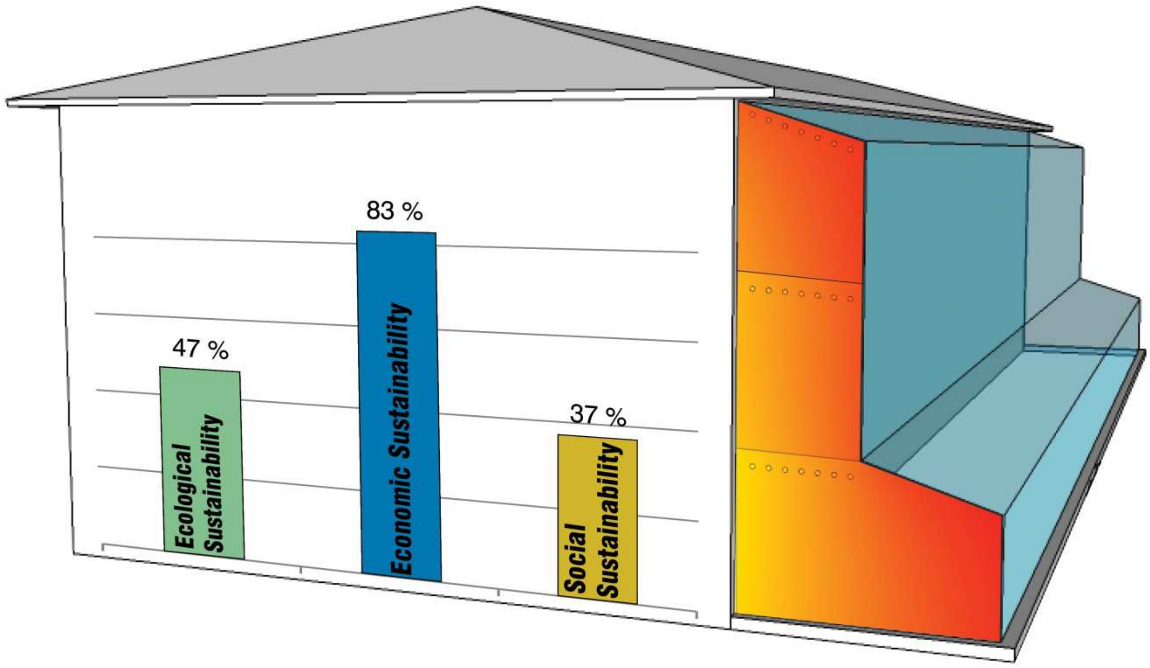

Renovating with a greenhouse and Phase Change Material

Assessing sustainability implications for million housing renovation

Master of Science Thesis in the Master´s Programme of Design for Sustainable Development and Structural Engineering and Building Technology

OSKAR MANGOLD
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Department of Civil and Environmental Engineering
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MASTER THESIS 2015:8

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ABSTRACT

The buildings produced during the million housing program 1964-1975 in Sweden are facing a dire renovation need. A method of both lowering energy consumption and letting tenants stay during the process is adding a building integrated greenhouse to the façade. This produces a warmer micro climate and reduces the temperature difference between the inside and outside of the building exterior wall. The greenhouse can also be used for social interaction. By the use of phase change materials as thermal energy storage the large temperature intervals in the greenhouse could be mitigated.

The greenhouse building addition was investigated as an alternate refurbishment strategy of Brogården buildings in Alingsås. These houses have gone through extensive refurbishment and have reached passive house standard. The project has been thoroughly documented which is why it was found to be a suitable object to study. The greenhouse building addition was compared to one of the buildings before and after renovation as reference cases. The greenhouse suggestion was analyzed within the three spheres of sustainability- ecology, economy and society - in relation to the reference cases.

The ecologic sphere was assessed by measuring the energy flow over the wall with the greenhouse. To achieve this, all cases were modelled in COMSOL Multiphysics® where influencing physics phenomena were implemented and the use of PCM analyzed.

The economic sphere was assessed by calculating the payback period for the retrofit investments.

For the assessment of the social sphere it was chosen to create a new assessment tool, specifically for refurbishment of multi-residential housing buildings that would enable a quick but holistic assessment. Relevant indicators from several building certification systems were collated into a new tool aimed at investigating social sustainability in only the physical building. The certification systems were BREEAM, DGNB, LEED and Miljöbyggnad. The tool was brought to a meeting between experts assessing the social sustainability for the two alternating refurbishment strategies.

