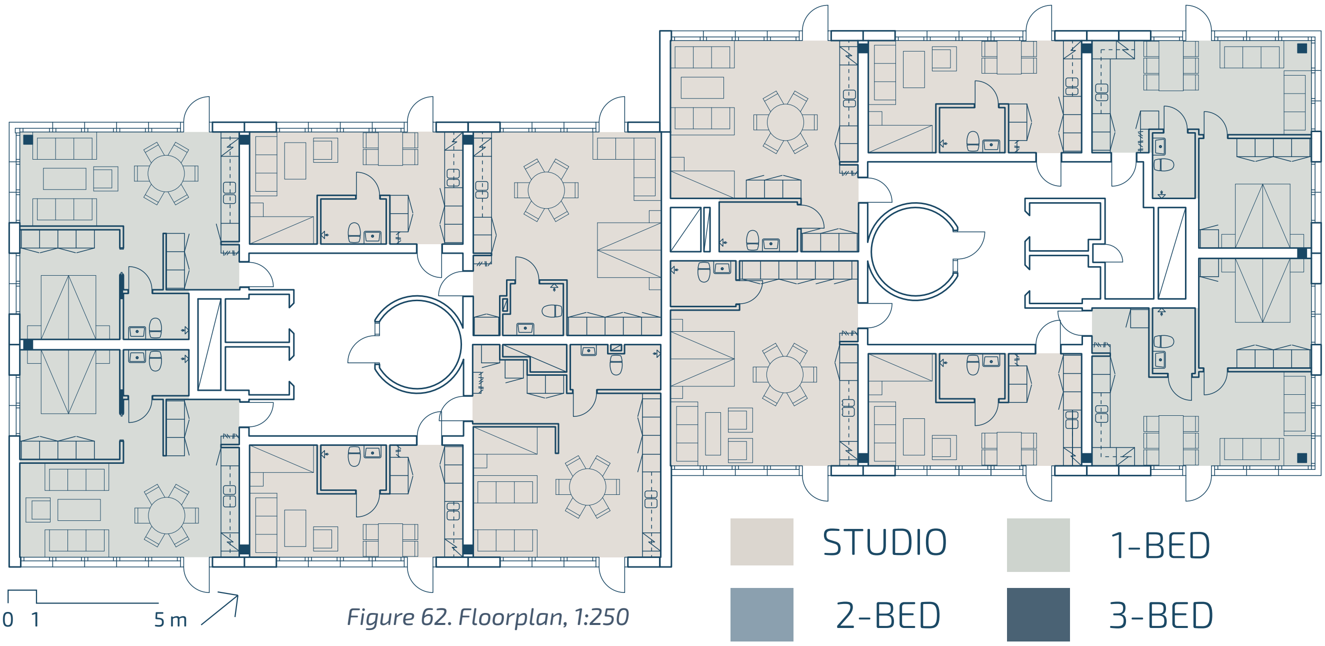


Figure 62. Floorplan, 1:250

Option concept

This option explores the same apartment distribution and sizes as the *Swedish standard - small*, although this option works with the lowered accessibility criteria in the Swedish standard. This means different function measurements for furniture and other bathroom dimensions.

The pillars are still placed inside the walls and decide the floor layout, and the shafts are kept. However, one difference is that the access to the electricity cabinet behind staircase B is preserved, removing furnishable space from the top corner unit.

Reflection around design

It can be concluded that with the same layout and a lowered standard of accessibility, more furnishable space is required, however, this does also result in more communication area.

Designing with the lowered accessibility standards would have created more benefits if the design had started from a new layout instead of using a plan adapted to accessibility.

The most challenging aspects of small apartment design are still the kitchens and the amount of storage required. There is no difference between using lowered or normal accessibility.

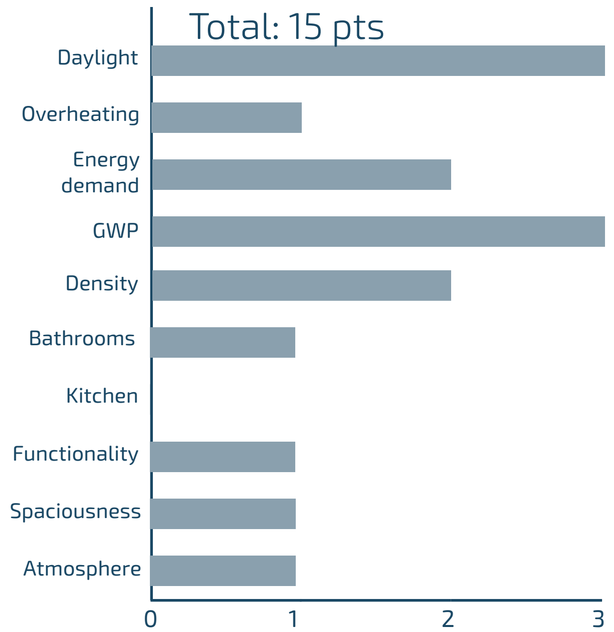


Figure 63. Design evaluation result

Reflection of result

In comparison to the normal standard option, the units are slightly less likely to overheat, providing lowered heat demand and by extension a lowered GWP. The density is higher due to the possibility of fitting a double bed in two studios. Due to the small, individual apartments, kitchen and bathroom results are still poor. It can also be concluded that extra furnishable space with the same layout does not result in a difference in design quality according to the evaluation.

Lowered standard - large

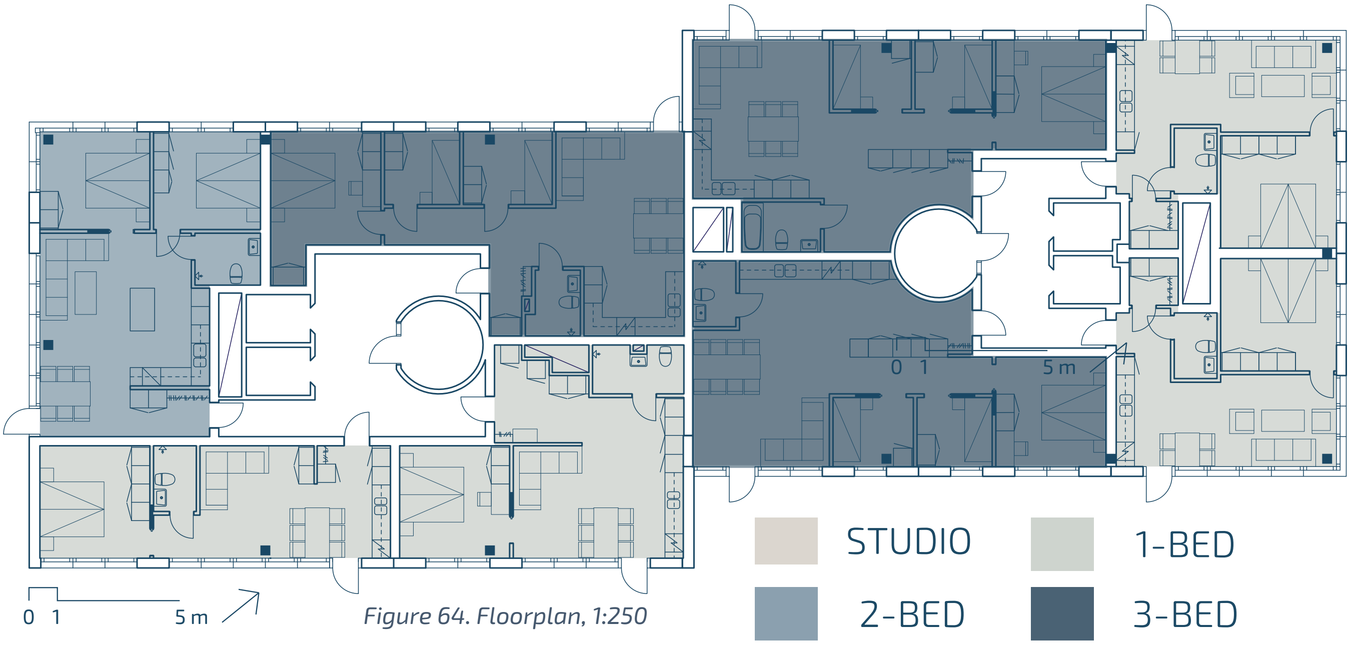


Figure 64. Floorplan, 1:250

Option concept

This option follows the same apartment distribution and layout as the *Swedish standard -large*, again with lowered accessibility instead of the normal criteria. The focus lies on the social areas and how these differ between the different accessibility options. This option offers the possibility to put bigger furniture while still keeping the units rather dense.

The concept of division within the apartment is still applied, and the functionality of a space is still in focus. Pillars are not strictly put inside walls, instead, the distribution of space follows design needs.

Reflection around design

The placement of the entrance doors can be improved on the left side of the building. Furthermore, it might not be the best to put the shaft within an apartment. In the corner units on the right, the wall placement could be improved with a straight wall.

The units are variable and provide plenty of options for furnishability, however, they are still lacking in terms of flexibility in size. Compared to *Swedish standard - small*, there is less communication area within the apartments, however there is still a lot of dark area.

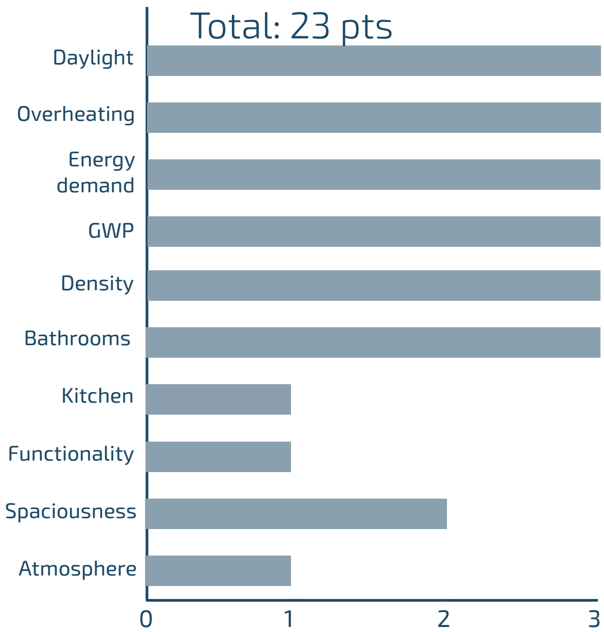


Figure 65. Design evaluation result

Reflection of result

This option gives the highest result in terms of technical qualities. This is due to the size of the apartments, the amount of dark area, and fewer walls. The density and the bathroom index are high, although the kitchen sizes are still poor. The functionality is low due to the long distance between the bedroom and entrance, and many apartments lack multiple facade directions. Furthermore, while dark area aids thermal comfort, it does not provide design quality.

Open co-living

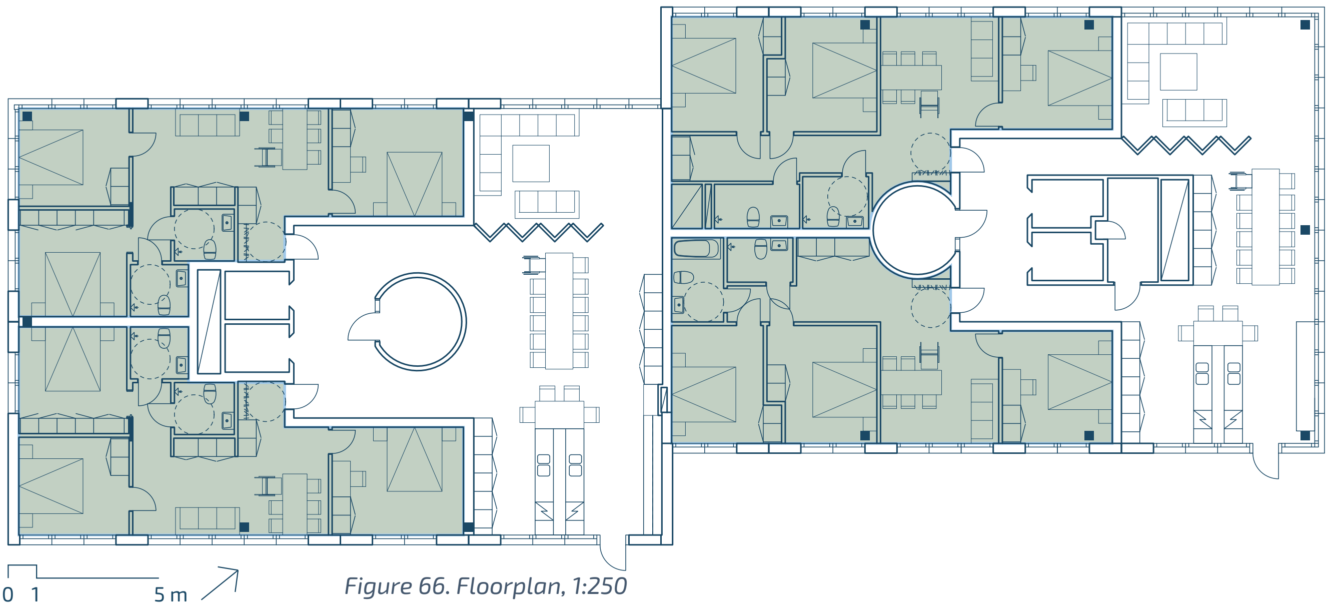


Figure 66. Floorplan, 1:250

Option concept

In this option, co-living is tested following the Swedish requirement for housing with shared areas, stating three people can share a bathroom and twelve people can share a kitchen.

As the co-living areas are the focus of this design, they are placed in the brightest parts of the building. Furthermore, this option works with an open floorplan for the shared spaces, keeping movement around the core and between the kitchen and living room. The living room is separable using a folding wall.

Reflection around design

This floorplan is divided into two apartments with six inhabitants each, due to the rules of bathrooms and kitchens. The bedrooms are all double bedrooms, as this can serve more various users than single rooms.

This also provides flexibility in size for a household. A smaller household can rent one room, and if need of more space rent more rooms within the same apartment. A bigger household can rent a whole apartment with three bedrooms while sharing social areas.

One possible improvement in this design is to keep more of the existing. On the left side, the entire bathroom cluster has been removed.

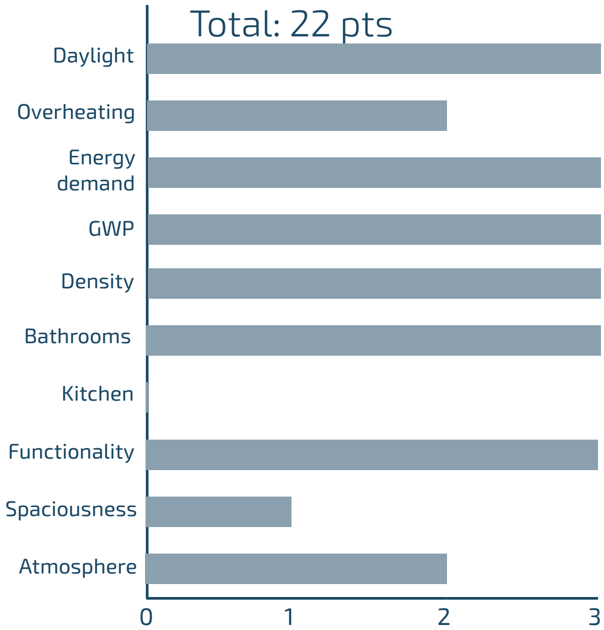


Figure 67. Design evaluation result

Reflection of result

The spaces overheat slightly due to plenty of openings. Few internal walls and a large dark area gives a good energy demand and GWP.
The kitchens are still extensive and can be optimised. It can be argued that the spaciousess is found outside the apartment and larger than other options, however measuring spaciousness in co-living is complicated. The dark area within each apartment is slightly large due to bathroom size and placement.

Divided co-living

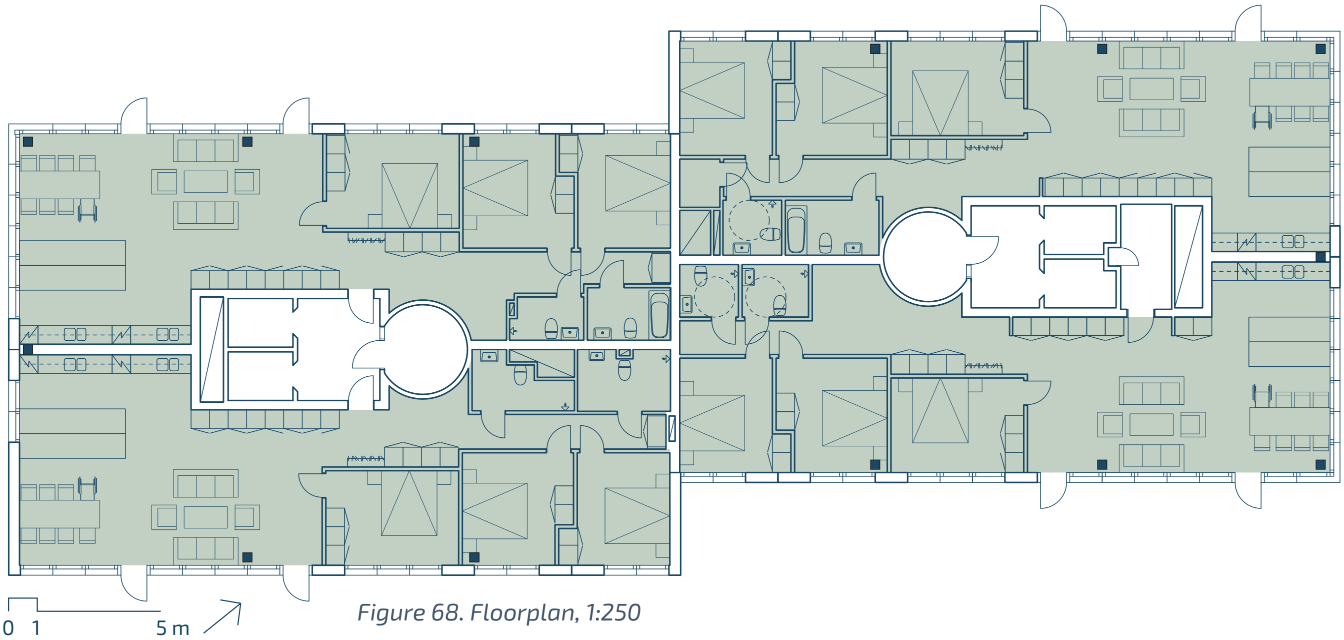


Figure 68. Floorplan, 1:250

Option concept

This option follows the same regulations for co-living in the Swedish standard, although this option explores a closed floor layout. Instead of one big, shared kitchen, and living room, these spaces are shared within the apartments. These areas are placed by the corner openings to create bright and open social spaces.

The stairwell is minimized, meaning the apartments utilize the maximum area possible. The existing shafts are kept and incorporated in the new design.

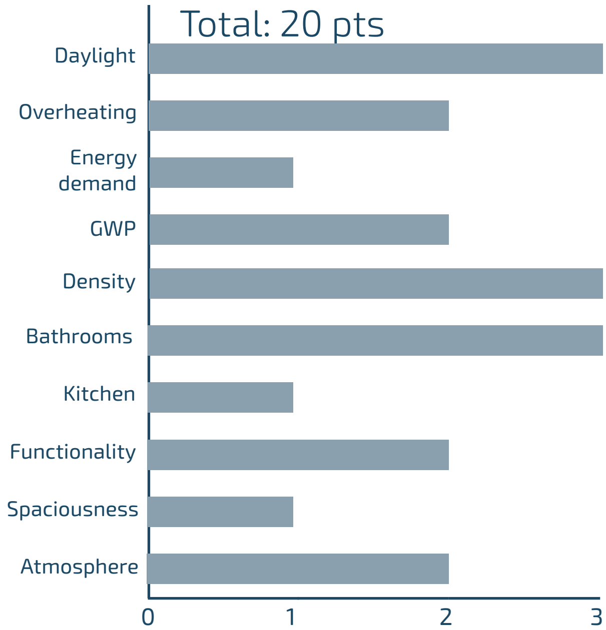


Figure 69. Design evaluation result

Reflection around design

The small stairwells are possible due to only two doors, maximizing the apartment size and giving plenty of space for storage and social areas. However, this results in a lot of dark corridors or other areas within the apartment instead. There is not a lot of light area to be gained by the optimization of staircases in this floorplan.

The placement of kitchen storage, freezers, and fridges is made difficult by the apartment separating wall. The current placement is far away from the kitchen, creating a hitch in the corridor and obstructing the living room area.

Reflection of result

This option shows slight overheating tendencies due to small spaces with plenty of openings. Furthermore, this option has more walls than the previous co-living option in combination with many windows, creating higher GWP and energy demand. While density and bathrooms are effective, kitchens can be optimized. The apartments have a lot of dark areas, and as mentioned, measuring spaciousness is difficult within co-living.

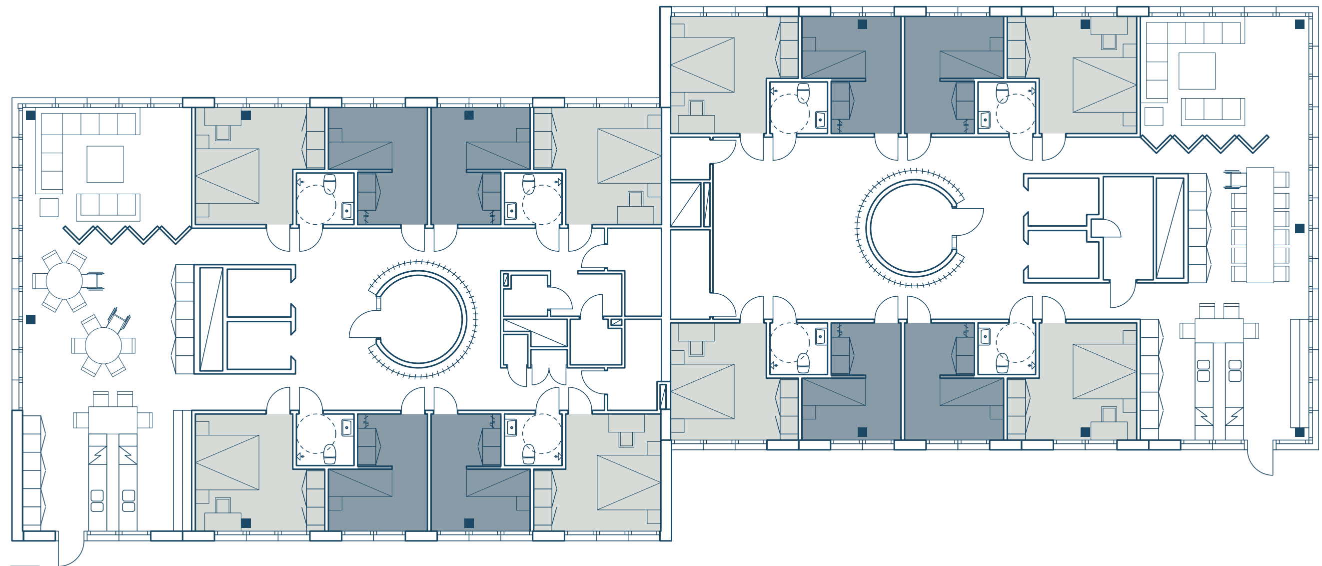


Figure 70. Floorplan, 1:250

Option concept

This option plays with the classical corridor layout of shared student housing. Instead of each room having a private bathroom, the bathrooms are placed in the corridor and shared by three people in two adjacent rooms. The rooms are a combination of single and double to accommodate various users.

The kitchen and living rooms are still placed in an open layout and shared by twelve people. This layout also works with the staircase as a central piece by turning it into a coat rack.

Reflection around design

This option works with a unit of three people instead of six. This layout enables preserving almost all of the existing layout in a way that enables the use of the functions. Although giving loads of dark space, the circulation possibility is a quality.

Regarding the design, the bathrooms are semi-private, although still not reachable from inside a room. This way of sharing the bathroom gives fewer units, although taking away the privacy of the classic corridor. Furthermore, all bathrooms are reachable from the entrance areas, which can provide further privacy or sharing issues. This option explores an interesting idea, however, not resulting in extra qualities outside of regular corridor life.

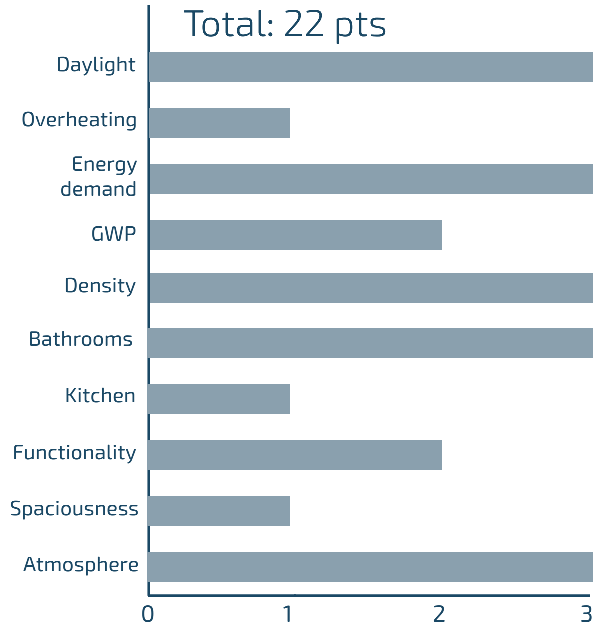


Figure 71. Design evaluation result

Reflection of result

Just like the previous co-living options, the rooms tend to overheat due to an imbalance between openings and room size. The GWP is impacted by the number of windows. The kitchens can still be optimized. The design is relatively functional as it gives the possibility for remained living. Flexibility in size is a bit difficult, although it is possible to rent two adjacent rooms of different sizes. The co-living spaces provide plenty of atmosphere qualities.

Closed co-living

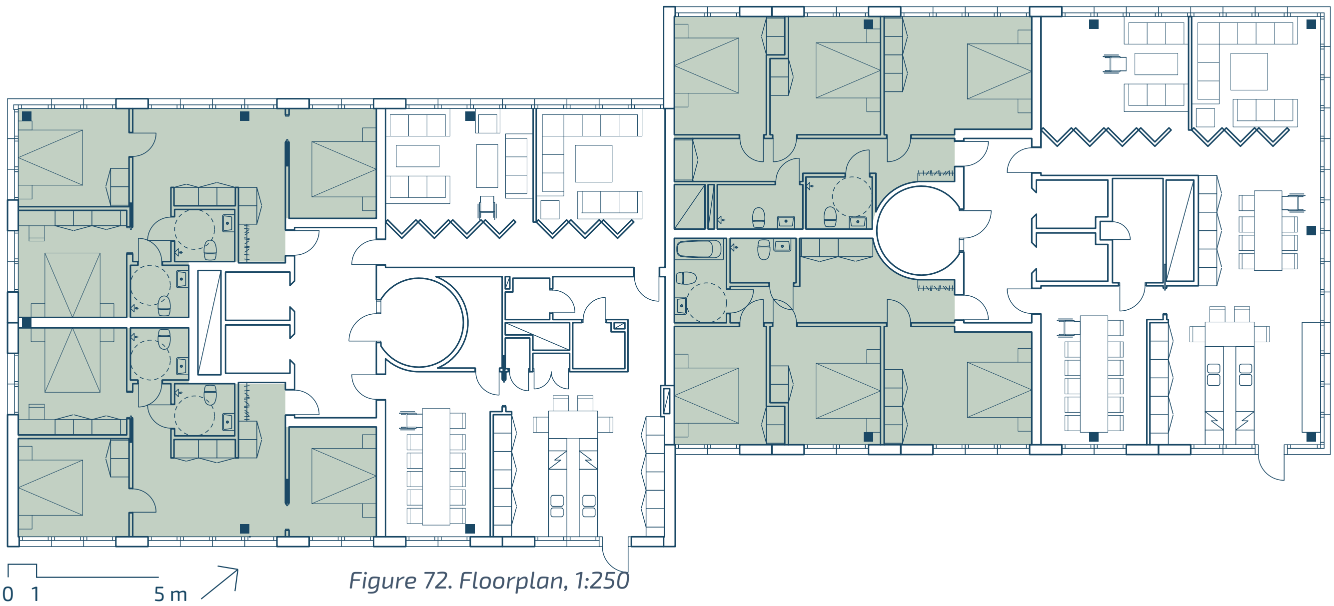


Figure 72. Floorplan, 1:250

Option concept

This floorplan explores an option with the same room distribution as the *Open co-living*, although with a more closed solution for the co-living spaces. The living rooms and kitchen are permanently separated, and the kitchen is separated from the hallway as well.

