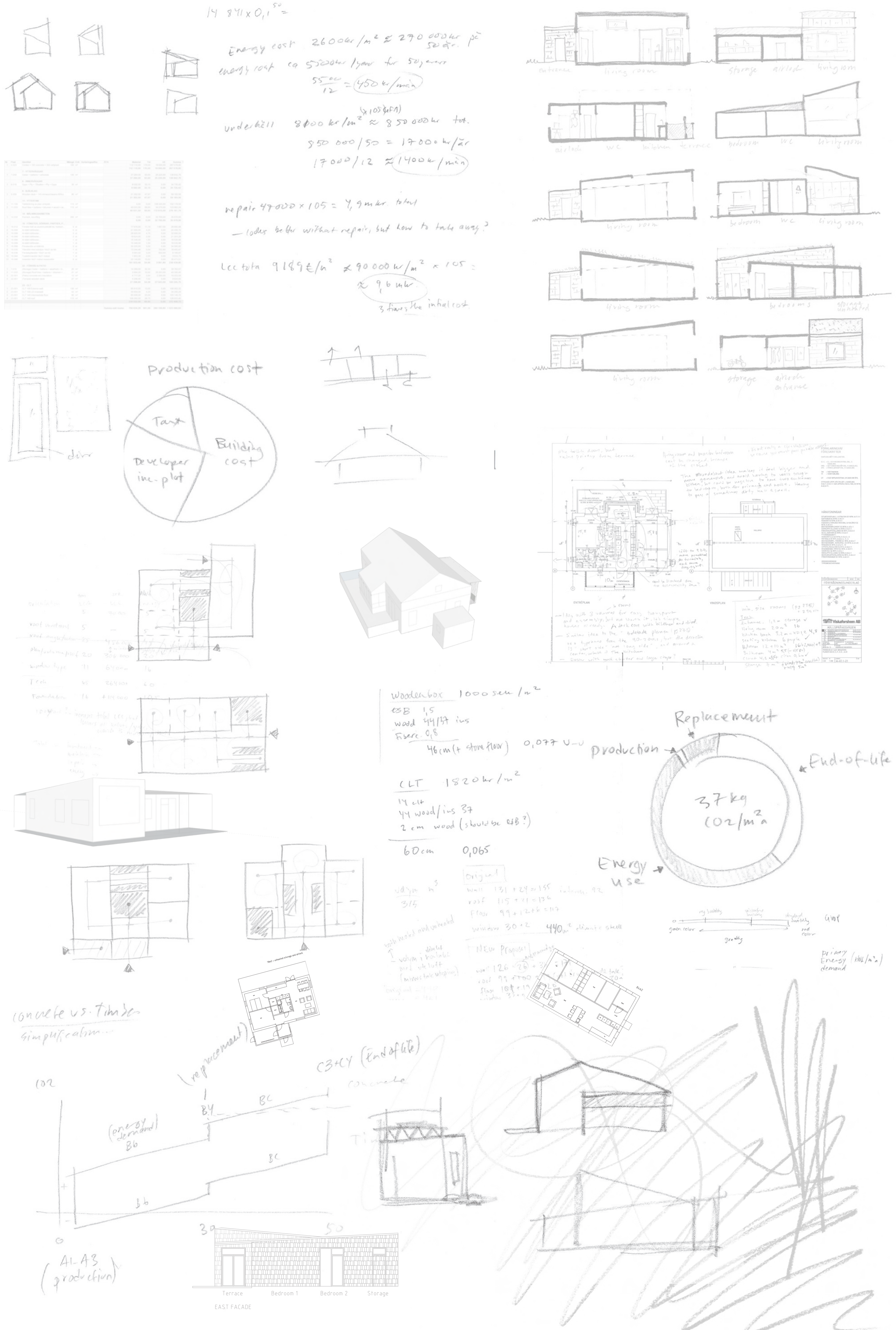
CHEAPER

BUT BETTER

An investigation of the interrelation between
building costs, life cycle costs, energy use, climate footprint
and architectural qualities, of a small rental villa in Sweden

© **Emanuel Johansson** Examiner Liane Thuvander Supervisor Walter Unterrainer
Chalmers School of Architecture Department of Architecture and Civil Engineering



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CHALMERS
UNIVERSITY OF TECHNOLOGY

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Master Thesis Spring 2021

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Chalmers **School of Architecture**
Department of Architecture and Civil Engineering

Architecture and Planning Beyond Sustainability (MPDSD)
Building Design for Sustainability

Gothenburg **Sweden**

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Case study Wooden rental villas,
Källsprångsvägen, Viskafors
Year 2020 Developer Viskaforshem
Architects Brunnberg & Forshed
Photo Robin Hayes

CHEAPER
BUT BETTER

WHAT ARE THE POTENTIALS TO MINIMIZE
LIFECYCLE COSTS AND CLIMATE FOOTPRINT IN HOUSING
AND AT THE SAME ENSURE [IMPROVE]
ARCHITECTURAL QUALITIES?

ABSTRACT

Economy in architecture is not primarily building costs, but resource optimization and life cycle costs (LCC). The building industry argue that high costs is hindering quality housing, even though construction prices in Sweden is among the highest in Europe. Economic incentives are missing to build more climate neutral. Life Cycle Assessments (LCA) can help architects identify the largest optimization opportunities for both cost and climate early in the design.

The Swedish building sector causes 20% of the nation's CO$_2$ emissions. The lifecycle of buildings is central to climate change, yet knowledge of LCA remain scarce in most architecture and construction companies. However, interest is increasing as LCAs will become a requirement in 2022.

Moreover, 240 out of 290 municipalities have a shortage of housing and many cannot afford new productions. The issue of high prices has caused a debate on how to build cheaper housing for everyone. A precarious path if lower quality means higher operational costs over the building's lifetime.

Architects have a reputation, often justified, of not caring about costs. Sustainable goals present at the start of projects get lost along the line, as economic calculations do not add up. The widespread neglection of economy teaching in Swedish architecture education is not helping.

The aim was to challenge the perspective of economy and demonstrate how to build cheaper, but better. I re-designed an existing rental villa from 2020 in Viskafors, and investigated the interrelation between building costs, life cycle costs, energy use, climate footprint and the improvement of architectural qualities, such as space, proportion, functionality, and materiality. This was performed through interviews, literature, design experiments and calculations.

According to the chosen parameters and price estimations, large optimization potentials were found. The result of re-designing and improving the building volume (e.g., orientation, roof, and plan layout) and selected materials (e.g., window and foundation), reduced lifecycle cost by 5,4%, energy by 18%, and CO$_2$ emissions by 31%. Replacing the technical equipment further increased total savings up to 10%, 33% and 55%. The result is a summary of plus and minus values, combining selected experiments into one final design proposal.

Keywords:
#economy #LCA #LCC #lifecycle #resource optimization #sustainable housing

SAMMANFATTNING

Ekonomi inom arkitektur är inte bara byggnadskostnader, utan resursoptimering och livscykelkostnader (LCC). Byggbranschen hävdar att höga kostnader hindrar bostäder av hög kvalitet, trots att byggpriserna i Sverige är bland de högsta i Europa. Ekonomiska incitament saknas för att bygga mer klimatneutralt. Livscykelanalyser (LCA) kan hjälpa arkitekter att identifiera de största optimeringsmöjligheterna inom både kostnad och klimat i tidigt designskede.

Den svenska byggsektorn orsakar 20% av landets totala koldioxidutsläpp. Byggnadernas livscykel är central för dess klimatpåverkan, men kunskapen om LCA är ännu bristfällig i de flesta arkitekt- och byggföretag. Dock finns ökat intresse, då LCA-deklarationer blir ett krav år 2022.

Dessutom har 240 av 290 kommuner bostadsbrist och många har inte råd med nyproduktion. Utmaningen med höga priser har lett till en debatt om hur man ska bygga billigare bostäder för alla. En riskfylld väg, då billigare kvalitet ofta innebär högre driftskostnader under byggnadens livstid.

Arkitekter har ett rykte, ofta motiverat, för att inte bry sig om kostnader. Uppsatta hållbarhetsmål i början av många projekt går förlorade längs vägen, då ekonomiska beräkningar inte går ihop. Den utbredda försummelsen av ekonomiundervisning i svensk arkitekturutbildning hjälper inte.

Mitt mål var att utmana vissa ekonomiska perspektiv och visa hur man kan bygga billigare, men bättre. Jag omformade en befintlig hyresvilla från 2020 i Viskafors och undersökte sambandet mellan byggnadskostnader, livscykelkostnader, energianvändning, klimatavtryck och samtidigt förbättring av arkitektoniska kvaliteter, såsom rum, proportioner, funktionalitet och materialitet. Detta utfördes genom intervjuer, litteratur, designexperiment och beräkningar.

Enligt de utvalda parametrarna och prisuppskattningarna hittades stor optimeringspotential. Resultatet genom omformning och förbättring av byggnadsvolymen (t.ex. orientering, tak och planlösning) och utvalda material (t.ex. fönster och fundament), minskade totala livscykelkostnader med 5,4%, energi med 18% och koldioxidutsläpp med 31%. Byte av teknisk utrustning ökade ytterligare de totala besparingarna upp till 10%, 33% och 55%. Resultatet är en sammanfattning av plus- och minusvärden, som kombinerar utvalda experiment i ett slutligt designförslag.

ABOUT THE AUTHOR

Emanuel Johansson grew up Hönö, an island off the coast of Gothenburg, and was raised working with furnitures and interior design within the family business. He lived abroad for 5 years in Australia, Hawaii and Norway, before returning to Sweden to do bachelor and master program at Chalmers.

I want to see architecture as a holistic profession that taps into many areas of life. It involves my interests for artistry, people and quality. I did all master courses within the track of sustainable design, as I appreciate the focus of not only designing beautiful buildings, but contributing to society and taking responsibility for the design. Economic thinking in relation to architecture has been limited in the education, but now I finally got the opportunity, time and support to investigate it.

Bachelor's degree | 2016-2019
CHALMERS SCHOOL OF ARCHITECTURE

Master Programme | 2019-2021
ARCHITECTURE AND PLANNING BEYOND SUSTAINABILITY (MPDSD)

Sustainable development and the design professions | 7.5 hp | ARK650	*Foundational sustainability theories*
Planning and design for sustainable development in a local context | 22.5 hp | ARK174	*Planning and key project in small swedish municipality*
Managing design projects | 4.5 hp | ARK630	*The building industry & real estate economy*
History, theory and method 4 | Light and Color | 3.0 hp | ARK605	*Study of windows & indoor climate*
Sustainable architectural design | 22.5 hp | ARK466	*Zero emission building & indoor climate*
Design and planning for social inclusion | 22.5 hp | ARK324	*Participatory design of a tram station in Million Homes Programme area*
Master Prep 1 & 2 | 4.5 + 3.0 hp | ARK636 + ARK641	*Thesis research & exploration of ideas*
Building Design for Sustainability | 30 hp | ACEX35	*Master's Thesis in Architecture*

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TO MY FAMILY, FRIENDS AND CLASSMATES who has cheered me on.

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Facade Cedar shingles
Photo Author

TABLE OF CONTENT

Källsprångsvägen Preserving selected trees
Photo Author

1 INITIATION

Källsprångsvägen CLT construction
Developer Viskaforshem
Architects Brunnberg & Forshed
Contractor Fristad Bygg
Photo Robin Hayes

MOTIVATION

Regarding costs, the UN sustainability goals states that all people should have access to safe and affordable housing (UN 2017). The same is stated in the Swedish constitutional law. Yet, Boverket (2019) states that 240 out of 290 municipalities in Sweden struggle with housing shortage (Kurvinen 2020). According to Crona (2018), Sweden plan to build cheaper housing to reach these goals, but that includes a high risk of cheap becoming expensive over time. Dahlberg and Norrbrand (2003) agrees by saying that, too often, the building cost receives most focus, and how to pay off the investment as quick as possible. Wiser consideration should be made between buidling cost and cost for maintainance, repair and operation. Furthermore, Crona (2018) explains how there are different ownership of housing in Sweden, each with their unique regulations and economic conditions, and in spite of the great need for rental houses in peripheral areas, they do not benefit from the current regulations and market, making it a struggle for developers who desire to build climate neutral and invest in quality materials. The building industry argue that economy is hindering quality housing, even though construction prices in Sweden is among the highest in Europe. According to the German Sustainable Building Council (DGNB, 2021), life cycle costs (LCC) is a tool for sensible use of economic resources throughout the entire life cycle of a building. They argue that significant optimisation potential for later economic management can be found in early design phases, where the architect has the most influence.

Regarding climate impact, Eberhardt et al. (2021) recalls that the UN, through the Sustainable Development Goals (SDGs), aims at reducing green house gas emissions (GHG) by 40% by 2030 and 80% by 2050 compared to 1990. The European Union (EU) alike, aims at net-zero emissions buildings by 2050. The building sector has an opportunity, or responsibility if you may, to evaluate their practice, as they account for 40% of all energy, 33% of all GHG, 30% of all raw materials and 40% of all waste, globally. According to Beemsterboer (2019), the lifecycle assessment (LCA) of buildings is crucial from both cost and climate concern, yet knowledge of LCC and LCA remain scarce in most architecture and construction companies. However, interest is increasing as LCA-based climate declarations will become a requirement in Sweden in 2022. Eberhardt et al. (2021) also points out that LCA is primarily used as a final assessment of completed building's, rather than an iterative design, which should be the case.

Regarding architectural qualities, whichever they are, it is important that the architecture is ensured and not diminished, when the life cycle cost and climate footprint is reduced. As previously mentioned, most impact can be made in early design. This amplifies the interrelation between architectural qualities, costs and climate footprint. A design based on life cycle thinking could include principles like adaptability, durability, use of low-impact materials, and perhaps as importantly, reducing the amount of materials. Femenias (2020) mentions in a study of apartment renovations in Sweden, that 20% chose to put up a wall between kitchen and living room, while another 20% chose the opposite and made an open play layout. This is an imperative for adaptive design that architects must consider.

AIM

The aim of this thesis has been to investigate how economy, especially from a life cycle perspective, can become either a driving force or hinder for sustainable housing in Sweden. It addresses cost calculations parallel and in relation to climate footprint and the architectural experience, specifically the parameters of space, proportion, functionality and materiality, in order to find the most balanced design solution. The starting point is a case study of a small rental villa in Viskafors, built in 2020. I re-designed that existing building and investigated how the design experiments impacted and improved the original building from the parameters above. I got support from involved stakeholders, such as builder, architect and building manager, to understand the project from their views and intensions.

GOALS

- Demonstrate potentials for higher architectural quality, with lower carbon emissions, at lower cost
- Challenge the traditional view of economy, in relation to sustainable building design

SUBGOALS

- Strengthen the role of the architect through new knowledge and interest in economy

Källsprångsvägen Durable stone clinker flooring in the whole house
Architects Brunnberg & Forshed
Photo Robin Hayes

RESEARCH QUESTION

- What are the potentials to minimize lifecycle costs and climate footprint in housing and at the same time ensure [improve] architectural qualities?

SUB-QUESTIONS

- How can economy become a driver [or hinder] for sustainable Swedish housing?
- What does economy mean in a sustainable building context?
- How can architects begin to work with economy?

DESIGN QUESTIONS

For example: What happens to cost, emissions and quality of the architectural space, if a material is changed, if the room is enlarged, if the walls are made thicker, the window moved to the west, if another energy source is chosen or if the building gets a simpler shape?

AUDIENCE

- *Chalmers school of architecture*,
to address the relevance of economy in the design education

- *Architecture students*,
to find interest and inspiration on how to start working with economy

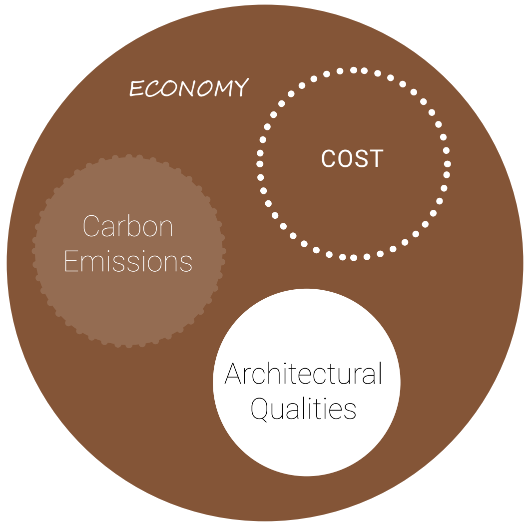
- *The case study stakeholders*,
to contribute with insight that could be useful in their next projects

- *Architects*
and others in the building sector, to highlight the benefit of working with lifecycle assessments in regards to sustainability and future challenges

Källsprångsvägen One out of 13 type houses Size 84m2 NFA Photo Robin Hayes

CONCEPT

DESIGN EXPERIMENTS
ON CASE STUDY
[change volume & materials]

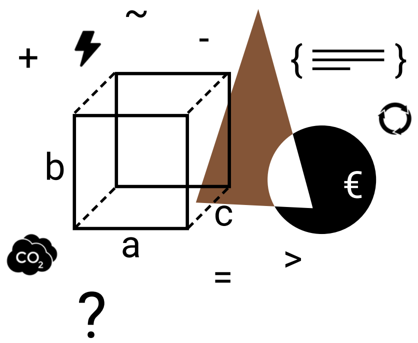


PARAMETERS

Life Cycle Costing (LCC)
Cost, €/m2 GFA

Life Cycle Analysis (LCA)
[Carbon Emissions,
kg CO_2-eq/m^2a]

Architectural Qualities
[Space]
[Proportion]
[Functionality]
[Materiality]



NEW DESIGN PROPOSAL
[Combine the best experiments]

METHOD

OVERVIEW
Research for Design (Theory) and Research By Design (Case study experiments) have run parallel for combined result. The workflow is explained more in detail graphically in the timeline on the next spread.

RESEARCH FOR DESIGN

INTERVIEWS
The role of the interviews was to learn from practice, not only academia. Most of the interviews were conducted before starting the MT officially. I interviewed seven architects to get a sense of economy in practice. This helped shape my thesis question and gave me tools, contacts and references to continue my research and create a framework for the thesis. Three interviews were done later with the involved stakeholders, in order to understand the case study material, discuss prices and create a correct enough model to use when comparing design experiments. Additional phone calls were made with material producers, software support and energy agency, as well as emails with academics working within the field of LCA. All notes from interviews are summarized digitally and kept in authors possession.

LITERATURE
The literature content are from both academia and practice and includes books, articles, webinars, videos and previous Master Thesises. The research focus has been on LCA, LCC and architectural qualities in housing.

RESEARCH BY DESIGN

CASE STUDY EXPERIMENTS
The book Universal Methods of Design (Hanington & Martin 2017), case studies are explained as a method useful in exploratory research, understanding existing solutions, as well as for comparison and studying the effects of change, new programs, or innovations". The data collection is normally through interviews (stakeholders), observation (site visit), and document analysis (architectural drawings and economic calculations).

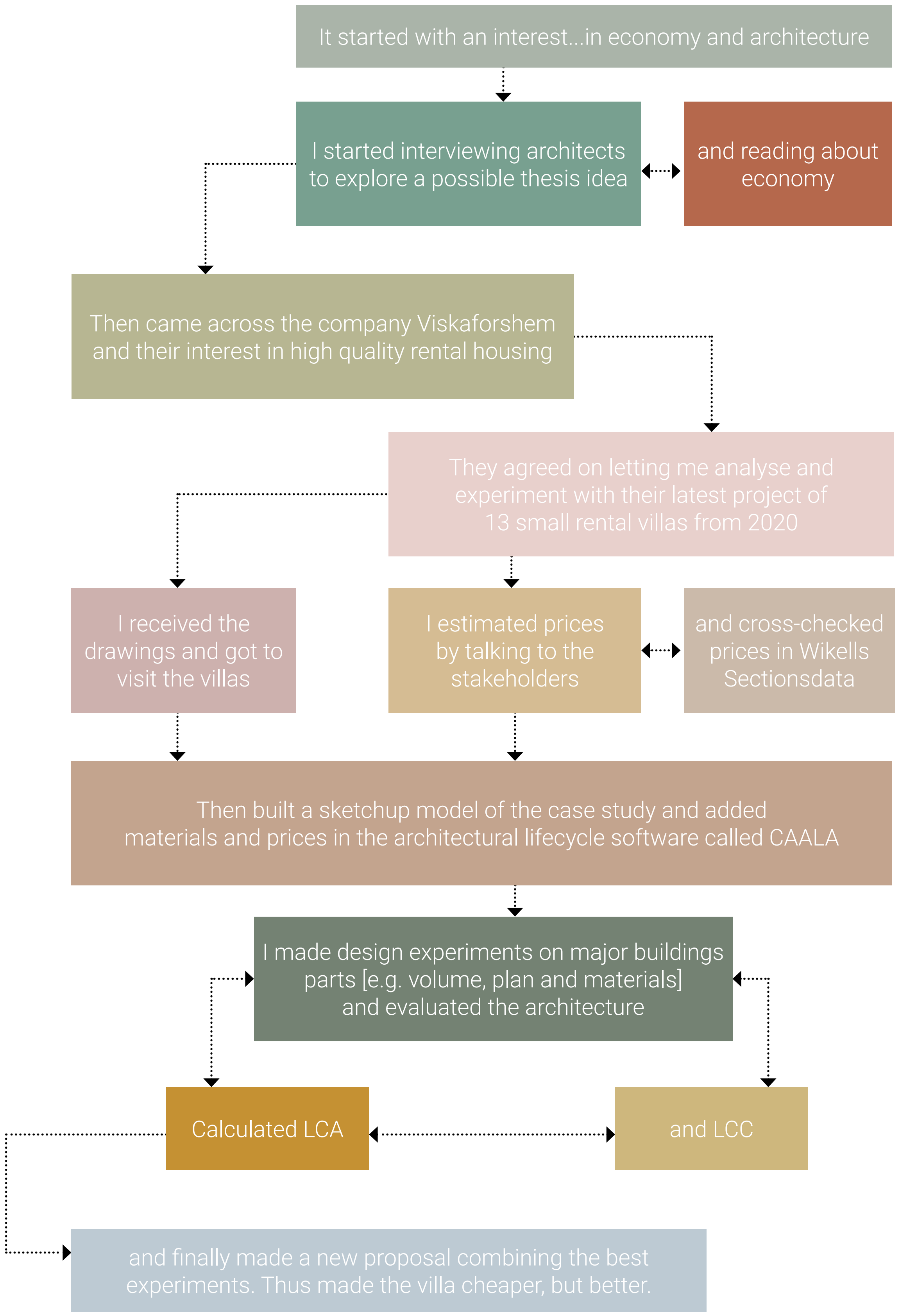
The case study in Viskafors is the starting point of the design research. The focus have been to first create a correct case study model in the digital lifecycle tool called CAALA, by adding material layers and prices (tools is explained in a later chapter), and thereafter carry out design changes, LCA & LCC calculations and architectural evaluation.

COST CALCULATIONS
Finding correct prices is difficult. When acquiring materials for larger project the prices get much cheaper due to the volume purchased. It is not comparable with prices on the public market. As some company once said "economy is the most secret thing we have". Entreprenours are reluctant to give away their prices and offers to the public. In this case, costs have been found in several ways. Some prices have been given by the entreprenur, some directly from producers, some from the client, and some are estimated in a calculation program with prices on material and work hours (Wikells Sectionsdata, 2021) and discussed with both supervisor and stakeholders. The final cost overview is confirmed by the entreprenour to be close to reality, in order to get a correct lifecycle cost analysis. The result will also be compared to previous research in the field. The lifecycle cost, LCC, was done in CAALA (Computer Aided Architectural Life-cycle Assessment), a sketch up plugin.

CARBON CALCULATIONS
The road to decide most relevant LCA-tool is discussed later on. In short, the LCA is done in CAALA as well, parallel to LCC. The software is is connected to the german material database called ÖKOBAUDAT, a platform with life cycle assessment datasets on building materials, construction, transport, energy and disposal processes.

ARCHITECTURAL QUALITIES
To make sure the experiments are improving the house, LCC & LCA is set in relation to architectural qualities. The qualities chosen are space, proportion, materiality and functionality, and will be introduced indepth in later chapter.

SIMPLIFIED WORKFLOW



It started with an interest...in economy and architecture

I started interviewing architects to explore a possible thesis idea

and reading about economy

Then came across the company Viskaforshem and their interest in high quality rental housing

They agreed on letting me analyse and experiment with their latest project of 13 small rental villas from 2020

I received the drawings and got to visit the villas

I estimated prices by talking to the stakeholders

and cross-checked prices in Wikells Sectionsdata

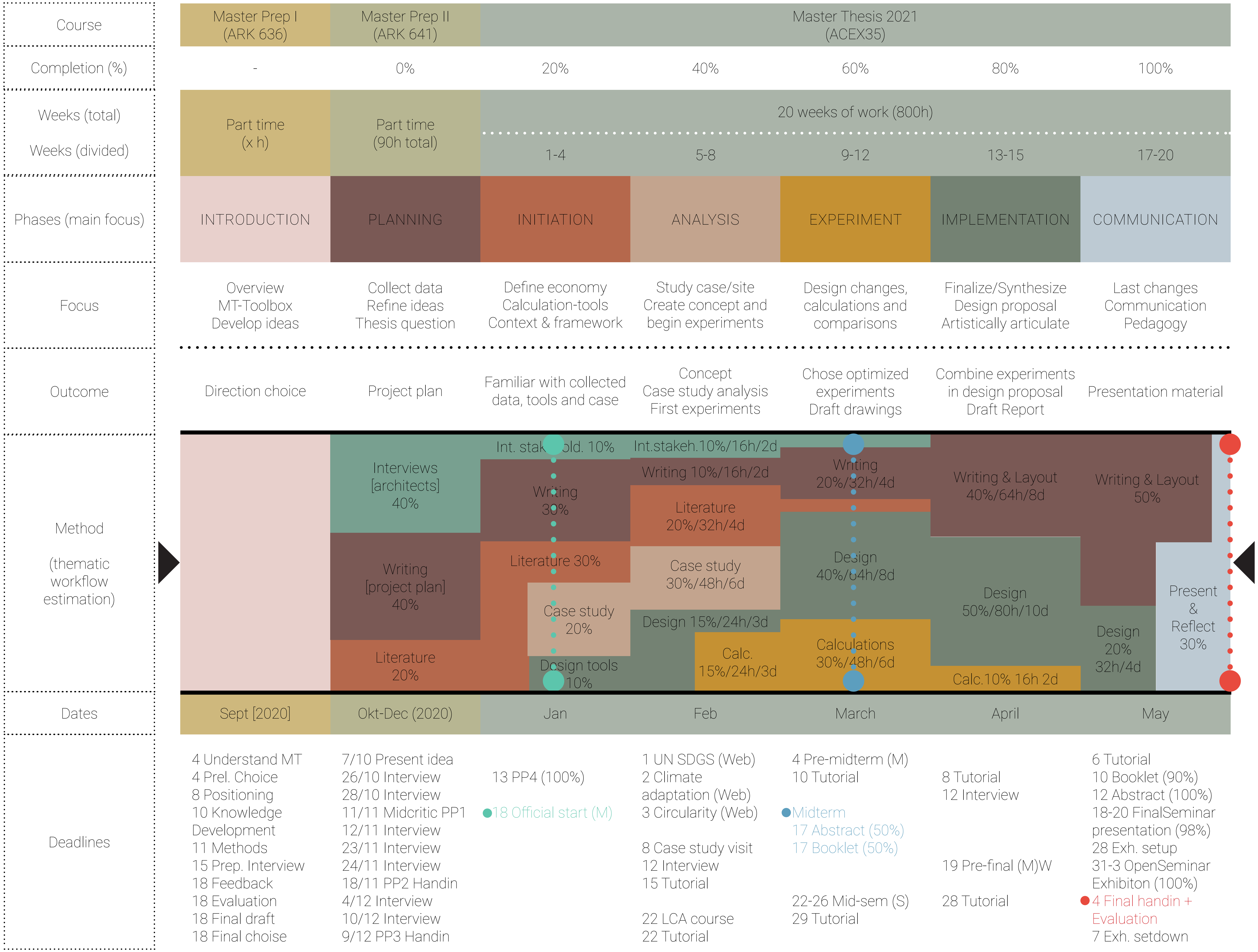
Then built a sketchup model of the case study and added materials and prices in the architectural lifecycle software called CAALA

I made design experiments on major buildings parts [e.g. volume, plan and materials] and evaluated the architecture

Calculated LCA

and LCC

and finally made a new proposal combining the best experiments. Thus made the villa cheaper, but better.



Course	Master Prep I (ARK 636)	Master Prep II (ARK 641)	Master Thesis 2021 (ACEX35)				
Completion (%)	-	0%	20%	40%	60%	80%	100%
Weeks (total)	Part time (x h)	Part time (90h total)	20 weeks of work (800h)				
Weeks (divided)			1-4	5-8	9-12	13-15	17-20
Phases (main focus)	INTRODUCTION	PLANNING	INITIATION	ANALYSIS	EXPERIMENT	IMPLEMENTATION	COMMUNICATION
Focus	Overview MT-Toolbox Develop ideas	Collect data Refine ideas Thesis question	Define economy Calculation-tools Context & framework	Study case/site Create concept and begin experiments	Design changes, calculations and comparisons	Finalize/Synthesize Design proposal Artistically articulate	Last changes Communication Pedagogy
Outcome	Direction choice	Project plan	Familiar with collected data, tools and case	Concept Case study analysis First experiments	Chose optimized experiments Draft drawings	Combine experiments in design proposal Draft Report	Presentation material
Method (thematic workflow estimation)		Interviews [architects] 40% Writing [project plan] 40% Literature 20%	Int. stakehold. 10% Writing 30% Literature 30% Case study 20% Design tools 10%	Int.stakeh.10%/16h/2d Writing 10%/16h/2d Literature 20%/32h/4d Case study 30%/48h/6d Design 15%/24h/3d Calc. 15%/24h/3d	Writing 20%/32h/4d Design 40%/64h/8d Calculations 30%/48h/6d	Writing & Layout 40%/64h/8d Design 50%/80h/10d Calc.10% 16h 2d	Writing & Layout 50% Design 20% 32h/4d Present & Reflect 30%
Dates	Sept [2020]	Okt-Dec (2020)	Jan	Feb	March	April	May
Deadlines	4 Understand MT 4 Prel. Choice 8 Positioning 10 Knowledge Development 11 Methods 15 Prep. Interview 18 Feedback 18 Evaluation 18 Final draft 18 Final choise	7/10 Present idea 26/10 Interview 28/10 Interview 11/11 Midcritic PP1 12/11 Interview 23/11 Interview 24/11 Interview 18/11 PP2 Handin 4/12 Interview 10/12 Interview 9/12 PP3 Handin	13 PP4 (100%) ● 18 Official start (M)	1 UN SDGS (Web) 2 Climate adaptation (Web) 3 Circularity (Web) 8 Case study visit 12 Interview 15 Tutorial 22 LCA course 22 Tutorial	4 Pre-midterm (M) 10 Tutorial ● Midterm 17 Abstract (50%) 17 Booklet (50%) 22-26 Mid-sem (S) 29 Tutorial	8 Tutorial 12 Interview 19 Pre-final (M)W 28 Tutorial	6 Tutorial 10 Booklet (90%) 12 Abstract (100%) 18-20 FinalSeminar presentation (98%) 28 Exh. setup 31-3 OpenSeminar Exhibiton (100%) ● 4 Final handin + Evaluation 7 Exh. setdown

DELIMITATIONS

SOCIAL

The thesis has an indirect context of housing shortage and affordable housing in Sweden, but it is not about social housing, unequality, segregation, health, well-being and so on.

ECONOMY

The theory chapter intends to give brief accounts on selected aspects of economy related to architecture and housing (e.g. production cost, building cost, energy costs and rate of return). Regarding the experiments, a precondition was to aquire the total building cost on the case study and from that price estimation, calculate and improve life cycle costs (LCC) through a software called CAALA, including the stages of investment, energy costs, repair, maintenance and replacements. It is not about calculating rents, profit or setting up a budget.

Prices on materials are different worldwide, and even locally between companies. The prices go up and down and depend on geography, timing, amount, work hours, unexpected risks and much more. Though prices are being added and subtracted in the experiments, the reality is likely more complex. The energy cost and inflation is estimated from a Swedish perspective, which is much lower than many other EU countries.

ECOLOGY

The focus is calculation of CO_2 emissions over the buildings lifetime, through life cycle assessment (LCA) in CAALA, including the stages of A1-A3 (Production), B4 (Replacements), B6 (Operational energy use), C3 (Waste processing) and C4 (Disposal). It excludes ecological aspects of air quality, land, water, biodiversity, ecosystem services and so on.

The energy source and quality differ between countries. Sweden has perhaps the most clean energy (in terms of CO_2) in all of the EU, but the life cycle software is German, which might have an effect on the CO_2 result, especially regarding the energy use.

THE BUILDING

I will not draw a new house, on a new site with new conditions, but rather start from the case study and re-draw that original villa. It is therefore a Swedish context, institutional frameworks, building regulations and type of ownership. Sweden has several types of housing ownerships, such as rental, condominium, tenure, or co-operative. I will focus only on rental.

I will not try to change the institutional framework of the Swedish building and housing industry today, though it is a necessary and ongoing task.

Though reuse is necessary for sustainable housing, the focus will be on new production and new materials, to avoid possible green washing and to enable fair comparisons in relation to the case study context.

THE ROLE OF THE ARCHITECT

The thesis has an architectural approach, where economy and ecology willl be put in relation to architectural qualities. The experiments will therefore focus on the major building parts most relevant to the influence of the architect (e.g. the climate shell, load bearing structure, foundation, windows and doors, and even the technical system). Detailed decorations, interiors, furnitures, bathroom and kitchen, despite being important factors, are not covered in the LCA of CO2, but some are included in the lifecycle cost. The focus is not on presenting detailed drawings and illustrations, but rather the investigation of the design in relation to the life cycle assessments.

EXPERIMENTS

LCA and LCC analysis are always a simplification of reality and must be approached in that way. The discussion around the results are therefore equally important as the result, which is why there are smaller reflections or longer discussions after each experiment. To compare with other LCAs, it is crucial to know which details, data and lifecycle stages are included, as the tools differ immensly. Even then, there will be many gaps to discuss.

The currency displayed is both € and SEK, where 1€ is 10SEK, to simplify manual calculations. How the prices have been aqquired and used is discussed later.

There are countless ways to evaluate architectural qualites, where in reality one quality might oppose another. The experiments are limited to space, proportion, functionality and materiality. The reason is explained later. Moreover, a spatial delimitation is to work with same netfloor area and keep similar architectural ideas in the re-design. There are unlimited plan layouts possible within the original 84m^2, but it is seen as important that the new proposal will somewhat ressemble the old, both interior and exterior, for better comparisons.

LIFE CYCLE ASSESSMENT

According to Beemsterboer (2019), the complexity of LCA is both "building-specific" and "methodology-specific". Regarding the building, there are a multitude of materials, secondary effects in the material chain, always unique projects and building systems, sub-systems, different stakeholder interests, changing technology, geographic differences in climate, site, and transport distances, and different lifespans of building, - and materials (e.g. longer life spans typically increase the uncertainty in assessment because future developments may be difficult to predict, such as renovations or technical developments). Further, the complexity of the method itself includes for example differences between lifecycle stages, databases, and standards. Beemsterboer (2019) argue that complexity can not be held accountable for the ineffective use of LCAs today. A complex system is not the same as a complicated system. In this case, LCA is not different from other complex systems tackled successfully elsewhere in the building process. This is especially true for the LCAs that are limited to global warming potential. More about LCA use and limitations is discussed in the LCA chapter.

DEFINITIONS

AIRTIGHTNESS
The uncontrolled air exchange per hour through the building envelope. The airtightness is checked on site with the blower door test.

ARCHITECTURAL QUALITIES
Refers to how the design is experienced and valued by the user. The chosen quality parameters in this thesis are space, proportion, functionality and materiality. They are later defined in detail.

AUXILIARY ENERGY
Required electricity to drive system components, such as circulation pumps and controls. It does not directly cover heat demand.

BUILDING COST
Building materials, construction work and salaries, w/o tax

CLIMATE CHANGE
Describes the change in the climate due to natural or man-made processes. The global rise in temperatures on the earth's surface is due to excessive emissions of greenhouse gases and will affect our planet's ecosystems in unpredictible ways.

CLIMATE IMPACT/FOOTPRINT
A measurement on humans impact on the planet and how much natural resources [and CO_2] it takes to provide for a society or a person.

CO_2 EQUIVALENTS
A common unit for all greenhouse gases interpreted into CO_2 amount, to compare global warming impacts between sectors.

CROSS LAMINATED TIMBER (CLT)
Cross-glued wood, or KL-wood in Swedish, is glued massive wooden boards, made up of an uneven number of layers, usually three-nine. It is load bearing and ressembles a very thick plywood.

ECONOMY
Orriginally derives from the greek words of "manage" and "household". Different aspects of economy is discussed in the thesis.

EMBODIED ENERGY
The sum of energy [CO_2] required to produce a material, considered as if that energy was "embodied" in the product itself.

ENERGY EFFICIENCY
A measurement of the energy used to achieve a specified benefit. A higher energy efficiency means less energy to achieve the benefit.

ENVIRONMENTAL PRODUCT DECLARATION (EPD)
A declaration document with data describing the environmental impact during a product's lifecycle (e.g. CLT or concrete)

GLOBAL WARMING POTENTIAL (GWP)
Greenhouse gases contribute in varying degrees to global warming depending on their heat absorptive capacity and their lifetime in the atmosphere. GWP describes the cumulative effect of a gas over a time period, compared to CO_2. For example, the GWP of methane gas (CH4) is 21, which means 1 kg of CH4 is 21 times higher than 1 kg of CO_2. GWPs provide a common unit of measure, which allows analysts to add up emissions of different gases to simplify comparisons between sectors. GWP is given in kilograms of CO_2 equivalent per functional unit.

GREENHOUSE GAS EMISSIONS (GHG)
Emissions of gases that cause climate change by creating a greenhouse effect in the earth's atmosphere. These emissions mainly include carbon dioxide from fossil fuels, but also deforestation and other changes in land use.

GROSS FLOOR AREA (GFA)
Floor area inside the building envelope, including external walls.

INVESTMENT COST
Money can be invested in different stages, but in the case of this life cycle cost analysis, the investment refers to the initial building cost

LAMBDA-VALUE (λ)
Specifies heat conductivity of a material [W/mK]. It is used for thermal calculations on buildings and components.

LIFECYCLE
The interconnected stages of a product system from raw material extraction to final disposal and/or reuse. Since buildings are used over very long periods of time, only a consideration of the entire life cycle (life cycle assessment) can provide information about the actual quality of a building.

LIFECYCLE ASSESSMENT (LCA)
A method for environmental evaluation of products [or building], processes and services over the course of the their entire life cycle. In this case "production, replacement, energy use, and disposal".

LIFECYCLE COSTS (LCC)
A method for cost evaluation over the buildings lifetime. This case includes the cost of investment, energy use, maintenance, replacement and repair. They are later defined in detail.

LIFE CYCLE STAGES/MODULES
Describes which phases of the life cycle taken into account, for example the production of materials including raw material extraction and transport to the manufacturer (A1-A3), but not the actual construction on site (A4-A5). Stages are later defined in detail.

NET FLOOR AREA (NFA)
The usable heated floor area of a building. Less than GFA, since it excludes exterior walls and interior walls less than 15cm thick.

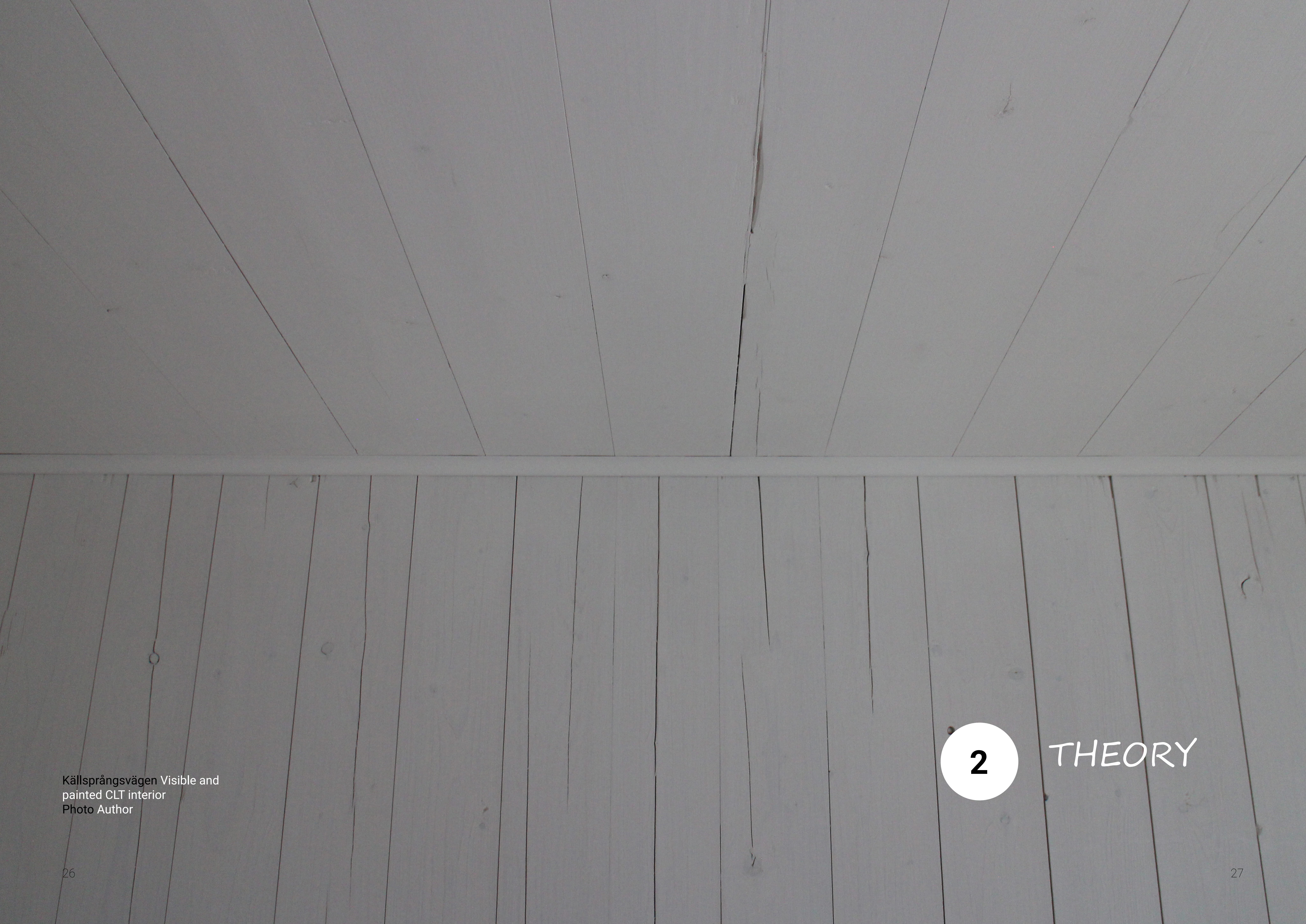
PRIMARY ENERGY DEMAND
Describes the energy taken from the environment, for example in the form of crude oil, natural gas, hard coal or also in hydropower. It is the computationally usable energy content that has not yet been subjected to any conversion.

PRODUCTION COST
Building cost, land and developer costs, w/o tax

RESOURCE
Natural raw materials, or reused matter, that can be made usable for human purposes. A distinction is commonly made between renewable and non-renewable materials.

THERMAL BRIDGE
A concept in building physics known as "cold bridge" in Sweden. A thermal bridge is a localised area in the building envelope where more heat is leaking out. This will require more energy to heat the space, or in some cases cause condensation (moisture) within the building envelope, and result in thermal discomfort.

U-VALUE
Specifies the insulation performance of a building element, by multiplying the lambda value and thickness of material. A lower u-value means better insulation.



Källsprångsvägen Visible and painted CLT interior
Photo Author

2 THEORY

ECONOMY

INTRODUCTION

Economy originally derives from the greek words of "manage" and "household". Everything seem to go through this system that penetrates all areas of life. According to the economist, Yanis Varoufakis, economics is closer to philosophy than it is to science. He puts it in contrast to a meteorologist predicting the weather forecast. No matter the prediction, the weather decides by itself. Economy is profoundly different. Economy, and the society for that matter, becomes what we predict. He says that: ***"what you and I do, depends on what you and I believe, and the change of our belief feeds into a different social and economic outcome"*** (KODX Seattle, 2018, 23:34). A few seconds later, he explains that: ***"economy is part of the same phenomenon it tries to explain, like a cat chaising its own tail"*** (KODX Seattle, 2018, 24:00). This is why economy can never be a science, and why it is not a topic exclusively for experts, and why economic ideas must be taught alongside economic and societal history.

ECONOMY AND ARCHITECTURE

In a recorded lecture by W. Unterrainer (personal communication, 15 Oct, 2020), named "architecture and economics, a difficult relationship both ways", he says that: ***"a large parts of the public, developers, mainstream media and many politicians, consider most architects ignorent and uninformed towards economic questions, or to say it bluntly, they think that architects do not care about budget"*** (Unterrainer, 2020, 00:45). He continues by mentioning how there unfortunetely are many examples and justified reasons for their position, and one of many aspects is the widespread negelection of economic teaching in architecture education. Economy is frequently seen in the list of project delimitations, as most students in Sweden, choose not to be limited by budget, nor learn about their project's economic context. One of the outcomes, according to Inobi (personal communication, 12 Nov, 2020), is that when a young architect enters their professional life, their take-off distance is sometimes quite long, due to lack of economic understanding. Further, from what they have seen in university, students tend to take a social or design track, but in reality, economy is more central. In fact, sustainable project goals like empowerment, equality, or organic materials, often get lost along the line due to unfulfilled economic budgets. Another aspect according to W. Unterrainer (personal communication, 15 Oct, 2020) is the many actors in the building industry and their conflicting goals and share of payment along the line, including the architect, engineer, investor, builder, municipality and even neighbors.

ECONOMY IN SWEDISH HOUSING

Kurvinen, A. (2020) has written a book on the economic questions within sustainable Swedish housing, such as the rate of return, profitability, write-off time, and how the initial cost of production is connected to the final rent. He says that strong economic motifs are needed to turn today's trends and build climate friendly. Kurvinen (2020) encourages architects and others in the building sector to get to know the economic logics, to critically and constructively take part of the economic discussions, challenge the standard building routines, and learn to stay on budget. He says that in a volatile market, values and assumptions are continually changed. Black and white does not exist. The economic evaluations must be project specific.

Crona (2018), who wrote the report "to build cheap is expensive", start by introducing the four main types of tenure in Sweden: ownership, condominium, rental and cooperatives. She explains how each type has different economic opportunities due to unique regulations for building, loans, accounting, and taxations. Together with the market, these will affect the cost, and thus what is built, and where.

Definitions are important in discussions for correct comparisons. Production cost is defined as the sum of building cost and land cost (SCB 2019) and can be seen with or without tax. The building cost is material, developer, constructtion, setup and connection cost for energy, internet, district heating, risk fees and so on. Land costs is the purchase price for the plot, connection for water and drainage, groundwork, registration of property, title deed, detail plan, geological investigations, municipal fees, street and roads, possible risks and so on (Kurvinen 2020).

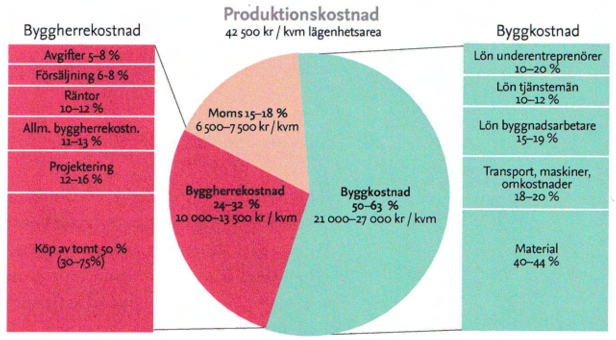


Figure 1. Production costs in Sweden. From Lönsamhetskalkyl för hållbart bostadsbyggande by Kurvinen (2020, p.35)

"Today, Sweden has the highest building costs in Europe" (Crona, 2018, p.1). But, even though the building costs are accused of the high housing prices, statistics show that a more reasonable explanation is the high demand and limited supply on the housing market. The production cost has increased rather as a consequence of the market situation, and the lack of capacity and flexibility of the building sector (Kurvinen 2020).

Since the price per m^2 has immensely increased the last years, apartments have been reduced in size. In the 70s a 3-room apartment was about 75 m^2. At the end of 90s it had increased to 85m^2, due to universal design. Today, the size is down to 70m^2, in spite of increased building standards. The result is a lack of larger flexible apartments. Extra rentable rooms, generational living, student housing, collectives and large families are some constellations that are difficult to fit in small modern housing. On top of that, common spaces in new productions are often minimized for better m^2-ratio and instant profit. If a developer desires to build with higher quality towards a lower instant profit, the banks might even consider that a higher risk and thereby demand additional security. So, in spite of the need for rental houses on the outskirts, they do not benefit from the current regulations. For example, if the market value of the building is considered lower than the initial building cost, the value will instantly go down and be seen as a loss for the company. Crona (2018) suggests the solution to wait with the valuation the first 10 years and let the initial building cost be the actual value, or perhaps extend the start of devaluation by certifying the house by environmental systems like Svanen or Miljöbyggnad Guld.

RATE OF RETURN

The required rate of return is based on the specific risk of each project and where it is located. If the risk is considered high, the required rate of return will increase, along with the rents. That is what happens in many peripheral places in Sweden. If the peripheral areas instead could use the same return rate as in central cities, the rents could go down. This is reasonable, especially since the vacancy risk would be close to zero because of the great need for housing today. Another helpful way is to connect the rate of return to the write-off time of the building, instead of market speculations. The normal write-off time since the 60s in Sweden has been only 50 years. By finding a way to extend the time to 70, 100 or even longer period, would lower the required rate of return each year. In that way, rents could be lowered because the profit is calculated over a longer lifespan (Kurvinen, A. 2020). In this way, durable materials and longer lifecycles are solutions for both cost, climate and affordable housing.

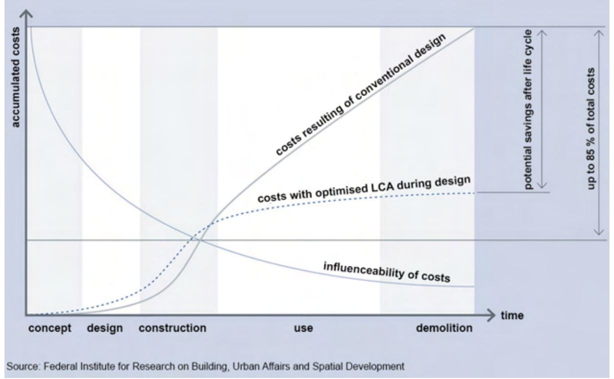
An investigation was made by Kurvinen (2020) to see how the required rate of return affects the rent. The production cost was same for all three cases, 42 000 SEK/m^2. A return rate of 2,7% gave 7500SEK/month. 3,5% gave 9800 SEK/month and 5% gave 12 400SEK/month. A significant difference in spite of the same production price. Crona (2018) wants to see specific declarations for each building component, called K3-declaration, because each material differ in lifespan. That would help, but even then she says, the high building costs of 40 000 SEK/m^2 does not make it easy for rental hosuing. The low interest rate is what saves the cash flow, but carry a risk if suddenly increased. Crona argues that the building sector must update their regulations and reward those who try to build better, because there is a need to prepare for an unstable climate and it is counterproductive to focus on the short profits.

PRODUCTION COST

The production cost (building + land) for rental housing has increased by 30%, from 25 000 SEK/m^2 up to 33 000 SEK, between 2010-2017. The difference between cities and country side is about 5000 SEK. Note that the cost for condominiums is much higher, 62 000 SEK/m^2 in the city and 40 000 SEK in the counties. The production cost increase is mainly due to building costs, but also the cost of land. Still, they only seem to be part of the reason for increased prices. The housing has increased more than the production and is therefore only part of the reason for increase. To conclude, the production costs has higher relevance to rental housing, while the condominiums are mostly driven by the market, by demand and supply. The supply of land in attractive areas are limited and being the places where most people want to move, the lack of housing will drive up the prices by a competition between those who can place the highest bid. The most effective way to solve the high market prices is simple in theory but not in practice; build more of what is demanded.

A reduction of 20% in building cost (materials, transport, workers etc) would only reduce the total production cost by 10%, since it is only half of the total cost. Taking it one step further looking at a new rental production at 9600sek/month. That price is divided in three main parts. 1. capital costs is 50% (4800sek/month), 2. operation 30% (2900sek/month) and 3. administration 20% (1900sek/month). The capital cost is further divided, in 50% building cost (2400sek/month), 32% developer cost (1500sek/month) and 18% tax (900sek/month). ***"That means, if the building cost is reduced by 20%, the final rent only reduces 5%"*** (Kurvinen, 2020, p.36). In other words, building costs is not the only reason or hinder for affordable rental housing.

In the last investigation, the author looked at how much the operation and maintenance had to be reduced to make up for higher quality in production, and still keep the same rent. Looking at the version with 3,8% in rate of return, 5% increase in production needs 25% lower operation and maintenance, and 10% price increase needs almost 50% lower maintenance. This can be quite hard to reach in reality. ***"If an investment in higher quality partly could compensated by lower operation an maintainance, it would not be impossible to add even more quality in some cases"*** (Kurvinen, 2020, p. 40). The 5% increase in production, would be about 100 000 SEK for a 100m^2 house, which could be re-invested elsewhere.



Source: Federal Institute for Research on Building, Urban Affairs and Spatial Development

Figure 2. The ability to influence costs in different stages of the building process (W. Unterrainer, personal communication, 29 Mar, 2021)

LIFE CYCLE COST

In a Master thesis by Dahlberg and Norrbrand (2003) regarding life cycle cost (LCC) analysis on buildings and parts of buildings, they say that:

> *"During new production planning, it is important to make wise consideration between investment costs [building cost], operation and maintenance costs. Too often, only the investment cost is regarded, alternatively in combination with a payoff-calculation that displays after how long time the investment is repaid. This is short-term thinking that might lead to higher total costs in the end. A good way to give a fair cost calculation is to do a so called life cycle cost (LCC) analysis"* (Dahlberg & Norrbrand, 2003, p. 7).

Ylmén (2017) has in his licentiate thesis written about environmental and cost assessments of buildings, where he lifts an imortant aspect of LCC:

> *"The idea of LCCA is that costs occurring in the future are discounted, compared to the costs occurring today. The reason is that money available can now be invested or deposited somewhere else, for example in a bank. If the cost occurs in the future you will gain the interest compared to if it was deposited at the present time"* (Ylmén, 2017, p.4).

According to Gluch (2014), far from all building projects use LCC as part of decision making. Scientists and professionals both, have expressed frustration the last 10-15 years about the missing LCC tools that could help make better long term decisions. She argues that: ***"if environmental calculations is to get a central place in the decision making it has to be connected to the economic consequences"*** (Gluch, 2014, p.11). She motivates the use of LCC, by recalling the long life of buildings, and how each decision during the initial investment will entail long-term economic consequences. Through the use of LCC, an expected total cost during its lifetime is portrayed, and through that understanding, wise decisions can be made regarding different design solutions. On the German Sustainable Building Council's webpage (DGNB, 2021), they define their LCC critera:

> *"Our objective is sensible and conscious use of economic resources throughout the entire life cycle of a building. In the conception and planning phases of a building, there are areas of significant optimisation potential for later economic management."*

In their opinion, the parties involved in the planning process should regularly follow-up costs associated with their design. In addition to profit from the production, the economic viability of a building depends on cost-efficient operation. Carrying out the LCC and communicating them clearly to the client, increase the likelihood of achieving solutions optimised for cost-efficiency in the long term.

ARCHITECTURAL QUALITIES

THE INTERRELATION BETWEEN RESIDENTIAL LAYOUT AND RENOVATIONS

Two research studies were done by Centrum för boendets Arkitektur (CBA), at Chalmers Architecture (Femenias 2019), about the possibilities of climate friendly residential building design . The initial study was looking at the interrelation between residential layout and interior renovation, and material flows. The second empirical study looked at the extent of renovation in apartments from 2001-2008, and further how design, usability and flexibility, could help limit unnecessary renovations and reduce climate impact. The result shows a much higher renovation extent than needed. The study is Swedish context including apartments mainly in Gothenburg and Stockholm. A total of 35% of all the 313 households in the study said they had changed the plan layout of their apartments. Note these are larger condominiums, not rentals like the case study in this thesis. A rebuilding refers to closing or opening new entrances, moving inner walls or storage units.

ADAPTABILITY, GENERALITY & FLEXIBILITY

There are normally two types of adaptability, general rooms, or flexible rooms. The general room is a space with multifunctional use, for different needs over time. The flexible room is a space that is easy to re-build. According to Femenias (2019), earlier studies have shown that flexibility is a way to save resources over time, when a space or building can be reused for a new function or be changed with smaller interferences. Flexibility taps into cost efficiency due to less rebuilding costs. Higher initial costs for integrating flexibility have at times been a hinder.There is also an ethical perspective that buildings should be an asset not a burden for future generations. Adaptability is an attractive quality that might raise the economic value, as well as possibilities to remain in the building when life changes in terms of economy or family growth. Many studies have raised awareness that residentials with too specific room functions will hinder the possibility for adaptation. Some sources in the study (Femenias 2019) say a general room is 4x4m to be able to host different needs over time. Some say 15,4-16,4m2 and a width of at least 3,1m. Less than 2,2m wide is considered a specific room. According to Nylander & Forshed (2011), the general room appears outside the functionalistic room types. It is somewhat larger than the normal bedroom but slightly smaller than normal living room. The room length and width should be at least 3,6m. They further add how similarity in material, detail and shape enhances generality and flexibility, since no room is then clearly defined in function by its materials or such. Femenias (2019) adds daylight and technical equipment to the list of things that affects the generality of a space. Room proportions and relation to each other will also define generality, where a plan with circular flow is more general than one with a chain structure. Rooms which are passages are harder to adapt, yet still in most renovations, both kitchen and living room becomes passage rooms.

CIRCULATION, SPACE & FUNCTIONALITY

Nylander & Forshed (2011) defines circulation as the movement between several rooms and how that makes the space feel larger, more generous and functional. Some circulations are more useful than others. Through circulation the rooms are experienced both separately and as a whole. Rooms with more openings could therefore increase flexibility and generality, but the study by Femenias (2019) said that 50% of the residents spoken to had removed their circulation by closing a door, adding a room, or removing free-standing storage units. One interpretation is that the residents value function and furnish-abilities above movement in the apartment. Another aspect is that adaptation and renovation was only possible due to the circulation that was built from the start. Further, the authors argue that: ***"the ultimate flexible floor plan is one having a core of kitchen and bathroom, and on top of that, lightweight walls that are easy to move"*** (Femenias, 2019, p.147). These are more often seen in office buildings which are more frequently rebuilt.

Other architectural valus like openness, light, and generous spaces are appreciated by more than 30% of the users spoken to, as is large windows and views to several cardinal directions. 5-10 % complaints about loud noise and overheating, which might be connected to open plans and large windows without proper sun protection. Nylander & Forshed (2011) explains how daylight enhances and defines the room character. A bright room feels more public, a darker room more private. A low breast height can give better connection with outside, even as a person is sitting in the couch or laying in bed, but in the wrong place it would disrupt the furnish-ability of the wall. Daylight also directs our movement and eyes, which is why axiality is an important concept. Axiality is normally known within city planning and infrastructure, but in housing, axiality is a line of sight combining two or more interesting points. The axis normally goes from two or more rooms and can be both straight and diagonal. It is a way to orchestrating interesting views and daylight to enhance the spatial experience. They explain further how this openness must be balanced by more private and embracing rooms, by having clear corners and whole wall surfaces to furnish. The same applies to outside spaces, trying to balance the private and public space. Nylander & Forshed (2011) calls this "integrity"; well defined boundaries between "yours and mine", such as street space, entrance, courtyard, terrace, patio or similar. Overview and clarity about private and public is fundamental for the feeling of safety and knowing what is expected. The boundaries between inside and outside are important, both practically and estethically. Boundaries can be created by height levels, trees, small objects and so on. The entrance is a place where public and private meet and should be express welcome, safety and integrity.

Going back to the renovation study (Femenias 2019), the author say that 18% rebuilt their kitchens, where L-shape was the most popular, complemented by a cooking island (30%). Generally, people seem to find their kitchens too small and thereby extends them during renovation. Further, ***"20% put up a wall between kitchen and living room, while 20% did the opposite to open up the apartment"*** (Femenias, 2019, p.148). This reflects the need for architects to design for adaptability. There is a tendency for younger to open up rooms and older to close, but these statistics are not yet fully belayed. Moreover, 11 % (36 households), created new rooms in their apartment and the majority of these households were families with children. They achieved more bedrooms by splitting double rooms (requires two windows) or taking part of the living room, or remaking a walk-in-closet. Some households did the opposite, by combining a bedroom and living room, or extending a bedroom by removing the closet.

MATERIALITY

Another reason for renovation is that people want to style their home, which tapps into the discussion on material and details. Nylander & Forshed (2011) takes a trip back to the architect Vitrivius in Rome, 2000 years ago. They say ***"architectural quality is when "beauty, durability and comfort is equally combined"*** (p.11). A material need to be more than durable. It needs to have patina; to age beautifully, and speak to our senses. Their opinion is that functionalistic view of "form follows function" has long been a devaluation of beauty, but the last decade beauty has come to take its place again in the architectural discussion. Though beauty is subjective, there are still parts of the experience which is not. The author argue that all people appreciate wholeness, such as harmonic proportions and when things fit well together. Moreover, to be met by a carefully performed craftmanship matters to our feeling of self-worth. "Someone has cared for the place, so I feel appreciated and will also take care of the place" and thus it will likely last longer. The same goes for the experience of a poor craftmanship and quick fixes. There is a similar conclusion by Femenias (2019), that using quality materials from start will reduce renovations and unneccessary material flows, climate footprint and economic costs over time.

ARCHITECTURAL QUALITIES

BRAINSTORMING METHOD

Architectural qualities can be a tricky field. Hereby follow a brainstorming list of qualities often related to architecture and housing. Note, these are certainly not a complete list of qualities. The words most relevant to the experiments of LCA & LCC were highlighted and selected. The qualites are specific enough to define, yet still wide enough to contain other qualities from the list as many are naturally connected. The workflow is to find cheaper solutions with less CO_2, and the same time ensure, improve and balance the architectural qualities, or even add new qualities and keep the same original price in the end.

HOLISTIC/LOGIC
SITE SPECIFIC/CONTEXT
SPACE
DAYLIGHT/LIGHT/CONTRAST
AXIALITY/DIRECTION/
FLOW/RHYTHM
INDOOR CLIMATE
FLEXIBILITY - GENERALITY
USABILITIY
DURABILITY
TRANSPARENCY - CLOSED
EMBRACING - OPENNESS
PRIVATE - PUBLIC (ZONING)
FRAMING/FOCUS
VIEWS (DAY/NIGHT)
INSIDE - OUTSIDE (BOUNDARIES)
SIMPLICITY
PROPORTION
SHAPE/SCALE
SIZE/MEASURMENT
VOLUME
SYMMETRY - VARIATION
ACCESSABILITY/INVITING
ARTISTIC/POETIC
EXPERIENCE/EXPERIMENTAL
EFFECTIVE/OPTIMIZED
INNOVATIVE
IDENTITY/CHARACTER
ENERGY
TIMELESS/AGING
ORIENTATION
MATERIALITY
ROOM CONFIGURATION
ORGANISATION
CIRCULATION
TECTONICS
CONSTRUCTION
DECORATION/DETAILS
FEASABLE/PRACTICAL
FUNCTIONALITY
PROGRAM
FURNISH-ABILITY
SAFETY/CLARITY
COLOR/LIGHT

SELECTED FOR THE THESIS

1. SPACE

The spatial experience is key to architectural work. The space refer to the experience of a 3-dimensional room and other surrounding aspects that contribute to the experience. For example distance, area, volume, views, daylight, axiality, circulation, openness and aethetics. E.g. making a room feel more generous by a higher ceiling and more window daylight.

DEFINITION
An abstract term to describe how an area, inside or outside, can feel embracing and pleasureable

2. PROPORTION

Changing space is one thing, but how the spaces relate to each other is another. That is the point of proportion, to discuss the harmony between spaces. For example balance, boundaries, symmetry, ratio, quantity, generality and flexibility. E.g. the ratio between window and wall, or generality to use a room or space in several ways.

DEFINITION
The harmonious size relation of parts to each other or to the whole

3. MATERIALITY

Some experiments only change material and not geometry. Materiality refers to experiencing the quality of materials, both close up, from distance and over time. For example aesthetics, tactile, details, durability, patina and aging. E.g. the feeling of walking on a stone floor or whether the facade will age beautifully or not.

DEFINITION
The character of composed matter and their attention to human senses

4. FUNCTIONALITY

Functionality is close connected to all the above, but is a way to discuss the program and practical use of spaces separetely. It includes program, flow, practicality, feasability, furnishability, access and livability. For example, enough storage space or a welcoming entrance.

DEFINITION
The quality of serving a purpose well

LIFECYCLE ASSESSMENT

PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARIES
Raw material supply	Transport	Manufacturing	Transport from the gate to the site	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D

Figure 3. Life cycle stages included in EPDs (Rheinzink 2021)

ABOUT LCA

The scientifically based method of LCA (Life Cycle Assessment) is a tool that can calculates the greenhouse gas emissions of a given product (or building) over its entire lifetime. The LCA can include all the stages from raw material extraction, processing, manufacture, distribution, use, maintenance, and disposal or recycling (i.e. cradle to grave). The idea is to help designers identify the largest climate impact reduction opportunities (Eberhardt et al. 2021).

The emissions can be divided in two main areas, called embodied energy and operational energy. The embodied is CO_2 emissions from materials, while operational energy is the CO_2 emitted through energy use. According to Eberhardt et al. (2021), the EU building sector has for long focused on operation, which has led to development mainly in energy-efficient buildings. This must be balanced with the embodied energy, as materials can account for 50-70% of entire lifecycle impacts. Beemsterboer (2019) mentions a study from the 90s showing that 80% of the operational energy demand was from space heating, hot water, and electricity use. Today, with improved insulation of buildings, the share of operational energy decreased, giving rise to a more active consideration of embodied energy in materials. Buildings are long-lived dynamic entities that consists of a multitude of materials where each has their own performance and connection to the whole. This complexity is often not adequately accounted for or discussed in current LCAs.

WHY LIFE CYCLE ASSESSMENT (LCA)

Climate change is one of many ecological sustainability aspects, but a major aspect where humanity has gone beyond their boundaries. It is therefore an urgent challenge and focus all over the globe. Not the least regarding the built environment. Eberhardt et al. (2021) explains how the building sector is responsible for 40% of all energy, 33% of all greenhouse gas emissions, 30% of all raw materials and 40% of all waste, globally. Much of which is based on a linear economy of "take-make-use-dispose". On the contrary, circular economy can help restore resources and minimize emissions, by closing the material loops by focusing on design principles like adaptability, durability, use of low-impact materials and reducing the amount of materials. To reach a circular built environment, the design stage is significant, since early decisions will influence a building's life cycle and climate footprint the most. However today, LCA is primarily used as a final assessment of completed building's, rather than an iterative design. This is often due to lack of data, knowledge and interpretation of the LCA result. This is not the most effective way of using the tool. While this is an ongoing development, the building industry would benefit from knowing which major building parts to focus on regarding the maximum reduction of emissions (Eberhardt et al. 2021), which is something that is investigated in this thesis.