It was found that the greenhouse suggestion is not a sufficient stand-alone renovation in the scenario investigated but could prove to be a reasonable investment for a building with a higher initial performance, or as a part of a renovation package. The greenhouse has an apparent effect on reducing the energy flows of the exterior wall but the addition of PCMs as heat storage has less effect than assumed. The building alterations are polarized and challenging to compare in the social and economic spheres. The social sustainability assessment tool was found to rather assess the preconditions for social sustainability rather than the actual social sustainability.

Suggestions for further investigation for the ecological analysis are to extend the system boundaries to include a whole building or introduce an active heat transport system. Furthermore improvements in the economic sphere could be to investigate the effects of enveloping the entire building or all façades in a greenhouse structure. To go further with the social sustainability assessment tool it is necessary to include the process and the neighborhood scale in the assessment. It is also important to further investigate how the indicators should be weighted to value them correctly.

Keywords: greenhouse, phase change material, PCM, social sustainability, building certification system, million housing program, refurbishment, renovation, retrofit

Renovera med växthus och fasbytande material
Utvärdering av påverkan på hållbarheten för ett miljonprogramshus
Examensarbete inom Design for Sustainable Development och Structural Engineering and Building Technology
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SAMMANFATTING

Byggnader som producerades under miljonprogrammet mellan 1964-1975 i Sverige står inför ett trängande renoveringsbehov. En metod för att både sänka energiförbrukning och låta hyresgäster bo kvar under processen är att bygga ett växthus över fasaden. Detta producerar ett mikroklimat och minskar temperaturskillnaden mellan insidan och utsidan av byggnadens yttervägg. Växthuset kan också användas för social interaktion. Genom användning av fasändringsmaterial som termisk energilagring skulle de extrema temperaturintervallen i växthuset kunna mildras.

Växthusbyggnaden undersöktes som en alternativ renoveringsstrategi för en av Brogårdens byggnader i Alingsås. Dessa hus har genomgått en omfattande renovering och lyckats uppnå passivhusstandard. Renoveringsprojektet har noggrant dokumenterats varför det visade sig vara ett lämpligt objekt till studien. Växthusbyggnaden jämfördes med en av byggnaderna före och efter renoveringen som referensfall. Växthusförslaget analyserades inom de tre hållbarhetssfärerna –ekologi, ekonomi och samhälle - i förhållande till referenserna.

Den ekologiska sfären utvärderades genom att mäta energiflödet över väggen med det anslutande växthuset. För att uppnå detta modellerades samtliga fall i COMSOL Multiphysics® där inverkande fysikaliska fenomen inkluderades och användningen av PCM analyserades.

Den ekonomiska sfären bedömdes genom att beräkna återbetalningstiden för renoveringsförslaget.

Bedömningen av den sociala sfären krävde skapandet av ett bedömningsverktyg för social hållbarhet. Relevanta indikatorer från flera miljöcertifieringssystem samlades in i ett nytt verktyg som syftar till att undersöka den sociala hållbarheten i enbart den fysiska byggnaden. Certifieringssystemen var BREEAM, DGNB, LEED och Miljöbyggnad. Verktyget fördes till ett möte mellan experter som bedömde den sociala hållbarheten för de två alternerande renoveringsstrategierna.

Man fann att växthusförslaget inte är tillräckligt som fristående renovering i det undersökta scenariot men kan visa sig vara en rimlig investering för en byggnad med högre initial prestanda, eller som en del av ett renoveringspaket. Växthuset har en märkbar effekt på energiflödet över ytterväggen men tillägget av PCM som värmelagring har mindre effekt än vad som tidigare föreslagits. Renoveringsalternativen är polariserade och utmanande att jämföra i de sociala och ekonomiska sfärerna. Verktyget för att utvärdera social hållbarhet fanns snarare bedömma förutsättningarna för social hållbarhet.

Förslag på ytterligare utredning för den ekologiska analysen är att vidga perspektivet för att inkludera hela byggnaden eller att introducera ett aktivt energitransportsystem. Vidare förbättringar i det ekonomiska området skulle kunna vara att undersöka effekterna av att omsluta hela byggnaden eller alla fasader i en växthuskonstruktion. För att gå vidare med verktyget för att utvärdera social hållbarhet är det nödvändigt att inkludera process och område i bedömningen. Det är också viktigt att undersöka hur indikatorerna bör viktas för att kunna värdera dem på rätt sätt.