The option enables keeping shafts and walls, providing bathrooms and storage. Furthermore, the stairwells are minimised, providing more space for apartments and social functions.

Reflection around design

The closure of spaces provides more flexibility in the use of the co-living spaces. However, this solution results in dark corridors and impacts the social use of spaces and the shared spaces as a natural meeting point.

Flexibility in size between the rooms is possible in the same way as in the previous option. Again, optimization of the stairwell provides dark areas, not usable ones. Multiple living rooms offer more flexibility in their use. However, this might give more living room area than necessary. The pantry also might provide unnecessary storage. Pillar placements make the co-living spaces hard to furnish.

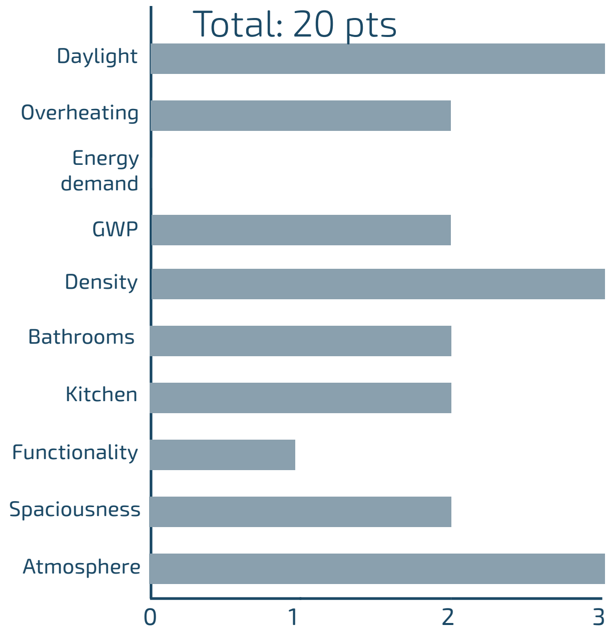


Figure 73. Design evaluation result

Reflection of result

This option contains more walls, has many openings, and small spaces overheating, resulting in high energy demand and slightly higher GWP. The kitchen index is higher, with one kitchen optimized and not the other. With the bathrooms kept, the bathroom index becomes worse. This means the bathroom situation can be optimized and that the evaluation itself could be improved. Functionality is lost within the closure of spaces and keeping the existing, as it provides more communication zones. Spaciousness is improved by removing social space within the apartments.

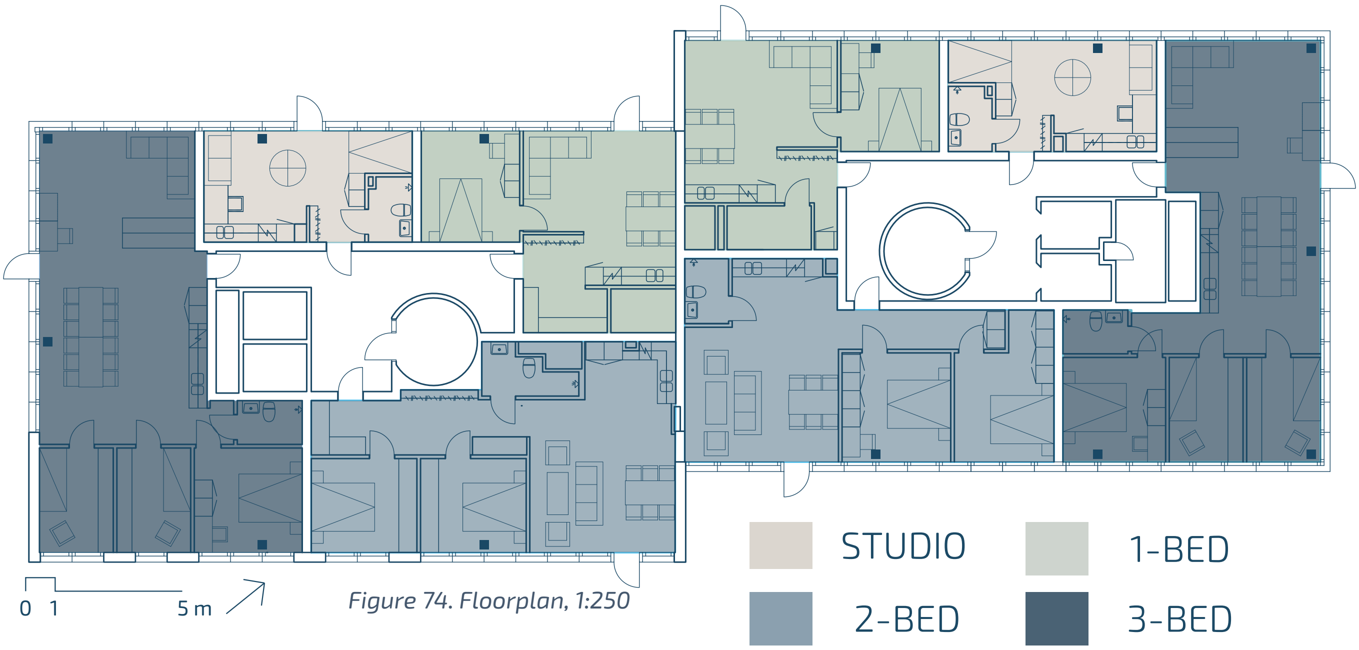


Figure 74. Floorplan, 1:250

Option concept

This option does not follow any level of the Swedish standard in any matter, instead, this plan has been designed more freely and inspired by international solutions. Multiple ideas from the references have been implemented, such as foldable desks, Murphy beds, and storage walls.

The pillars have not influenced the design at all, they are entirely placed within units instead of inside walls. This limits the flexibility of furnishing within the apartments, although giving a more free distribution of space. A majority of the shafts are kept and incorporated in the new floorplan layout.

Reflection around design

This design provides the best combination of units out of all the options, with one unit of each type per stairwell. This is the most sufficient floor plan, although it does not provide the most space-effective solutions. However, the apartment sizes are given by optimization of the stairwells and can be denser by removing dark areas. Furthermore, flexibility in size is simplified if daylight standards are ignored. Here, the living rooms in the larger apartments can be divided into extra rooms, without being too oversized.

Another big difference is kitchens, which do not follow any size standard. Instead, the kitchen that fits is used. The bathrooms and storage solutions are also non-compliant.

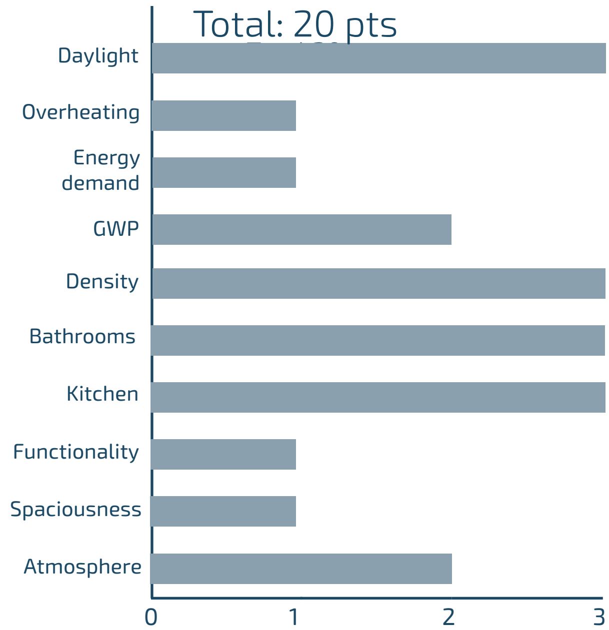


Figure 75. Design evaluation result

Reflection of result

Like previous cases, spaces overheat due to the lack of balance between openings and room size. This further leads to higher energy demand and GWP, although GWP presents a medium score due to fewer walls but high energy demand. High density, bathroom, and kitchen scores indicate a very sufficient design. However, design-wise there are still issues with space effectiveness due to dark areas. The dark spaces also affect the atmosphere. Flexibility in size exists, although the other flexibility qualities are not achieved.

Daylight and thermal comfort

Putting the results of the daylight and the thermal comfort study together, it can be concluded that in rooms with a very high daylight factor, spaces are likely to overheat. Dark spaces are bad for daylight, however with regards to overheating from solar gains, they are beneficial. Furthermore, as expected, the direction of the space is very important.

For example, in the *Open co-living* floorplan, of which the daylight and thermal comfort map are shown in figures 76 and 77, multiple spaces can be further optimized regarding the daylight and thermal comfort balance. This would decrease the need for space conditioning and optimize solar gains. For example, the bedroom in the southwest corner is very bright, with openings in multiple directions, but also relatively bad comfort percentage. Investigating the balance and testing the number of openings for a typical double room is also something that can significantly improve the design.

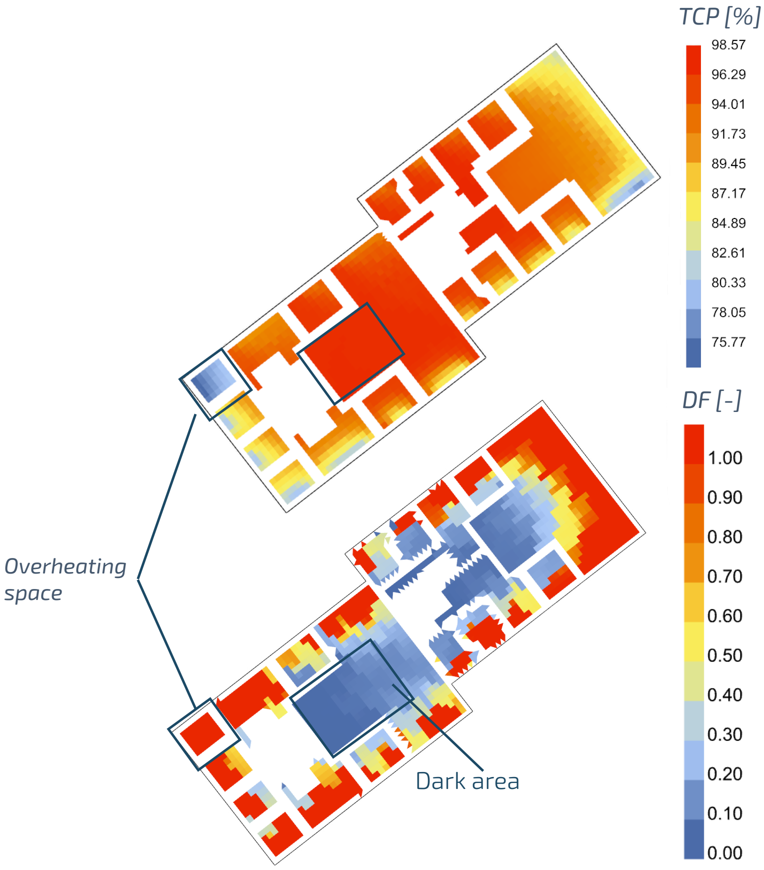


Figure 76 & 77. Thermal comfort and daylight results for Open co-living

Comparison of floor plans

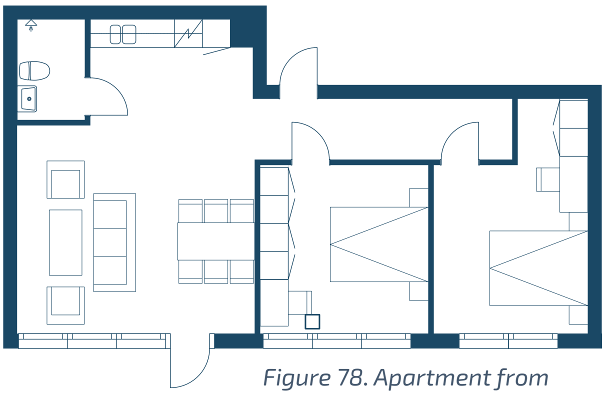


Figure 78. Apartment from International option

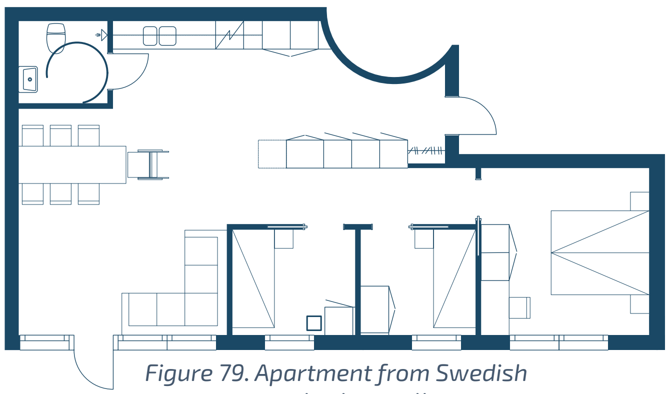


Figure 79. Apartment from Swedish standard - small

Comparing individual units based on the Swedish standard and freely designed, internationally inspired options highlights the sufficiency limits in a Swedish context. Generally, the most significant difference is the less strict storage. The storage amount is regulated per apartment type in the Swedish standard. This limits the possibilities of sufficiency for reduced consumption and by extension the flexibility of storage solutions. The standard does state that the wardrobes can be replaced by comparable storage, although it could be difficult to confirm what comparable storage would be, and the amount is still regulated. Other major differences are the free positioning of doors and kitchen sizes.

These ideas could likely to some extent be implemented in a way compliant with the Swedish Standard, but nonetheless, in this design case, the amount and type of storage is the biggest difference, and something that is limiting in the Swedish context. However, it is not certain that noncompliance with the standard would bring benefit to the apartments in the case of a transformation. It is possible that stepping away from the daylight notion, or the notion about functionality of furniture results in cramped, dark apartments of low quality.

Process takeaways

Individual apartments compared to co-living

A concept often mentioned within sufficiency and low-impact living is the sharing of costly spaces and appliances. Co-living can be executed in many different ways, but generally means sharing common spaces, most commonly kitchen, living room and bathroom. Within the solutions tested in this project, the only completely private functions are bedrooms and storage.

This results in a loss of privacy and lower flexibility within your own dense space. However, with multiple rooms within the same apartment, flexibility in size can be achieved for a household by increasing the number of rooms rented. In conclusion, co-living can be a way to balance density and flexibility.

In a Swedish context, co-living standards are relatively strict regarding the number of people sharing amenities. This makes having different-size units while maintaining sufficiency difficult. For example, units of four people, which might be a more optimal sharing size for some users, require two bathrooms and are less sufficient.

Density and flexibility within sufficient design

Generally, density is easier to achieve in larger units than smaller, as the area needed for kitchens, bathrooms and entrances is relatively lower compared to remaining area.
In smaller units, the kitchen and bathroom areas per person are larger, however these units are needed for variety in size and usability for different people. A mix of apartments would be the best for both users and density.

It can be identified in all these options that there is a clash between density and flexibility in individual units. Flexibility in size or number of rooms requires bigger units or more variable furniture solutions. However, with more variable solutions, the notion of space comes back. Being able to change the number of bedrooms in an apartment requires larger living rooms or transformable spaces possible to remove. This contradicts the notion of density and decreased living area.

This can also be seen in references, where flexible units can be dense with one setup but not others. This is also made even more difficult within the transformation, where conditions for design and daylight are less influenceable.

Difficulties in design related to transformation

The design in this case needs to work around the existing construction. With the choice of removing the internal office walls, the existing floor space is rather open. However, placement of units is limited by the position of the core and the decision to keep the existing shafts. The stairwell design can impact the layout of the design, however it is only possible to gain dark space. Design is still highly limited by the current shape of the outer layer regarding openings.

Furthermore, a decision of how to handle the existing pillars will impact the design. Placing the pillars inside the walls means that the apartment layout can be designed more freely, but the size of the apartment is limited by the structure.

The goal in this project is low cost sufficiency, which means keeping as much of the structure as possible. However, this does limit the design possibilities and could clash with other aspects of sufficiency, such as flexibility in size and density.

A clear example in this transformation is the existing section with bathrooms, shafts, storage etc (one on each side). Various decisions about how to handle this cluster are tested throughout the design process, each affecting design and cost differently.

Removing the section completely gives ultimate freedom in design, meaning units can be placed completely without impact. This does however result in higher building costs.

Another concept tested is keeping the shafts and incorporating them into new bathrooms. This limits the placement of bathrooms and separating walls, but enables reuse of costly design elements. This is the option that is the most used in the individual apartment design, giving the most balanced design and cost.

A third option is to keep the whole section, which is only possible in co-living apartments, where circulation can include the cluster, and bathroom measurements does not need to be increased for accessibility.

Design evaluation conclusion

Based on the matrices, the overall best option from the early tests is the *Lowered standard - large* option, with a score of 23 points. However, most of these points come from the technical aspects, which are easier to improve than the design aspects. It is also likely that for this design, optimizing the design aspects would impact the technical aspects. For example, changing the amount of dark area will strongly influence thermal comfort and daylight.

Furthermore, a significant part of sufficiency is the flexibility in size aspect, which is not specifically measured in the matrix, however, it can be concluded that to have flexibility in size within this option, walls would have to be taken down or size would need to be increased, which would require extra space.

Instead, the option chosen for design optimization is the *Open co-living* option. This decision is partly based on the matrix, with the option scoring 22 points in total, with more points in the design quality aspects than other options.

Furthermore, this floor plan offers more flexibility than other options regarding possible users and versatile unit sizes. Couples can rent one bedroom, friends can have separate bedrooms, and a family can rent the whole apartment.

Moreover, this option can be optimized regarding kitchens and overheating, which is less challenging and invasive than improving qualitative design elements.

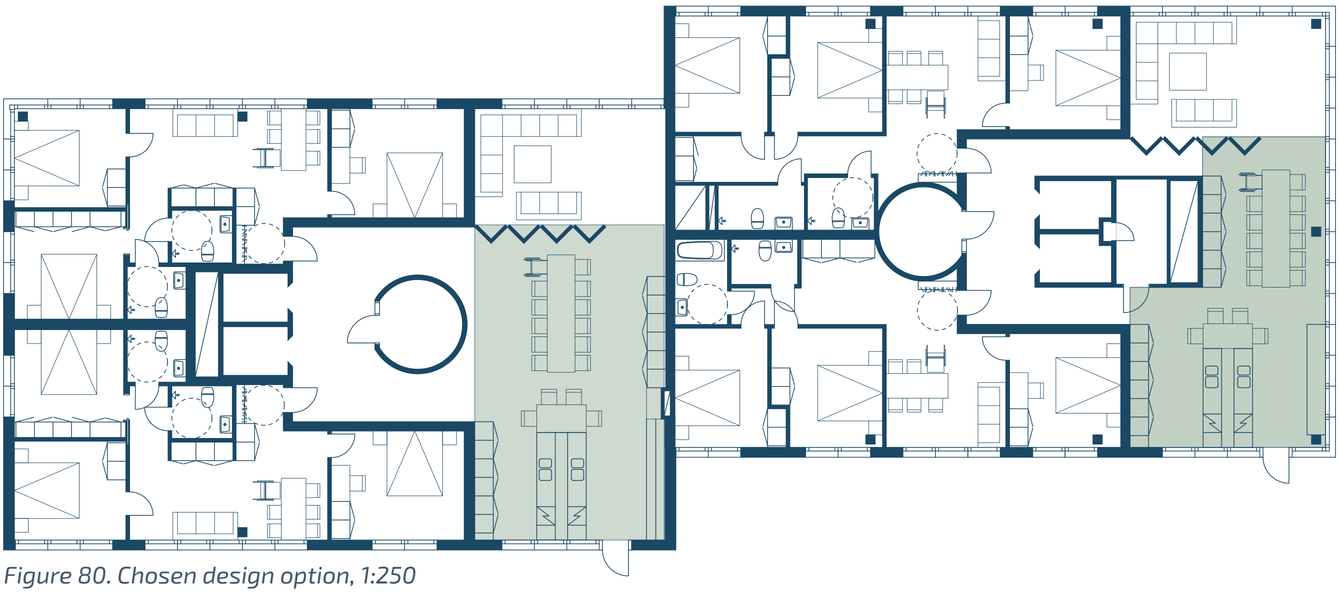


Figure 80. Chosen design option, 1:250

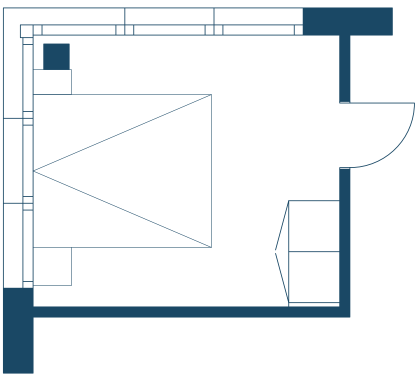


Figure 81. Overheating bedroom

The northwest corner bedroom is an example of a space overheating. This space has plenty of windows for a small space.
These aspects will be optimisable without affecting other aspects of design.

Other bedrooms on the west side of the building also need to be optimised with regards to thermal balance.

Other building parts

Function analysis - bottom floor

Since the entrance floor is situated right on street level, there is a need for another function on the entrance floor. Therefore, the location map is used to perform an analysis of the functions of the surrounding buildings, in order to identify a function useful to the neighbourhood.

A summary of the location map shows that there are plenty of restaurants, hotels and cafés nearby. There are also a number of various shops and grocery stores in the area.

It can be seen that while there are several second-hand shops in town, there are no stores in the near vicinity. Second-hand is also a growing concept that goes hand in hand with sufficiency and decreased climate impact. Furthermore, the existing locales are optimal to house a store in the west part of the building, with large display areas, a separate entrance, and staff areas including a bathroom.

Existing locales in the east part of the building, are suitable for functions requiring product storage, conference and staff areas. The space is also equipped with loading bay. Examples of such functions are plumbers, electricians or painters.

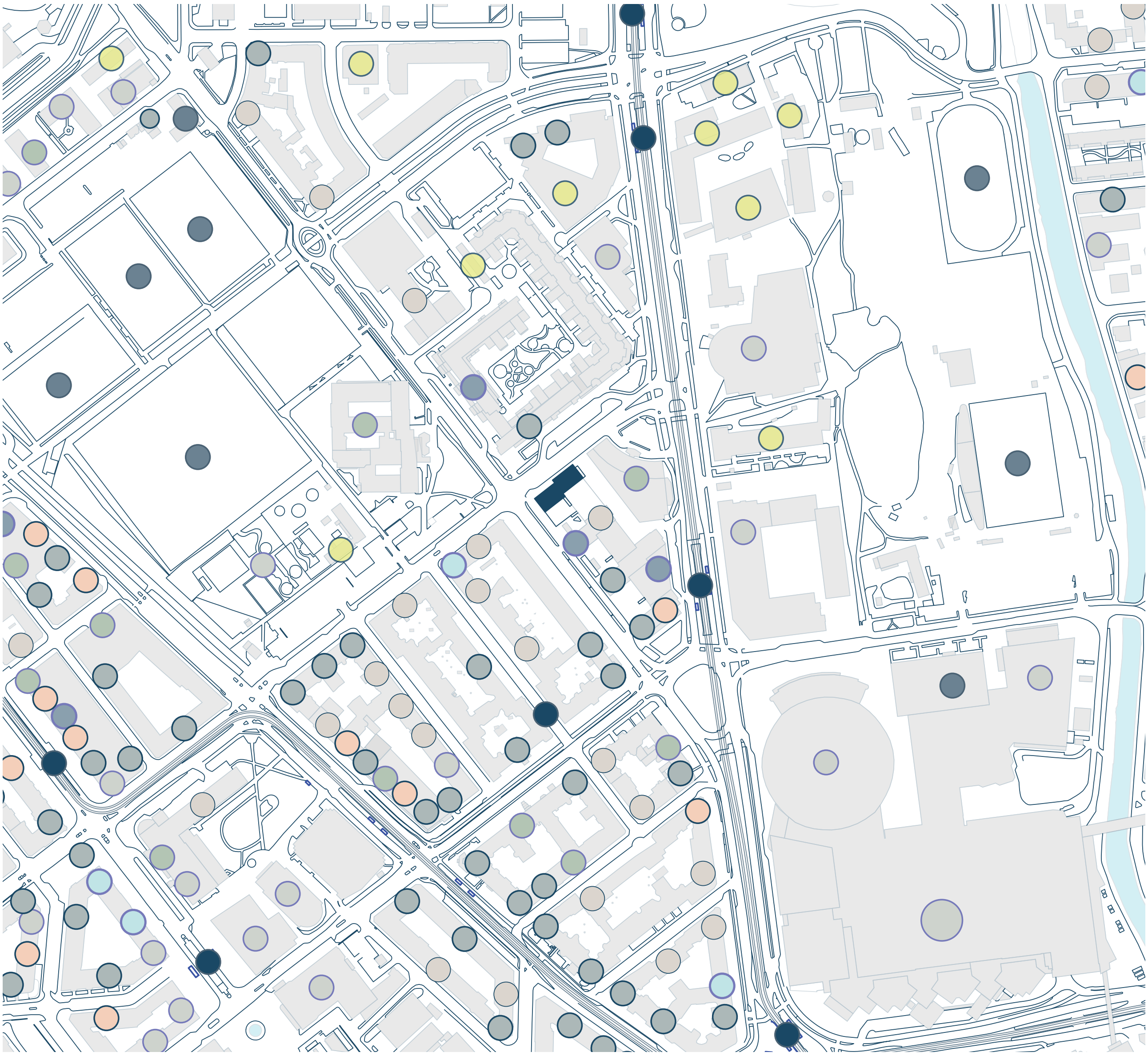


Figure 82. Context map of the area, 1:2500

GROCERY STORE
RESTAURANT
HOTEL
SPORTS FIELD/ARENA
FUNCTIONS
CINEMA/MUSEUM
SERVICES
PUBLIC TRANSPORT
OTHER STORES
EDUCATION

For the entrance floor, the goal is to preserve as much as possible of the existing layout. The function of the floor will be left public, however the adaptive reuse of the other floors requires separating the private and public.

The second-hand shop is implemented on the west side of the building, making one of the existing entrances solely public. The connection from the locale to the staircase is removed, creating a clear separation between public and private. Staircases and elevators are only reachable for tenants using the other, private entrance. Fitting rooms are added in the store, and staff areas are located in the back of the store for privacy.

Separating public and private is slightly more difficult on the east side of the building. The remaining entrance on the west side links to the east stairwell and is therefore used as a private entrance. The remaining entrances both have height differences requiring stairs. Therefore, turning the entrance on the right side into a semi-public access point and replacing the stairs with a ramp enables accessibility for both customers and workers. Changing the walls around the elevators separates the locale from the stairwell. This results in a division of private and public, ensuring only residents can reach the private floors above.

Other significant changes are the addition of an emergency exit and the extension of the recycling space to serve all tenants.