According to Beemsterboer (2019), the lifecycle of a residential building is important from a climate concern, yet the knowledge of LCA remain scarce and uneven in most construction companies. The interest in LCA is increasing, and in 2022, the use of LCA-based climate declarations (A1-A3) will become a requirement in the Swedish building sector. Yet agian, it must be seen throughout the whole lifetime of the building, not just the finished proposal. "***If the ambition is to make use of the full potential of LCA for industry and ecology, it is necessary to more actively integrate LCA in the planning, design, and construction of residential buildings"***. (Beemsterboer, 2019, p4). The use of LCA is complex, but not more complex than many other parts of the building process.

Moreover, many companies experience difficulties making effective use of the LCA potential. The main problem seems to be with demand (e.g. since it is voluntary and not yet legalized), resources (e.g. time, money, ability, and data availability), competence (e.g. lack of understanding and experience with the method), and concern about its accuracy (because of large amounts of data and simplified modelling of complex environmental cause-effect chains). LCA is a data-intensive practice, and it seems as if data is unfortunately especially scarce in early design phases where it is needed the most.If LCA is used effectively, it offers a potential beyond the reduction of CO_2 emissions (e.g. energy questions and resource management).

Beemsterboer (2019) highlights a wide variety of established simplification techniques with five simplifying logics: exclusion, data-substitution, expert judgement, automation, and standardization. These strategies can make LCA easier and quicker, but one should be careful not to simplify too much. Still, ***"It is difficult to imagine an LCA study which does not contain any simplification in at least part of the assessment. Simplifications are a way of getting work done and reducing the complexity of the task"*** (Beemsterboer et al. 2020, p1)

LCA TOOLS

There are many lifecycle stages of a building and each LCA-tool will focus on certain stages, giving them different benefits and limitations. An investigation was done to find the most suitable tool, which included looking at the following tools: LCAbyg (all stages), Bombyx, BM (A1-A5), Bidcon (A1-A3) Anavitor, Klimatkalkyl, EC3tool, Tally, OneClickLCA (all stages), HBERT, LCAquick, Etool and CAALA (A1-A3, B4, B6, C3-C4). The CAALA (Computer Aided Architectural Life-cycle Assessment) software was chosen due to its specific focus and simplification of giving architects a tool to achieve both cost, energy and CO_2-emission savings on a large scale early in the design phase. Many other tools requires more heavy details and is not directly connected to real-time 3D-modelling like CAALA. More about the CAALA software is explained on next page.

LIFETIME

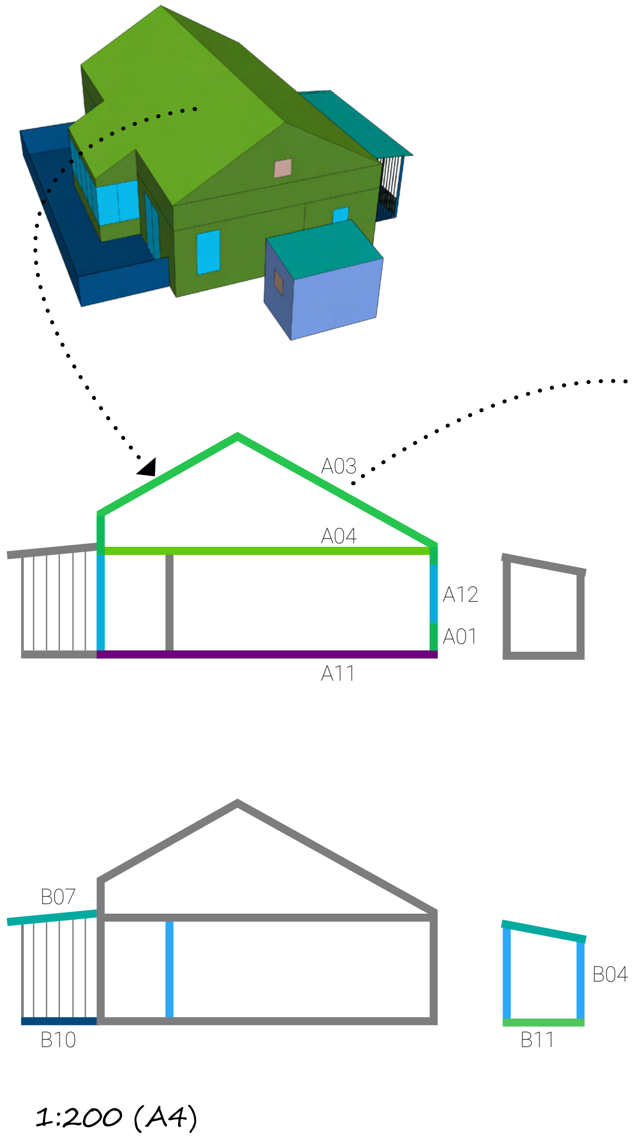
According to Andersson and Nilsson (2020), the buildings in the city have considerably shorter life spans than buildings in the countryside, due to development reasons. They refer to a study saying that "***25% of all buildings demolished in Sweden since 1980, were less than 30 years old*** (p.21). This is very significant from an LCA point of view, which will be discussed later in the lifecycle experiments.

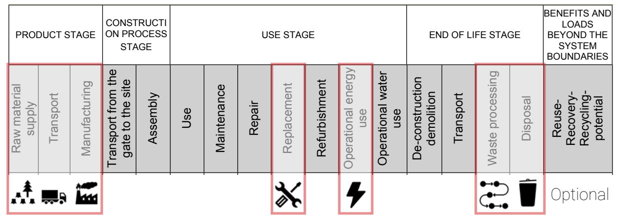
CAALA MODELLING

COMPUTER **A**IDED **A**RCHITECTURAL **L**IFE-CYCLE **A**SSESSMENT (CAALA)

The CAALA software is especially made for architects to optimize their design in early stages, in order to reach the climate potential and avoid exceeding the budget. It is one of the first plug-ins that includus both lifecycle cost (LCC), energy demand and CO_2 emissions in the same simulation (F6S, 2020). The software includes the stages A1-A3 (Production), B4 (Replacements), B6 (Operational energy use), C3 (Waste processing) and C4 (Disposal). In that way, it integrates both embodied and operational energy in the LCA, and both investment cost and operating costs in the LCC. Thus displays the interesting interrelation between cost, climate and design (architectural qualities). Building planners can then easily modify individual parameters (e.g. the wall material, insulation thickness or a new roof) and instantly see the consequences of the design choice just made. The designer builds their model in Sketch up and without any wall thicknesses, each surface must be assigned correctly to a CAALA-layer. The colour coding gives the user instant visual feedback to help verify the correct boundary conditions (Hollberg et al. 2017).

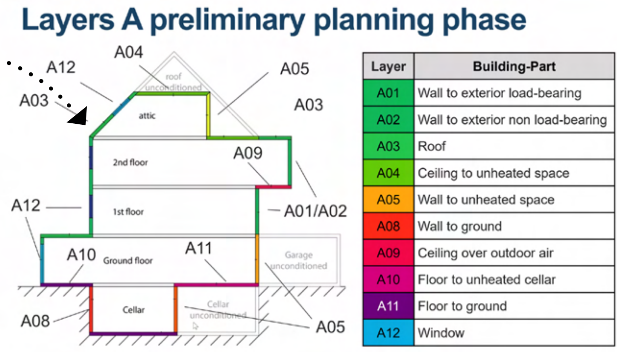
The A-layers are those affected by thermal losses during operation. B-layers are unheated spaces, and mainly embodied energy from the materials. In the CAALA-software, specific materials is assigned to each layer. The materials can be taken from a dropdown meny or be customized as desired. The thickness is added when materials have been defined. The data is collected from the DGNB system and the Ökobaudat data. The materials can partly be manipulated manually by the desiger, for example changing the lamda value (insulation performance) or material lifespan (important for replacement stage), and of course material thicknesses. The investment costs (initial building cost) is added manually for each layer. Material cost is not built-in. For maintainance and repair cost, the software will calculate a certain exponential cost in % on the initial building cost, as a qualified simplification. The energy price per kWh is added manually because prices vary enormously between countries. After adding the required data, and thereby get a total LCC (Lifecycle cost) for the assigned lifetime of the building. The lifetime can be adjusted between 1-100 years (CAALA, 2020).



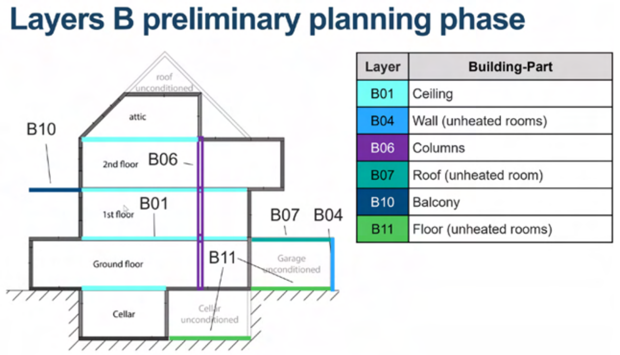


PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARIES
Raw material supply	Transport	Manufacturing	Transport from the gate to the site	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
																Optional

Figure 4. Seleted life cycle stages in CAALA



Layer	Building-Part
A01	Wall to exterior load-bearing
A02	Wall to exterior non load-bearing
A03	Roof
A04	Ceiling to unheated space
A05	Wall to unheated space
A08	Wall to ground
A09	Ceiling over outdoor air
A10	Floor to unheated cellar
A11	Floor to ground
A12	Window



Layer	Building-Part
B01	Ceiling
B04	Wall (unheated rooms)
B06	Columns
B07	Roof (unheated room)
B10	Balcony
B11	Floor (unheated rooms)

(Figure 5 & 6. Boundary conditions in CAALA software.
A. Hollberg, personal communication, 23 Feb, 2021.
Illustrations based on Hollberg et al. 2017)

Exhibition house Small bedroom
Year 2020 Developer Viskaforshem
Architects Brunnberg & Forshed
Photo Robin Hayes

ENERGY PRICE

ELECTRICITY PRICES

Today's price for electricity and the exponential price increase in the future must be manually added in CAALA. The price make a large impact on the LCC and therefore time was spent on trying to understand and estimate reasonable energy prices and inflation in the future. Note that even good estimations are highly speculative. The prices of the future can change due to new laws, taxations, innovations or similar. The values and tools of calculation was done with help from the Swedish Energy Agency (L. Nilsson, personal communication, 2021 March 15). Energy prices are different depending on private or public sector, household, or companies, what kind of company and where the activity takes place. In this case, it is a small household villa with heat pump. There are four different energy areas in Sweden, divided from north to south. Most people live and pay the costs within area 3, including this case study in Viskafors. All energy use in Sweden is liable to tax but it is not included in the modelling software. Prices also go up and down, depending on weather, wind, temperature, and other factors. Especially energy coming from "green technology".

ENERGY PRICE DIVIDED IN FOUR PARTS:

1.Power distribution grid (transport of energy is same for all in same area)
2.Energy price (Deal with energy company)
3.Energy tax (government decides)
4.Value added tax (VAT) (an additional 25% on total sum)

AVERAGE ENERGY PRICE (KWH) IN SWEDEN?

1.Power distribution grid (0.4 SEK/0.04 €)
2.Energy price (0.4 SEK/0.04 €)
3.Energy tax (0.36 SEK/0.036 €)
4.Value added tax (VAT) (Not included in CAALA model)
•Total 1,16 SEK/0.16 € (SCB 2021). Note that the price is much lower than many other parts of Europe (see graph).

ESTIMATE THE PRICE OF 2050?

1. POWER DISTRIBUTION GRID (25 year Historical Comparison gave 1,4 %/year. See calc. below):

The price from 1996 until 2019 has changed from 0,19 to 0,347 (SCB 2021). This change has not taken to account inflation and to equalize the percentage increase and see the real price development, we must first look at CPI (Costumer Price Index) for the same year span. The values were "156" in 1996 and "334" in 2019 (SCB 2021). 334/156=1,3. This means the starting point price in 1996 must first increase with 30% to be comparable, so 0,19 SEK x 30% = 0,24 SEK. This can now be set in relation to the price in 2019, 0,34 SEK. The price development between 1996-2019 has gone from 0,24-0,34 SEK (in 25 years). This is 0,04 SEK/year for 25 years. In exponential increase, the equation is $0,24x^{25}=0,34$. The exponential x is then 1,4% each year. Inflation is then already "included" in the price like a discount. This means including the price of 1996, as if it was the price of 2020.

2. ENERGY PRICE (30 year Future Scenario = 1,46%/year)

The energy price is calculated from The Swedish energy agency scenarios for the spot-price on electricity in the power market (L. Nilsson, personal communication, 2021 March 15). In other words the price on the Nordic electricity market NordPool. The price in year 2020 is 0.31 SEK and is estimated to be 0,479 SEK in 2050. (An increase of about 0,17 SEK in real terms, ca 50% in total). The exponential equation is $0,31x^{30}=0,479$. Making x=1,46%/year

3.ENERGY TAX (unchanged at 0.36 SEK in real terms, so 0% increase)

4.VALUE ADDED TAX (VAT) (unchanged and not included)

SUMMARY: Power grid 1,4%, energy price 1,46%, energy tax 0%. Since they are almost 30% each of the total price, you might summarize by the equation (1,4+1,46+0)/3= ca 0.98% average. So more or less 1% increase of total energy price (already adjusted to inflation)

ENERGY PRICES IN CAALA

There are three values to decide in CAALA lifecycle modelling.
1.Energy price today (starting point)
2.Exponential increase of energy price (estimated in %/year)
3.Inflation discount (%/year works as discount on energy price).

Inflation can be confusing when estimating prices. There are two ways to calculate price and inflation which will have the same outcome in the model.

1. If adding a value to the inflation rate (discount) in the model, the energy price must be in "nominal terms", which means a price not yet adjusted for inflation. Otherwise, the "inflation discount" will be counted twice.
2. The second option is to set inflation discount to 0% and instead include it directly in the energy price. The energy price development will then be in "real terms", which means a price already adjusted for inflation and thereby excluded the effect of inflation (It means the prices have been compared as if they were all in 2020).

Since the calculations show a price increase in real terms (adjusted to inflation), the energy will be more expensive in 2050 than today in 2020. If the inflation is 1, 5 or 10% does not affect the "real price", but only the "nominal price". So, if adding 5% inflation, it must also be added to the energy price. The difference between them must always be 1% according to the calculations above. Since I included inflation in my energy price calculation, I will set inflation to 1% and energy price to 2%. Price today (ex VAT) is 1,16 SEK. In 50 years the energy price will be 1,16 SEK x $1,01x^{50}$=1,9SEK/kWh. Looking at the diagram below, it is important to say that Swedish price/kWh is very low. Almost half that of Germany.

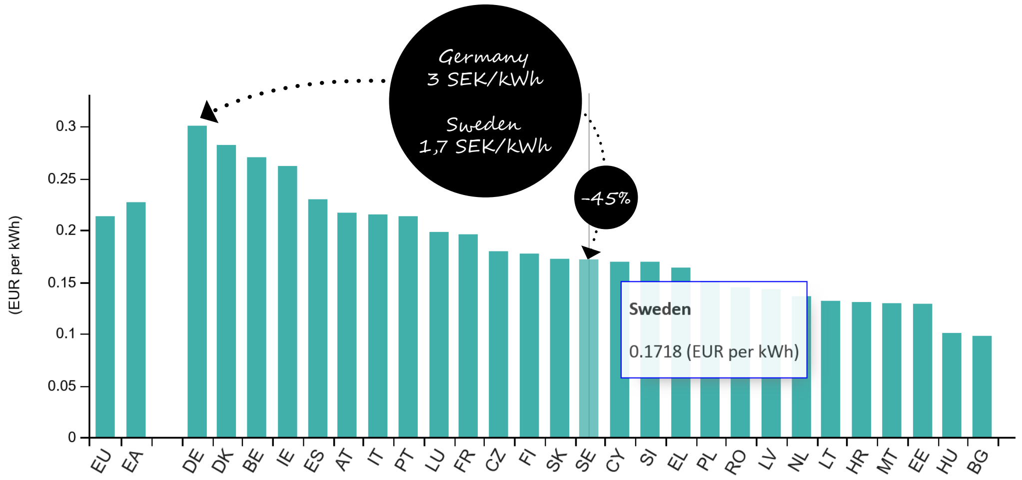
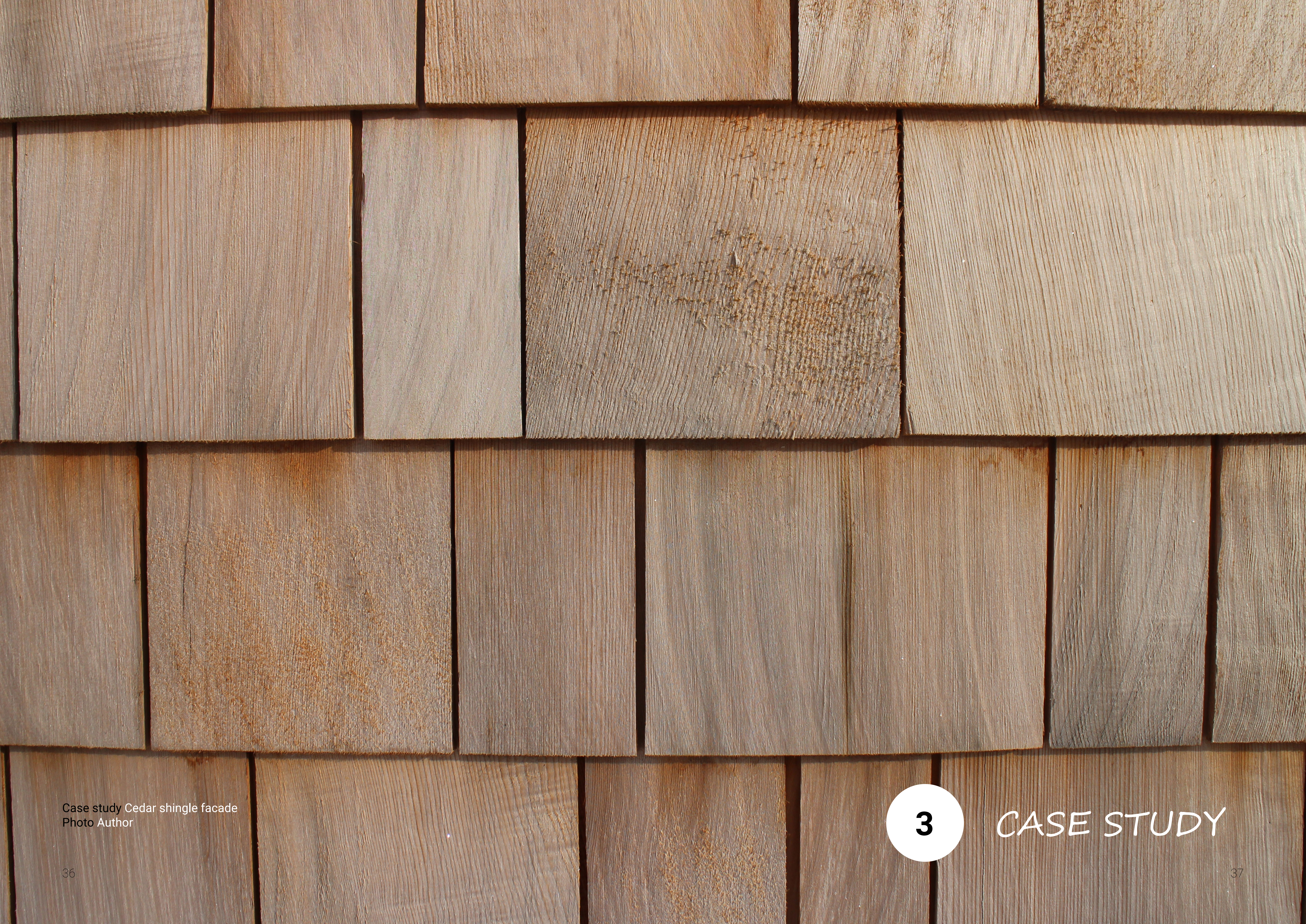


Figure 7. Electricity prices (including taxes) for household consumers, second half 2020 by Eurostat (2020). Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statistics



Case study Cedar shingle facade
Photo Author

3

CASE STUDY

THE SITE

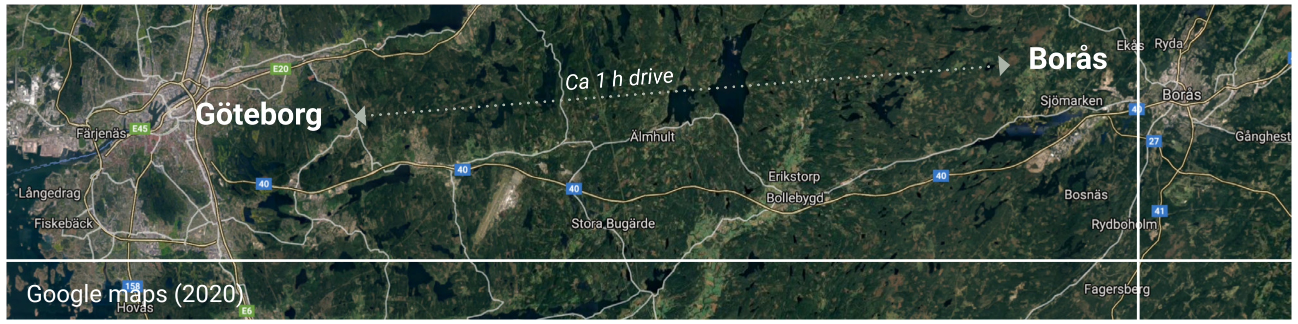


Photo Mikael Bengtsson

THE ORIGINAL PROJECT

PROJECT: 13 detached rental villas of $84m^2$.
Källsprångsvägen, Viskafors. Year 2020.
CLIENT: Viskaforshem AB
ARCHITECT: Brunnberg & Forshed
CONTRACTOR: Fristad Bygg

VISKAFORSHEM AB

Viskaforshem is a public non-profit housing organisation owned by Borås municipality. Companies like these exist all over Sweden to offer good rental housing for everyonw, no matter background. They are to take active responsibility for the building of society, and operate with normal business principles.

VISKAFORS

Viskafors i located 10km outside of Borås city and has about 3800 inhabitants. Historically it is an old factory town, but after the textile and rubber industry closed down, fewer workers settled there. Viskaforshem wants to attract new people by attractive architectural housing.

WHY VISKAFORSHEM?

The client Viskaforshem explores a relevant question about how it could be profitable to spend money on quality. It is a wise invesment that goes hand in hand with sustainability, longterm thinking and resource optimization (Brunnberg & Forshed, personal communication, 2021 Feb 12). Mikael Bengtsson (VD), says the demand for small houses are clear, yet densification is the popular strategy. Viskaforshem works against mainstreem trying to build high quality rental housing (personal communication, 2020 Dec 10).

WHY THIS CASE STUDY?

The scale fit well with the scope of the thesis and there was mutual interest in knowledge exchange, since lifecycle assesments had not been done. It is an interesting case because the quality, from many aspects, is already above average swedish standard and is therefore a challenge to optimize.

TASK & TIMELINE

The task was specifically three-room housing, since previous project at Pumpkällehagen had four rooms and the desire was to widen their building stock. The plan was 19 houses at first but was reduced to 13 due to ground quality (normally in projects it is the other way). First sketches was in 2016 and the opening will happen in 2021.

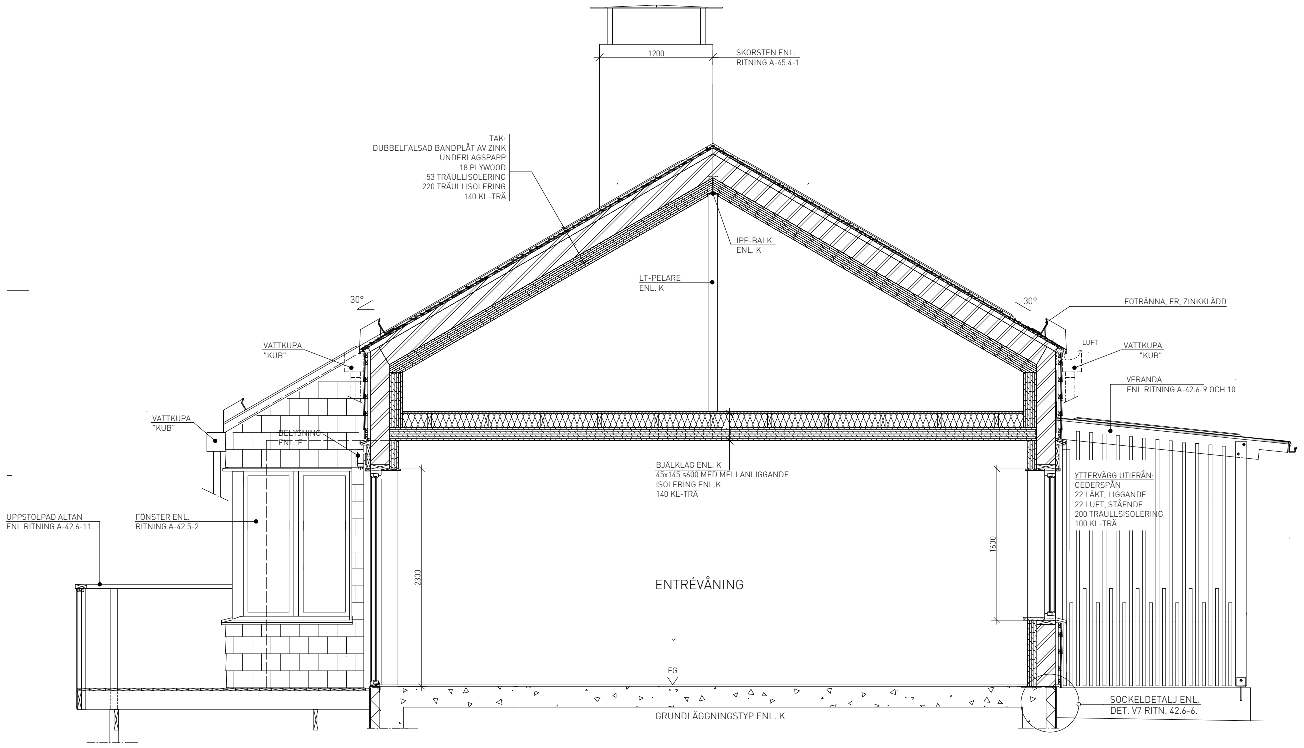
1:1500 (A4)

Drawings by Brunnberg Forshed

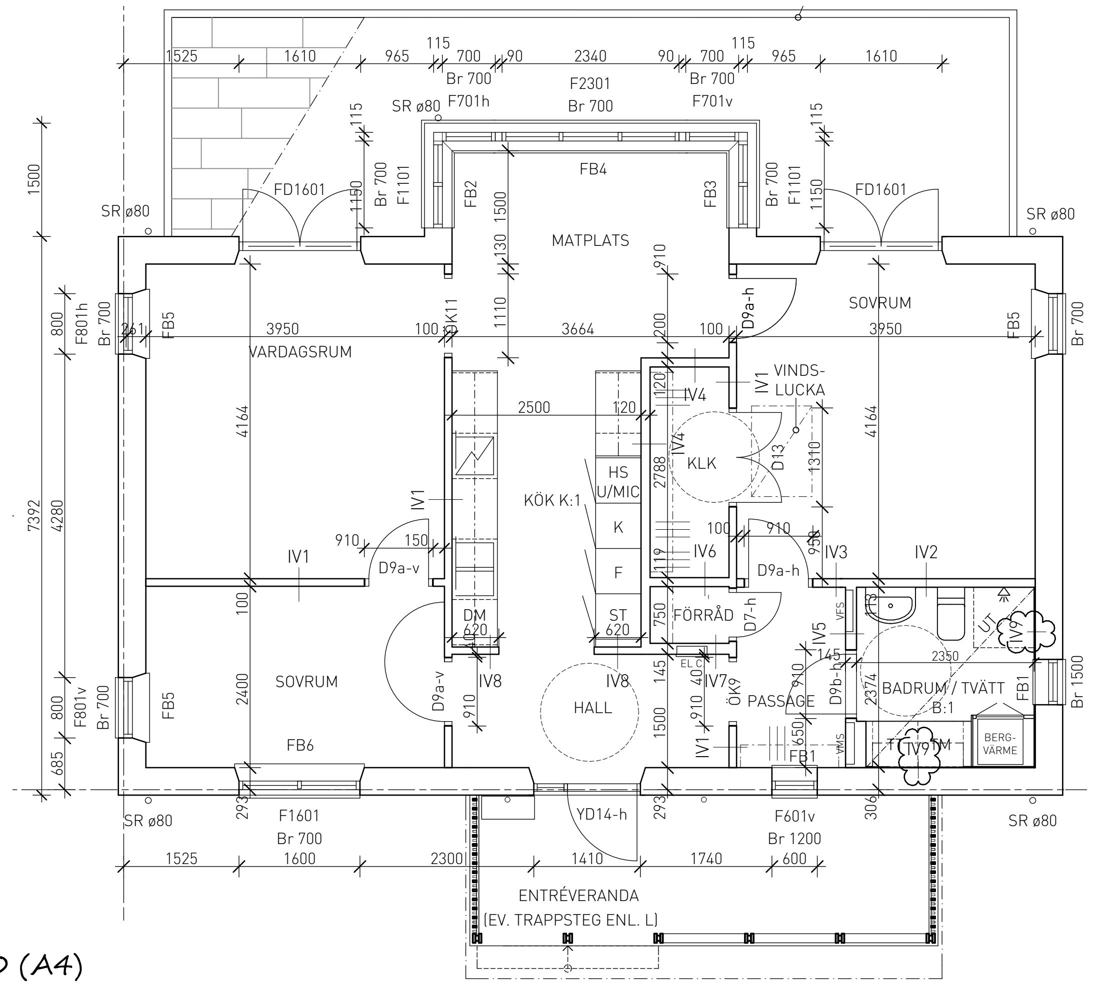
CASE STUDY VISIT

Exhibition house Källsprångsvägen Details of stone sills, massive metall sink, cedar shingles, core pine patio, painted CLT interior and Swedish made doors
Developer Viskaforshem
Contractor Fristad Bygg
Photos Author

THE ORIGINAL BUILDING



DETALJSEKTION A-A
SKALA 1:20



1:100 (A4)
Drawings by Brunnberg Forshed

REAL ESTATE ECONOMY

General calculations on the original buildings to help get a sense of the project scale and costs, before zooming into one villa.

PROJECT BRIEF
Type: 13 detached rental houses
Gross floor area (GFA): 99sqm
(incl outer walls. excl patio, terrace and attic storage)
Net floor area (NFA): 85sqm livable rental space
NFA/GFA (key ratio): 85/99=0,86

PRICE OVERVIEW
Total price incl VAT (value added tax): ca 60MSEK (exVAT 50MSEK)
Total price/villa: 60/13=4,6MSEK (ca 3,8MSEK ex VAT)
Total rentable space (sqm NFA): 1105sqm
Total Production cost incl VAT (SEK/sqmNFA): 60/1105=54 298 SEK/sqm (incl land and building)
Price division: Land 10MSEK and building 50MSEK
Land price incl VAT (SEK/sqmNFA): 10/1105=9050 SEK/sqm land
Building price incl VAT (SEK/sqmNFA): 50/1105=45 248 SEK/sqm

RENT
Rent (SEK/villa/month): 10 114 SEK/month (excl heating, electricity, water and waste disposal)
Rent (SEK/sqm/month): 10 114/85= 119 SEK/sqm
Rent (SEK/sqm/year): 119x12= 1433SEK/m2/year

(There is a maximum permitted standard rent when receiving investment support for new rentals or student housing. Support from Boverket (2020) may only be provided if the project ensures relatively lower housing costs, in this case 1450 SEK/sqm)

ADDITIONAL COST
The additional cost includes heating, electricity, water and waste disposal. The cost depends on personal usage but is estimated to 2000 SEK/month. By having additional costs, Viskaforshem desires to teach the tenants about sustainability as they become in control of their own usage and costs and as a company avoid, to some degree, increased administrative work.

OTHER
Rate of return/yield (depend on location and estimated risks): 3,25%, general for the municipality
Devaluation (decrease in value of time): 70 years
Heat source: Geothermal heat pump with unit inside each house. Floor heating in all rooms. Their own estimation is 30 kwh/sqm/year.

Volume sketches by Brunnberg Forshed

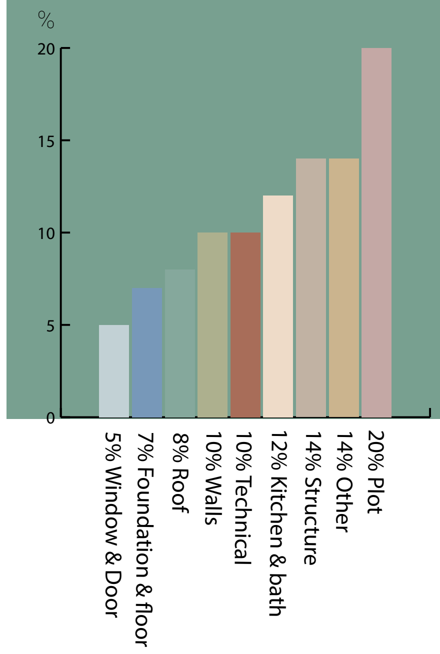
PRODUCTION COST

OBS! This is en estimation of the production cost of one villa. The € is highlighted because it is the currency used in the life cycle software. The SEK-currency is to help conversion for Swedish readers. Some are not measued in m2 because they are split into different categories, or not experimented with. Estimating correct prices is difficult because it depends on timing, place, volume, details, work hours, unexpected risks and much more. The prices are therefore not comparable with prices on the public market.

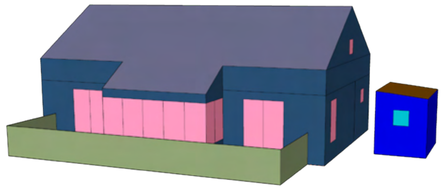
This table does not include everything, only that which is most useful for this thesis and for comparable calculations in the life cycle tool. The costs have been estimated in several ways. Some prices have been given by the entrepreneur, some directly from producers, some from the client, and some are estimated in a calculation program (Wikells Sectionsdata, 2021). Out of respect for each stakeholder, the connection to each cost is kept secret to protect private interests from the public.

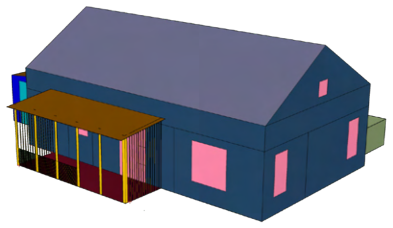
Prices include work hours, ex. VAT
1 € = 10 SEK

Description	Specifications	Investment SEK	Area m²	Price SEK/m²	**Price €/m²**
Land	Plot, infrastructure	710 000	-	-	71 000 €
Load-bearing structure	Cross-laminated timber (CLT)	500 000	380	1316	132 €
Kitchen and appliances	Solid wood, metal and natural stone	290 000	-	-	29 000 €
Roofing	Rheinzink or brick tiles	240 000	136	1765	176 €
Exterior wall	Cedar shingles, cellulose insulation	225 000	130	1731	173 €
VVS-installations	Geo. Heatpump, floor heat, FTX	200 000	-	-	20 000 €
El-installations	Normal, behind CLT	170 000	-	-	17 000 €
Bathroom	Wall finish, appliances	150 000	-	-	15 000 €
Unheated spaces	Storage, patio, terrace structures	125 000	-	-	-
Foundation	Concrete, EPS insulation	110 000	118	932	93 €
Flooring	Stone clinker, glue	100 000	100	1000	100 €
Windows	Wood-alu 2+1, openable vertical	90 000	30	3000	300 €
Doors	Inside and outside, high quality	75 000	15	5000	500 €
Inner walls	Standard gypsum solutions	70 000	30	2333	233 €
Paint	Painting directly on CLT	40 000	260	154	15 €
Other	Establishment, planning, expenditure, supplement charge, risk, salaries etc	500 000	-	-	50 000 €
	Total investment	3 595 000 SEK			359 500 €



MODEL OF ORIGINAL BUILDING





INTRODUCTION
These two pages intends to present the so called original model. Basically it is the case study house with values estimated through many investigations and interviews. It is the base for which all the experiments are compared to. This is the detailed data used in the modelling, explainations about what the life cycle parameters include and exclude, and how to understand the result. And at last, some related research for comparison.

GENERAL MODEL DATA
New construction - Single family house
Region 10 - Hof (area in Germany similar to our climate)
DGNB System (German Sustainable Building Council)
Database Ökobau.dat (2016)

LIFE CYCLE MODULES
A1-A3 Production - B4 replacement - B6 Energy demand in use phase - C3+C4 End of life - D Benefits beyond system boundaries (optional, not included)

OBJECT DATA
Average floor height 3m (floor-floor), 1 floor, NFA 84 m2, BFA 105m2, energy reference area 100m2, thermal bridge ”enhanced 0,05 W/m2K” (medium) and air tightness ”new construction - general n50=4h^{-1} ” (medium).

U-VALUES
Average climate shell 0.21, Foundation 0.125, Wall 0.158,
Roof 0.073, Window 0.9

MATERIAL LIFESPAN BEFORE REPLACEMENT

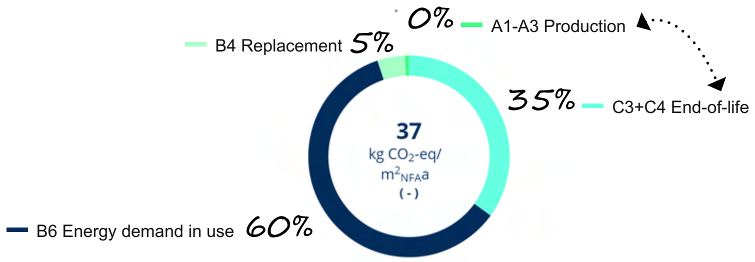
BELOW 50 YEARS: Painting 15 years, Construction wood varies, Windows 30 years, Wood terrace 30 years

50 YEARS: Interior walls (lasts longer, but is often replaced), Tar paper below roof, Technical system (TGA)

75-100 YEARS: Doors, Cedar Facade, Stone clinker flooring, Roof cladding, Cellulose insulation, Intermediate floor

NEVER REPLACED IN CAALA Foundation (concrete, EPS, XPS), Load-bearing structure (CLT)

NOT INCLUDED IN THIS LCA Bathroom, kitchen, furnitures and other details. Focus is major building parts.



GLOBAL WARMING POTENTIAL (GWP)
This graph displays the Lifecycle assessment (LCA), measured in global warming potential with the units, kg CO_2/m^2 per year. The reference area used in the experiments is $100m^2$ and the reference study period for is 50 years (which of course can be adjusted). In other words, the figure say 37 kg CO_2 x 100m2 x 50 years = 185 tons of CO_2 (3,7ton/year or counting 3 people living in the house: 3,7/3=1,2ton/person/year).

To make a few CO_2 comparisons, one roundtrip flight Sweden-New York (12000km) is the same CO_2 cost per person, 1,2 tons (Kortspelet klimatkoll 2020), as the buildings lifecyle (if three people live there).

FLIGHT SWE-NY
ROUND-TRIP
(1300 MIL)

= 1200 KG CO_2

Or a mixed food diet is in Swedish average 2 tons CO_2/person/year (Kortspelet klimatkoll 2020). Which means, the building costs each year is the same as two people eating for a whole year.

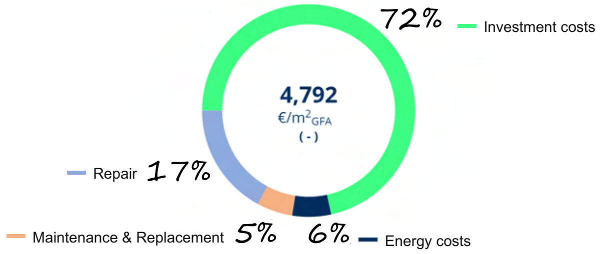
MIXED-FOOD
AVERAGE 1 YEAR

= 2000 KG CO_2

The use phase is 60%, End of life 35%, replacements 5% and production almost 0%. Production and end-of-life should be seen together in a sense and is mostly dependent on embodied energy in materials. Production is almost 0% due to wooden materials that binds CO_2, but importantly, that CO_2 will be released again at the end-of-life, making it 35%. Replacements are different for each material and has been manually decided in CAALA software (see material lifespan list). After its expected lifespan is is replaced and counted once more into the LCA. In this way, long-lasting materials will be cheaper.

Energy in use phase is connected to the primary energy demand. It is based on the building's shape factor and volume, insulation and u-values, thermal bridges, air tightness and the efficiency of the technical equipment. The original model has a heat pump ground/water with mechanical ventilation and heat recovery and a default CO_2-Intensity [kg CO2eq/kWh] set to 0.53 (this will be experimented and discussed later). The LCA can not take into account how materials might loose insulation-performance over time. Estimations like these have to be done manually. As energy use is 60% of CO2, it motivates architects and builders to investigate and use effective technical equipment.

Though the LCA includes many major lifecycle stages but not all of them, for example construction phase or some parts of the use phase, like maintainance. The lifecycle costs is different regarding this. To compare an LCA to another LCA, one must be sure to compare the same lifecycle stages, lifetime of the building, and same level of material data. This can be difficult and much study is being done abour how to simplify LCAs to create more comparable results. Still, if LCA is used early in the design phase, it is possible to find the largest opportunities for optimization, even if the complete CO2 can be uncertain.



LIFE CYCLE COSTS (LCC)
This graph displays the LCC measured in €/m^2 with same reference area of $100m^2$. Note this is a total cost for 50 years, and not a yearly cost like the LCA. The yearly cost must be calculated manually by dividing by the amount of years. The 50-year lifecycle cost for the whole building is 4792€ x10 SEK x $100m^2$ = 4 792 000 SEK (including a 200 000 SEK heat pump). This is 96 000 SEK/year or 8000 SEK/month.

The investment cost is the estimated building cost ex VAT and including work hours, about 3,4 million SEK (70% of total LCC!). This is the cost used in the modelling by assigning costs for each material layer, but in reality this number is likely +- 200 000 SEK due to details that can not be covered in the LCC software. Maintainance and repair are calculated by adding an exponential %-increase/year, on the investment cost. It differs between the built structure and technical system by following: Building maintenance: 0,1% and repair: 0,35%. Technical maintainance 0,41% and repair 0,66%. This is a good estimation by the DGNB system, but it has some flaws. As investment cost gets higher, repair also gets higher, but in reality it is sometimes the opposite. An investment in better quality will likely lower the need for repair and maintenance, which in return, lowers expenses over time. This concept is then not really visible in the LCC today. The LCC does not reconize the lifespan of the material like the LCA does.

The last parameter is the energy cost. This cost is added manually, since it is different around the globe. In this case, the initial price for electricity is 0,12 €/kWh (ex Vat), the rate of energy price increase is 2%/year and the price discount rate for inflation is 1 %/year. In other words 1,2 SEK/kWh with 1% cost increase each year of the building's lifetime. This cost is not only for energy use but also general costs like repair and maintenance. Sweden has very low energy cost (and very clean energy). It is therefore only 6% of total LCC (compared to 60% for the LCA). Since the energy cost made a large impact on total LCC, indepth calculations was done for realistic price estimation (see separate chapter on energy).

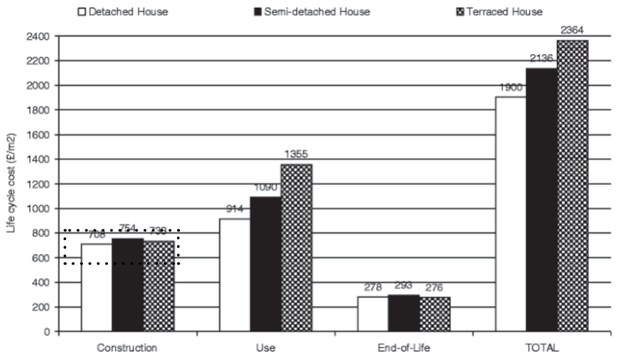
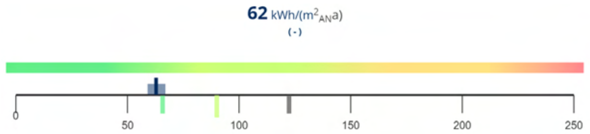
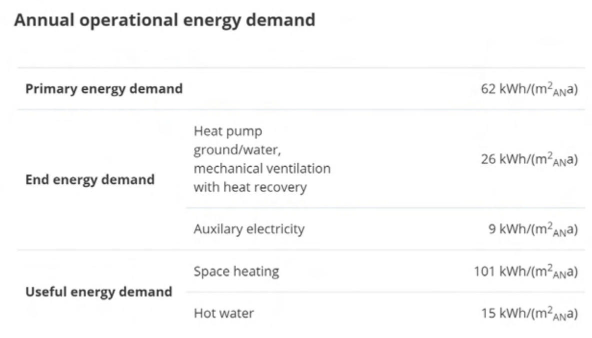


Figure 8. Lifecycle cost £/m2 in the UK (W. Unterrainer, personal communication, 29 Mar, 2021)

White staples shows villa costs. Construction is 37% of total LCC. This means the initial building cost is paid 3 times over the entire lifetime! The study period is unfortunetely not known, making comparison more difficult. Still, knowing construction costs are higher in Sweden compared to UK, it is plausable that construction/investment cost in the original model is 70% of total LCC over 50 years.



PRIMARY ENERGY DEMAND
This graph displays the Primary energy demand, measured in kWh/m^2 per year. The total is 62kWh x 100m2 x 50 years =310 000 kWh (or 6200kWh/year). This operational energy is compiled according to the parameters below.



Annual operational energy demand

Primary energy demand		62 kWh/(m^2_{AN}a)
End energy demand	Heat pump ground/water, mechanical ventilation with heat recovery	26 kWh/(m^2_{AN}a)
	Auxilary electricity	9 kWh/(m^2_{AN}a)
Useful energy demand	Space heating	101 kWh/(m^2_{AN}a)
	Hot water	15 kWh/(m^2_{AN}a)

The energy depends on the technical system for both heating and ventilation, in this case a heat pump with mechanical ventilation. Changing to natural gas, oil boiler, district heating or pellets, will drastically change the result (see technical experiment). The auxilary electricity is needed to run the water pump, fans and so on. The space heating depends on shape factor, floor area, the ceiling height, the solar gains and losses through windows, as well the building's insulation. The hot water is a fixed value. The primary energy demand is a summary of the above, including the energy generated from the heat pump. The values also depend on climate, geography and other factors. Minimizing the thermal bridges and air tightness in the software would lower result by 10kWh. The result is plausible for a small detached house with only one floor.

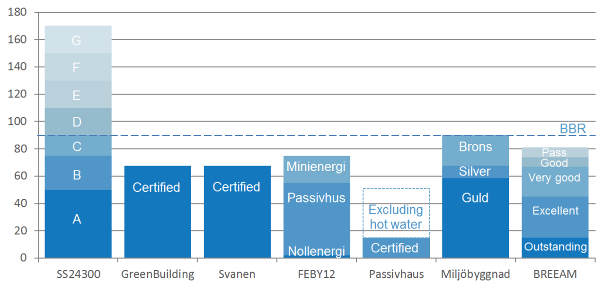
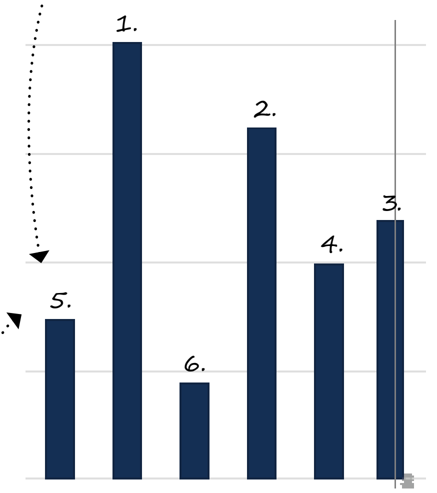


Figure 9. Environmental certifications. A comparison of energy usage in multi-residential buildings in Southern Sweden (Lundgren 2014).

The Viskafors villa with 62kWh will reach green building certification, Svanen and Miljöbyggnad Guld. A real passivehouse are as low as 15 kWh, but it is difficult to reach that low when having an uneffective building shape and only one floor.

CO_2 VS BUILDING COST

IN MAJOR BUILDING PARTS



EMBODIED ENERGY [CO_2/M^2]

This is the embodied CO_2 in materials connected to each major building part. It is measured in $kgCO_2/m^2a$ and the lifespan is 50 years. It includes all life cycle stages, which means some of these materials are counted twice due to replacement. A different total lifespan of the building would change graph.

5. The exterior wall is fairly low due to high percentage of wooden materials that binds CO^2.

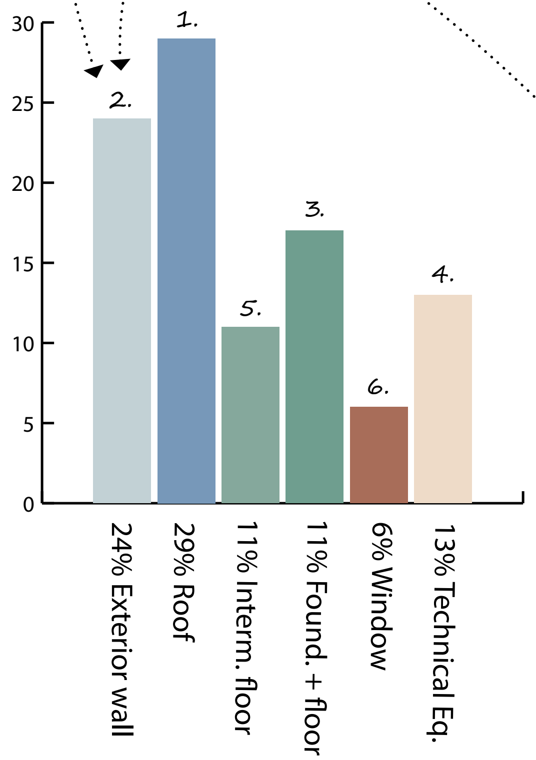
1. The roof has the highest impacts, likely due to zink roofing, 30% thicker insulation and 14cm CLT load bearing construction compared to the 10cm for the exterior wall.

6. The intermediate floor is lowest, but still made the list of highest impacts, also due to thicker CLT and insulation.

2. The foundation is second highest, due to concrete, armory and cell plastic insulations.

4. The windows have impact due to glass and aluminium, and because it is replaced once after 30 years.

3.The technical equipment (heating system) is not yet replaced in this graph. If it is counted once more due to longer building life, it would be same as the roof and move to second place.



BUILDING COSTS [€/M²]

The building costs are also calculated per m² for comparison with CO_2/m^2. One important note is that not all elements are the same thickness (e.g. the exterior wall includes more material layers than the windows), so even if area is the same, the volume is not. The result from comparing the two graphs shows that embodied CO_2 emissions in some sense follows the building cost, but not fully. It is only the roof that appear the same in both diagrams, as number 1 on the list. The others are different.

2. The cost of the exterior wall changes perhaps the most, from 5-2. The materials has high cost/m² due to much materials, but low CO_2/m^2 due to much wood. The potential to improve here is lower than the other.

1. The roof cost is the highest (same for CO_2) and thus has potential to lower both parts i re-designed or changing materials.

5. Intermediate floor cost is mostly due to thick CLT. The cost/m² is lower than the CO_2/m^2, but the project would potentially save large costs and CO_2 by removing it.

3. Foundation of concrete, EPS and stone flooring has high CO_2/m^2 compared to the cost/m². Since it is cheap it is likely more used, but should be questioned and improved.

6. The windows changes the most. They are very cheap compared to the CO_2/m^2. Which means high CO_2 saving potentials.

4. The technical equipment is quite similar in both graphs, but again, if the system was once replaced, the CO_2 would be much higher compared to its cost.

Källsprångsvägen **Facade construction**
Contractor **Fristad Bygg**
Photo **Robin Hayes**

4

EXPERIMENTS

Case study View from the living room
Year 2020 Developer Viskaforshem
Architects Brunnberg & Forshed
Photo Robin Hayes

OVERVIEW

Case study Wooden rental villas, Källsprångsvägen, Viskafors
Year 2020 **Developer** Viskaforshem
Architects Brunnberg & Forshed
Photo Robin Hayes

READING INSTRUCTIONS

Chapter 4 [Experiments] is meant to be read in a certain order, from wide to narrow.

There are two main categories: VOLUME & MATERIALS.

Drawings appear not mainly in the end, but connected to each related experiment and calculation.

The following chapter 5 [Summary], a new proposal combining the best experiments are displayed together with the total life cycle savings.

1. VOLUMES

LIFECYCLE STAGES
Explaining the stages

LIFESPAN
25-50-75-100 years

ORIENTATION
West vs south-east

ROOF
Pitched roof vs flat roof

PLAN & VOLUME
Plan
Volume
Section
Facade

2. MATERIALS

FOUNDATION
Concrete vs foamglas
Slab vs punctual

WINDOW
Alu-Wood-PVC
(including Vertical vs horizontal montage and Openable vs fixed)

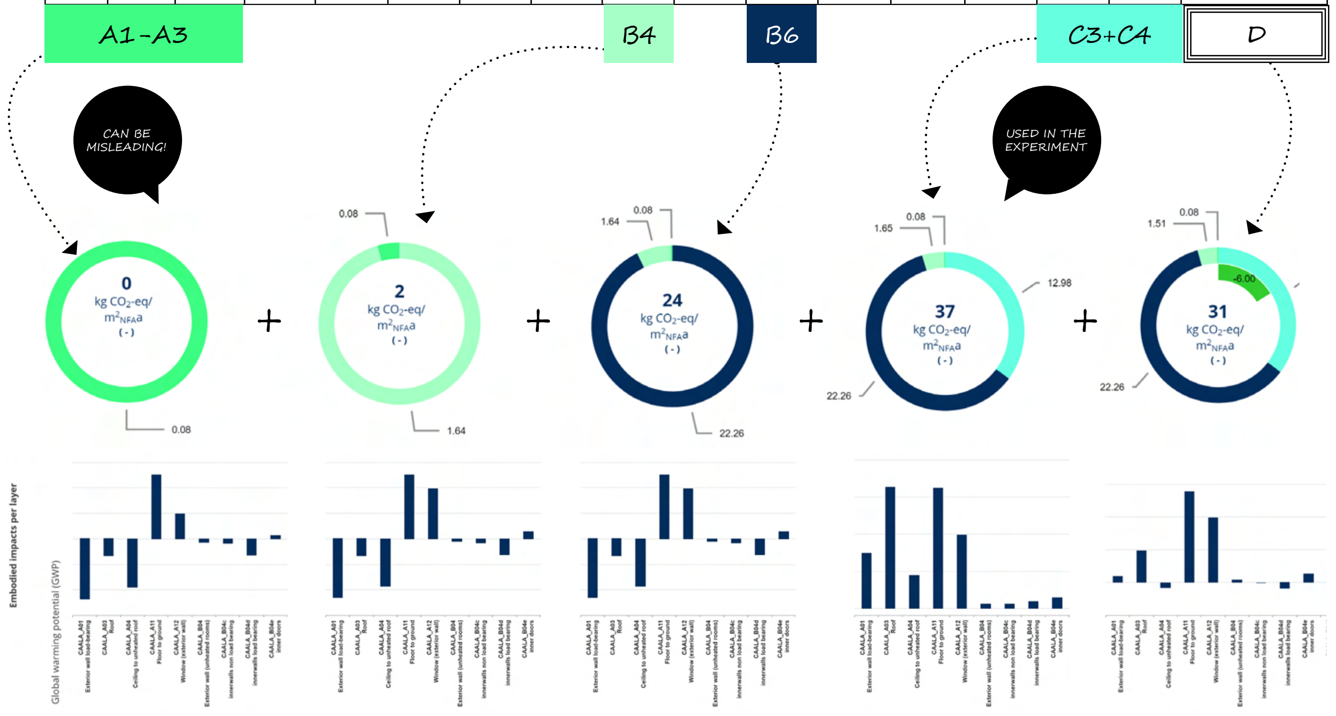
ROOF
Zink vs brick tiles

TECHNICAL SYSTEM
Heat pump vs pellets

1. LIFE CYCLE INTRODUCTION

LIFECYCLE STAGES IN THE LCA

PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARIES
Raw material supply	Transport	Manufacturing	Transport from the gate to the site	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse- Recovery- Recycling- potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D



This is the stage where all materials are produced. The result is 0, because wood has a minus value in production since it binds CO². The loadbearing wall and roof is below 0 because it is CLT, cellulose insulation and cedar facade.

A1-A3 is used by many companies to calculate LCA and will become required for new buildings in 2022, acc. to Boverket. This is a step in the right direction, but the graphs show how A1-A3 can be misleading. Wood will release CO_2 in the end-of-life stage, and will then reach a +-0 at best.

The replacement stage calculates that some materials will be replaced after their expected lifespan, for example 30 or 50 years. The load bearing structure will never be replaced and is therefore not changed in the graph. The replacing of wooden products make small difference in LCA as mentioned. The largest change is windows and doors, due to glass and aluminium.

The circular graph changes alot when adding energy use over 50 years, but the staple graph is unchanged here because it only includes embodied energy in materials and not the CO_2 through energy used to run the building.

What mostly effects the circular graph and energy use, is how well the building materials will insulate and what type of technical equipment used for heating and electricity.

Adding the end-of-life stage and CO_2 emissions for waste disposal is crucial to balance the LCA and create a realistic picture. This combination of lifecycle stages is used in the experiments. Note that some staples have been mirrored, which means the wood products released the CO_2 that was previously binded, and almost create a net zero between production and end-of-life. However, none of the staples are now below 0, which means all material layers have a CO_2 cost if the entire 50-year life of the building is counted for. Largest is roof, ground and windows, due to metals and concrete.

The D-stage is in many cases speculations about the future potentials of how materials can be reused or recycled. Though it is important part of the lifecycle, it gives LCA credit for something today that might not be true tomorrow. Therefore it is excluded in the experiments, to avoid green washing.

For example it could be about how burning wood in the future might be connected to a new innovation where the energy and CO_2 emissions can be reused for a benefit, instead of being released back into the atmosphere.

25 YEARS

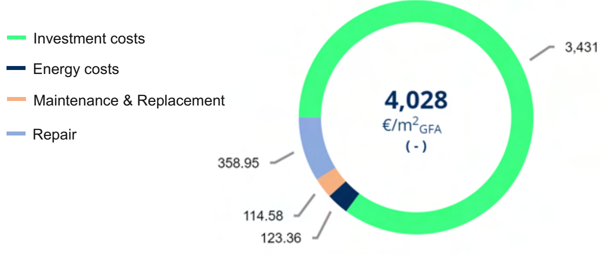
The lifespan of a building is at the core of lifecycle thinking. The longer the building stands the better. The years reflect the time from construction to demolition. The total lifecycle cost/m2 increases each year due to maintainance, repair and energy costs, but note how cost per year gets lower. The LCC graph does not display yearly cost like the GWP does, only total cost. The yearly cost is therefore calculated manually and displayed in the black boxes. CO^2/m^2a (GWP) gets lower each year, with some bumps when materials are replaced (timeline illustration below. OBS! Not complete and not in scale, mainly for visual help). The energy demand is constant but in reality it could increase when materials get older and looses performance, but in a way also get better, since the replacement is likely better due to new future innovations.

Tearing down the building after 25 years will drastically increase CO_2 emissions. ***As much as 25% of the buildings demolished in Sweden since 1980, were less than 30 years old (Andersson & Nilsson, 2020, p.21).*** The demolition after 25 years stands for 55% of the total GWP (potential reuse not included). Replacement is almost zero because most materials lasts more than 25 years anyways. The second problem with a short lifespan is that the villa will most likely be replaced by a new building, either on the same site, or elsewhere. This will lead to even higher costs, both financially and for the climate. If the building lasts longer, new buildings will not be needed in the same extent, which reduces costs for everyone.

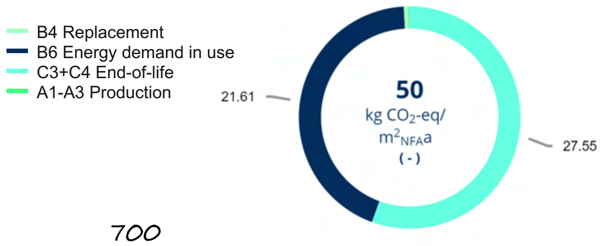
160 000 SEK/YEAR
13 000 SEK/MONTH
for 25 years

BUILDING
COST 85% OF
TOTAL LCC

LIFE CYCLE COSTS



GLOBAL WARMING POTENTIAL (GWP)



50 YEARS (ORIGINAL)

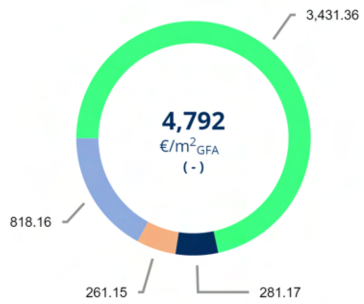
The heating system (TGA) is changed after 50 years, so at year 51, the TGA is counted twice. This is shown in the GWP timeline below. So TGA is lowest at 50 years, $2.1kgCO_2/m^2$, but also the same for 100 years. For example: 1 year is $105kgCO_2/m^2$. Then divide with amount of years. 105/50=2.1kg. Same at 100 years: 105+105/100=2.1kg. If the year was set to 51, meaning once replaced: 105+105/51years=4,1kg/year. Then total GWP would be 39 instead of 37.

Windows are replaced every 30 years. At year 30, 60, 90 the values appear best. While year 31, 61 and 91, the values are at its worst because then they are counted twice without having lasted so long. Year 1 is 50kg/m2/a. Then add 50 for each replacement and divide by amount of years. This means the window element will be same during 25-50-75 and 100 year lifespan.

Repair and maintainance is based on an average expense in x-% on investment cost, which means those costs will increase exponentially in the graph. Similar regarding the energy costs, which will depend on set price for electricity and inflation. This also means the program can not fully distinguish different material qualities, but only their lifespan before replacement. For example, the maintainance cost would be the same for a brick wall compared to a wooden wall if they had the same investment cost and expected lifespan. But in reality, a wooden wall will only last as long as a brick will if careful maintainance is upheld.

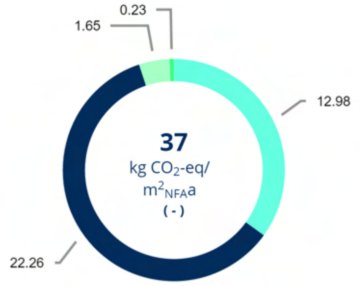
96 000 SEK/YEAR
8000 SEK/MONTH
for 50 years

BUILDING
COST 70% OF
TOTAL LCC



Total cost 4 MSEK
96 000 SEK/YEAR
for 25 years

+764€/m²
+0,764 MSEK



-12 kg CO_2
-1200 kg/year
-60 ton/50yrs

75 YEARS

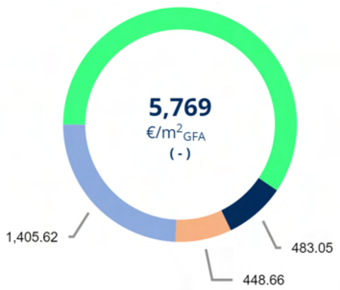
Extending from 50-75 years, the CO_2 emissions are lowered, but not as much as between 25-50 years. Looking at the GWP graph, the largest difference is seen in disposal stage. Likely because some materials have lasted longer by then. Moreover, the emissions from energy use is now 62% of total LCA and is getting higher in percentage the longer the building stands, because the building will always need energy while the embodied energy in materials are constant and evens out over the years.

Important to know is that CAALA software will not replace the loadbearing structure and foundation, since replacing them often means replacing the entire building. It is therefore important to invest in durable loadbearing materials that will keep its performace and aesthetics over time.

The step from 50-75 years saved more money per year (ca 20 000 SEK), than going from 75-100 years (ca 7000SEK), this seem to be because both repair, maintenance and energy cost is increasing exponentially, at the same time as the investment cost is being spread out on more years.

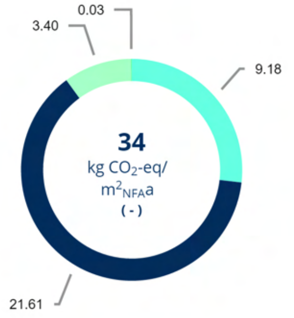
77 000 SEK/YEAR
6400 SEK/MONTH
for 75 years

BUILDING
COST 60% OF
TOTAL LCC



Total cost 5,7 MSEK
77 000 SEK/YEAR
for 75 years

+977€/m²
+0,977 MSEK



-1 kg CO_2
-100 kg/year
-5 ton/50yrs

100 YEARS

100 years is the maximum for CAALA to calculate but it is important to argue for an even longer durability than 100 years if we are to reduce climate change. Architecturally, historical and cultural buildings are appreciated by most and even upholds a high financial value on the market, if it is built with quality materials that age beautifully.

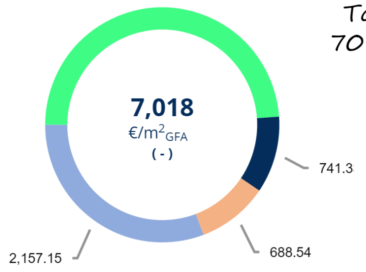
After 100 years, the investment cost is 45% of the total LCC, which means the initial price for the building has been paid twice over 100 years. If construction costs would be lower and energy prices higher, like in other parts of Europe, this would happen even faster, which add importance to quality that can bring down maintenance and energy costs.

A reflection. Maintainance is 570sek/month for 100 years compared to 430sek/month for 50 years. It might seen strange, but it is important to calculate the same amount of years, in other words, adding two 50-year buildings to compare the same "product". That is 430+430=860sek/month compared to one 100-year building with 570sek/month.

PAID THE HOUSE TWICE OVER!

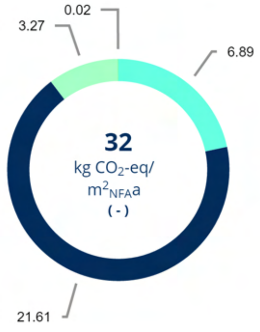
70 000 SEK/YEAR
5800 SEK/MONTH
for 100 years

BUILDING
COST 45% OF
TOTAL LCC



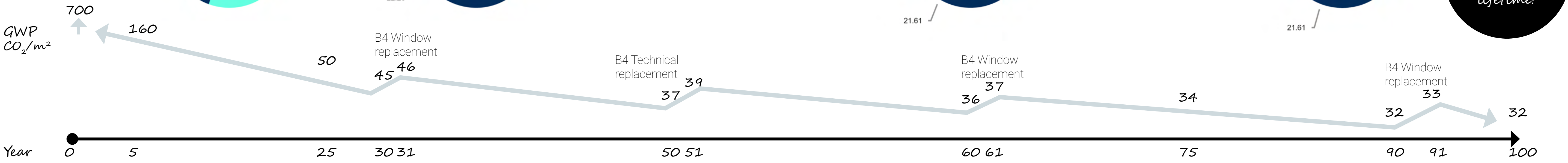
Total cost 7 MSEK
70 000 SEK/YEAR
for 100 years

+ 2226€/m²
+ 2,22 MSEK



-3 kg CO_2
-300 kg/year
-15ton/50yrs

SAVE 36%
CO_2 just by
prolonging the
lifetime!