Nyckelord: växthus, fasbytarmaterialmaterial, PCM, social hållbarhet, certifieringssystem, miljonprogram, renovering, ombyggnation

CONTENTS

PREFACE

Working with this master thesis has been a great opportunity to learn more about processes, phase change materials, energy modelling and social sustainability. We would like to thank the Department of Civil and Environmental Engineering and all who have provided support and input to our work.

We would like to specifically thank our supervisor and examiner Bijan Adl-Zarrabi, and supervisor Holger Wallbaum and assistant supervisor Tommy Månsson for guiding our work. We would also like to thank our opponent, Jacob Flårback, for having a continuous feedback during the thesis process. A special gratitude is also directed to Jenny Bengtsson, communicator at Alingsåshem, Cecilia Wretlind, building engineer at White architects and Kia Bengtson, architect at MA Arkitekter for taking part in the social sustainability evaluation meeting. We would also want to thank Linda Martinsson, building physicist at Skanska and the staff members at Alingsåshem who have been very helpful by providing information about Brogården.

We hope you enjoy reading this report.

Göteborg, February 2015

Oskar & Peter

NOTATIONS

Explanation of names of institutes or certifications

BREEAM	Building Research Establishment Environmental Assessment Method
BEEM-UP	Building Energy Efficiency for Massive market Uptake
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council)
LEED	Leadership in Energy and Environmental Design
SGBC	Sweden Green Building Council
SMHI	Sveriges Meterologiska och Hydrologiska Institut (the Swedish Institute for Meterology and Hydrology)

Abbreviations

BOA	"Boarea" – amount of space for living
BTA	"Bruttoarea" – gross area
CFD	Computational Fluid Dynamics
PCM	Phase Change Material
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
SDI	Sustainable Development Indicator
TES	Thermal Energy Storage

Variables

λ	Thermal Conductivity [W/mK]
ε	Emissivity [-]
ρ	Density [kg/m^3]
C_p	Specific heat capacity [J/kgK]

1. INTRODUCTION

During 1961 and 1975 approximately 1.4 million housing units were produced in Sweden. Out of these, 600 000 apartments now require extensive renovation since they display poor energy efficiency and are often associated with social problems such as segregation. There is, thus, a great need for renovation strategies. Out of those 1.4 million housing units, 65% were of the type two to four stories multi-residential houses with at least two staircases[1]. Assuming this percentage is also applicable for the 600 000 of apartments needing renovation, this gives a number of 390 000 apartments requiring refurbishment. This provides a massive market opportunity and is at the moment a large waste of thermal energy in Sweden.

Attempts to increase the energy efficiency in the buildings from this era have not been entirely successful. Most of them have either been so focused on chasing Watt Hours that social values were forgotten, or have been extensive and expensive to the point of gentrification. Social values like cohesion and continuity are jeopardized when a large part of tenants are replaced at once, which has moral implications that could call for some discussion. Brogården in Alingsås is an area developed during the million housing program era and a well-documented pilot study of extensive renovation, and a part of the BEEM-UP project. During the retrofitting of Brogården, the space heating energy reduction reached an impressive 89%[2], but all the tenants had to be evacuated for roughly 10 months and 46% of the tenants permanently moved out[3].

To address both energy consumption and evacuation, a building integrated greenhouse[4] is suggested, see Figure 1. A greenhouse increases the temperature outside the building exterior wall by capturing solar energy[5], thereby reducing energy losses over the external wall. Additionally, Phase Change Materials (PCM) used as heat storages in the greenhouse could stabilize the temperature by storing some of the excessive heat during the day and releasing it during the night. Analyzing the benefit of utilizing PCM is one scope of the thesis. The greenhouse suggestion can also induce social interaction, and does not force the tenants to be evacuated since it is a building addition. The benefit of the greenhouse suggestion needs further investigation. Since the retrofitting of Brogården was documented to a great extent, there was an opportunity to compare the greenhouse suggestion to the performed retrofitting as well as to the building before alteration to estimate a relative performance. The investigation requires a holistic analysis covering all the three spheres of sustainability: ecological, economic and social.