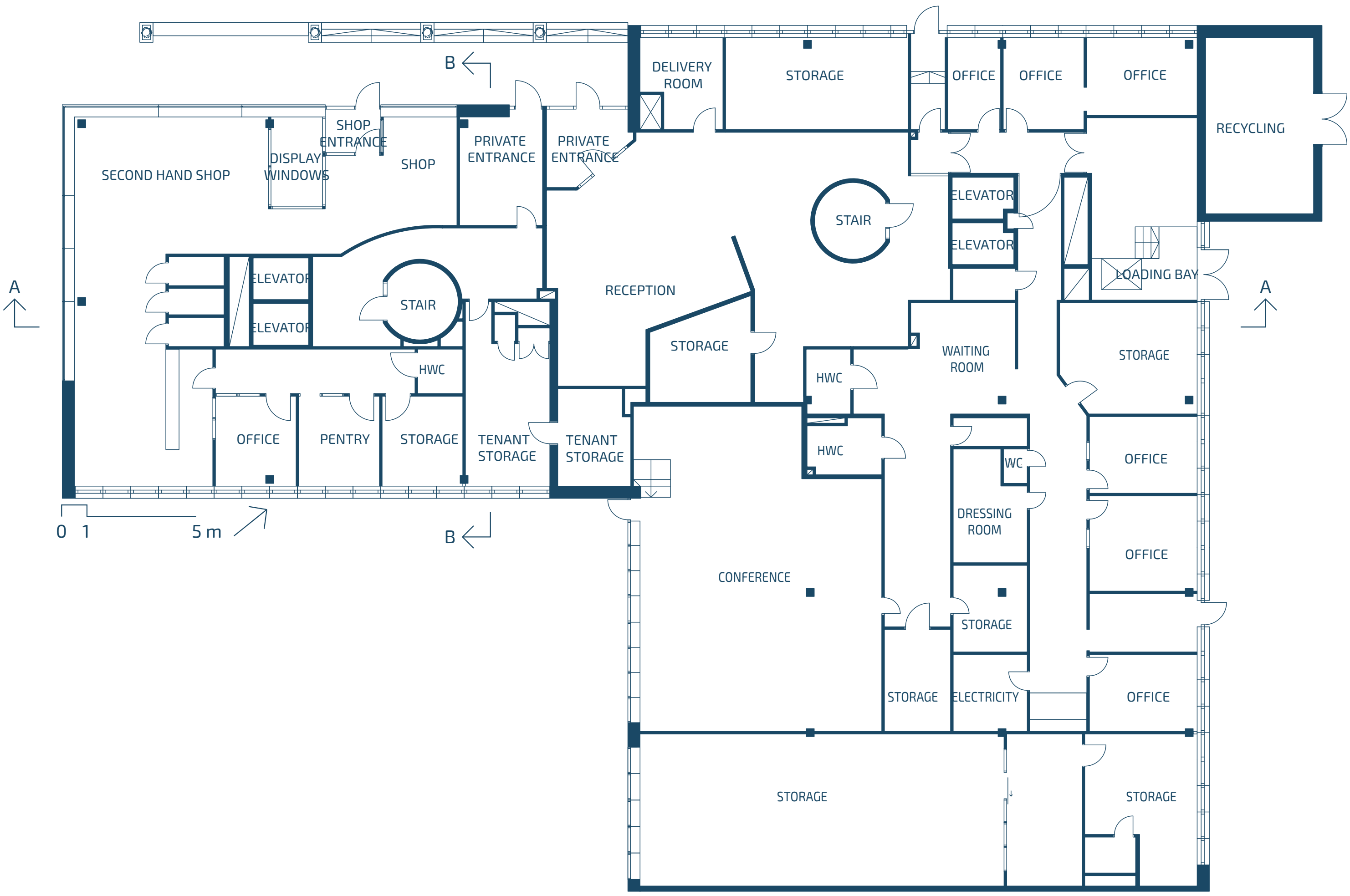


Figure 83. Entrance floor, 1:250

Basement

As for the entrance floor, the aim is to keep as much of the basement design as possible. Amenities usable by residents, such as the sauna, dressing rooms, and gym are kept as shared spaces.

Technology rooms are untouched, as well as the core and shafts. Most of the existing storage is turned into individual storage units for residents. Laundry rooms are added, with shared industrial laundry machines weighting the laundry for efficiency.

With paid street parking and other facilities nearby, the basement does not need as much parking. Therefore, plenty of parking is removed and replaced by residential and bike storage. Part of the remaining parking lots are used for the community carpool, and the rest can be rented out for additional income.

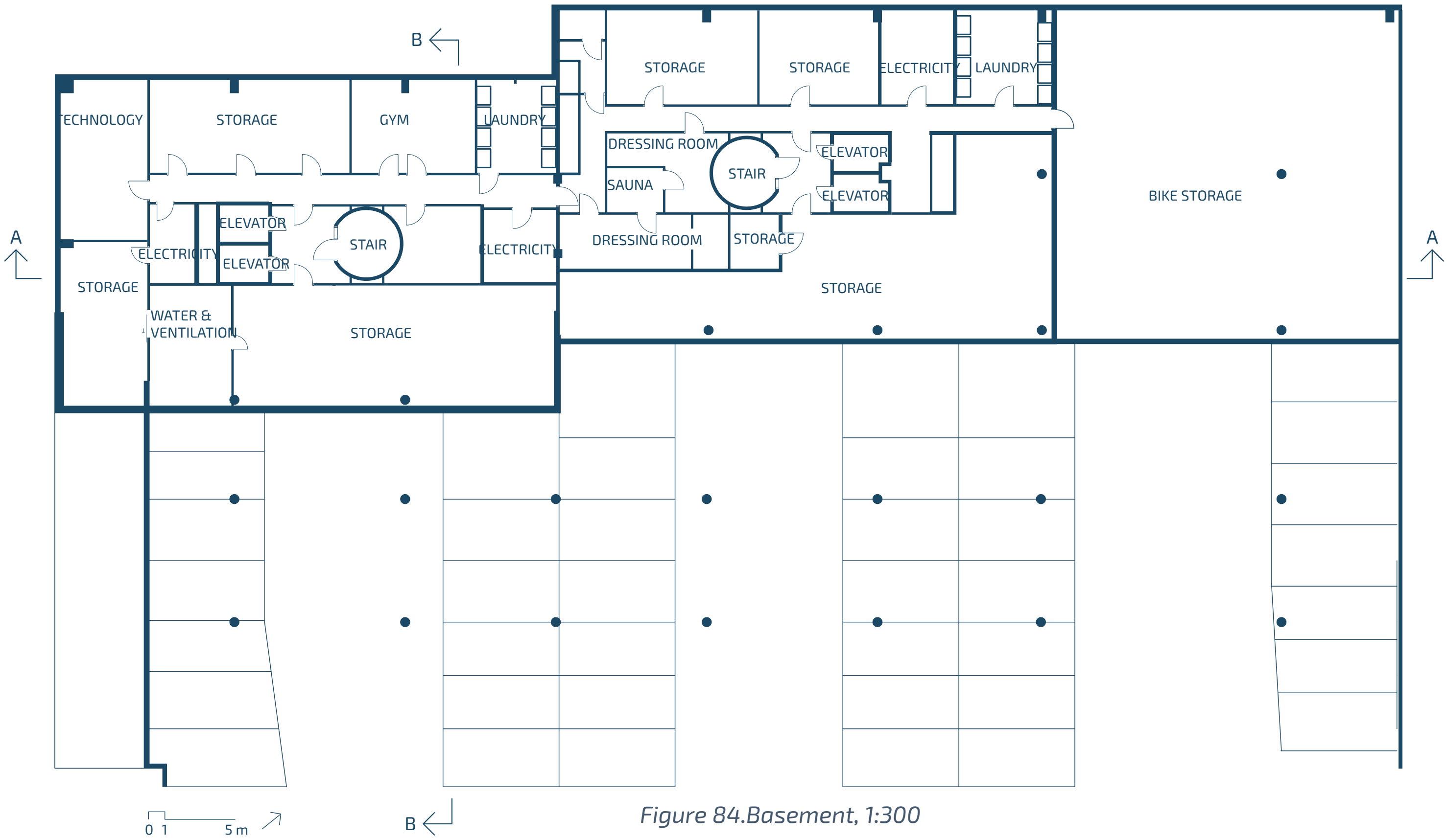


Figure 84.Basement, 1:300

Floor 1 - co-housing

Co-housing is central to sufficiency, helping bring costs and area sizes down. Due to the overhang on the street and the proximity to the pavement, there is no possibility to put balconies on floor 1, which makes this a good location for cohousing areas.

The co-housing areas serve as an extension of the rooms, units, and apartments, with facilities shared by all residents in the building. The purpose of these areas is to move functions away from the individual rooms, units, and apartments. A co-housing program promotes sufficiency and social sustainability at the same time.

The co-housing areas include venues, individual office spaces, guest apartments, hangout spaces, hobby rooms, and tool rooms.

Three rentable venues of two different sizes enable divergent uses, and the locales all include a kitchen to serve various purposes. As not all rooms can fit a desk, bookable offices fulfil this need. The offices are separate due to feedback from BRF Viva mentioned earlier. Rentable guest apartments compensate for the lack of sleeping space for visitors within the rooms. Bookable hangout spaces provide flexibility for social activities. Hobby and tool rooms offer sufficiency and affordability through sharing while also providing creative space.

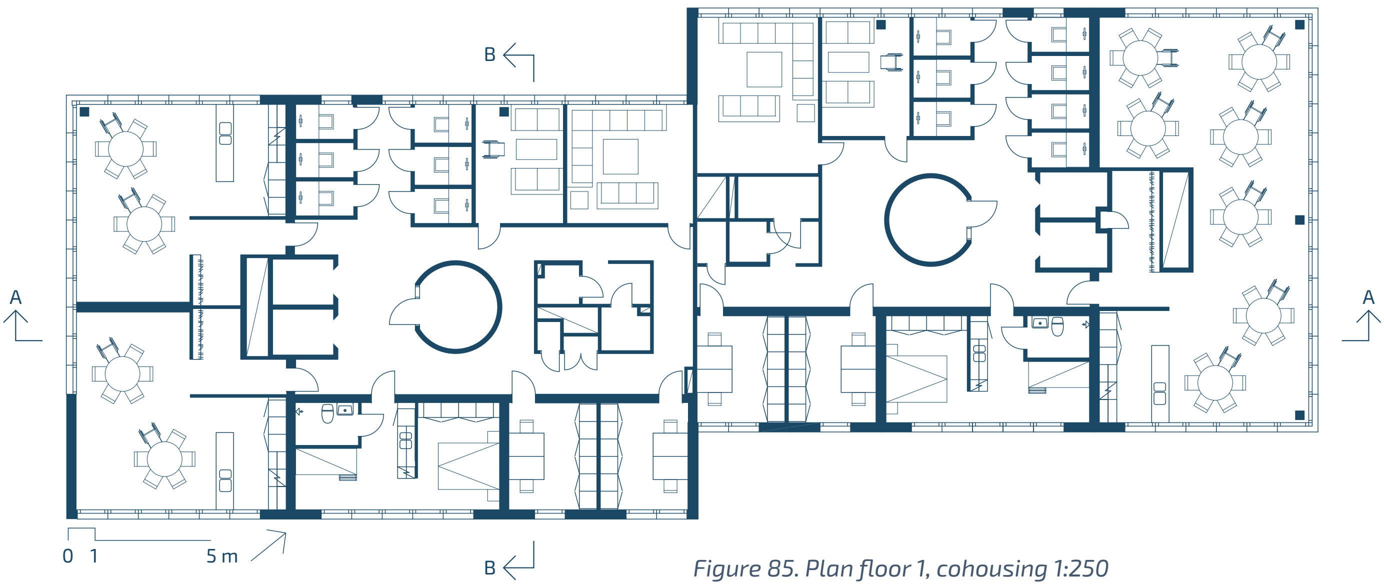


Figure 85. Plan floor 1, cohousing 1:250

Design optimisation

Introduction

In this chapter, the chosen design is further processed, focusing on passive design, materials, and balance between evaluated qualities. The section includes balancing openings, testing balcony depth, and testing envelope solutions.

Airtight envelope

Improving thermal bridges is crucial to cut leakages and achieve low energy demand in this project

Optimal insulation

Testing various insulations enables balance between minimized transmittance losses and material use

High performance openings

Heat escapes easily through openings from connections and transmittance, hence they are tested and replaced

Maximise solar gains

A balance between daylight and thermal comfort, optimising solar gains, lowers energy demand.

Heat & moisture recovery

Exhaustion of air and water creates losses of energy. Recovering heat lowers the remaining energy demand

Minimal space conditioning

By optimising the daylight and solar gain balance, the requirement for heating and cooling of spaces is lowered

Bioclimatic design

Optimising the building to the local climate, ensuring thermal comfort using the environment

Sustainable materials

The need for and impact of materials is tested, and their GWP is considered to measure their sustainability

Optimisation

Optimising the building for new use is crucial in transformation and includes both design and technology

Balconies and openings

In the chosen option, as mentioned, some spaces overheat. It can be noted, however, that only the openings requiring closure based on the floor plan requirements are removed. Furthermore, the option is tested without balconies, giving plenty of space for optimising shading and opening ratio for required spaces.

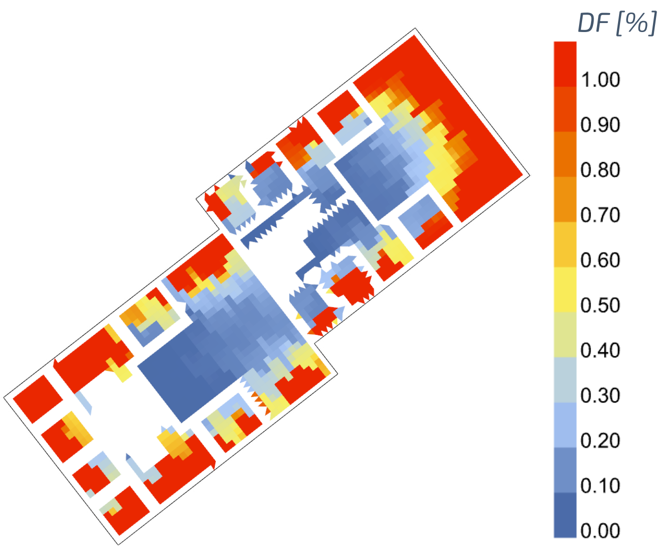


Figure 86. Daylight diagram for chosen option

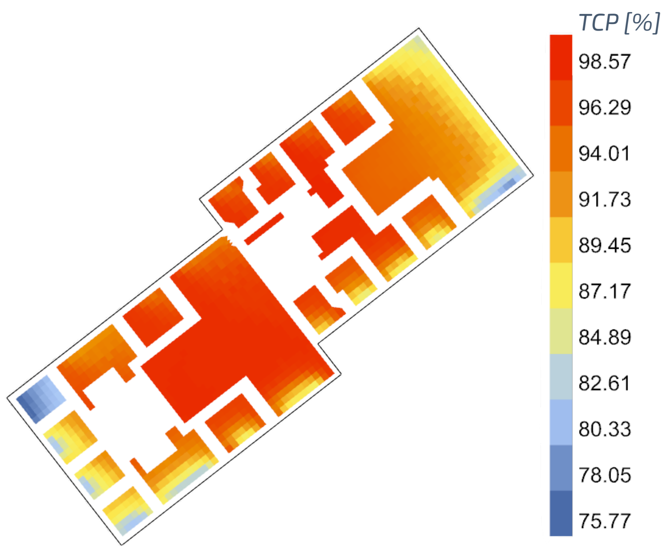


Figure 87. Overheating diagram for chosen option

Optimum balcony depth

In the early design process, the doors were placed in the kitchen, which remains the best place for balconies design-wise. The balconies cover the width of the kitchen. The depth of the balcony is determined through daylight and thermal comfort analysis.

The analysis started with a depth of 3 m. This impacts daylight, however, further analysis shows that reducing the balcony depth to 2 m does not improve daylight significantly while resulting in overheating kitchen space.

Bedroom opening ratio

As mentioned, the northwest bedroom, with openings in two directions, is very bright, although with resulting heat gains. Closing four out of the seven apertures, while keeping the corner windows and the design quality provided, gives a more comfortable space without compromising on daylight.

For a bedroom with openings in one direction, it can be concluded that one opening per bedroom is enough for daylight and decreases overheating.

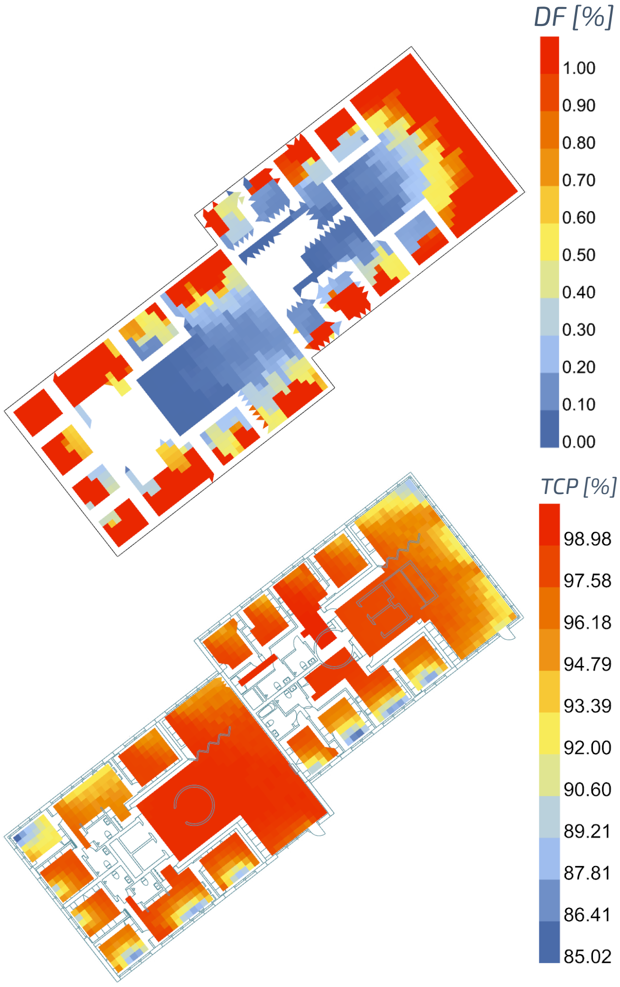


Figure 88 & 89. Resulting daylight and thermal comfort diagram

Resulting floor plan

Following the result from the analysis, balconies are added to the building and a number of openings are decreased in the bedrooms. This results in an improved daylight and thermal comfort balance, where daylight still meets the requirements and thermal comfort percentage is increased.

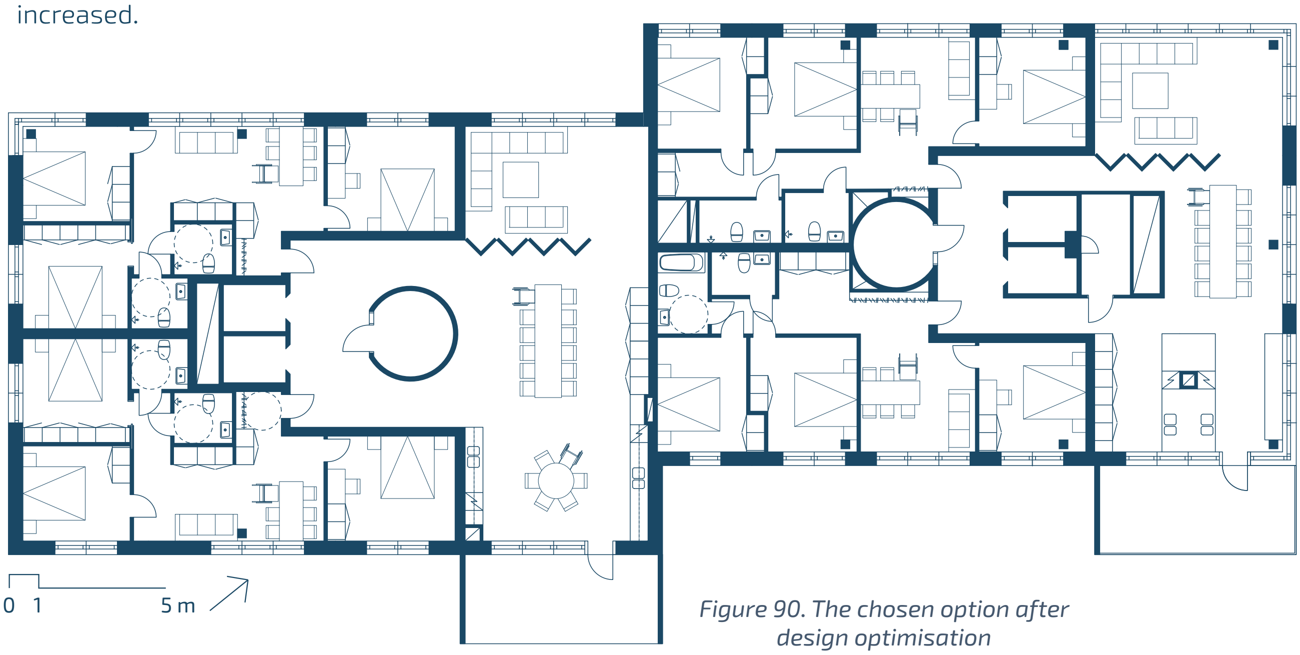


Figure 90. The chosen option after design optimisation

Construction/insulation tests

The current construction provides a major problem for the building.

An investigation performed during the current renovation shows that the existing wall construction is wrongly constructed creating issues with moisture, cracks, thermal bridges and carbonatisation of the concrete. The insulation capacity is too low for current requirements, and furthermore the slab provides a huge thermal bridge throughout the building.

The conclusion of this investigation is that the envelope of the building needs to be replaced, and that extra insulation need to be added outside of the load-bearing concrete. Insulating inwards will not solve the current problems with the construction and the thermal bridges will remain. Their chosen solution is an added air gap and 16 cm of insulation, while replacing the brick and the existing openings. This means an impinch on the pavements with 14 cm, which has been approved by the city.

Based on the investigation, the optimisation in CAALA works with thermal bridges, insulation of brick walls, concrete walls, roof structure and ground, and replacement of existing doors and windows. The starting value for this optimization is a primary energy demand of 90 kWh/m^2 and GWP of 61 CO_2-eq/m^2.

The impact of airtightness:
Due to the existing extent of the thermal bridges, the starting values used for the tests are:
- General: 0.1 W/mK
- Air tightness: Old construction - 6h^{-1}

Only changing the values for thermal bridges to the following:
- Optimised: 0.05 W/mK
- Air leakage: "With verification" - 2h^{-1}

Result in a saving of 9 kWh/m^2 and 7 kg CO_2-eq/m^2

Wall insulation:
Changing thermal bridges + change of wall insulation to 10 cm results in a total saving of 10 kWh/m^2 and 7 kg CO_2-eq/m^2.

Insulation of concrete roof walls:
With the starting values used, 6 cm insulation results in a saving of 14 kWh/m^2 and 9 kg CO_2-eq/m^2. 10 cm gives a saving of 15 kWh/m^2 and 8 kg CO_2-eq/m^2, 15 cm gives same results as 10 cm.

Based on the material analysis, the starting values used for the existing envelope are:

Walls & closed openings:
15 cm reinforced concrete
4/6 cm insulation
11.5 cm facing brick

Concrete roof walls:
17 cm reinforced concrete

Ground:
22 cm reinforced concrete

Top slab:
22 cm reinforced concrete

Roof:
Copper roof covering
17 cm reinforced concrete

Windows:
Windows with wooden frame, U-value 1.3

Doors:
Wooden or glass doors, U-value 1.3

Insulating the roof
From the starting point of 90 kWh/m^2 and 61 CO_2-eq/m^2, an addition of 6 cm mineral wool insulation results in a saving of 3 kWh/m^2 and 2 kg CO_2-eq/m^2. 10 cm of insulation saves an additional 1 kg CO_2-eq/m^2. 15 cm insulation gives the same results as 10 cm.

Insulation of both roof and concrete walls
From the starting point of 90 kWh/m^2 and 61 CO_2-eq/m^2, an addition of 10 cm mineral wool insulation in both roof and walls results in a total saving of 18 kWh/m^2 and 12 kg CO_2-eq/m^2.

Adding it together
Putting together the thermal bridge changes and the insulation additions, using 10 cm insulation in walls, roof and concrete walls results in a total saving of 32 kWh/m^2 and 21 kg CO_2-eq/m^2.

Insulation of top slab
In addition to the previous changes, an addition of 10 cm of insulation on the top slab gives further savings of 12 kWh/m^2 and 7 kg CO_2-eq/m^2

Replacing existing windows and doors:
Replacing the existing windows and doors with triple insulating, wooden framed openings with a U-value of 0.9 gives an additional saving of 2 kWh/m² and 1 CO_2-eq/m².

Insulation of the ground
Finally, insulating the ground with 10 cm gives additional savings of 2 kWh/m² and 1 CO_2-eq/m².

Total savings from insulation and thermal bridges:
All additions and changes to the existing envelopes results in a primary energy demand of 42 kWh, saving 53% of the energy demand. Furthermore, the GWP is decreased from 61 to 31, a total saving of around 49%.

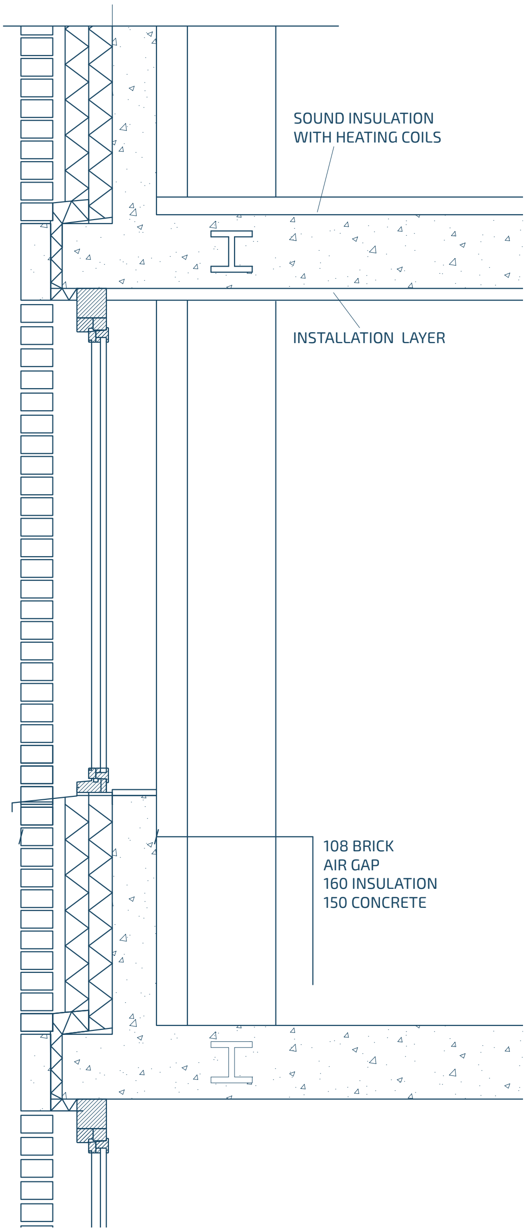


Figure 91. Resulting construction detail

Changing the heating and water system
In addition to all savings from the building envelope, installing an air-water electricity heat pump would give additional savings of 10 kWh/m² and 15 CO_2-eq/m²

Changing the ventilation system
All tests have been performed using natural ventilation only. A change to mechanical ventilation, on top of energy systems, giving savings of 3 kWh/m² and 2 CO_2-eq/m²

Total savings from results
All additions and changes to the existing envelopes and energy systems results in a primary energy demand of 29 kWh, saving 68% of the energy demand. Furthermore, the GWP is decreased from 61 to 14, a total saving of 78%.

Reflection

It can be seen that properly insulating and removing thermal bridges makes a huge difference on the climate impact of the building. Furthermore, it can be concluded that based on the values from simulations, the most important aspect of this building is creating an airtight envelope. Insulating the bare roof and ground is important for the energy demand, but the major problems with the existing are, as listed in the investigation during the performed renovation, the thermal bridges.

Moreover, it can be concluded that changing of the heating, ventilation and water systems can give further savings, putting the energy demand at a third of the original. However, these measures are costly and uncertain, hence the upcoming calculations are based solely on the changes in envelope and thermal bridges, since this can be supported by the performed investigation.

Technology applications

Introduction

In this chapter, efficiency and renewables applications are applied to the optimised design, showcasing how this can be done and what impact the concepts have on the final result.

HVAC systems — Technical systems are the heart and veins of building technology, and these are crucial to optimise

Water heating — Water heating is an efficient way to provide heating for residential units and crucial for everyday life

Appliances — Appliances are an important source of energy use, and better appliances improves carbon footprint

Lighting — Lighting are another large source of energy use, and their usage times can be greatly improved by design

Smart systems — Systems for measuring and controlling energy consumption enables efficient technology use

Low maintenance — Material maintenance have huge impact on cost and energy demand and should therefore be optimised

Renewable energy — The remaining energy demand should to the largest extent possible be met by renewable energy

Batteries — Batteries are a good complement to renewable energy and to enable extended use of energy

Efficiency applications

The aim of this chapter is to show how efficiency can be worked with in design to enable smart systems and ventilation application. The exact implementation of these systems is outside the scope of the thesis, however the concepts previously listed within efficiency are all required to include in the design stage of a process.

Heating, ventilation and plumbing systems have a huge impact on the impact of the final design. It is important to consider these in design, as these are costly measures to change later.
Furthermore, within transformation it is crucial to understand the existing systems and work with their placement in the current floor plan.