ORIENTATION OVERVIEW


Case study **Natural landscape**
Photo **Robin Hayes**

ANALYSIS INTRODUCTION
The original site plan shows a "social and equal orientation" with repeated entrances towards the street and not oriented according to sun. They are placed in two circles; the outer circle points entrances inwards, inner circle points outwards. Entrances close to the street is practical, but perhaps there are more spatially interesting,- and energy efficient orientations?

EXPERIMENT DATA
The original house is rotated in the sketch up model to different compass directions, in search for the most optimized orientation.

RESULT & REFLECTION
The experiment shows that pointing the largest window exterior to south-southeast would improve energy demand and CO_2 emissions. The cost was more or less unchanged. The result shows lower energy demand in the use phase, because of reduced need for space heating [due to solar gains and less heat losses]. On the original site plan, eight villas are in this way ineffective and five are effective. A new orientations could eventually lead to higher inital cost in infrastructure, if the entrances are further away and the villas are uniquely oriented, but not necessarily. The new proposal shows a variant without extensive road changes. Note, the experiment is done with the original villa. If the villa was re-designed with larger windows in south and smaller in north, the result would become even better.

EVALUATION MATRIX
5 MWh in 50 years (1kWh/m^2a)
5 ton CO_2 in 50 years (1kg/m^2a)
7000 SEK in 50 years

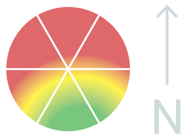
Note that this is the result of one house. Adding all 13 houses, the CO_2 saving would be 65 tons.

ARCHITECTURAL QUALITIES
In the new proposal, eight of the thirteen houses have been rotatated, creating new architectural qualities. The entrance driveway of each house have been kept in the same place for fair comparison, in case the site is not flexible in reality. All entrances are within 15m from main road, all have a driveway for easy access, and all can be seen from the road, same as before.

Not all terraces are now directly towards a private side, but instead, some entrace patios are. The best part is that all terraces, some more than other, are facing the southern sun. Four of them was previously facing the northern cold! A warmer terrace is more often used. Nature views, both outside and inside, are kept, but in some cases, the best views might now be from the bedroom rather than the living room.

There is a new spatial variation between the villas. The orientation is more diverse and unique, which avoids boring repetition of practial entrances facing the street. There are now all types of facades visible for the visitor on the street.

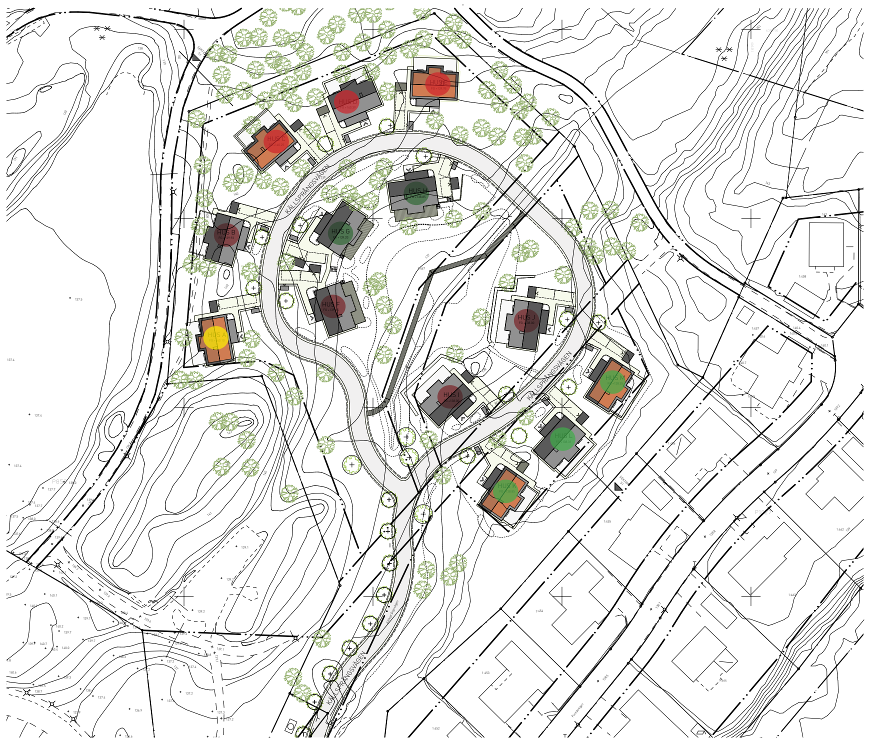
ORIGINAL VS NEW

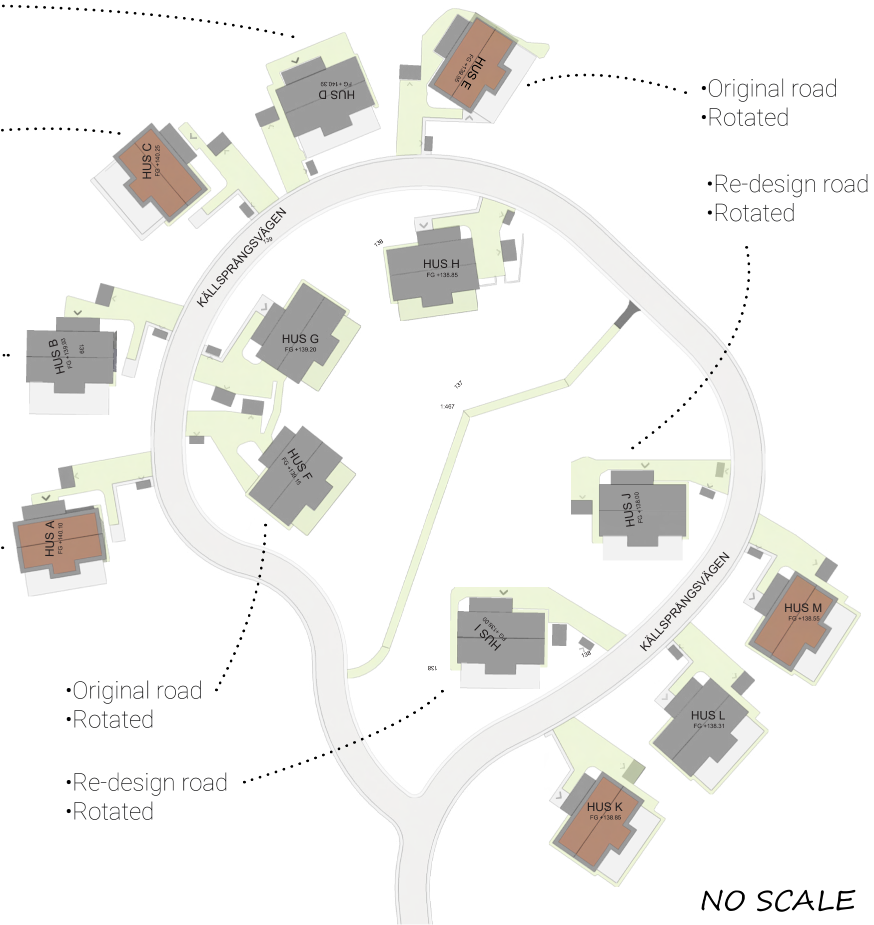


Solar gains

- 🟥 Ineffective
- 🟨 Semi-effective
- 🟩 Effective

Original site drawing by Brunnberg Forshed
1:2000 (A4)





•Original road
•Rotated
•Back entrance

•Original road
•Rotated
•Mirrored
•South-west compromize

•Original road
•Rotated
•Mirrored

•Original road
•Rotated

•Original road
•Rotated

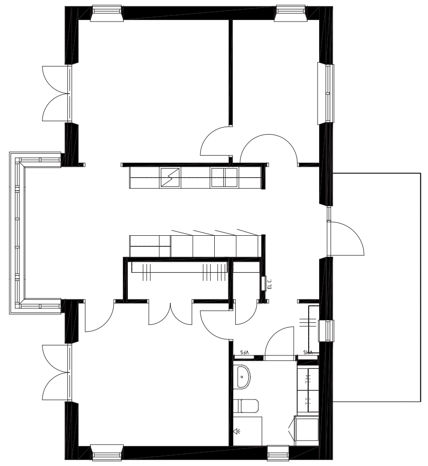
•Re-design road
•Rotated

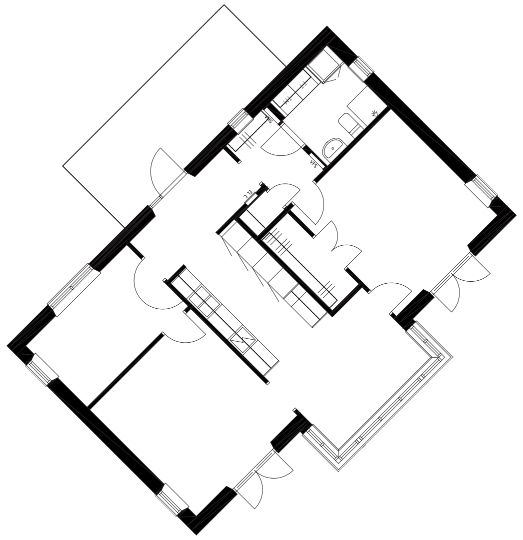
•Original road
•Rotated

•Re-design road
•Rotated

NO SCALE

WEST VS SOUTH-EAST





WEST

Eight out of 13 villas are oriented more to the west and was therefore chosen as the original orientation in the experiment. The direction is measured from the facade with most windows. The idea is to experiment with solar gains.

ARCHITECTURAL QUALITES

The west side of buildings are normally the warmest, because the house have been warmed up during the day and when afternoon sun comes, the heat peaks. This sometimes causes heat problems, but could also be pleasurable to still have the sun on your terrace after work.

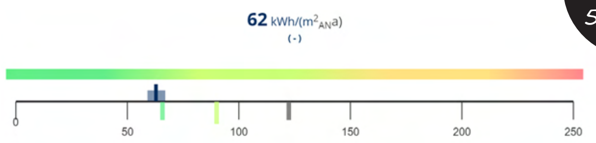
SOUTH-EAST

Five villas are originally oriented to the south/south-east, which seem to be the most effective orientation according to the results below. There is more solar gains and less heat losses during morning and midday, which helps to heat up the house. However, the result showed smaller difference than imagined. The oprientation principle worked, but to optimize it, more window area could be added to the southern facade to increase solar gains further.

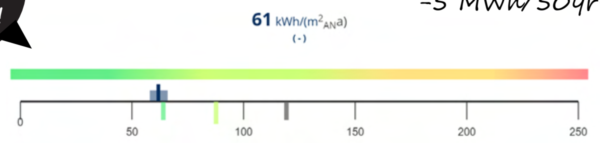
ARCHITECTURAL QUALITES

More than the indoor cliamte, the location of entrances must be looked into, as well as the space between the villas.

ENERGY DEMAND

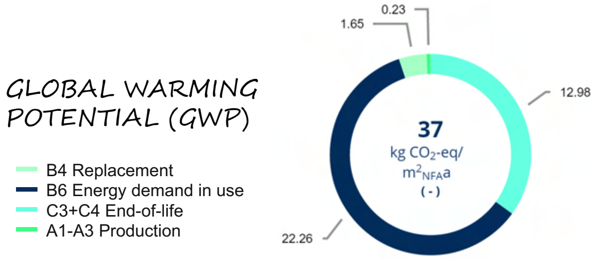


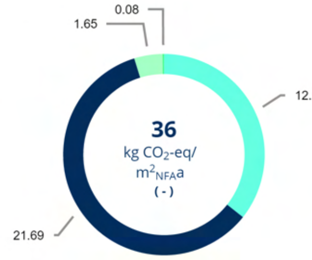
1 kWh becomes 5 MWh!



-1 kWh
-100 kWh/year
-5 MWh/50yrs

GLOBAL WARMING POTENTIAL (GWP)

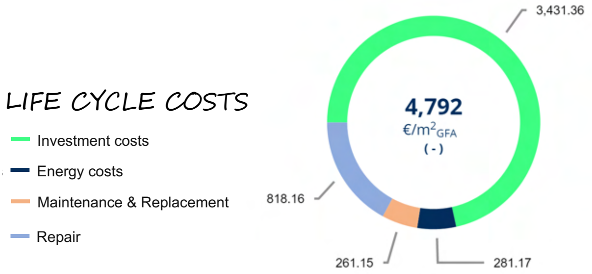


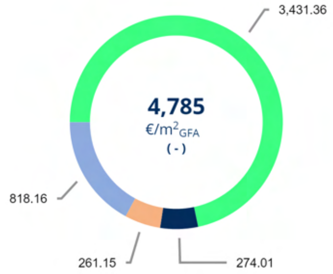


1 kg becomes 5 tons!

-1 kg CO$_2$
100 kg/year
5 ton/50yrs

LIFE CYCLE COSTS

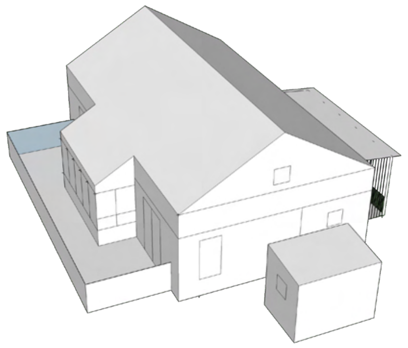


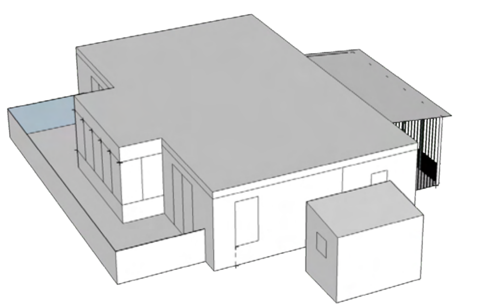


- 7€/m^2

-7 000SEK/50yrs
- Unnoticable
change

PITCHED VS FLAT





INTRODUCTION

The roof is one of the largest building elements and has immense impact on cost and climate footprint. In this case, the roof ratio is high compared to functional floor area. The main issue is the intermediate floor which has high cost compared to its use. Taking it away without changing the pitched roof, would lead to high ceiling height inside and much larger demand for heating. Thus the idea of a flat roof experiment. In the experiment, the roof construction materials are the same. To simplify: 140mm CLT, 270mm cellulose insulation (λ 0,04) and rheinzink roofing. The pitched roof is 115 m2. The intermediate floor is an unheated attic space for storage, accessable only by a foldable stair inside.

ARCHITECTURAL QUALITES

The pitched roof is practical in terms of water protection and makes the villa volume more generous in scale. The roof materials are visible which adds to the spatial experience. Still, the attic space is not functional and its ceiling is too low to ever become an extra floor in the future. That motivates an experiment of reducing materials.

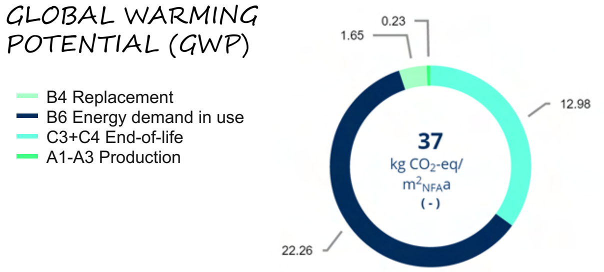
REFLECTIONS

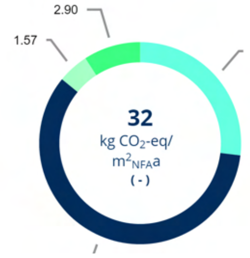
The flat roof displays an alternative of maximized reduction, down to 100m^2 roof area, thus saving 15m^2 (15%). On top of that, a total reduction of the intermediate floor. This saves about 340 000 SEK in investment cost, plus 150 000 in energy and maintainance the next 50 years according to LCC. This allows for new priorities and investments in architectural solutions that would add more value than the pitched roof and attic space. It will also be possible to invest in more climate friendly materials in places like foundation and windows.

ARCHITECTURAL QUALITES

The space inside is unchanged since ceiling height is still 2.6m. The space outside between the houses changes when the scale is lowered. Less roof variation will be experienced, because the roof material is not visible anymore. Regarding materiality, it makes no sense to hide quality materials like zink and brick. A small angle is to consider for the final proposal. The proportions could work. The volume relfects the floor area inside, compared to the original that appears larger than it is.

GLOBAL WARMING POTENTIAL (GWP)

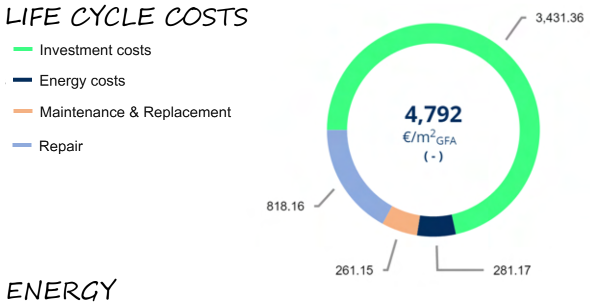


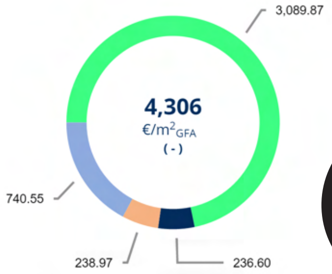


-5 kg CO$_2$
500 kg/year
25 ton/50yrs

Saves 14% CO$_2$!

LIFE CYCLE COSTS

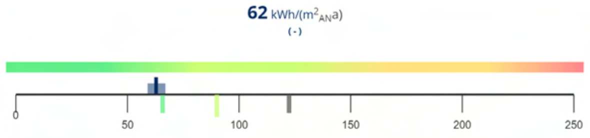


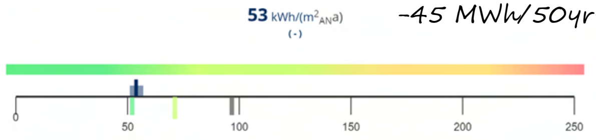


- 486€/m^2
-486 000SEK/50yrs
- 9720 SEK/year
- 810 SEK/month

Saves 500 000 SEK!

ENERGY DEMAND



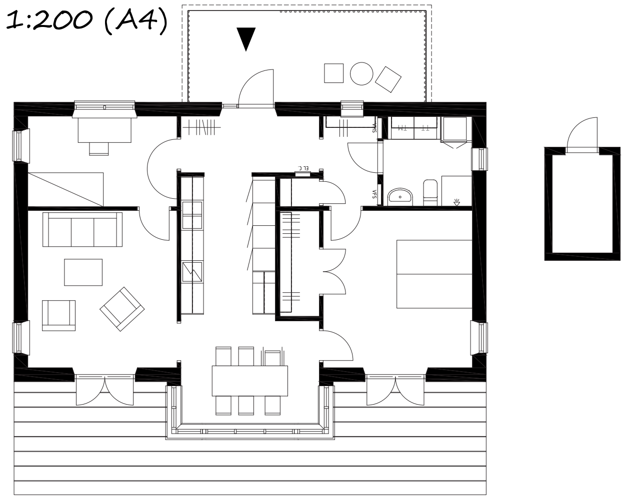


-9 kWh
-900 kWh/year
-45 MWh/50yrs

ORIGINAL PLAN

DRAWING BY BRUNNBERG & FORSHED

1:200 (A4)



ARCHITECTURAL QUALITIES

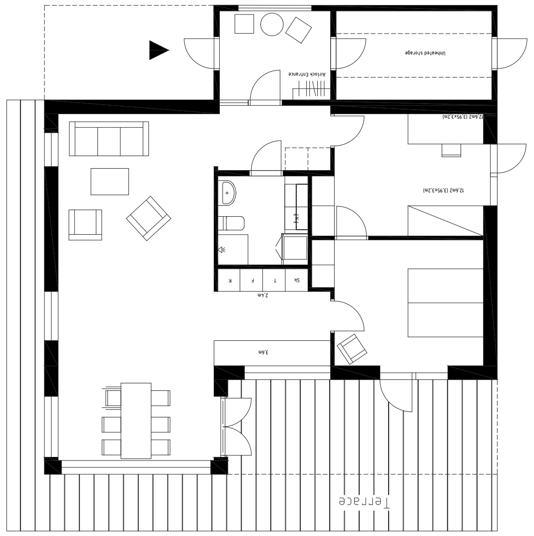
The original plan has three sections with six equal room divisions, perhaps to simplyfy construction modules in transport and assembly. Main ideas seem to be circulation, axiality and general rooms. They have gone to great lengths to accomplish circulation and walkability, to make the space feel larger. You walk accross and around the open kitchen core, but to do so, you must pass private bedrooms and an extra passage by the bathroom has to be added (not very space effective). Having to pass other rooms, which most likely will be bedrooms, will at times disturb privacy. A door between parent and child bedroom is practical, but other than that it is a questionable circulation. Continuing, the kitchen is generous in space and size, but in spite of the transparent window bay, the kitchen core is quite dark. The window bay extension feels squized in and could have been larger, but it gives generous daylight and views in several directions. Regarding windows, there are often two in each room with well-planned axis views. The window height is 700mm, which works for most dining tables, but not so well in other rooms, e.g for work stations, beds or sofas. It makes it harder to furnish practically.

The two larger rooms of 16m2 are symmetric and general but does not fully work. The sizes are not optimized for its function. It is true that they are general and functions can be switched over time, but at what cost? They are generally too small for a living room and unneccessarily large for a bedroom. Also, one of them has a walk in closet, making it more suitable for a bedroom and therefore less general. To make it general the storage should be split in two. There are few walls to furnish with a couch or TV without blocking doors or windows. The functionality of a room is not just about the area, but the room proportions. One could argue that the dining room of 10m2 has to be included in the living room area, but it is a separate room, which of course, some might appreciate. However, it is not flexible to use in other ways than dining, nor adaptable enough to add a dividing wall or such. The function is quite fixed. Having specific rooms compared to larger general rooms, both have their benefits, but in a small villa like this, at least one large and generous room should be considered, as more time is spent in the living room than the bedroom, but also to increase adaptability over time. This is why the two equal rooms can be questioned.

The smaller room of 9m2 and it has no built in storage, which is unpractical. The bed can more or less only be in one good place. The extra entrance patio feels randomly placed and does not fit the otherwise strict symmetry. There is no roof over the terrace, due to aesthetic preferences of some, but it makes the terrace less useful. The average ceiling height of 2.6m is above average. The materiality is of high quality, with visible painted CLT walls, floor clinker, kitchen bench and window sill made of stone and so on.

NEW PLAN

DRAWING BY AUTHOR



ARCHITECTURAL QUALITIES

Unlimited plan variations can be made within the 84m2 limitation. The new design ressembles the old, trying to keep and improve the original ideas of circulation, views and general rooms. The circulation is around a core of bathroom, storage and kitchen. As said by Femenias: ***"the ultimate flexible floor plan is one having a core of kitchen and bathroom, and on top of that, lightweight walls that are easy to move"*** (2019, p.147).

Bathroom has gotten a skylight for natural daylight. The kitchen is similar size as the original (1m less, still above recommended size), with more daylight and views to the terrace and nature while cooking. There are now two general rooms of 13m2 with possibility for double beds. The open living room has generously 38m2 and a ceiling height from 2.6-3.5m, with more possibilities to furnish. The window sills are lifted to 900mm to simplify furnishing further.

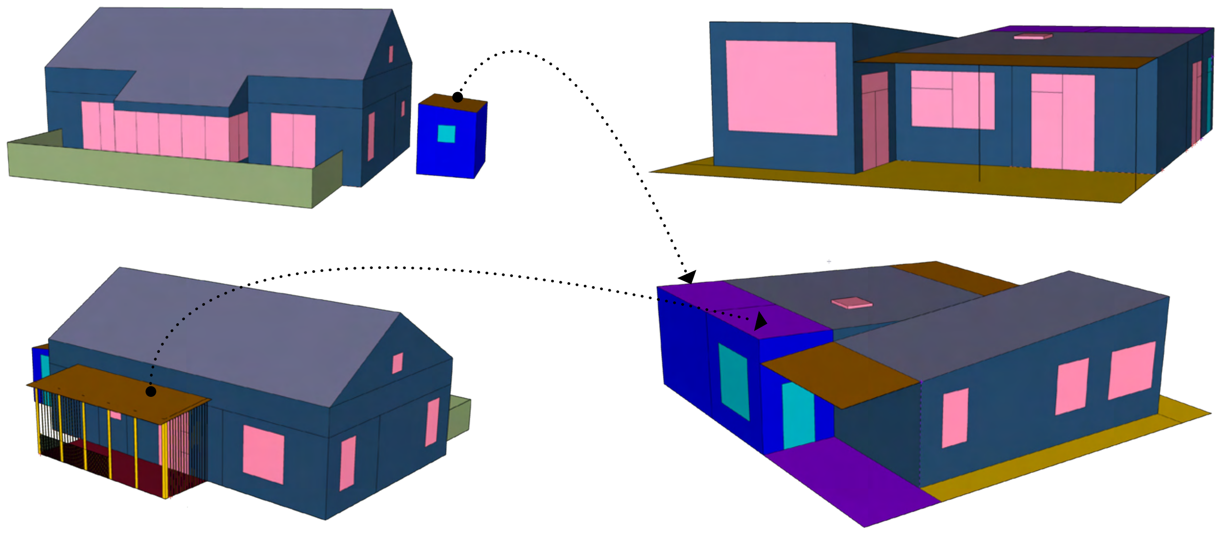
There are larger windows to the south for solar gains, while reducing windows to the north to avoid heat loss. The large window in the living room frames the outside view and is designed to have an external vertical screen shading. The windows toward the terrace extends down to the floor, to create connection with the outside, and thus make the space feel more generous. They are shaded by the new extended roof.

Having to reduce materials to optimize cost and climate footprint, called for a new roof solution. The new shape gets quite new proportions and spaces. Instead of a classic barn-shape villa, the two shifted volumes with single roof angles appears more "functionalistic" and perhaps minimalistic with fewer but larger windows and higher ceiling. The two volumes reflects the program inside. The roof angles are 3/5 degrees, creating variation in spatial experience. The roof material can be seen from both long sides. The shifted volumes create natural spaces for entrances, and by extending the lower part of the roofs, the entrances will receive rain protection and sun shading and become more defined, safe and welcoming.

The new plan might seem larger, which is desired, but the heated space is the same. The old external storage is integrated into the villa, to save facadematerial and help insulate the exterior wall. It is doubled in volume (important since the attic storage is removed). The cold storage can be used for food, clothes, bikes etc. The entrance patio becomes a closed airlock; a space that keeps heated air inside when entering the house. Being 9m^2, the space can be used as a hangout space as well as a dirty zone before entering the indoor hallway. The terrace is now on both south and west side and is doubled in size, which makes it more useful throughout the day and different weathers. The terrace is semi-private and an important transition between the public and private.

ORIGINAL VOLUME

NEW VOLUME



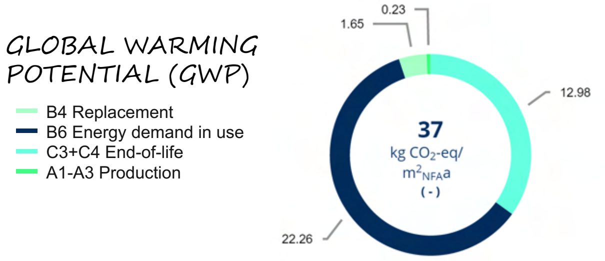
EXPERIMENT DATA

Total climate shell (incl patio & storage),	440m^2
Floor area, heated space,	84m^2
Ceiling height	2.6m
Attic space, unheated, pitched ceiling,	100m^2
Windows to heated space,	30m^2
Storage separated outside (add in plan),	6m^2
Entrance patio, open and unheated	12m^2
Terrace on one side,	30m^2
Roof over heated space, pitched type,	115m^2
Roof over unheated space	20m^2

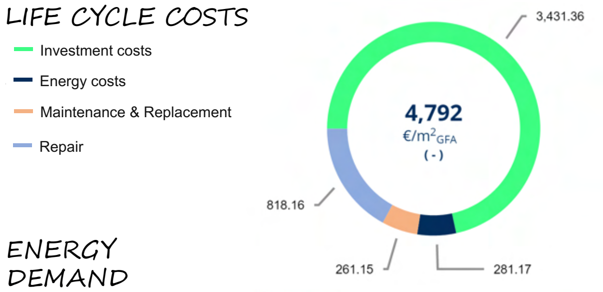
INTRODUCTION

The plan and volume are connected and must both be redesigned. Note that floor area is the same, but other areas and spaces have been extended or reduced. Further, for fair comparison, <u>all material types are unchanged</u>. E.g same rheinzink roof and concrete foundation. The idea is to improve space and shape while still lowering cost and climate footprint.

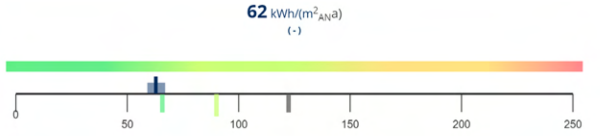
GLOBAL WARMING POTENTIAL (GWP)



LIFE CYCLE COSTS



ENERGY DEMAND

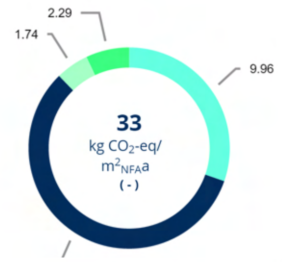


EXPERIMENT DATA

Total climate shell (ex. roof extensions) 451m^2	**+ 11m^2**
Floor area, heated space, 84m^2	**+- 0**
Ceiling height 2.6m-3,5m.	**+ 0-0,9m**
~~Attic space, unheated, 100m2 pitched ceiling~~	
Windows to heated space, 34m^2	**+ 4m^2**
Storage integrated, 10m^2	**+ 4m^2**
Entrance, closed airlock with windows, 9m^2	**NEW**
Terrace on two sides, 62m^2	**+ 32m^2**
Roof over heated space, shed type, 100m^2	**- 15m^2**
Roof over unheated space 50m^2	**+ 30m^2**

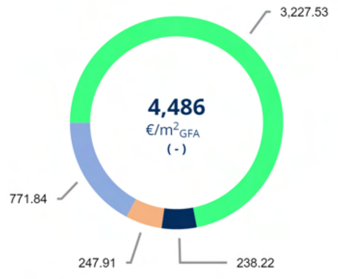
REFLECTIONS

The higher ceiling increased energy demand by 6kWh compared to a flat roof; quite a large impact while "only" gaining 20cm ceiling height. But, having reduced the intermediate floor, the total demand is still 4kWh lower than the original. The new volume saves 300 000 SEK in investment cost, 40 000 SEK in energy, 15 000 SEK in maintainance and 50 000 in repair over 50 years time.



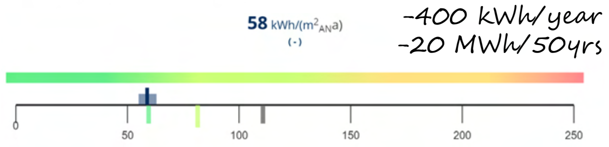
-4 kg CO_2
400 kg/year
20 ton/50yrs

Same materials, new shape!



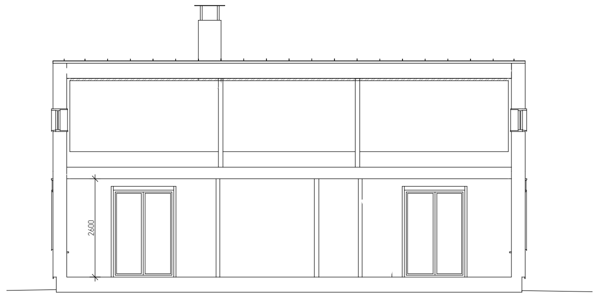
- 306€/m^2

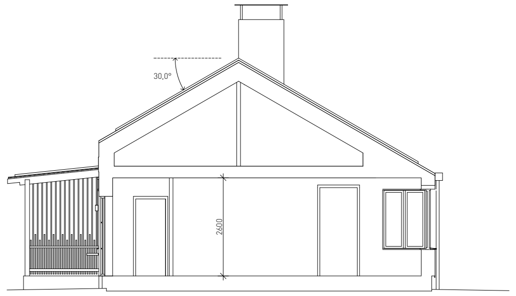
-306 000SEK/50yrs
- 6120 SEK/year
- 510 SEK/month



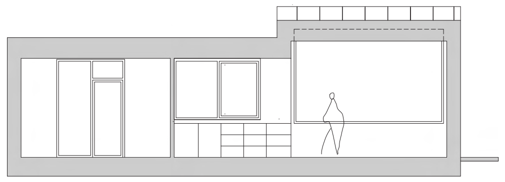
-4 kWh
-400 kWh/year
-20 MWh/50yrs

ORIGINAL SECTION
BY BRUNNBERG & FORSHED

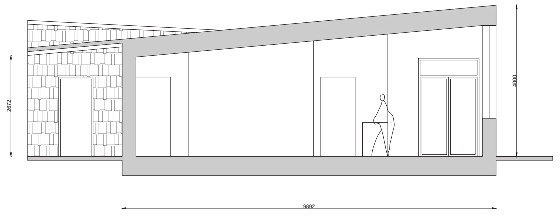


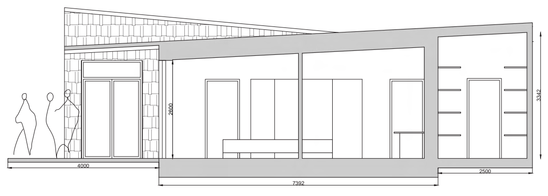


NEW SECTIONS
BY AUTHOR



SECTION B-B





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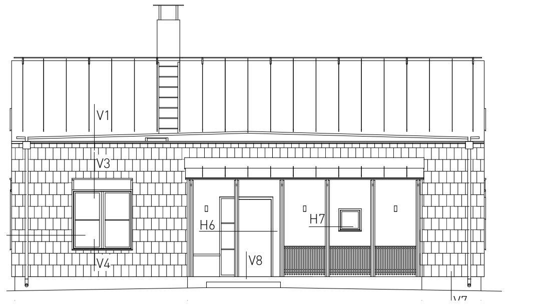
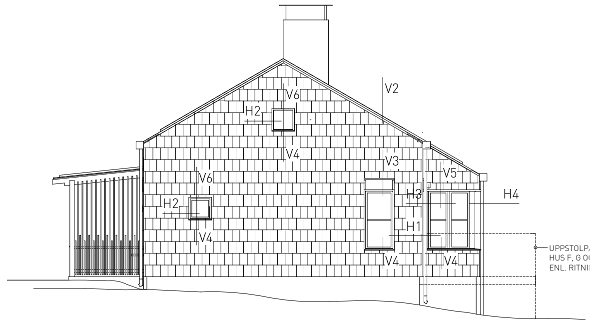
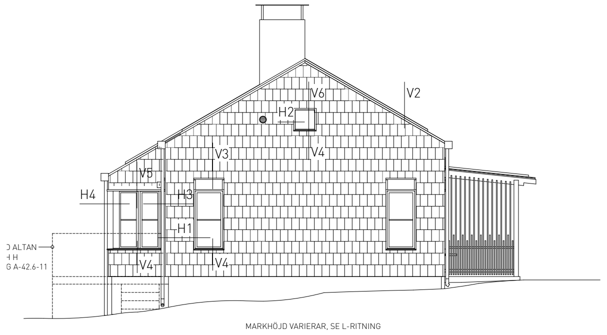
ORIGINAL FACADES
BY BRUNNBERG & FORSHED

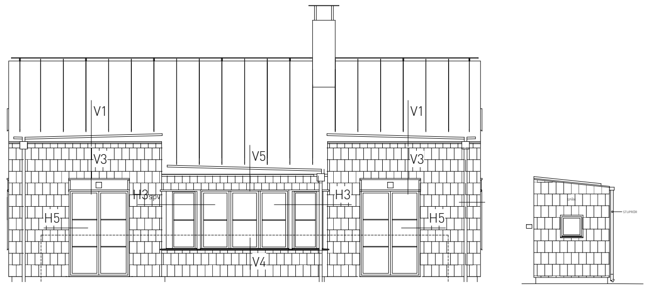




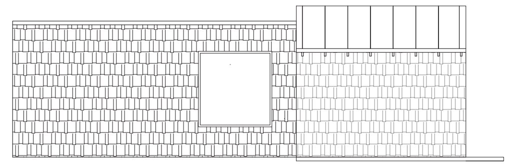
GAVELFASAD



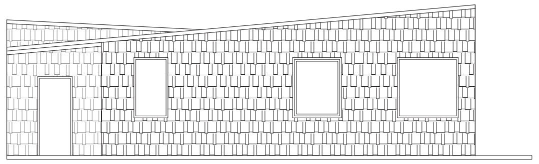
GAVELFASAD



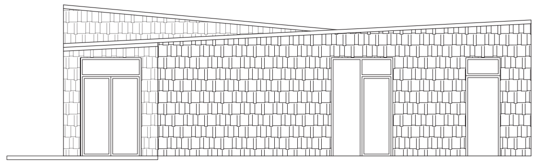
NEW FACADES
BY AUTHOR



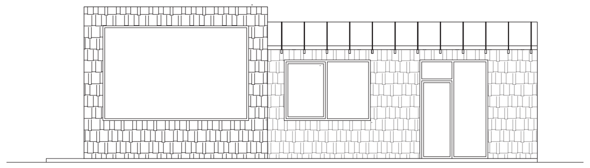
north



west



east



South

1:200 (A4)

CONCRETE FOUNDATION

Case study Entrance patio
Photo Author

INTRODUCTION TO CONCRETE

The orignal villa has a swedish standard foundation; a concrete slab on the ground. It is made up of 150mm concrete slab, a surrounding concrete plinth in various thicknesses, 200 EPS,- and 100 XPS insulation. These kind of foundations happen by routine and is rarely questioned, which is why it is intentionally challenged in this thesis. Concrete is loadbearing, cheap and quite easy to make. Therfore very popular. It is not flexible to change or easy to reuse, and most importantly, it is a main cause for high CO_2 emissions in buildings. Finding alternatives to concrete is therefore essential for the goal to lower climate footprint.

To make up for the uneven terrain on site, some foundations have more insulation and larger concrete plinths. That means increased CO_2. There are extra reinforcements around the edges and in the middle, which increases the amount of armory [and CO_2]. Around the plinth, there is only one layer of 100 XPS-insulation. Less insulation means higher thermal bridges [heat loss]. The foundation of entrance patios and storage are also made of concrete, but does not include heat losses, since it is unheated space.

Both cost and CO_2 levels of concrete can be very different on the market. It depends on quality, character, load-bearing capacity and even weather and geography - and where the data is collected from! Options of greener concrete to reduce CO_2 exist, but it normally has longer drying times. In some cases, to hurry up the drying process, workers might add more plastic on top, or even cement and armory within, to keep it from cracking, and they thereby counteract the lower emissions (N. Holmquist, personal communication, 2021 April 12).

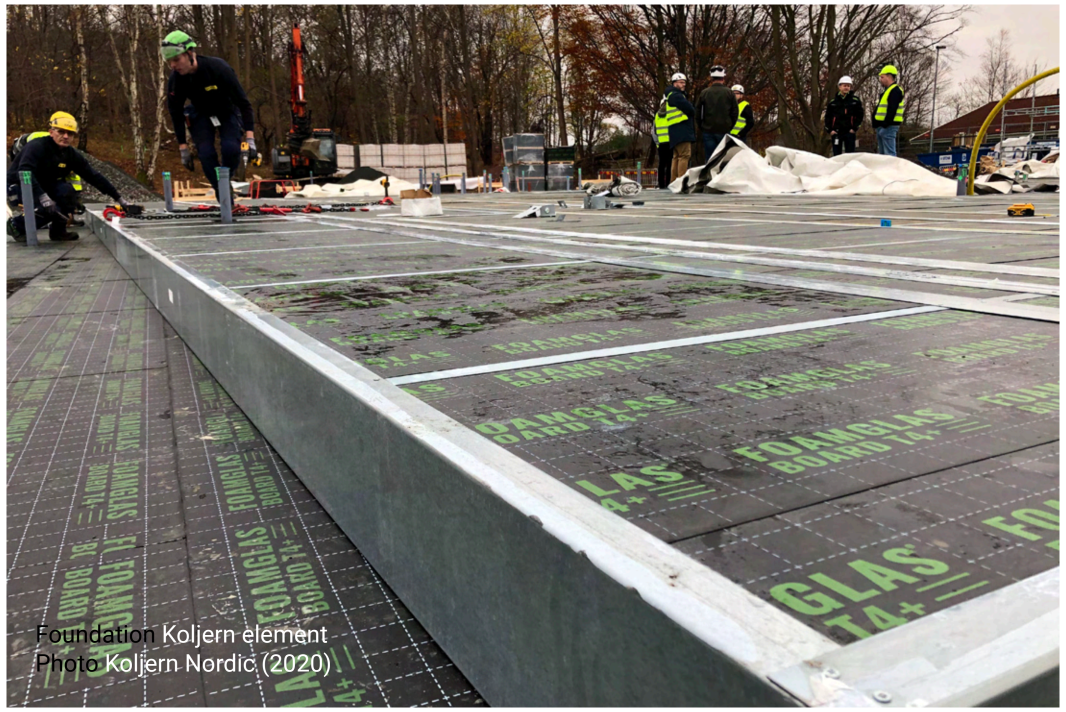
EXPERIMENT DATA

The concrete used in the model is from Ökobaudat (2016) and is called "Beton der Druckfestigkeitsklasse C 25/30" with 2% reinforced iron. 1m^3 concrete has 211 GWP during the production phase (A1-A3). EPS insulation has 75 GWP/m^3 . Both high CO_2 values.

The LCA in CAALA reads the load-bearing structure [e.g. foundation] as a permanent element that will never be replaced, because replacing the foundation likely means the end of the building. Concrete is durable but CO_2 costly. The plastic foam insulation (EPS and XPS) on the other hand, will get worse in insulation performance over time, yet still never be changed. According to Choi et. al., (2017), the EPS will become 40% worse after 13 years, which is very significant. In another study from Germany about water in EPS (Pfeifer 2013), the author confirms that EPS can absorb up to 10 times its normal water levels, from about 1% up to 10%. Similar values was seen for XPS. Water channels heat, which effects insulation performance. These aspects of reality are seldom talked about and rarely included in LCAs. The building sector trusts the material because it is standard and videly used. A lifecycle experiment ressembling this reality is therefore done in this thesis.

The price of concrete foundations vary alot on the market. In this case study, the price estimation is 930SEK/m^2, which seem rather cheap. Insulation is normally about 30-40% of the price (Wikells Sectionsdata, 2021). Interesting note is that plastic insulation such as EPS was doubled in price from april 2021, due to lack of the raw material styropor. From that point of view, the experiment would look different even from next year (C. Lindström, personal communication, 2021 Feb 18). Prices go up and down.

FOAMGLAS FOUNDATION



Foundation Koljern element
Photo Koljern Nordic (2020)

INTRODUCTION TO KOLJERN

Koljern ® is a prefabricated building element made by FOAMGLAS ®. A koljern ® element normally consists of FOAMGLAS ® T3+ 208mm and 1,5mm galvanized metal frames to keep it together. This relatively new product did not exist in the database, however FOAMGLAS T3+ did and was chosen due to similar properties and same producer. The CO_2 data is 1,26 GWP/kg in production phase, A1-A3 (Ökobaudat 2016), and U-value 0.036. Concrete and Koljern values are compared in the experiment on the next page. The cost is given by producers of Koljern; about 2000-2500 SEK/m2 (N.Holmquist, personal communication, 4 April 2021). Moreover, foamglas consists of 60% recycled glass (mostly from cars), which could easily be recycled or reused again. Compared to concrete, Koljern also has no drying time and comes as prefabricated elements, but that aspect is also difficult to account for in the model.

Koljern-elements are both load-bearing and insulating, making total thickness of the floor only half that of concrete. That means saving floor height, or in this case, getting more ceiling height. In larger buildings that would be even more valuable, as gaining space and perhaps even an extra floor would yield higher income. It also means that thermal bridges in the area where wall meets ground will be less than concrete, because the whole thickness of the Koljern element is insulation, compared to the 50-100mm XPS around the concrete. Foamglas is further said to keep its insulation abilities better than EPS over time, as plastic will react to moist and glass will not. Therefore, in the model comparison the thermal bridge value was manually improved for Koljern, from 0,05 to 0,035 W/m2K in order to simulate a better insulation.

Koljern can be used in the whole climate shell, such as foundation, intermediate floor, wall and roof, but the largest savings can be made in foundation and sometimes roof, especially flat roofs with terrace or grass, because of load-bearing and water proof properties. In this comparison, Koljern is only investigated as a foundation.

The result show that foamglass had better values in both energy demand and CO2 emissions, but was more expensive initially, but will slightly even out during the buildings lifetime, which is discussed later. This off course depends largely on the price of concrete foundation for each project and location, how prices of EPS plastic insulation will develop in the future and many more aspects.

Koljern is for example used in the fossile-free preschool Hoppet in Gothenburg (Hall et el. 2019) which helped reduce 50% of CO2 in their foundation compared to environmental concrete (Koljern, 2021).

EVALUATION MATRIX

- 11,5 MWh in 50 years (2,3 kWh/m^{2}a)
- 26 ton CO_2 in 50 years (5,2kg/m^{2}a)
+114 000 SEK in 50 years (2280SEK/a)

CONCRETE VS FOAMGLAS
PART 1

1 CONCRETE VERSION 1

INTRODUCTION

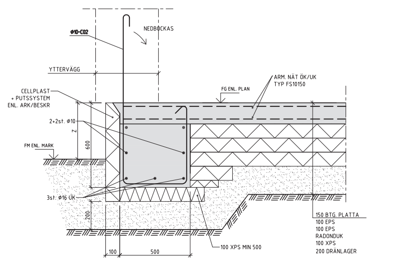
There are *two* comparisons between concrete and foamglas foundations, to prove a point about the importance of correct data, for concrete in this case. Both concrete versions exist on the original building. The amount of concrete and insulation depends on ground levels and how much has to be filled out. There is therefore not only one original drawing in reality, but several.

The first comparison does not include the concrete plinth and its insulation, but the second version does. The comparison shows the difference between including the plinth or not. The interesting thing is that *the plinth contains as much concrete as the entire slab*, and contains extra armory. Thus the concrete and armory is doubled! The insulation increased as well. On top of that, the second version calculates a worse u-value (0,06) for the EPS & XPS insulation, due to their likely loss of insulation performance over time. The foamglas foundation is same in both comparisons. The second comparison is the more realistic one, yet the first comparison is more commonly seen. See discussion for further clarifications.

150 CONCRETE/ 2% ARMORY
300 INSULATION (Λ 0,04)

A1-A3 (PRODUCTION)= 125 kg co^2/m^2
C3+C4 (END OF LIFE)= 40 kg co^2/m^2

(930 SEK/M2)

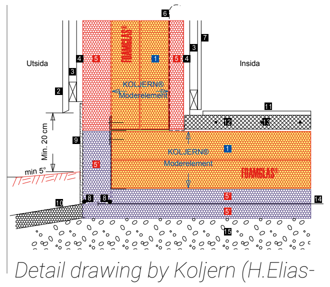


Drawing by Brunnberg Forshed

300 FOAMGLAS T3+ (Λ 0,04)
=KOLJERN ELEMENT

A1-A3= 59 kg co^2/m^2
C3+C4= 2 kg co^2/m^2

(2000 SEK/M2)

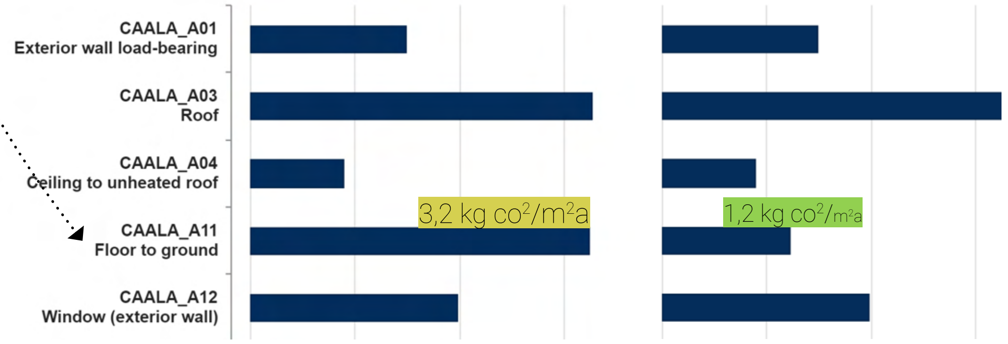


Detail drawing by Koljern (H.Eliasson, personal communication, 11 March, 2021)

Energy parameters					
Primary energy demand	[kWh / (m^2_{AN} *a)]	62.45	60.34 -3.38%	- 2,1 kWh	-10,5 MWh
Life cycle assessment					
Global warming potential (GWP)	[kg CO_2-Äqv / (m^2_{NGF}*a)]	37.12	33.97 -8.49%	- 3,2 kWh	-16 ton
Life cycle costs					
Total life cycle costs	[€ / (m^2_{BGF})]	4791.84	4906.54 +2.39%	+ 2280 SEK	+114 000 SEK

Original values
Savings SEK/year
Savings 50 year
Savings m2/year

GWP IN ONLY THE FOUNDATION ELEMENT



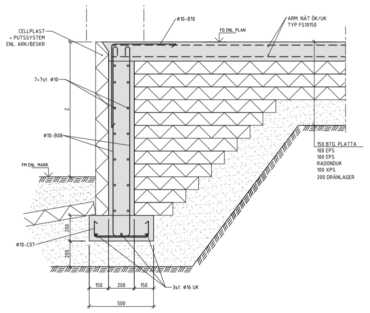
CONCRETE VS FOAMGLAS
PART 2

2 CONCRETE VERSION 2

300 CONCRETE/ 4% ARMORY
400 INSULATION (Λ 0,06)

A1-A3 (PRODUCTION) = 210 kg co^2/m^2
C3+C4 (END OF LIFE) = 50 kg co^2/m^2

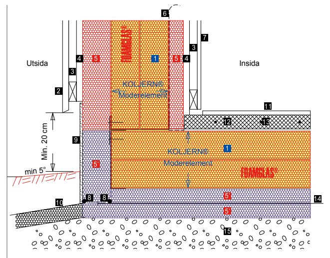
(930 SEK/M2)



300 FOAMGLAS T3+ (Λ 0,04)
=KOLJERN ELEMENT

A1-A3= 59 kg co^2/m^2
C3+C4= 2 kg co^2/m^2

(2000 SEK/M2)

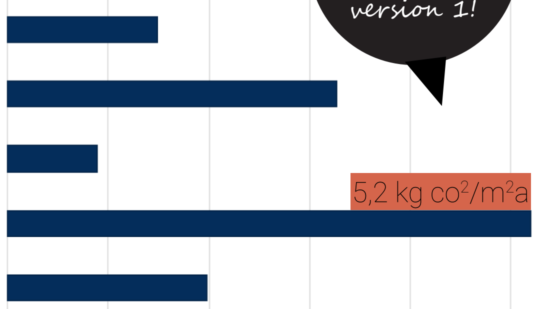


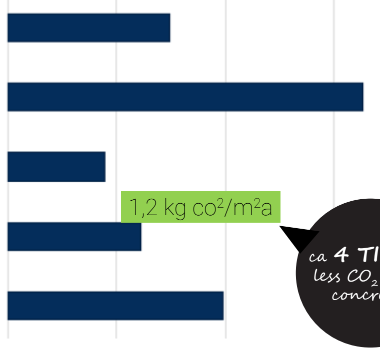
62.68	+0,37%		60.34 -3.73%	- 2,3 kWh	-11,5 MWh
39.15	+5,5%	+10 ton	33.97 -13.23%	- 5,2 kWh	-26 ton
4792.84	+-0		4906.54 +2.37%	+ 2280 SEK	+114 000 SEK

WINNER

This version displays reality best and has largest savings of energy and CO2. The extra cost can be paid by e.g. removing the intermediate floor.

60% worse than concrete version 1!





ca 4 TIMES less CO_2 than concrete!

SUMMARY & DISCUSSION

CONCRETE VS KOLJERN

CORRECT DATA

It is helpful that CAALA software has a broader approach to avoid getting stuck in details and maintaining an effective workflow, as details are not always known in project beginnings. Nevertheless, it is of importance to realize that in professional settings it is all about the detailed data and correct detailed drawings. Using generalizations are quicker but offers misleading results, both for cost and climate. In reality, according to N.Holmquist (personal communication, 4 April 2021), discussions can be about bizarre things like which type of glue to use in a certain scenario, as a detail like that can have an impact on both cost and climate in the end.

CLEAN ENERGY

The cleaner and more renewable energy used in a building, the less some materials matter. At least in theory. If the energy is clean, the high energy demand will not matter as much. What is the point of investing in insulation to lower energy demand, if the energy has almost no cost or climate impact? However, if clean, it still has to be available and we are still increasing our energy consumption.

EMBODIED ENERGY

Morover, if the energy demand and CO2 intensity/kWh is low during the use phase, the embodied energy in materials would become a larger percentage of the total GWP. In this way, one could argue that production of certain elements, such as loadbearing foundation, then holds a larger impact on total GWP. Anyhow, finding substitutes to concrete, steel, gypsum, mineral wool, and other Swedish standards are crucial for sustainable development of the building industry.

NORMAL CONCRETE FOUNDATIONS

Normal villa foundations in concrete have a total of ca 200 GWP/m2 in production phase (A1-A3) in Sweden (N.Holmquist, personal communication, 12 April 2021). This number is calculated by a multiplication of the material mass and their GWP-value. For example, in CAALA database called Ökobaudat, concrete has 211 kgCO2/m3 material, armory/concrete reinforcement has 0,75kg/kg material, steel 2,5kg/kg and EPS insulation 75kg/m3. Note that some are measured in kg and some in m3, so the manual calculation for them is different. This is where the detailed data becomes important, as armory has high CO2 impact, the diameter of the metal is crucial to know and can often be found in the construction drawings. 8mm instead of 6mm diameter would actually double the mass and the GWP result for that material. On top of that, the builders do not always follow the original drawings. For example, if builders are in a hurry during construction and want the concrete slab to dry faster, it is possible to increase the cement amount. However, when doing that, they must also increase the armory, to compensate for the risk of cracks in the concrete. This reality off adding more cement and armory, would drastically increase the CO2 emissions.

THE PLINTH

Another important factor when making the experiment in CAALA is to not forget the loadbearing concrete plinth around the edges. In this case study, they look different due to the terrain. Sometimes more concrete and insulation is needed to fill out uneven ground. A plinth of 500mmx500mm buried below ground would, perhaps surprisingly, be the same volume amount as the whole flat concrete slab (100m2 of 150mm thick concrete). Therefore two experiments on concrete were done, one with 150mm of concrete and another with 300mm. On top of that, there is thicker armory in the loadbearing plinth than in the slab, which must be considered. That is why extra armory was added in the experiment.

THE COMPARISON

Moreover, there is also XPS insulation to be added on the sides of the foundation, not just below it. The original CAALA model used, this was not taken into account to prove a point but is shown through one of the foundation experiments. 150mm concrete, 300mm insulation and 2% armory was used originally, giving a GWP of 120 kg CO2/m2 (only A1-A3 Production). By adding the concrete socket and more armory as discussed, the material layers in CAALA calculates +150mm concrete, +100mm insulation + 2% armory, and will then arrive closer to reality, at 210 kg CO2/m2 (A1-A3 Production). Comparing this result to a Koljern foundation (Foamglas T3+) of 59 kg CO2/m2, one might save 50% of CO2 on the "kind" experiment, and 70% on the one closer to reality (still A1-A3). If adding the "end-of-life" (C3+C4) phase in the lifecycle, Koljern comes out as a winner even more, as the CO2 cost of recycling Koljern is close to 0 GWP, compared to the concrete foundation with an additional 50 GWP. (Koljern-elements might even be reused as it is, even efter 50 years, and thus has no cost at all the second time around). Koljern has then 78% less CO2 than concrete (59kg/260kg=0,22-1=0,78, for production and end-of-life phase). If this result is seen in light of the whole building and its 50 year lifespan, the results show that Koljern will reduce the total CO2 by 12 %. This is because total GWP is divided in two main parts; embodied energy in materials (40% of total GWP) and energy use (60% of total GWP). Since the concrete foundation is "only" 30% of the total material GWP, the impact of changing from concrete to Koljern will display a smaller percentage of the total GWP.

GROUND INSULATION OVER TIME

Now to the use phase (B4 Replacement + B6 Energy demand). The next important discussion is how the cell plastic insulation (EPS and XPS) will keep its thermal and insulating capabilities over time, which affects both energy use during the building's lifetime, as well as the possibility to reuse the material in the end-of-life. The lambda value often used for foam insulations is 0,036- 0,04 (W/mK). The same goes for Koljern. Research shows (Pfeifer 2013) that EPS and similar foam materials will absorb moist from the ground over time. Moisture contributes to lower performance in all foam materials, resulting in both deformations and less insulation capabilities. Another study of EPS in a window in south Korea shows a loss of performance standards after about 80–150 days from its production date and after about 5000 days (13 years), its thermal resistance decreased by 25.7% to 42.7% in comparison with the initial thermal resistance (Choi et. al. 2017). One could also argue that a foundation has more moist than a window, since there is no air to dry it out.

That said, more research must be done in the field, both in lab and in reality, as to how much the foam is affected, but the point is that EPS becomes worse over time, while Koljern will not (partly since it is completely inorganic). Therefore, to make a more fair comparison in CAALA, the average insulation of EPS could be changed from lambda "0.04 to 0.07". By that, Koljern will lower the energy demand, and therefore both CO2 emissions and economic costs. Since the energy price in Sweden is so low, the result in lifecycle cost is smaller than it would be in other parts of Europe. Still, it is possible to argue that the higher investment cost of koljern compared to concrete, will even out as time goes by. Just how much, will depend on how long the building will last and the initial difference in building cost.

THERMAL BRIDGES

The koljern foundation, being both load bearing and insulating, reduces thermal bridges where the ground meets the exterior wall. A concrete foundation only has one 50mm layer of XPS around the load bearing socket, while Koljern has 300mm insulation everywhere. This is displayed in the original CAALA model by lowering the thermal bridges from "enhanced 0,05 W/m2K" to "detailed "0,035 W/m2K". This change affects the total u-value of the house, from 0.22 W/(m2K) to 0.21 W/(m2K).

MANAGEMENT PERSPECTIVES

A main issue is that individuals will not think longterm perspective on their house like a building manager who will own and rent it out over a long time. An individual will think "I will not live here for so long that I will have to think about the end-of-life cost". The initial prices tag is more important to them. While the building manager wants as low maintenance and durability as possible.

OTHER COST ASPECTS

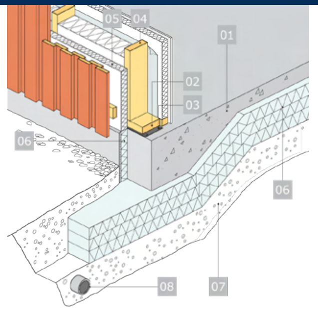
Risk can also be a cost. Regarding a foundation, EPS is not fire proof and holds a risk of burning. If the misfortune against most odds happens, it is fatal.

The drying time of concrete could be a cost, but not necessarily. If the waiting is planned, then it doesn't really cost the builders anything extra.

Speculating about the future, there might also be an economic cost or environmental taxations on for example CO2 emissions. In that case, LCA and LCC will have an even closer relation, where materials like Koljern, in spite of its higher investment price, will be cheaper than materials with high CO2. It is possible to add this reality to CAALA, but it is not done in this case study since it doesn't exist in Sweden today.

CONCRETE SLAB

Figure 10. Platta på mark, principlösning (Träguiden 2014).

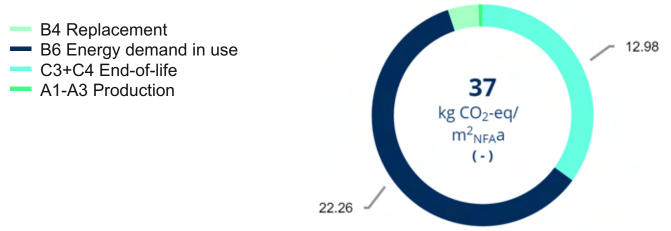


INTRODUCTION

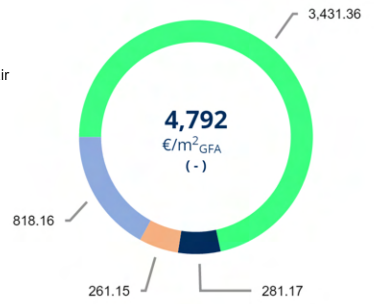
This comparison was made because a slab foundation on the ground (930SEK/m2) might not be the best solution when the site has large amount of wetlands and level differences. The punctual foundation could be a good alternative.

In the experiment it is needed to say that the comparison of material is not complete in itself. The construction changes and so does the ground work. The foundation price in the model only calculates material price and so the price for ground work must be reduced from the land price. For example, a punctual foundation does not need digging for drainage, gravel to even the ground, removing of rocks, nor transport of the digged up soil. 50 000 SEK was reduced from the land price in both punctual scenarios as a symbolic estimation. The concrete pillars diameter is 30cm, 1m high and 10pc. Another interesting experiment would be to compare with the same material thickness, or same u-values. Now it is three more distinct solutions.

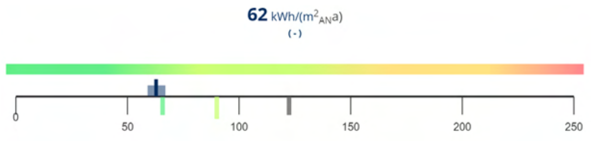
GLOBAL WARMING POTENTIAL (GWP)



LIFE CYCLE COSTS

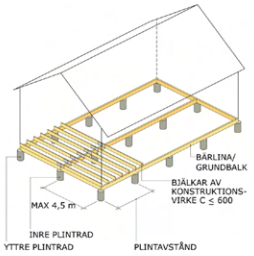


PRIMARY ENERGY DEMAND



PUNCTUAL WOOD

Figure 11. Öppen plintgrund (Träguiden 2020).

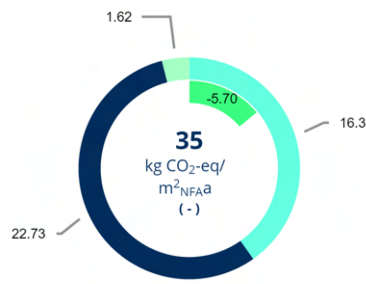


DATA

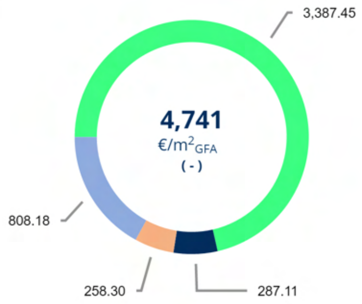
20mm stone clinker
15mm OSB
440 beams 600cc/370 cellulose insulation
10mm fibercementboard
Total 460mm thick
U-value 0,077
1000 SEK/m2

REFLECTIONS

More insulation than 370 did not help the punctual foundation. It was the balance point between material and energy. This is the cheapest solution and is not as thick as the CLT version. The energy is 1kWh worse, because CLT is more airtight and contributes to a better u-value. A positive side to punctual foundations is the ability to check the foundation and make repairs and improvements. That is not possible with a slab on ground. The CLT seem to have the same GWP, but different divisions. The CLT has less CO2 in production, but more in waste disposal.



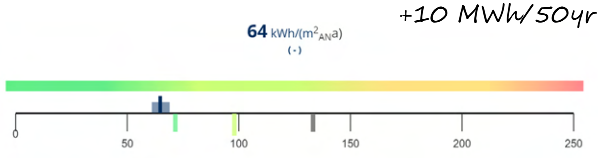
-2 kg CO_2
200 kg/year
10 ton/50yrs



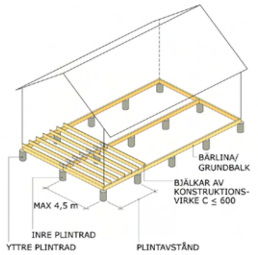
- 51€/m²
- 1020 SEK/year

(-51 000 SEK
in 50 years)

+2 kWh
+200 kWh/year
+10 MWh/50yrs



PUNCTUAL CLT



+

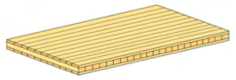


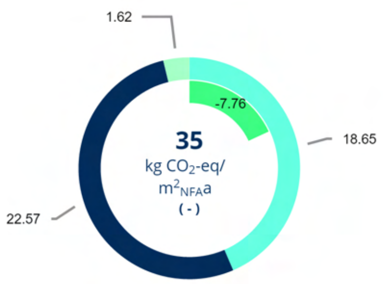
Figure 12. Plattbjälklag av KL-trä (Träguiden 2020)

DATA

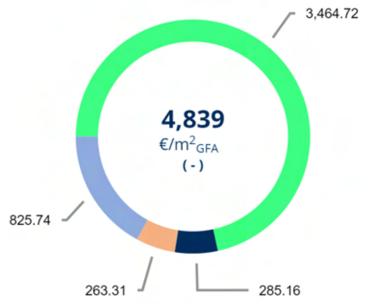
20mm stone clinker
20mm wooden floor
440 beams 600cc/370 cellulose insulation
140mm CLT
Total 600mm thick
U-value 0,065
1820 SEK/m2

REFLECTIONS

The concrete slab is cheaper than CLT and thus the punctual foundation becomes more expensive in this case, in spite of the small ground work reduction. The energy demand is higher, most likely because the foundation is now towards the open air instead of the ground. In reality, if the experiement were to include that the EPS insulation in the concrete foundation becomes worse over time and is never changed, then the result would look in favor for the punctual CLT. The CO_2 is lower, since it is wood instead of concrete, but not much lower, since energy demand is higher.



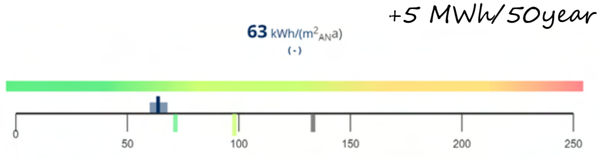
-2 kg CO_2
200 kg/year
10 ton/50yrs



+ 47€/m²
+ 940 SEK/year

(+ 47 000 SEK
in 50 years)

+1 kWh
+100 kWh/year
+5 MWh/50years



REFERENCES

Reference photos of punctual wooden foundation in CLT in Austria. (W. Unterrainer, personal communication, 10 March 2021)

ARCHITECTURAL QUALITIY

The quality of a punctual foundation is how it is placed more naturally in the terrain, which keeps the original beauty of the site and avoids introduing ecological systems. The space below the house, depending on how tall the pillars are, can be a functional space as well for play or storage, as long as it is not completely filled out. The space also needs to air out to avoid moist in the construction.

WINDOW TYPE


Case study Dining room window bay
Photo Author

INTRODUCTION

Windows are important architectural elements, both regarding spatial experience and technical performance, and should therefore be chosen and placed with care. In this original case study, windows holds 10-15% of embodied energy (CO_2 in material), mostly due to aluminium and glass. The u-value of windows are normally 10 times worse than an exterior wall, which means they are also key to lower energy demand, and thus minimize both CO^2 emissions and costs for each kWh saved during the whole lifespan.

The original windows are rather small and have glass surfaces divided by frames and bars for desired esthetics, but this increases thermal bridges and heat loss, as the u-value of frames are always higher than the u-value of glass, for example frame 1 W/m^2K compared to glass 0,9 W/m^2K. The frame/glass ratio can be optimized by making larger windows. The bars also make the window more expensive.

Note that window sizes have boundaries. Rotating windows in this case, have a maximum width of 2388mm and max height of 1788mm. Width plus height also cannot exceed 3400mm and frame weight is max 80kg. Fixed windows don't have the same limitations.