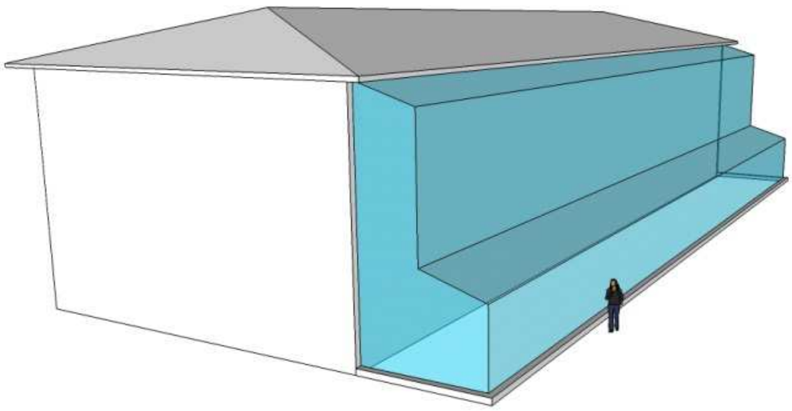

Figure 1: The greenhouse suggestion.

1 Johansson, Birgitta (red.) (2012). Miljonprogrammet - utveckla eller avveckla?

2 BEEM-UP (2012) www.beem-up.eu

3 Jenny Bengtsson (communicator, Alingsåshem) Interviewed by the authors 16th of September 2014.

4 Örneblad, Eva (1997). Solhuset i Järnbrott: grönrum och kreativa sociala processer på väg mot en bärkraftig arkitektur.

5 Wright, D. (2008). The passive solar primer: sustainable architecture.

Sustainability is a vague notion and more of an ideal goal than a measurable benchmark. For example, sustainability usually encompasses three spheres but there is no widely acknowledged method of bringing analyses of all spheres together. However, the BEEM-UP project uses a promising method for fusing two of the spheres, the Pareto-assembly[6]. The next step would be to add the social dimension, which has been suggested as a further outlook in the literature, and was therefore included in the scope of this master thesis. It was however found that assessing social sustainability in a quantitative way is in many ways difficult. And after conducting a literature study presented in chapter *3 THEORY* it was possible to conclude that the current state of the art is found in the many building certification systems where aspects and indicators for social sustainability are used. Since no single system includes all aspects, assessing them all for a given project would demand significant resources. A simplification and summary of aspects would be useful, particularly in the early stage of a building renovation process[7].

Purpose and goal

The goal of this thesis is to find a single quantitative value for sustainability for the greenhouse suggestion.

The purpose is to analyze a greenhouse suggestion as an alternative retrofit concept of a façade, by comparing it with realized retrofitting in all three spheres of sustainability, and fuse them into a holistic evaluation. The ecological sustainability analysis focuses on investigating how the use of PCM as heat storage medium can improve the performance of the greenhouse. The social sustainability analysis implies an attempt to create an assessment tool, and the economic analysis concerns assessing costs through payback period perspective.

Method, Tools and Course of Action

A study visit, literature studies and interviews with key experts initiated the project.

The economic sphere was assessed by conducting a discounted payback period analysis.

The social sphere demanded the creation of a tool for the purpose. Social aspects from *BREEAM*, *DGNB*, *LEED* and *Miljöbyggnad* were extracted, cross-referenced to literature and assembled into a new tool. A meeting between experts was used to evaluate social sustainability.

The ecological sphere was assessed by measuring the energy flow over the building exterior wall. COMSOL Multiphysics® version 4.4 was used to simulate thermal bridges and global energy models. Radiation data was taken from Meteonorm and temperature data from measurements at Landvetter.

Three cases were analyzed through the same procedures. They are further explained in *chapter 2 ANALYZED CASES* and are here briefly described:

- *Lower Reference*: The scenario if no action would have been taken.
- *Upper reference*: The scenario if conducting the extensive renovation that was done in Brogården.
- *Greenhouse suggestion*: The scenario if adding a greenhouse to the lower reference, with installed heat storage in a PCM-system.

Output from all analyses of all cases was gathered, using a Pareto assembly as well as a simple comparison, to assess the overall sustainability performance of the greenhouse suggestion.

The plan of action in the master thesis process is described in Figure 2.

6 Ostermeyer, Y. Reuter, F. Wallbaum, H. (2013) Multidimensional Pareto optimization as an approach for site-specific building refurbishment solutions applicable for life cycle sustainability assessment.
7 Thuvander, L. et al. (2012) Unveiling the Process of Sustainable Renovation.