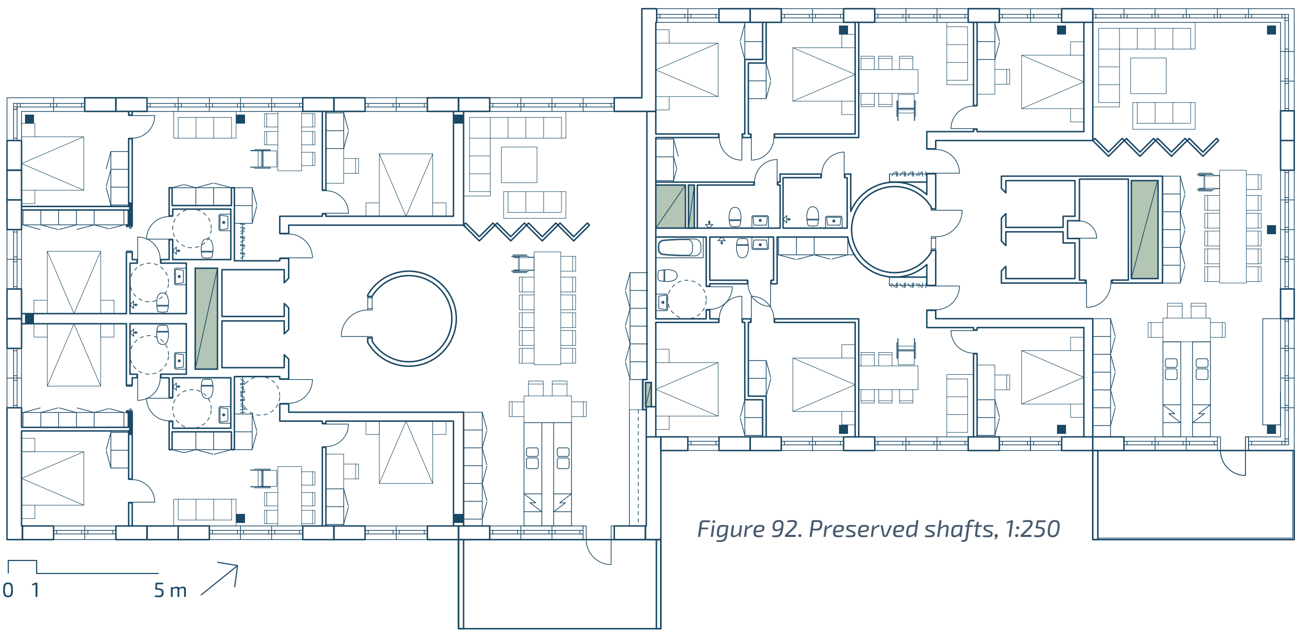


Figure 92. Preserved shafts, 1:250

In this building, the heating system is assumed to be district heating. This is a system that can be used for both space and water heating. Since the slabs need to be insulated for sound insulation, this enables the addition of floor heating coils within the insulation boards. This enables more efficient water heating, as floor heating provides a more even temperature. Furthermore, this enables lowering the indoor temperature by a whole degree, severely decreasing the primary energy demand.

Regarding the need for shafts and plumbing, the existing shafts can be used to a large extent. Thanks to the placement of bathrooms next to the new apartment separating walls and the similarity of typical floors, the water and sewing pipes can be placed within these walls. Furthermore, it can be assumed that the ventilation systems need to be renewed and that these can be replaced by FTX systems with heat recovery while using existing shafts.

In addition to the ventilation system, a low-carbon footprint building should implement natural ventilation as a passive design solution. In this case, a hybrid ventilation solution is optimal, as the shafts already exist, and replacing the walls and closing windows enables the installation of natural ventilation, preferably with heat recovery. Implementing a hybrid solution promotes climate resilience by preparing the building for future heat waves, which are commonly increasing due to climate change and global warming.

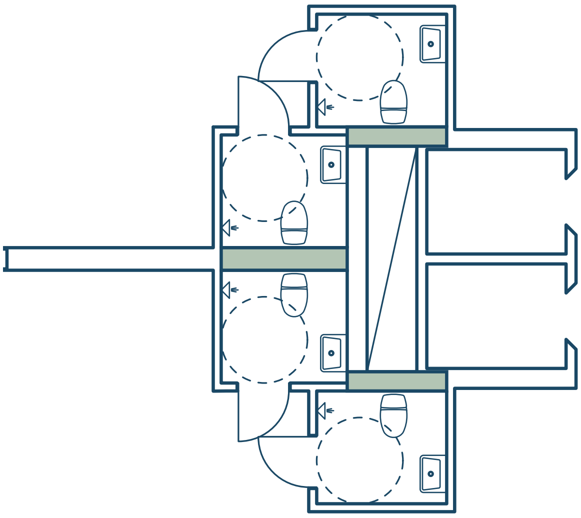


Figure 93. Bathroom pipe placement

Regarding appliances and their impact, this has already been reduced through co-living and sharing of appliances. Furthermore, no individual laundry machines are possible in this building. Instead, efficient industry laundry machines weighing the laundry are placed in the basement. Sharing appliances enables higher efficiency for remaining units.

Lastly, the design should enable smart systems and efficient lighting. Sensor lighting should be used in staircases and common areas. The design should include a smart system usable by tenants for turning off lights and measuring electricity demand, further reducing the impact of required technology systems.

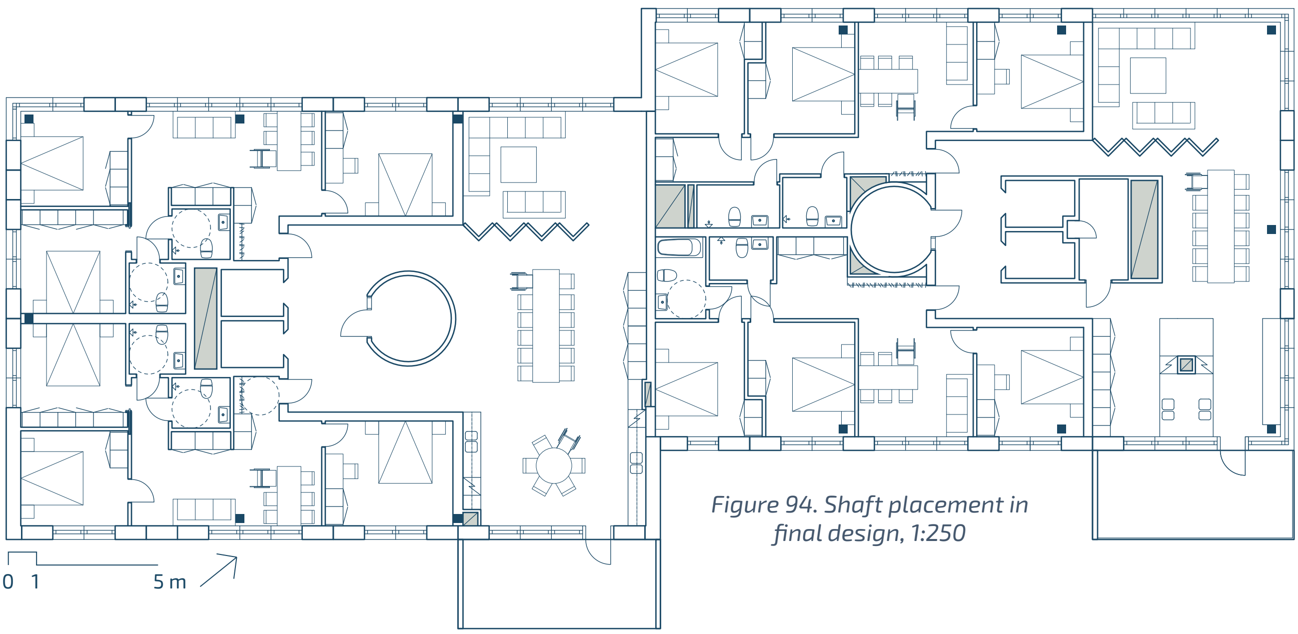


Figure 94. Shaft placement in final design, 1:250

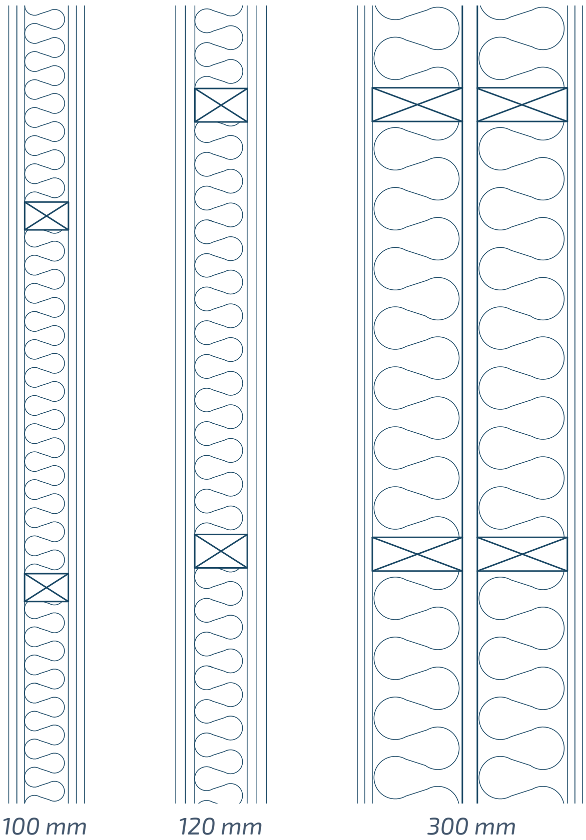
Renewable applications

Sustainable, low maintenance materials

As previously mentioned, sustainable materials have been considered throughout the design phase. The construction of new elements is wooden, meaning lower environmental impact and the possibility of reusing removed interior walls. The wall thickness requirements for wood were investigated early in the project, therefore no redesign is necessary to implement renewables.

The only new concrete added in this project is used for the closure of openings, to keep the character of the building and minimise thermal bridges. For the surface, brick keeps the character while having a long technical lifetime and low maintenance requirements, affecting the economy of the building and the footprint in the long run.

In addition to the insulation in the new constructions, the roof, top walls, and ground need to be insulated. This is done using sustainable materials with a low climate impact while keeping the existing bearing structure.



Figures 95, 96 & 97. New wall constructions, 1:10

Embodied carbon

Embodied carbon cost for a transformation project is greatly impacted by how much of the building is preservable and how the removed material is handled. The choices of sustainable materials and keeping the existing structure severely limit the loss of embodied carbon caused by the construction.

It can be noted that a majority of the GWP for this design comes from the primary energy demand, with low impact from production and other embodied carbon factors. In this case, this is further amplified by the reuse of wooden stud walls.

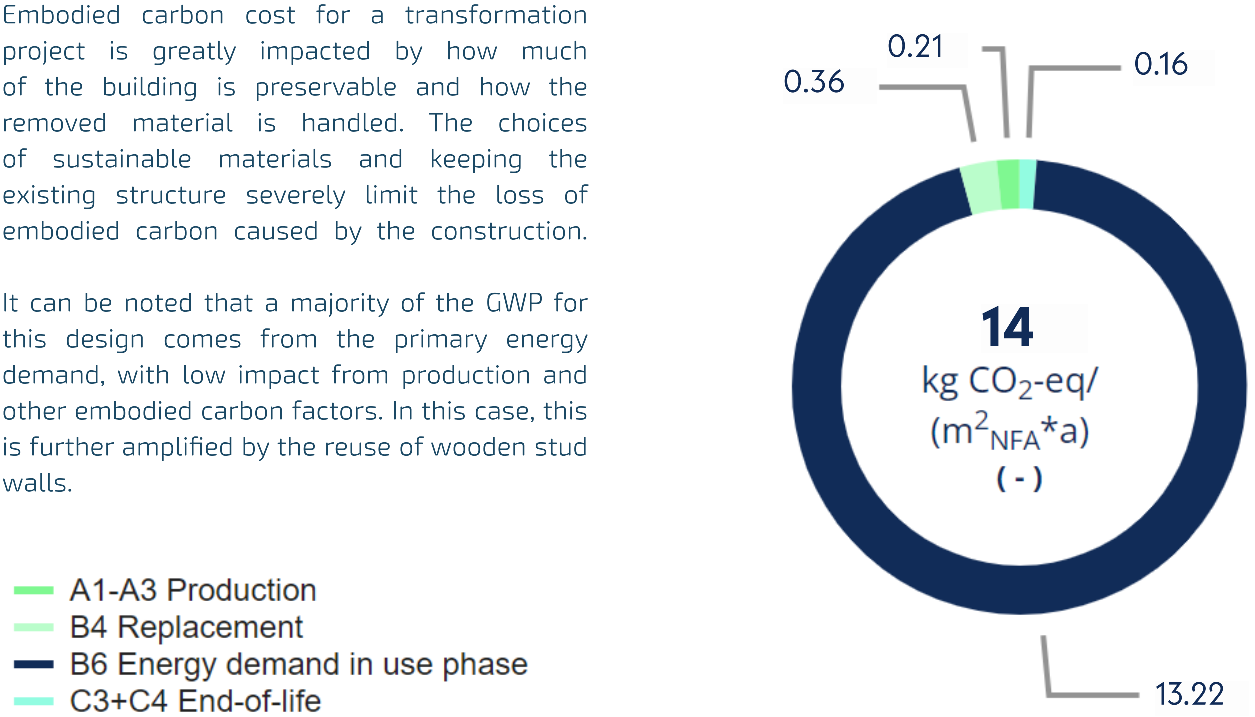


Figure 98. Resulting GWP

Renewable energy - solar panels

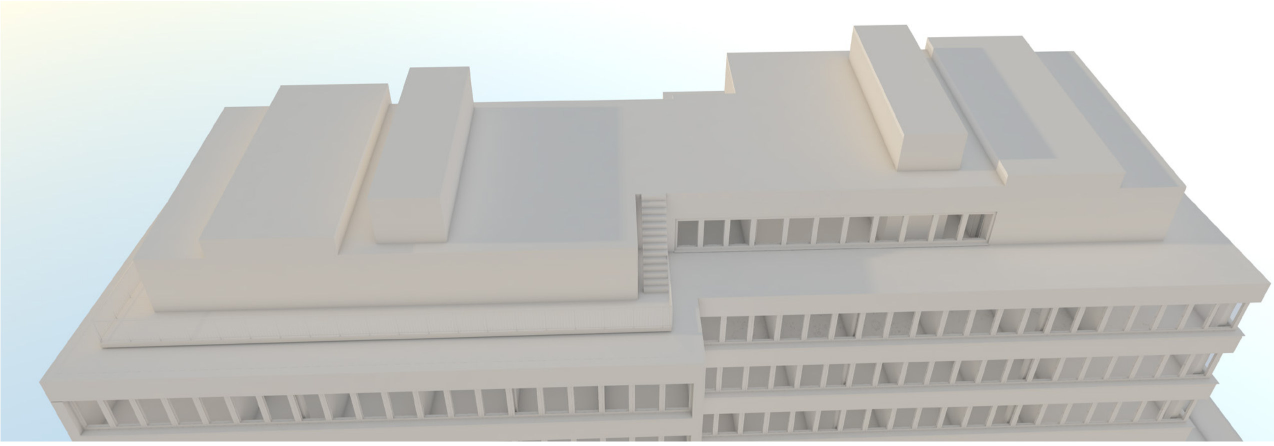


Figure 99. Coverable roof area

The calculated primary energy demand for the building is 42 kWH/sqm (excluding unsure numbers from technology replacement). Each floor has an area of around 650 sqm. 8 floors are to be heated, in addition to the roof and cellar. Therefore, this calculation is based on an energy demand of around 5500 sqm. This gives an energy demand of around 220,000 kWh for the whole building. Solar panels taking up 5 sqm produce around 1000 kWh per year. This means that around 220 panels would be needed to cover the electricity needed for the whole year.

The roof is leaning towards the southeast, with a tilt of around 5 degrees. The roof has a coverable area of around 350 sqm, fitting around 70 panels. Furthermore, the roof area in front of the terrace on the south can be used, adding an extra 100 sqm and 20 panels to the usable area. This means that the maximum number of solar panels can cover 40% of the energy consumption.

The area coverable by solar panels is impacted by the complicated structure of the roof, and the low ratio of roof area compared to floor area. This means that although it can cover part of the energy needs, complements through other energy sources is necessary. Providing enough renewable energy can be hard to do in transformation projects, as the outer shell of the building already exists. Furthermore, replacing the roof could be necessary before adding the solar panels, to avoid removing the panels for maintenance.

This is a clear example of a situation where renewables are not scalable to meet energy demand. This clearly shows why sufficiency, efficiency, and renewables are needed, reducing the energy consumption before meeting the remaining demand sustainably.

Figure 100. Example solar panel (Adobe Stock, n.d.)