When windows are acquired for larger project the prices are discounted due to the volume purchased. It is not comparable with prices on the public market. The prices are in constant change and these are from 2019.

ORIGINAL DATA

90 000 sek ex Vat/ villa
16 windows with aluminium frame and wooden cores, side hinged, open inwards, u-value =0,9
Glass-dividing window bars
Ca 30m2 window area and ca 3000 sek/m2.
2+1 glas with integrated venetian blinds

EXPERIMENT DATA

A comparison was made between different window types to find most balanced option. The experiment is about the product, not their sizes and placements. The original windows were compared to 3-glass windows made of wood and PVC with different opening functions, investment costs and same u-values. (Specific information is seen on the experiment page.)

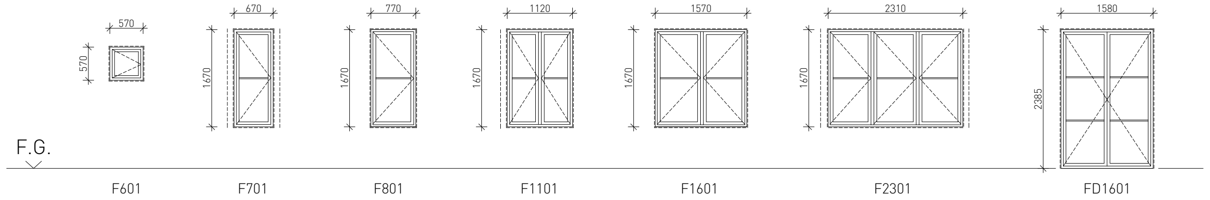
The glass-diving bars on the original windows were taken away, because without them, the thermal bridge setting can be changed from "general 0,05 W/(m2K) to detailed 0,035 W/(m2K)" and improve insulation on all. Moreover, the fixed window was given a lower u-value of 0,8 since it will insulate better when it cannot be opened. In terms of other qualites they are of the same standard and brand. A ten year guarantee applies to all window options. The lifespan should be the same if product is taken care of.

RESULT

"Total building savings, not just the windows"
<u>Wood, 50% rotate/50% fixed (1680sek/m2)</u>

Energy:	- 5,2% =3,2kWh/m^2a (16 MWh/50a)
CO2:	- 5,9% =2,2kgCO2/m^2a (11ton/50a)
Cost:	- 1,3% =64€/m^2a (64 000 SEK/50a)

WINDOW SUMMARY



Original window drawings by Brunnberg Forshed


Photo Author

ALU/WOOD, SIDE HINGED,
OPEN INWARDS, CROSS-BARS
(3000 SEK/M^2)


Figure 13.
Vridfönster
(NorDan 2020)


Figure 14.
Fast fönster
(NorDan 2020)

WOOD,
50% ROTATE / 50% FIXED
(1680 SEK/M2)

-6%
of total CO_2
emissions!

30% window
discount =
-1,3% of
total LCC!

ARCHITECTURAL QUALITIES

Only changing window product will have smaller architectural impacts, compared to new window placement and sizes seen in the volume experiments. However, removing the cross bars can be sensitive as they are strongly connected to ideologies of beauty. Removing the window bars can create a cleaner look and the bars are less important for esthetics when the facade cladding already is detailed, but certainly not all would agree. The bars can create a distance to the outside, but also help make it more private. The bars make it more expensive, harder to clean and increased maintenance. Further, fixed windows instead of openable have less frame which increases daylight and insulation performance. The proportions are not changed in this material experiments, but there is a new combination of fixed and rotating windows. Wood has a more authentic feel compared to alu or PVC, as it is a natural product.

Functionality might be the architectural value that improves the most in this case. The original inward opening fits better for safety reasons in taller buildings, but serves no purpose here. Opening windows outward enables better use of window sill inside, for plants, lamps and so on. Moreover, it makes it easier to install a wider range of solar blinds on the inside. The original integrated venetian blinds are neither very practical, pretty or effective. Moreover, the the 2+1 glass is often chosen for sound insulation performance or integrated venetian blinds, both which is not needed on this nature site.

REFLECTION

It would not have been impossible to guess wood as a winner, compared to aluminium and PVC which both has higher emissions. Alu is often chosen because it is believed to have less maintenance and PVC seem to have the cheapest intial price. Wood is believed to have higher maintenance, but the fact is that all windows need maintenance no matter the material, because it is often the mechanical parts that needs attention after some years, such as hinges and handles. Wood just needs repainting, but other than that, it is a lasting material. With all products, it also depends on quality.

The CAALA software calculates maintenance the same for all, by adding a cost percentage on the investment, might sometimes be misleading. Perhaps a mix of wood inside and PVC outside would be a balanced option? PVC seem to be cheapest, but wood will save twice as much CO^2, and is still much cheaper than aluminium, and is therefore chosen as the winner. The cost savings matters, but are fairly low due to cheap windows (see production cost). The total savings in CO2 is higher. Still, both are improved.

WINDOW COMPARISON
PART 1

ORIGINAL

Figure 15.
PVC vridfönster
(NorDan 2020)

Figure 13.

Variant Information	ALU, SIDE HINGED, OPEN INWARDS, CROSS-BARS (3000 SEK/M²)	PVC, ROTATE, OPEN OUTWARDS, NO BARS (2160 SEK/M2)	WOOD, ROTATE, OPEN OUTWARDS, NO BARS (2100 SEK/M2)
Energy parameters			
[kWh / (m²$_{AN}$ *a)]	62.45	60.30 -3.44% - 2,15 kWh -10 MWh	60.30 -3.44% - 2,2 kWh -10 MWh
Life cycle assessment			
[kg CO$_2$-Äqv / (m²$_{NGF}$*a)]	37.12	36.19 -2.51% - 1 kgCO² -5 tons	35.32 -4.85% - 1,8 kgCO² -9 tons
Life cycle costs			
[€ / (m²$_{BGF}$)]	4791.84	4750.93 -0.85% -840 SEK -42 000 SEK	4748.70 -0.9% -880 SEK -44 000 SEK

Note! The result is in relation to the building as a whole!

WINDOW COMPARISON
PART 2

Figure 16.
PVC Kipp-dreh
(NorDan 2020)

	WOOD, 50% ROTATE / 50% FIXED (1680 SEK/M2)	PVC, 50% ROTATE / 50% FIXED (1600 SEK/M2)	PVC, SIMPLER ”KIPP-DREH”, OPEN INWARDS (1470 SEK/M2)
	59.20 -5.2% - 3,2 kWh -16 MWh	59.20 -5.2% - 3,2 kWh -16 MWh	60.30 -3.44% - 2,2 kWh -10 MWh
	34.93 -5.9% - 2,2 kgCO² -11 tons	35.80 -3.56% - 1,3 kgCO² -6,6 tons	36.19 -2.51% - 1 kgCO² -5 tons
	4728.18 -1.33% -1200 SEK -64 000 SEK	4725.21 -1.39% -1340 SEK -67 000 SEK	4725.31 -1.39% -1340 SEK -67 000 SEK

WINNER

Largest savings in energy and CO2 in relation to lifecycle cost.

Case study Two roof types
Photo Robin Hayes

RHEINZINK VS BRICK TILES

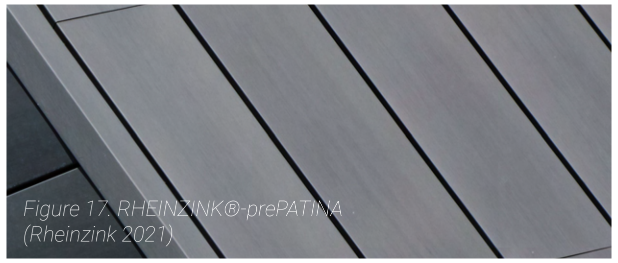


Figure 17. RHEINZINK®-prePATINA (Rheinzink 2021)


Figure 18. RT 821 Höjslev 1-kupig Lille Dansk (Randers Tegel 2021)

INTRODUCTION

The villas have 50/50 rheinzink/brick tile roofing, due to a durability experiment between client and architect, which motivates this experiment. As the client said, "the one who lives will see the result". When comparing zink and tile roofs, one must include the whole roof construction and work hours, including all metal work on the house. The tiles are not complete in themselves, but has to be complemented with zink where the tiles cannot cover, such as gutter, drainpipes and around windows and chimney. Thus, complete costs must be compared, which interestingly led to the same building costs. Rheinzink 186 000 SEK (complete), and brick tiles 126 000 (zink work) + 60 000 (batten and tiles).

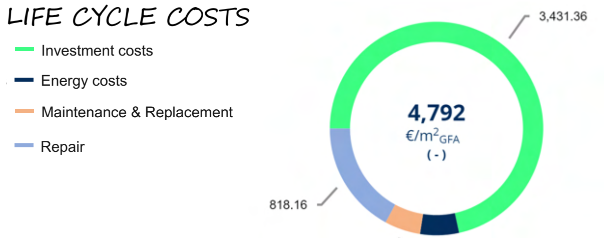
RHEINZINK®-prePATINA (Ökobaudat 2016)
A1-A3 (Production)= 3,9kg co2/kg (16 kg co2/m2)
C3+C4 (End of life)= 0 (+phase D=100% recycleable)

ARCHITECTURAL QUALITES

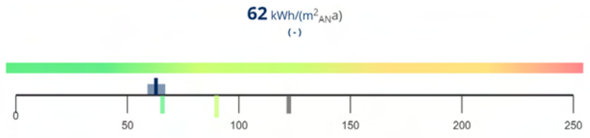
The variation of zink and brick was initially a sustainability question, but in fact it became an interesting material variation that lifted the whole expression of the area. So in a way, the real-life experiment became an architectural quality.

GLOBAL WARMING POTENTIAL (GWP)

LIFE CYCLE COSTS



ENERGY DEMAND



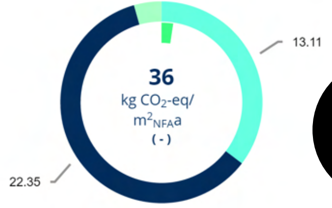
REFLECTIONS

The lifecycle experiment result show that they are close in both LCA and LCC. Brick tiles had 1kgCO2/m2a less, due to lower production, but considering phase D, that zink can be 100% recycled and reused and generally be 70% reimbursed in value, it might still be the better option over time. Note that rheinzink is a specific product, different from other metals. Same with the tiles. Rheinzink existed in the database, but this specific tile did not. Data of a general brick tile is used for the experiments. In reality it is best to crosscheck with EPD. The result does not mean that all metal and tile roofs are this equal. It is a comparison between two quality materials which have the possibility to age beautifully over time and keep high functionality and low maintenance for the building manager.

RT 821 HÖJSLEV (Brick tile roof in Ökobaudat 2016)
A1-A3 (Production)= 0,35kg co2/kg (16 kg co2/m2)
C3+C4 (End of life)= 0,0065 kgco2/kg

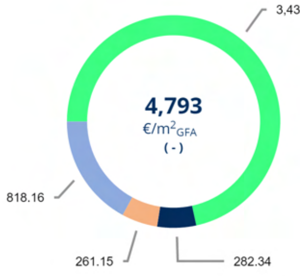
ARCHITECTURAL QUALITES

These are classic roof tiles for rough nordic climate, made in Denmark. A unique and durable claymix burnt in 1050° C - a higher temperature than many tiles on the market (Randers Tegel 2021). The tiles have color variations which lifts the unique material expression of each roof and resembles well with nature.



-1 kg CO_2
100 kg/year
5 ton/50yrs

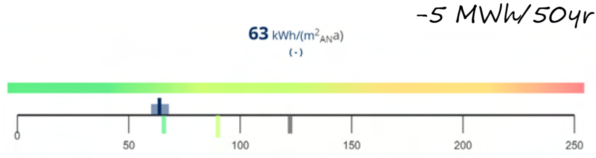
1 kg becomes 5 tons!



Unchanged

Two good options!

-1 kWh
-100 kWh/year
-5 MWh/50yrs



HEAT PUMP


Figure 19. Bergvärmepump F1255. (Nibe 2021).

INTRODUCTION

The technical equipment for heating, distribution and transfer is a central part in energy efficient buildings and a good indoor climate. The technological systems in CAALA show a large difference in energy demand and GWP, as each system are also assigned a CO2 intensity/kWh, based on European standards. Sweden has a much lower CO2 intensity as our energy production is clean due to nuclear power, water, wind and sun. The Europeen context is kept in this experiment, since Sweden is connected to the EU energy grid.

TECHNICAL EQUIPMENT

The original house have a geothermal heatpump, ground/water, with mechanical ventilation (FTX) and floor heating. FTX is a a controlled ventilation with fans and heat recovery. The hot air going out, through a heat exchanger, pre-warms the incoming cold air (and/or the water). More accurately, a NIBE F1255 is installed; an inverter-controlled ground source heat pump with integrated water heater. That specific product can not be chosen in CAALA, but one with similar function.The assigned CO2 intensity is 530gramCO2/kWh and Performance coefficient (ep): 0.55

PELLETS BOILER


Figure 20. Pelletsbrännare ivo tower (Wodke 2021).

REFLECTION

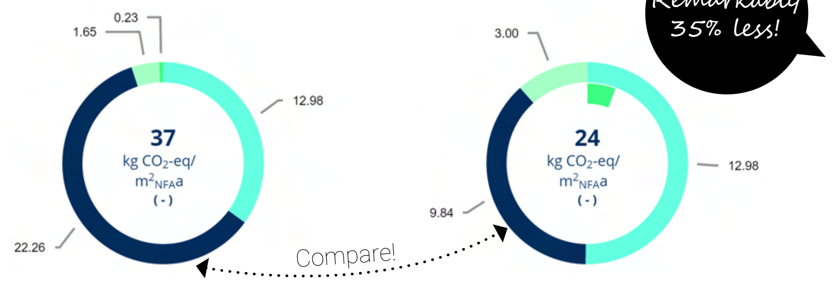
Some equipments will increase the buildings energy demand, but have a smaller CO2 intensity. Others will do the opposite. E.g. some will increase the kWh and therefore energy cost, but still have low GWP, given that the CO2 intensity/kWh for that system is low. It is important to look at both when choosing the most balanced option. Another reality to consider is what the equipment needs from the tenant in terms of work, and the level of maintainance for the client since this is a rental villa. The work must be considered in the lifecycle cost, not just the price of purchase and installation. Further reflection follows on the next page.

TECHNICAL EQUIPMENT

Wood pellets boiler with natural ventilation (air through windows and fixed dampers in the walls). Since wood pellets boiler is considered as biofuel, the assigned CO2 intensity is as low as 20gramCO2/kWh. The value is also low due to natural ventilation instead of mechanical. This is why the GWP in energy use phase is less than half, looking at the GWP graph.

GLOBAL WARMING POTENTIAL (GWP)

- 🟩 B4 Replacement
- 🟦 B6 Energy demand in use
- 🟩 C3+C4 End-of-life
- 🟩 A1-A3 Production

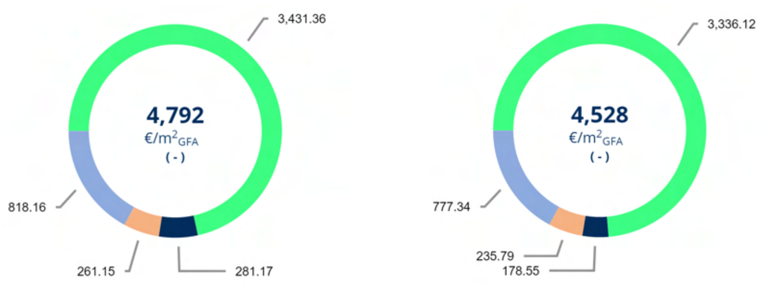


Remarkably 35% less!

-13 kg CO_2
1300 kg/year
65 ton/50yrs

LIFE CYCLE COSTS

- 🟩 Investment costs
- 🟦 Energy costs
- 🟧 Maintenance & Replacement
- 🟦 Repair



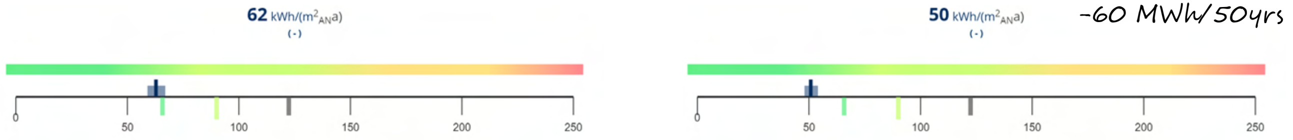
- 264€/m²

-264 000SEK/50yrs
- 5280 SEK/year
- 440 SEK/month

ENERGY DEMAND

20% less energy!

-12 kWh
-1200 kWh/year
-60 MWh/50yrs



HEATING SYSTEM DISCUSSION

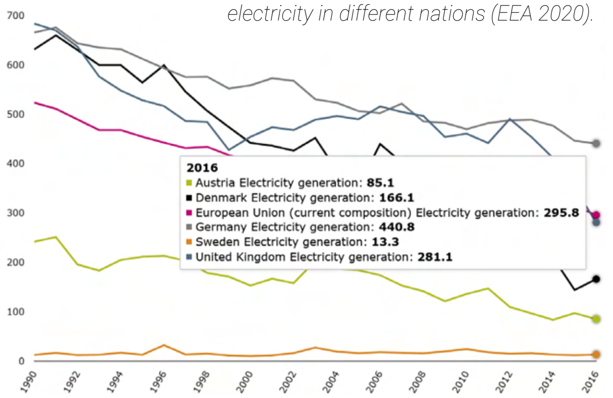


Figure 21. CO2 emission intensity for electricity in different nations (EEA 2020).

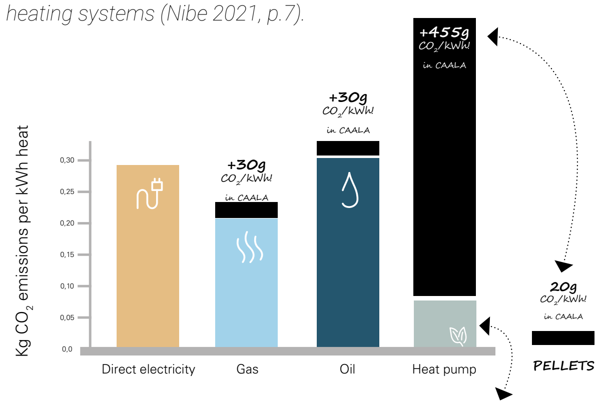


Figure 22. CO2 emissions for various heating systems (Nibe 2021, p.7).

DISCUSSION ON ENERGY

Sweden has among the cleanest energy in the EU and the world. Our CO2 intensity in g/kWh is 13 grams. EU average is about 300 gram and Germany 440 gram. By comparison, Sweden is 23 times lower than EU average and 33 times lower than Germany. This is key when looking at the technical equipment and heating system of the house in CAALA, since by default it uses German/EU data. Since the energy use phase of a buildings lifecycle is at least 50% of total CO2 emissions (GWP), lowering the CO2/kWh would have a large impact on final result. Therefore, a discussion is motivated about using the correct data.

One could additionally argue that Sweden is part of the common European energy market and a global CO2 footprint. When so called plus-energy houses are calculating their positive climate footprint, it is by saying that selling clean energy to other European nations would push out other unclean fossil energy from the grid. In similar way, if Sweden would use more energy than nationally produced, there would be a need to acquire unclean energy from the EU to compensate. Limiting energy demand is in any case of uttermost importance. That said, it could be fair to use EU context (average of 300gCO2/kWh) when making energy experiments in CAALA. However, this value also depends on chosen technical system for heating and distribution in the house. A geothermal heat pump, solar panels, wood pellets boiler, district heating or oil boiler, the CO2/kWh will vary intensely. Another example where using general and average values would be misleading. In the original CAALA model the default values (German context) will be used in the experiments, followed by a discussion.

DISCUSSION ON GWP

Often pellets are calculated as CO_2 neutral, because the CO_2 they produce has been sequestrated when the trees were growing. Than mainly transport remains, but is not included in this LCA. Moreover, the pellets burner that CAALA seem to use is far too strong for the house. The probable need is 6- 8 KW and not 20 – 120 KW which is currently used in the experiment. Changing this in theory, should lead to even better GWP because a too effective machine will not help but make heat losses worse. The machine can not be changed in the software and thus reflections are needed to actualize the result. That said, changing to a wood pellets boiler with natural ventilation markedly lowered the GWP by 35% and energy demand by 20%, making it an interesting option to consider. The natural ventilation requires less material, installations and maintainance. The CO_2-intensity is extremely low for the pellets in CAALA, namely 20gramsCO_2/kWh (0.02kg). Note, this is based on German data. Both EU-average and Swedish context would be different.

Looking at the graph from EEA regarding CO_2-intensity for several systems, and comparing the values to the CAALA software, the gas is 0.2 vs 0.23 in CAALA, the oil 0.3 vs 0.33 in CAALA, but the heat pump is deviate, 0.075 vs 0.53 in CAALA. To sum up, the values for gas and oil are corresponding, but heat pump is considerably different, making the experiment data questionable in Swedish context.

Wood pellets does not exist in the graph unfortunetely. Heat pumps are popular in Scandinavia and the above graph from EEA estimates 75gramCO_2/kWh, not 530gram as CAALA says. CAALA likely includes the mechanical ventilation and perhaps other aspects too, such as the production of the heat pump and energy use for installation and drilling. The drilling is not needed for the pellets boiler.To conclude, if the CO_2 intensity is manually set to 75 grams in the experiment, as the graph suggests, the GWP result for the heat pump is exactly the same as for the pellets boiler (GWP 24), only twice the price in this case. But perhaps there are other hidden factors that explains the difference, such as performance efficiency?

DISCUSSION ON COSTS

The investment price of the pellets boiler is estimated to 100 000 SEK, 50k for product and 50k for installations. This is half the price of the heat pump investment. The price can certainly vary and is only an estimation. The LCC-experiment over 50 years reduces another 40 000 SEK in repair, 25 000 in maintainance and as much as 100 000 SEK in energy cost. CAALA adds these cost in percent/year on the investment, same for both pellets and heat pump. The pellets boiler requires refill of wood pellets and a storage space, which must be solved architecturally. The boiler requires work from the tenants, perhaps even for the client who will have to buy pellets and perhaps have to deal with problems the tenants face in the matter. The boiler could be a cozy fireplace, which adds to architectural experience. The cost of pellets vary from country to country, just like electricity, but it is a local material. In Austria at the moment, the price is around 22 cent/kg which is equivalent to 4,5 cent/kWh. Knowing the primary energy demand from the experiment (50KWh/m2/year), the pellets will cost around 2500 SEK/year. Comparing to Swedish the prices from Stora Enso, 2800 SEK/ton pellets, or 2,8 SEK/kg (ca 28 cent/kg). Close to the Austrian price but slightly higher. An estimation of yearly pellets cost would be 2500-3000 SEK. This somehow has to be added to LCC.

A geothermal heat pump still needs electricity, which is a cost, but since electricity is not the main energy source for the heat pump, the amount of electricity is low. The pump only needs electricity to start the heat extraction process, which generally allows a saving up to 75% of energy costs in Sweden. Slowly the investment cost will be compensated by the energy savings. In the end, the LCA-result depends on which values are given the heat pump in terms of CO_2-intensity and which effect is given the pellets boiler. Secondly, the cost of a pellets boiler in reality, and the cost to run it over time, is difficult to estimate.

CONCLUSION

What can be said is that pellets seem cheaper initially due to the drilling needed for heat pumps, and much less CO_2, if the data is correct regarding the Swedish context for the heat pump? Perhaps even a good architectural addition with a fire place. The choice depends on correct data, and if the client can accept the possible extra work of buying and storing the pellets. If so, then pellets seem to be a better choice.

Case study View from the street
Year 2020 Developer Viskaforshem
Architects Brunnberg & Forshed
Photo Author

5

SUMMARY

SUMMARY

COMBINED EXPERIMENTS

This is a summary of all the chosen experiments from the investigation. All the best options were combined into one final proposal. The next pages describe the architectural changes, and total savings of life cycle cost and climate footprint, followed by different conclusive discussions. Large optimization potentials were found. Some design experiments saved resources, while some new improvements added resources. The final savings are thus plus and minus values combined into a final saving percentage, which is seen on the next spread, but first out are the architectural qualites.

VOLUME SUMMARY

LIFESPAN

The lifespan experiment to prolong the life of the building is not implemented, since both buildings have more or less the same lifespan potentials. In both original and new proposal, 50 years was used for fair comparison. Still important to remember the immense improvement if the building could last 100 years or more.

ORIENTATION

The new proposal orients the facade with most windows to south-southest to make better use of passive energy, southern sun on the large terrace and to create more unique spatial experiences along the street. Originally the villa orientations were a placed in two circles with entrances facing the street, and with a heat demand based on west facing facade.

ROOF

The pitched roof was changed to a flat shed roof with small 3/5 degree angle with extension for shading and rain protection by entrance and terrace. Due to the overlapping angles, the roof material will be visible from both entrance and terrace side.

NEW VOLUME AND PLAN - New villa has two shifted volumes in different scales. A rationalized plan with circulation around a dark core, new window proportions, increased daylight and ceiling height for generous and flexible living room, two general bedrooms, closed airlock entrance, integrated and expanded storage, and doubled terrace.

MATERIAL SUMMARY

FOUNDATION

Both construction types and new materials were investigated to find alternative to concrete. Koljern (foamglas) slab was chosen due to best performace in GWP and energy demand, and least maintenance over time. Punctual foundations would also work, but would be worth more if the ground levels were even more diverse than the original site.

WINDOW TYPE

The new window is made of wood instead of aluminium. A possible compromize to reduce re-painting would be to have wood inside and PVC outside, but that option was never tried. They now open by rotating outwards. The glass-dividing bars are taken away and 50% are not openable. All in all it improves u-values, creates cleaner appearances and practical window use.

ROOF

Regarding roof materials, brick tile roofing showed slightly less climate impact, but after reflections they were considered very equal. A mix was chosen to appreciate the diversity and to evaluate both materials over time in real life.

TECHNICAL SYSTEM

A separate proposal was made for the technical system experiment, because it had such large impact that it did not feel fair to use the result without clear explainations. The change from heat pump and mechanical ventilation, to pellets boiler with natural ventilation, saved almost as much as all the other experiments combined. The two seperate proposals are displayed on the next spread.

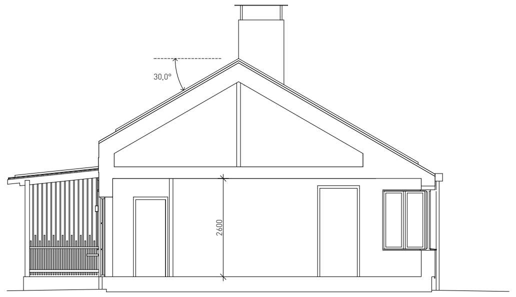
ORIGINAL BUILDING

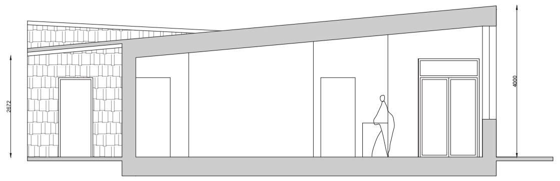
BY BRUNNBERG FORSHED

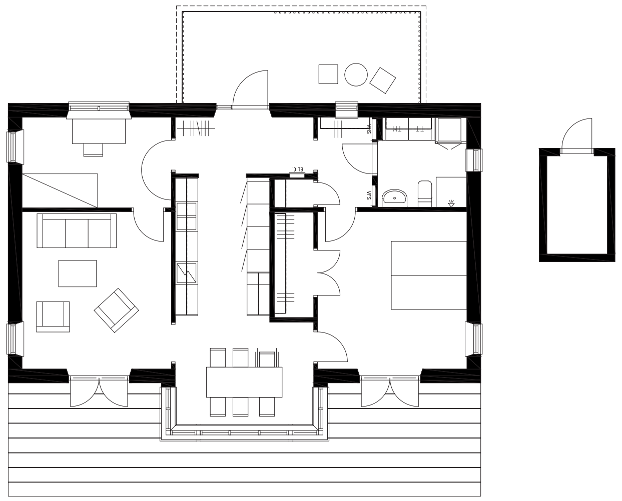
PROPOSAL

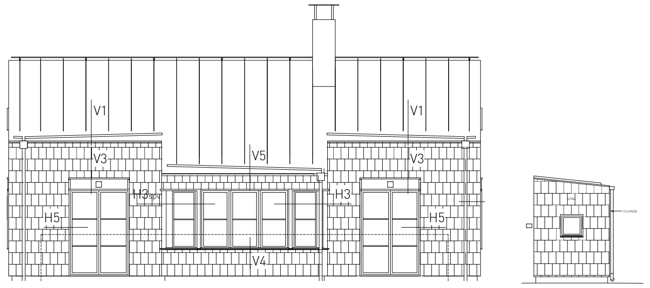
BY AUTHOR

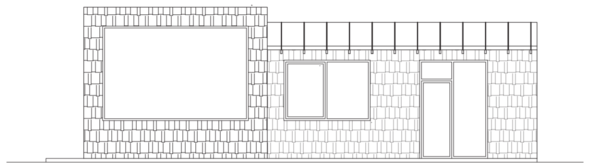
1:4000 (A4)
Excluding the new volume.



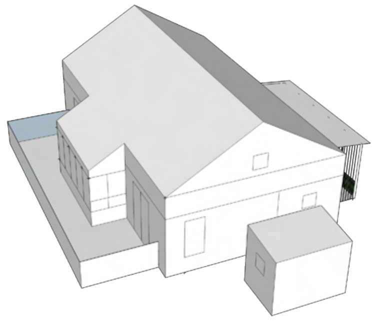


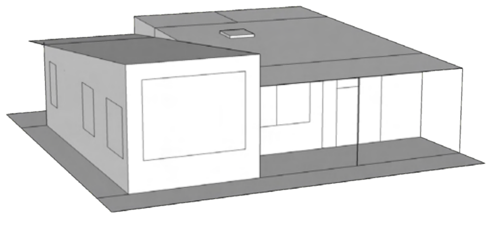




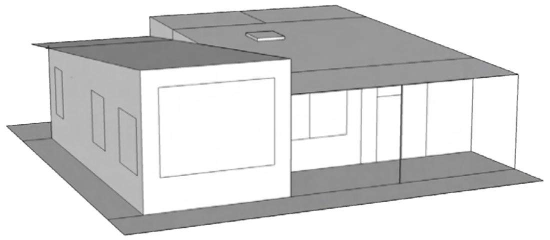


1:200 (A4)





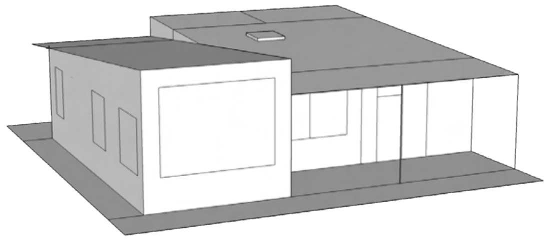
PROPOSAL 1
WITH HEAT PUMP



\+ 

\+ MECHANICAL VENTILATION

PROPOSAL 2
WITH PELLETS



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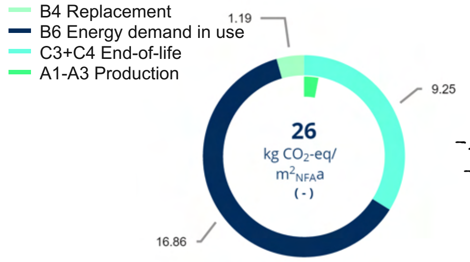
\+ NATURAL VENTILATION

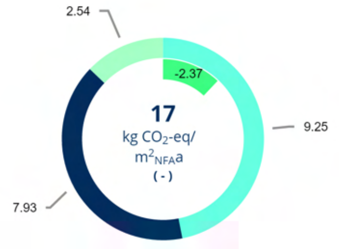
ALL RESULTS IN RELATION TO ORIGINAL BUILDING.

SAME IMPACT AS ALL OTHER BUILDING EXPERIMENTS COMBINED!

GLOBAL WARMING POTENTIAL

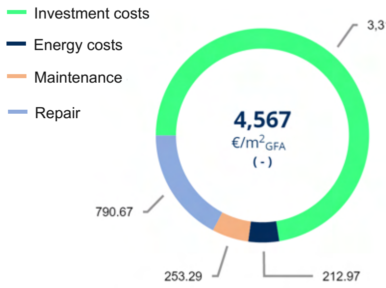


-11 kg CO_2
-1100 kg/year
-55 ton/50yrs



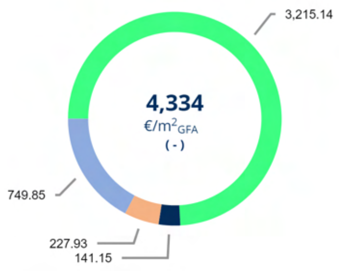
-20 kg CO_2
-2000 kg/year
-100 ton/50yrs

LIFE CYCLE COSTS



\- 225€/m²

-225 000SEK/50yrs
\- 4500 SEK/year
\- 375 SEK/month

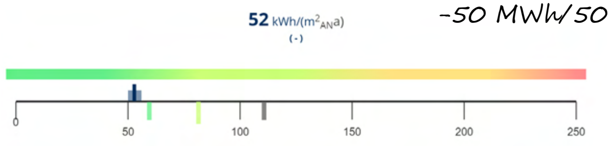


\- 458€/m²

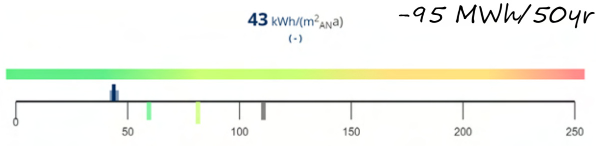
-458 000SEK/50yrs
\- 38 000 SEK/year
\- 3200 SEK/month

ENERGY DEMAND

-10 kWh
-1000 kWh/year
-50 MWh/50yrs

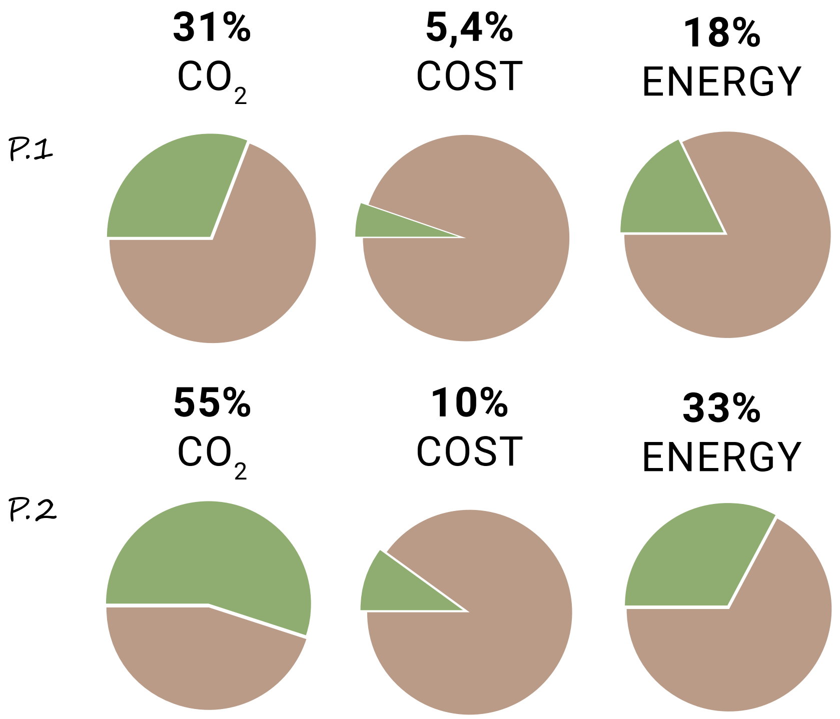


-19 kWh
-1900 kWh/year
-95 MWh/50yrs



TOTAL SAVING

	LCA ($kgCO_2$)	LCC (SEK)	Energy (kWh)
ORIGINAL BUILDING WITH HEAT PUMP			
TOTAL 50 YEARS	185 000	4 792 000	310 000
PROPOSAL 1 WITH HEAT PUMP			
Orientation	-5000	-7000	-5000
Window type	-11 000	-64 000	-16 000
Foundation	-16 000	+114 000	-11 000
Roof material	-5000	-+0	-5000
Flat roof	-25 000	-486 000	-45 000
New plan/volume	+5000	+180 000	+25 000
SAVING	-57 000	-263 000	-57 000
%	31%	5,4%	18%
PROPOSAL 2 WITH PELLETS BOILER			
Pellets heating	-45 000	-228 000	-45 000
% Addition	24%	4,7%	15%
NEW SAVING	55%	10%	33%



LEARNINGS & RECOMMENDATIONS

1 • THINK BEYOND 50 YEARS

To apply lifecycle thinking on all aspects is the main purpose of the experiments, proving that higher initial costs will even out in the future by savings during operation, maintainance and replacement, and at the same time reduce climate footprint. The lifespan experiment is a clear example where the yearly costs [LCA and LCC] follows the lifetime of the building. Even with identical materials, a 25-year building will emit 50kgCO_2/m^2a compared to 32 kg for a 100-year-building. That is 36% less CO_2, just by prolonging the lifetime of the building! On top of that, the yearly cost is 160 000 SEK [25 years] compared to 70 000 SEK [100 years], which is less than half the cost per year!

2 • REDUCE UNNESSECARY MATERIALS

By re-designing the roof and removing the intermediate floor, about 500 000 SEK was saved over 50 years [340 000 SEK in building costs and 150 000 in operation, maintenance and repair]. One share was re-invested in better architectural qualities, such as a new plan layout, larger terrace with roof extensions for weather protection, a closed (still unheated) entrance patio with windows, larger windows elsewhere, increased ceiling height and changing to a climate friendly foundation of foamglas instead of concrete. All this and more, was paid by re-designing the roof! Reducing the floor size of one bedroom to enlarge another, created two general rooms. The new window placements simplifies furnishment. Moreover, removing the window bars and making selected windows fixed, will reduce cost that could be spent on better u-values, which in turn will save energy cost (Some of the re-designing and re-investment might not even be extra cost in the long run). By lowering the building cost, the client can also offer more affordable rents and lower the risk of vacancies, and thereby even tap into social sustainability.

3 • PRIORITIZE UNREPLACEABLE MATERIALS

People have a tendency to invest more in the visible, rather than the invisible. For example, no one can lay any foundation other than what is already laid. A beatiful kitchen can easily cost 300 000 SEK (or much more!) and be replaced after 25 years, while a concrete foundation only cost 100 000 SEK and must last the entire lifetime of the buidling. It should be an obvious choice to prioritize an additional 100 000 SEK on a foundation like Koljern, to improve insulation performance, safety and climate neutrality. Investing in the invisble loadbearing structure, which normally compose the largest climate impact of all major builidng elements, is a central strategy.

4 • INVEST IN ARCHITETURAL QUALITIES

The architectural qualities are close connected to cost and climate footprint. A house that breathes quality will reflect care for its user and that appreciation will reduce the possibility of the house being torn down [remember the impact of prolonged lifetime]. Designing for adaptability, imagining how spaces can be used differently over time, will be useful for more people, and the client, and will reduce the need for costly renovations. The architectural spaces must be perceived as pleasurable, the proportions be in harmony, the materials age beautifully and the functions serve their purpose well. In that way, lifecycle thinking will lead to a balanced architecture that builds a better society for all.

5 • LOW MAINTENANCE MATERIALS

Everyone, both landlord, tenant, future owner, and society, benefits from low maintenance materials. The materials should be durable and age beautifully. In this case, both the zink and brick tile roof will last 100 years with very little maintenance. The cedar facade is rot-resistant and will naturally change color over time with no need for painting [but perhaps other small treatment]. The interior floor is stone clinker and near impossible to wear out. The terrace is wood of core pine, a finer selection. Window sills and kitchen bench is made of granite. Heat pumps normally work quite well, but most technical systems are anyways high on the list of maintenance and replacements.

6 • ENCOURAGE WOOD PRODUCTS

The adaptation to renewable resources are key to lower CO_2 emissions. Wood binds CO_2 and releases it when disposed or burned. It is like borrowing emissions, but also preventing much worse emission sources, e.g. concrete, steel and many plastics. Trees can also be re-grown, while sand for concrete or iron from mining will one day run out. Wood is lighter and more flexible to move and requires less transport to construction. The villa had originally wood on facade, insulation, loadbearing structure and terrace - which all contribute to lower climate footprint - and nothing of that was changed after the experiments.

7 • ADAPT TO SUN AND SITE

Placing the buildings on site is normally seen as an architectural quality of accessability, nature interrelation, views from the inside and getting sun on the terrace. But more than that, the experiments show that orientation can lower energy demand and thereby CO_2 emissions and cost. Eight houses were re-oriented with largest windows towards south-southeast for best result.

8 • BALANCE EMBODIED- & OPERATIONAL ENERGY

Adding insulation to the climate shell and better u-values in windows might have a higher initial cost, but the reduced energy use will save cost and climate impact over time. This was balanced to the point where the energy savings are still worth the extra material cost [the case study was already quite effective]. At some point, the extra insulation will not help anymore and just become an unnecessary cost. Note that adding insulation thickness will also reduce floor area. Removing the glass-dividing window bars and changing to 50% fixed windows, improved the u-values and saved about 5% of total energy use. Another 4% in energy was reduced by the foamglas foundation.

9 • DARE TO CHALLENGE BUILDING ROUTINES

The building sector is quite conservative and many materials are used mainly by routine. The materials are considered good only because they are so widely used. Routine materials can be concrete, steel, mineral wool, aluminium and gypsum. Many of which have high embodied energy. Luckily, this case study is already above average and against maintstream in some sense. For example, there was not much gypsum, which is normally added to walls and ceilings even when not required. The standard concrete foundation was replaced by foamglas, which saved 16-26 tons of CO_2, 10-15% of total emissions. The routine is to use EPS and XPS insulation below the concrete. This is seldom talked about, but these plastic foams that is below most houses will absorb moist and loose their insulation performance (Pfeifer 2013). This is significant and a routine that is challanged in the new proposal.

10 • DO NOT FORGET THE HEATING SYSTEM

The heating system had a remarkable impact on LCA [and LCC] due to energy use and CO_2 intensity/kWh. If the experiment data is correct, the impact was as large as all the other building experiments combined! That says something about the importance for architects to investigate and integrate well, early in their design.

RESEARCH QUESTION

CHEAPER
BUT BETTER

"An investigation of the interrelation between building costs, life cycle costs, energy use, climate footprint and architectural qualities, of a small rental villa in Sweden"

TITLE DISCUSSION

The result show that through life cycle thinking and cost calculations, it is possible to build cheaper but better. Making a building cheaper by removing building parts and choosing lower quality materials is not difficult, but improving it while making it cheaper is something entirely different. That is what the title refers to. For example, the experiments show that making a flat roof would save 10% of total lifecycle cost, 14 % of CO_2 and 9% of energy, but that would also change the building appearance so much that they are not fully comparable anymore. In this case, to make up for the lost qualities of the larger volume, the flat roof were given some angles and thereby a higher indoor ceiling. In that way, a quality has not just been taken away, but been replaced with a new, and better. That addition has a cost also in CO_2 and energy use. Whether the new roof is "better" or not, is of course up to interpretation of ones esthetics and which architectural parameters that are chosen. If an architectural parameter would be to "maximize storage space", then perhaps a different experiment would be better. The point is again, what other values were added by the cost saved by the re-design? That can be seen in the list of calculations. The interrelation of the different parameters is about balancing, comparing and prioritizing what is worth the most and where the investment create the highest value. Both cost and CO_2 follow the energy use, since energy has a price/kWh and a CO_2-intensity/kWh. Reducing building cost can go both ways for CO_2. Removing materials will lower CO_2 but cheaper materials might have higher CO_2, but not always. The building cost is a certain percentage of the life cycle cost, depending on how long the building stands. The repair and maintenance is decided by the building cost and type of materials. Changes in the design often affects all parameters.

For the title to work it has another delimitation. It is easy to add new functions, change the program and increase the sizes and thereby claim an improvement. However, the new proposal must address the client's need. The focus was rather to improve the ideas already present. For example, there are endless plan layouts possible within the original limit of 84 m^2, but too immense changes make the plans less comparable in terms of similar architectural values. Therefore the new design still resembles ideas from the old, both in regards to plan layout and materials.

An important note about prices in the model is that the same m^2/price is used no matter the amount of that specific material, which might not be the case in reality. If reducing the amount of CLT purchased, perhaps the price/m^2 would get more expensive. Similar the other way around, e.g. increasing the amount of windows would lead to a better price/m^2, but perhaps more work hours and cost. Every element is part of the whole and every change has secondary effects. Since it goes both ways in this case, materials are both added and removed in the same way, perhaps that evens out the results.

WHAT ARE THE POTENTIALS TO MINIMIZE LIFECYCLE COSTS AND CLIMATE FOOTPRINT IN HOUSING AND AT THE SAME ENSURE [IMPROVE] ARCHITECTURAL QUALITIES?

According to the chosen parameters and price estimations, large life cycle optimization potentials were found. The result of re-designing and improving the building volume (e.g., orientation, roof, and plan layout) and selected materials (e.g., window and foundation), ***reduced lifecycle cost by 5,4%, energy by 18%, and CO_2 emissions by 31%. Replacing the technical equipment further increased total savings up to 10%, 33% and 55%.*** The result is a summary of plus and minus values, combining selected experiments into one final design proposal. For more indepth summary of the calculations and design changes made, see previous pages. Note that this was done on a villa that was already above Swedish average in terms of low carbon and high qualities. ***Doing the same to a simpler standard villa would increase the result much further!***

SUB-QUESTIONS

- *How can economy become a driver (or hinder) for "sustainable Swedish housing"?*

This question depends on how economy is defined. If economy focus is mainly building costs, then it can be seen as hinder. If adding life cycle perspective, some economic choices today can be a driver for better economic management tomorrow. In the total lifecycle cost, the cost of operation, repair and maintenance is just as much, if not more, than the initial building cost, especially if the building lasts for 100 years. It is therefore important to find out early where the best potentials for saving operational cost can be found. Is it the technical equipment, the building shape, or in a certain material or elsewhere? If an overestimated economic value can be found in the design, for example an unneccessary material or architectural function, and then be erazed or even re-located to a better place regarding climate footprint and architecture, than the economic analysis has become a driver for sustainability.

By increasing the building cost in the right way, money should be spent on materials that requires lower maintenance costs. In that way, investing in quality is not even an extra cost and thus, economic analysis is a driver for lower emissions and better architecture. If economy is seen from a lifecycle perspective, it will also be easier to communicate and motivate higher initial cost to the client. If the architects are part of the economic planning process, they can regularly follow-up costs associated with their design. Staying on budget will prevent sustainable goals from disappearing along the way.

- *How can architects begin to work with economy?*

It has to start with an interest. Realizing how economy affects everything and everyone. Every project must be economically feasible, and if architects learn about production prices, building prices, material and work prices, energy prices, economic planning and logics, real estate economy, business principles, budgets, risks, rate of return, regulations for different building types, life cycle thinking of buildings and so on, the role of the architect will become more important in the future. The first step is to start showing interest and lean towards learning. Talk to architects who has the experience. Talk to other disciplines to undertand their economic perspectives. Start do add economy in school projects.

DISCUSSION ON OBSTACLES

What are the obstacles to implement the result and ideas of this thesis in the industry?

This is a discussion combining personal reflections as well as aspects heard or read throughout the thesis work.

INCENTIVES

What is in it for me? Even if the building lasts 100 years (or hopefully much longer) and immensly lowers lifetime cost and climate footprint, the stakeholder might not care because who knows whether they will own the building for that long? One obstacle is an ethical and moral one, where design decisions can either be based on a short term or long term perspective and a responsible analysis of how the building will affect people and planet in the years to come. As Crona says: ***"What is built today must support our lives for many generations if we are to make a sustainable building claim. From a long term perspective, it is expensive to build cheap".*** (2018, p.6).

Similar attitude was expressed in a conversation with M. Bengtsson: ***"it could be nice not just leaving behind large amounts of maintenance work for the company and society"*** (personal communication, 25 May, 2021). Settling for less profit, for the sake of others, is certainly difficult to sell. Settling for less instant profit, but increased profit over time, is easier, but perhaps a different business model. Or as in this thesis, finding ways to both lower instant building cost, and life cycle cost, should be interesting for everyone. Economic incentives is crucial if the building sector is to change at the speed neccessary to reduce global warming. As many people in the industry might not care enough for the climate, it is important to find ways of making quality and less climate footprint profitable. Caring for the climate is in some cases a luxury not all people and nations can afford, but at the same time, not caring is counterproductive, because we destroy the very thing that gives us life and resources. Architects and others, must learn to use the tools available, to design and communicate how to make buildings cheaper but better. It must be economically interesting to build "better", which is why this thesis can spark an important dialoge.

IDEOLOGY

Ideology can be an obstacle to change and introducing new materials. What is a good house? What is standard? What is considered beautiful? Ideologies, cultures and trends affect our view of architecture. The ideology differ between countries even in scandinavia. Take for example our neighbour, Denmark. Their widespread view of a good house is a one storey building, heavy weight, made of concrete and bricks and no bars on the windows. A wooden house to them is built by those who cannot afford brick. Mostly it is not built at all, because companies are unsure of how to calculate and build it. The ideology of the Swedish villa is the opposite, two storey building, light weight, made of wood and preferably window bars. There are of course reasons for this, such as how our local materials have chaped our building industry. No matter the reason, new design can be sensitive. In the case study experiments, some sensitivity can be seen in removing the window bars (e.g. better insulation), replacing concrete with foamglas (e.g. less CO_2), going for a flat roof instead of pitched (e.g. saving money) and so on. When challenging the ideology, it is important to explain why and what they get in return. The new ways could very well work and be bought by the client, because one of the main issues is that materials normally are not questioned at all, just accepted because they are commonly used elsewhere. It is important to start a dialogue between the different stakeholders and give insight to help others make the choice by their own.

CONSERVATIVE BUILDING SECTOR

Why is the building sector so difficult to wield and transform? One reason is the long chains and how one change, means another change somewhere else. The sustainable transition affects all. The industry is not too quick to adapt new innovation and ways of working. The sector is conservative in their scepticism to new things. A new kind of system and work method, means new time plans, educating the company workers and increased work hours. Even if you tell them it will help them in the end, why should they change their system just because your system is changed? They have worked a certain way with certain methods, proceedures and materials for many years and feel confident in their work and can take responsibility for the result. There are uncertainties on how to calculate the costs of new materials and methods. Perhaps they must invite specialstsis when their own workers on site are unsure of the new method, which can get costly. If the leader is to teach their workers to learn something new, then at least they want some money for it, because if something goes wrong, who stands responsible? That is the question. A new type of construction might even need new cranes and thereby new safety regulations and so on.

One way to convice the sector to change is to communicate well how the new method, or material, is really the future of the sector. That motivates investment. They are also aware that the first and second house they build in this "new way", they might loose money due to high risk and little experience. But number three, they have learnt from their experiences and can start making money. New ways is a risk, because the road has not been walked before, not by them at least.

Moreover, large companies can stear their projects and see the future clearer. They have better opportunity to build-in the new methods from start and follow the whole way. New systems are harder to implement when the entreprenour is changed along the way and has no experience of that new system of work. A few failed projects can also create a bad reputation and concern, making the industry even more sceptical. One example is building a passive house and not teaching the users and building manager how the system works. If used in the wrong way, the energy is no longer lower. Technical education is important in that case.

GAP BETWEEN PROFESSIONS

In many of the interviews conducted there are expressions of a gap between architects, engineers, constructors, building manager and similar disciplines. The gap is caused by conflicting goals, knowledge, understanding or just mis-communication. The early collaboration and planning is important, as later changes are either very difficult to achieve, or very costly, causing budgets to exceed their limitations. There are trivial problems of irritation in the construction phase as well. E.g. architectural design is not always the same measures as the supplier's measures. This creates margins of error when, for example, installing roof tiles. Or the accuracy of the CLT structure, where the tectonics is difficult to achieve due to different dimensional margins of error between concrete and CLT. According to the builders, the architects draw a lot that cannot be built or that is difficult to achieve due to lack of construction understanding. While the architects thinks their ideas are ignored and changed to make it easier for the builders.

LEGISLATION AND CERTIFICATION

Politics can be an obstacle, especially when being a municipal owned company that builds rental housing. Regarding the case study, they were lucky to have positive politicians that understood the value of what they were doing. A real estate economy professor apparently said that it is possible to build this way if one has creative municipal council (M.Bengtsson, personal communication, 25 May, 2021). There is otherwise often opposition when doing new things against mainstream.

The legislations and other important contextual aspects differ between private and public companies, rental or condominiums and so on. E.g. the Public Procurement Act is a law in Sweden that regulates purchases made by authorities and other organizations that are financed with public funds. The law is based on EU directives and seem to be strictly followed. In other words, Viskaforshem would not be able to tell the builder to sharpen up otherwise they choose another company next time, because it is not fully up to them, being a non-private company.

The accounting regulations does not directly seem to be written to simplify sustainability either. The annual accounting actually requires that the house be written down to the value it had on day 1, even if the company and project is showing profit. Not all accountants can handle that (M.Bengtsson, personal communication, 25 May, 2021). There is similar challenges in regulations regarding the rate of return and estimated risks. Crona (2018) suggested a way to facilitate higher architectural qualities by waiting with the real estate valuation the first 10 years and let the initial building cost be the actual value, before the devaluation (write-off time) begins.

If the Swedish governmental strategy against high building costs is to build cheaper, this will be an obstacle for companies wanting to build with higher quality. The legislations should help, not hinder sustainable buildings.

Lifecycle costs and life cycle assessments matter most when it might lead to a "building certification" and points as proof of quality, giving the company prestige, marketing and possibility of raised prices. An idea again by Crona (2018) is to extend the start of devaluation by certifying the house by an environmental system like Svanen or Miljöbyggnad Guld.

INADEQUATE KNOWLEDGE AND RESOURCES

The building sector trusts the material because it is standard and videly used, but also because their experience says the material "works". Climate friendly materials can not always be measured by experience. Proven science could well get a renaissance. This was partly done in the case study, as the client collaborated with academia and tried to implement proven architectural research (e.g. CBA, Chalmers). Moreover, wrong reputation through inadequate analysis is another issue. Speaking to some manufacturers, they express how their product has not been presented truthfully, using partial data and not seeing it holistically. Bad reputation becomes an obstacle for their climate friendly options. The public might not have material knowledge and thus architects has a responsibility to educate.

The reputation of architects not caring about costs is also an obstacle. The architecture education could help with that, by implementing economy better in school.

Another issue of transition can be lack of material supply and to deliver on time. The concrete industry is widespread. What happens if the Koljern foundation made of foamglas would become widespread accross Sweden and Europe? One material is certainly not good in all situations, but it has the performance potential to grow. Is the supplier able to meet the demand?

COMPANIES AND PROFITS

The size of the company seem to matter. Larger companies seem to have larger obstacles, or perhaps less interest, in building with higher quality. This might seem strange, as larger companies often has more available resources and thereby possibilities, but they consist of a multitude of departments with increased bureaucracy, all needing their share of the profit. There are many lines in the chain, perhaps too many, which makes the building sector unwieldy. This might be one of the reasons why architecture companies more and more build in-house, by own initiative. To lead the project from start to finish, the original ideas are easier to keep and there are fewer stakeholders in the chain. Another reason for many intermediaries is the possibility to share the burden to deliver the product on time. In the case study, the windows were aquired from Derome, who then aquired from the manufacturer. Derome thus has its own profit. This is to pass on a responsibility to deliver on time, even if money could be saved on fewer intermediaries (C. Lindström, personal communication, 18 Feb, 2021). An advantage of larger companies is explained by the Committee on Modern Building Regulations: the price of land has immensly increased the last years but larger companies with resources have been able to aquire their own land, getting an advantage in the competition, making them less dependant on municipal land allocation (SOU 2019:68).

The construction industry suggests materials with largest profit margins. As a customer you must be aware of the material details yourself and decide properly, because you are constantly exposed to the wish of changing materials. This is logical, being a business, trying to find ways of earning money. Market driven prices can thus be an obstacle, because changing a material detail might change the architectural quality intended. According to the architect A. Svensson (personal communication, 12 Feb, 2021) this happened to a small scale in the case study, where the window lintel was built in cedar instead of painted wood as intended. The reason could very well have been mis-communication, which is another common obstacle, but anyhow, it had to be replaced, which likely meant a cost for all stakeholders, in terms of time, new material and work hours.

FINAL THOUGHTS

The discussion have addressed some areas of obstacles, but is certainly not a complete or unquestionable summary. Moreover it is mostly within scandinavian context but likely extends much further. It hopefully gives a direction for further investigations and in some sense, sums up the thesis work. There are a few unattended ambitions personally, where if I had more time, I would have enjoyed presenting and discussing the result with the main case study stakeholders and add their perspectives to the thesis as a natural ending. That dialogue will most hopefully happen in spite of the thesis closure, but I wish I could have passed it on here.

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CHALMERS
UNIVERSITY OF TECHNOLOGY

CHEAPER *BUT* BETTER

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Master Thesis Spring 2021

Building Design for
Sustainability

Examiner Liane Thuvander
Supervisor Walter Unterrainer

Presentation 21-05-31

Case study Wooden rental villas,
Källsprångsvägen, Viskafors
Year 2020 Developer Viskaforshem
Architects Brunnberg & Forshed
Photo Robin Hayes

WHAT ARE THE POTENTIALS *TO MINIMIZE* **LIFE CYCLE** *COSTS* **&** *CLIMATE FOOTPRINT* IN HOUSING AND AT THE SAME TIME ENSURE [IMPROVE] **ARCHITECTURAL QUALITIES?**

An investigation of the interrelation between building costs, life cycle costs, energy use, climate footprint and architectural qualities, of a small rental villa in Sweden

PRESENTATION OUTLINE

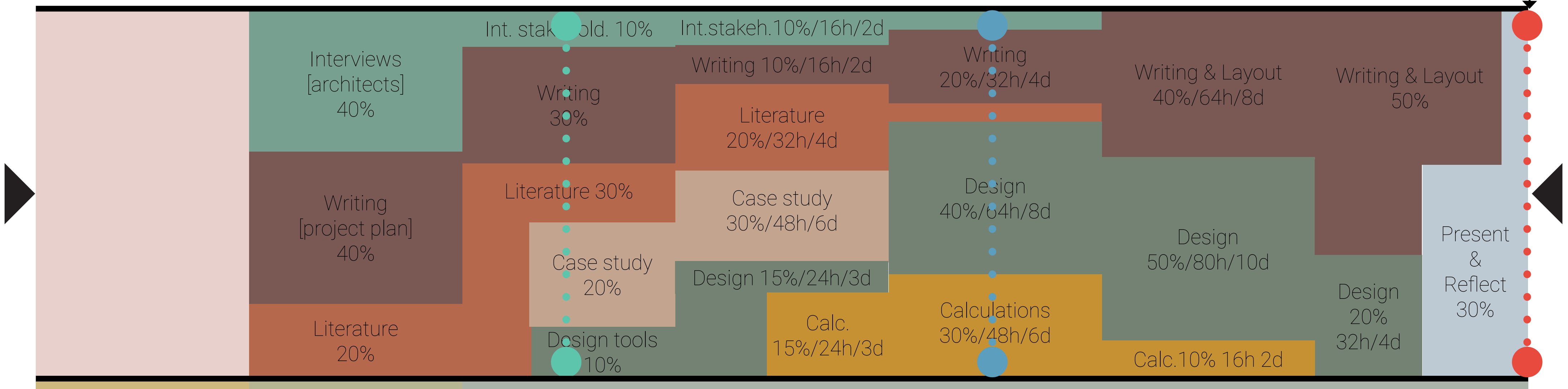
Method • Concept • Motivation • Case study • Cost • Tool • **Experiments** • Summary

Course	Master Prep I (ARK 636)	Master Prep II (ARK 641)	Master Thesis 2021 (ACEX35)				
Completion (%)	-	0%	20%	40%	60%	80%	100%
Weeks (total)	Part time (x h)	Part time (90h total)	20 weeks of work (800h)				
Weeks (divided)			1-4	5-8	9-12	13-15	17-20
Phases (main focus)	INTRODUCTION	PLANNING	INITIATION	ANALYSIS	EXPERIMENT	IMPLEMENTATION	COMMUNICATION
Focus	Overview MT-Toolbox Develop ideas	Collect data Refine ideas Thesis question	Define economy Calculation-tools Context & framework	Study case/site Create concept and begin experiments	Design changes, calculations and comparisons	Finalize/Synthesize Design proposal Artistically articulate	Last changes Communication Pedagogy
Outcome	Direction choice	Project plan	Familiar with collected data, tools and case	Concept Case study analysis First experiments	Chose optimized experiments Draft drawings	Combine experiments in design proposal Draft Report	Presentation material

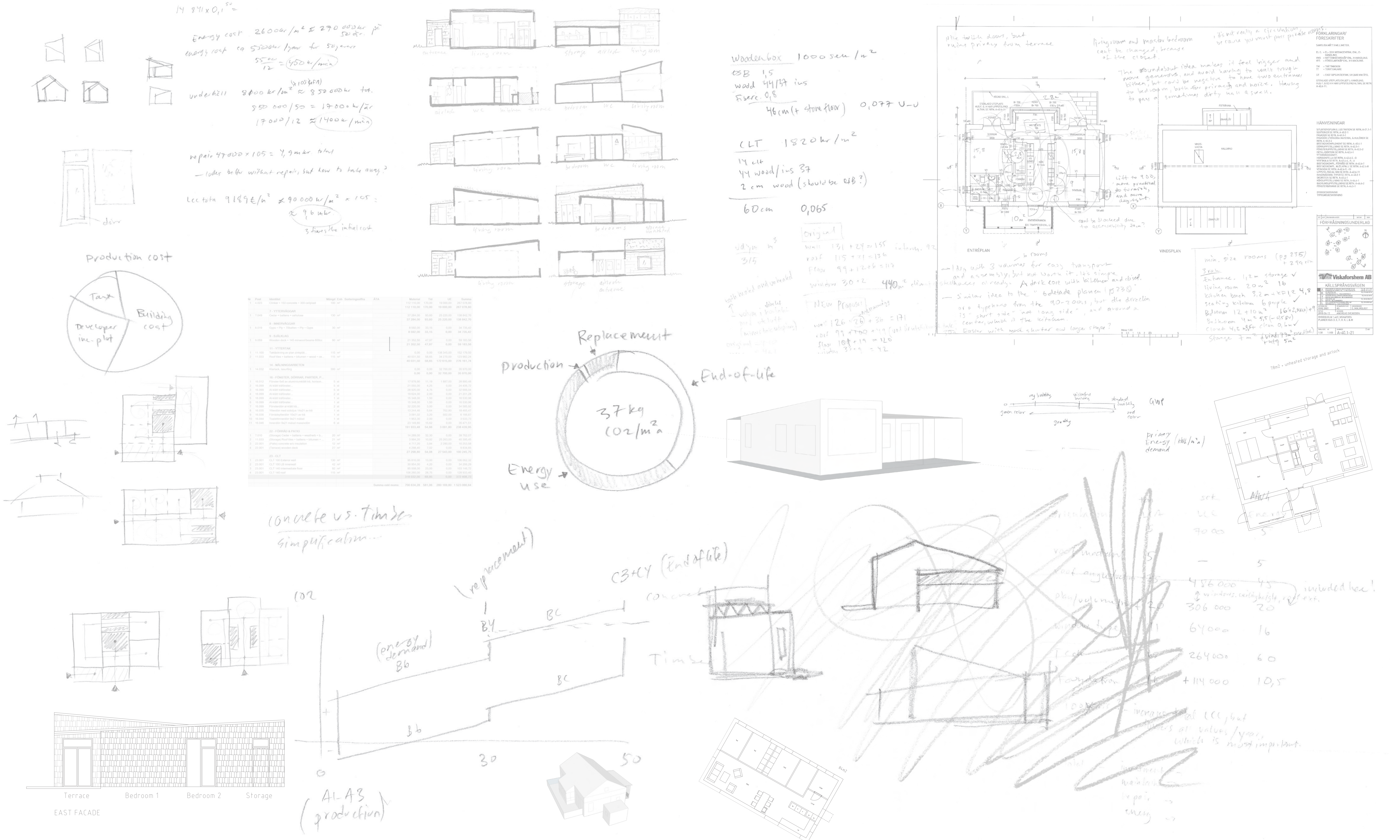
We are here!