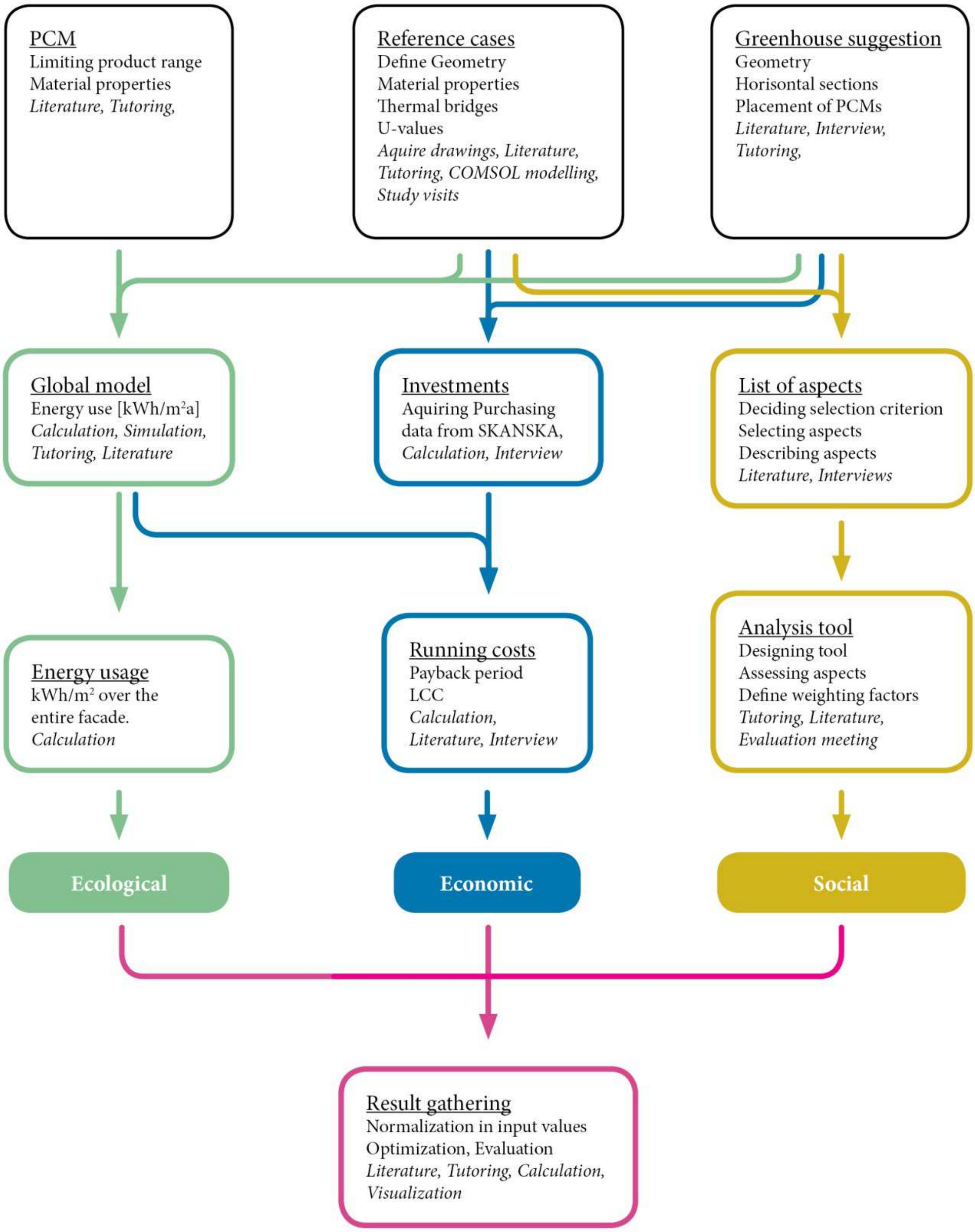

Figure 2: Plan of action flowchart displaying the master thesis parts and process order.

Assumptions and limitations

The thesis regards a single building based on input from Brogården in Alingsås.

For the energy simulations, the reference building has been simplified through simulating thermal bridges one-by-one, and then including their thermal resistance in an average U-value for the façade wall. The façade was defined by the interior measurements of the inner walls.

A CFD analysis of the greenhouse air flows has been rationalized into a value for conduction, which mainly affects the greenhouse. The greenhouse geometry has been shaped so that the air flow can more easily be disregarded. The energy system in the greenhouse was considered to be passive, i.e. there is no heat source or heat transfer medium in the greenhouse.