Final design proposal

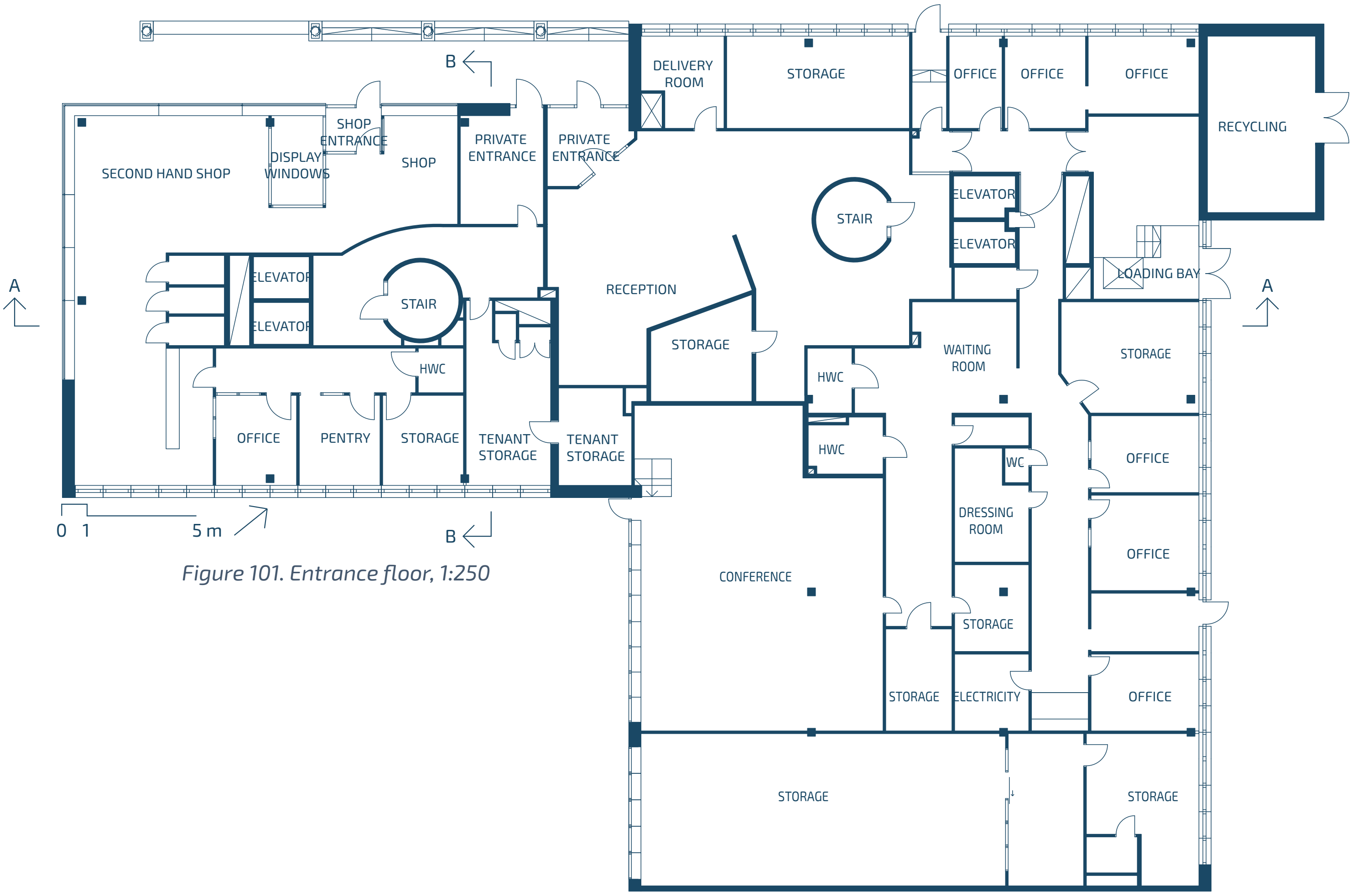


Figure 101. Entrance floor, 1:250

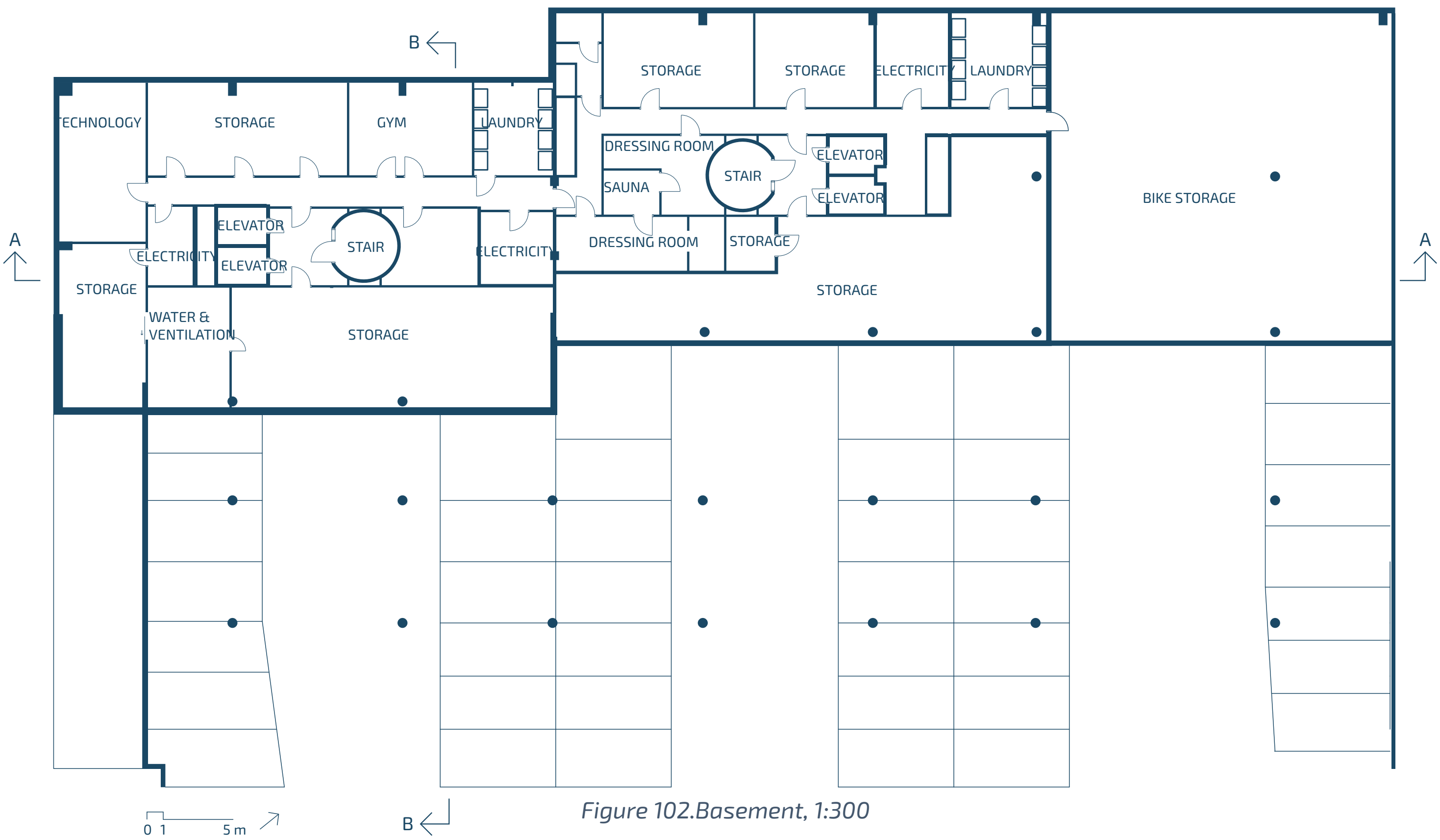


Figure 102.Basement, 1:300

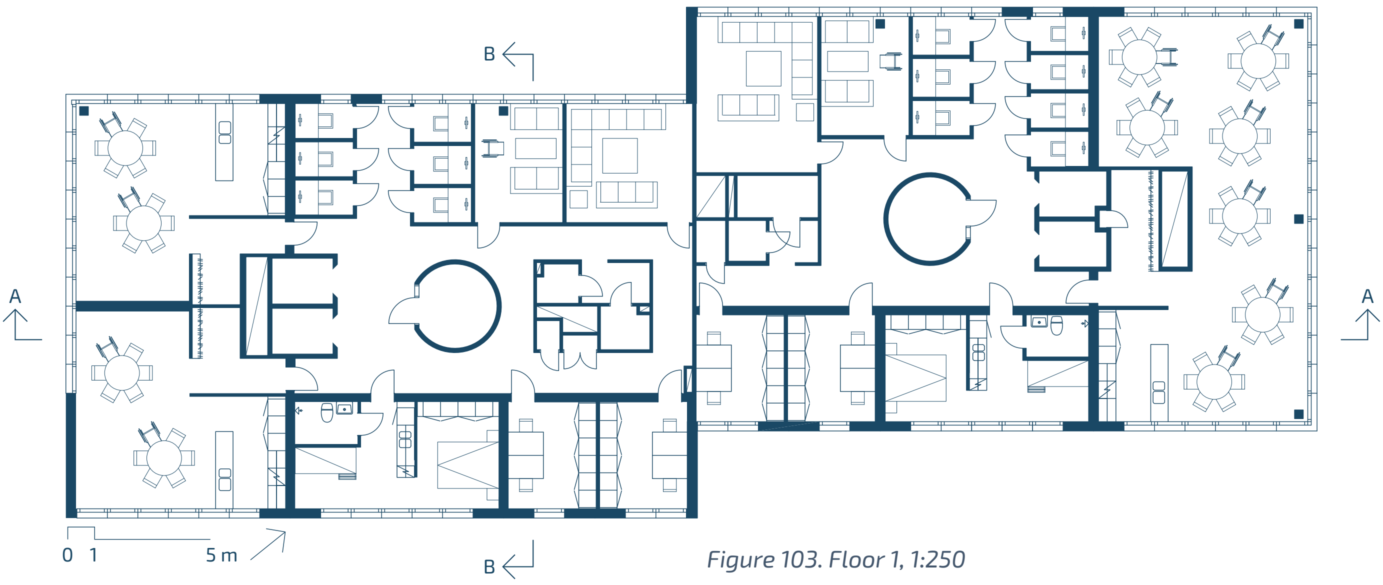


Figure 103. Floor 1, 1:250

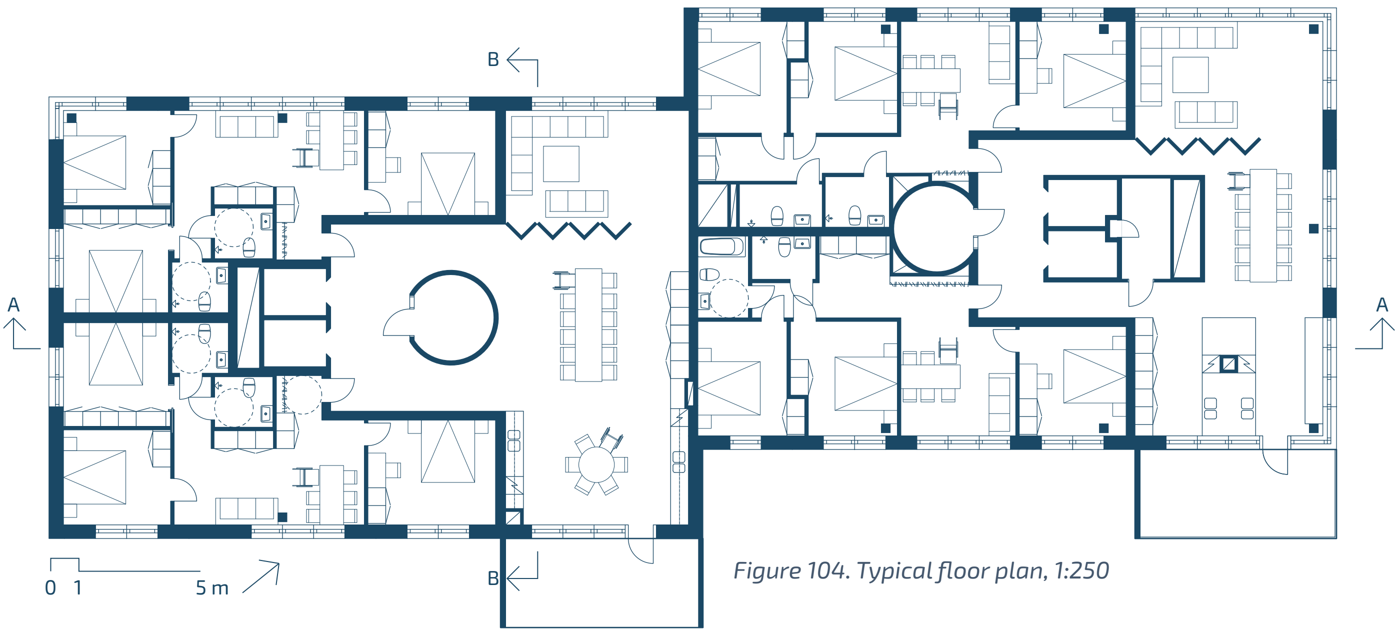


Figure 104. Typical floor plan, 1:250

0 1 5 m

Figure 105. Northeast elevation, 1:250

0 1 5 m

Figure 106. Northwest elevation, 1:250

Figure 107. Southeast elevation, 1:250

Figure 108. Southwest elevation, 1:250

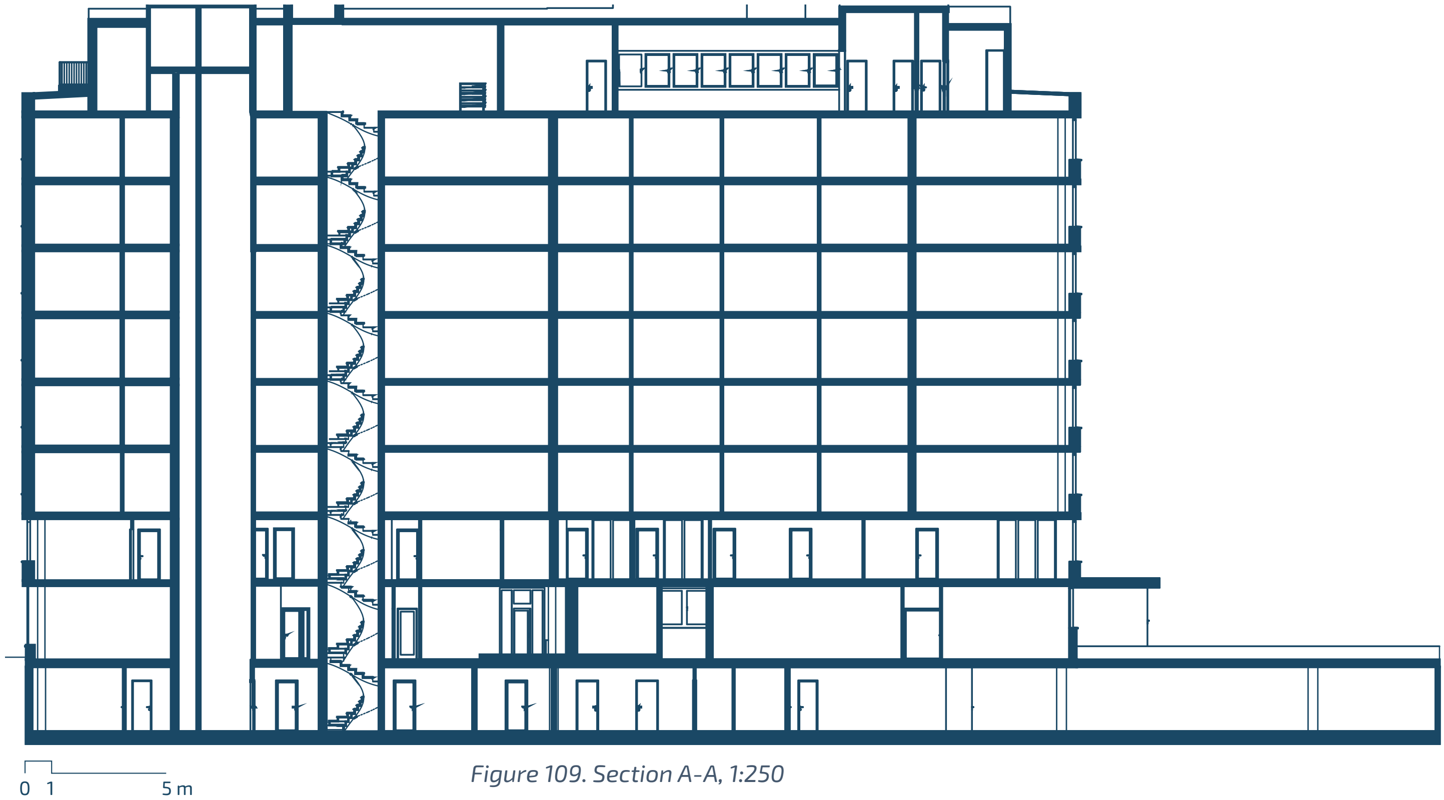


Figure 109. Section A-A, 1:250

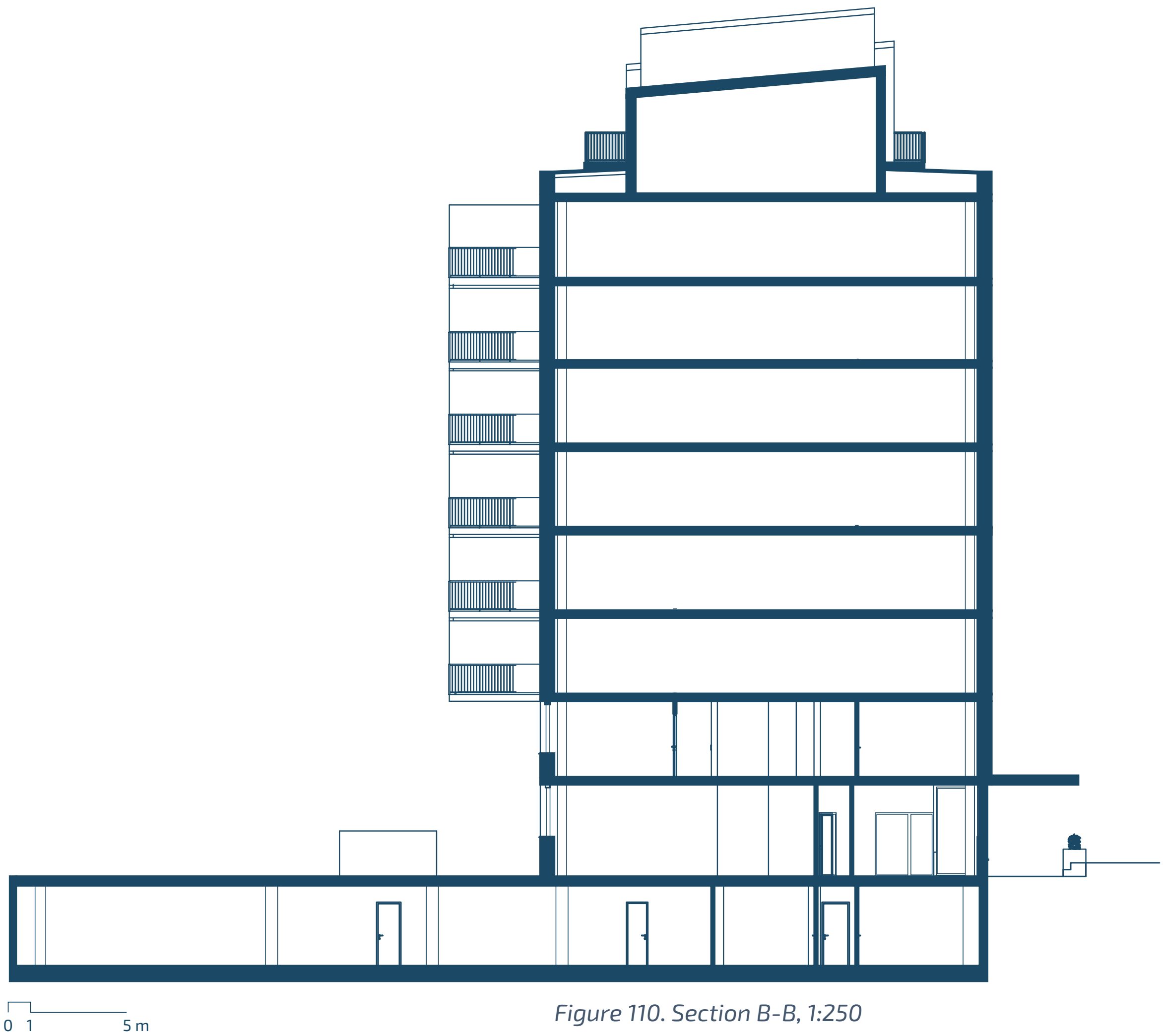


Figure 110. Section B-B, 1:250

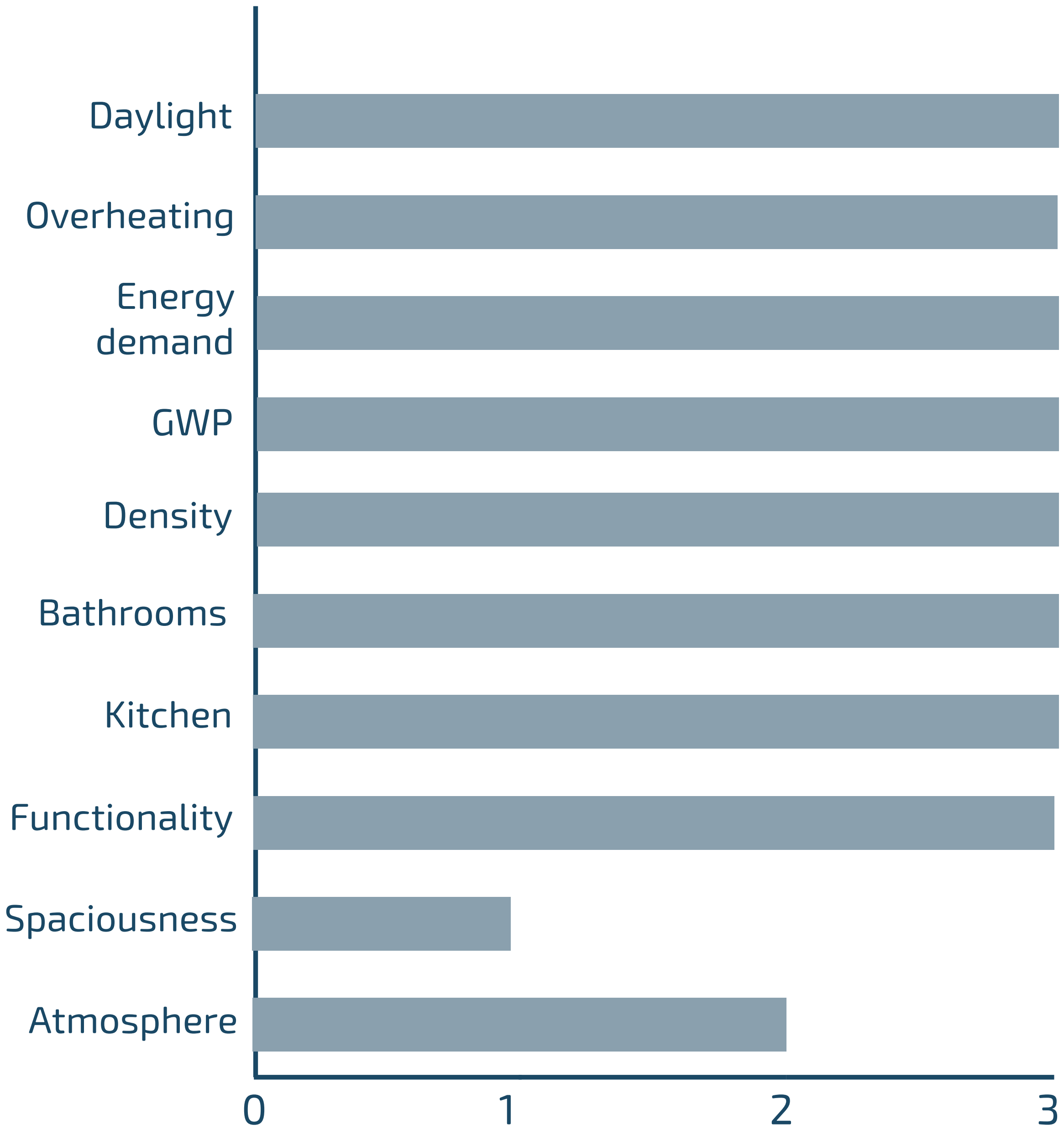


Figure 111. Resulting evaluation matrix

Discussion

In this chapter, the findings, process, and final result are discussed and reflected upon. Furthermore, my thoughts about the frameworks used, the implementation of theory in design, and conflicts within the concepts are presented. Lastly, the research questions are answered with both theoretical and design-based parts.

Sufficiency, efficiency and renewables

Using theory as a starting point, it is clear that sufficiency should be the starting point for taking action for a positive environmental impact. However, this is not the case in reality at the moment, and strong opinion differences can be found within the field.

I think a problem is that people are not prepared to make lifestyle changes. There is a search for an easy solution, which is given by efficiency and renewables. Plenty of greenwashing occurs using these two concepts. Furthermore, when talking about efficiency and renewables, only operational carbon is considered, while embodied carbon tends to be less considered or even excluded. It is also common that embodied carbon is considered compensated by planting trees or renewable energy or other similar measures making consumption climate neutral, however, this can be considered greenwashing.

It is easy to think renewable energy and renewable materials solve the whole problem, however, it is a bit more complicated than that. First of all, research shows that renewable energy and materials cannot be scaled to meet the demand to stop climate change. Furthermore, in the case of sustainable materials, carbon opportunity cost, meaning the loss of possible carbon storage, can be considered, showing that using too much of renewable materials also has a climate impact.

However, sufficiency alone cannot solve the situation, neither can efficiency or renewables. A combination of these three concepts is needed, which is supported by research. Sufficiency needs to be implemented first to reduce the impact of consumption, then efficiency and renewables can be used to reduce and meet the remaining demand.

The concepts within architecture

Sufficiency is not a spread concept within architecture, it is rarely mentioned in project descriptions and finding references for design is difficult. There are several example projects that apply sufficiency, but not as a spoken concept.
However, sufficiency is starting to reach architecture, for example mentioned "greatly" in the latest IPCC report.

Application of the concepts are clarified through the hierarchical SER Framework, stating how sufficiency, efficiency and renewables should be applied in buildings. Specific measures are listed and exemplified, along with a strict order of application in the process. This supports the "common" research that sufficiency should come first, followed by efficiency and lastly renewables.

The application of efficiency and renewables are much more common within architecture, partly in the trendy concept of net-zero carbon and energy. However, net-zero carbon often focuses on meeting and offsetting demand rather than decreasing it. A factor within measuring of carbon footprint of buildings is that values are always measured per sqm and not per total impact or per person. This means that the size of a building will not impact the final results.

Furthermore, within the concept of net-zero energy, embodied carbon is not considered, and therefore purchasing more solar panels than required can be done to produce more energy than required and offsetting the energy demand of the building.

In conclusion, sufficiency is a less spread concept in architecture as well, and is needed in combination with the existing concepts of efficiency and renewables.

Application of concepts in design

According to the framework, sufficiency needs to be applied first in the design, by reducing living area, using low-impact, maintainable materials, and offering density and flexibility in design. This is true, the starting point of design should be reduced consumption through the mentioned strategies.

However, efficiency and renewable interventions need to be enabled by the design. In the case of efficiency, shaft requirements, HVAC systems and plumbing need to be included in the layout design. This also applies to renewables, where the materials used and the requirements this brings should be included early in the process to avoid redesign or costly changes later in the process.

The application of sufficiency, efficiency, and renewables cannot be a strict line, as design is a circular process. Efficiency and renewables cannot be the starting point or main focus of design, but to work the best, the interventions need to be kept in mind during the process. Therefore, the SER framework needs to be implemented iteratively as well, not just hierarchically.

Furthermore, there is a greyscale between what counts as a sufficiency intervention and what falls under the efficiency category. This also applies to passive design measures. While it is clear from theory that these should be implemented. they are difficult to categorise within the SER framework.

In conclusion, it can be seen that all three of these aspects are required and fulfil a purpose within the design. I agree that the thought process and concepts should be applied in the correct order, however, the implications of an efficient design using renewable energy and materials need to be taken into consideration during the whole process, they cannot just be applied as an afterthought in a sufficient design.

Application of sufficiency in design

Within sufficiency, there are a few core concepts when applied to buildings. Two of most significant ones are density and flexibility in size.

During the early design process, a number of floorplans designs testing these concepts practically were produced. There are different ways to implement these concepts in design, and while not necessarily contradicting concepts in theory, they have proven to be conflicting while implemented in this project.

Denser apartments are space-effective and with minimised living area. However, the possibility of flexibility in size is severely impacted by this, as flexibility in size requires changeable area not required by other functions. In a dense apartment, flexibility can usually only be achieved by removing a bedroom, which results in a less dense living area. Adding space in an already dense apartment, keeping the space-effectiveness is virtually impossible.
The study of co-living options show that this can be easier implemented within shared apartments, where the number of bedrooms per household can be changed without interfering with the design.

This conflict is interesting, as it puts the concepts against each other and limits the implementability of sufficiency in design.

Measuring sufficiency in design

Another difficulty with sufficiency is measuring the qualities in design. MAB, the chosen qualitative design framework, tends to premier bigger apartments, with requirements of multiple doors, autonoumous rooms, multiple facades etc. There is one density requirement, but only evaluating living area.

Overall, measuring sufficiency in design is difficult. Measurements used in this design are density, no of bathrooms and kitchen, however these numbers are highly concatenated and does not measure the quality of design. Swedish Standard partly ensures usable design, but not measuring quality. In conclusion, there are several difficulties implementing and measuring sufficiency in design.

Challenges within transformation

This thesis concerns challenges with transforming offices into housing from both a theoretical and practical perspective.

Firstly, challenges about knowing the extent of the renovation and the rules that apply are mentioned in the investigation by Boverket. Secondly, challenges within the transformation process itself are listed, such as reusing existing elements outside of the load-bearing construction, having to redo installations, needing to divide the bathroom clusters, limitations from window placement, and replacing existing shafts. It is stated though that the load-bearing construction can generally be spared if made up of pillars and slabs. Furthermore, with generous ceiling heights, the installations can often be placed in the ceilings.

Regarding the economy within a transformation project, the budget calculation can be challenging, as the uncertainty is higher, possibly due to a lack of, or older drawings. Furthermore, the different needs of housing compared to offices often require plenty of changes in the building, which often brings up the cost of renovation and affects the economy within transformation. There are a number of changes that are mentioned as costly, such as staircase changes, alterations to the building envelope, kitchens, bathrooms, and installations.

Finally, taxes and fees impact the transformation cost, with transformations having higher taxes than new housing, but lower than locales. In general, income from offices is higher, and it might be more beneficial to leave offices partly vacant than to transform them.

Most of the issues listed apply to this building, for example, older documentation, needing to divide bathroom clusters, limitations from bathrooms, an existing pillar deck construction, changes in the building envelope, and required installations of bathrooms and kitchens. However, one thing not applicable is the high ceiling height, as the internal height is only 2.53 meters.

It is also likely that economic aspects are part of the decision to keep the building as offices, as it is located in the heart of Gothenburg, and with modern facilities, plenty of services, and city views, rent possibilities are high.

Transformation and design

As mentioned, most of the challenges with transforming offices apply to this building.

During the process, different ways of handling the existing building elements have been explored and evaluated. In all options, the elevators and round staircases are kept and incorporated into the new design in various ways. Minimising the stairwells results in more apartment areas, however, the area gained consists of dark areas and adds limited quality to the apartments. More units also result in a higher number of entrances and therefore larger stairwells. This often results in awkward corners between the new walls and the round staircase. A third option is co-living, where staircases can either be closed off or placed like furniture in the common spaces. This impacts the openness of spaces and the possible placement of interior walls.

Another aspect explored in the design is the bathroom clusters. In a few options, these are removed completely, enabling a free design but causing higher costs for new shafts and bathrooms. The option of keeping the shafts and extending the bathrooms for accessibility has also been explored. This results in a set bathroom placement, but more flexibility in terms of measurements.

The third option is to keep the whole cluster, although they do not fulfil the requirements for accessible bathrooms, hence they are only possible to keep as extra bathrooms within co-living options. Similarly, the pillars have been explored, with the discovery that putting pillars inside the wall limits apartment distribution on floors, but enables free placement of furniture within the units.

In conclusion, there are multiple ways of handling existing elements within the design process, and the choices made for keeping or tearing down severely impact design limits and economy.

Regarding the design, measuring quality in a transformation project is challenging. Generally, MAB is created for new apartments and is slightly complicated to apply to transformation projects. There are several aspects that are very difficult to reach with an existing structure, for example, facades and designed daylight.

Sufficiency in a Swedish context

In a Swedish context, all new housing design needs to be compliant with the Swedish building rules, regulating furniture and functions that should be present within the living space.

Furthermore, all units within a housing project need to fulfil the normal accessibility requirements. A comparison between design compliant with the Swedish Standard and design based on international examples shows that the flexibility in design and elements of an apartment is much higher abroad.

In a Swedish context, the size of the bathroom, kitchen sizes, amount and types of storage and the accessibility rules for doors tend to be limiting aspects of the design. Furthermore, using height and stairs within an apartment is less common within Swedish design.
In an international context, smaller design is often made possible through other storage solutions, foldable elements and inaccessible bedrooms working with lofts or platforms. While space-effective, this increases cost and limits inclusion and social sustainability.

While the Swedish standard provides a more limited design with strict requirements, it can also be discussed if noncompliance with the design would really improve the overall result.

While the international examples are usually smaller in size, they do not necessarily offer quality and functionality in design. A space can often feel cramped, and functionality can easily create a conflict with usability. Furthermore, storage in kitchen and wardrobe is often something sought after in an apartment.

A wider aspect of the Swedish context is the balance between accessibility, inclusion and density. Inclusion is achieved by all units needing to be accessible, however this often results in larger apartments than necessary for most people. This is one of the major ethical dilemmas that comes with sufficiency, reducing size is not always inclusive and can come with other impacts on the everyday life of residents. One solution could be that only part of the units would be accessible, but that would also mean limiting the freedom of those in need of extra space. There is simply no easy answer to this question.

Swedish standard in co-living

In a co-living context, there are several limiting requirements in the Swedish building rules for housing with shared amenities. Only three people are allowed to share a bathroom, while twelve people are allowed to share a kitchen.

This does not mean twelve people have to share a kitchen, although optimizing the areas for sufficiency means the largest benefits are gained with twelve people sharing a kitchen and three people sharing a bathroom. For example, units of four people are the common size of house shares abroad, however, in a Swedish context, this requires one extra bathroom compared to co-living units with three people. And if two bathrooms are required anyway, two extra bedrooms need to be added to optimize the unit and the shared areas.

Therefore, the co-living units tested in this option all work with units of three or six, with twelve people sharing the common kitchen and bathroom on each floor. With these rules, sufficiency in a Swedish context can be applied in a co-living situation, however, for full sufficiency, the standards need to be completely followed. Flexibility in unit sizes in combination with maximized sufficiency is impossible within the Swedish settings.

This aspect of the Swedish standard can also be discussed. Why can four people in an apartment share a bathroom, but only three strangers? Furthermore, this is one way to limit the accessibility standards, as only one accessible bathroom is needed in larger units. In order for sufficiency to be fully implemented using co-living, a larger flexibility within the Swedish rules for shared housing is required.

Process reflection

The process of this thesis has focused on the concepts and the current research, analysis of the existing building, and testing possible implementations of sufficiency on a floor plan level. This is complemented by design optimization and finally technology applications. The result is a study where the combination of sufficiency, efficiency, and renewables has been explored. While I am satisfied with the final result, a few things could have been improved during the process.

The process, while exploring various options of design, could have been a bit more playful if sketching had been more used, instead of digital drawings. The biggest improvable aspect during the process and result though is the affordable housing, which is something I have not succeeded all the way with. Affordable housing is very difficult to measure and not something I have worked with before, however, it could have taken up more focus within this thesis, and more calculations could have been used instead of only theory.

The choice of methods has overall worked for this thesis, however, the execution of evaluation could be improved by testing designs earlier, improving research criteria, and performing tests with different material, for example including balconies and not only balcony doors. Exploring other aspects of the design would have been possible as well. The evaluation criteria could have followed frameworks instead of test results. The qualitative evaluation using MAB has already been discussed in other sections, and this is something that could have improved the study.

With all this said, I am proud of my result and my work, I feel that this is a reflection of who I am as an architect and what I want to work with. I have put my heart and soul into this project, and I have shown my skillset within sustainable buildings.

The result is a good combination of engineering and architecture, where the concepts I have learned from Industrial Ecology are put into an architectural context. The difficulty of finding case studies and references shows that this research and project application is necessary. Furthermore, this thesis reflects my opinions about how the climate crisis should be solved and where to start, which is also supported by theory.

Reflections on the final design

The final design is a co-living option with open circulation. The floorplan contains four equally sized apartments with three double bedrooms each. The kitchens and other social are shared by twelve people. As mentioned in the discussion about the Swedish standard and co-living, the apartment sizes and number of people per floor are given by the standard and the desire to maximize the sufficiency of the floorplans.

The methods used to evaluate the design highlight the crucial aspects of design optimization during the process. They show that the design is functional and provides high design qualities. Remaining improvements of the design could be to try including the bathroom clusters on the left side of the building in the design, as well as working with the placement of the kitchens in relation to walls and existing shafts.

Balconies are also something that can be further optimized. It is likely that more balconies can be added to the west of the building, providing more space for residents and balancing the heat gains even further. Furthermore, more shading in terms of extension of the slab could be useful and is something that could be tested and implemented.

With regard to the technical applications, there is a large uncertainty in the calculations of energy demand and solar panels. This is something that can be improved with the project in general.

Overall though, the thesis ended with a well-working design, keeping key aspects of the building while showing sufficiency and its restrictions in a Swedish context. In my opinion, the final design fulfils the aim of the project and supports the thesis research and conclusions.

Conclusion

Here the discussion is summarised and each research question answered.

How can the concepts of sufficiency, efficiency and renewables be applied in transformation of an existing office building to achieve resilient affordable housing?

The concepts of sufficiency, efficiency, and renewables and their implementation in society are debated. This research concludes that all three are required to effectively reduce carbon footprint and overturn climate change. As all three concepts have limits and rebound effects, a combination of the concepts is necessary for optimal results.

Sufficiency should come first, as reducing the consumption before offsetting the impact is crucial. However, this needs to be complemented by efficiency to reduce the resource demand per consumed unit and finally be met by renewable resources. In this way, impact is reduced the most.

In design, combining these three concepts follows the same order, however as the design process is iterative, there needs to be a bit of flexibility within the combination.

First, sufficiency should be introduced in the planning stage using density, flexibility in size, shared facilities, reducing maintenance and repurposing empty or unused buildings through adaptive reuse. The requirements of efficiency should be considered during planning, but not be decisive for design. The same goes for renewables, where renewable energy should be applied last, however material choices need to be considered during the process.

What are the main challenges with transforming existing offices into housing?

General and economic aspects mentioned as challenges are uncertainty regarding the existing structure, limitations from the existing structure, possibly costly changes to envelope and floorplan layout, tax changes, and possible loss of income. These aspects might lead to a transformation being both complicated and expensive, even if the building exists and currently might be vacant.

Regarding the design itself, decisions regarding how to work with the existing, for example, pillars, bathroom clusters, and stairwells, strongly impact the freedom of design. Keeping the elements is more cost-efficient, however giving strict design conditions. Furthermore, the outer limits are inclined, and window placement might be strict and difficult to work with.

How can sufficiency in buildings be achieved in a Swedish context in relation to the Swedish Standard?

The Swedish building rules are strict regarding accessibility and the required functions of an apartment, which increases the size of Swedish apartments. However, the testing of sufficiency in an international setting shows that the design is not necessarily improved regarding quality if the standard is not considered. Sufficiency can certainly be implemented with the Swedish standard. However, more limiting is the conflict between flexibility in size and density.

Sufficiency is easier to achieve in a co-living setting because of the balance between flexibility in size and density, however, the strict Swedish building rules have a higher impact. For optimum sufficiency, the rules are followed, which give set constraints on unit sizes, number of inhabitants, and design of shared spaces. Sufficiency would likely be smoother to implement if these requirements were slightly more flexible.

Final words

This thesis shows that there is plenty of room for improvement for the sustainable building community. The wider inclusion of sufficiency would open up a whole new set of tools to decrease climate impact and reverse the effects of climate change around the world.

I believe that there needs to be a combination of all the concepts in this thesis, there needs to be a holistic view on sustainability. We can no longer just do what is comfortable, the fact is that we need to decrease consumption to reduce impact, no matter how uncomfortable that might be.