METHOD

(thematic workflow estimation)



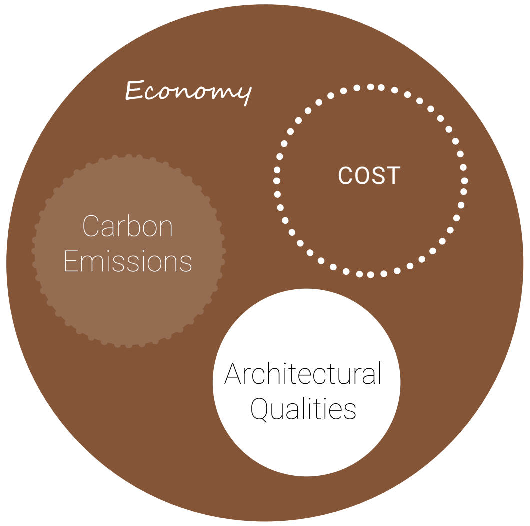
Dates	Sept [2020]	Okt-Dec (2020)	Jan	Feb	March	April	May
Deadlines	4 Understand MT 4 Prel. Choice 8 Positioning 10 Knowledge Development 11 Methods 15 Prep. Interview 18 Feedback 18 Evaluation 18 Final draft 18 Final choise	7/10 Present idea 26/10 Interview 28/10 Interview 11/11 Midcritic PP1 12/11 Interview 23/11 Interview 24/11 Interview 18/11 PP2 Handin 4/12 Interview 10/12 Interview 9/12 PP3 Handin	13 PP4 (100%) ● 18 Official start (M)	1 UN SDGS (Web) 2 Climate adaptation (Web) 3 Circularity (Web) 8 Case study visit 12 Interview 15 Tutorial 22 LCA course 22 Tutorial	4 Pre-midterm (M) 10 Tutorial ● Midterm 17 Abstract (50%) 17 Booklet (50%) 22-26 Mid-sem (S) 29 Tutorial	8 Tutorial 12 Interview 19 Pre-final (M)W 28 Tutorial	6 Tutorial 10 Booklet (90%) 12 Abstract (100%) 18-20 FinalSeminar presentation (98%) 28 Exh. setup ● 31-3 OpenSeminar Exhibiton (100%) 4 Final handin + Evaluation 7 Exh. setdown


14 841 x 0,1^50 =
Energy cost 2600kr/m² ≈ 270 000kr på 50 år.
energy cost ca 5500kr/year for 50 years
5500/12 = 450 kr/mån
underhåll 8000 kr/m² (x105 BFA) ≈ 850 000kr tot.
850 000/50 = 17 000kr/år
17000/12 ≈ 1400kr/mån
repair 47000 x 105 = 4,9mkr total
— looks better without repair, but how to take away?
Lcc tota 9189€/m² ≈ 90 000kr/m² x 105 =
≈ 9,6 mkr
3 times the initial cost
door
Production cost
Tax
Building cost
Developer inc. plot
entrance
living room
storage
airlock
WC
kitchen
bedroom
Woodenbox 1000sek/m²
OSB 1,5
wood 44/37 ins
Fibercement 0,8
46cm (+ stone floor) 0,077 U-v
CLT 1820kr/m²
14 clt
44 wood/ins 37
2 cm wood (should be OSB?)
60cm 0,065
Original
volym m³
315
wall 131 + 24 = 155 interm. 92
roof 115 + 21 = 136
Floor 99 + 12 + 6 = 117
window 30 + 2
440m² climate shell
NEW Proposal
wall 126 + 26 + 36 = 171
roof 97 + 100 + 49
floor 101 + 19 = 120
window 33 + 9 = 42
Nice with doors, but ruins privacy from terrace
livingroom and master bedroom cant be changed, because of the closet.
it's not really a circulation, because you must pass private rooms.
The roundabout idea makes it feel bigger and more generous, and avoid having to walk trough kitchen, but could be negative to have two entrances to bedroom, both for privacy and noise. Having to pass a sometimes dirty hall aswell.
28m²
15,8
10m²
cant be blocked due to accessibility 70cm?
ENTRÉPLAN
VINDSPLAN
6 rooms
→ Idea with 3 volumes for easy transport and assembly, but not worth it. It's simple shellhouses already. A dark core with kitchen and closet.
— Similar idea to the "6delade planen (pg 238)" or a typehouse from the 90-2000s, but the direction is "short side" not "long side", and around a center, which is the kitchen.
Easier with ~~more~~ shorter and longer shape?
min. size rooms (pg 235) + 299 kn
3 rok
Entrance. 1,2m storage ✓
living room 20m² 16
kitchen bench 3,2m + KF 1,2 4,8
seating kitchen 6 people ✓
Bedroom 12 + 10m² 16 + 2,8 kök + 9
Bathroom 4m² 5,5 (−0,5 BV)
Closet 4,2 m 3,5 + clean 0,6 m ✓
Storage 7m² + vind 77m² + snedtak + utg 5m²
FÖRKLARINGAR/ FÖRESKRIFTER
HÄNVISNINGAR
FÖRFRÅGNINGSUNDERLAG
Viskaforshem AB
KÄLLSPRÅNGSVÄGEN
78m2 + unheated storage and airlock
my building
viskafors building
standard
GWP
green colour
red colour
Primary energy (kWh/m²a) demand
Replacement
production
End-of-life
37 kg CO2/m²a
Energy use
concrete vs. timber
simplification...
CO2
(replacement)
C3+C4 (End of life)
concrete
Timber
B4
BC
(energy demand) B6
B6
0
30
50
A1-A3 (production)
sek
LCC
7000
5
roof material
5
roof angle/volume
486 000 45
windows, ceilingheight, roof ext.
included here!
plan/volume/roof
306 000 20
window type
64000 16
Tech
264000 6 0
Foundation
+114 000 10,5
100 Y
increase total LCC, but lowers all values/year, which is most important.
investment
maintenance
repair
energy
Energy
84m2
Terrace
Bedroom 1
Bedroom 2
Storage
EAST FACADE

Källsprångsvägen One out of 13
type houses Size 84m2 NFA
Photo Robin Hayes

CONCEPT

DESIGN EXPERIMENTS
ON CASE STUDY
[change volume & materials]

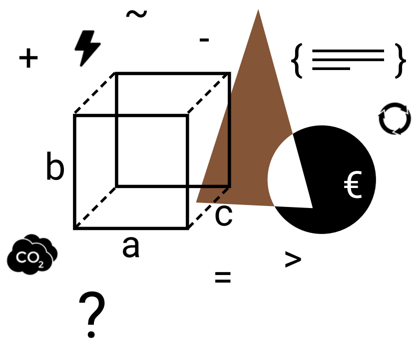


PARAMETERS

Life Cycle Costs (LCC)
Cost, €/m2 GFA

Life Cycle Analysis (LCA)
[Carbon Emissions,
kg CO_2-eq/m²a]

Architectural Qualities
[Space]
[Proportion]
[Functionality]
[Materiality]



NEW DESIGN PROPOSAL
[Combine the best experiments]

MOTIVATION

LIFECYCLE COST

"During new production it is important to make wise consideration between production cost, operation and maintenance costs. Too often, only the production cost is regarded (...).

(Dahlberg & Norrbrand, 2003, p. 7).

LIFE CYCLE ASSESSMENT

"LCA (...) can help identify the largest environmental impact reduction opportunities throughout a building's life cycle".

(Eberhardt et al., 2021, p.2)

ARCHITECTURAL QUALITIES

"20% put up a wall between kitchen and living room, while 20% did the opposite to open up the apartment"

(Nylander et al., 2019, p.148)

THE CASE STUDY

PROJECT: 13 detached rental villas of 84m^2.
Källsprångsvägen, Viskafors. Year 2020.
CLIENT: Viskaforshem AB
ARCHITECT: Brunnberg & Forshed
CONTRACTOR: Fristad Bygg

WHY VISKAFORSHEM?

CASE STUDY VISIT

[8 FEB 2021]

Rental villa 84m^2

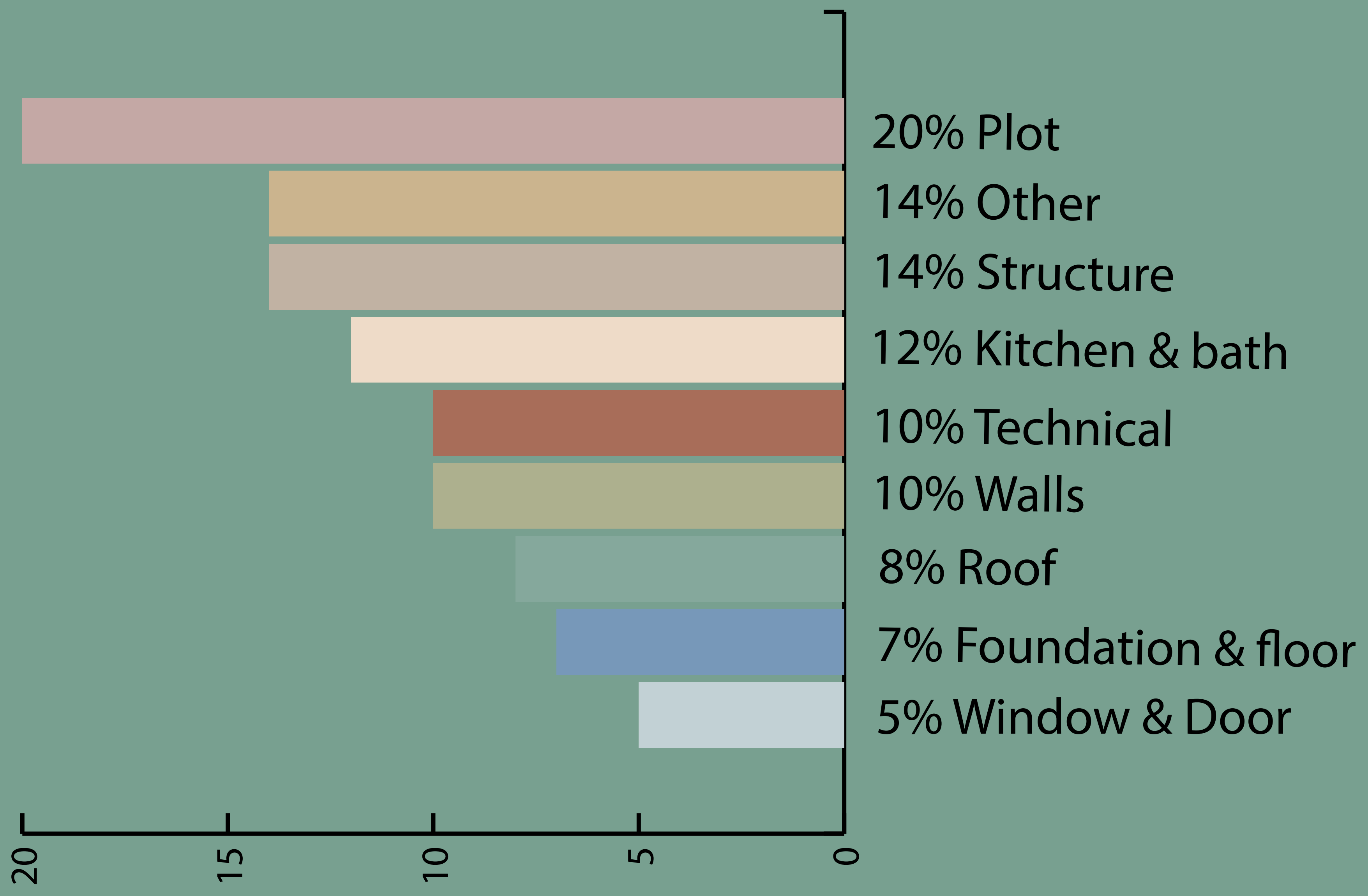
Rent 10 000 SEK/month + ca 2000 SEK energy use

PRODUCTION COSTS

Prices include work hours, ex. VAT
€ currency
10

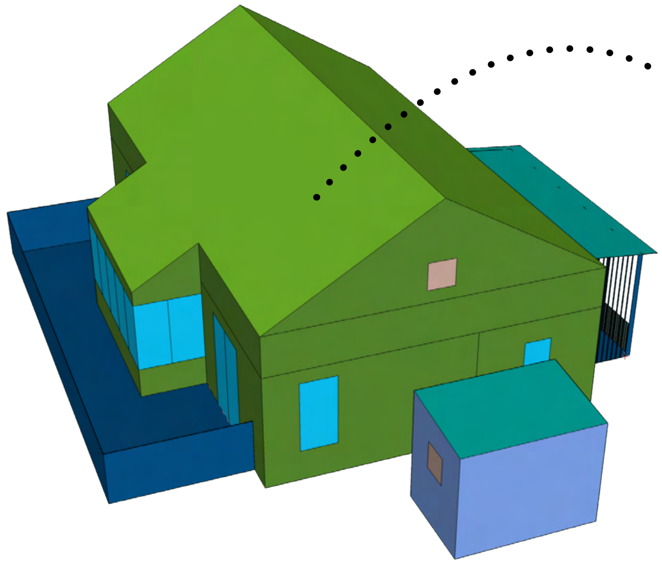
Building part	Specifications	Price total (TSEK)	m2	Price (SEK/m2)	Price (€/m2)
Land	Plot, infrastructure	710 000	-	-	71 000 €
Load-bearing structure	Cross-laminated timber (CLT)	500 000	380	1316	132 €
Kitchen and appliances	Solid wood, metal and natural stone	290 000	-	-	29 000 €
Roofing	Rheinzink or brick tiles	240 000	136	1765	176 €
Exterior wall	Cedar shingles, cellulose insulation	225 000	130	1731	173 €
VVS-installations	Geo. Heatpump, floor heat, FTX	200 000	-	-	20 000 €
El-installations	Normal, behind CLT	170 000	-	-	17 000 €
Bathroom	Wall finish, appliances	150 000	-	-	15 000 €
Unheated spaces	Storage, patio, terrace structures	125 000	-	-	-
Foundation	Concrete, EPS insulation	110 000	118	932	93 €
Flooring	Stone clinker, glue	100 000	100	1000	100 €
Windows	Wood-alu 2+1, openable vertical	90 000	30	3000	300 €
Doors	Inside and outside, high quality	75 000	15	5000	500 €
Inner walls	Standard gypsum solutions	70 000	30	2333	233 €
Paint	Painting directly on CLT	40 000	260	154	15 €
Other	Establishment, planning, expenditure, supplement charge, risk, salaries etc	500 000	-	-	50 000 €
	Total investment	3 595 000 SEK			359 500 €

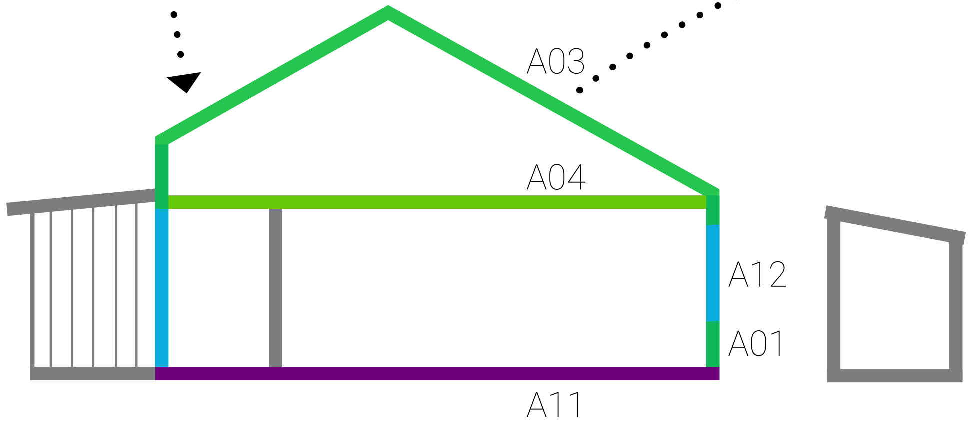
PRODUCTION COSTS



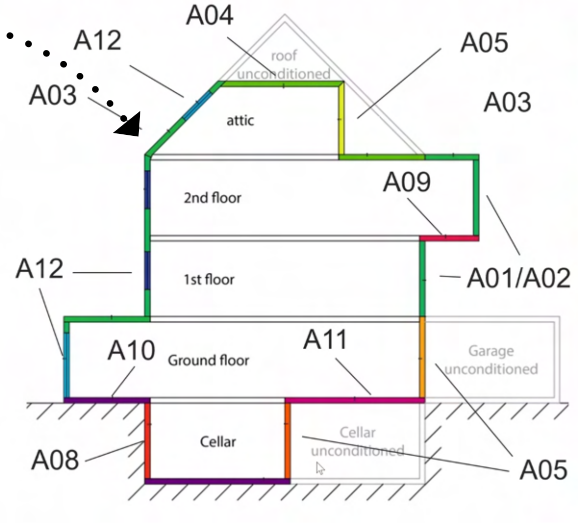
CAALA

Computer Aided Architectural Life-cycle Assessment

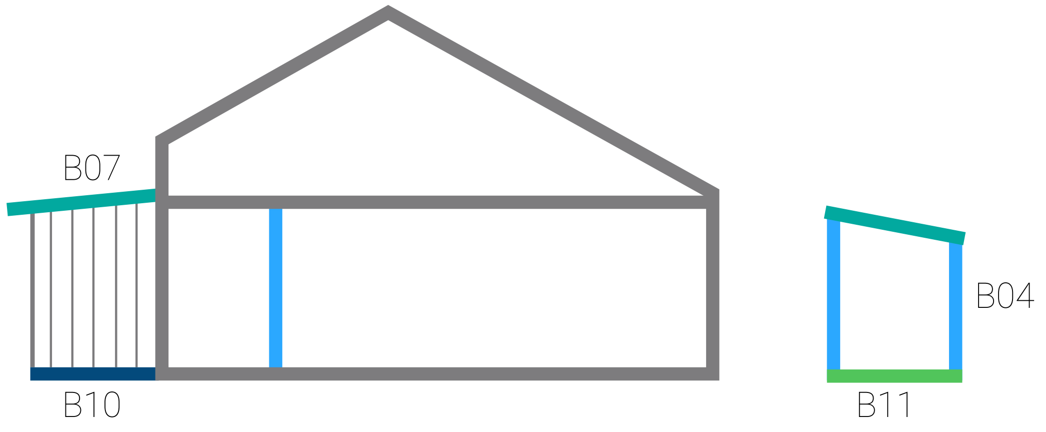




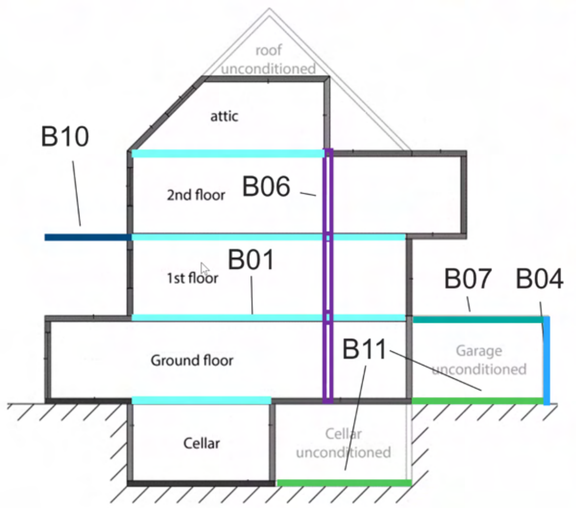
Layers A preliminary planning phase



Layer	Building-Part
A01	Wall to exterior load-bearing
A02	Wall to exterior non load-bearing
A03	Roof
A04	Ceiling to unheated space
A05	Wall to unheated space
A08	Wall to ground
A09	Ceiling over outdoor air
A10	Floor to unheated cellar
A11	Floor to ground
A12	Window



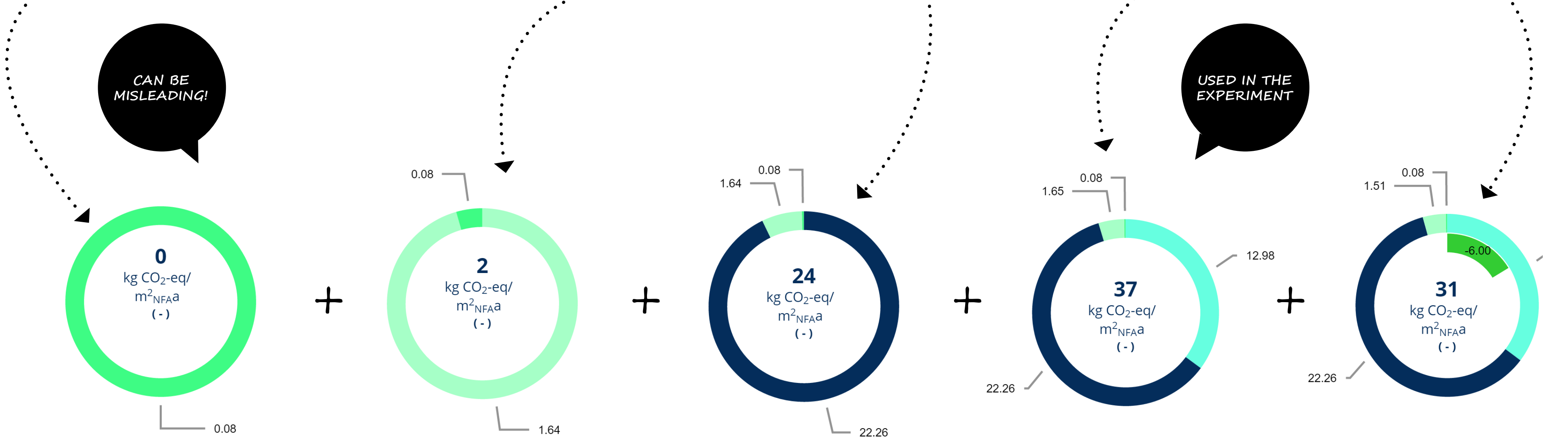
Layers B preliminary planning phase

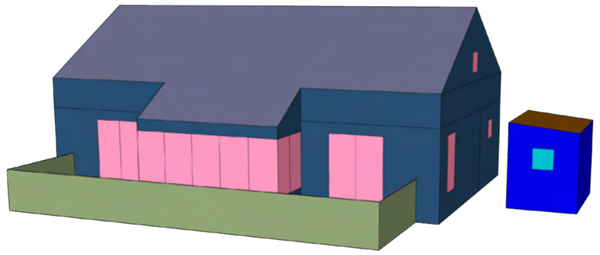


Layer	Building-Part
B01	Ceiling
B04	Wall (unheated rooms)
B06	Columns
B07	Roof (unheated room)
B10	Balcony
B11	Floor (unheated rooms)

LIFECYCLE STAGES

PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARIES
Raw material supply	Transport	Manufacturing	Transport from the gate to the site	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**	**D**
A1-A3								B4		B6				C3+C4		D

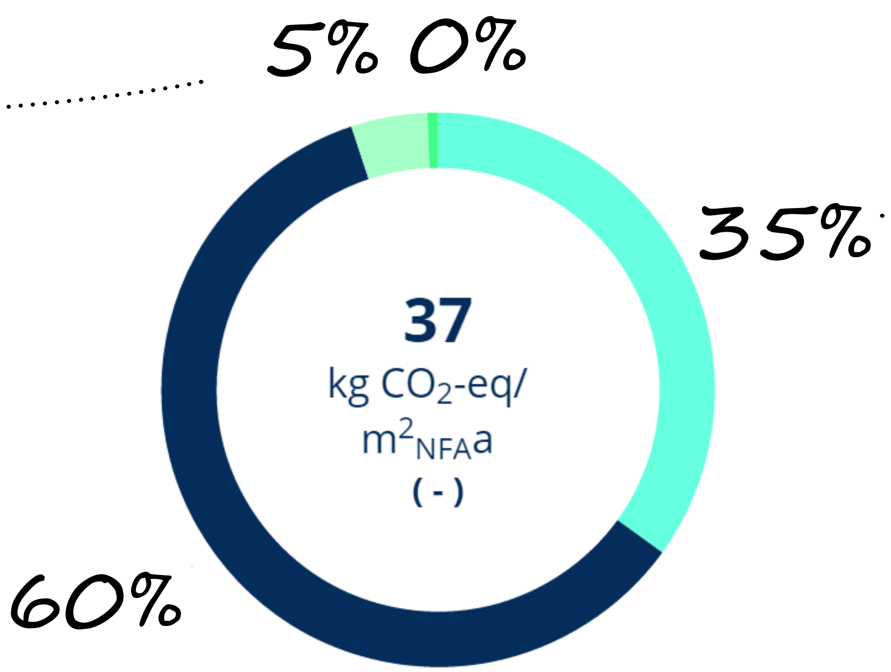




REF. AREA 100m²
NFA 84m²

LIFECYCLE ASSESSMENT

37 $kgCO_2$ x 100m² x 50 years = 185 ton CO_2



A1-A3 Production

DGNB System
(German Sustainable Building Council)
Database Ökobau.dat (2016)

C3+C4 End-of-life

DGNB System
(German Sustainable Building Council)
Database Ökobau.dat (2016)

B4 Replacement

MATERIAL LIFESPANS IN MODELLING

BELOW 50 YEARS: Painting 15 years, Construction wood varies, Windows 30 years, Wood terrace 30 years

50 YEARS: Interior walls (lasts longer, but is often replaced), Tar paper below roof, Technical system (TGA)

75-100 YEARS: Doors, Cedar Facade, Stone clinker flooring, Roof cladding, Cellulose insulation, Intermediate floor

NEVER REPLACED IN CAALA Foundation (concrete, EPS, XPS), Load-bearing structure (CLT)

NOT INCLUDED IN THIS LCA Bathroom, kitchen, furnitures and other details. Focus is major building parts.

B6 Energy demand in use

GEOGRAPHY

New construction - Single family house
Region 10 - Hof (area in Germany similar to our climate)

TECHNICAL EQUIPMENT

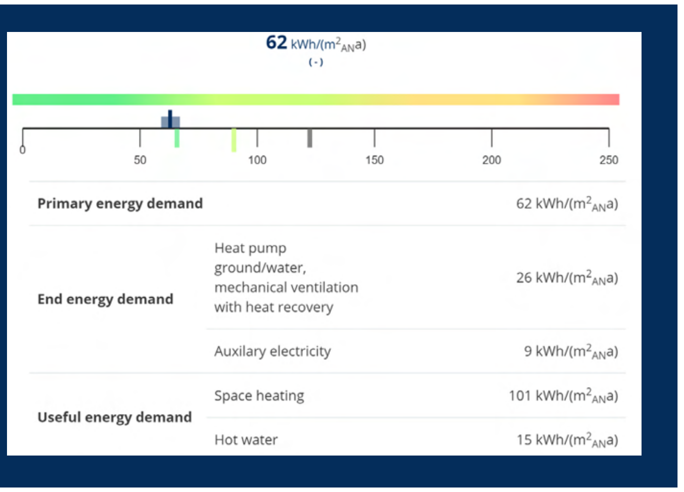
Heatpump, ground/water
Mechanical ventilation (FTX)
Floor heating.
CO_2 intensity 530gramCO_2/kWh

BUILDING PERFORMANCE

Average floor height 3m (floor-floor)
Thermal bridge "enhanced 0,05 W/m2K" (medium)
Air tightness "new construction - general n50=4h^{-1}" (medium).

U-VALUES

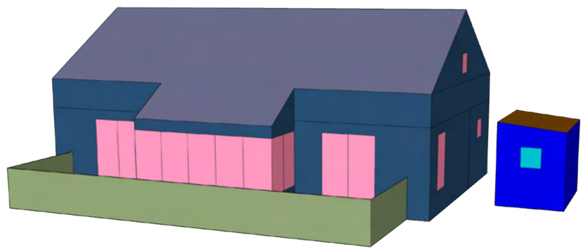
Average climate shell 0.21
Foundation 0.125
Wall 0.158
Roof 0.073
Window 0.9



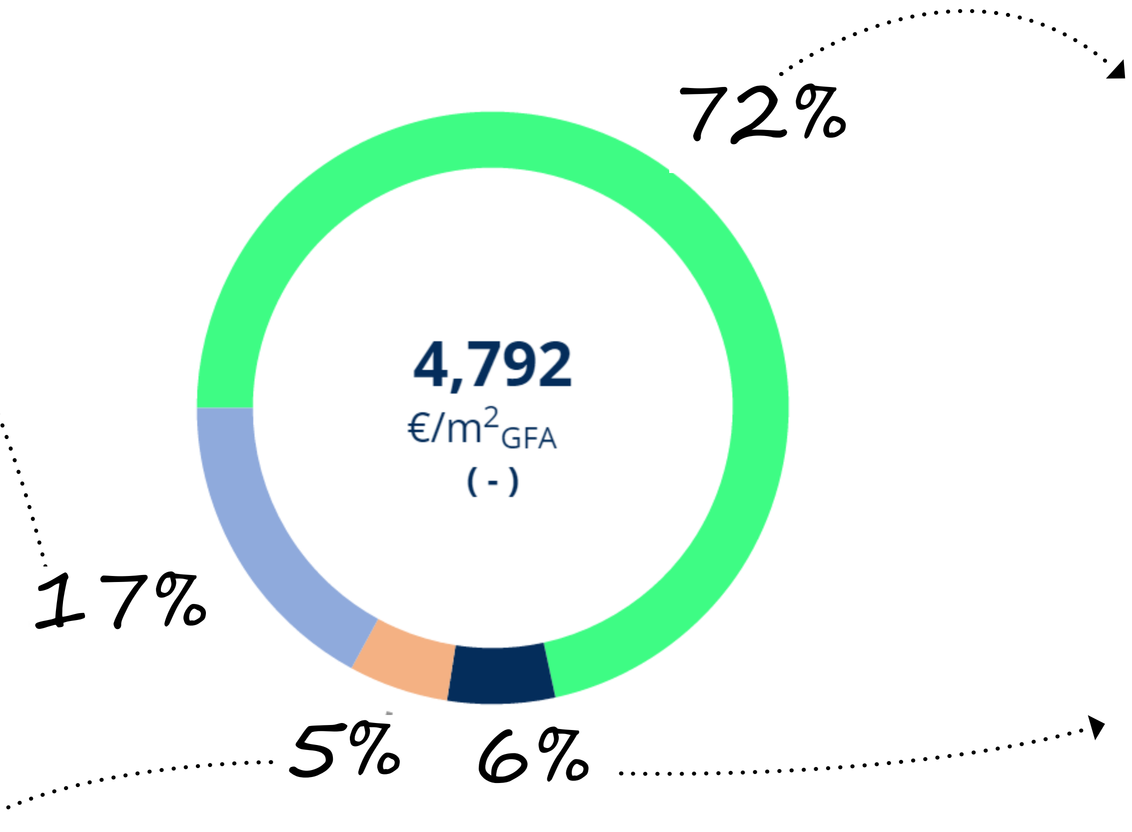
Primary energy demand		62 $kWh/(m^2_{AN}a)$
End energy demand	Heat pump ground/water, mechanical ventilation with heat recovery	26 $kWh/(m^2_{AN}a)$
	Auxilary electricity	9 $kWh/(m^2_{AN}a)$
Useful energy demand	Space heating	101 $kWh/(m^2_{AN}a)$
	Hot water	15 $kWh/(m^2_{AN}a)$

LIFECYCLE COST

$$4792€ \text{ X } 10\text{SEK X } 100\text{m}2 = \frac{\underline{4\ 792\ 000 \text{ SEK}}}{50 \text{ years}} = 96\ 000 \text{ SEK/year}$$



REF. AREA 100m²
NFA 84m²



🟩 Investment costs

PRODUCTION COST
ex VAT and incl work hours

Estimation from client, contractor, producers and calculation softwares (wikells)

🟦 Repair

EXPONENTIAL %-INCREASE/YEAR
based on the investment cost, and the energy costs.

BUILDING REPAIR
0,35%.

TECHNICAL REPAIR
0,66%.

🟧 Maintenance & Replacement

EXPONENTIAL %-INCREASE/YEAR
based on the investment cost, and the energy costs.

BUILDING MAINTENANCE
0,1%

TECHNICAL MAINTAINANCE
0,41%

■ Energy costs

INITIAL PRICE FOR ELECTRICITY
0,12 €/kWh (ex Vat)

ENERGY PRICE INCREASE
2%/year

DISCOUNT RATE FOR INFLATION
1 %/year

SUMMARY
1,2 SEK/kWh with 1% cost increase each year of the building's lifetime.

This cost is not only for energy use but also general costs like repair and maintenance. Sweden has very low energy cost compared to the EU and Germany.

EXPERIMENTS

Case study Wooden rental villas, Källsprångsvägen, Viskafors
Year 2020 Developer Viskaforshem
Architects Brunnberg & Forshed
Photo Robin Hayes

1. VOLUME EXPERIMENTS

LIFESPAN
25-50-75-100 years

ORIENTATION
Placing houses on the site

ROOF
Pitched roof vs flat roof

PLAN & VOLUMES
Plans
Volume
Section
Facade

2. MATERIAL EXPERIMENTS

FOUNDATION
Concrete vs foamglas
Slab vs punctual

WINDOWS
Alu-Wood-PVC, including Vertical vs horizontal montage and Openable vs fixed

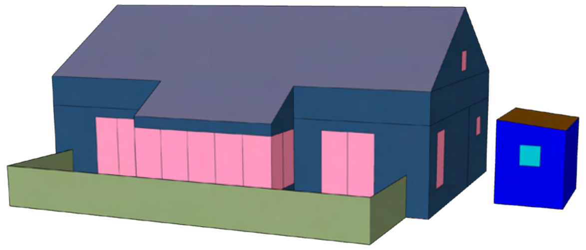
ROOF
Zink vs brick tiles

TECHNICAL
Heat pump vs pellets

3. SUMMARY & LEARNINGS

Final savings
Design strategies
Answer to research question

25 years

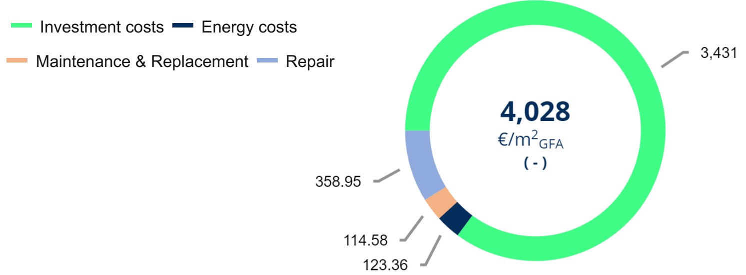


"25% of all buildings demolished in Sweden since 1980, were less than 30 years old" (Andersson & Nilsson, 2020, p.21).

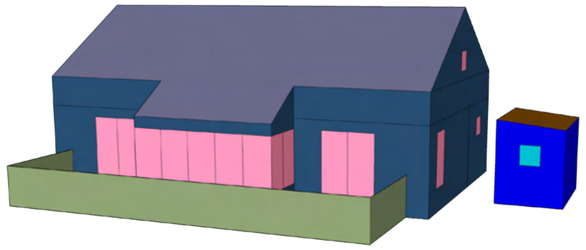
160 000 SEK/YEAR
13 000 SEK/MONTH
FOR 25 YEARS

BUILDING COST 85% OF TOTAL LCC

LIFE CYCLE COSTS

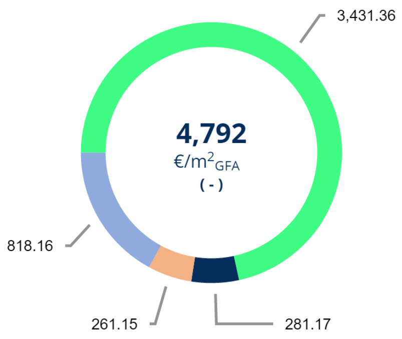


50 years (original)



96 000 SEK/YEAR
8000 SEK/MONTH
FOR 50 YEARS

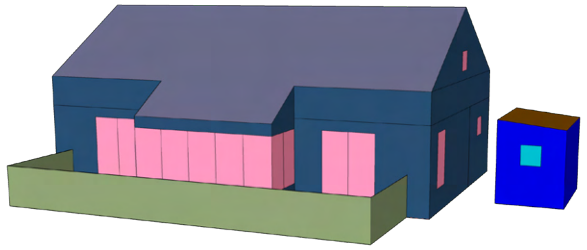
BUILDING COST 70% OF TOTAL LCC



Total cost 4 MSEK
96 000 SEK/YEAR
for 25 years

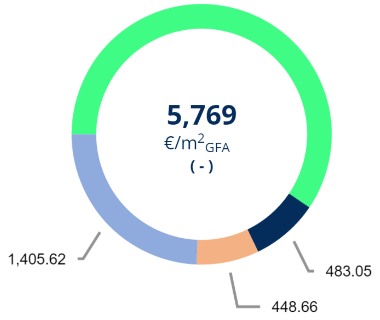
+764€/m²
+0,764 MSEK

75 years



77 000 SEK/YEAR
6400 SEK/MONTH
FOR 75 YEARS

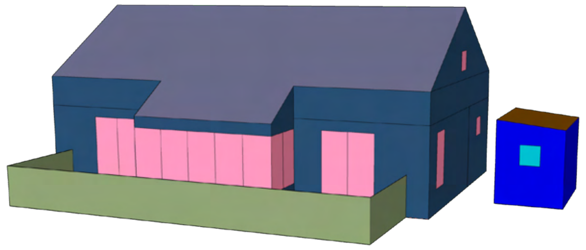
BUILDING COST 60% OF TOTAL LCC



Total cost 5,7 MSEK
77 000 SEK/YEAR
FOR 75 YEARS

+977€/m²
+0,977 MSEK

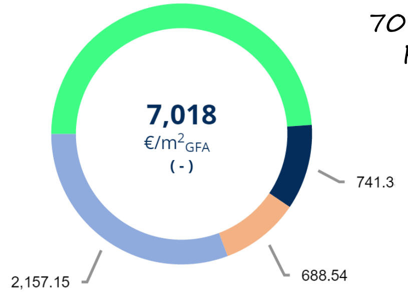
100 years



Paid the house twice over!

70 000 SEK/YEAR
5800 SEK/MONTH
FOR 100 YEARS

BUILDING COST 45% OF TOTAL LCC



Total cost 7 MSEK
70 000 SEK/YEAR
FOR 100 YEARS

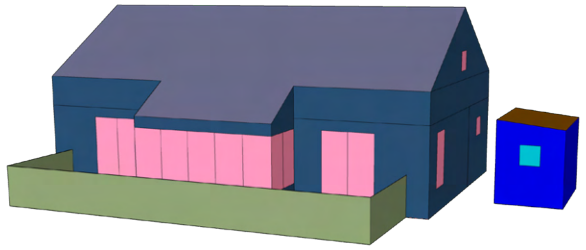
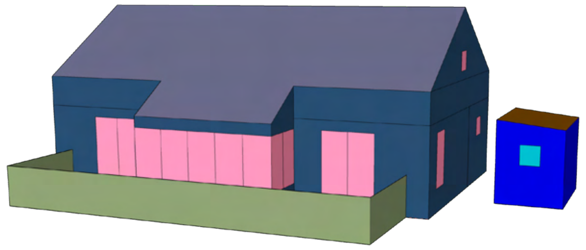
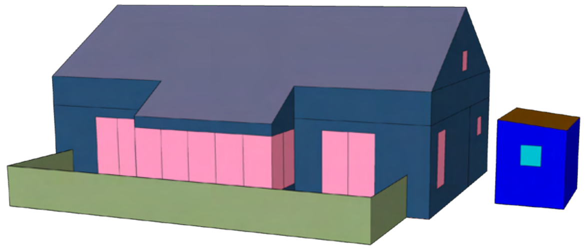
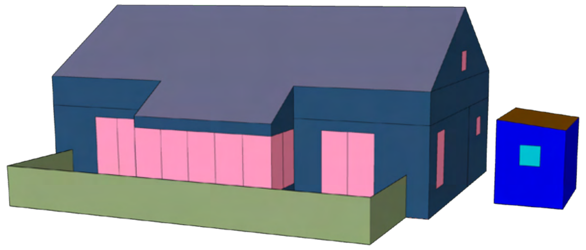
+ 2226€/m²
+ 2,22 MSEK

25 years

50 years (original)

75 years

100 years

"25% of all buildings demolished in Sweden since 1980, were less than 30 years old" *(Andersson & Nilsson, 2020, p.21).*

Paid the house twice over!

160 000 SEK/YEAR
13 000 SEK/MONTH
FOR 25 YEARS

BUILDING COST **85%** OF TOTAL LCC

96 000 SEK/YEAR
8000 SEK/MONTH
FOR 50 YEARS

BUILDING COST **70%** OF TOTAL LCC

77 000 SEK/YEAR
6400 SEK/MONTH
FOR 75 YEARS

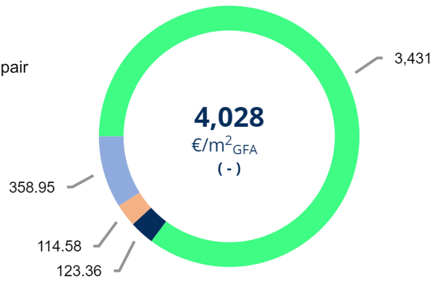
BUILDING COST **60%** OF TOTAL LCC

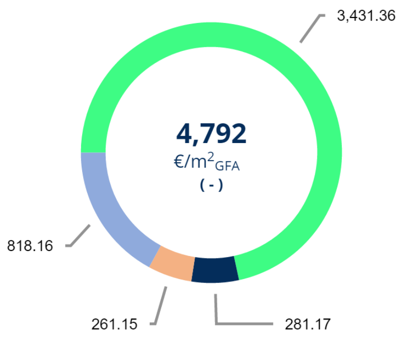
70 000 SEK/YEAR
5800 SEK/MONTH
FOR 100 YEARS

BUILDING COST **45%** OF TOTAL LCC

LIFE CYCLE COSTS

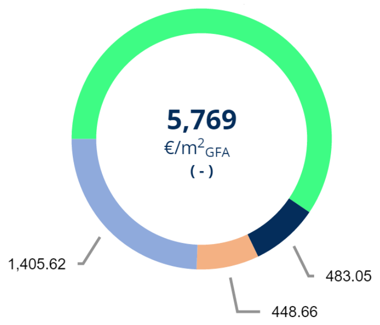
- 🟩 Investment costs
- ■ Energy costs
- 🟧 Maintenance & Replacement
- ▨ Repair





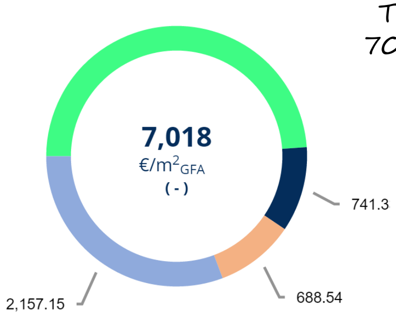
Total cost 4 MSEK
96 000 SEK/YEAR
for 25 years

+764€/m²
+0,764 MSEK



Total cost 5,7 MSEK
77 000 SEK/YEAR
FOR 75 YEARS

+977€/m²
+0,977 MSEK

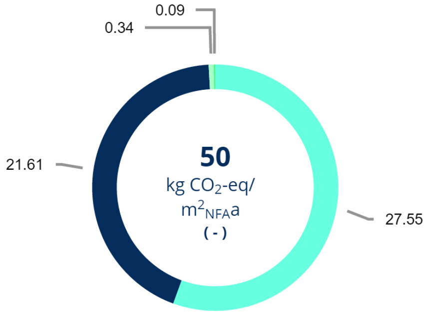


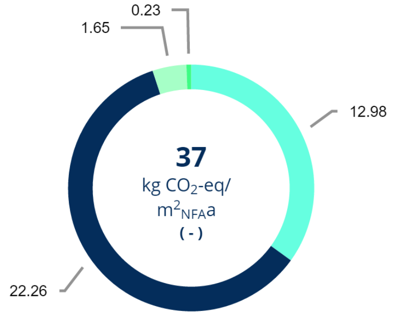
Total cost 7 MSEK
70 000 SEK/YEAR
FOR 100 YEARS

+ 2226€/m²
+ 2,22 MSEK

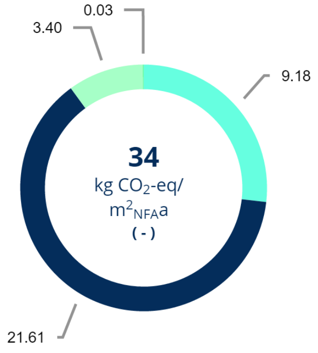
GLOBAL WARMING POTENTIAL (GWP)

- B4 Replacement
- B6 Energy demand in use
- C3+C4 End-of-life
- A1-A3 Production

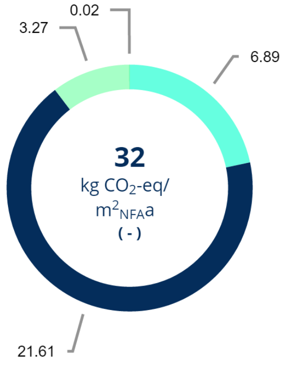




-12 kg CO_2
-1200 kg/year
-60 ton/50yrs

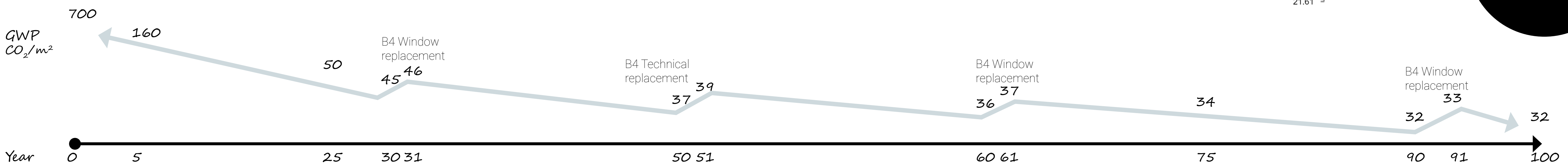


-1 kg CO_2
-100 kg/year
-5 ton/50yrs



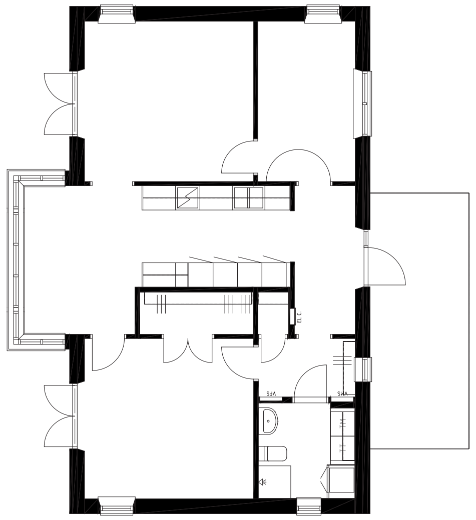
-3 kg CO_2
-300 kg/year
-15ton/50yrs

SAVE 36% CO_2 JUST BY PROLONGING THE LIFETIME!

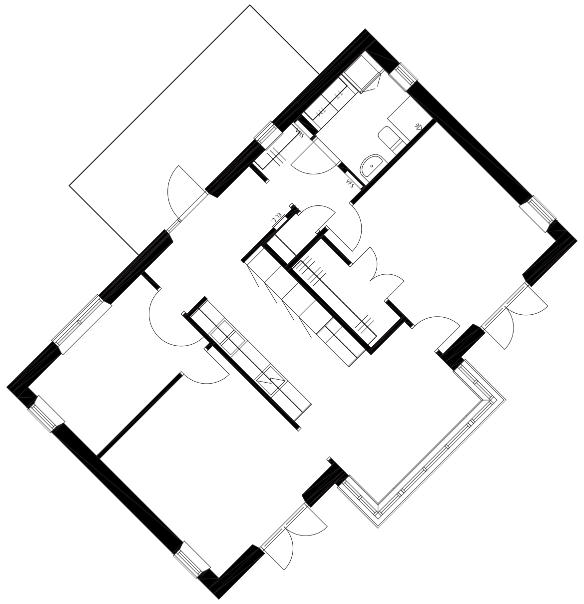


ORIENTATION COMPARISON

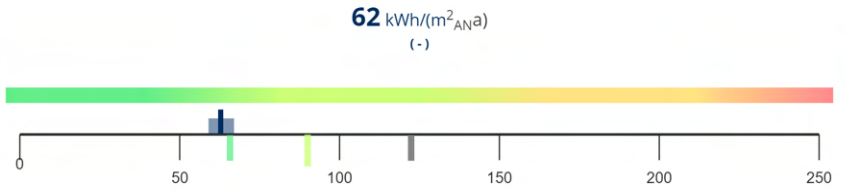
WEST

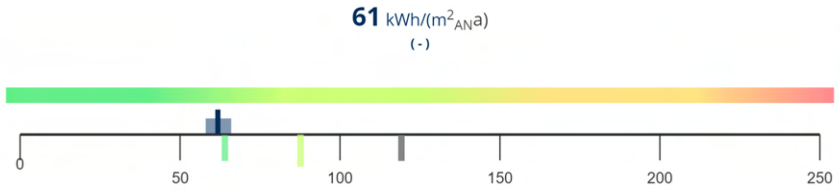


SOUTH-EAST



ENERGY DEMAND

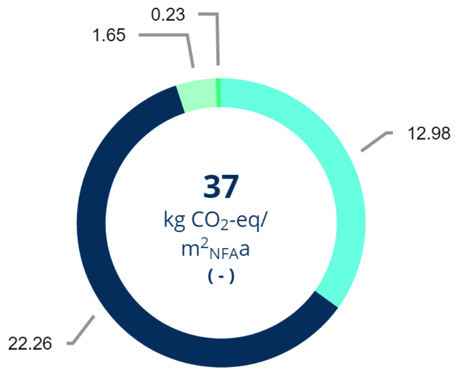


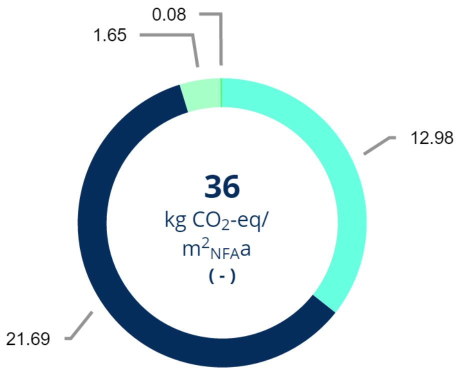


-1 kWh
-100 kWh/year
-5 MWh/50yrs

GLOBAL WARMING POTENTIAL (GWP)

- 🟩 B4 Replacement
- ■ B6 Energy demand in use
- 🟩 C3+C4 End-of-life
- 🟩 A1-A3 Production





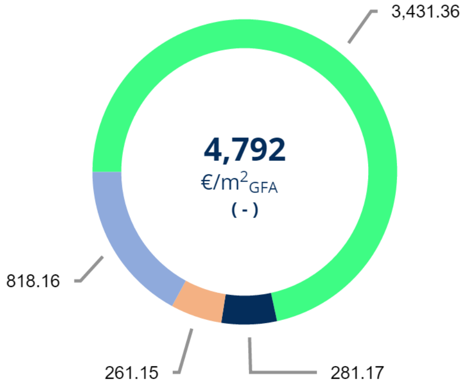
Kitchen renovation = 2,4 ton co$_2$

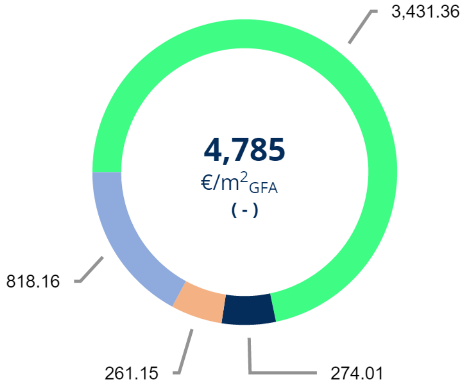
1 kg becomes 5 tons!

-1 kg CO$_2$
100 kg/year
5 ton/50yrs

LIFE CYCLE COSTS

- 🟩 Investment costs
- ■ Energy costs
- 🟧 Maintenance & Replacement
- 🟦 Repair

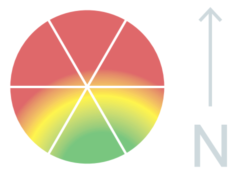




- 7€/m^2

-7 000SEK/50yrs
- Unnoticable change

ORIENTATION COMPARISON



Solar gains

- 🔴 Ineffective 7
- 🟡 Semi-effective 1
- 🟢 Effective 5

original

drawing by brunnberg & forshed

new

drawing by author

−5 tonCO$_2$
x 8 villas
= −40 tons

- Original road
- Rotated
- Back entrance

- Original road
- Rotated
- Mirrored
- South-west compromize

- Original road
- Rotated
- Mirrored

- Original road
- Rotated

- Original road
- Rotated

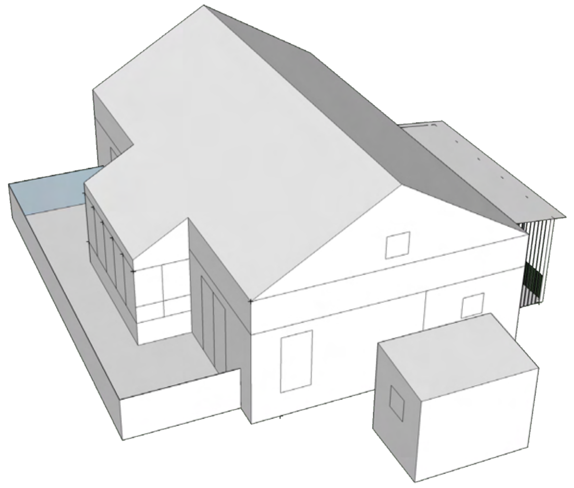
- Re-design road
- Rotated

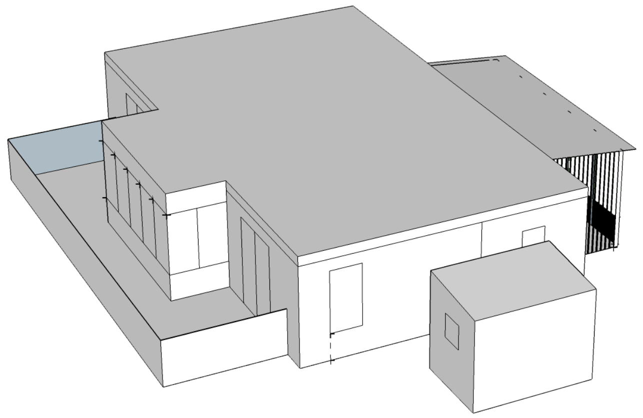
- Original road
- Rotated

- Re-design road
- Rotated

SOUTHERN TERRACES & LESS BORING REPETITIONS!

ROOF COMPARISON

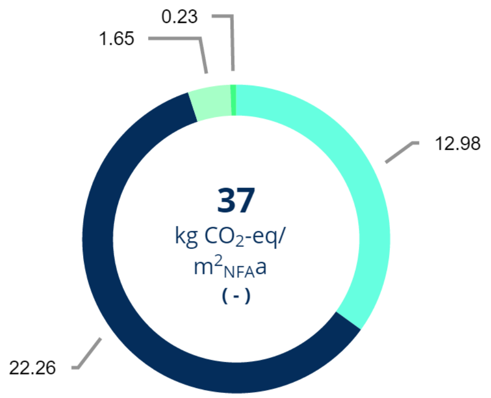


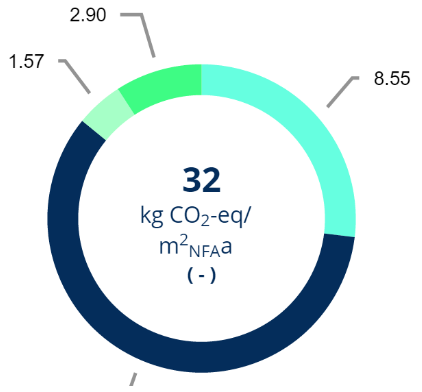


Saves 14% CO_2!

GLOBAL WARMING POTENTIAL (GWP)

- 🟩 B4 Replacement
- ■ B6 Energy demand in use
- 🟩 C3+C4 End-of-life
- 🟩 A1-A3 Production

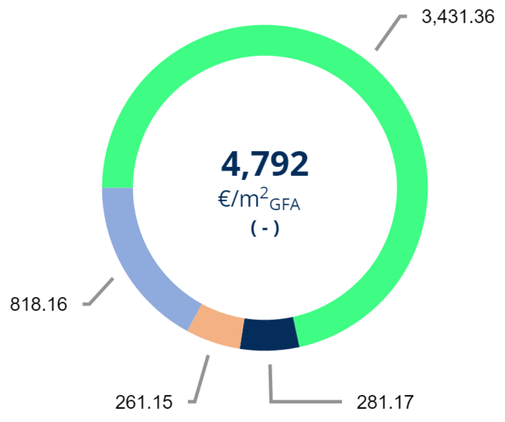


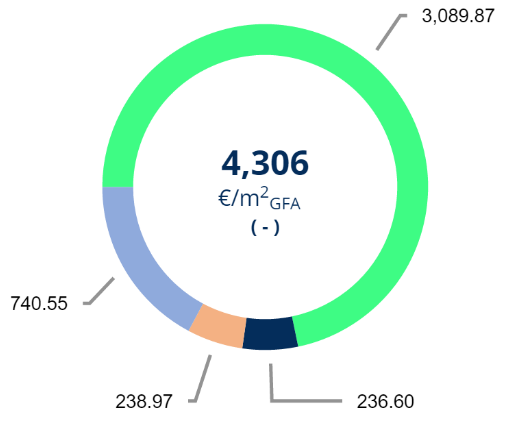


-5 kg CO_2
500 kg/year
25 ton/50yrs

LIFE CYCLE COSTS

- 🟩 Investment costs
- ■ Energy costs
- 🟧 Maintenance & Replacement
- 🟦 Repair

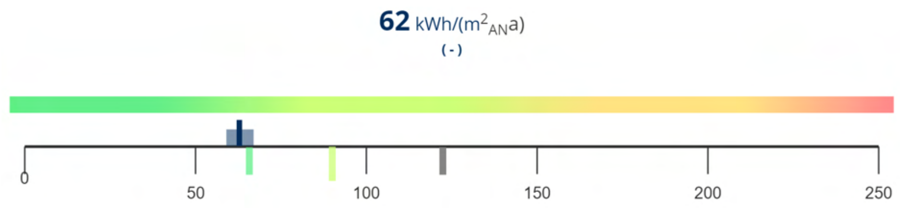


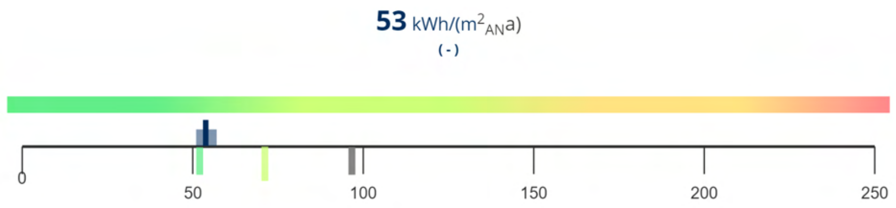


- 486€/m²
-486 000SEK/50yrs
- 9720 SEK/year
- 810 SEK/month

Saves 500 000 SEK!

ENERGY DEMAND





-9 kWh
-900 kWh/year
-45 MWh/50yrs

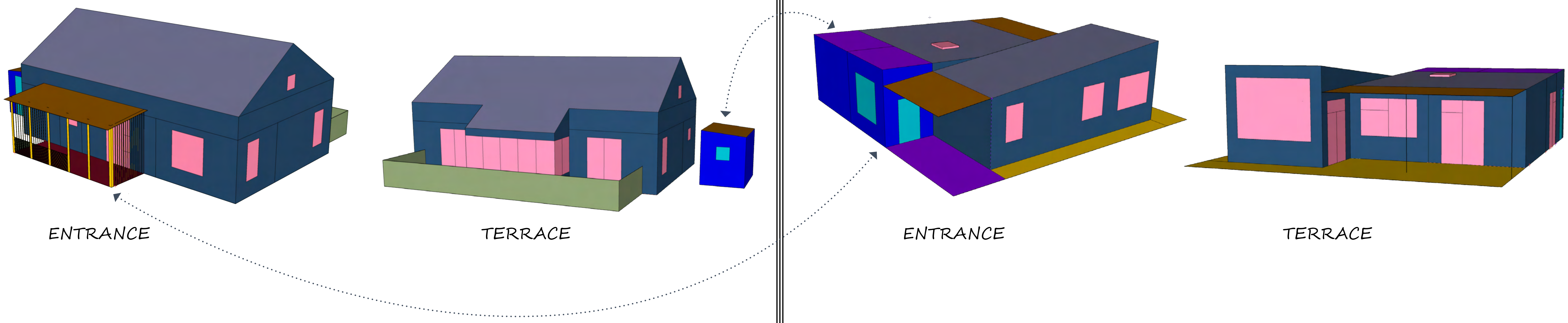
VOLUME COMPARISONS

original

drawing by brunnberg & forshed

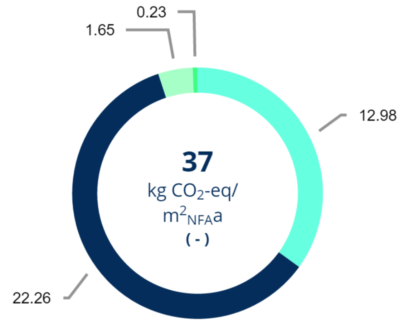
new

drawing by author



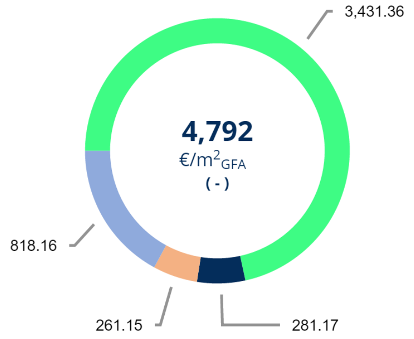
GLOBAL WARMING POTENTIAL (GWP)

- B4 Replacement
- B6 Energy demand in use
- C3+C4 End-of-life
- A1-A3 Production

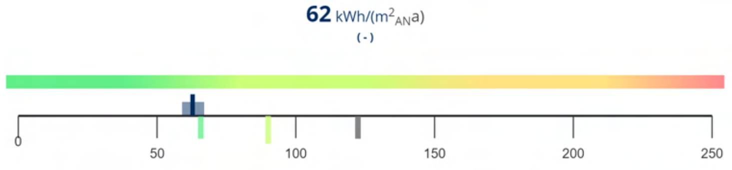


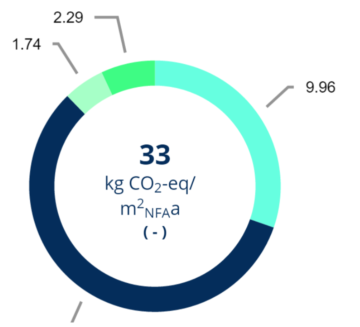
LIFE CYCLE COSTS

- Investment costs
- Energy costs
- Maintenance & Replacement
- Repair



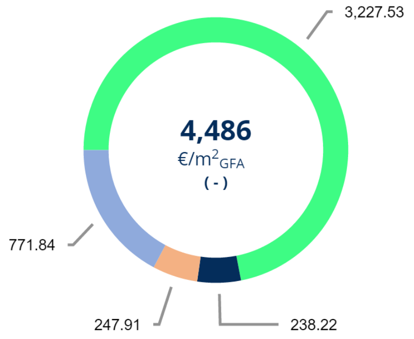
ENERGY DEMAND





-4 kg CO_2
400 kg/year
20 ton/50yrs

Same materials, new shape!

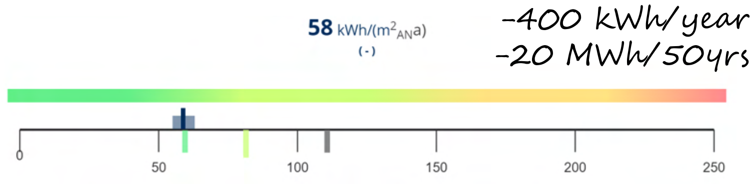


- 306€/m²

-306 000SEK/50yrs
- 6120 SEK/year
- 510 SEK/month

- 200 000 SEK IN BUILDING COST
- 40 000 SEK IN ENERGY
- 15 000 SEK IN MAINTAINANCE
- 50 000 IN REPAIR

OVER 50 YEARS TIME.