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Images

Figure 1. SER Framework appplication to buildings (Saheb, 2021).
Box 9.1, Figure 1 in Trisos, C.H., I.O. Adelekan, E. Totin, A. Ayanlade, J. Efitre, A. Gemeda, K. Kalaba, C. Lennard, C. Masao, Y. Mgaya, G. Ngaruiya, D. Olago, N.P. Simpson, and S. Zakieldeen, 2022: Africa. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1285–1455, doi:10.1017/9781009325844.011.Retireved from https://www.ipcc.ch/report/ar6/wg3/figures/chapter-9/box-9-1-figure-1 (2024-05-10)

Figure 6. 1-bed unit 30.5 sqm (ArchDaily, 2021)
"Brf Viva Housing Complex / Malmström Edström Arkitekter Ingenjörer" 15 Apr 2021. ArchDaily. Accessed 21 May 2024. <https://www.archdaily.com/960035/brf-viva-housing-complex-malmstrom-edstrom-arkitekter-ingenjorer> ISSN 0719-8884

Figure 7. 1-3-bed unit 72 sqm (ArchDaily, 2021)
"Brf Viva Housing Complex / Malmström Edström Arkitekter Ingenjörer" 15 Apr 2021. ArchDaily. Accessed 21 May 2024. <https://www.archdaily.com/960035/brf-viva-housing-complex-malmstrom-edstrom-arkitekter-ingenjorer>

Figure 8. 1-bed unit 47.1 sqm (ArchDaily, 2021)
"Brf Viva Housing Complex / Malmström Edström Arkitekter Ingenjörer" 15 Apr 2021. ArchDaily. Accessed 21 May 2024. <https://www.archdaily.com/960035/brf-viva-housing-complex-malmstrom-edstrom-arkitekter-ingenjorer>

Figure 9. Office space (Riksbyggen, n.d.)
Riksbyggen (n.d) *Brf Viva i Göteborg - Referensprojekt.* https://www.riksbyggen.se/kommun/referensprojekt/bostadsratter-riksbyggen/vastra-gotaland/brf-viva-referensprojekt/Retrieved 2024-05-07

Figure 10. Inside BRF Viva (Ulf Celander, 2021)
"Brf Viva Housing Complex / Malmström Edström Arkitekter Ingenjörer" 15 Apr 2021. ArchDaily. Accessed 21 May 2024. <https://www.archdaily.com/960035/brf-viva-housing-complex-malmstrom-edstrom-arkitekter-ingenjorer>

Figure 11. Piano apartment, Taipei, (Hey!Cheese, 2019)
Beath, J. & Price, E. (2021). *Never too small: reimagining small space living.* Naarm/Melbourne, Vic.: Smith Street Books.

Figure 12. Piano apartment, Taipei, (Hey!Cheese, 2019)
Beath, J. & Price, E. (2021). *Never too small: reimagining small space living.* Naarm/Melbourne, Vic.: Smith Street Books.

Figure 13. Boneca, Sydney (Tom Ferguson, 2020)
Beath, J. & Price, E. (2021). *Never too small: reimagining small space living.* Naarm/Melbourne, Vic.: Smith Street Books.

Figure 14. Cairo Flat, Fitzroy (Tom Ross, 2020)
Beath, J. & Price, E. (2021). *Never too small: reimagining small space living.* Naarm/Melbourne, Vic.: Smith Street Books.

Figure 15. Urban Cabin, Bergamo (Francesca Perani, 2019)
Beath, J. & Price, E. (2021). *Never too small: reimagining small space living.* Naarm/Melbourne, Vic.: Smith Street Books.

Figure 16. Darlinghurst apartment, Sydney (Katherine Lu, 2020)
Beath, J. & Price, E. (2021). *Never too small: reimagining small space living.* Naarm/Melbourne, Vic.: Smith Street Books.

Figure 17. Type Street Apartment (Tess Kelly, 2020)
Beath, J. & Price, E. (2021). *Never too small: reimagining small space living.* Naarm/Melbourne, Vic.: Smith Street Books.

Figure 18. Zollhaus building (Martina Meier, n.d.)
https://www.kalkbreite.net/en/media/downloads/

Figure 20. Flex meeting rooms (Saloon, n.d.)
https://www.kalkbreite.net/en/media/downloads/

Figure 21. Hall Living (Annette Landsmann, n.d.)
https://www.kalkbreite.net/en/media/downloads/

Figure 22. Original facade (Moatti-Riviere, n.d.)
Transformation of Office Building To 90 Apartments / MOATTI-RIVIERE. https://www.archdaily.com/800178/transformation-of-office-building-to-90-apartments-moatti-riviere

Figure 23 & 24. Floor plan (ArchDaily, 2016)
Transformation of Office Building To 90 Apartments / MOATTI-RIVIERE. https://www.archdaily.com/800178/transformation-of-office-building-to-90-apartments-moatti-riviere

Figure 25 & 26. Transformed facade (Michel Denancé, n.d.)
Transformation of Office Building To 90 Apartments / MOATTI-RIVIERE. https://www.archdaily.com/800178/transformation-of-office-building-to-90-apartments-moatti-riviere

Figure 27. Photo by Saleh Abdul-Rahman (2023), used with permission.

Figure 28. The planned Central Station area (Göteborgs Stad, 2024)
https://goteborg.se/wps/portal/start/goteborg-vaxer/hitta-projekt/stadsomrade-centrum/centrum/centralenomradet/om-centralenomradet

Figure 29. Engelbrektsgatan 69-71 (Sofia Larsson, 2015)
https://www5.goteborg.se/prod/fastighetskontoret/etjanst/planobygg.nsf/vyFiler/Heden%20-%20P%C3%A5byggnad%20av%20bost%C3%A4der%20vid%20Sten%20Sturegatan-Plan%20-%20samr%C3%A5d-Kulturmilj%C3%B6utredning/$File/08_Kulturmiljoutredning.pdf?OpenElement

Figure 31. Kv. Opalen, 1888, (Riksarkivet, Landsarkivet i Göteborg),
https://sok.riksarkivet.se/arkiv/PrmoBcBYQKczt3VF0Ggld2

Figure 32. Characteristic buildings in the area, early 1900s (Göteborg Stadsmuseum)
https://samlingar.goteborgsstadsmuseum.se/carlotta/web/object/323516

Figure 33. Kv. Opalen, 1960 (Lantmäteriet)
https://goteborg.se/wps/portal/start/bygga-bo-och-leva-hallbart/lantmateri-kartor-och-matning/kartor-och-geodata/kartprodukter/flygbilder

Figure 34. Overview of Kv. Opalen (Sofia Larsson, 2015)
https://www5.goteborg.se/prod/fastighetskontoret/etjanst/planobygg.nsf/vyFiler/Heden%20-%20P%C3%A5byggnad%20av%20bost%C3%A4der%20vid%20Sten%20Sturegatan-Plan%20-%20samr%C3%A5d-Kulturmilj%C3%B6utredning/$File/08_Kulturmiljoutredning.pdf?OpenElement

Figure 35.The current building (Wikimedia Commons, 2017)
https://commons.wikimedia.org/wiki/File:Engelbrektsgatan_69.jpg

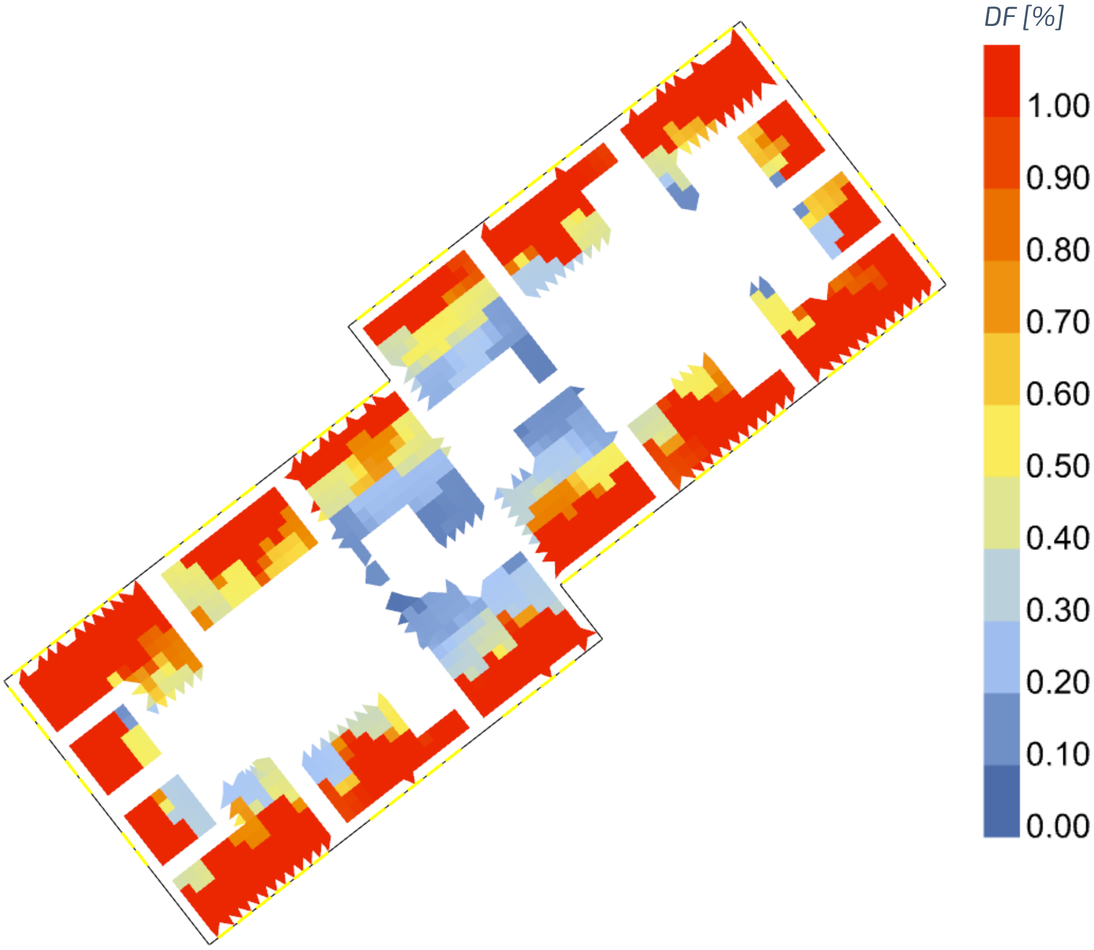
Figure 37.The current building (Wikimedia Commons, 2017)
https://commons.wikimedia.org/wiki/File:Engelbrektsgatan_69.jpg

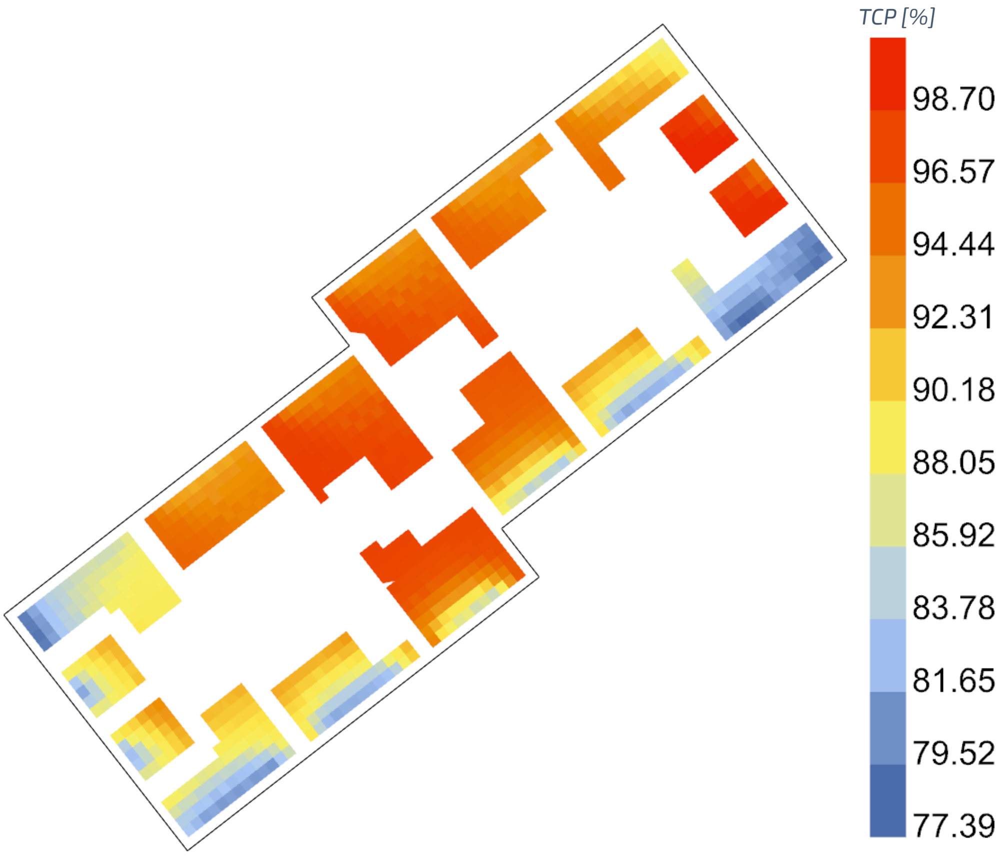
Figure 100. Example solar panel (Adobe Stock, n.d.)
https://stock.adobe.com/se/images/soft-focus-of-solar-panels-or-solar-cells-on-factory-rooftop-or-terrace-with-sun-light-industry-in-thailand-asia-can-saving-energy-sun-energy-renewable-energy-clean-energy/125618781?prev_url=detail

Appendix

In this Appendix, the test results for each option are shown in detail.

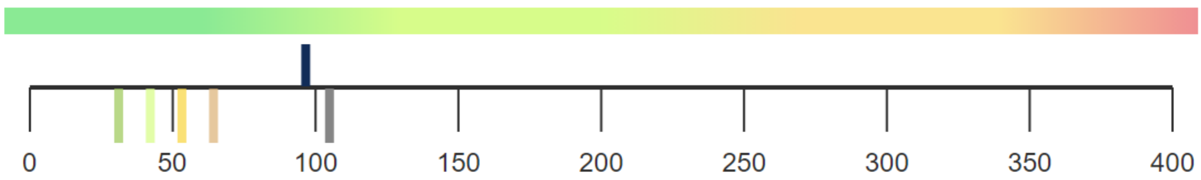
Swedish standard - small





Primary energy demand

95 kWh/(m^2_{AN}*a)
(+2)

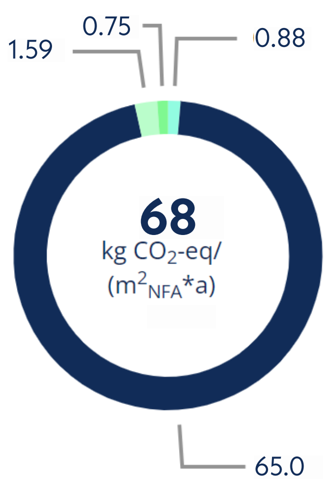


Current variant | Requirement value GEG 2023 Existing building (EH 140)

EH 40 | EH 55 | EH 70 | EH 85

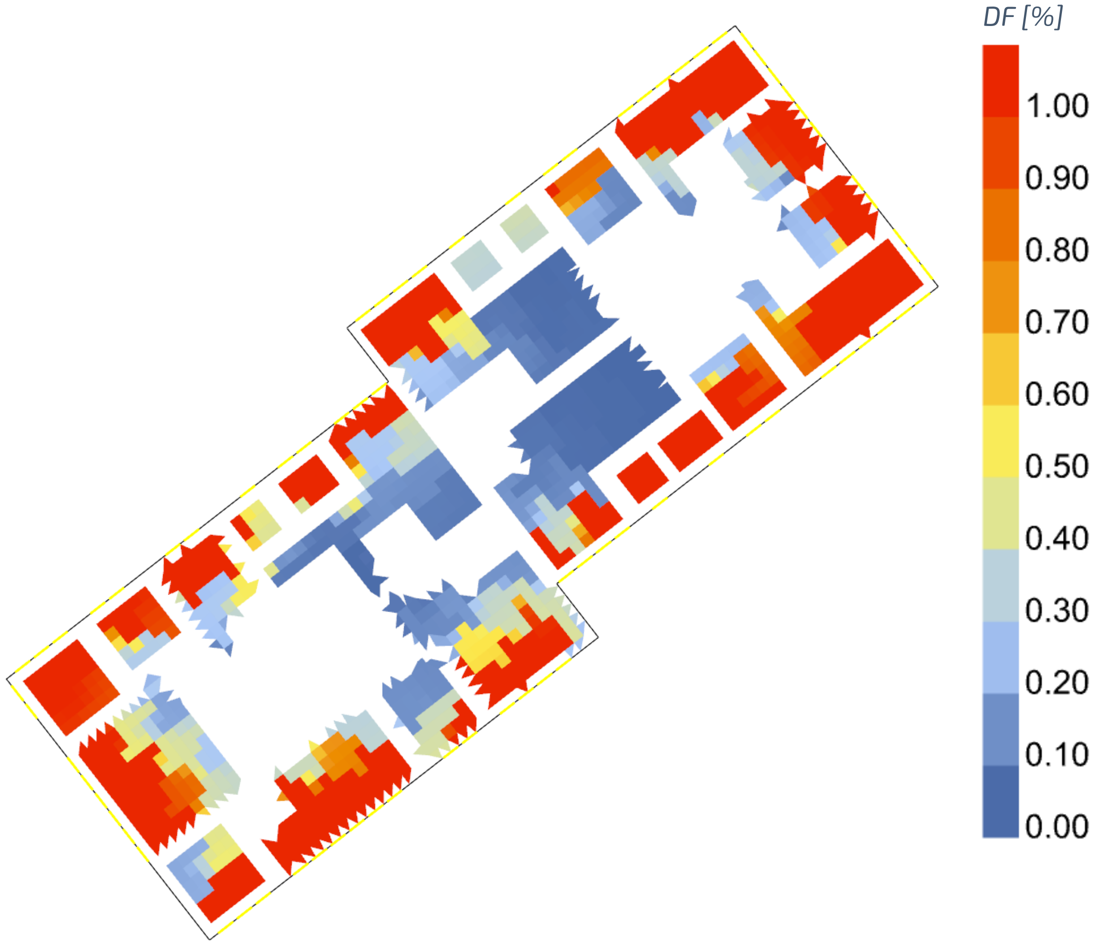
Primary energy demand		95 kWh/(m^2_{AN}*a)
End energy demand	District heating CHP	158 kWh/(m^2_{AN}*a)
	Hot water	25 kWh/(m^2_{AN}*a)
	Auxiliary electricity	1 kWh/(m^2_{AN}*a)
	User Electricity	0 kWh/(m^2_{NFA}*a)
Useful energy demand	Space heating	115 kWh/(m^2_{AN}*a)
	Hot water	9 kWh/(m^2_{AN}*a)

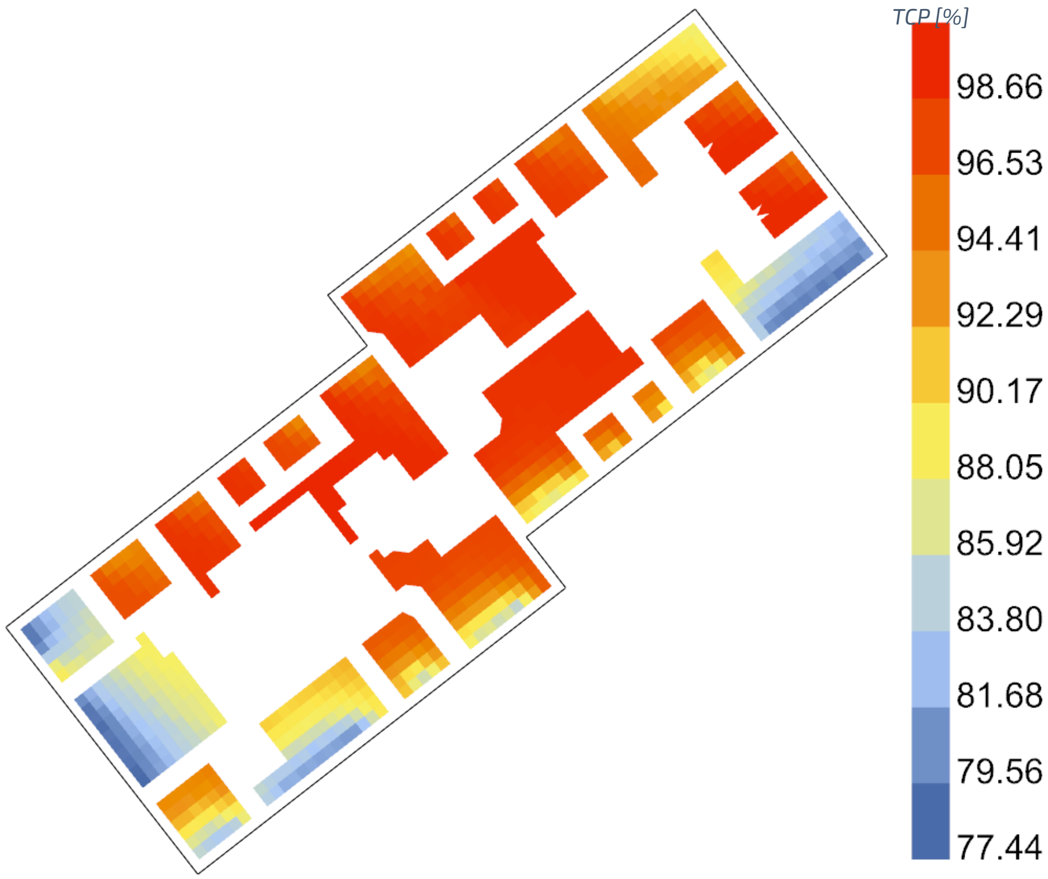
Global warming potential (GWP)



Other parameters:
Density: 16 people
Bathrooms: 12
Kitchen length: 40 m
Functionality: 2 (Criteria 3 and 4 passed)
Spaciousness: 2 (Criteria 5 and 7 passed)
Atmosphere: 2 (Criteria 10 and 12 passed)

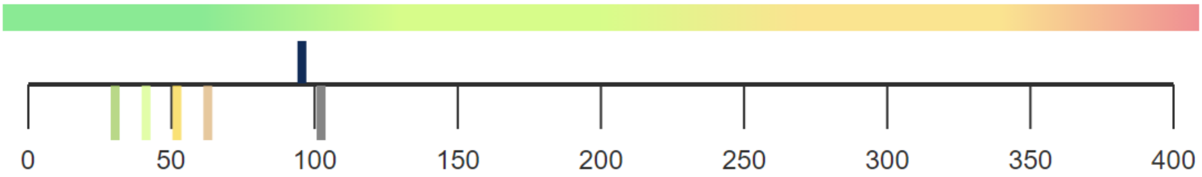
Swedish standard - large





Primary energy demand ⓘ

94 kWh/(m$^2_{AN}$*a)
(-)

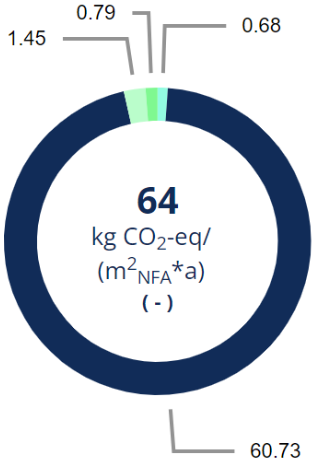


Current variant | Requirement value GEG 2023 Existing building (EH 140)

EH 40 | EH 55 | EH 70 | EH 85

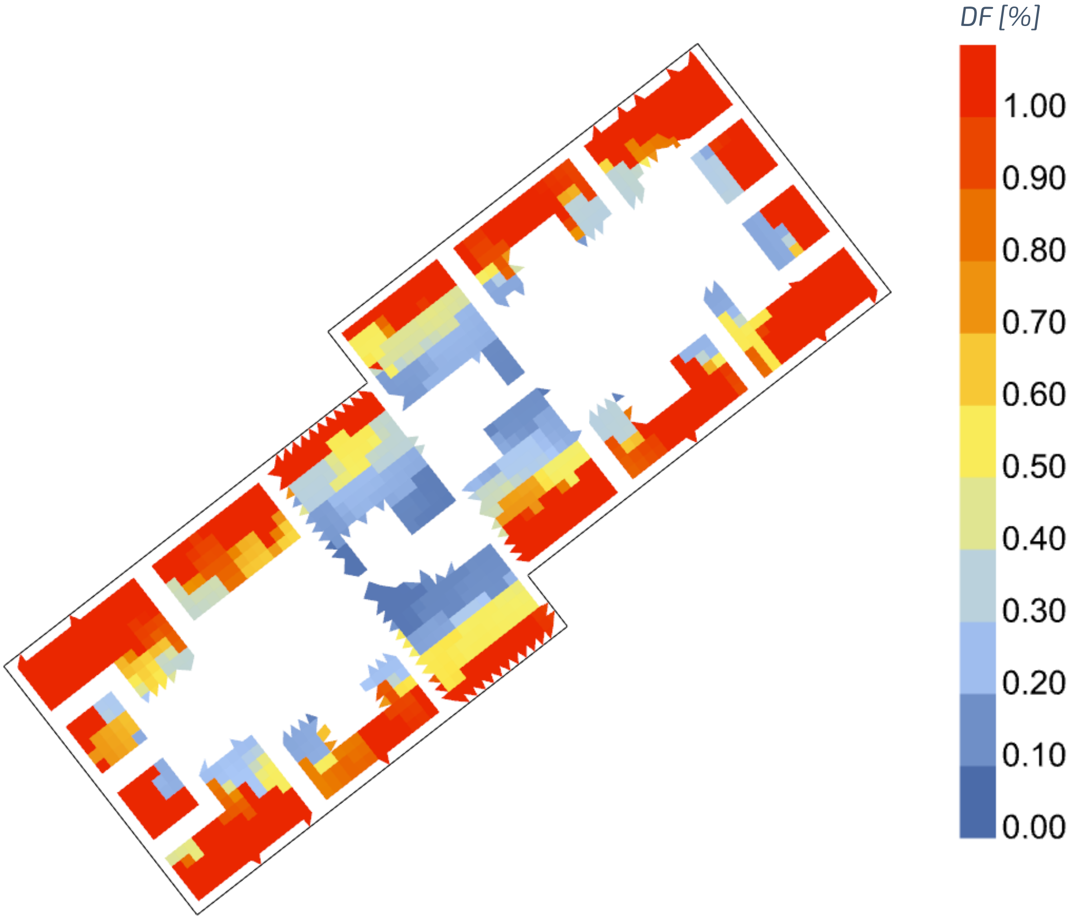
Primary energy demand		94 kWh/(m$^2_{AN}$*a)
End energy demand	District heating CHP	156 kWh/(m$^2_{AN}$*a)
	Hot water	25 kWh/(m$^2_{AN}$*a)
	Auxiliary electricity	1 kWh/(m$^2_{AN}$*a)
	User Electricity	0 kWh/(m$^2_{NFA}$*a)
Useful energy demand	Space heating	114 kWh/(m$^2_{AN}$*a)
	Hot water	9 kWh/(m$^2_{AN}$*a)

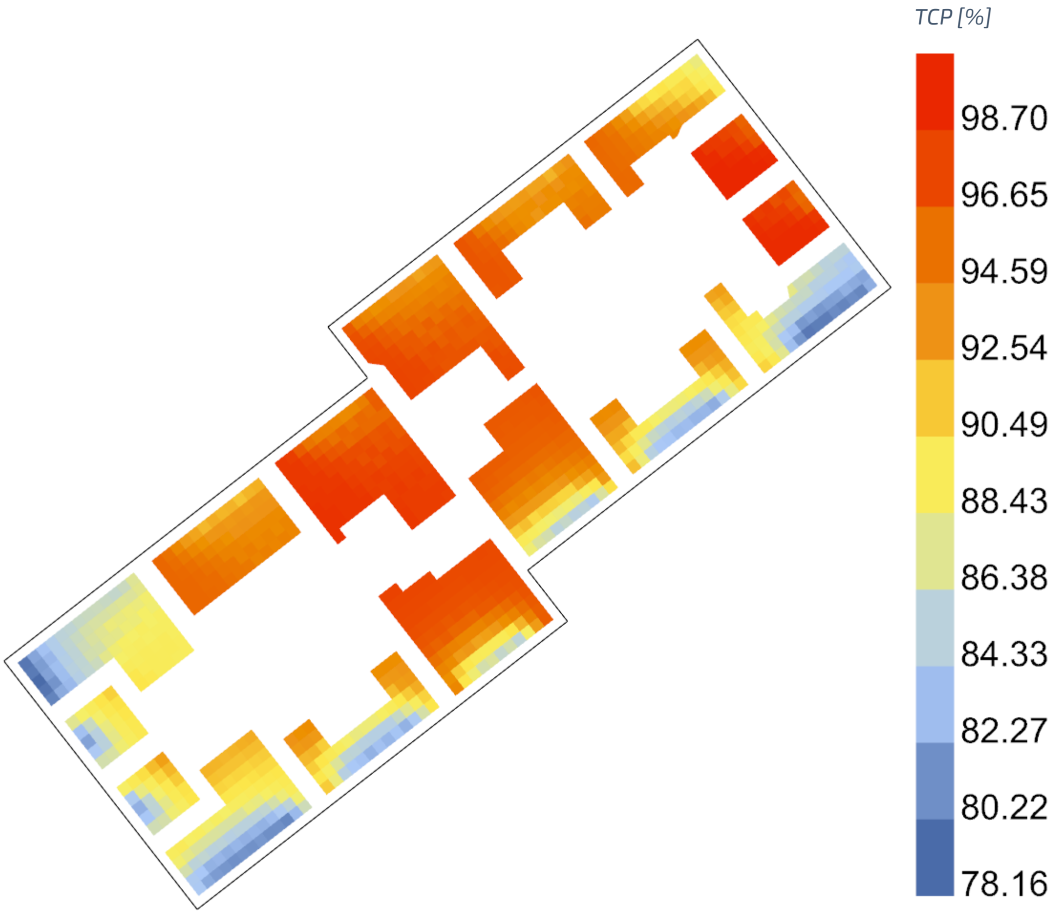
Global warming potential (GWP)



Other parameters:
Density: 24 people
Bathrooms: 8
Kitchen length: 37.1 m
Functionality: 1 (Criteria 1 passed)
Spaciousness: 2 (Criteria 5 and 7 passed)
Atmosphere: 1 (Criteria 10 passed)

Lowered standard - small

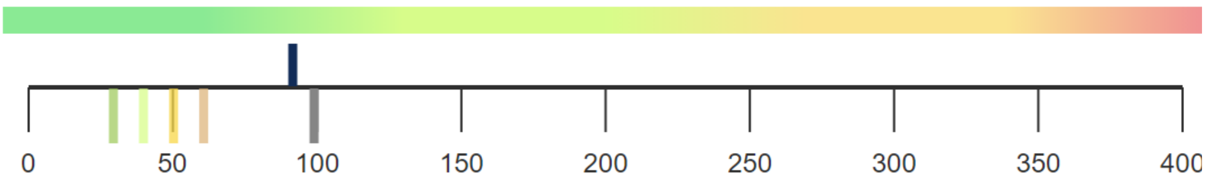




Primary energy demand ⓘ

90 kWh/(m^2_{AN}*a)

(-)

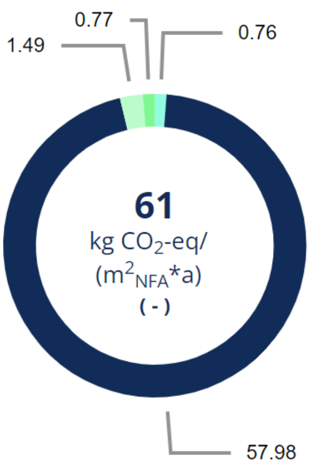


Current variant | Requirement value GEG 2023 Existing building (EH 140)

EH 40 | EH 55 | EH 70 | EH 85

Primary energy demand		90 kWh/(m^2_{AN}*a)
End energy demand	District heating CHP	148 kWh/(m^2_{AN}*a)
	Hot water	25 kWh/(m^2_{AN}*a)
	Auxiliary electricity	1 kWh/(m^2_{AN}*a)
	User Electricity	0 kWh/(m^2_{NFA}*a)
Useful energy demand	Space heating	108 kWh/(m^2_{AN}*a)
	Hot water	9 kWh/(m^2_{AN}*a)

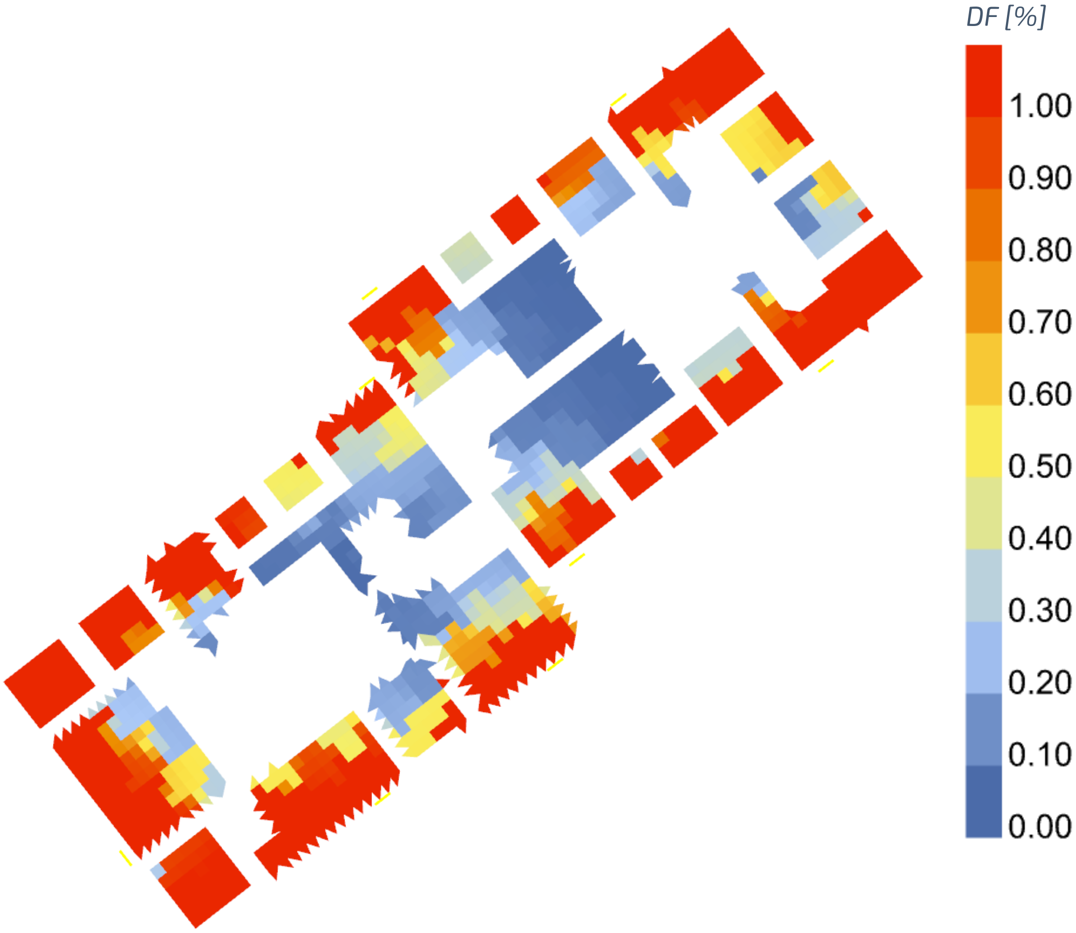
Global warming potential (GWP)

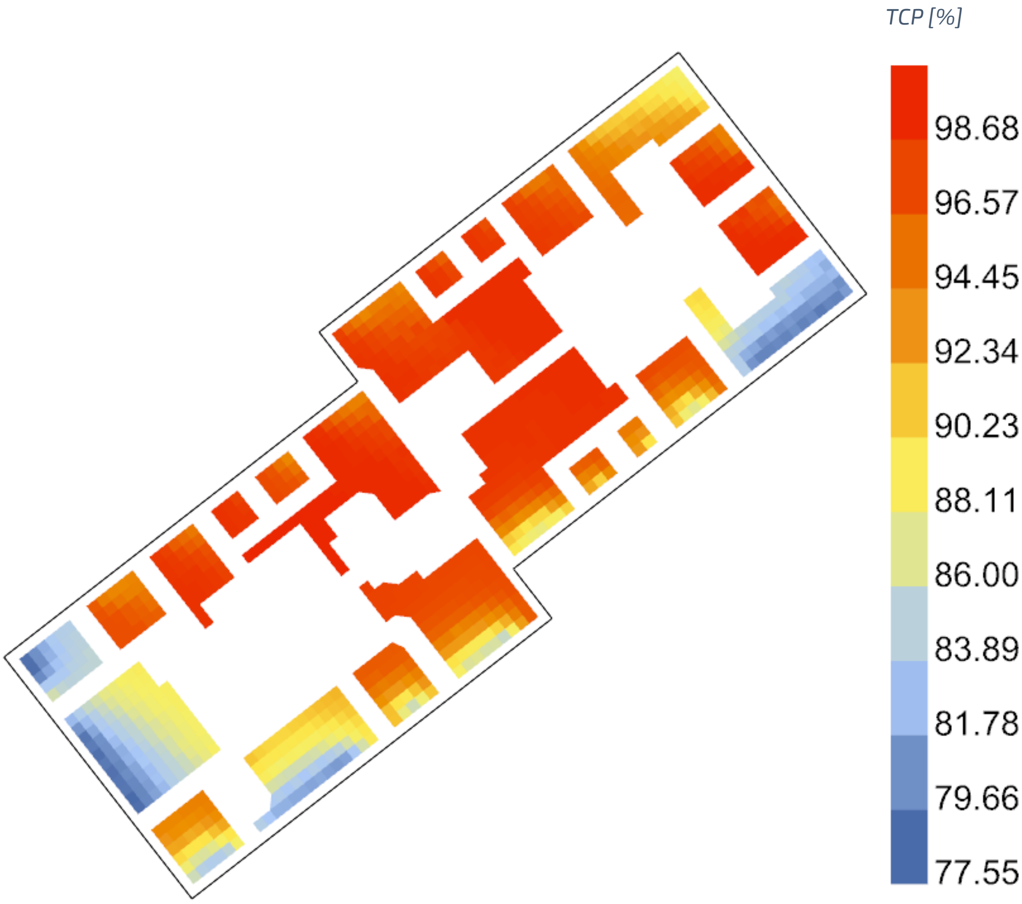


Other parameters:

Density: 18 people
Bathrooms: 12
Kitchen length: 45.2 m
Functionality: 1 (Criteria 3 passed)
Spaciousness: 1 (Criteria 7 passed)
Atmosphere: 1 (Criteria 10 passed)

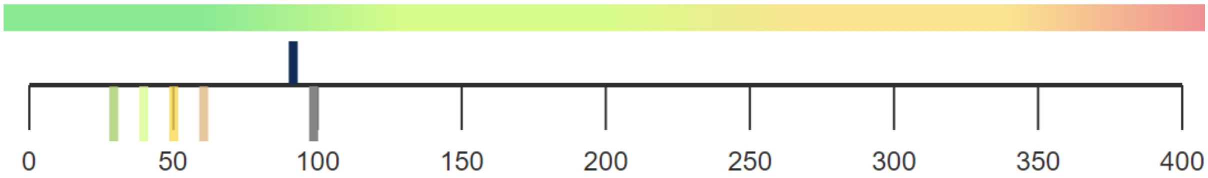
Lowered standard - large





Primary energy demand ⓘ

90 kWh/(m^2_{AN}*a)
(-)

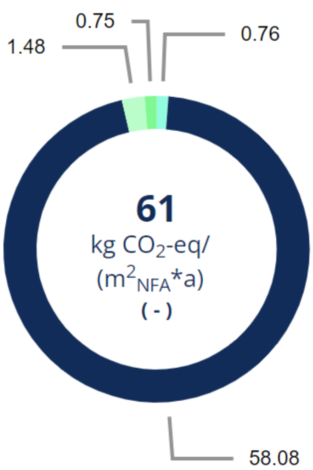


Current variant | Requirement value GEG 2023 Existing building (EH 140)

EH 40 | EH 55 | EH 70 | EH 85

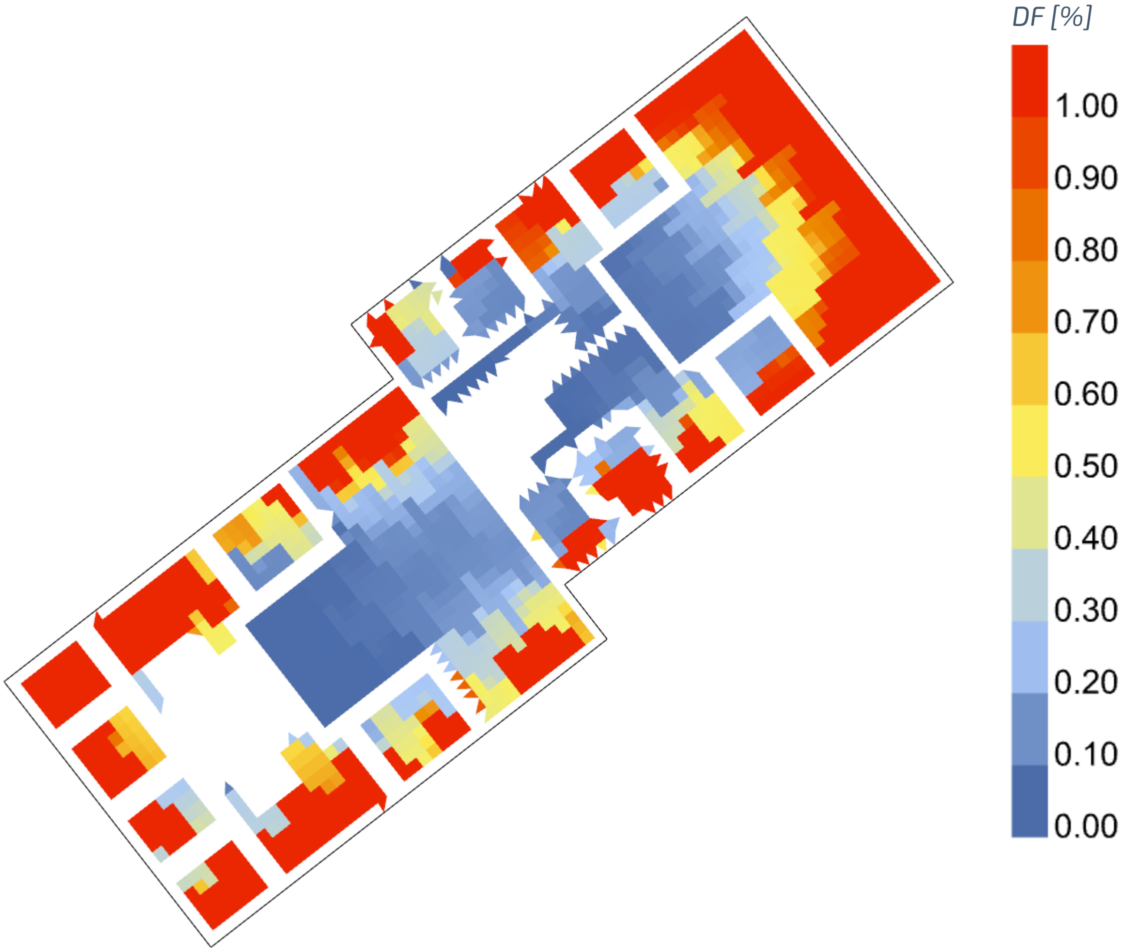
Primary energy demand		90 kWh/(m^2_{AN}*a)
End energy demand	District heating CHP	148 kWh/(m^2_{AN}*a)
	Hot water	25 kWh/(m^2_{AN}*a)
	Auxiliary electricity	1 kWh/(m^2_{AN}*a)
	User Electricity	0 kWh/(m^2_{NFA}*a)
Useful energy demand	Space heating	108 kWh/(m^2_{AN}*a)
	Hot water	9 kWh/(m^2_{AN}*a)

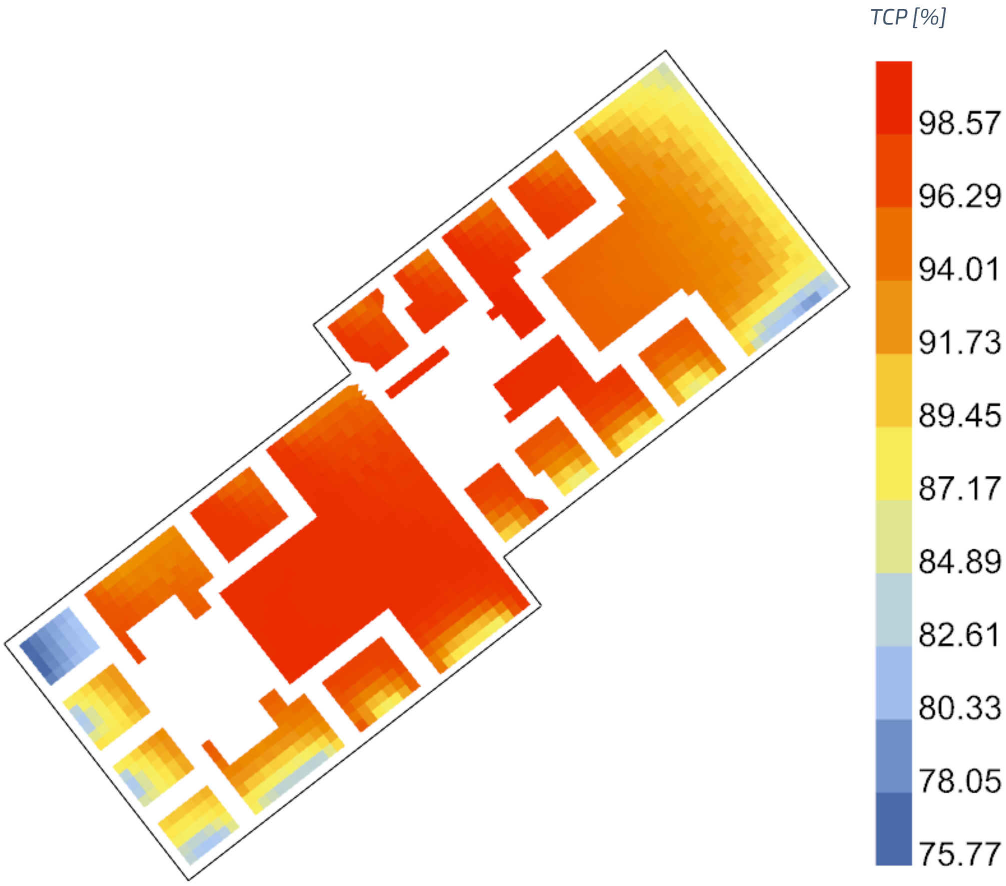
Global warming potential (GWP)



Other parameters:
Density: 24 people
Bathrooms: 8
Kitchen length: 36 m
Functionality: 1 (Criteria 1 passed)
Spaciousness: 2 (Criteria 5 and 7 passed)
Atmosphere: 1 (Criteria 10 passed)

Open co-living

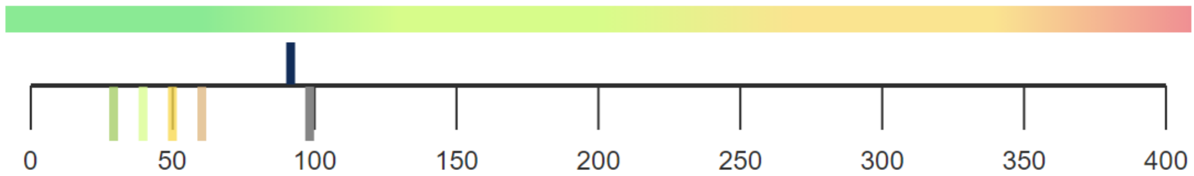




Primary energy demand ⓘ

90 kWh/(m^2_{AN}*a)

(-)

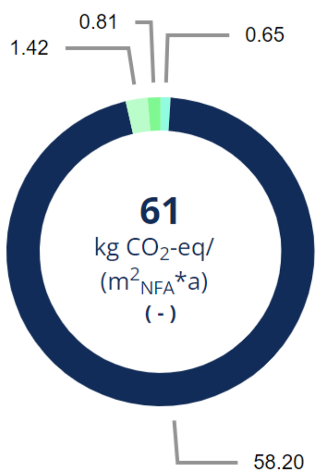


Current variant | Requirement value GEG 2023 Existing building (EH 140)

EH 40 | EH 55 | EH 70 | EH 85

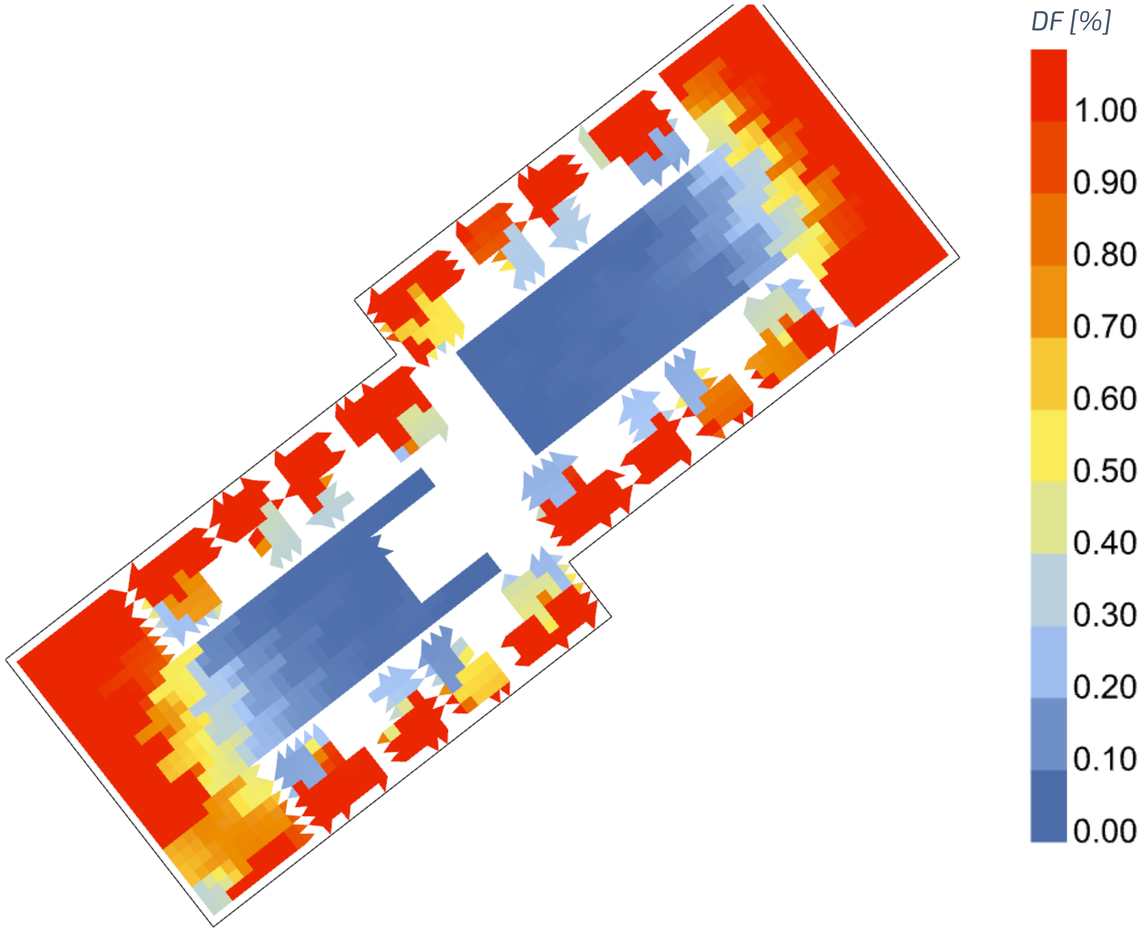
Primary energy demand		90 kWh/(m^2_{AN}*a)
End energy demand	District heating CHP	149 kWh/(m^2_{AN}*a)
	Hot water	25 kWh/(m^2_{AN}*a)
	Auxiliary electricity	1 kWh/(m^2_{AN}*a)
	User Electricity	0 kWh/(m^2_{NFA}*a)
Useful energy demand	Space heating	108 kWh/(m^2_{AN}*a)
	Hot water	9 kWh/(m^2_{AN}*a)

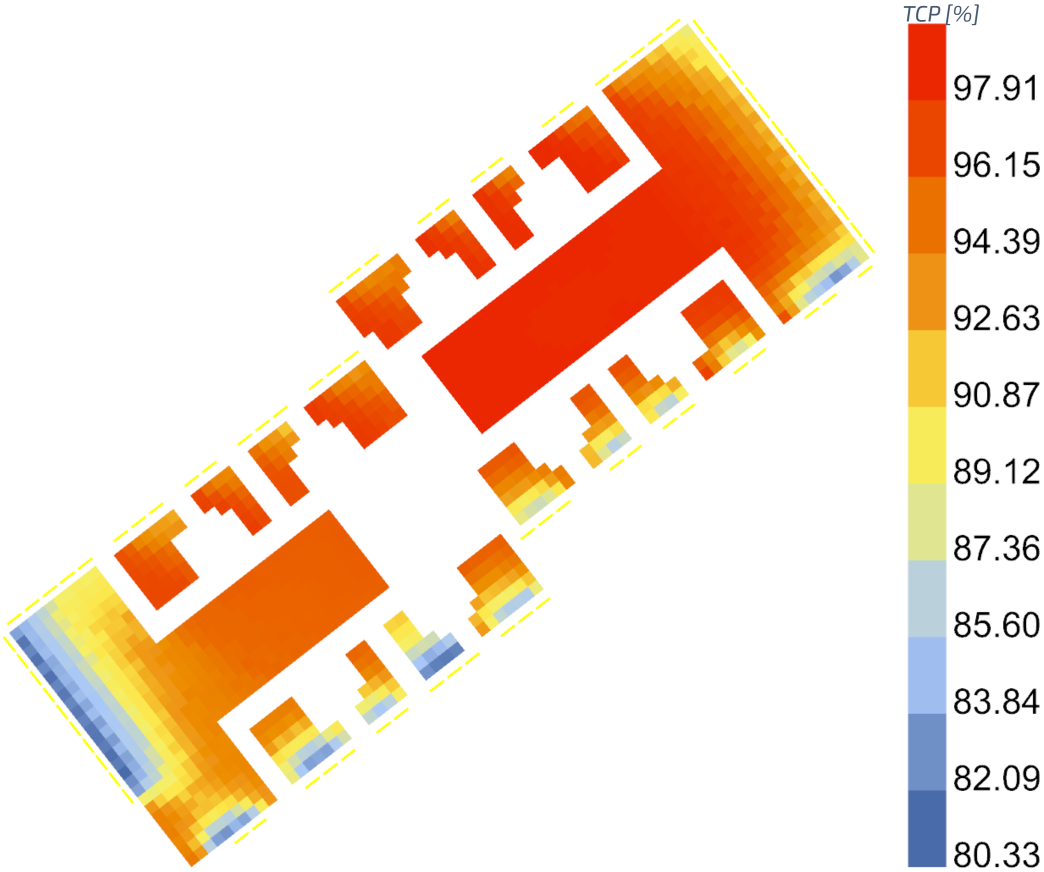
Global warming potential (GWP)



Other parameters:
Density: 24 people
Bathrooms: 8
Kitchen length: 37 m
Functionality: 3 (Criteria 1, 3 and 4 passed)
Spaciousness: 1 (Criteria 7 passed)
Atmosphere: 2 (Criteria 9 and 10 passed)

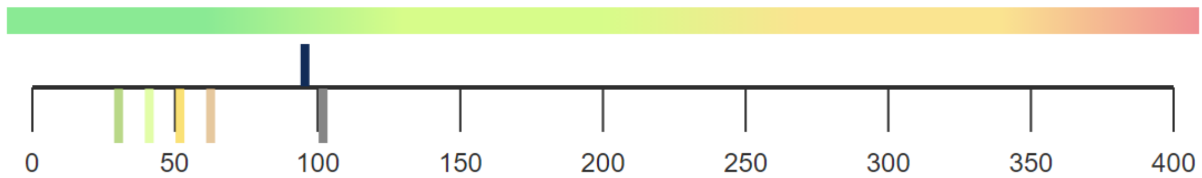
Divided co-living





Primary energy demand

94 $kWh/(m^2_{AN}*a)$
(-)