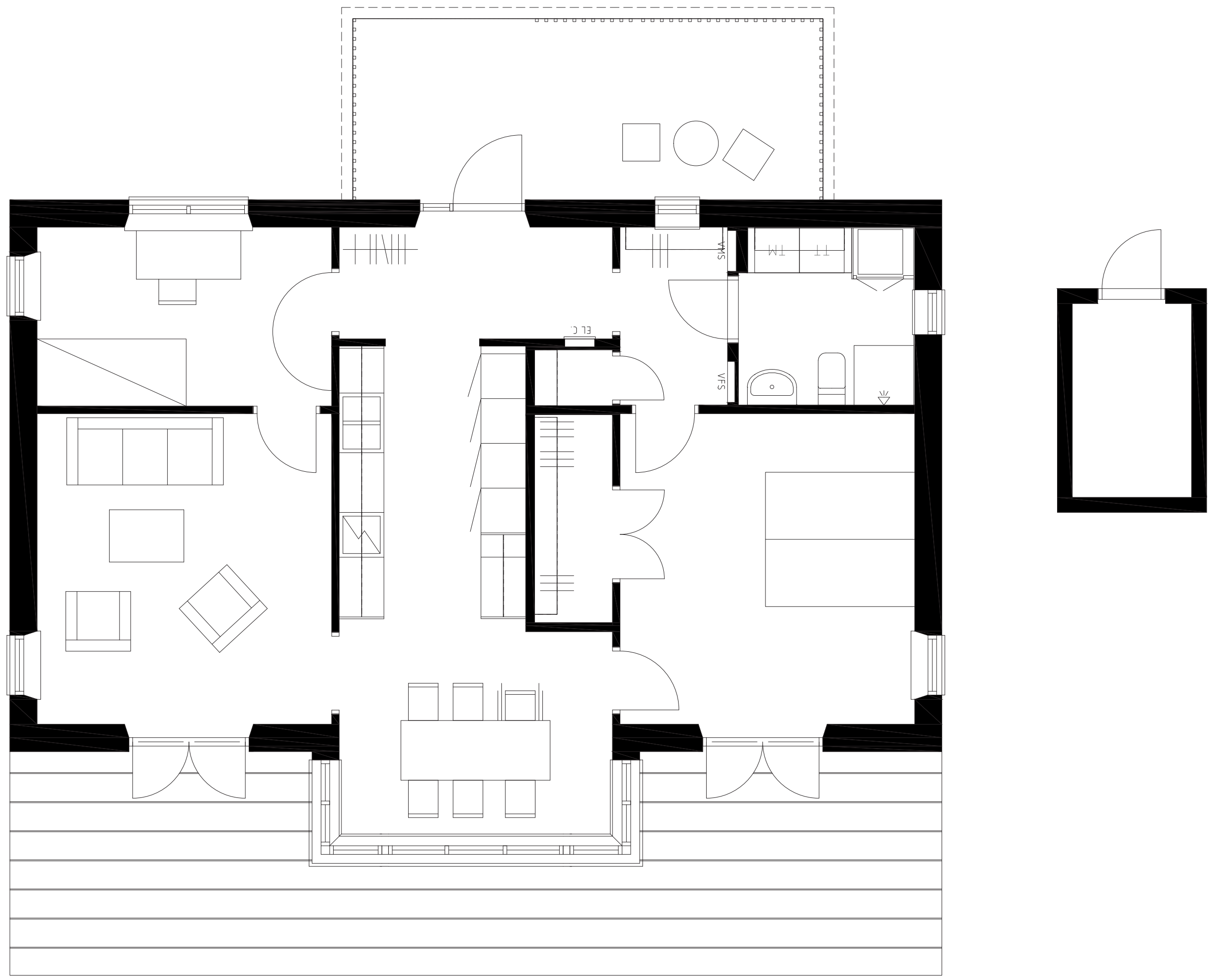


-4 kWh
-400 kWh/year
-20 MWh/50yrs

PLAN COMPARISONS

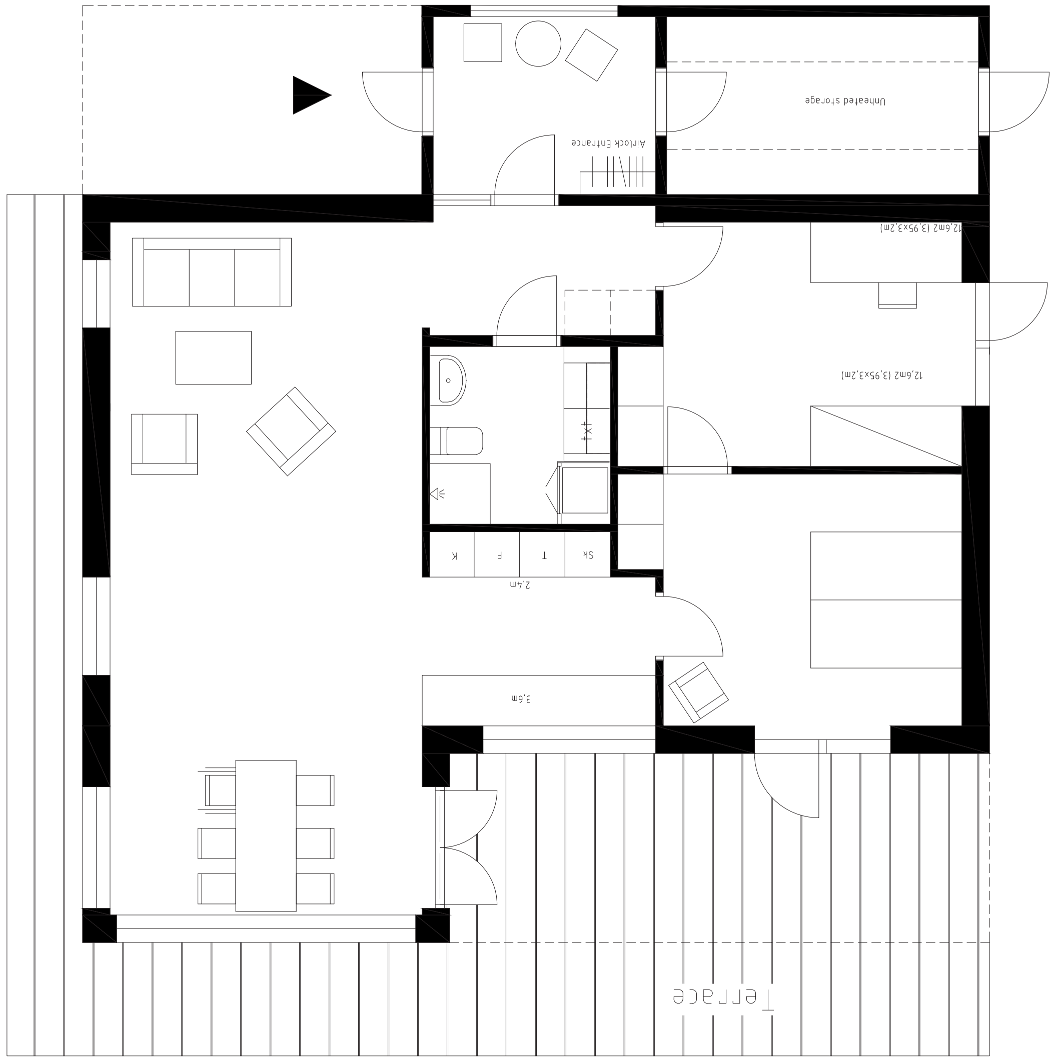
original

drawing by brunnberg & forshed



new

drawing by author

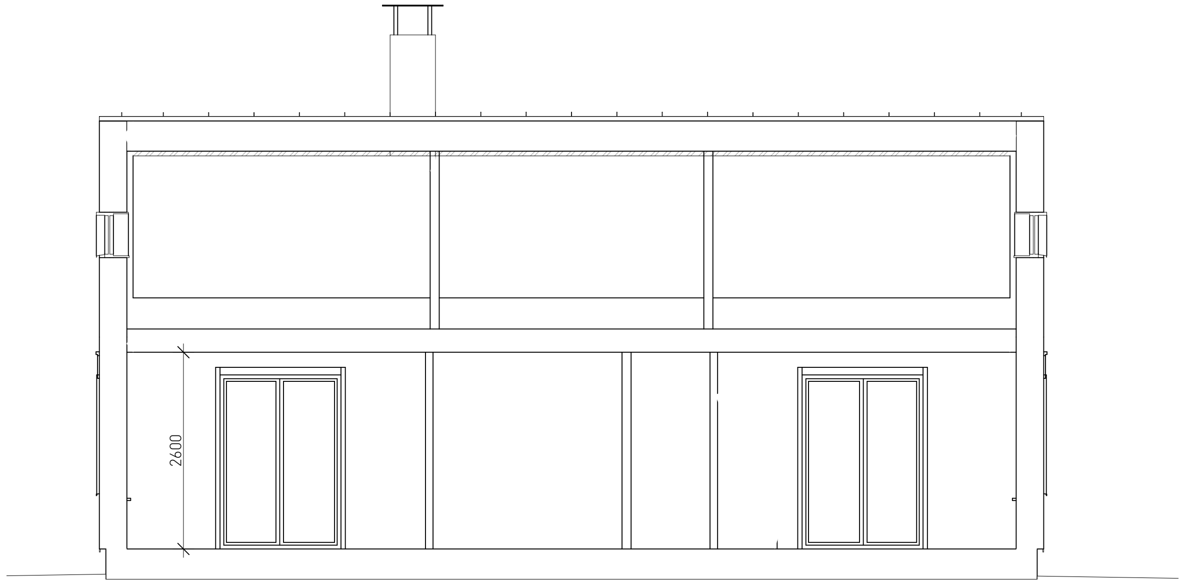


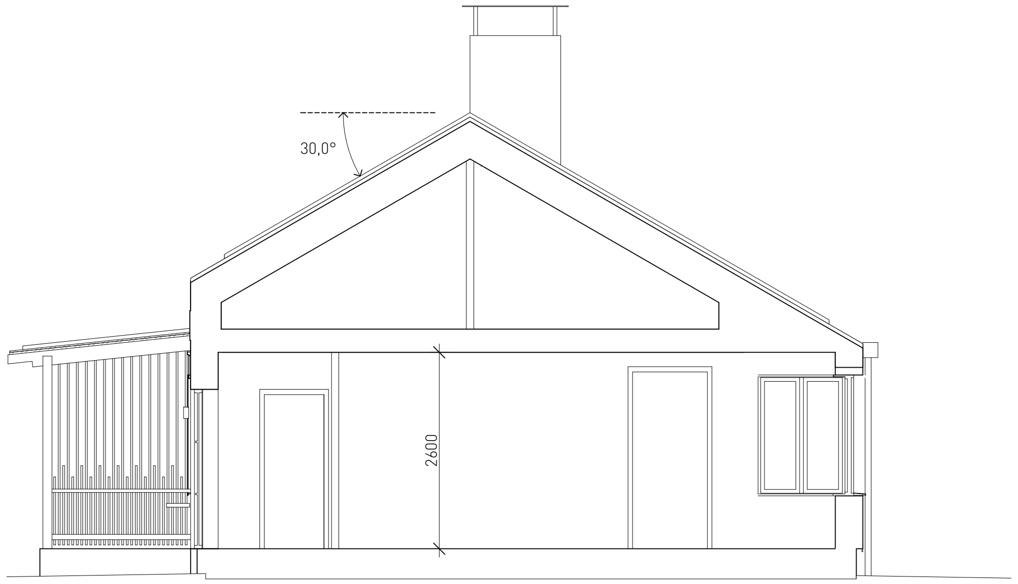
1:100 (A3)

SECTION COMPARISON

original

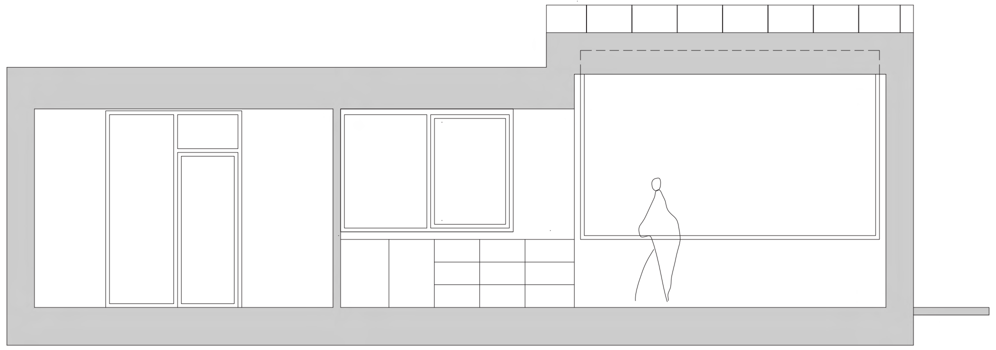
drawing by brunnberg & forshed



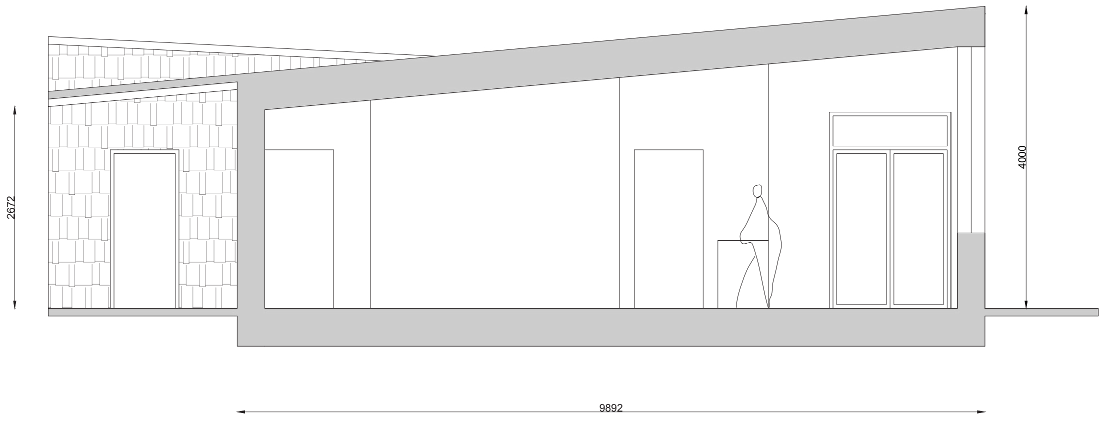


new

drawing by author



SECTION B-B

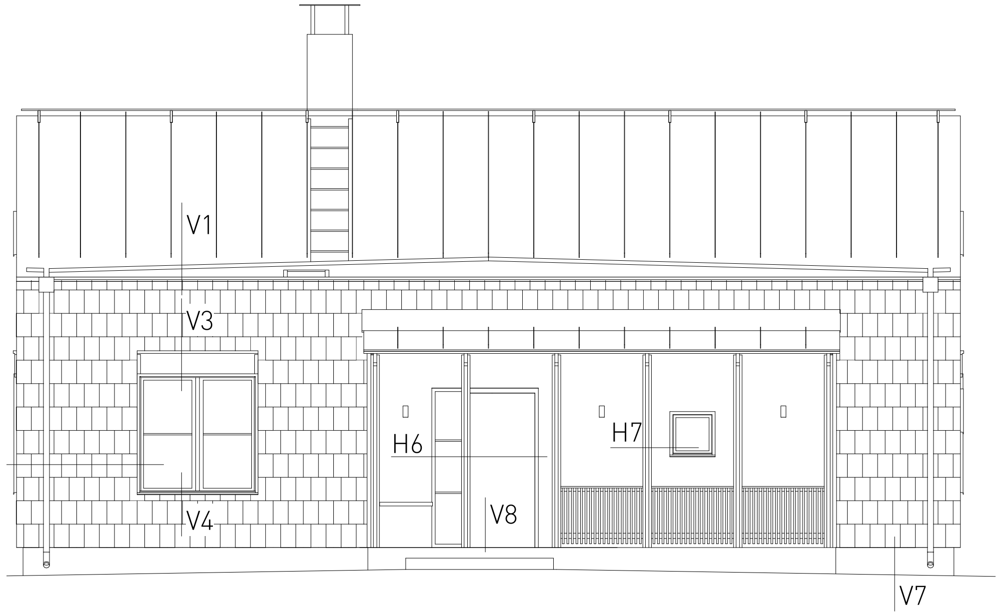


1:100 (A3)

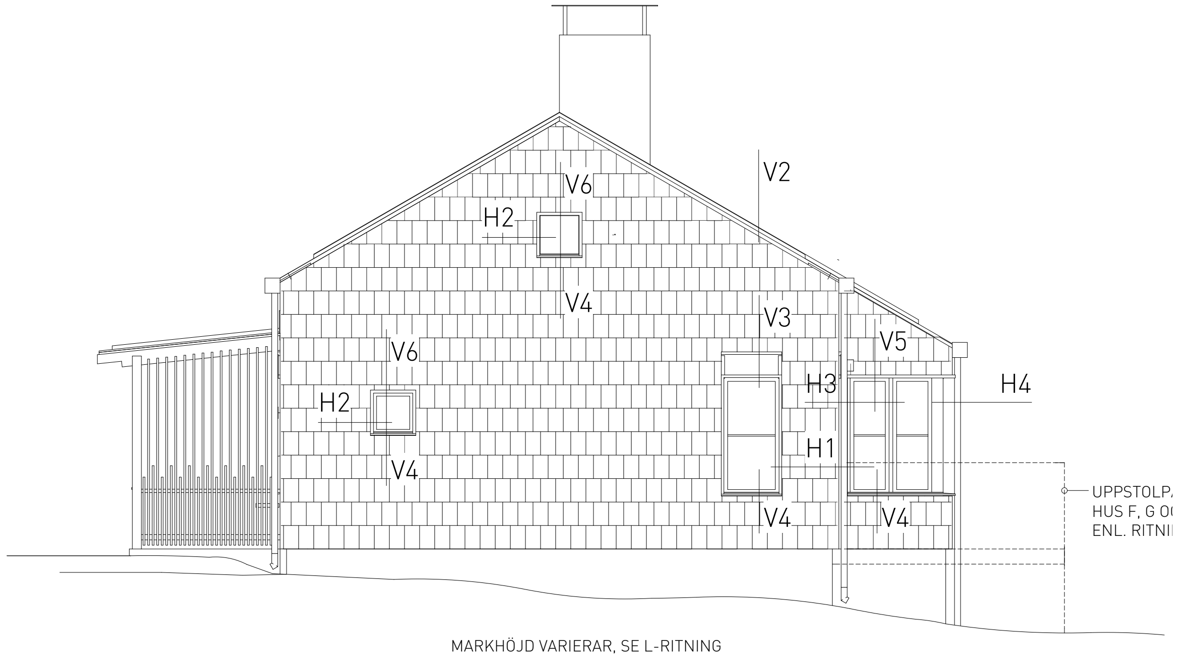
FACADE COMPARISON

original

drawing by brunnberg & forshed



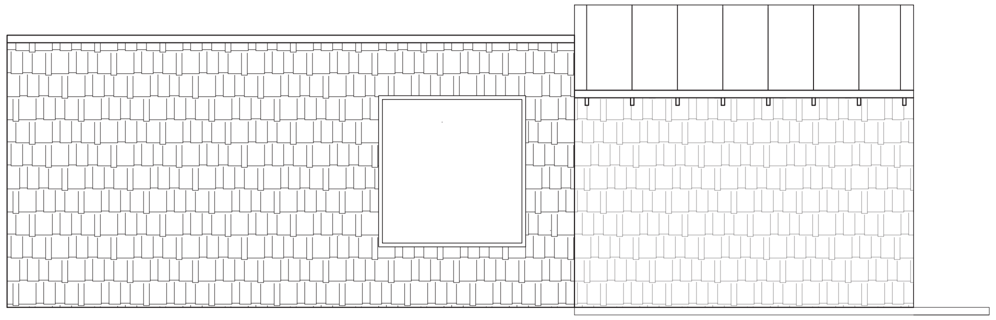
FASAD MED ENTRÉ



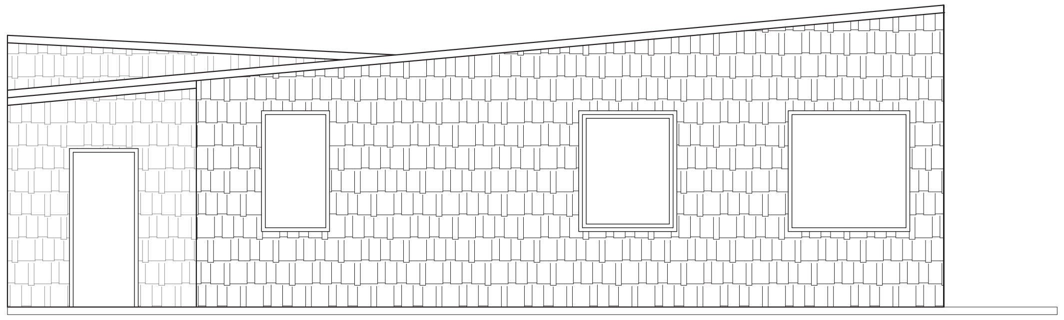
GAVELFASAD

new

drawing by author



NORTH FACADE



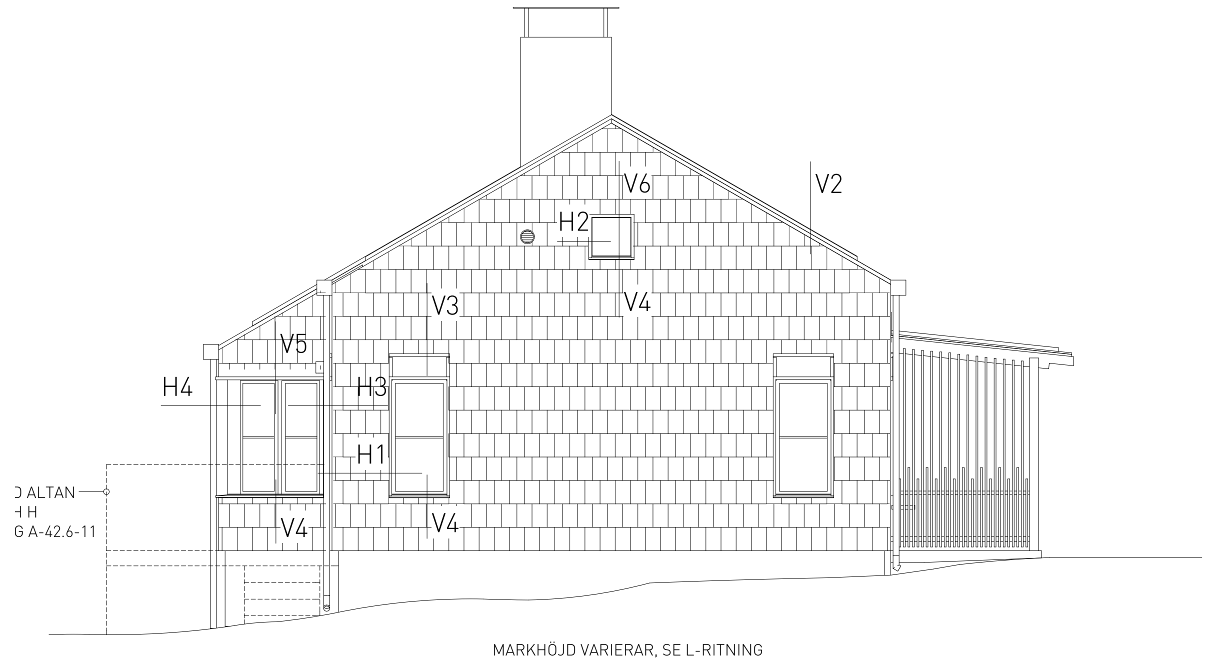
WEST FACADE

1:100 (A3)

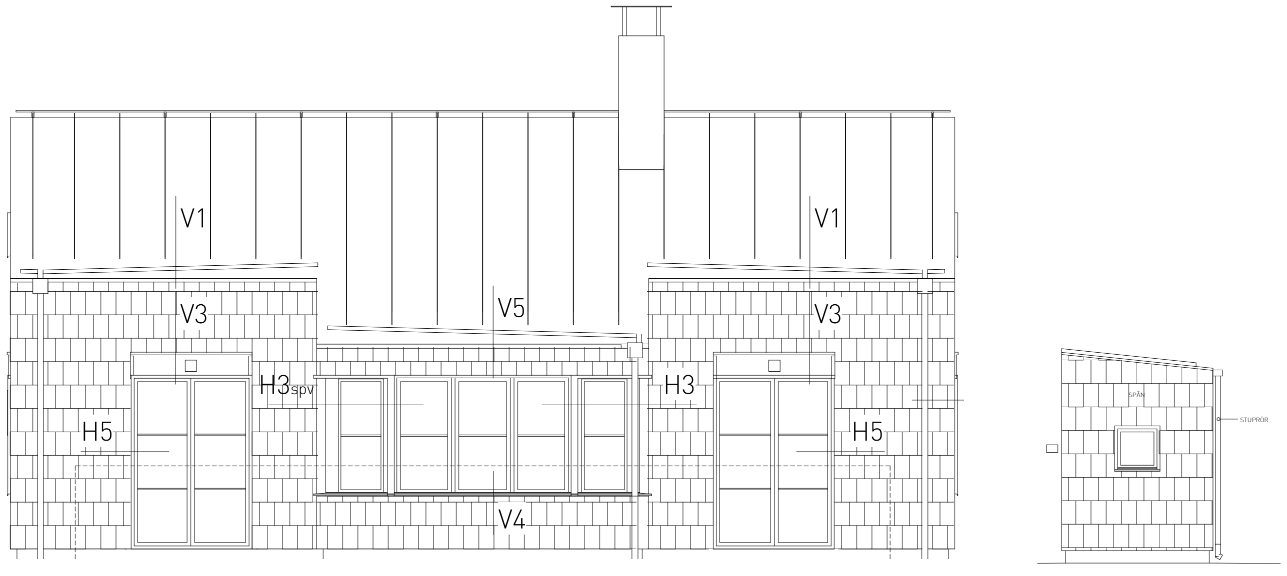
FACADE COMPARISON

original

drawing by brunnberg & forshed

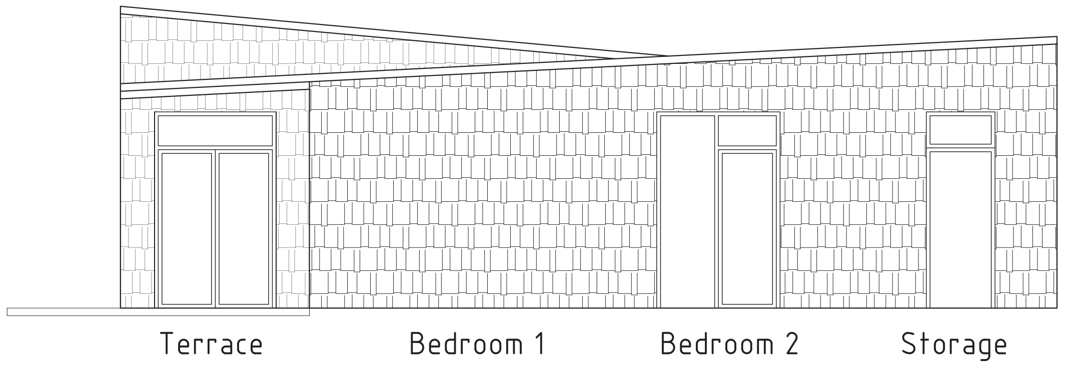


GAVELFASAD

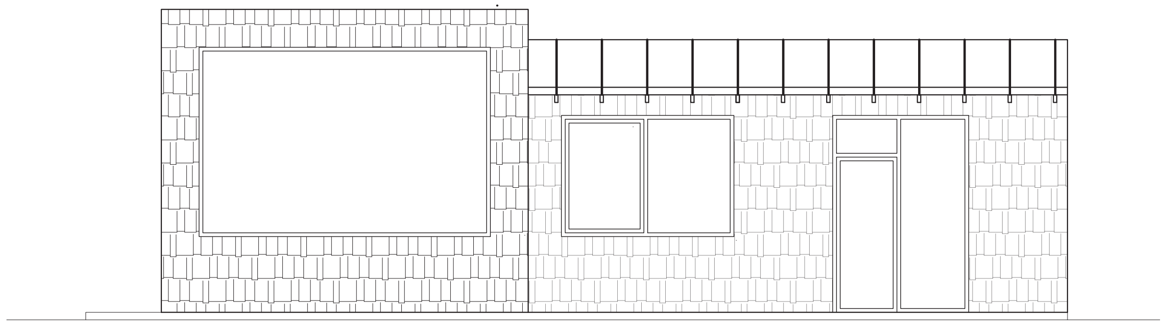


new

drawing by author



EAST FACADE

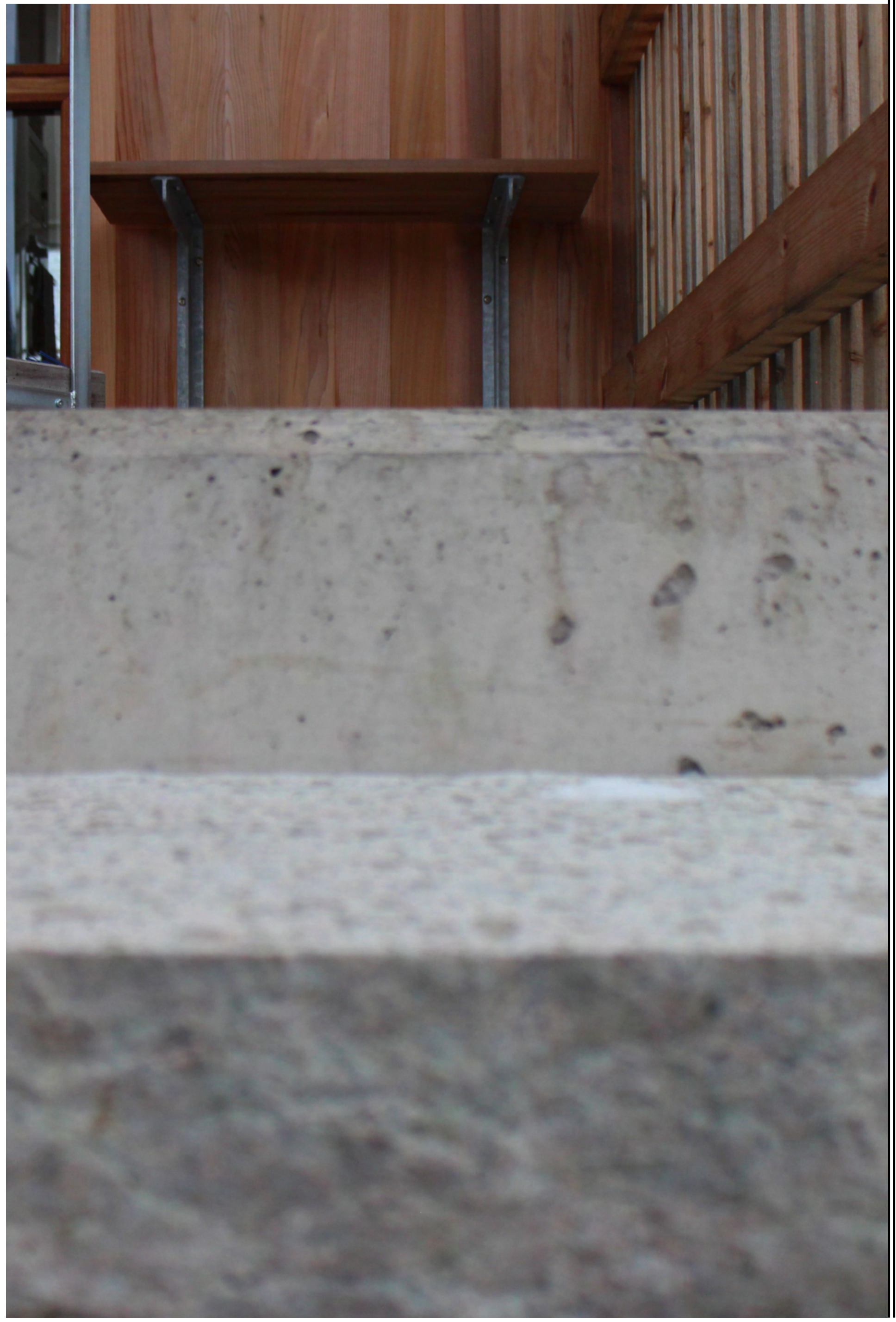


SOUTH FACADE

1:100 (A3)

FOUNDATION COMPARISON

original
Concrete slab



new
Koljern-elements ® by FOAMGLAS ®

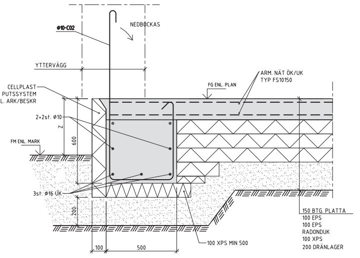
new
Punctiual wooden foundation

FOUNDATION COMPARISON

Concrete version 1

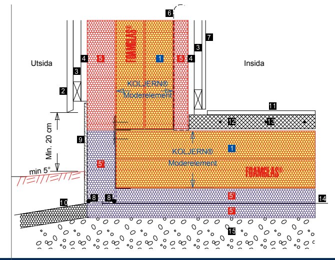
150 CONCRETE/ 2% ARMORY
300 INSULATION (Λ 0,04)

A1-A3 (PRODUCTION)= 125 kg co^2/m^2
C3+C4 (END OF LIFE)= 40 kg co^2/m^2



300 FOAMGLAS T3+ (Λ 0,04)
=koljern element

A1-A3= 59 kg co^2/m^2
C3+C4= 2 kg co^2/m^2

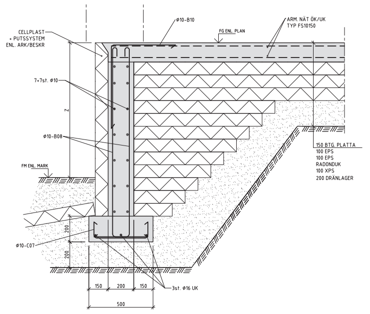


Concrete version 2

300 CONCRETE/ 4% ARMORY
400 INSULATION (Λ 0,06)

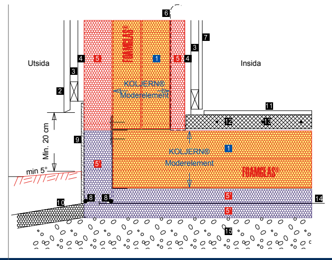
A1-A3 (PRODUCTION) = 210 kg co^2/m^2
C3+C4 (END OF LIFE) = 50 kg co^2/m^2

EPS will become 40% worse after 13 years (Choi et. al., 2017)



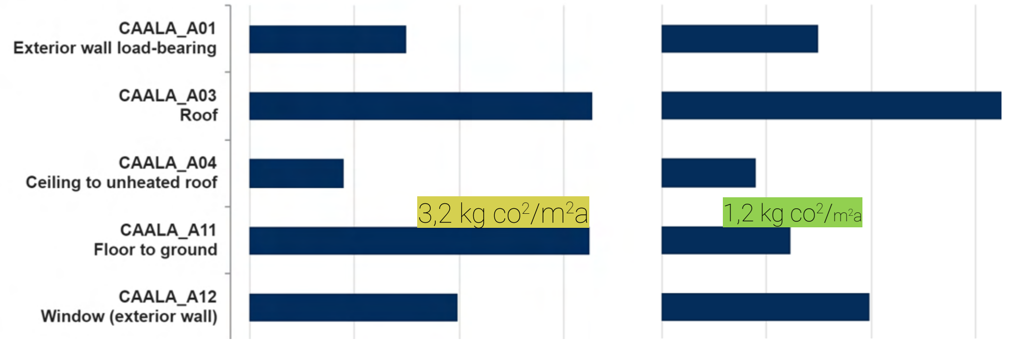
300 FOAMGLAS T3+ (Λ 0,04)
=koljern element

A1-A3= 59 kg co^2/m^2
C3+C4= 2 kg co^2/m^2

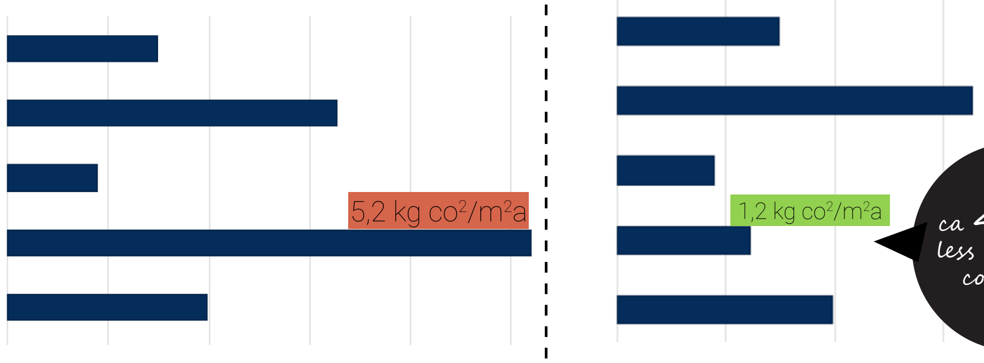


Energy parameters		(930 SEK/M2)	(2000 SEK/M2)	(930 SEK/M2)	(2000 SEK/M2)
Primary energy demand	[kWh / (m^2_{AN} *a)]	62.45	60.34 -3.38% - 2,1 kWh -10,5 MWh	62.68 +0,37%	60.34 -3.73% - 2,3 kWh -11,5 MWh
Life cycle assessment					
Global warming potential (GWP)	[kg CO_2-Äqv / (m^2_{NGF}*a)]	37.12	33.97 -8.49% - 3,2 kWh -16 ton	39.15 +5,5% +10 ton	33.97 -13.23% - 5,2 kWh -26 ton
Life cycle costs					
Total life cycle costs	[€ / (m^2_{BGF})]	4791.84	4906.54 +2.39% + 2280 SEK +114 000 SEK	4792.84 +-0	4906.54 +2.37% + 2280 SEK +114 000 SEK

Global warming potential (GWP)



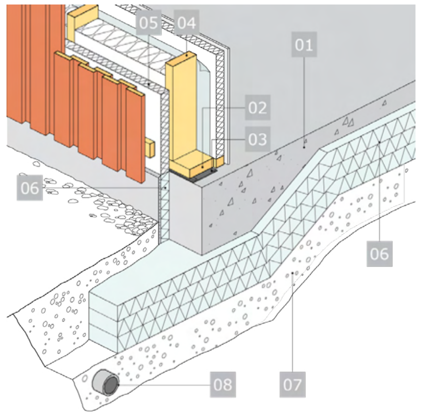
60% worse than concrete version 1!



ca 4 times less CO_2 than concrete!

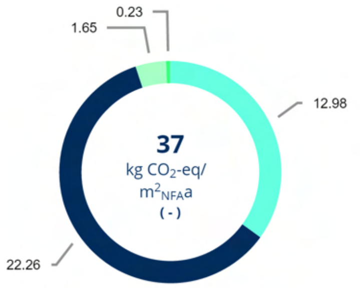
FOUNDATION COMPARISON

concrete slab



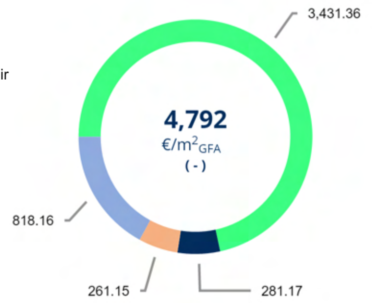
GLOBAL WARMING POTENTIAL (GWP)

- 🟩 B4 Replacement
- ■ B6 Energy demand in use
- 🟩 C3+C4 End-of-life
- 🟩 A1-A3 Production

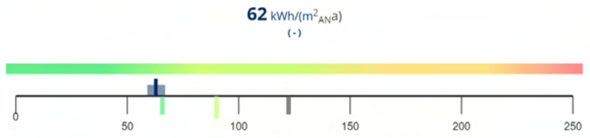


LIFE CYCLE COSTS

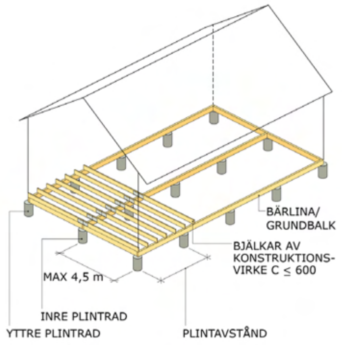
- 🟩 Investment costs
- ■ Energy costs
- 🟧 Maintenance & Replacement
- 🟦 Repair



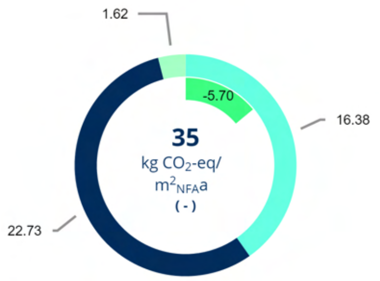
PRIMARY ENERGY DEMAND



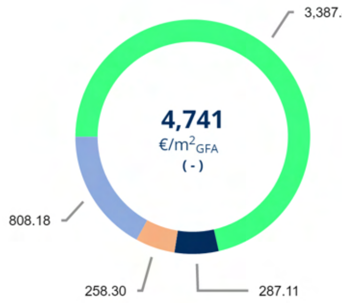
punctual wood



DATA
20mm stone clinker
15mm OSB
440 beams 600cc/370 cellulose insulation
10mm fibercementboard
Total 460mm thick
U-value 0,077
1000 SEK/m2



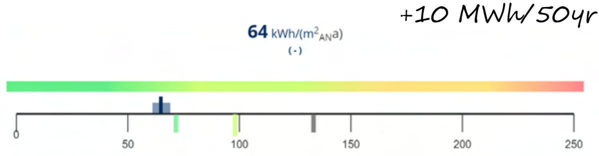
-2 kg CO_2
200 kg/year
10 ton/50yrs



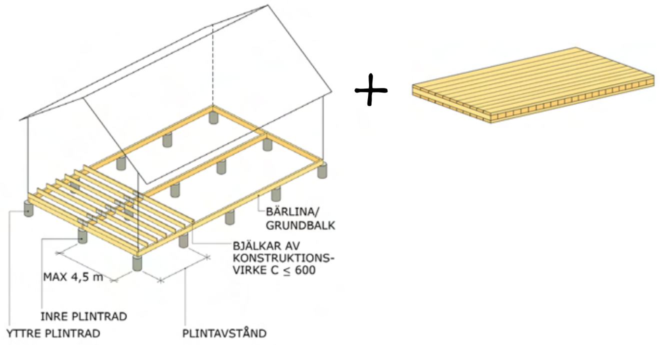
- 51€/m²
- 1020 SEK/year

(-51 000 SEK
in 50 years)

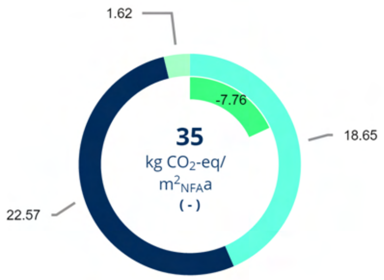
+2 kWh
+200 kWh/year
+10 MWh/50yrs



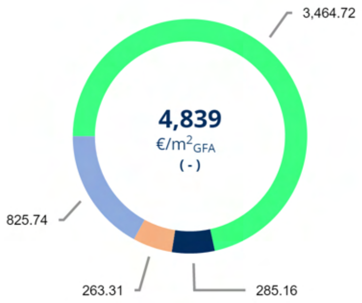
punctual clt



DATA
20mm stone clinker
20mm wooden floor
440 beams 600cc/370 cellulose insulation
140mm CLT
Total 600mm thick
U-value 0,065
1820 SEK/m2



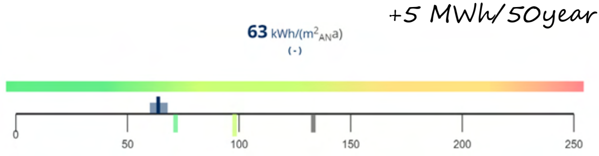
-2 kg CO_2
200 kg/year
10 ton/50yrs



+ 47€/m²
+ 940 SEK/year

(+ 47 000 SEK
in 50 years)

+1 kWh
+100 kWh/year
+5 MWh/50years



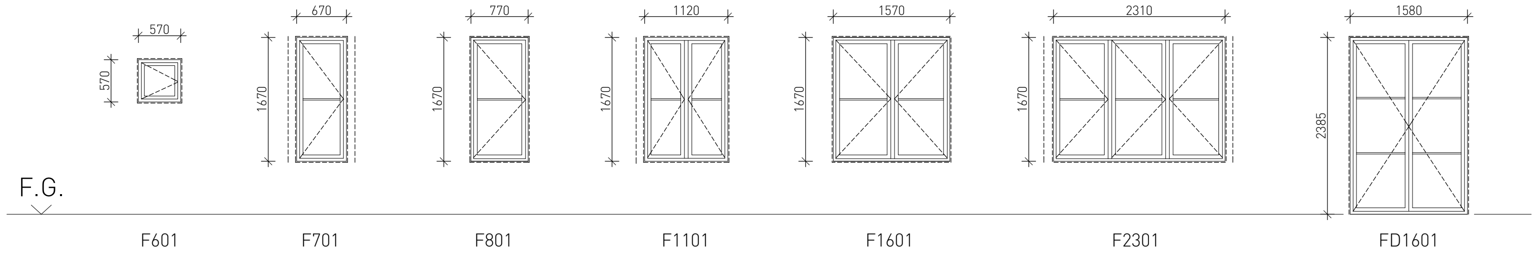
references

CAREFULLY PLACED IN THE TERRAIN & LESS GROUND WORK.

WINDOW COMPARISON

original

drawing by brunnberg & forshed



WINDOW COMPARISON

Variant Information		ALU/WOOD, SIDE HINGED, OPEN INWARDS, CROSS-BARS (3000 SEK/M²)	PVC, ROTATE, OPEN OUTWARDS, NO BARS (2160 SEK/M2)	WOOD, ROTATE, OPEN OUTWARDS, NO BARS (2100 SEK/M2)	WOOD, 50% ROTATE / 50% FIXED (1680 SEK/M2)	PVC, 50% ROTATE / 50% FIXED (1600 SEK/M2)	PVC, SIMPLER "KIPP-DREH", OPEN INWARDS (1470 SEK/M2)
Energy parameters							
Primary energy demand	[kWh / (m$^2_{AN}$ *a)]	62.45	60.30 -3.44% - 2,15 kWh -10 MWh	60.30 -3.44% - 2,2 kWh -10 MWh	59.20 -5.2% - 3,2 kWh -16 MWh	59.20 -5.2% - 3,2 kWh -16 MWh	60.30 -3.44% - 2,2 kWh -10 MWh
Life cycle assessment							
Global warming potential (GWP)	[kg CO_2-Äqv / (m$^2_{NGF}$*a)]	37.12	36.19 -2.51% - 1 kgCO² -5 tons	35.32 -4.85% - 1,8 kgCO² -9 tons	34.93 -5.9% - 2,2 kgCO² -11 tons	35.80 -3.56% - 1,3 kgCO² -6,6 tons	36.19 -2.51% - 1 kgCO² -5 tons
Life cycle costs							
Total life cycle costs	[€ / (m$^2_{BGF}$)]	4791.84	4750.93 -0.85% -840 sek -42 000 sek	4748.70 -0.9% -880 sek -44 000 sek	4728.18 -1.33% -1200 sek -64 000 sek	4725.21 -1.39% -1340 sek -67 000 sek	4725.31 -1.39% -1340 sek -67 000 sek

○ Original values
○ Savings m2/year
● Savings 50 year
◌ Savings SEK/year

winner

-6% of total CO_2 emissions!

30% window discount = -1,3% of total LCC!

ROOF COMPARISON

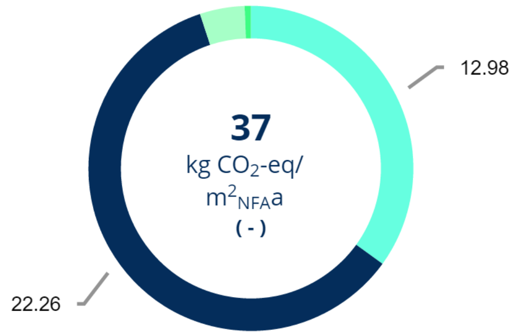
ROOF COMPARISON

original 1

RHEINZINK ®-prePATINA

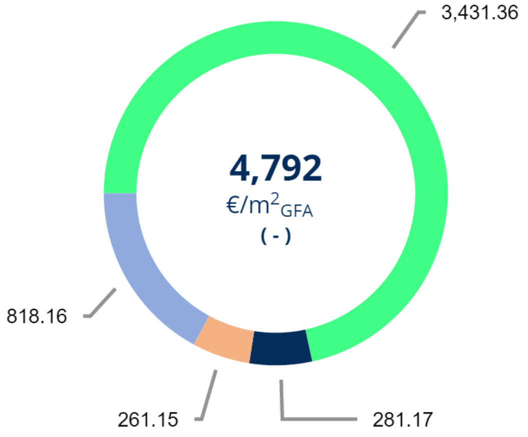
LCA

- B4 Replacement
- B6 Energy demand in use
- C3+C4 End-of-life
- A1-A3 Production

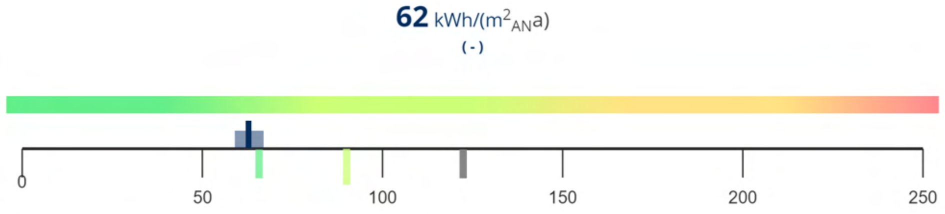


LCC

- Investment costs
- Energy costs
- Maintenance & Replacement
- Repair

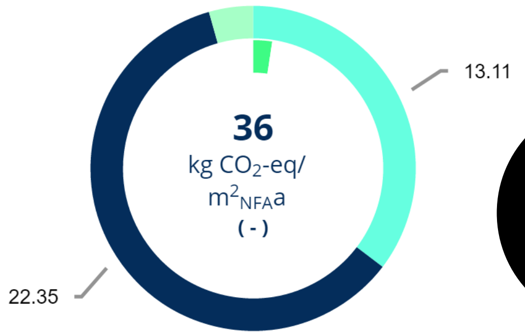


ENERGY DEMAND



original 2

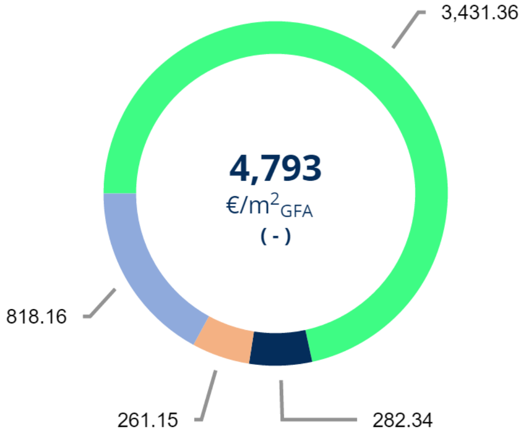
RT 821 Höjslev 1-kupig Lille Dansk



-1 kg CO_2
100 kg/year
5 ton/50yrs

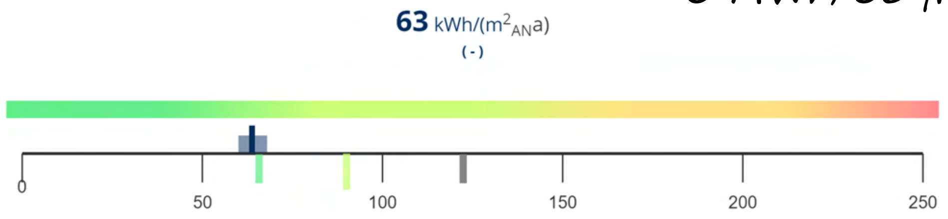
1 kg becomes 5 tons!

Unchanged



Two good options!

-1 kWh
-100 kWh/year
-5 MWh/50yrs



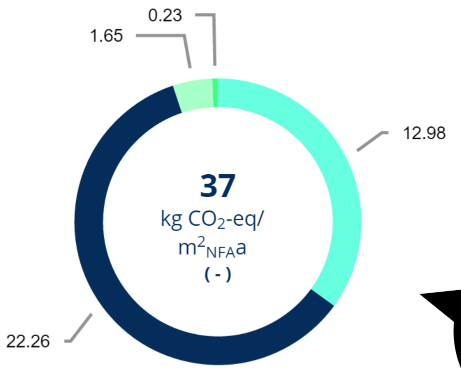
TECHNICAL SYSTEM COMPARISON

original

Geothermal heat pump & mechanical ventilation

GLOBAL WARMING POTENTIAL (GWP)

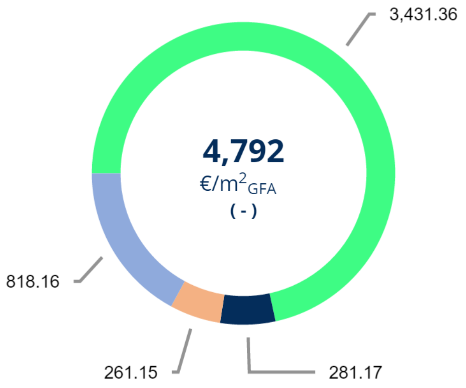
- 🟩 B4 Replacement
- ■ B6 Energy demand in use
- 🟩 C3+C4 End-of-life
- 🟩 A1-A3 Production



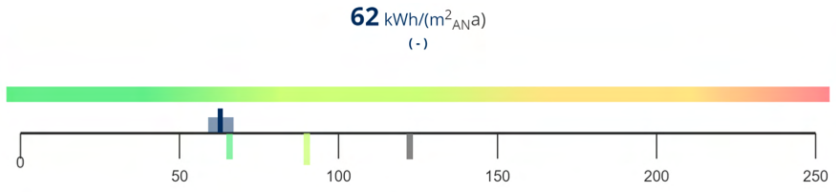
CORRECT DATA?

LIFE CYCLE COSTS

- 🟩 Investment costs
- ■ Energy costs
- 🟧 Maintenance & Replacement
- 🟦 Repair



ENERGY DEMAND

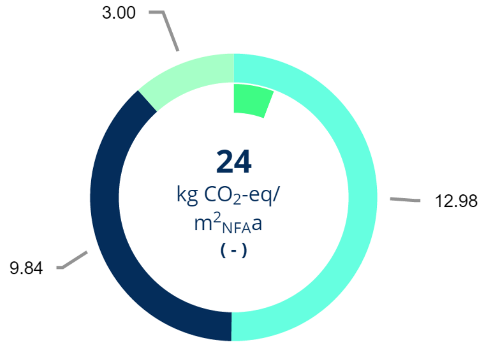


new

Pellets boiler & natural ventilation

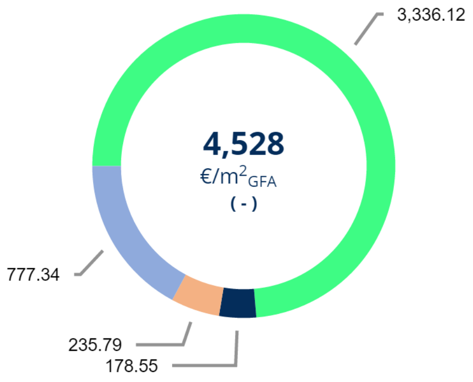
-13 kg CO_2
1300 kg/year
65 ton/50yrs

Remarkably
35%
less CO_2!



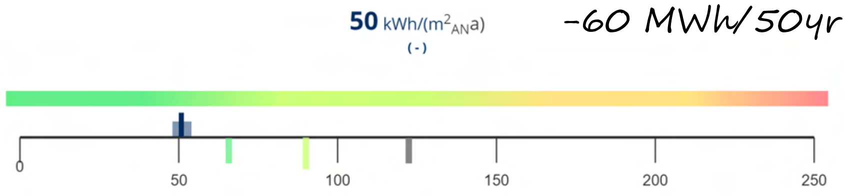
- 264€/m²

-264 000SEK/50yrs
- 5280 SEK/year
- 440 SEK/month



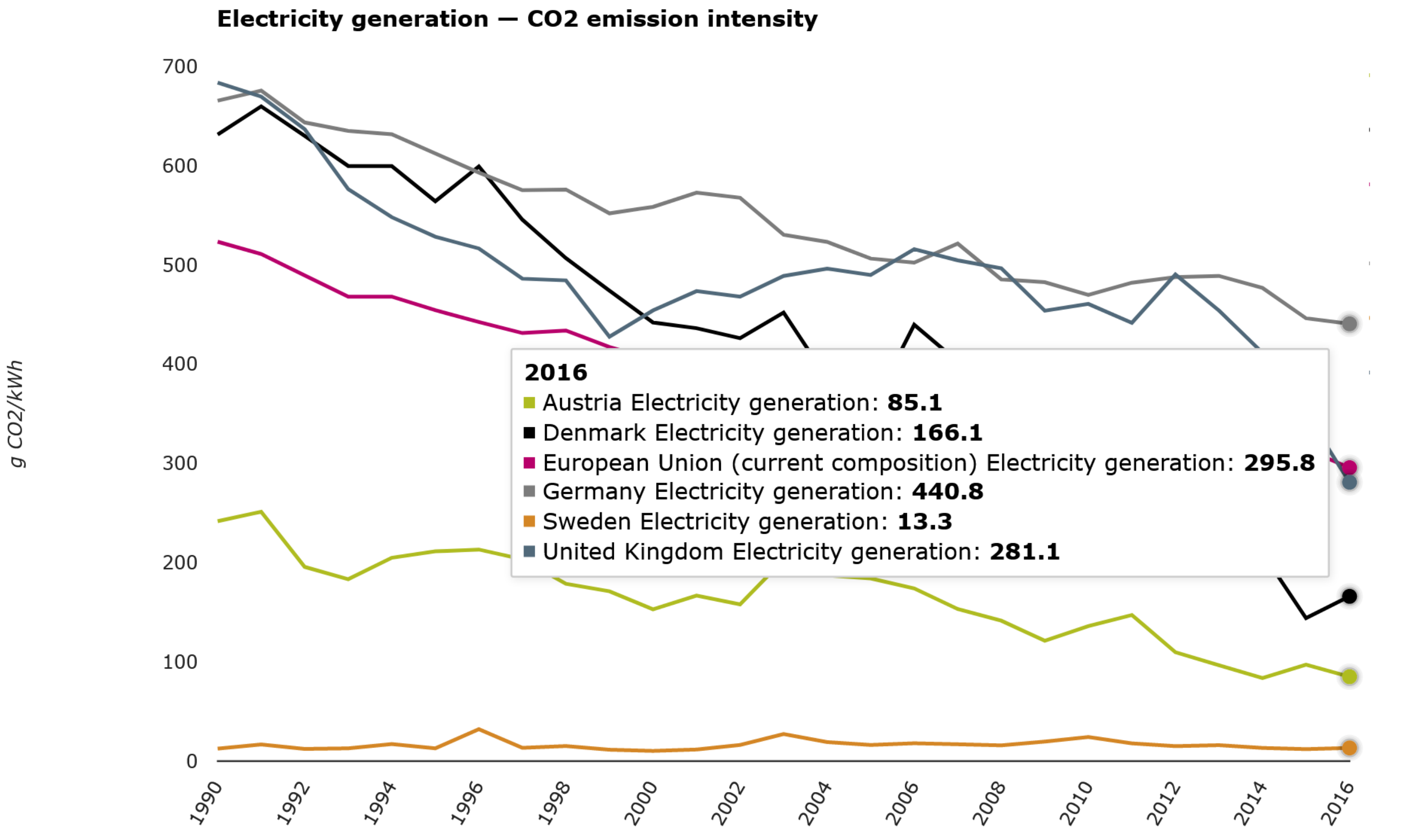
20%
less energy!

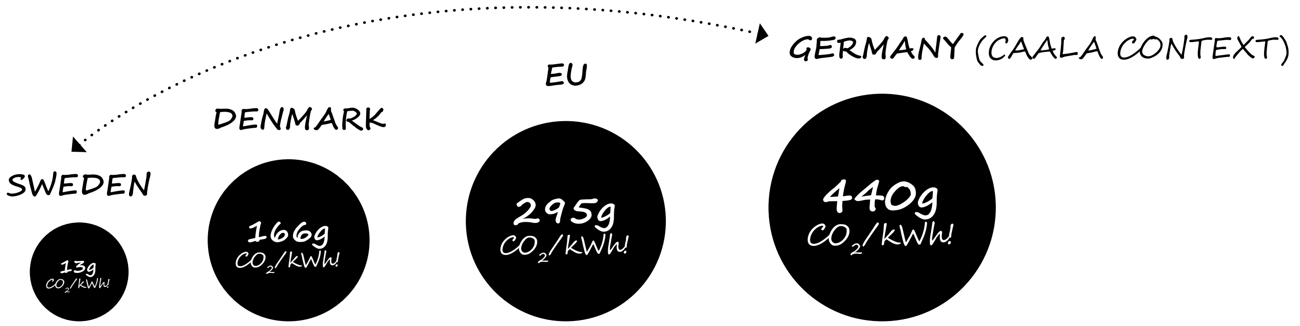
-12 kWh
-1200 kWh/year
-60 MWh/50yrs



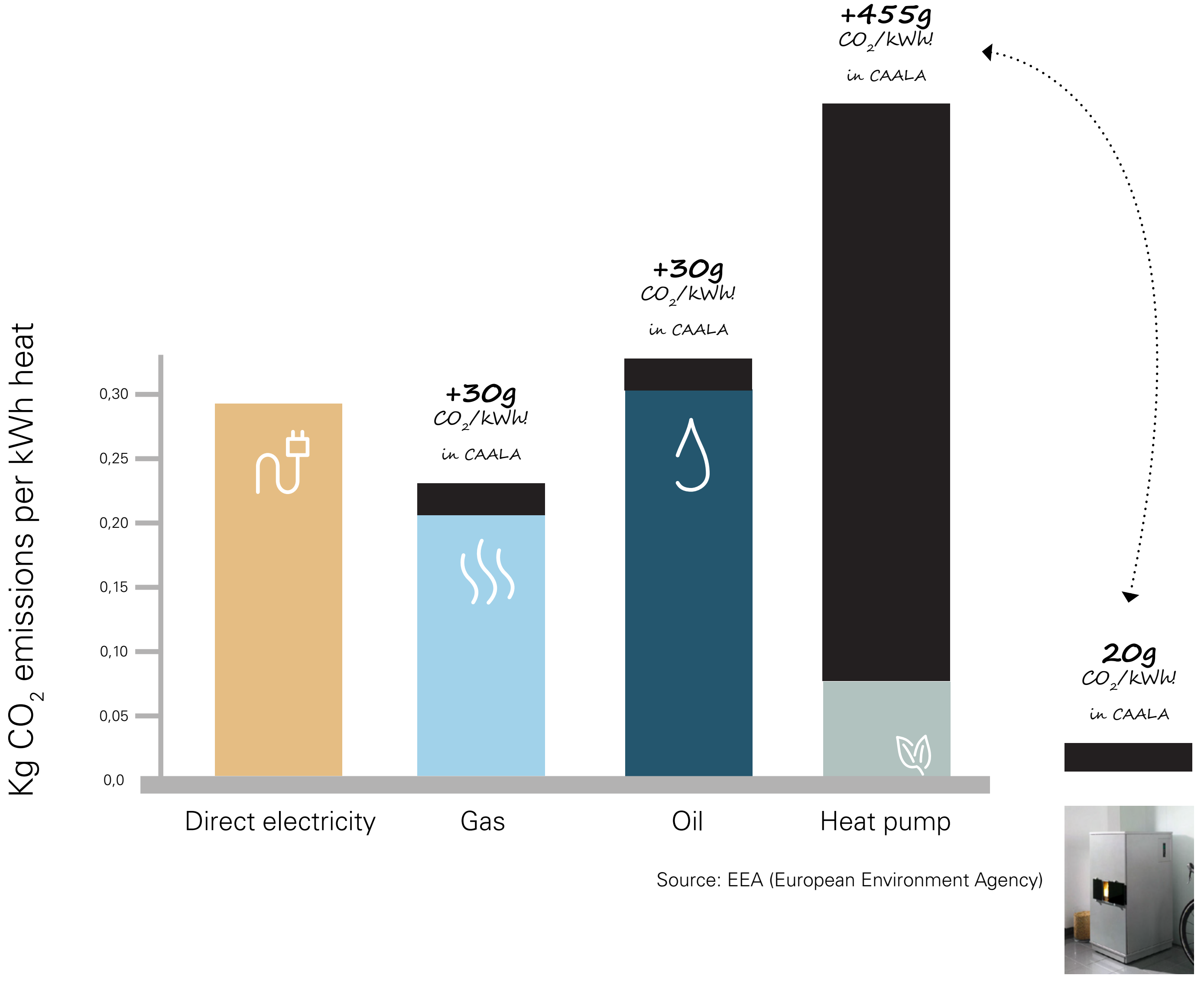
CO_2-INTENSITY/kWh

Country comparison





Equipment comparison



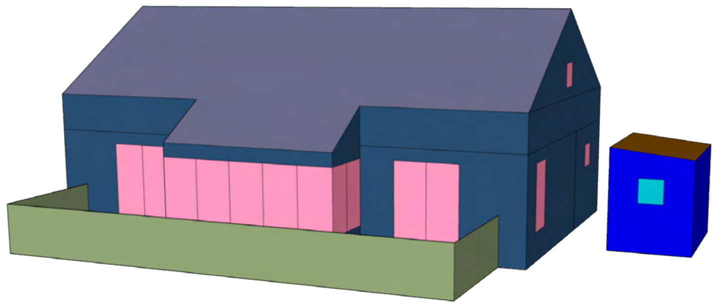
Source: EEA (European Environment Agency)

PELLETS

FINAL PROPOSAL COMPARISON

original

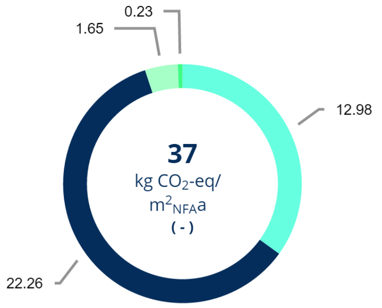
Heat pump



+

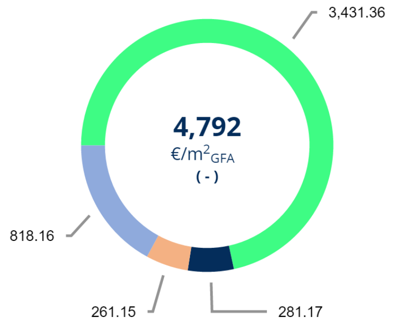
GLOBAL WARMING POTENTIAL (GWP)

- 🟩 B4 Replacement
- ▬ B6 Energy demand in use
- 🟩 C3+C4 End-of-life
- 🟩 A1-A3 Production

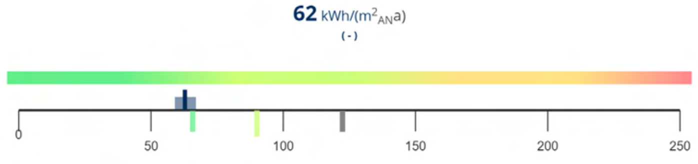


LIFE CYCLE COSTS

- 🟩 Investment costs
- ▬ Energy costs
- 🟧 Maintenance & Replacement
- 🟦 Repair

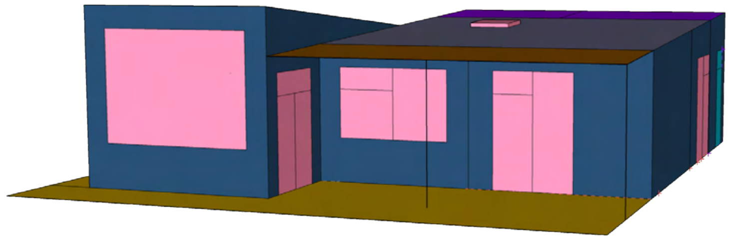


ENERGY DEMAND



proposal 1

Heatpump



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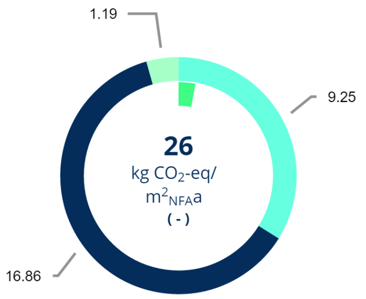
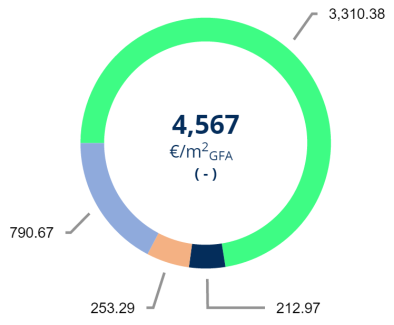


-11 kg CO_2

-1100 kg/year

-55 ton/50yrs

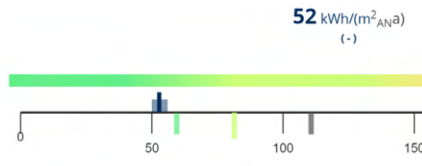


- 225€/m^2

-225 000SEK/50yrs

- 4500 SEK/year

- 375 SEK/month



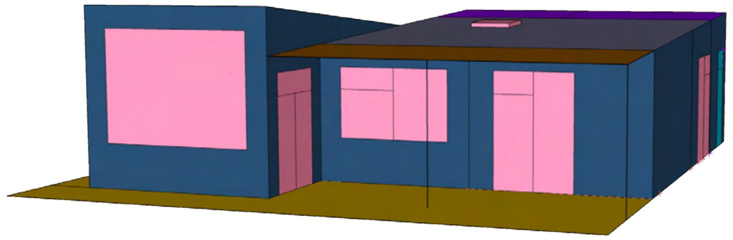
-10 kWh

-1000 kWh/year

-50 MWh/50yrs

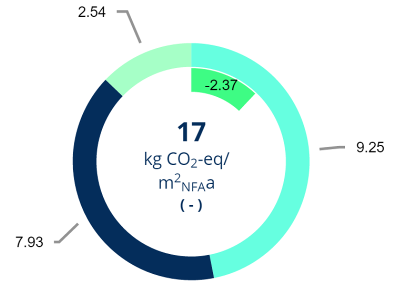
propsal 2

Pellets boiler



SAME AFFECT AS ALL THE OTHER EXPERIMENTS COMBINED!

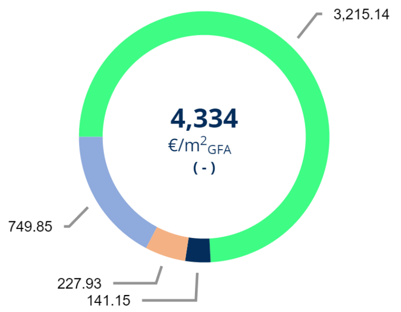
+



-20 kg CO_2

-2000 kg/year

-100 ton/50yrs

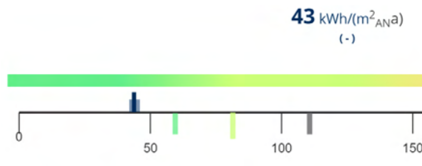


- 458€/m^2

-458 000SEK/50yrs

- 38 000 SEK/year

- 3200 SEK/month



-19 kWh

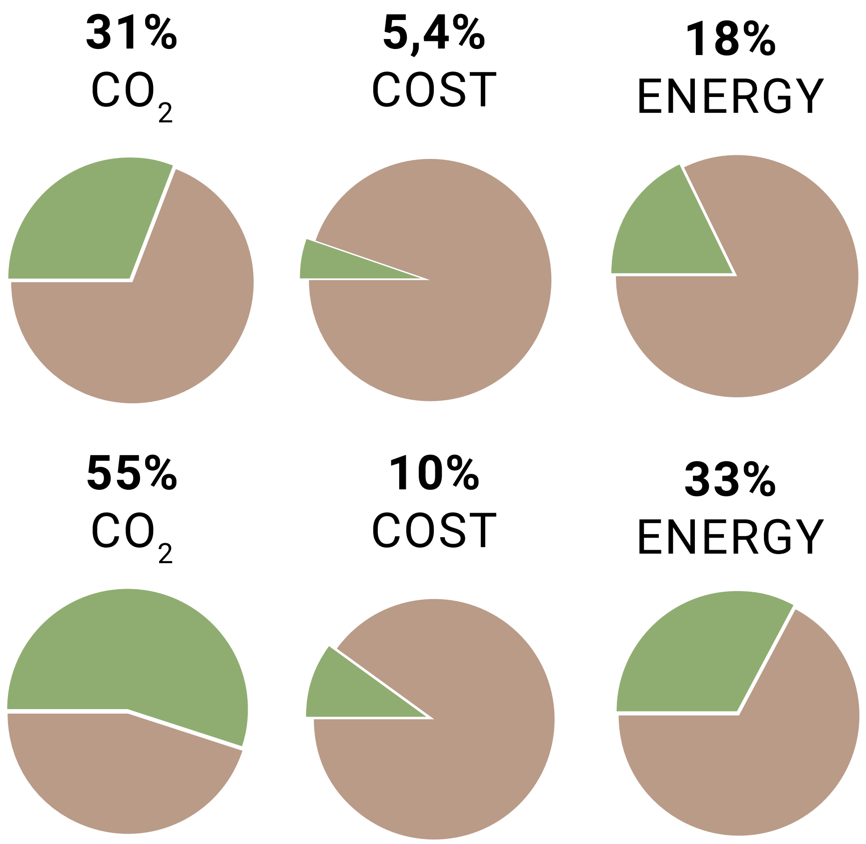
-1900 kWh/year

-95 MWh/50yrs

TOTAL IMPROVEMENTS

	LCA ($kgCO_2$)	LCC (SEK)	Energy (kWh)
original building *with heat pump*			
ORIGINAL TOT.	185 000	4 792 000	310 000
50 year savings:			
proposal 1 *with heat pump*			
Orientation	-5000	-7000	-5000
Window type	-11 000	-64 000	-16 000
Foundation	-16 000	+114 000	-11 000
Roof material	-5000	-+0	-5000
Flat roof	-25 000	-486 000	-45 000
New plan/volume	+5000	+180 000	+25 000
SAVING	-57 000	-263 000	-57 000
%	31%	5,4%	18%
proposal 2 *with pellets boiler*			
Pellets heating	-45 000	-228 000	-45 000
%	24%	4,7%	15%
TOTAL SAVING	55%	10%	33%

50 year savings!