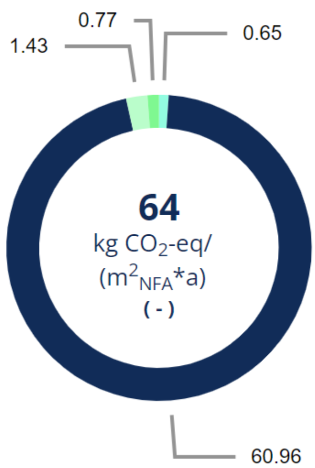


Current variant | Requirement value GEG 2023 Existing building (EH 140)

EH 40 | EH 55 | EH 70 | EH 85

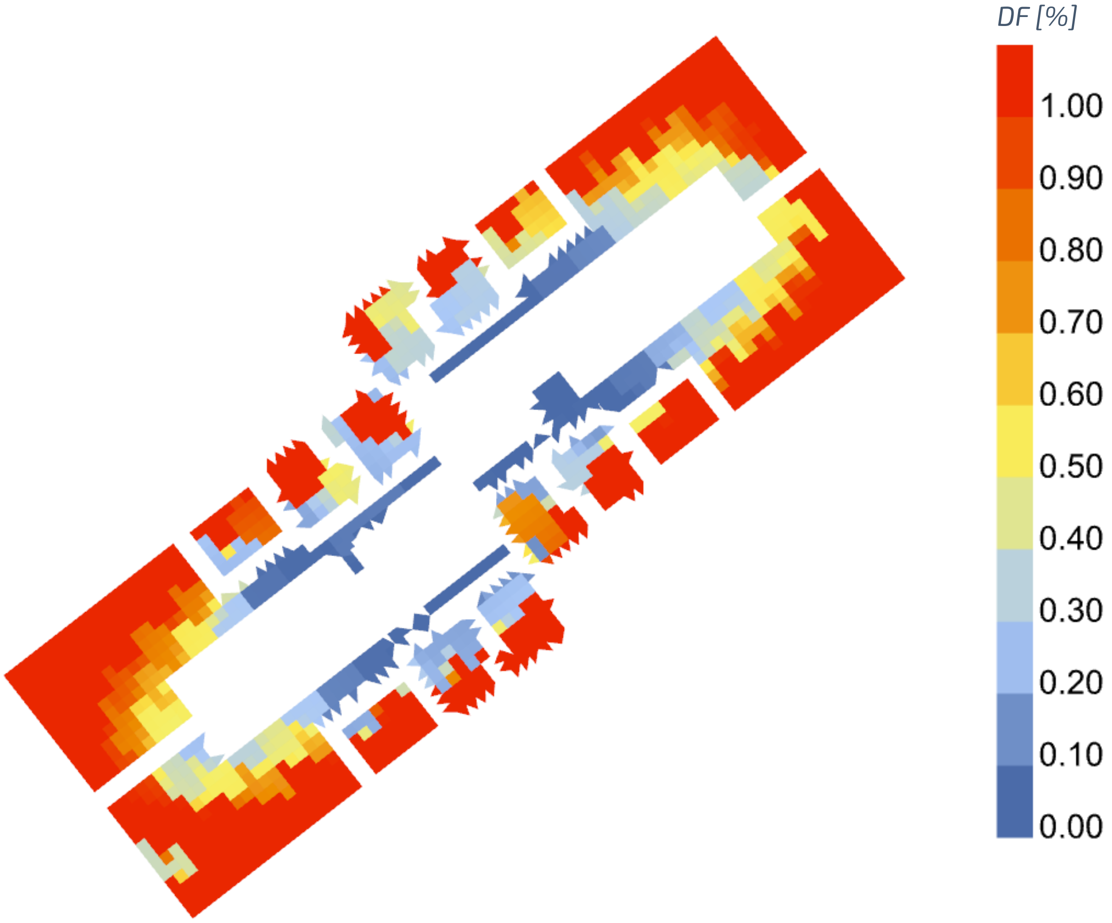
Primary energy demand		94 $kWh/(m^2_{AN}*a)$
End energy demand	District heating CHP	157 $kWh/(m^2_{AN}*a)$
	Hot water	25 $kWh/(m^2_{AN}*a)$
	Auxiliary electricity	1 $kWh/(m^2_{AN}*a)$
	User Electricity	0 $kWh/(m^2_{NFA}*a)$
Useful energy demand	Space heating	114 $kWh/(m^2_{AN}*a)$
	Hot water	9 $kWh/(m^2_{AN}*a)$

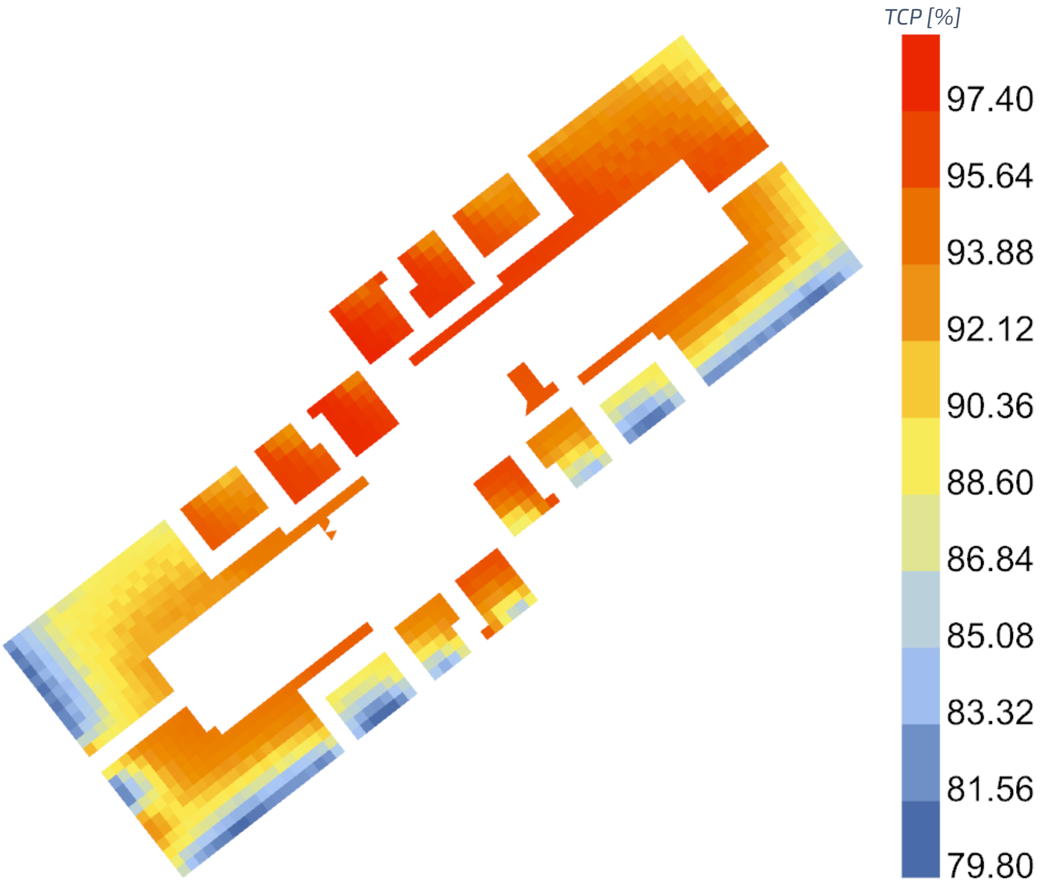
Global warming potential (GWP)



Other parameters:
Density: 24 people
Bathrooms: 10
Kitchen length: 35.4 m
Functionality: 2 (Criteria 1 and 4 passed)
Spaciousness: 1 (Criteria 7 passed)
Atmosphere: 2 (Criteria 10 and 12 passed)

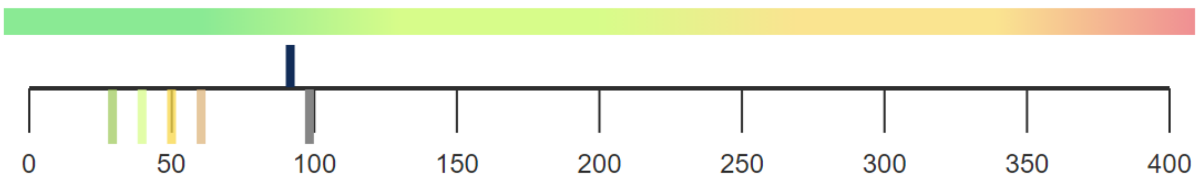
Co-living - units of 3





Primary energy demand ⓘ

90 kWh/(m^2_{AN}*a)
(-)

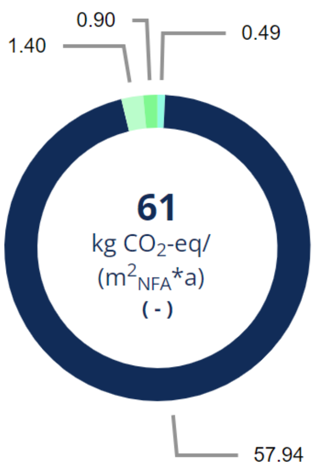


Current variant | Requirement value GEG 2023 Existing building (EH 140)

EH 40 | EH 55 | EH 70 | EH 85

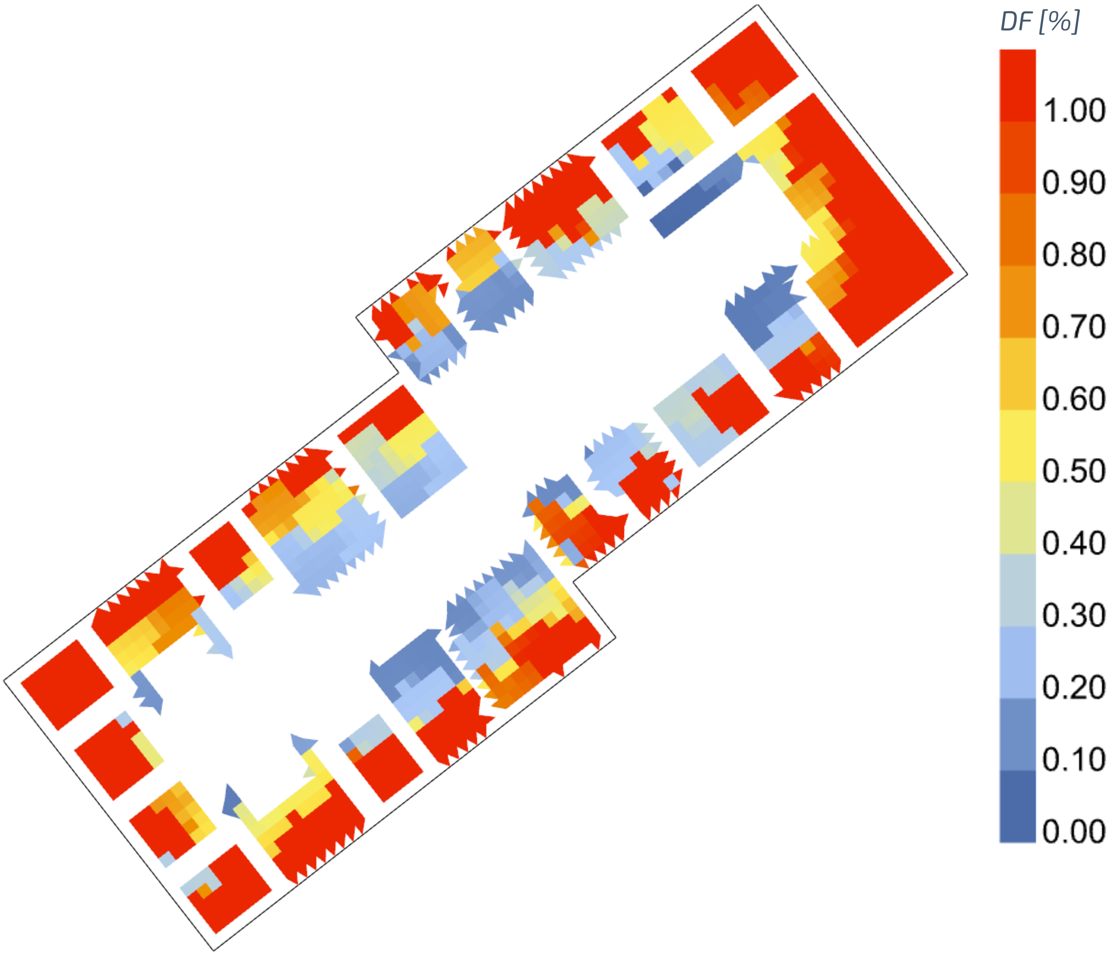
Primary energy demand		90 kWh/(m^2_{AN}*a)
End energy demand	District heating CHP	148 kWh/(m^2_{AN}*a)
	Hot water	25 kWh/(m^2_{AN}*a)
	Auxiliary electricity	1 kWh/(m^2_{AN}*a)
	User Electricity	0 kWh/(m^2_{NFA}*a)
Useful energy demand	Space heating	108 kWh/(m^2_{AN}*a)
	Hot water	9 kWh/(m^2_{AN}*a)

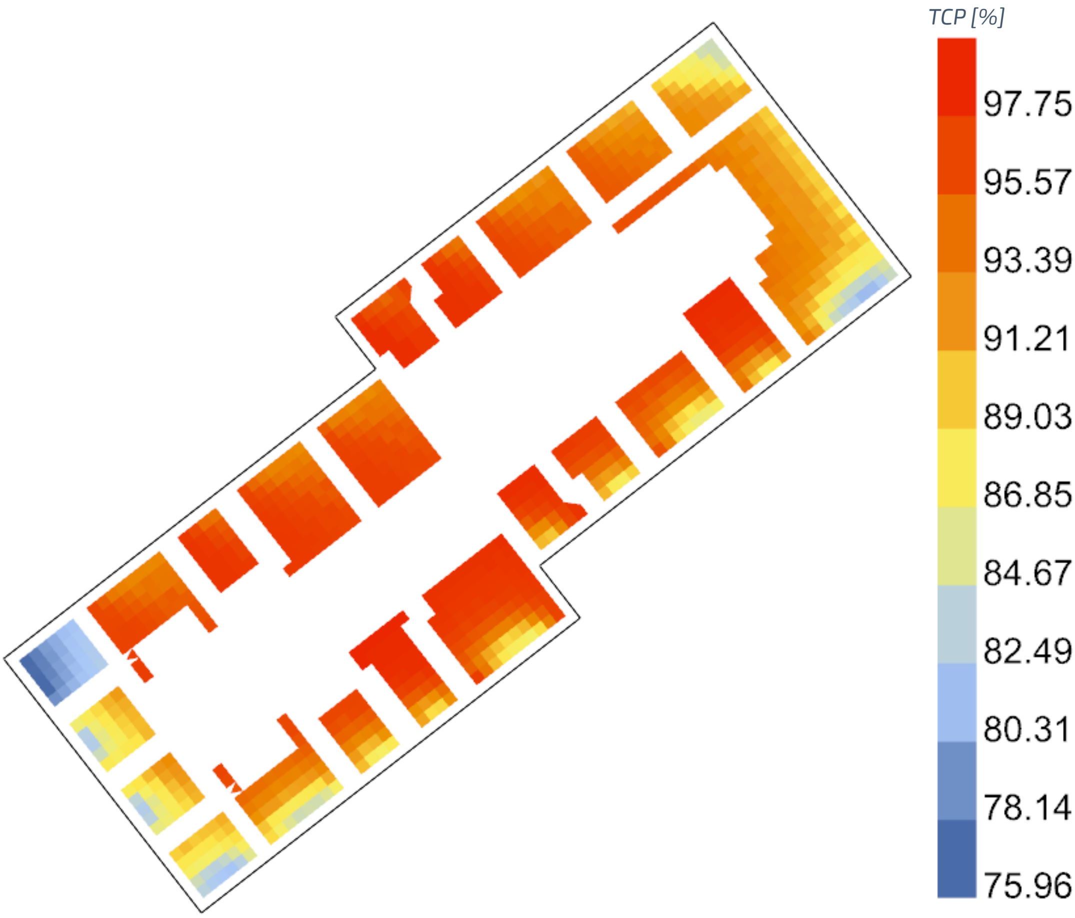
Global warming potential (GWP)



Other parameters:
Density: 24 people
Bathrooms: 8
Kitchen length: 34.4 m
Functionality: 2 (Criteria 3 and 4 passed)
Spaciousness: 1 (Criteria 7 passed)
Atmosphere: 3 (Criteria 9, 10 and 12 passed)

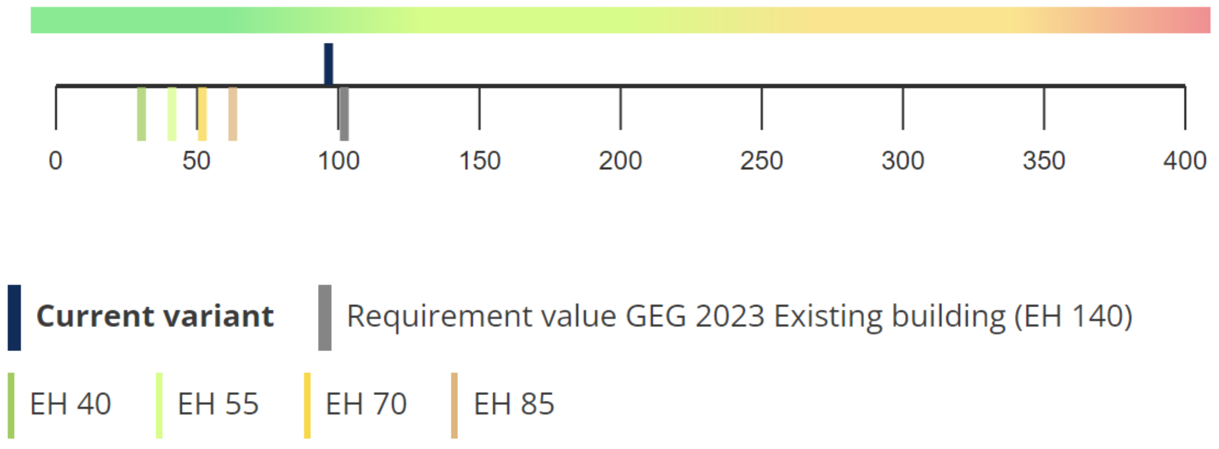
Closed co-living





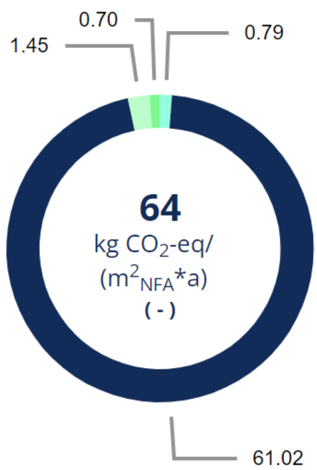
Primary energy demand ⓘ

95 kWh/(m$^2_{AN}$*a)
(-)



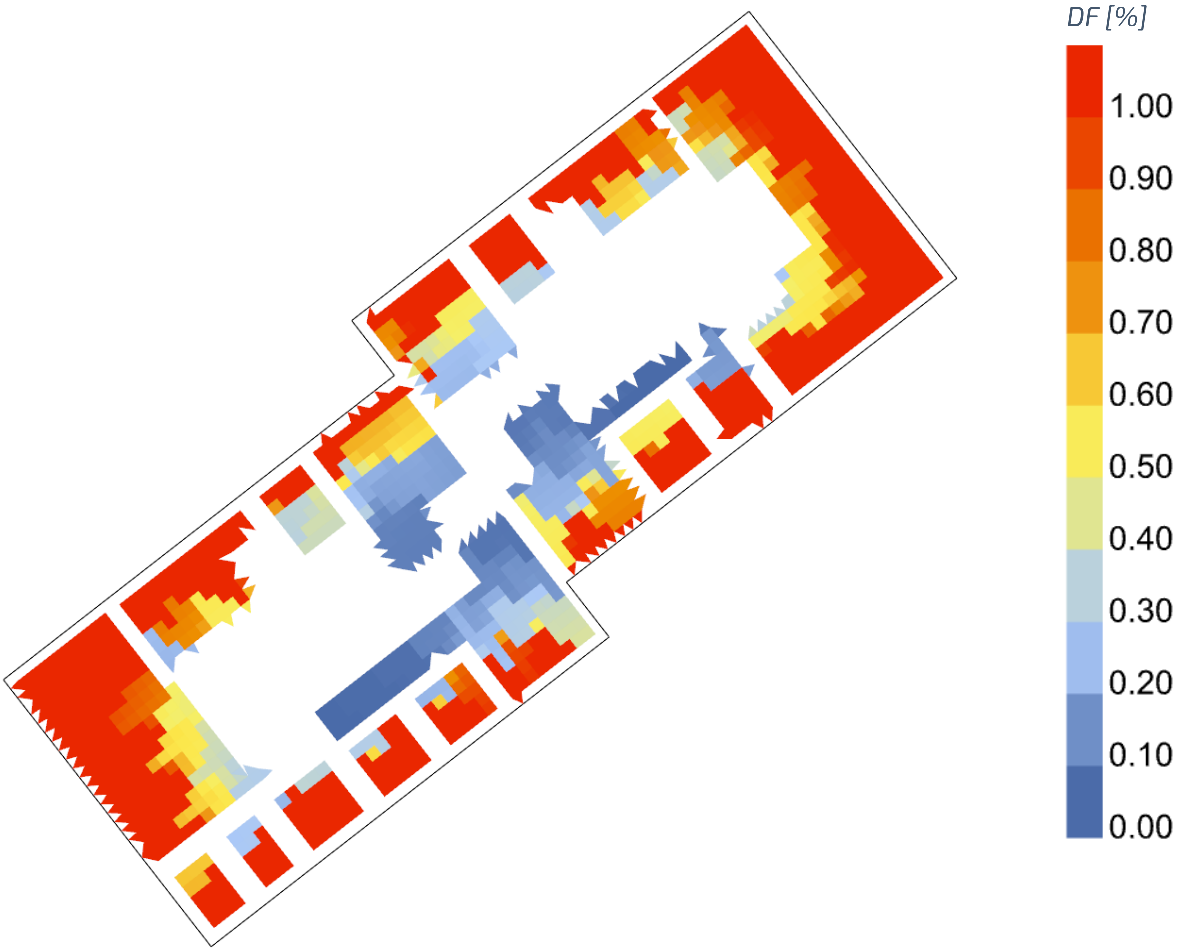
Primary energy demand		95 kWh/(m$^2_{AN}$*a)
End energy demand	District heating CHP	157 kWh/(m$^2_{AN}$*a)
	Hot water	25 kWh/(m$^2_{AN}$*a)
	Auxiliary electricity	1 kWh/(m$^2_{AN}$*a)
	User Electricity	0 kWh/(m$^2_{NFA}$*a)
Useful energy demand	Space heating	115 kWh/(m$^2_{AN}$*a)
	Hot water	9 kWh/(m$^2_{AN}$*a)

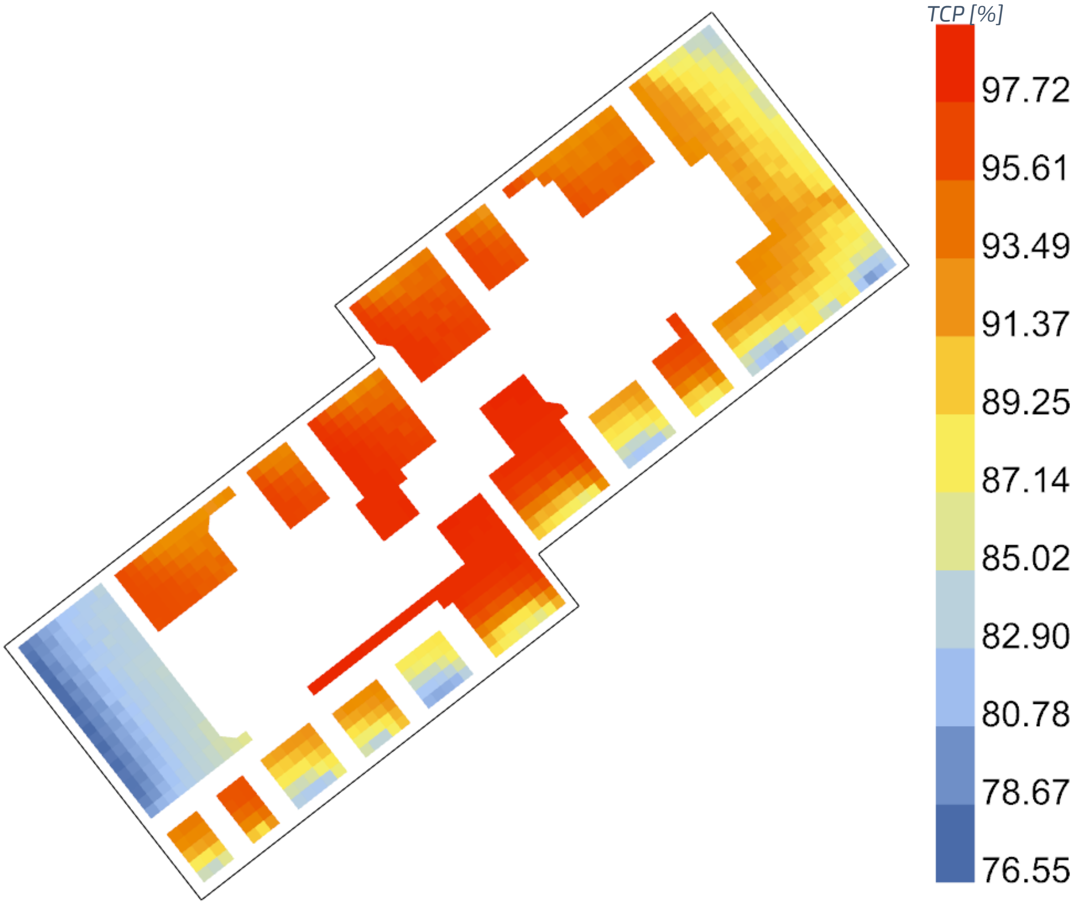
Global warming potential (GWP)



Other parameters:
Density: 24 people
Bathrooms: 10
Kitchen length: 31.9 m
Functionality: 1 (Criteria 1 passed)
Spaciousness: 2 (Criteria 5 and 7 passed)
Atmosphere: 3 (Criteria 9, 10 and 12 passed)

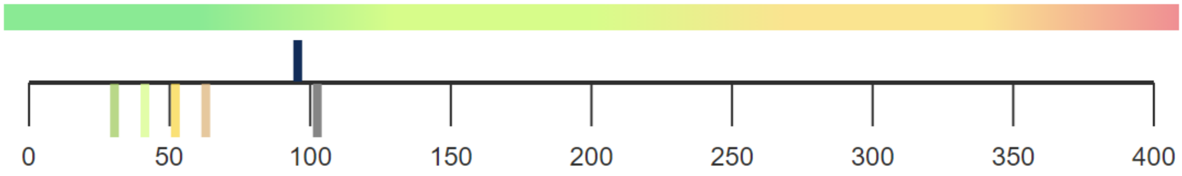
International standard





Primary energy demand ⓘ

94 kWh/(m^2_{AN}*a)
(-)

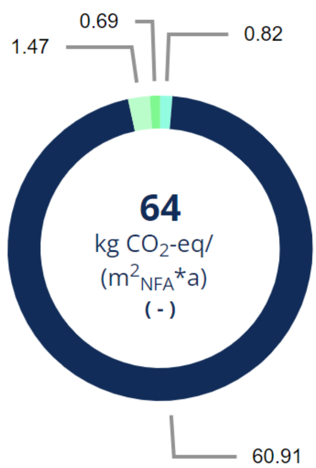


Current variant Requirement value GEG 2023 Existing building (EH 140)

EH 40 EH 55 EH 70 EH 85

Primary energy demand		94 kWh/(m^2_{AN}*a)
End energy demand	District heating CHP	157 kWh/(m^2_{AN}*a)
	Hot water	25 kWh/(m^2_{AN}*a)
	Auxiliary electricity	1 kWh/(m^2_{AN}*a)
	User Electricity	0 kWh/(m^2_{NFA}*a)
Useful energy demand	Space heating	114 kWh/(m^2_{AN}*a)
	Hot water	9 kWh/(m^2_{AN}*a)

Global warming potential (GWP)



Other parameters:
Density: 24 people
Bathrooms: 10
Kitchen length: 28 m
Functionality: 1 (Criteria 3 passed)
Spaciousness: 1 (Criteria 7 passed)
Atmosphere: 2 (Criteria 10 and 12 passed)

Efficient renewable sufficiency

Lina Eriksson
Master thesis 2024

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