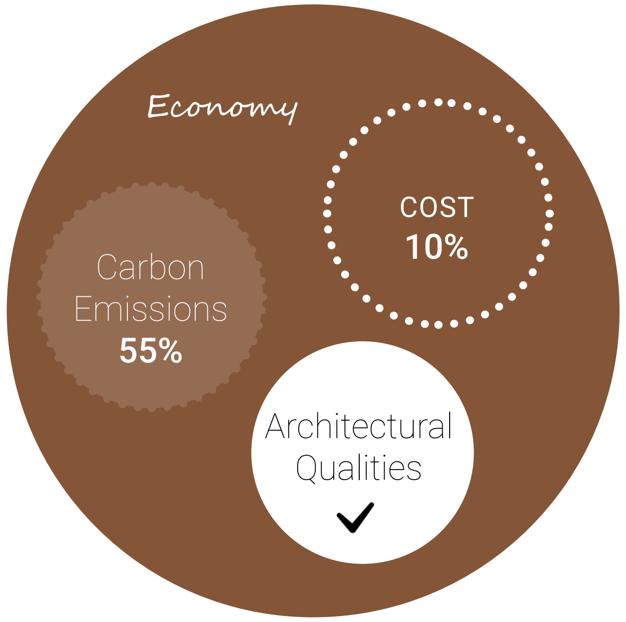
SUMMARY & LEARNINGS

1. THINK BEYOND 50 YEARS!
2. REDUCE UNNESSECARY MATERIALS
3. PRIORITIZE UNREPLACABLE MATERIALS
4. INVEST IN ARCHITETURAL QUALITIES
5. CHOOSE MATERIALS WITH LOW MAINTENANCE
6. ENCOURAGE WOOD PRODUCTS
7. ADAPT TO SUN AND SITE
8. BALANCE ENERGY AND MATERIALS
9. DARE TO CHALLENGE BUILDING ROUTINES
10. DO NOT FORGET THE TECHNICAL SYSTEM!

CHEAPER
BUT BETTER

"An investigation of the interrelation between building costs, life cycle costs, energy use, climate footprint and architectural qualities, of a small rental villa in Sweden"

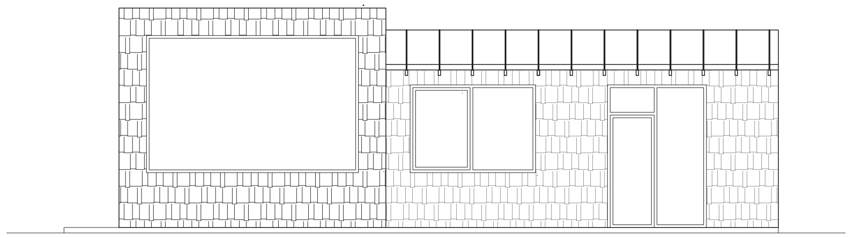
DESIGN EXPERIMENTS
ON CASE STUDY
[Volume & materials]



Life Cycle Costs (LCC)
Cost, €/m2 GFA

Life Cycle Analysis (LCA)
[Carbon Emissions,
kg CO_2-eq/m^{2}a]

Architectural Qualities
[Space]
[Proportion]
[Functionality]
[Materiality]



NEW DESIGN PROPOSAL
[Combine best experiments]

THANK YOU.

Master Thesis Spring **2021**

Building Design for
Sustainability

Examiner **Liane Thuvander**
Supervisor **Walter Unterrainer**

Presentation **21-05-31**

Caala Report

For Project: Källsprångsvägen

Table of Content

1. Object data

1.1. Object

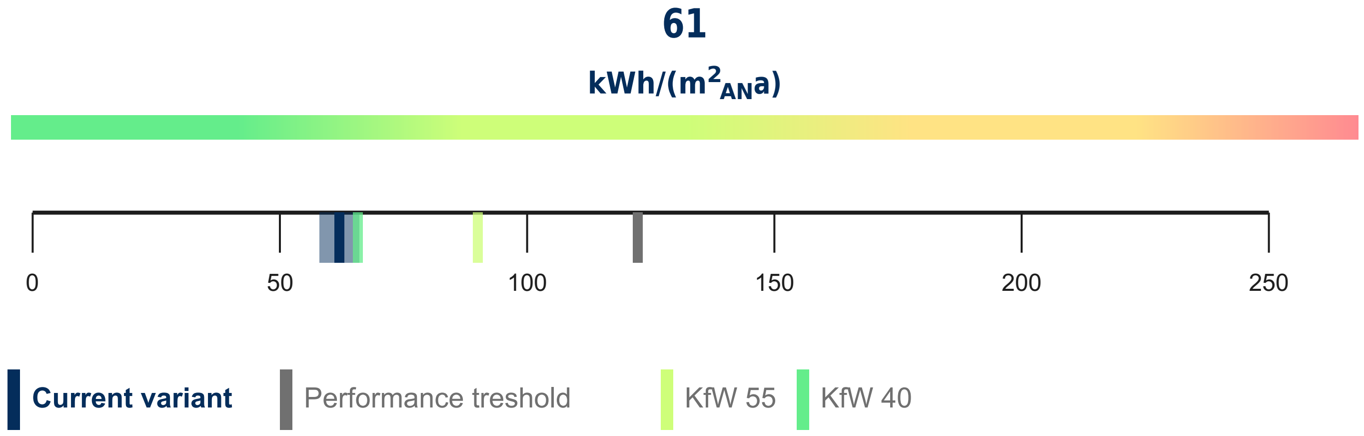
Model	210225 Källsprång modell CAALA Original (Full price)
Scope of analysis	Full Life Cycle
Level of detail	Blueprint planning
Building type	Apartment building
Energy standard	EnEV 2016
Reference study period	50 Jahre
Climate region - reference location	Region 10 - Hof

1.2. Geometry

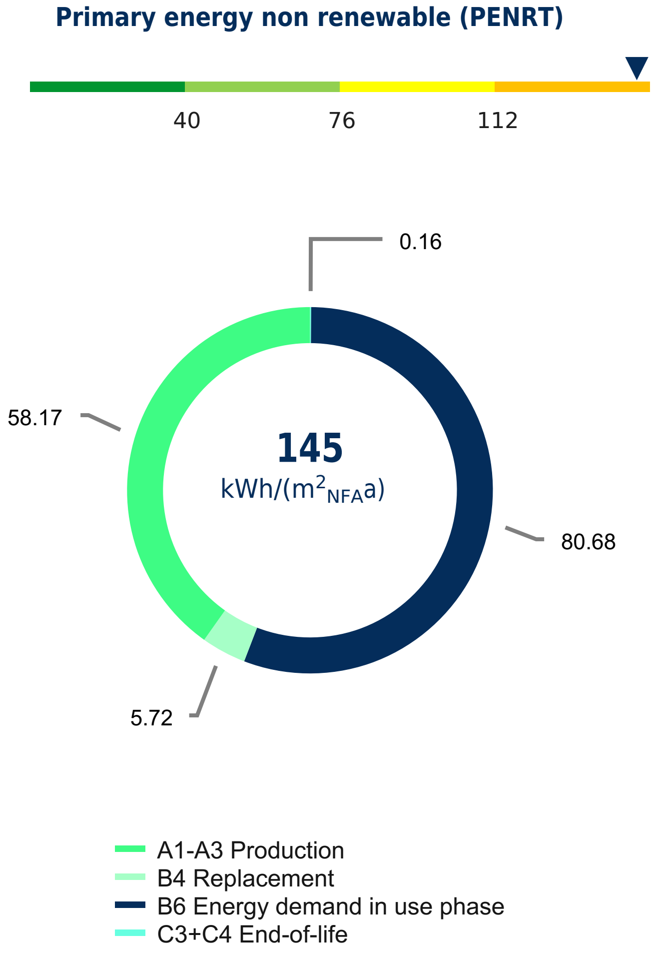
Average floor height	3.00 m
V	315.00 m³
GFA th.	105.00 m²
NFA	84.00 m²
Reference area	100.80 m²

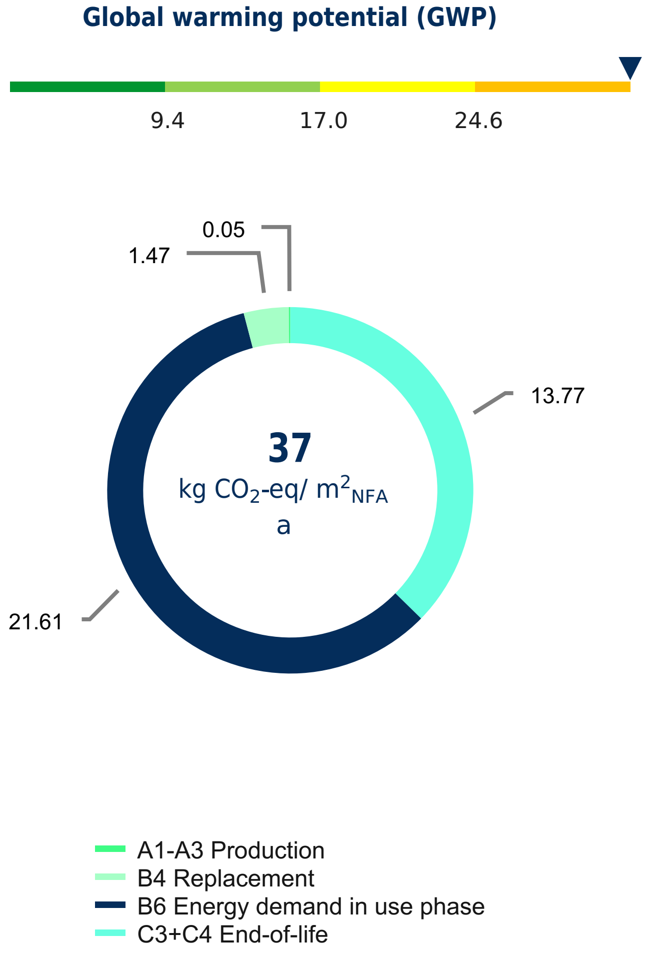
2. Overview

2.1. Primary energy demand

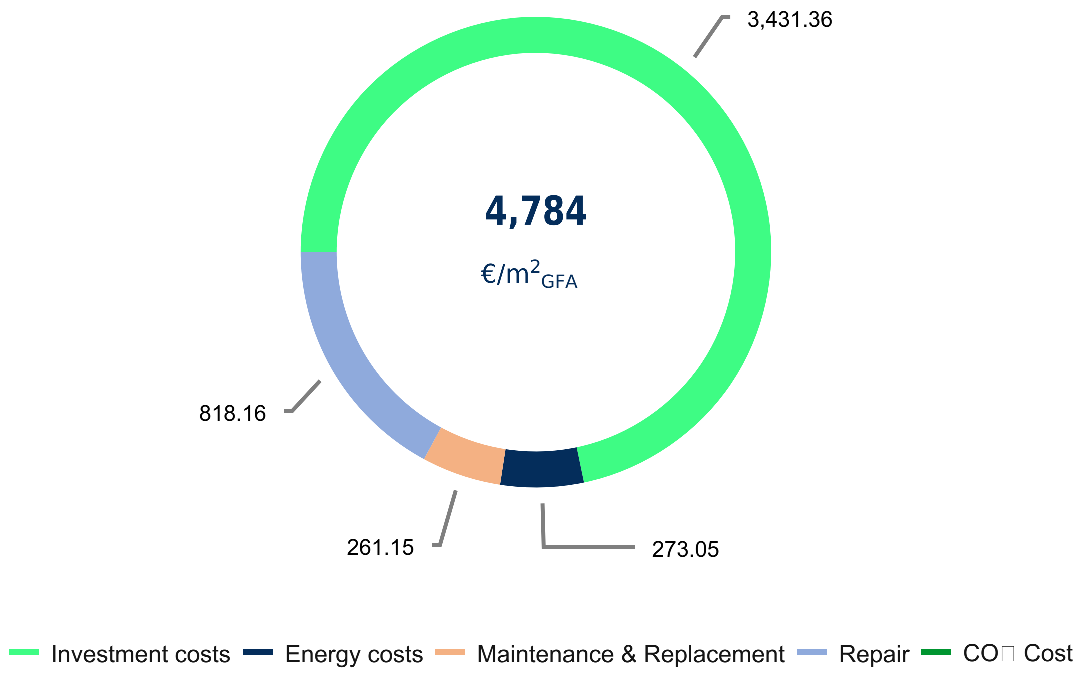


2.2. Life Cycle Assessment





Life cycle costs

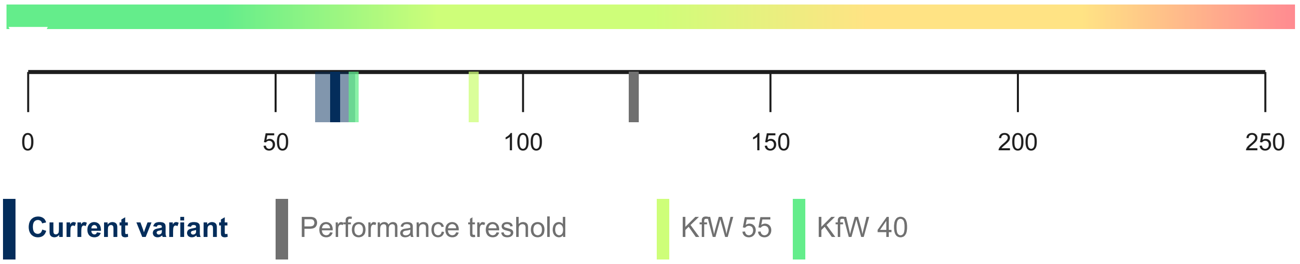


3. Operational energy demand

3.1. Overview

61

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



Annual energy requirement operation

Primary energy demand		61 kWh/m^2a
End energy demand		25 kWh/m^2a
	Auxiliary energy (electricity)	9 kWh/m^2a
Useful energy requirement	Space heating	97 kWh/m^2a
	Hot water	15 kWh/m^2a

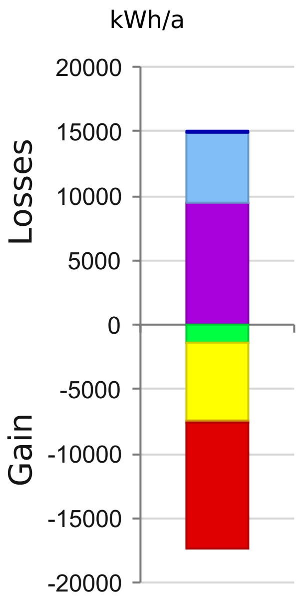
Energetic parameters

Energy reference area	100.80 m^2
Specific area-based transmission heat loss H'_T	**0.21 W/(m^2K)**
Max. specific area-based transmission heat loss H'_T	0.33 W/(m^2K)

3.2. Result per year

Legend

Losse	🟦 Solar losses opaque	44 kWh
	🟦 Ventilation heat losses	5,513 kWh
	🟪 Transmission heat losses	9,428 kWh
Gain	🟩 Internal gains	1,376 kWh
	🟨 Solar gains transparent	6,020 kWh
	🟧 Solar gains opaque	201 kWh
	🟥 Heating demand	**9,730 kWh**

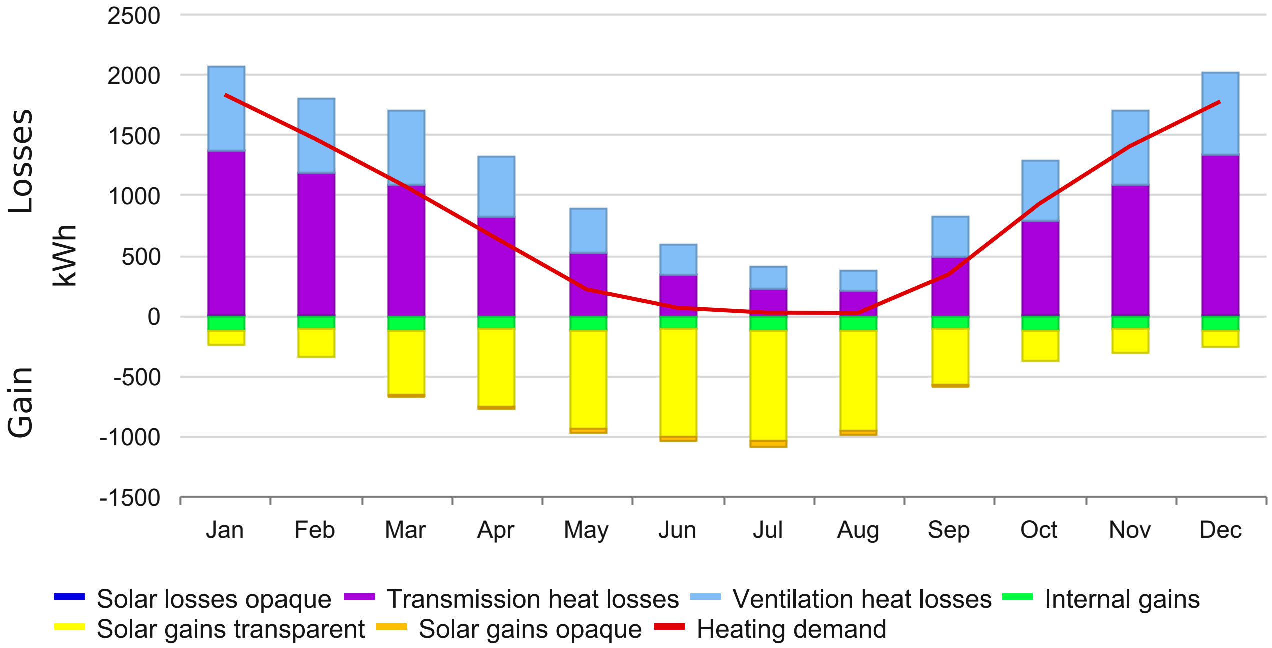


Annual balance of energy generation on site (photovoltaics)

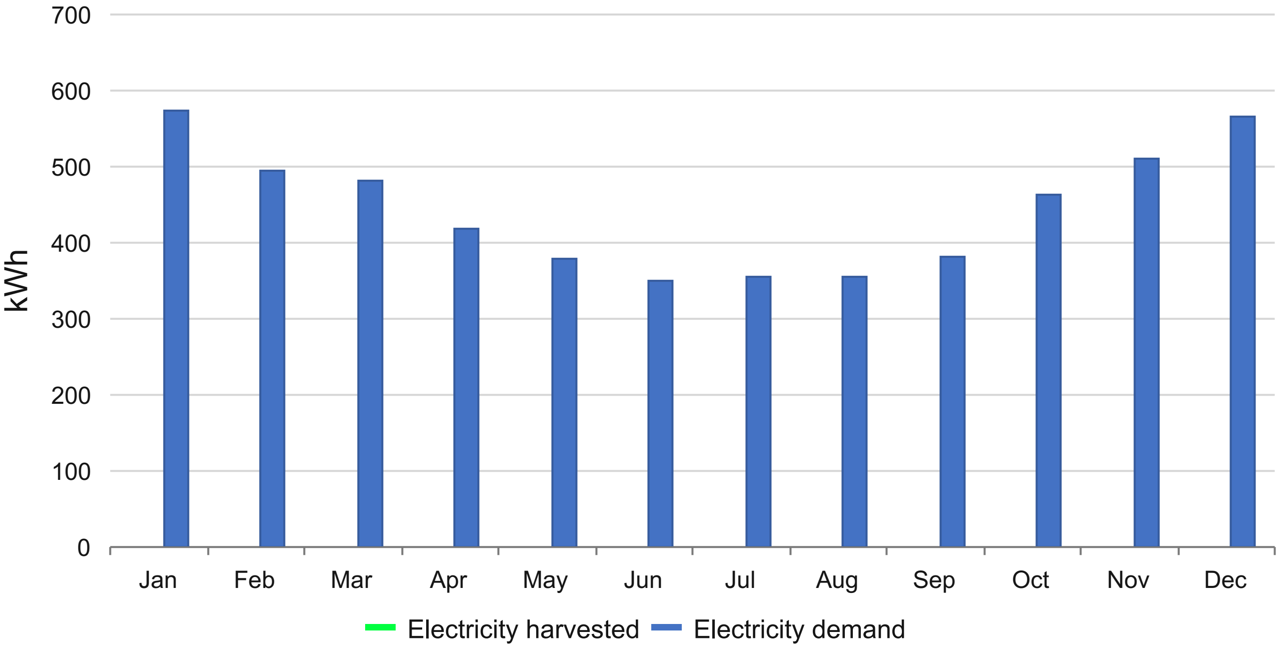
🟩 Electricity harvested	0 kWh
🟦 Electricity demand	5,328 kWh

3.3. Result monthly per year sheet

Monthly energy balance



Monthly energy harvesting on site (photovoltaics)



Monthly values

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Natural ventilation $H_{V, win, mth}$ (W / K)	25.5	26.5	30.9	36.0	42.9	46.7	49.2	49.6	43.3	37.4	30.2	26.1
Ref: Natural ventilation $H_{V, win, mth}$ (W / K)	28.0	29.2	34.0	39.7	47.3	51.4	54.1	54.6	47.7	41.2	33.3	28.8
Internal temperature balance(°C)	18.1	18.1	18.2	18.6	19.2	19.4	19.6	19.7	19.2	18.7	18.2	18.1
Ref: Internal temperature balance(°C)	18.0	18.0	18.2	18.5	19.1	19.4	19.6	19.6	19.1	18.6	18.1	18.0
Transmission heat sinks QT_{sink} (kWh)	1,358.2	1,177.8	1,087.0	819.5	524.5	336.4	233.8	214.9	489.3	783.6	1,084.8	1,324.3
Ref: Transmission heat sinks QT_{sink} (kWh)	2,128.7	1,846.0	1,703.7	1,282.0	820.5	526.2	365.8	336.1	765.4	1,225.8	1,700.2	2,075.6
Ventilation heat sinks QV_{sink} (kWh)	692.7	614.2	616.6	509.5	364.4	247.1	177.8	164.3	342.0	498.4	607.6	684.9
Ref: Ventilation heat sinks QV_{sink} (kWh)	562.8	502.8	518.5	438.9	322.7	221.7	160.7	148.7	303.3	431.9	508.9	559.1
Solar gains transparent $QS_{tr,source}$ (kWh)	120.5	232.0	538.6	642.3	812.5	884.5	919.4	833.6	461.0	256.3	190.1	134.4
Ref: Solar gains transparent $QS_{tr,source}$ (kWh)	120.5	232.0	538.6	642.3	812.5	884.5	919.4	833.6	461.0	256.3	190.1	134.4
Solar gains opaque $QS_{opaq,source}$ (kWh)	0.0	0.0	14.8	23.2	34.5	40.6	41.4	35.8	10.1	0.0	0.0	0.0
Ref: Solar gains opaque $QS_{opaq,source}$ (kWh)	0.0	0.0	29.6	48.5	73.6	87.1	88.6	76.0	20.5	0.0	0.0	0.0
Solar losses opaque $QS_{opaq,sink}$ (kWh)	14.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	8.4	13.0
Ref: Solar losses opaque $QS_{opaq,sink}$ (kWh)	14.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	8.4	13.0
Internal heat sources QI_{source} (kWh)	117.2	105.8	117.2	113.4	117.2	113.4	117.2	117.2	113.4	117.2	113.4	117.2
Ref: Internal heat sources QI_{source} (kWh)	117.2	105.8	117.2	113.4	117.2	113.4	117.2	117.2	113.4	117.2	113.4	117.2

Utilization factor η^{M}	1.0	1.0	1.0	0.9	0.7	0.5	0.4	0.4	0.8	1.0	1.0	1.0
Ref: Utilization factor η^{M}	1.0	1.0	1.0	0.9	0.7	0.6	0.4	0.4	0.9	1.0	1.0	1.0
Heat demand $Q_{h,b}$	1,827.8	1,461.1	1,065.8	636.6	212.2	59.8	18.8	17.6	337.2	922.1	1,399.5	1,771.4
Ref: Heat demand $Q_{h,b}$	2,486.3	2,024.8	1,568.2	995.9	397.2	137.7	52.0	48.6	552.5	1,304.3	1,928.1	2,414.0
Electricity demand (kWh)	572.9	494.7	481.3	418.3	378.7	349.0	355.4	355.3	382.3	464.0	510.0	566.1

4. Life cycle assessment

4.1. Boundary conditions

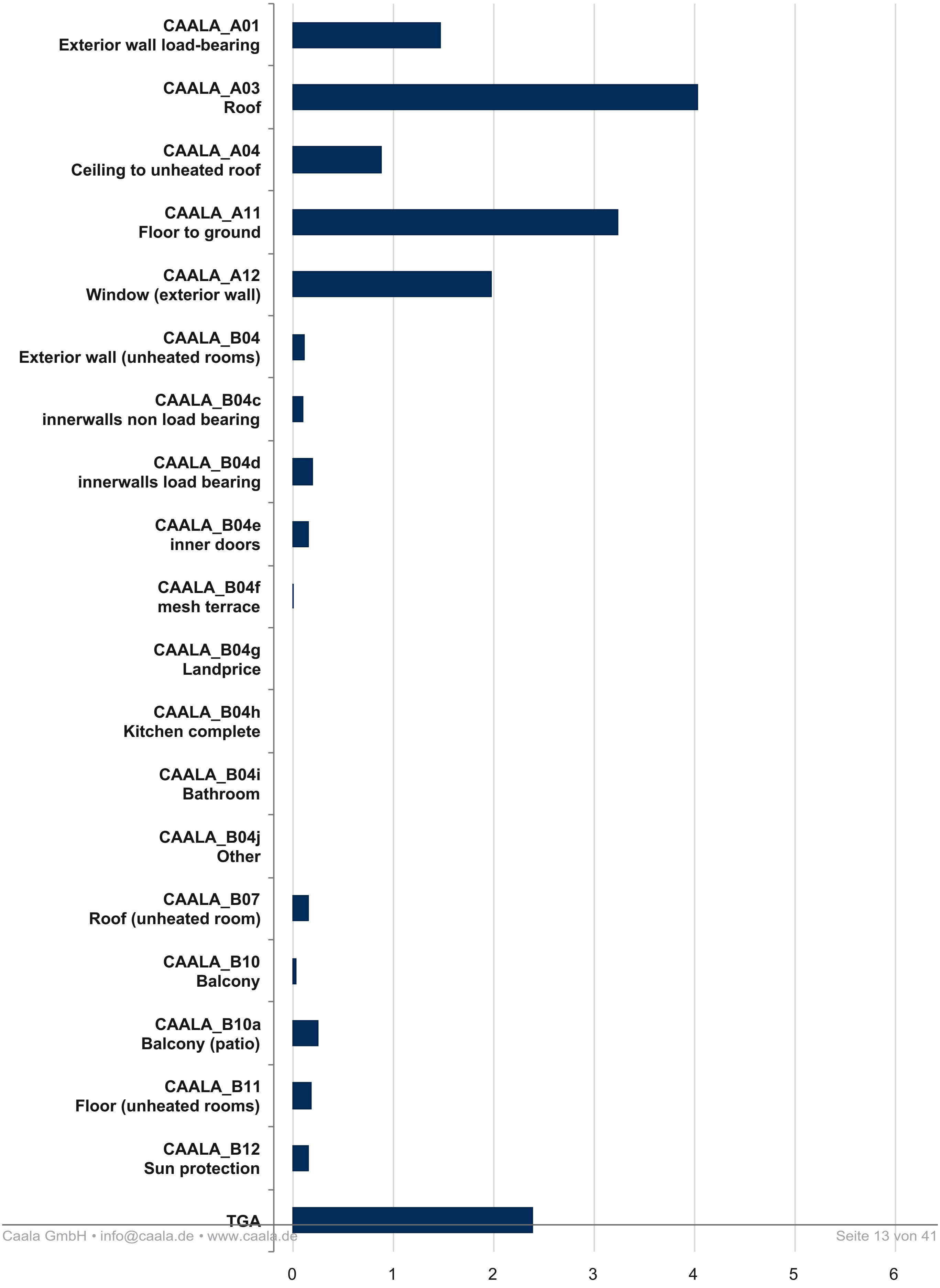
Assessment period	50 Jahre
Net floor area (NFA)	84.00 m²
Database	Ökobau.dat 2016
Assessed life cycle modules	A1-A3, B4, B6, C3+C4

4.2. Overview of the results

	MODULE	GWP	ODP	POCP	AP	EP	PENRT	PERT
Embodied	A1-A3, B4, B6, C3+C4	15.28	1,187e-6	9,002e-3	5,837e-2	1,007e-2	64.05	25.9
Operational	B6	21.61	1,475e-9	2,471e-3	3,302e-2	5,349e-3	80.68	43.68
Total		36.9	1,189e-6	1,147e-2	9,139e-2	1,542e-2	144.73	69.58

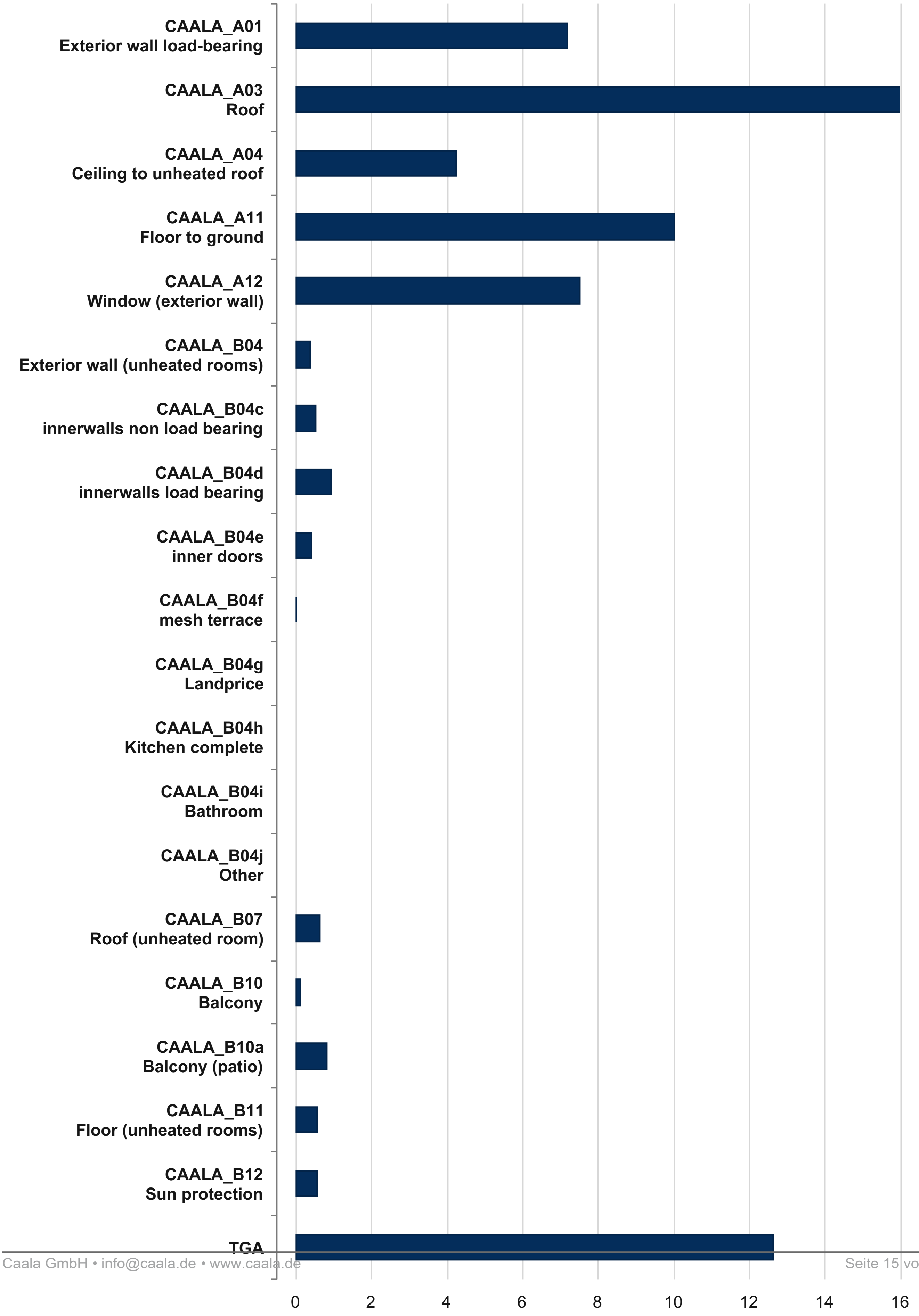
4.3. Results for integrated environmental impacts

Global warming potential (GWP)



kg CO_2-eq/ m^2_{NFA}a

Primary energy non renewable (PENRT)



$kWh/(m^2_{NFA}a)$

4.4. Results for integrated environmental impacts per layer

	m^2	GWP	ODP	POCP	AP	EP	PENRT	PERT
CAALA_A01 Exterior wall load-bearing	131.48	1	8,673e-8	7,540e-4	7,374e-3	1,816e-3	7.19	5.91
CAALA_A03 Roof	115.02	4	2,401e-7	1,758e-3	2,220e-2	4,458e-3	17.56	11.15
CAALA_A04 Ceiling to unheated roof	92.35	8	6,592e-8	5,159e-4	4,237e-3	1,015e-3	4.25	2.79
CAALA_A11 Floor to ground	98.94	3	5,210e-9	3,162e-3	4,980e-3	6,361e-4	10.03	0.81
CAALA_A12 Window (exterior wall)	30.17	1	5,290e-10	5,737e-4	8,446e-3	8,731e-4	7.52	1.59
CAALA_B04 Exterior wall (unheated rooms)	21.66	1	1,741e-9	2,608e-4	5,752e-4	1,226e-4	0.38	0.81
CAALA_B04c innerwalls non load bearing	28.8	1	1,184e-8	7,535e-5	3,917e-4	8,604e-5	0.51	0.97
CAALA_B04d innerwalls load bearing	42.46	1	2,729e-8	1,374e-4	6,813e-4	1,375e-4	0.92	0.46
CAALA_B04e inner doors	14.38	1	2,267e-9	6,505e-5	7,190e-4	5,238e-5	0.4	0.07
CAALA_B04f mesh terrace	20.63	4	1,630e-15	1,867e-8	3,161e-7	1,704e-8	0	0
CAALA_B04g Landprice	0	0	0,000e+0	0,000e+0	0,000e+0	0,000e+0	0	0
CAALA_B04h Kitchen complete	0	0	0,000e+0	0,000e+0	0,000e+0	0,000e+0	0	0
CAALA_B04i Bathroom	0	0	0,000e+0	0,000e+0	0,000e+0	0,000e+0	0	0
CAALA_B04j Other	0	0	0,000e+0	0,000e+0	0,000e+0	0,000e+0	0	0
CAALA_B07 Roof (unheated room)	21.36	1	5,560e-9	6,590e-5	4,716e-4	6,238e-5	0.62	0.15
CAALA_B10 Balcony	32.18	2	3,366e-9	2,327e-5	1,034e-4	2,051e-5	0.1	0.11
CAALA_B10a Balcony (patio)	12.4	2	4,401e-10	3,661e-4	3,325e-4	3,804e-5	0.81	0.04
CAALA_B11 Floor (unheated rooms)	6	1	3,152e-10	1,896e-4	2,750e-4	3,519e-5	0.55	0.05
CAALA_B12 Sun protection	2.28	1	3,998e-11	4,336e-5	6,383e-4	6,598e-5	0.57	0.12
TGA	0	2	7,360e-7	1,011e-3	6,953e-3	6,528e-4	12.63	0.88

5. Life cycle cost analysis

5.1. Boundary conditions

Assessment period	50 Jahre
Gross Floor Area (GFA)	105 m²
Price increase rate for energy, maintenance, replacment and repair	2 %/Jahr
Price discount rate	1 %/Jahr
Initial Price for electricity	0,13 €/kWh
Price for [Electricity]	0,13

5.2. Overview of results

Investment costs				
KG 300 Building construction	3,240.89	€/m$^2_{\text{GFA}}$	64.82	€/m$^2_{\text{GFA}}$a
KG 400 Technical building equipment	190.48	€/m$^2_{\text{GFA}}$	3.81	€/m$^2_{\text{GFA}}$a
Operational costs				
Energy costs	273.05	€/m$^2_{\text{GFA}}$	5.46	€/m$^2_{\text{GFA}}$a
Inspection & maintenance costs for KG 300	210.44	€/m$^2_{\text{GFA}}$	4.21	€/m$^2_{\text{GFA}}$a
Inspection & maintenance costs for KG 400	50.71	€/m$^2_{\text{GFA}}$	1.01	€/m$^2_{\text{GFA}}$a
Repair Cost				
Repair Cost for KG 300	736.53	€/m$^2_{\text{GFA}}$	14.73	€/m$^2_{\text{GFA}}$a
Repair Cost for KG 400	81.63	€/m$^2_{\text{GFA}}$	1.63	€/m$^2_{\text{GFA}}$a

5.3. Results by cost group 2nd level

	Construction	Maintenance & Replace	Repair
KG 300 - Building construction	340,292.99€	22,095.97€	77,335.88€
KG 320 Foundation	19,653.42€	1,276.14€	4,466.49€
KG 330 Exterior walls	258,889.90€	16,810.29€	58,836.00€
KG 350 Ceilings	22,564.15€	1,465.14€	5,127.99€
KG 360 Roofs	39,185.52€	2,544.40€	8,905.40€
KG 400 - Technical building equipment	20,000.00€	5,324.44€	8,571.05€
KG 420 + 430 Heat generation equipment	20,000.00€	5,324.44€	8,571.05€

5.4. Results by cost group 3rd level

	Construction	Maintenance & Replacement		Repair	
	Costs	Expenses per year	Costs	Expenses per year	Costs
300 - Building construction	340,292.99€		22,095.98€		77,335.90€
322 Flat foundation	558.00€	0.1%	36.23€	0.35%	126.81€
324 Base plate	9,201.42€	0.1%	597.47€	0.35%	2,091.14€
325 Base flooring	9,894.00€	0.1%	642.44€	0.35%	2,248.54€
326 Sealing	0.00€	0.1%	0.00€	0.35%	0.00€
331 Load-bearing exterior wall	210,151.36€	0.1%	13,645.59€	0.35%	47,759.55€
334 Exterior doors and windows	9,051.00€	0.1%	587.70€	0.35%	2,056.95€
335 Exterior wall cladding outside	29,456.44€	0.1%	1,912.67€	0.35%	6,694.35€
336 Exterior wall finishing inside	10,231.10€	0.1%	664.33€	0.35%	2,325.15€
351 Ceiling strucutre	16,561.40€	0.1%	1,075.37€	0.35%	3,763.79€
352 Ceiling flooring	4,617.50€	0.1%	299.82€	0.35%	1,049.39€
353 Ceiling finishing	1,385.25€	0.1%	89.95€	0.35%	314.82€
361 Roof structure	18,942.00€	0.1%	1,229.95€	0.35%	4,304.81€
363 Roof covering	20,243.52€	0.1%	1,314.46€	0.35%	4,600.60€
364 Roof finishing inside	0.00€	0.1%	0.00€	0.35%	0.00€
400 - Technical building equipment	20000€		5,324.44€		8,571.05€
420 + 430 Heat generation equipment	20000€	0.41%	5,324.44€	0.66%	8,571.05€

6. Building envelope and building technology

6.1. Surfaces

Overview

	ID	Layer	Orientation	Net area	Gross area	Length	Angle (Azimut
▶	**CAALA_A01 Exterior wall load-bearing (Count: 26 , Net area: 131.48 m² , Gross area: 160.15 m² , Length: 0.00 m)**						
▶	**CAALA_A03 Roof (Count: 2 , Net area: 115.02 m² , Gross area: 115.02 m² , Length: 0.00 m)**						
▶	**CAALA_A04 Ceiling to unheated roof (Count: 13 , Net area: 92.35 m² , Gross area: 92.35 m² , Length: 0.00 m)**						
▶	**CAALA_A11 Floor to ground (Count: 10 , Net area: 98.94 m² , Gross area: 99.23 m² , Length: 0.00 m)**						
▶	**CAALA_A12 Window (exterior wall) (Count: 27 , Net area: 30.17 m² , Gross area: 30.17 m² , Length: 0.00 m)**						
▶	**CAALA_B04 Exterior wall (unheated rooms) (Count: 6 , Net area: 21.66 m² , Gross area: 23.94 m² , Length: 0.00 m)**						
▶	**CAALA_B04c innerwalls non load bearing (Count: 11 , Net area: 28.80 m² , Gross area: 28.80 m² , Length: 0.00 m)**						
▶	**CAALA_B04d innerwalls load bearing (Count: 20 , Net area: 42.46 m² , Gross area: 43.67 m² , Length: 0.00 m)**						
▶	**CAALA_B04e inner doors (Count: 8 , Net area: 14.38 m² , Gross area: 14.38 m² , Length: 0.00 m)**						
▶	**CAALA_B04f mesh terrace (Count: 3 , Net area: 20.63 m² , Gross area: 20.63 m² , Length: 0.00 m)**						
▶	**CAALA_B04g Landprice (Count: 1 , Net area: 1.00 m² , Gross area: 1.00 m² , Length: 0.00 m)**						
▶	**CAALA_B04h Kitchen complete (Count: 1 , Net area: 1.00 m² , Gross area: 1.00 m² , Length: 0.00 m)**						
▶	**CAALA_B04i Bathroom (Count: 1 , Net area: 1.00 m² , Gross area: 1.00 m² , Length: 0.00 m)**						
▶	**CAALA_B04j Other (Count: 1 , Net area: 1.00 m² , Gross area: 1.00 m² , Length: 0.00 m)**						
▶	**CAALA_B07 Roof (unheated room) (Count: 2 , Net area: 21.36 m² , Gross area: 21.36 m² , Length: 0.00 m)**						
▶	**CAALA_B10 Balcony (Count: 83 , Net area: 32.18 m² , Gross area: 32.18 m² , Length: 0.00 m)**						
▶	**CAALA_B10a Balcony (patio) (Count: 1 , Net area: 12.40 m² , Gross area: 12.40 m² , Length: 0.00 m)**						
▶	**CAALA_B11 Floor (unheated rooms) (Count: 1 , Net area: 6.00 m² , Gross area: 6.00 m² , Length: 0.00 m)**						
▶	**CAALA_B12 Sun protection (Count: 2 , Net area: 2.28 m² , Gross area: 2.28 m² , Length: 0.00 m)**						

Detailed areas

	ID	Layer	Orientation	Net area	Gross area	Length	Angle (Azimu
◢	**CAALA_A01 Exterior wall load-bearing (Count: 26 , Net area: 131.48 m² , Gross area: 160.15 m² , Length: 0.00 m)**						
	10355	CAALA_A01 Exterior wall load-bearing	W90	6.85	10.53	0	270
	6349	CAALA_A01 Exterior wall load-bearing	W90	1.46	2.87	0	270
	6310	CAALA_A01 Exterior wall load-bearing	N90	7.74	8.1	0	360

	5981	CAALA_A01 Exterior wall load-bearing	E90	1.68	1.68	0	90
	6849	CAALA_A01 Exterior wall load-bearing	S90	7.74	8.1	0	180
	7604	CAALA_A01 Exterior wall load-bearing	E90	9.98	9.98	0	90
	4986	CAALA_A01 Exterior wall load-bearing	S90	10.62	11.9	0	180
	4947	CAALA_A01 Exterior wall load-bearing	N90	10.62	11.9	0	360
	4905	CAALA_A01 Exterior wall load-bearing	E90	7.97	10.53	0	90
	4835	CAALA_A01 Exterior wall load-bearing	S90	6.96	7.32	0	180
	4970	CAALA_A01 Exterior wall load-bearing	N90	1.17	2	0	360
	5584	CAALA_A01 Exterior wall load-bearing	S90	1.17	1.17	0	180
	10335	CAALA_A01 Exterior wall load-bearing	W90	6.85	10.53	0	270
	4842	CAALA_A01 Exterior wall load-bearing	E90	2.61	2.61	0	90
	5594	CAALA_A01 Exterior wall load-bearing	N90	1.05	1.43	0	360
	6340	CAALA_A01 Exterior wall load-bearing	W90	3.74	3.74	0	270
	6908	CAALA_A01 Exterior wall load-bearing	E90	4.15	4.15	0	90
	7603	CAALA_A01 Exterior wall load-bearing	E90	6.62	9.43	0	90
	6270	CAALA_A01 Exterior wall load-bearing	N90	6.82	6.82	0	360
	5202	CAALA_A01 Exterior wall load-bearing	E90	3.41	3.77	0	90
	6264	CAALA_A01 Exterior wall load-bearing	S90	6.82	6.82	0	180
	6268	CAALA_A01 Exterior wall load-bearing	W90	3.74	3.74	0	270
	5433	CAALA_A01 Exterior wall load-bearing	W90	3.07	8.71	0	270
	4967	CAALA_A01 Exterior wall load-bearing	S90	1.05	3.45	0	180
	6261	CAALA_A01 Exterior wall load-bearing	E90	1.55	1.55	0	90

4904	CAALA_A01 Exterior wall load-bearing	N90	6.04	7.32	0	360
◢ CAALA_A03 Roof (Count: 2 , Net area: 115.02 m² , Gross area: 115.02 m² , Length: 0.00 m)						
6280	CAALA_A03 Roof	W30	61.34	61.34	0	270
6309	CAALA_A03 Roof	E30	53.68	53.68	0	90
◢ CAALA_A04 Ceiling to unheated roof (Count: 13 , Net area: 92.35 m² , Gross area: 92.35 m² , Length: 0.00 m)						
6060	CAALA_A04 Ceiling to unheated roof	HOR	11.4	11.4	0	90
6070	CAALA_A04 Ceiling to unheated roof	HOR	0.59	0.59	0	90
6232	CAALA_A04 Ceiling to unheated roof	HOR	13.4	13.4	0	57.24
6066	CAALA_A04 Ceiling to unheated roof	HOR	1.11	1.11	0	90
6062	CAALA_A04 Ceiling to unheated roof	HOR	4.08	4.08	0	90
6061	CAALA_A04 Ceiling to unheated roof	HOR	7.32	7.32	0	90
6073	CAALA_A04 Ceiling to unheated roof	HOR	1.81	1.81	0	90
6230	CAALA_A04 Ceiling to unheated roof	HOR	9.95	9.95	0	69.92
6065	CAALA_A04 Ceiling to unheated roof	HOR	3.79	3.79	0	90
6069	CAALA_A04 Ceiling to unheated roof	HOR	1.23	1.23	0	90
6064	CAALA_A04 Ceiling to unheated roof	HOR	18.54	18.54	0	90
6063	CAALA_A04 Ceiling to unheated roof	HOR	18.54	18.54	0	237.05
6074	CAALA_A04 Ceiling to unheated roof	HOR	0.59	0.59	0	90
◢ CAALA_A11 Floor to ground (Count: 10 , Net area: 98.94 m² , Gross area: 99.23 m² , Length: 0.00 m)						
4996	CAALA_A11 Floor to ground	HOR	18.54	18.54	0	90
5802	CAALA_A11 Floor to ground	HOR	1.81	1.81	0	90
5653	CAALA_A11 Floor to ground	HOR	0.59	0.59	0	90
5825	CAALA_A11 Floor to ground	HOR	0.59	0.59	0	90
5024	CAALA_A11 Floor to ground	HOR	7.32	7.32	0	90
5000	CAALA_A11 Floor to ground	HOR	3.79	3.79	0	90
5690	CAALA_A11 Floor to ground	HOR	1.81	1.81	0	90
5486	CAALA_A11 Floor to ground	HOR	1.23	1.23	0	90
4997	CAALA_A11 Floor to ground	HOR	51.86	52.15	0	90
5082	CAALA_A11 Floor to ground	HOR	11.4	11.4	0	90
◢ CAALA_A12 Window (exterior wall) (Count: 27 , Net area: 30.17 m² , Gross area: 30.17 m² , Length: 0.00 m)						
5928	CAALA_A12 Window (exterior wall)	S90	0.36	0.36	0	180
10331	CAALA_A12 Window (exterior wall)	W90	1.41	1.41	0	270
10353	CAALA_A12 Window (exterior wall)	W90	1.84	1.84	0	270
10339	CAALA_A12 Window (exterior wall)	W90	1.84	1.84	0	270
5950	CAALA_A12 Window (exterior wall)	N90	1.28	1.28	0	360
4875	CAALA_A12 Window (exterior wall)	E90	2.23	2.23	0	90

6017	CAALA_A12 Window (exterior wall)	E90	2.56	2.56	0	90
5535	CAALA_A12 Window (exterior wall)	W90	1.41	1.41	0	270
6866	CAALA_A12 Window (exterior wall)	N90	0.36	0.36	0	360
5564	CAALA_A12 Window (exterior wall)	W90	1.41	1.41	0	270
10337	CAALA_A12 Window (exterior wall)	W90	1.84	1.84	0	270
5939	CAALA_A12 Window (exterior wall)	S90	1.28	1.28	0	180
5988	CAALA_A12 Window (exterior wall)	E90	0.29	0.29	0	90
5604	CAALA_A12 Window (exterior wall)	N90	0.83	0.83	0	360
10351	CAALA_A12 Window (exterior wall)	W90	1.84	1.84	0	270
10417	CAALA_A12 Window (exterior wall)	N90	0.38	0.38	0	360
5959	CAALA_A12 Window (exterior wall)	N90	1.28	1.28	0	0
10419	CAALA_A12 Window (exterior wall)	S90	1.2	1.2	0	180
10421	CAALA_A12 Window (exterior wall)	N90	0.38	0.38	0	0
5598	CAALA_A12 Window (exterior wall)	N90	0.83	0.83	0	0
5576	CAALA_A12 Window (exterior wall)	W90	1.41	1.41	0	270
5570	CAALA_A12 Window (exterior wall)	W90	1.41	1.41	0	270
5970	CAALA_A12 Window (exterior wall)	E90	0.36	0.36	0	90
5997	CAALA_A12 Window (exterior wall)	E90	0.29	0.29	0	90
6003	CAALA_A12 Window (exterior wall)	E90	0.29	0.29	0	90
6104	CAALA_A12 Window (exterior wall)	S90	0.36	0.36	0	180
5580	CAALA_A12 Window (exterior wall)	S90	1.2	1.2	0	180

◢ **CAALA_B04 Exterior wall (unheated rooms) (Count: 6 , Net area: 21.66 m² , Gross area: 23.94 m² , Length: 0.00 m)**

10496	CAALA_B04 Exterior wall (unheated rooms)	N90	3.75	3.75	0	0
10514	CAALA_B04 Exterior wall (unheated rooms)	E90	2.86	4.78	0	90
10483	CAALA_B04 Exterior wall (unheated rooms)	W90	4.42	4.78	0	270
10497	CAALA_B04 Exterior wall (unheated rooms)	N90	3.75	3.75	0	0
10531	CAALA_B04 Exterior wall (unheated rooms)	S90	3.44	3.44	0	180
10530	CAALA_B04 Exterior wall (unheated rooms)	S90	3.44	3.44	0	180

◢ **CAALA_B04c innerwalls non load bearing (Count: 11 , Net area: 28.80 m² , Gross area: 28.80 m² , Length: 0.00 m)**

5452	CAALA_B04c innerwalls non load bearing	N90	2.47	2.47	0	360
5878	CAALA_B04c innerwalls non load bearing	W90	0.74	0.74	0	270

5658	CAALA_B04c innerwalls non load bearing	W90	1.61	1.61	0	270
5909	CAALA_B04c innerwalls non load bearing	N90	1.91	1.91	0	0
5151	CAALA_B04c innerwalls non load bearing	W90	0.31	0.31	0	270
5205	CAALA_B04c innerwalls non load bearing	S90	5.4	5.4	0	180
5826	CAALA_B04c innerwalls non load bearing	W90	0.56	0.56	0	270
5490	CAALA_B04c innerwalls non load bearing	E90	3.38	3.38	0	90
5429	CAALA_B04c innerwalls non load bearing	N90	5.66	5.66	0	0
5484	CAALA_B04c innerwalls non load bearing	E90	3.38	3.38	0	90
5451	CAALA_B04c innerwalls non load bearing	W90	3.38	3.38	0	270
CAALA_B04d innerwalls load bearing (Count: 20 , Net area: 42.46 m² , Gross area: 43.67 m² , Length: 0.00 m)						
5439	CAALA_B04d innerwalls load bearing	N90	0.45	0.45	0	360
5165	CAALA_B04d innerwalls load bearing	N90	2.93	2.93	0	0
5441	CAALA_B04d innerwalls load bearing	S90	1.7	1.7	0	180
5437	CAALA_B04d innerwalls load bearing	S90	1.44	1.44	0	180
5169	CAALA_B04d innerwalls load bearing	S90	1.14	1.14	0	180
5168	CAALA_B04d innerwalls load bearing	N90	0.45	0.45	0	360
5447	CAALA_B04d innerwalls load bearing	S90	2.47	2.47	0	180
5751	CAALA_B04d innerwalls load bearing	S90	3.5	3.5	0	180
4998	CAALA_B04d innerwalls load bearing	N90	2.93	2.93	0	0
5881	CAALA_B04d innerwalls load bearing	S90	0.86	0.86	0	180
5883	CAALA_B04d innerwalls load bearing	S90	1.46	1.46	0	180
5443	CAALA_B04d innerwalls load bearing	S90	0.32	0.32	0	180

5880	CAALA_B04d innerwalls load bearing	S90	2.62	2.62	0	180
5483	CAALA_B04d innerwalls load bearing	S90	0.52	0.52	0	180
5170	CAALA_B04d innerwalls load bearing	E90	8.61	8.61	0	90
5193	CAALA_B04d innerwalls load bearing	W90	1.85	1.85	0	270
5025	CAALA_B04d innerwalls load bearing	E90	6.76	6.76	0	90
5183	CAALA_B04d innerwalls load bearing	S90	0.32	0.32	0	180
5851	CAALA_B04d innerwalls load bearing	S90	0.48	0.48	0	180
5060	CAALA_B04d innerwalls load bearing	S90	1.65	2.86	0	180
CAALA_B04e inner doors (Count: 8 , Net area: 14.38 m² , Gross area: 14.38 m² , Length: 0.00 m)						
5083	CAALA_B04e inner doors	N90	1.92	1.92	0	0
5139	CAALA_B04e inner doors	E90	1.92	1.92	0	90
5243	CAALA_B04e inner doors	S90	1.38	1.38	0	180
6035	CAALA_B04e inner doors	N90	2.02	2.02	0	0
5037	CAALA_B04e inner doors	W90	1.92	1.92	0	270
5226	CAALA_B04e inner doors	S90	1.92	1.92	0	180
5166	CAALA_B04e inner doors	S90	1.92	1.92	0	180
5237	CAALA_B04e inner doors	S90	1.38	1.38	0	180
CAALA_B04f mesh terrace (Count: 3 , Net area: 20.63 m² , Gross area: 20.63 m² , Length: 0.00 m)						
10347	CAALA_B04f mesh terrace	S90	3.6	3.6	0	180
10343	CAALA_B04f mesh terrace	N90	3.6	3.6	0	360
10345	CAALA_B04f mesh terrace	W90	13.43	13.43	0	270
CAALA_B04g Landprice (Count: 1 , Net area: 1.00 m² , Gross area: 1.00 m² , Length: 0.00 m)						
73902	CAALA_B04g Landprice	HOR	1	1	0	90
CAALA_B04h Kitchen complete (Count: 1 , Net area: 1.00 m² , Gross area: 1.00 m² , Length: 0.00 m)						
73911	CAALA_B04h Kitchen complete	HOR	1	1	0	90
CAALA_B04i Bathroom (Count: 1 , Net area: 1.00 m² , Gross area: 1.00 m² , Length: 0.00 m)						
73920	CAALA_B04i Bathroom	HOR	1	1	0	90
CAALA_B04j Other (Count: 1 , Net area: 1.00 m² , Gross area: 1.00 m² , Length: 0.00 m)						
73929	CAALA_B04j Other	HOR	1	1	0	90
CAALA_B07 Roof (unheated room) (Count: 2 , Net area: 21.36 m² , Gross area: 21.36 m² , Length: 0.00 m)						
10478	CAALA_B07 Roof (unheated room)	S0	6	6	0	180

6914	CAALA_B07 Roof (unheated room)	E0	15.36	15.36	0	90
CAALA_B10 Balcony (Count: 83 , Net area: 32.18 m² , Gross area: 32.18 m² , Length: 0.00 m)						
7694	CAALA_B10 Balcony	N90	0.07	0.07	0	360
7697	CAALA_B10 Balcony	N90	0.07	0.07	0	0
6946	CAALA_B10 Balcony	N90	0.32	0.32	0	0
6926	CAALA_B10 Balcony	E90	0.32	0.32	0	90
7693	CAALA_B10 Balcony	N90	0.07	0.07	0	0
7699	CAALA_B10 Balcony	N90	0.07	0.07	0	360
7696	CAALA_B10 Balcony	N90	0.07	0.07	0	0
7845	CAALA_B10 Balcony	S90	0.07	0.07	0	180
7984	CAALA_B10 Balcony	E90	0.09	0.09	0	90
7703	CAALA_B10 Balcony	N90	0.07	0.07	0	360
7850	CAALA_B10 Balcony	S90	0.07	0.07	0	180
8370	CAALA_B10 Balcony	E90	0.02	0.02	0	90
7698	CAALA_B10 Balcony	N90	0.07	0.07	0	360
7705	CAALA_B10 Balcony	N90	0.07	0.07	0	0
7844	CAALA_B10 Balcony	S90	0.07	0.07	0	180
7695	CAALA_B10 Balcony	N90	0.07	0.07	0	0
7853	CAALA_B10 Balcony	S90	0.07	0.07	0	180
7995	CAALA_B10 Balcony	E90	0.09	0.09	0	90
7855	CAALA_B10 Balcony	S90	0.07	0.07	0	180
7706	CAALA_B10 Balcony	N90	0.07	0.07	0	360
7704	CAALA_B10 Balcony	N90	0.07	0.07	0	360
6918	CAALA_B10 Balcony	S90	0.32	0.32	0	180
9414	CAALA_B10 Balcony	E90	0.02	0.02	0	90
9549	CAALA_B10 Balcony	E90	0.02	0.02	0	90
9489	CAALA_B10 Balcony	E90	0.02	0.02	0	90
9534	CAALA_B10 Balcony	E90	0.02	0.02	0	90
8047	CAALA_B10 Balcony	E90	0.23	0.23	0	90
8028	CAALA_B10 Balcony	E90	0.32	0.32	0	90
7847	CAALA_B10 Balcony	S90	0.07	0.07	0	180
9444	CAALA_B10 Balcony	E90	0.02	0.02	0	90
9691	CAALA_B10 Balcony	E90	0.02	0.02	0	90
9609	CAALA_B10 Balcony	E90	0.02	0.02	0	90
9579	CAALA_B10 Balcony	E90	0.02	0.02	0	90
9459	CAALA_B10 Balcony	E90	0.02	0.02	0	90
9504	CAALA_B10 Balcony	E90	0.02	0.02	0	90

	9564	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9751	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9681	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9624	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9631	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9731	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9661	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9761	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9671	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9594	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9741	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9972	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9768	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9641	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9877	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9701	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9721	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9968	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9926	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	7849	CAALA_B10 Balcony	S90	0.07	0.07	0	180
	7702	CAALA_B10 Balcony	N90	0.07	0.07	0	0
	7846	CAALA_B10 Balcony	S90	0.07	0.07	0	180
	8017	CAALA_B10 Balcony	E90	0.32	0.32	0	90
	7854	CAALA_B10 Balcony	S90	0.07	0.07	0	180
	7848	CAALA_B10 Balcony	S90	0.07	0.07	0	180
	7856	CAALA_B10 Balcony	S90	0.07	0.07	0	180
	9870	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9961	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9933	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9905	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9912	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9651	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9711	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9891	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9940	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9884	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9954	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9947	CAALA_B10 Balcony	E90	0.02	0.02	0	90

	9919	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9898	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	10426	CAALA_B10 Balcony	HOR	26.98	26.98	0	90
	9474	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9429	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	9519	CAALA_B10 Balcony	E90	0.02	0.02	0	90
	8006	CAALA_B10 Balcony	E90	0.32	0.32	0	90
	7857	CAALA_B10 Balcony	S90	0.07	0.07	0	180
	8048	CAALA_B10 Balcony	E90	0.23	0.23	0	90
	9399	CAALA_B10 Balcony	E90	0.02	0.02	0	90
◢	**CAALA_B10a Balcony (patio) (Count: 1 , Net area: 12.40 m² , Gross area: 12.40 m² , Length: 0.00 m)**						
	6901	CAALA_B10a Balcony (patio)	HOR	12.4	12.4	0	90
◢	**CAALA_B11 Floor (unheated rooms) (Count: 1 , Net area: 6.00 m² , Gross area: 6.00 m² , Length: 0.00 m)**						
	10444	CAALA_B11 Floor (unheated rooms)	HOR	6	6	0	90
◢	**CAALA_B12 Sun protection (Count: 2 , Net area: 2.28 m² , Gross area: 2.28 m² , Length: 0.00 m)**						
	10486	CAALA_B12 Sun protection	E90	1.92	1.92	0	90
	10528	CAALA_B12 Sun protection	W90	0.36	0.36	0	270

6.2. Building Construction

Layer Name	CAALA_A01 Exterior wall load-bearing
Area	131.48 m²
Thickness	35.11 cm
U-value	0.158
Reference U-Value	0.280
Cost group	331 Load-bearing exterior wall
Name	CLT 10
Id	5d882bd6-02b1-42f8-99e8-2631802f199f
Thickness	10 cm
Cost group	335 Exterior wall cladding outside
Name	cedar+batten+cellulose
Id	6789f521-203f-4363-a337-7c9f95562748
Thickness	20 cm
Cost group	336 Exterior wall finishing inside
Name	Painting
Id	73c687d9-ffe0-4131-9c90-6e23597f656b
Thickness	0 cm
Layer Name	CAALA_A03 Roof
Area	115.02 m²
Thickness	60.20 cm
U-value	0.073
Reference U-Value	0.200
Cost group	361 Roof structure
Name	CLT 14
Id	83dc1c20-a8e8-4164-831a-aea5603c22cf
Thickness	10 cm
Cost group	363 Roof covering

Name	Cellulose, plywood, tar paper, rheinzink
Id	fa85c221-a14a-4561-a7b2-a9ace0304a63
Thickness	28.000000000000004 cm
Cost group	364 Roof finishing inside
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_A04 Ceiling to unheated roof
Area	92.35 m²
Thickness	40.31 cm
U-value	0.175
Reference U-Value	0.200
Cost group	351 Ceiling strucutre
Name	CLT 14
Id	c6083f01-2d90-496e-b8f4-124b783edf28
Thickness	10 cm
Cost group	352 Ceiling flooring
Name	Cellulose + wooden deck
Id	c7e5efdd-7c77-412d-ba1c-273190b1168b
Thickness	30 cm
Cost group	353 Ceiling finishing
Name	Painting
Id	536d608f-1600-44d7-80ac-a744750d9970
Thickness	0 cm
Layer Name	CAALA_A11 Floor to ground
Area	98.94 m²
Thickness	72.60 cm
U-value	0.125
Reference U-Value	0.350

Cost group	322 Flat foundation
Name	- empty -
Id	
Thickness	0 cm
Cost group	324 Base plate
Name	Concrete, eps, xps
Id	454d5640-5eb5-459e-9979-197ba4a9f79d
Thickness	70 cm
Cost group	325 Base flooring
Name	Stone clinker
Id	d4b8c30f-52e3-4ca0-b245-896b367f4789
Thickness	2 cm
Cost group	326 Sealing
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_A12 Window (exterior wall)
Area	30.17 m²
Thickness	0.00 cm
U-value	0.900
Reference U-Value	1.300
Cost group	334 Exterior doors and windows
Name	Fenster, Dreifach-Isolierverglasung, Alu-Rahmen, U=0,9, g=0,6
Id	0fe99fc1-a831-440a-a18a-b29e3735c752
Thickness	0 cm
Layer Name	CAALA_B04 Exterior wall (unheated rooms)
Area	21.66 m²
Thickness	24.70 cm
U-value	NaN

Reference U-Value	0.000
Cost group	331 Load-bearing exterior wall
Name	Ceder, batten, windshield, beam, fiberb
Id	fc8507e8-247d-42f6-bb16-cfc391ff41c5
Thickness	24 cm
Cost group	335 Exterior wall cladding outside
Name	fibercement
Id	dbdb5984-17a4-4329-9392-3f83b494efd4
Thickness	1 cm
Cost group	336 Exterior wall finishing inside
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_B04c innerwalls non load bearing
Area	28.80 m²
Thickness	12.01 cm
U-value	NaN
Reference U-Value	0.000
Cost group	331 Load-bearing exterior wall
Name	- empty -
Id	
Thickness	0 cm
Cost group	335 Exterior wall cladding outside
Name	Gypsum-plywood-batten-pw-gyp
Id	d582e3b6-7625-47e3-8930-19aa5041aa31
Thickness	12 cm
Cost group	336 Exterior wall finishing inside
Name	Painting
Id	73c687d9-ffe0-4131-9c90-6e23597f656b

Thickness	0 cm
Layer Name	CAALA_B04d innerwalls load bearing
Area	42.46 m²
Thickness	10.01 cm
U-value	NaN
Reference U-Value	0.000
Cost group	331 Load-bearing exterior wall
Name	CLT 10
Id	95889ac1-509a-4e45-a187-28b7eeeaba74
Thickness	10 cm
Cost group	335 Exterior wall cladding outside
Name	- empty -
Id	
Thickness	0 cm
Cost group	336 Exterior wall finishing inside
Name	Painting
Id	73c687d9-ffe0-4131-9c90-6e23597f656b
Thickness	0 cm
Layer Name	CAALA_B04e inner doors
Area	14.38 m²
Thickness	5.00 cm
U-value	NaN
Reference U-Value	0.000
Cost group	331 Load-bearing exterior wall
Name	- empty -
Id	
Thickness	0 cm
Cost group	335 Exterior wall cladding outside
Name	- empty -

Id	
Thickness	0 cm
Cost group	336 Exterior wall finishing inside
Name	Inside door
Id	a3916428-dbac-4f68-8622-902748f33e4a
Thickness	5 cm
Layer Name	CAALA_B04f mesh terrace
Area	20.63 m²
Thickness	0.50 cm
U-value	NaN
Reference U-Value	0.000
Cost group	331 Load-bearing exterior wall
Name	metal mesh
Id	541d603f-7f57-4633-919f-3767955e0c08
Thickness	1 cm
Cost group	335 Exterior wall cladding outside
Name	- empty -
Id	
Thickness	0 cm
Cost group	336 Exterior wall finishing inside
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_B04g Landprice
Area	1.00 m²
Thickness	0.00 cm
U-value	NaN
Reference U-Value	0.000
Cost group	331 Load-bearing exterior wall

Name	- empty -
Id	
Thickness	0 cm
Cost group	335 Exterior wall cladding outside
Name	- empty -
Id	
Thickness	0 cm
Cost group	336 Exterior wall finishing inside
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_B04h Kitchen complete
Area	1.00 m²
Thickness	0.00 cm
U-value	NaN
Reference U-Value	0.000
Cost group	331 Load-bearing exterior wall
Name	- empty -
Id	
Thickness	0 cm
Cost group	335 Exterior wall cladding outside
Name	- empty -
Id	
Thickness	0 cm
Cost group	336 Exterior wall finishing inside
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_B04i Bathroom

Area	1.00 m²
Thickness	0.00 cm
U-value	NaN
Reference U-Value	0.000
Cost group	331 Load-bearing exterior wall
Name	- empty -
Id	
Thickness	0 cm
Cost group	335 Exterior wall cladding outside
Name	- empty -
Id	
Thickness	0 cm
Cost group	336 Exterior wall finishing inside
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_B04j Other
Area	1.00 m²
Thickness	0.00 cm
U-value	NaN
Reference U-Value	0.000
Cost group	331 Load-bearing exterior wall
Name	- empty -
Id	
Thickness	0 cm
Cost group	335 Exterior wall cladding outside
Name	- empty -
Id	
Thickness	0 cm

Cost group	336 Exterior wall finishing inside
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_B07 Roof (unheated room)
Area	21.36 m²
Thickness	19.20 cm
U-value	NaN
Reference U-Value	0.000
Cost group	361 Roof structure
Name	Beam, råspont, papp, zink
Id	bd0eab35-deca-4d8e-9173-dc3351966133
Thickness	19 cm
Cost group	363 Roof covering
Name	- empty -
Id	
Thickness	0 cm
Cost group	364 Roof finishing inside
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_B10 Balcony
Area	32.18 m²
Thickness	2.80 cm
U-value	NaN
Reference U-Value	0.000
Cost group	351 Ceiling strucutre
Name	Wooden deck
Id	169ad472-bb33-42b3-a9a8-7510cad309e1

Thickness	3 cm
Cost group	352 Ceiling flooring
Name	- empty -
Id	
Thickness	0 cm
Cost group	353 Ceiling finishing
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_B10a Balcony (patio)
Area	12.40 m²
Thickness	40.00 cm
U-value	NaN
Reference U-Value	0.000
Cost group	351 Ceiling strucutre
Name	Concrete+eps+xps
Id	a86b47f0-4210-4e12-8ae1-6702dc231cc8
Thickness	10 cm
Cost group	352 Ceiling flooring
Name	- empty -
Id	
Thickness	0 cm
Cost group	353 Ceiling finishing
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_B11 Floor (unheated rooms)
Area	6.00 m²
Thickness	70.20 cm

U-value	NaN
Reference U-Value	0.000
Cost group	322 Flat foundation
Name	Concrete, eps, xps
Id	454d5640-5eb5-459e-9979-197ba4a9f79d
Thickness	70 cm
Cost group	324 Base plate
Name	- empty -
Id	
Thickness	0 cm
Cost group	325 Base flooring
Name	- empty -
Id	
Thickness	0 cm
Cost group	326 Sealing
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_B12 Sun protection
Area	2.28 m²
Thickness	0.00 cm
U-value	NaN
Reference U-Value	0.000
Cost group	334 Exterior doors and windows
Name	Fenster, Dreifach-Isolierverglasung, Alu-Rahmen, U=0,9, g=0,6
Id	0fe99fc1-a831-440a-a18a-b29e3735c752
Thickness	0 cm

6.3. Building Technology

420+430 Heat generation equipment	Heat pump ground/water, mechanical ventilation with heat recovery
Primary energy factor electricity	20000.00
Production costs KG	20000.00 €
Performance coefficiente$_p$	0.56
440 Photovoltaik 1 Orientierung	South (default)
Inclination	30°
Area	0 m²
440 Photovoltaik 2 Orientierung	South (default)
Inclination	30°
Area	0 m²
Production costs KG	20000.00 €

6.4. Other input values and boundary conditions

Thermal bridge surcharge	Enhanced 0,05 W/m²K
Air tightness	New construction - general: n50 = 4 h^{-1}

Caala Report

For Project: Källsprångsvägen

Table of Content

1. Object data

1.1. Object

Model	210308 Källsprång modell CAALA Original (proposal)
Scope of analysis	Full Life Cycle
Level of detail	Blueprint planning
Building type	Apartment building
Energy standard	EnEV 2016
Reference study period	50 Jahre
Climate region - reference location	Region 10 - Hof

1.2. Geometry

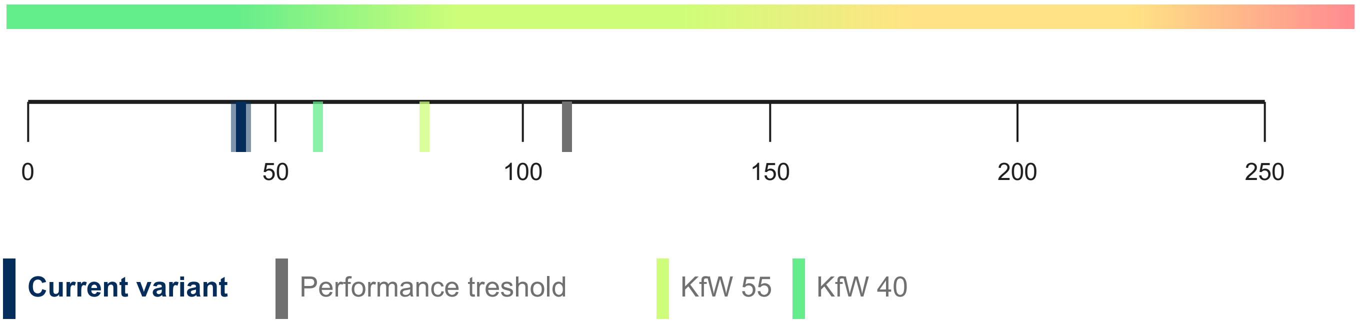
Average floor height	3.20 m
V	336.00 m³
GFA th.	105.00 m²
NFA	84.00 m²
Reference area	91.56 m²

2. Overview

2.1. Primary energy demand

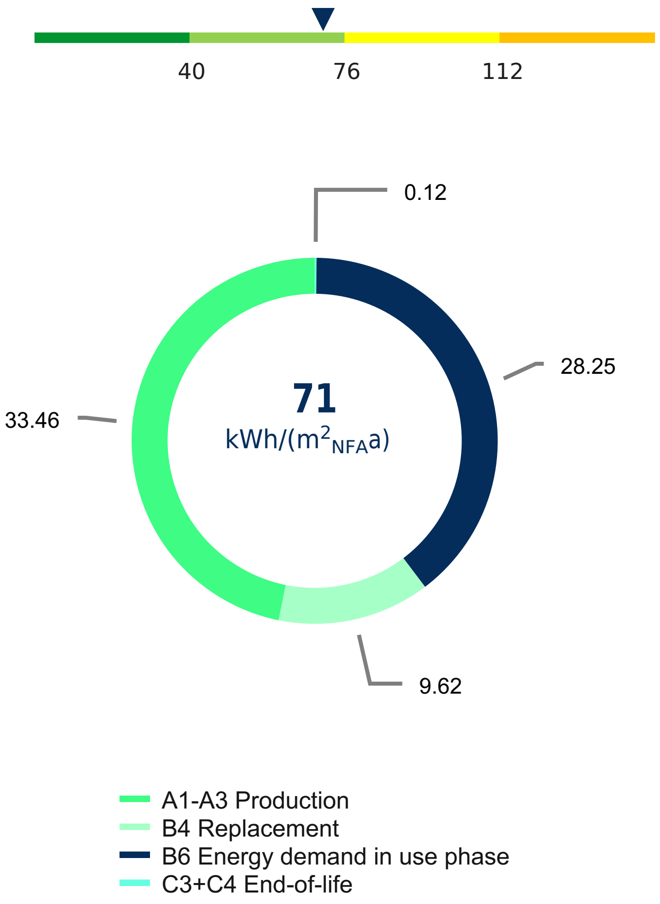
42

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

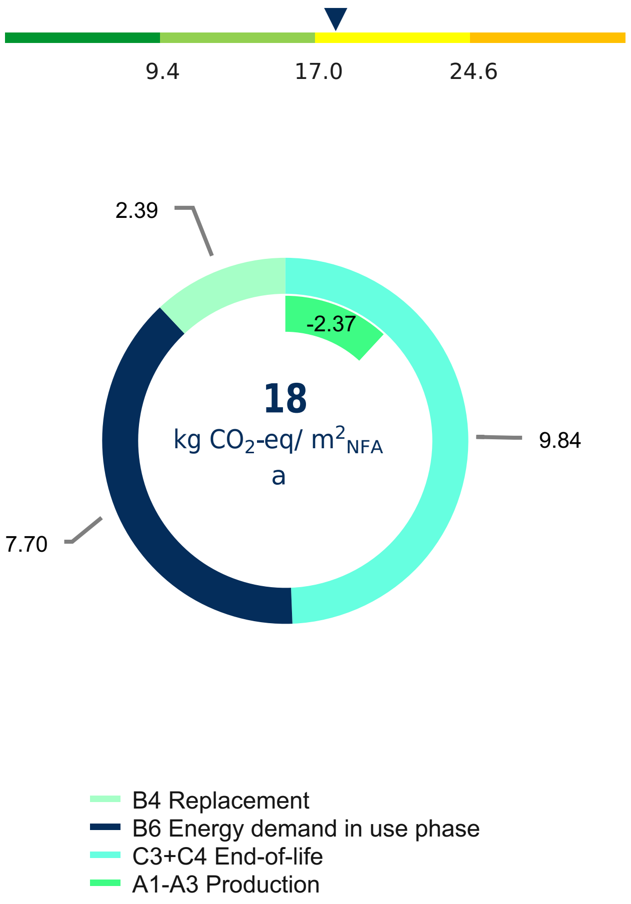


2.2. Life Cycle Assessment

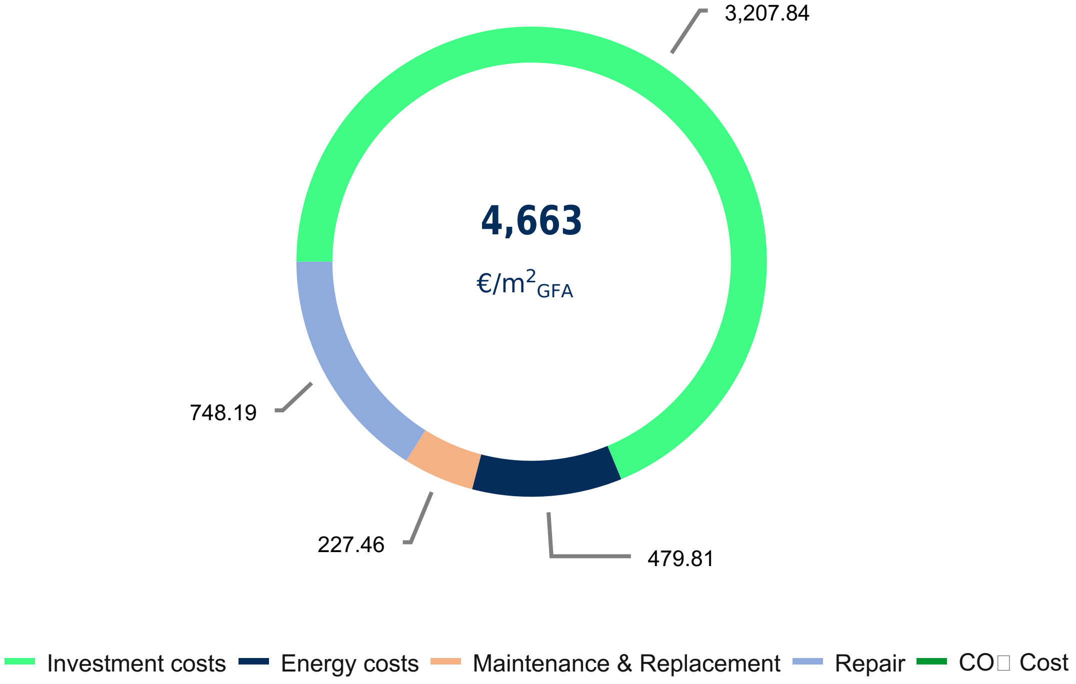
Primary energy non renewable (PENRT)



Global warming potential (GWP)

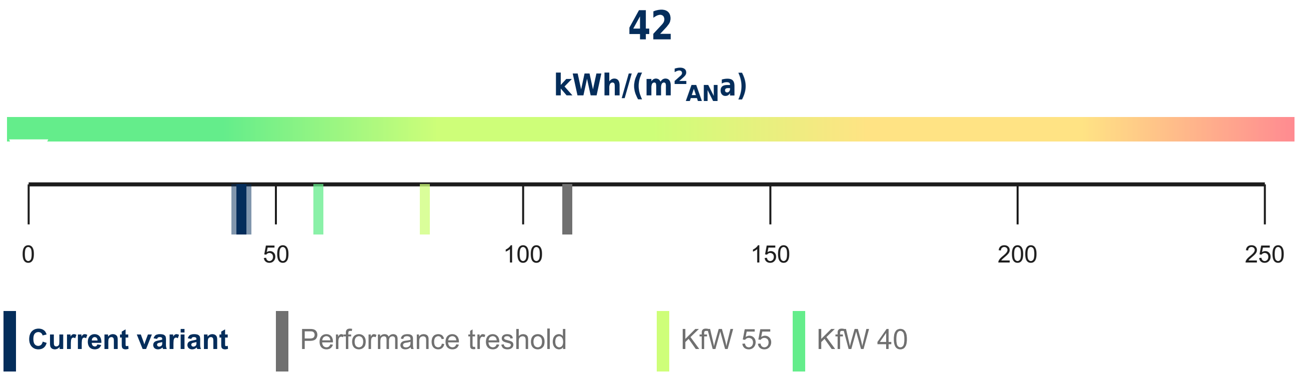


Life cycle costs



3. Operational energy demand

3.1. Overview



Annual energy requirement operation

Primary energy demand		42 kWh/m^{2}a
End energy demand		153 kWh/m^{2}a
	Auxiliary energy (electricity)	6 kWh/m^{2}a
Useful energy requirement	Space heating	68 kWh/m^{2}a
	Hot water	15 kWh/m^{2}a

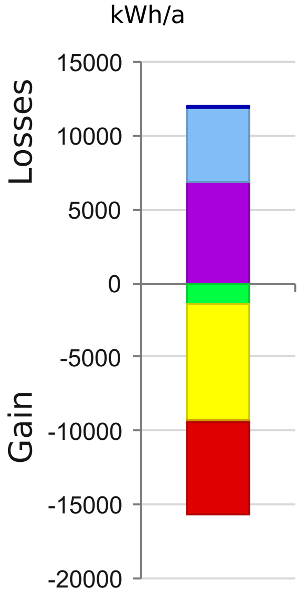
Energetic parameters

Energy reference area	91.56 m^2
Specific area-based transmission heat loss H'_T	**0.20 W/(m^{2}K)**
Max. specific area-based transmission heat loss H'_T	0.36 W/(m^{2}K)

3.2. Result per year

Legend

Losse	🟦 Solar losses opaque	34 kWh
	🟦 Ventilation heat losses	5,049 kWh
	🟪 Transmission heat losses	6,880 kWh
Gain	🟩 Internal gains	1,376 kWh
	🟨 Solar gains transparent	7,881 kWh
	🟧 Solar gains opaque	168 kWh
	🟥 **Heating demand**	**6,206 kWh**

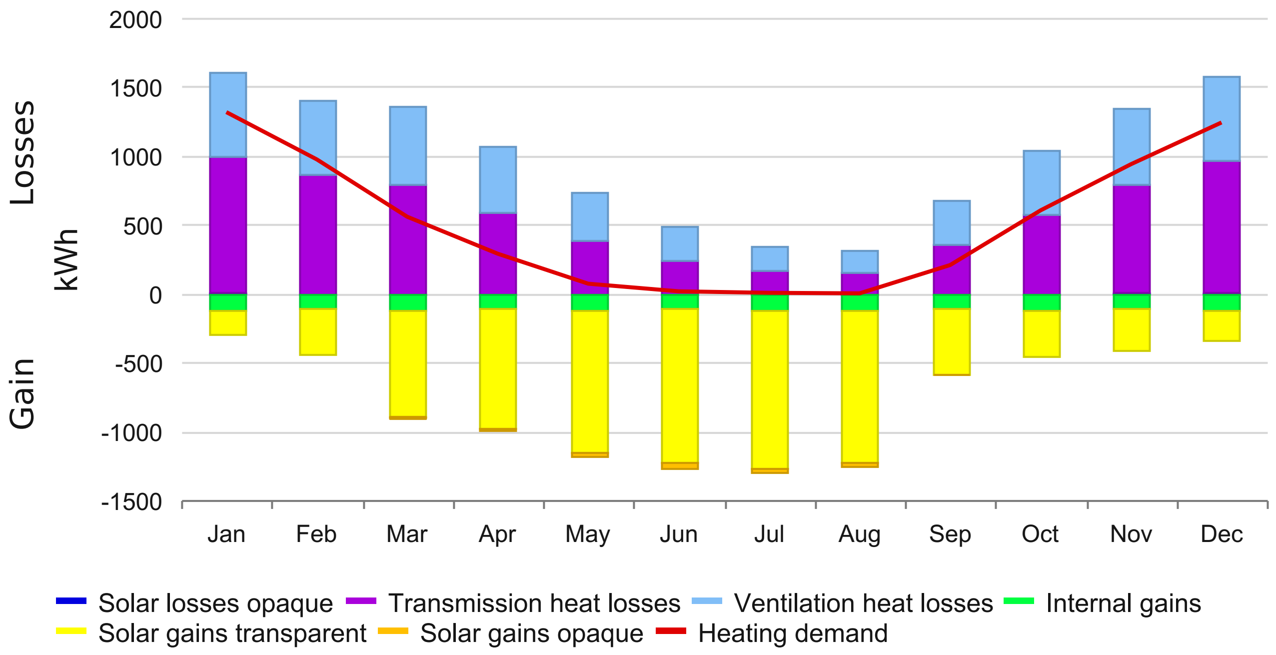


Annual balance of energy generation on site (photovoltaics)

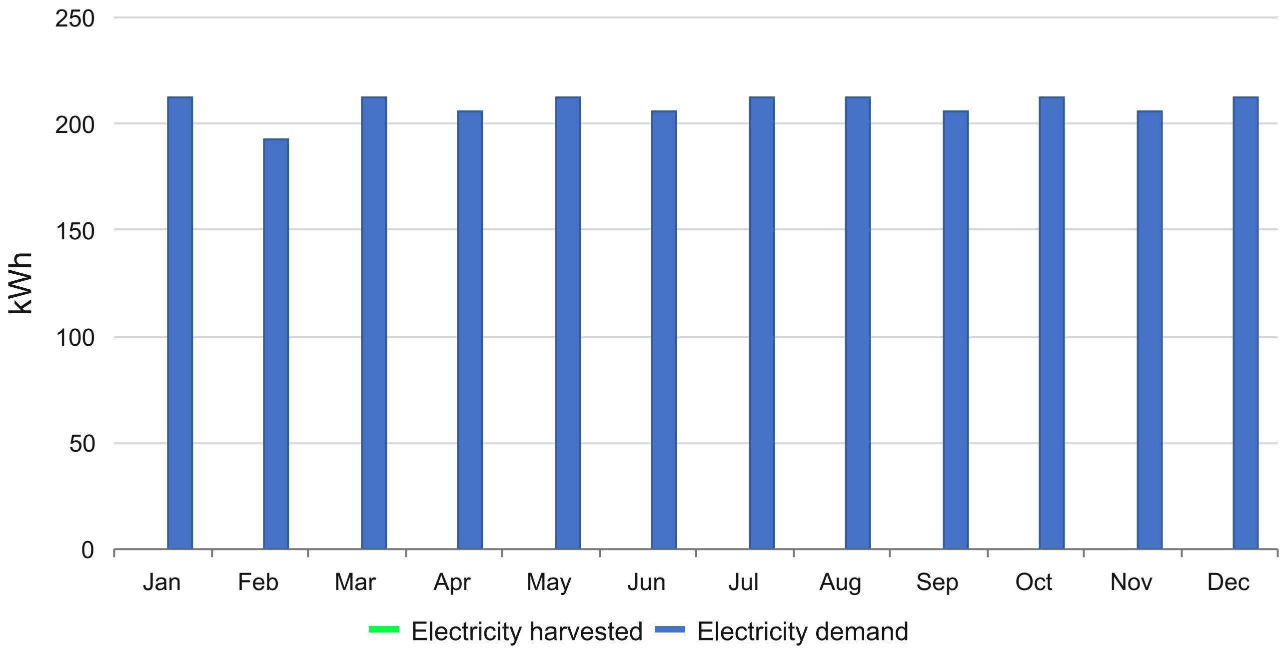
🟩 Electricity harvested	0 kWh
🟦 Electricity demand	2,506 kWh

3.3. Result monthly per year sheet

Monthly energy balance



Monthly energy harvesting on site (photovoltaics)



Monthly values

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Natural ventilation $H_{V, win, mth}$ (W / K)	29.9	31.2	36.3	42.3	50.4	54.9	57.7	58.2	50.9	43.9	35.5	30.7
Ref: Natural ventilation $H_{V, win, mth}$ (W / K)	29.9	31.2	36.3	42.3	50.4	54.9	57.7	58.2	50.9	43.9	35.5	30.7
Internal temperature balance(°C)	18.2	18.2	18.3	18.7	19.2	19.5	19.6	19.7	19.2	18.8	18.3	18.2
Ref: Internal temperature balance(°C)	18.0	18.1	18.2	18.6	19.1	19.4	19.6	19.6	19.1	18.7	18.2	18.0
Transmission heat sinks QT_{sink} (kWh)	990.6	859.0	794.4	598.9	383.3	245.8	170.9	157.0	357.5	572.7	791.1	965.8
Ref: Transmission heat sinks QT_{sink} (kWh)	1,779.9	1,543.4	1,424.5	1,072.7	686.6	440.3	306.1	281.2	640.4	1,025.7	1,421.5	1,735.5
Ventilation heat sinks QV_{sink} (kWh)	606.7	542.0	560.1	475.0	349.3	240.0	173.9	160.9	328.3	467.5	548.7	602.8
Ref: Ventilation heat sinks QV_{sink} (kWh)	601.6	537.5	554.3	469.5	345.3	237.2	171.9	159.1	324.5	462.1	544.1	597.7
Solar gains transparent $QS_{tr,source}$ (kWh)	176.8	333.8	769.3	865.3	1,039.3	1,113.5	1,148.8	1,101.4	469.3	343.7	302.4	223.6
Ref: Solar gains transparent $QS_{tr,source}$ (kWh)	176.8	333.8	769.3	865.3	1,039.3	1,113.5	1,148.8	1,101.4	469.3	343.7	302.4	223.6
Solar gains opaque $QS_{opaq,source}$ (kWh)	0.0	0.0	12.4	19.6	29.4	34.5	35.1	30.3	7.3	0.0	0.0	0.0
Ref: Solar gains opaque $QS_{opaq,source}$ (kWh)	0.0	0.0	25.3	41.7	63.4	75.0	76.0	65.0	15.7	0.0	0.0	0.0
Solar losses opaque $QS_{opaq,sink}$ (kWh)	11.3	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	6.8	10.5
Ref: Solar losses opaque $QS_{opaq,sink}$ (kWh)	11.3	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	6.8	10.5
Internal heat sources QI_{source} (kWh)	117.2	105.8	117.2	113.4	117.2	113.4	117.2	117.2	113.4	117.2	113.4	117.2
Ref: Internal heat sources QI_{source} (kWh)	117.2	105.8	117.2	113.4	117.2	113.4	117.2	117.2	113.4	117.2	113.4	117.2

Utilization factor η^M	1.0	1.0	0.9	0.8	0.6	0.4	0.3	0.3	0.8	1.0	1.0	1.0
Ref: Utilization factor η^M	1.0	1.0	0.9	0.8	0.7	0.5	0.3	0.3	0.9	1.0	1.0	1.0
Heat demand $Q_{h,b}$	1,315.6	972.3	555.9	287.7	70.0	14.7	3.7	0.0	205.4	602.4	937.7	1,240.4
Ref: Heat demand $Q_{h,b}$	2,114.3	1,656.8	1,143.7	683.7	237.1	71.2	24.2	20.7	451.9	1,052.1	1,572.6	2,018.7
Electricity demand (kWh)	212.8	192.2	212.8	205.9	212.8	205.9	212.8	212.8	205.9	212.8	205.9	212.8

4. Life cycle assessment

4.1. Boundary conditions

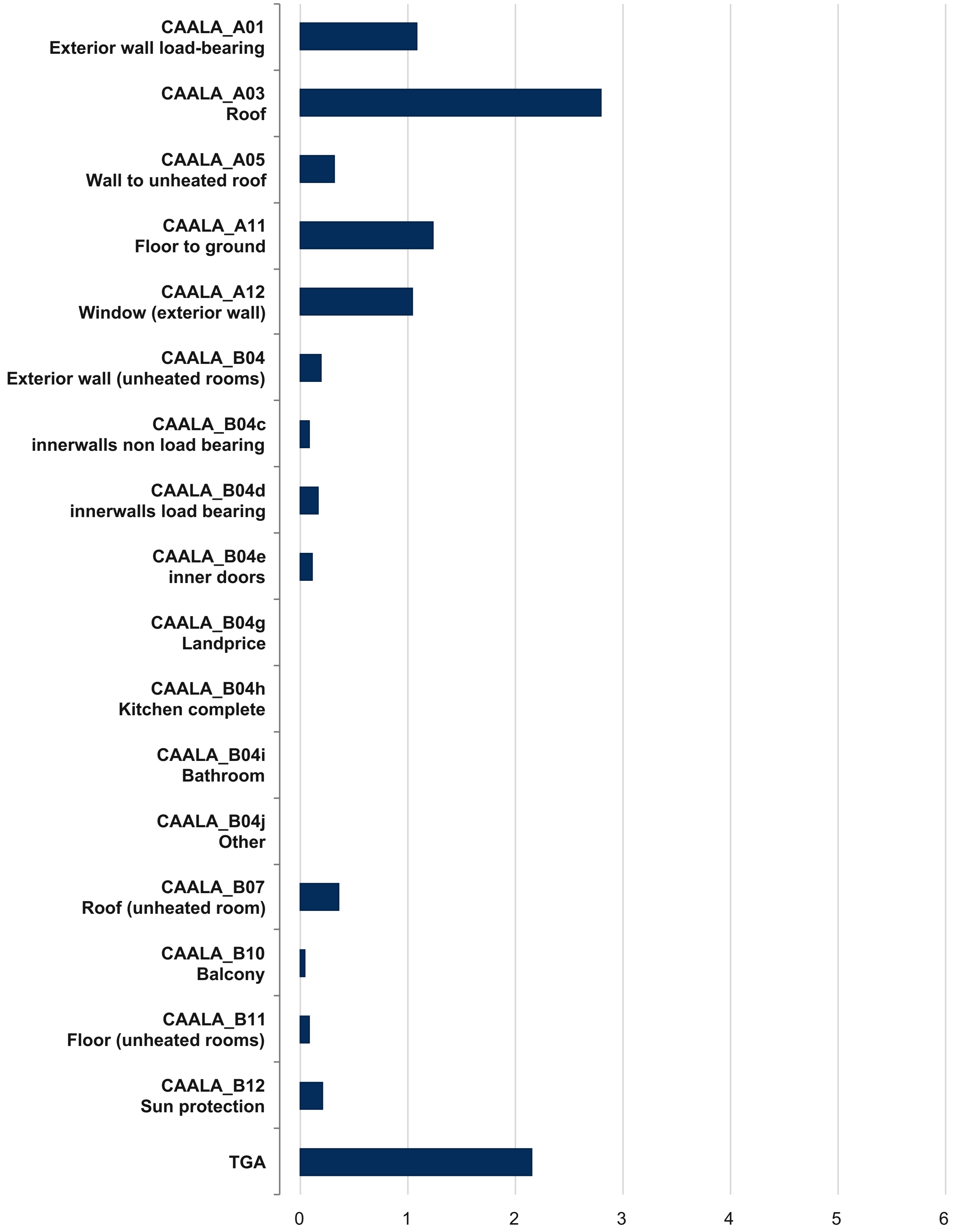
Assessment period	50 Jahre
Net floor area (NFA)	84.00 m²
Database	Ökobau.dat 2016
Assessed life cycle modules	A1-A3, B4, B6, C3+C4

4.2. Overview of the results

	MODULE	GWP	ODP	POCP	AP	EP	PENRT	PERT
Embodied	A1-A3, B4, B6, C3+C4	9.86	2,596e-7	5,652e-3	4,307e-2	7,628e-3	43.2	28.4
Operational	B6	7.7	2,493e-10	5,532e-3	5,795e-2	1,304e-2	28.25	251.66
Total		17.56	2,598e-7	1,118e-2	1,010e-1	2,067e-2	71.45	280.06

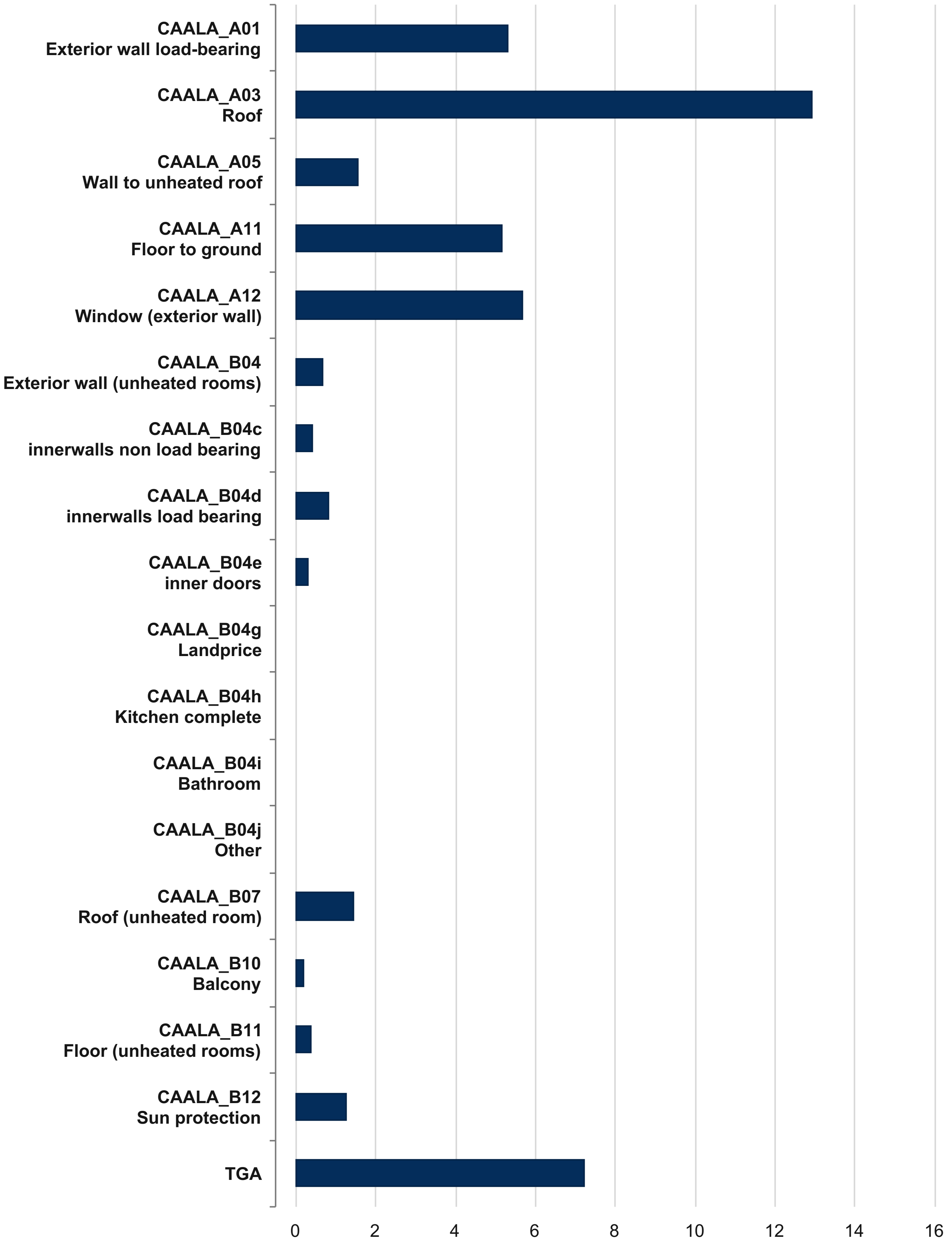
4.3. Results for integrated environmental impacts

Global warming potential (GWP)



$\text{kg CO}_2\text{-eq/ m}^2_{NFA}\text{a}$

Primary energy non renewable (PENRT)



$kWh/(m^2_{NFA}a)$

4.4. Results for integrated environmental impacts per layer

	m^2	GWP	ODP	POCP	AP	EP	PENRT	PERT
CAALA_A01 Exterior wall load-bearing	96.6	1	6,372e-8	5,540e-4	5,418e-3	1,334e-3	5.28	4.34
CAALA_A03 Roof	98.88	2	1,053e-7	1,240e-3	1,309e-2	3,099e-3	12.92	8.96
CAALA_A05 Wall to unheated roof	26.39	3	3,233e-8	1,642e-4	1,557e-3	3,713e-4	1.54	0.91
CAALA_A11 Floor to ground	99.63	1	3,587e-11	2,165e-4	2,760e-3	3,520e-4	5.16	1.84
CAALA_A12 Window (exterior wall)	33.05	1	1,213e-10	1,240e-3	5,401e-3	8,542e-4	5.69	6.88
CAALA_B04 Exterior wall (unheated rooms)	36.49	1	2,932e-9	4,394e-4	9,691e-4	2,065e-4	0.65	1.37
CAALA_B04c innerwalls non load bearing	23.43	8	9,632e-9	6,130e-5	3,187e-4	7,000e-5	0.42	0.79
CAALA_B04d innerwalls load bearing	38.1	1	2,448e-8	1,233e-4	6,113e-4	1,234e-4	0.82	0.42
CAALA_B04e inner doors	10.54	1	1,661e-9	4,768e-5	5,270e-4	3,840e-5	0.29	0.05
CAALA_B04g Landprice	0	0	0,000e+0	0,000e+0	0,000e+0	0,000e+0	0	0
CAALA_B04h Kitchen complete	0	0	0,000e+0	0,000e+0	0,000e+0	0,000e+0	0	0
CAALA_B04i Bathroom	0	0	0,000e+0	0,000e+0	0,000e+0	0,000e+0	0	0
CAALA_B04j Other	0	0	0,000e+0	0,000e+0	0,000e+0	0,000e+0	0	0
CAALA_B07 Roof (unheated room)	49.07	3	1,277e-8	1,514e-4	1,083e-3	1,433e-4	1.42	0.34
CAALA_B10 Balcony	61.86	4	6,471e-9	4,473e-5	1,988e-4	3,942e-5	0.19	0.22
CAALA_B11 Floor (unheated rooms)	18.99	8	1,607e-12	1,456e-5	1,884e-4	2,278e-5	0.35	0.15
CAALA_B12 Sun protection	8.54	2	3,030e-11	3,004e-4	1,153e-3	1,746e-4	1.26	1.77
TGA	0	2	7,202e-11	1,054e-3	9,787e-3	7,994e-4	7.21	0.37

5. Life cycle cost analysis

5.1. Boundary conditions

Assessment period	50 Jahre
Gross Floor Area (GFA)	105 m²
Energy price evolution rates	2 %/Jahr
Price discount rate	1 %/Jahr
Energy carrier's initial prices	0,13 €/kWh
Price for [Wood Pellet]	240

5.2. Overview of results

Investment costs				
KG 300 Building construction	3,112.60	€/m^2_{GFA}	62.25	€/$m^2_{GFA}a$
KG 400 Technical building equipment	95.24	€/m^2_{GFA}	1.90	€/$m^2_{GFA}a$
Operational costs				
Energy costs	479.81	€/m^2_{GFA}	9.60	€/$m^2_{GFA}a$
Inspection & maintenance costs for KG 300	202.11	€/m^2_{GFA}	4.04	€/$m^2_{GFA}a$
Inspection & maintenance costs for KG 400	25.35	€/m^2_{GFA}	0.51	€/$m^2_{GFA}a$
Repair Cost				
Repair Cost for KG 300	707.38	€/m^2_{GFA}	14.15	€/$m^2_{GFA}a$
Repair Cost for KG 400	40.81	€/m^2_{GFA}	0.82	€/$m^2_{GFA}a$

5.3. Results by cost group 2nd level

	Construction	Maintenance & Replace	Repair
KG 300 - Building construction	326,823.20€	21,221.34€	74,274.70€
KG 320 Foundation	32,737.50€	2,125.72€	7,440.01€
KG 330 Exterior walls	242,654.11€	15,756.06€	55,146.21€
KG 340 Interior walls	4,671.03€	303.30€	1,061.55€
KG 350 Ceilings	6,186.00€	401.67€	1,405.85€
KG 360 Roofs	40,574.56€	2,634.59€	9,221.08€
KG 400 - Technical building equipment	10,000.00€	2,662.22€	4,285.52€
KG 420 + 430 Heat generation equipment	10,000.00€	2,662.22€	4,285.52€

5.4. Results by cost group 3rd level

	Construction	**Maintenance & Replacement**		**Repair**	
	Costs	Expenses per year	Costs	Expenses per year	Costs
300 - Building construction	326,823.20€		21,221.35€		74,274.71€
322 Flat foundation	2,848.50€	0.1%	184.96€	0.35%	647.36€
324 Base plate	19,926.00€	0.1%	1,293.84€	0.35%	4,528.44€
325 Base flooring	9,963.00€	0.1%	646.92€	0.35%	2,264.22€
326 Sealing	0.00€	0.1%	0.00€	0.35%	0.00€
331 Load-bearing exterior wall	206,093.17€	0.1%	13,382.08€	0.35%	46,837.28€
334 Exterior doors and windows	6,748.00€	0.1%	438.16€	0.35%	1,533.57€
335 Exterior wall cladding outside	22,170.99€	0.1%	1,439.61€	0.35%	5,038.64€
336 Exterior wall finishing inside	7,641.95€	0.1%	496.21€	0.35%	1,736.73€
341 Load-bearing interior wall	3,483.48€	0.1%	226.19€	0.35%	791.66€
345 Interior wall finishing (outside)	791.70€	0.1%	51.41€	0.35%	179.92€
345 Interior wall finishing (inside)	395.85€	0.1%	25.70€	0.35%	89.96€
351 Ceiling strucutre	6,186.00€	0.1%	401.67€	0.35%	1,405.85€
352 Ceiling flooring	0.00€	0.1%	0.00€	0.35%	0.00€
353 Ceiling finishing	0.00€	0.1%	0.00€	0.35%	0.00€
361 Roof structure	21,688.48€	0.1%	1,408.28€	0.35%	4,928.98€
363 Roof covering	17,402.88€	0.1%	1,130.01€	0.35%	3,955.02€
364 Roof finishing inside	1,483.20€	0.1%	96.31€	0.35%	337.08€
400 - Technical building equipment	10000€		2,662.22€		4,285.52€
420 + 430 Heat generation equipment	10000€	0.41%	2,662.22€	0.66%	4,285.52€

6. Building envelope and building technology

6.1. Surfaces

Overview

	ID	Layer	Orientation	Net area	Gross area	Length	Angle (Azimut
▶	**CAALA_A01 Exterior wall load-bearing (Count: 11 , Net area: 96.60 m² , Gross area: 126.57 m² , Length: 0.00 m)**						
▶	**CAALA_A03 Roof (Count: 2 , Net area: 98.88 m² , Gross area: 99.28 m² , Length: 0.00 m)**						
▶	**CAALA_A05 Wall to unheated roof (Count: 6 , Net area: 26.39 m² , Gross area: 26.39 m² , Length: 0.00 m)**						
▶	**CAALA_A11 Floor to ground (Count: 13 , Net area: 99.63 m² , Gross area: 101.31 m² , Length: 0.00 m)**						
▶	**CAALA_A12 Window (exterior wall) (Count: 20 , Net area: 33.05 m² , Gross area: 33.05 m² , Length: 0.00 m)**						
▶	**CAALA_B04 Exterior wall (unheated rooms) (Count: 5 , Net area: 36.49 m² , Gross area: 45.03 m² , Length: 0.00 m)**						
▶	**CAALA_B04c innerwalls non load bearing (Count: 22 , Net area: 23.43 m² , Gross area: 23.43 m² , Length: 0.00 m)**						
▶	**CAALA_B04d innerwalls load bearing (Count: 49 , Net area: 38.10 m² , Gross area: 38.10 m² , Length: 0.00 m)**						
▶	**CAALA_B04e inner doors (Count: 6 , Net area: 10.54 m² , Gross area: 10.54 m² , Length: 0.00 m)**						
▶	**CAALA_B04g Landprice (Count: 1 , Net area: 1.00 m² , Gross area: 1.00 m² , Length: 0.00 m)**						
▶	**CAALA_B04h Kitchen complete (Count: 1 , Net area: 1.00 m² , Gross area: 1.00 m² , Length: 0.00 m)**						
▶	**CAALA_B04i Bathroom (Count: 1 , Net area: 1.00 m² , Gross area: 1.00 m² , Length: 0.00 m)**						
▶	**CAALA_B04j Other (Count: 1 , Net area: 1.00 m² , Gross area: 1.00 m² , Length: 0.00 m)**						
▶	**CAALA_B07 Roof (unheated room) (Count: 4 , Net area: 49.07 m² , Gross area: 49.07 m² , Length: 0.00 m)**						
▶	**CAALA_B10 Balcony (Count: 4 , Net area: 61.86 m² , Gross area: 61.86 m² , Length: 0.00 m)**						
▶	**CAALA_B11 Floor (unheated rooms) (Count: 3 , Net area: 18.99 m² , Gross area: 18.99 m² , Length: 0.00 m)**						
▶	**CAALA_B12 Sun protection (Count: 4 , Net area: 8.54 m² , Gross area: 8.54 m² , Length: 0.00 m)**						

Detailed areas

	ID	Layer	Orientation	Net area	Gross area	Length	Angle (Azimu
◢	**CAALA_A01 Exterior wall load-bearing (Count: 11 , Net area: 96.60 m² , Gross area: 126.57 m² , Length: 0.00 m)**						
	92272	CAALA_A01 Exterior wall load-bearing	NE90	5.41	7.89	0	45
	86644	CAALA_A01 Exterior wall load-bearing	SE90	9.09	17.58	0	135
	88465	CAALA_A01 Exterior wall load-bearing	SW90	0.49	0.49	0	225
	86636	CAALA_A01 Exterior wall load-bearing	SW90	29.04	35.12	0	225

86795	CAALA_A01 Exterior wall load-bearing	SE90	7.88	12.56	0	135
88371	CAALA_A01 Exterior wall load-bearing	NE90	3.72	3.72	0	45
87374	CAALA_A01 Exterior wall load-bearing	NE90	3.43	7.59	0	45
87375	CAALA_A01 Exterior wall load-bearing	NE90	2.27	2.27	0	45
87321	CAALA_A01 Exterior wall load-bearing	NE90	14.72	14.72	0	45
88460	CAALA_A01 Exterior wall load-bearing	NW90	13.63	13.63	0	315
86767	CAALA_A01 Exterior wall load-bearing	SE90	6.92	11	0	135
◢ **CAALA_A03 Roof (Count: 2 , Net area: 98.88 m² , Gross area: 99.28 m² , Length: 0.00 m)**						
88624	CAALA_A03 Roof	SE0	55.22	55.62	0	135
88484	CAALA_A03 Roof	NW0	43.66	43.66	0	315
◢ **CAALA_A05 Wall to unheated roof (Count: 6 , Net area: 26.39 m² , Gross area: 26.39 m² , Length: 0.00 m)**						
87082	CAALA_A05 Wall to unheated roof	NW90	5.54	5.54	0	315
87106	CAALA_A05 Wall to unheated roof	NW90	2.1	2.1	0	315
87108	CAALA_A05 Wall to unheated roof	NW90	1.58	1.58	0	315
88388	CAALA_A05 Wall to unheated roof	NW90	3.54	3.54	0	315
88421	CAALA_A05 Wall to unheated roof	NW90	3.1	3.1	0	315
87351	CAALA_A05 Wall to unheated roof	NW90	10.53	10.53	0	315
◢ **CAALA_A11 Floor to ground (Count: 13 , Net area: 99.63 m² , Gross area: 101.31 m² , Length: 0.00 m)**						
88607	CAALA_A11 Floor to ground	HOR	0.73	0.73	0	97.78
4996	CAALA_A11 Floor to ground	HOR	18.54	18.54	0	97.73
5802	CAALA_A11 Floor to ground	HOR	1.81	1.81	0	97.75
5825	CAALA_A11 Floor to ground	HOR	0.59	0.59	0	97.75
5653	CAALA_A11 Floor to ground	HOR	0.59	0.59	0	97.75
5000	CAALA_A11 Floor to ground	HOR	3.79	3.79	0	97.75
5690	CAALA_A11 Floor to ground	HOR	1.81	1.81	0	97.75
5024	CAALA_A11 Floor to ground	HOR	1.1	1.1	0	98.12
5082	CAALA_A11 Floor to ground	HOR	59.88	59.88	0	95.46
5486	CAALA_A11 Floor to ground	HOR	1.23	1.23	0	97.75
87089	CAALA_A11 Floor to ground	HOR	0.35	0.35	0	96.7
88621	CAALA_A11 Floor to ground	HOR	6.71	8.39	0	97.75
88620	CAALA_A11 Floor to ground	HOR	2.5	2.5	0	97.8
◢ **CAALA_A12 Window (exterior wall) (Count: 20 , Net area: 33.05 m² , Gross area: 33.05 m² , Length: 0.00 m)**						

87476	CAALA_A12 Window (exterior wall)	SE90	1.89	1.89	0	135
88679	CAALA_A12 Window (exterior wall)	NW90	0.1	0.1	0	315
88572	CAALA_A12 Window (exterior wall)	SE90	2.34	2.34	0	135
92290	CAALA_A12 Window (exterior wall)	NE90	0.4	0.4	0	45
88580	CAALA_A12 Window (exterior wall)	SE90	0.45	0.45	0	135
92286	CAALA_A12 Window (exterior wall)	NE90	2.08	2.08	0	45
86882	CAALA_A12 Window (exterior wall)	NE90	1.68	1.68	0	45
86949	CAALA_A12 Window (exterior wall)	SW90	2.08	2.08	0	225
88511	CAALA_A12 Window (exterior wall)	SE90	8.49	8.49	0	135
88721	CAALA_A12 Window (exterior wall)	SE90	2.04	2.04	0	135
86919	CAALA_A12 Window (exterior wall)	NE90	0.8	0.8	0	45
87420	CAALA_A12 Window (exterior wall)	NE90	1.68	1.68	0	45
86413	CAALA_A12 Window (exterior wall)	NE90	1.68	1.68	0	45
86666	CAALA_A12 Window (exterior wall)	SW90	1.44	1.44	0	225
88646	CAALA_A12 Window (exterior wall)	SE0	1	1	0	135
88674	CAALA_A12 Window (exterior wall)	SW90	0.1	0.1	0	225
88678	CAALA_A12 Window (exterior wall)	NE90	0.1	0.1	0	45
88717	CAALA_A12 Window (exterior wall)	SE90	2.04	2.04	0	135
88676	CAALA_A12 Window (exterior wall)	SE90	0.1	0.1	0	135
92250	CAALA_A12 Window (exterior wall)	SW90	2.56	2.56	0	225

◢ **CAALA_B04 Exterior wall (unheated rooms) (Count: 5 , Net area: 36.49 m² , Gross area: 45.03 m² , Length: 0.00 m)**

88587	CAALA_B04 Exterior wall (unheated rooms)	NE90	6.5	8.84	0	45
87328	CAALA_B04 Exterior wall (unheated rooms)	NW90	14.58	14.58	0	315
88425	CAALA_B04 Exterior wall (unheated rooms)	NW90	8.87	12.76	0	315
86597	CAALA_B04 Exterior wall (unheated rooms)	SW90	5.16	7.47	0	225
88471	CAALA_B04 Exterior wall (unheated rooms)	SW90	1.38	1.38	0	225

◢ **CAALA_B04c innerwalls non load bearing (Count: 22 , Net area: 23.43 m² , Gross area: 23.43 m² , Length: 0.00 m)**

86986	CAALA_B04c innerwalls non load bearing	SE90	0.81	0.81	0	135
86990	CAALA_B04c innerwalls non load bearing	NW90	1.69	1.69	0	315
87040	CAALA_B04c innerwalls non load bearing	SE90	1.69	1.69	0	135
87018	CAALA_B04c innerwalls non load bearing	SW90	2.33	2.33	0	225

87026	CAALA_B04c innerwalls non load bearing	SW90	1.23	1.23	0	225
87029	CAALA_B04c innerwalls non load bearing	SW90	0.96	0.96	0	225
86989	CAALA_B04c innerwalls non load bearing	NW90	1.69	1.69	0	315
86963	CAALA_B04c innerwalls non load bearing	SE90	0.16	0.16	0	135
86987	CAALA_B04c innerwalls non load bearing	SE90	0.81	0.81	0	135
86962	CAALA_B04c innerwalls non load bearing	SE90	0.16	0.16	0	135
87041	CAALA_B04c innerwalls non load bearing	SE90	1.69	1.69	0	135
86978	CAALA_B04c innerwalls non load bearing	NW90	1.69	1.69	0	315
87019	CAALA_B04c innerwalls non load bearing	SW90	1.52	1.52	0	225
86960	CAALA_B04c innerwalls non load bearing	SE90	0.37	0.37	0	135
87030	CAALA_B04c innerwalls non load bearing	SW90	0.96	0.96	0	225
87027	CAALA_B04c innerwalls non load bearing	SW90	1.23	1.23	0	225
86959	CAALA_B04c innerwalls non load bearing	SE90	0.37	0.37	0	135
87017	CAALA_B04c innerwalls non load bearing	SW90	0.51	0.51	0	225
87016	CAALA_B04c innerwalls non load bearing	SW90	1.31	1.31	0	225
86979	CAALA_B04c innerwalls non load bearing	NW90	1.69	1.69	0	315
86950	CAALA_B04c innerwalls non load bearing	SE90	0.28	0.28	0	135
86951	CAALA_B04c innerwalls non load bearing	SE90	0.28	0.28	0	135
◢ **CAALA_B04d innerwalls load bearing (Count: 49 , Net area: 38.10 m² , Gross area: 38.10 m² , Length: 0.00 m)**						
87010	CAALA_B04d innerwalls load bearing	NE90	0.28	0.28	0	45
86994	CAALA_B04d innerwalls load bearing	SE90	0.29	0.29	0	135
87005	CAALA_B04d innerwalls load bearing	NE90	0.57	0.57	0	45

	86993	CAALA_B04d innerwalls load bearing	SE90	0.36	0.36	0	135
	86992	CAALA_B04d innerwalls load bearing	SE90	0.38	0.38	0	135
	87051	CAALA_B04d innerwalls load bearing	SW90	0.04	0.04	0	225
	87043	CAALA_B04d innerwalls load bearing	NE90	0.16	0.16	0	45
	87059	CAALA_B04d innerwalls load bearing	NE90	0.05	0.05	0	45
	87048	CAALA_B04d innerwalls load bearing	SW90	0.03	0.03	0	225
	87057	CAALA_B04d innerwalls load bearing	NE90	0.26	0.26	0	45
	86974	CAALA_B04d innerwalls load bearing	NE90	0.72	0.72	0	45
	86953	CAALA_B04d innerwalls load bearing	SW90	0.22	0.22	0	225
	86973	CAALA_B04d innerwalls load bearing	NE90	0.58	0.58	0	45
	86956	CAALA_B04d innerwalls load bearing	NE90	0.73	0.73	0	45
	86996	CAALA_B04d innerwalls load bearing	SE90	0.26	0.26	0	135
	87009	CAALA_B04d innerwalls load bearing	NE90	1.47	1.47	0	45
	87006	CAALA_B04d innerwalls load bearing	NE90	0.57	0.57	0	45
	87049	CAALA_B04d innerwalls load bearing	SW90	0.09	0.09	0	225
	87037	CAALA_B04d innerwalls load bearing	NE90	0.23	0.23	0	45
	87032	CAALA_B04d innerwalls load bearing	NW90	3.38	3.38	0	315
	86984	CAALA_B04d innerwalls load bearing	NE90	0.43	0.43	0	45
	87047	CAALA_B04d innerwalls load bearing	SW90	0.09	0.09	0	225
	87046	CAALA_B04d innerwalls load bearing	SW90	0.1	0.1	0	225
	87035	CAALA_B04d innerwalls load bearing	NE90	1.24	1.24	0	45
	87050	CAALA_B04d innerwalls load bearing	SW90	0.1	0.1	0	225

	86995	CAALA_B04d innerwalls load bearing	SE90	0.22	0.22	0	135
	87058	CAALA_B04d innerwalls load bearing	NE90	0.21	0.21	0	45
	87023	CAALA_B04d innerwalls load bearing	NE90	1.31	1.31	0	45
	87013	CAALA_B04d innerwalls load bearing	NE90	0.24	0.24	0	45
	87086	CAALA_B04d innerwalls load bearing	SW90	2.93	2.93	0	225
	87088	CAALA_B04d innerwalls load bearing	SW90	6.5	6.5	0	225
	86957	CAALA_B04d innerwalls load bearing	NE90	0.73	0.73	0	45
	86997	CAALA_B04d innerwalls load bearing	SE90	0.32	0.32	0	135
	86970	CAALA_B04d innerwalls load bearing	NE90	0.16	0.16	0	45
	87044	CAALA_B04d innerwalls load bearing	NE90	0.16	0.16	0	45
	86983	CAALA_B04d innerwalls load bearing	NE90	0.43	0.43	0	45
	86969	CAALA_B04d innerwalls load bearing	NE90	0.85	0.85	0	45
	86998	CAALA_B04d innerwalls load bearing	SE90	0.02	0.02	0	135
	87014	CAALA_B04d innerwalls load bearing	NE90	0.24	0.24	0	45
	86975	CAALA_B04d innerwalls load bearing	NE90	0.14	0.14	0	45
	87008	CAALA_B04d innerwalls load bearing	NE90	1.75	1.75	0	45
	88429	CAALA_B04d innerwalls load bearing	SW90	2.34	2.34	0	225
	86954	CAALA_B04d innerwalls load bearing	SW90	0.22	0.22	0	225
	86966	CAALA_B04d innerwalls load bearing	NE90	0.16	0.16	0	45
	87033	CAALA_B04d innerwalls load bearing	NW90	3.38	3.38	0	315
	86968	CAALA_B04d innerwalls load bearing	NE90	0.69	0.69	0	45
	86965	CAALA_B04d innerwalls load bearing	NE90	0.16	0.16	0	45

	87024	CAALA_B04d innerwalls load bearing	NE90	1.31	1.31	0	45
	87036	CAALA_B04d innerwalls load bearing	NE90	1	1	0	45
◢	**CAALA_B04e inner doors (Count: 6 , Net area: 10.54 m² , Gross area: 10.54 m² , Length: 0.00 m)**						
	5226	CAALA_B04e inner doors	NE90	1.92	1.92	0	45
	5237	CAALA_B04e inner doors	NE90	1.38	1.38	0	45
	5166	CAALA_B04e inner doors	NE90	1.92	1.92	0	45
	5243	CAALA_B04e inner doors	NE90	1.38	1.38	0	45
	6035	CAALA_B04e inner doors	SW90	2.02	2.02	0	225
	5037	CAALA_B04e inner doors	SE90	1.92	1.92	0	135
◢	**CAALA_B04g Landprice (Count: 1 , Net area: 1.00 m² , Gross area: 1.00 m² , Length: 0.00 m)**						
	87171	CAALA_B04g Landprice	HOR	1	1	0	90
◢	**CAALA_B04h Kitchen complete (Count: 1 , Net area: 1.00 m² , Gross area: 1.00 m² , Length: 0.00 m)**						
	87180	CAALA_B04h Kitchen complete	HOR	1	1	0	90
◢	**CAALA_B04i Bathroom (Count: 1 , Net area: 1.00 m² , Gross area: 1.00 m² , Length: 0.00 m)**						
	87189	CAALA_B04i Bathroom	HOR	1	1	0	90
◢	**CAALA_B04j Other (Count: 1 , Net area: 1.00 m² , Gross area: 1.00 m² , Length: 0.00 m)**						
	87198	CAALA_B04j Other	HOR	1	1	0	90
◢	**CAALA_B07 Roof (unheated room) (Count: 4 , Net area: 49.07 m² , Gross area: 49.07 m² , Length: 0.00 m)**						
	91147	CAALA_B07 Roof (unheated room)	SE0	8.88	8.88	0	135
	88375	CAALA_B07 Roof (unheated room)	SE0	19.01	19.01	0	135
	88475	CAALA_B07 Roof (unheated room)	NW0	11.04	11.04	0	315
	91389	CAALA_B07 Roof (unheated room)	SE0	10.14	10.14	0	135
◢	**CAALA_B10 Balcony (Count: 4 , Net area: 61.86 m² , Gross area: 61.86 m² , Length: 0.00 m)**						
	91512	CAALA_B10 Balcony	HOR	18.99	18.99	0	72.08
	90723	CAALA_B10 Balcony	HOR	13.49	13.49	0	94.56
	86553	CAALA_B10 Balcony	HOR	19.49	19.49	0	89.21
	88786	CAALA_B10 Balcony	HOR	9.89	9.89	0	92.63
◢	**CAALA_B11 Floor (unheated rooms) (Count: 3 , Net area: 18.99 m² , Gross area: 18.99 m² , Length: 0.00 m)**						
	87078	CAALA_B11 Floor (unheated rooms)	HOR	6.5	6.5	0	97.75
	10426	CAALA_B11 Floor (unheated rooms)	HOR	3.63	3.63	0	99.92
	87077	CAALA_B11 Floor (unheated rooms)	HOR	8.86	8.86	0	94.96
◢	**CAALA_B12 Sun protection (Count: 4 , Net area: 8.54 m² , Gross area: 8.54 m² , Length: 0.00 m)**						
	4835	CAALA_B12 Sun protection	NE90	1.89	1.89	0	45
	86184	CAALA_B12 Sun protection	SW90	2.31	2.31	0	225
	87435	CAALA_B12 Sun protection	NW90	3.89	3.89	0	315

	88380	CAALA_B12 Sun protection	NE90	0.45	0.45	0	45

6.2. Building Construction

Layer Name	CAALA_A01 Exterior wall load-bearing
Area	96.60 m²
Thickness	35.11 cm
U-value	0.158
Reference U-Value	0.280
Cost group	331 Load-bearing exterior wall
Name	CLT 10
Id	5d882bd6-02b1-42f8-99e8-2631802f199f
Thickness	10 cm
Cost group	335 Exterior wall cladding outside
Name	cedar+batten+cellulose
Id	6789f521-203f-4363-a337-7c9f95562748
Thickness	20 cm
Cost group	336 Exterior wall finishing inside
Name	Painting
Id	73c687d9-ffe0-4131-9c90-6e23597f656b
Thickness	0 cm
Layer Name	CAALA_A03 Roof
Area	98.88 m²
Thickness	66.31 cm
U-value	0.076
Reference U-Value	0.200
Cost group	361 Roof structure
Name	CLT 14
Id	83dc1c20-a8e8-4164-831a-aea5603c22cf
Thickness	10 cm
Cost group	363 Roof covering

Name	Brick tile construction
Id	ad51323e-425c-4a34-a13a-576fb76a1282
Thickness	36 cm
Cost group	364 Roof finishing inside
Name	Anstrich
Id	981a2e03-cdcf-4b21-a589-788acb0d01ce
Thickness	0 cm
Layer Name	CAALA_A05 Wall to unheated roof
Area	26.39 m²
Thickness	31.81 cm
U-value	0.163
Reference U-Value	0.200
Cost group	341 Load-bearing interior wall
Name	CLT 10
Id	95889ac1-509a-4e45-a187-28b7eeeaba74
Thickness	10 cm
Cost group	345 Interior wall finishing (outside)
Name	Cellulose and OSB
Id	77c28e53-0fbe-404f-b112-02ef075c2229
Thickness	22 cm
Cost group	345 Interior wall finishing (inside)
Name	Anstrich
Id	981a2e03-cdcf-4b21-a589-788acb0d01ce
Thickness	0 cm
Layer Name	CAALA_A11 Floor to ground
Area	99.63 m²
Thickness	42.40 cm
U-value	0.128
Reference U-Value	0.350

Cost group	322 Flat foundation
Name	- empty -
Id	
Thickness	0 cm
Cost group	324 Base plate
Name	Foam 30
Id	393bbdef-698e-4ef9-8db5-b78b97adc738
Thickness	40 cm
Cost group	325 Base flooring
Name	Stone clinker
Id	d4b8c30f-52e3-4ca0-b245-896b367f4789
Thickness	2 cm
Cost group	326 Sealing
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_A12 Window (exterior wall)
Area	33.05 m²
Thickness	0.00 cm
U-value	0.800
Reference U-Value	1.300
Cost group	334 Exterior doors and windows
Name	Fenster, Dreifach-Isolierverglasung, Holz-Rahmen, U=0,8, g=0,6
Id	af4e8253-4d74-476d-9f51-9913392f1a59
Thickness	0 cm
Layer Name	CAALA_B04 Exterior wall (unheated rooms)
Area	36.49 m²
Thickness	24.70 cm

U-value	NaN
Reference U-Value	0.000
Cost group	331 Load-bearing exterior wall
Name	Ceder, batten, windshield, beam, fiberb
Id	fc8507e8-247d-42f6-bb16-cfc391ff41c5
Thickness	24 cm
Cost group	335 Exterior wall cladding outside
Name	fibercement
Id	dbdb5984-17a4-4329-9392-3f83b494efd4
Thickness	1 cm
Cost group	336 Exterior wall finishing inside
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_B04c innerwalls non load bearing
Area	23.43 m²
Thickness	12.01 cm
U-value	NaN
Reference U-Value	0.000
Cost group	331 Load-bearing exterior wall
Name	- empty -
Id	
Thickness	0 cm
Cost group	335 Exterior wall cladding outside
Name	Gypsum-plywood-batten-pw-gyp
Id	d582e3b6-7625-47e3-8930-19aa5041aa31
Thickness	12 cm
Cost group	336 Exterior wall finishing inside
Name	Painting

Id	73c687d9-ffe0-4131-9c90-6e23597f656b
Thickness	0 cm
Layer Name	CAALA_B04d innerwalls load bearing
Area	38.10 m²
Thickness	10.01 cm
U-value	NaN
Reference U-Value	0.000
Cost group	331 Load-bearing exterior wall
Name	CLT 10
Id	95889ac1-509a-4e45-a187-28b7eeeaba74
Thickness	10 cm
Cost group	335 Exterior wall cladding outside
Name	- empty -
Id	
Thickness	0 cm
Cost group	336 Exterior wall finishing inside
Name	Painting
Id	73c687d9-ffe0-4131-9c90-6e23597f656b
Thickness	0 cm
Layer Name	CAALA_B04e inner doors
Area	10.54 m²
Thickness	5.00 cm
U-value	NaN
Reference U-Value	0.000
Cost group	331 Load-bearing exterior wall
Name	- empty -
Id	
Thickness	0 cm
Cost group	335 Exterior wall cladding outside

Name	- empty -
Id	
Thickness	0 cm
Cost group	336 Exterior wall finishing inside
Name	Inside door
Id	a3916428-dbac-4f68-8622-902748f33e4a
Thickness	5 cm
Layer Name	CAALA_B04g Landprice
Area	1.00 m²
Thickness	0.00 cm
U-value	NaN
Reference U-Value	0.000
Cost group	331 Load-bearing exterior wall
Name	- empty -
Id	
Thickness	0 cm
Cost group	335 Exterior wall cladding outside
Name	- empty -
Id	
Thickness	0 cm
Cost group	336 Exterior wall finishing inside
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_B04h Kitchen complete
Area	1.00 m²
Thickness	0.00 cm
U-value	NaN
Reference U-Value	0.000

Cost group	331 Load-bearing exterior wall
Name	- empty -
Id	
Thickness	0 cm
Cost group	335 Exterior wall cladding outside
Name	- empty -
Id	
Thickness	0 cm
Cost group	336 Exterior wall finishing inside
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_B04i Bathroom
Area	1.00 m²
Thickness	0.00 cm
U-value	NaN
Reference U-Value	0.000
Cost group	331 Load-bearing exterior wall
Name	- empty -
Id	
Thickness	0 cm
Cost group	335 Exterior wall cladding outside
Name	- empty -
Id	
Thickness	0 cm
Cost group	336 Exterior wall finishing inside
Name	- empty -
Id	
Thickness	0 cm

Layer Name	CAALA_B04j Other
Area	1.00 m²
Thickness	0.00 cm
U-value	NaN
Reference U-Value	0.000
Cost group	331 Load-bearing exterior wall
Name	- empty -
Id	
Thickness	0 cm
Cost group	335 Exterior wall cladding outside
Name	- empty -
Id	
Thickness	0 cm
Cost group	336 Exterior wall finishing inside
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_B07 Roof (unheated room)
Area	49.07 m²
Thickness	19.20 cm
U-value	NaN
Reference U-Value	0.000
Cost group	361 Roof structure
Name	Beam, råspont, papp, zink
Id	bd0eab35-deca-4d8e-9173-dc3351966133
Thickness	19 cm
Cost group	363 Roof covering
Name	- empty -
Id	

Thickness	0 cm
Cost group	364 Roof finishing inside
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_B10 Balcony
Area	61.86 m²
Thickness	2.80 cm
U-value	NaN
Reference U-Value	0.000
Cost group	351 Ceiling strucutre
Name	Wooden deck
Id	169ad472-bb33-42b3-a9a8-7510cad309e1
Thickness	3 cm
Cost group	352 Ceiling flooring
Name	- empty -
Id	
Thickness	0 cm
Cost group	353 Ceiling finishing
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_B11 Floor (unheated rooms)
Area	18.99 m²
Thickness	14.00 cm
U-value	NaN
Reference U-Value	0.000
Cost group	322 Flat foundation
Name	Foam 20

Id	3c3c82c1-b460-49fa-878e-a3afb3c752fe
Thickness	14.000000000000002 cm
Cost group	324 Base plate
Name	- empty -
Id	
Thickness	0 cm
Cost group	325 Base flooring
Name	- empty -
Id	
Thickness	0 cm
Cost group	326 Sealing
Name	- empty -
Id	
Thickness	0 cm
Layer Name	CAALA_B12 Sun protection
Area	8.54 m²
Thickness	0.00 cm
U-value	NaN
Reference U-Value	0.000
Cost group	334 Exterior doors and windows
Name	Fenster, Zweifach-Isolierverglasung, Holz-Rahmen, U=1,3, g=0,65
Id	7017f100-b362-46c3-8b35-2c033115e9e5
Thickness	0 cm

6.3. Building Technology

420+430 Heat generation equipment	
Primary energy factor electricity	10000.00
Production costs KG	10000.00 €
Performance coefficiente$_p$	0.52
440 Photovoltaik 1 Orientierung	South (default)
Inclination	30°
Area	0 m²
440 Photovoltaik 2 Orientierung	South (default)
Inclination	30°
Area	0 m²
Production costs KG	10000.00 €

6.4. Other input values and boundary conditions

Thermal bridge surcharge	Detailed 0,035 W/m²K
Air tightness	With verification: n50 = 2 h^{-1}