The condition of the lower reference building was bad and it was in dire need of refurbishment. It was however assumed that the lower reference building is in good condition, i.e. it looks like on the original drawings and performs alike. The brick façade, for instance, was in reality in very bad shape in the lower reference, and for the greenhouse suggestion to be a reasonable alternative, it was necessary to assume that the brick façade was in an acceptable condition.

The floor plan of the building was not regarded.

The load bearing system of the greenhouse is not analyzed but a feasible geometry for the structure is chosen assuming that the chosen structure could be built. Fire regulations are not investigated. Safety issues, acoustics and moisture are considered only in the social sustainability analysis.

2. ANALYZED CASES

A total of three cases have been considered. This chapter describes them, their definitions, context and background. Most attention is given to the greenhouse suggestion, since this case is the novelty and the point of interest for the thesis.

Brogården in Alingsås is an area that has gone through an extensive and well documented retrofitting process[8]. Since the thesis aims to investigate a greenhouse suggestion as retrofitting strategy for Brogården, it is reasonable to compare the effects of the greenhouse suggestion to the pre- and post-retrofitting status. These two well-documented states of the building can then be used as a lower and an upper reference giving the opportunity to get an idea of the performance of the greenhouse suggestion. The different cases for investigation, which will be more thoroughly explained in their respective part of this chapter, are:

1. Lower reference, no renovation and only maintenance as an action.
2. Upper reference, the actual retrofitting.
3. Greenhouse suggestion.

Background and context
During 1961 and 1975 Sweden produced approximately 1.4 million accommodations. 600 000 of the apartments built during this period now require extensive renovation, at the same time displaying poor energy efficiency and are often associated with social problems such as segregation. There is clearly a need for renovation strategies. Most buildings in the million housing program are similar to the ones in Brogården[1].

Brogården is part of the million housing program and was built between 1971 and 1973[9]. Brogården consists of about 300 apartments in 16 buildings[8]. The site plan is shown in Figure 3 below. The buildings are three stories tall but some of the buildings have one cellar wall towards north since the ground is sloping towards south. The buildings have two to three entrances. The building under observation is most similar to house Q, K and E, the southern buildings in Figure 3, when it comes to orientation. The building has two entrances, instead of three, and does not have any cellar walls.

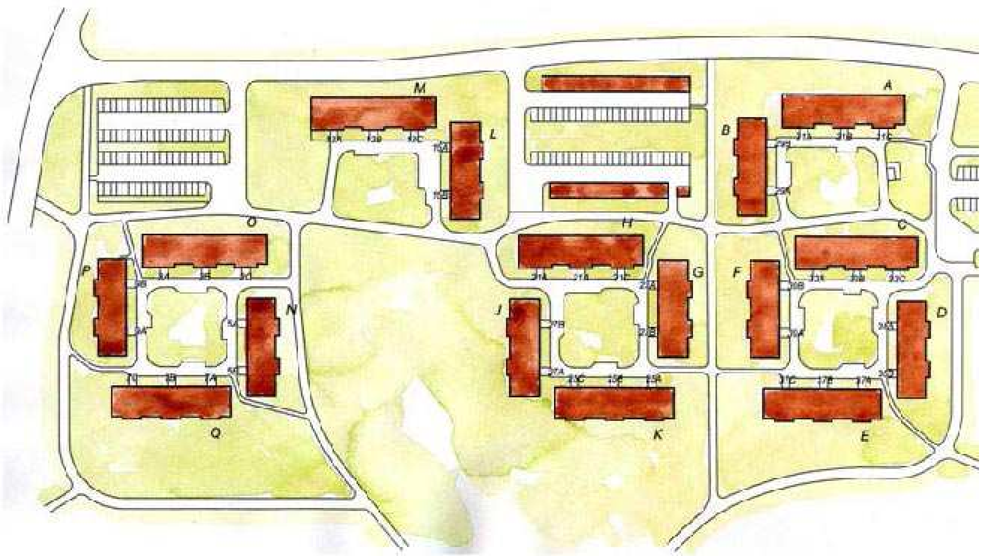

Figure 3: The site plan of Brogården. [10]

8 Alingsåshem et al. (2013) Brogården – med fokus på framtiden.
9 Janson, Ulla (2008). Passive houses in Sweden: experiences from design and construction phase.
10 BEEM-UP (2011) D.2.3.FirstbuildinginAlingsasretrofitted.

About the BEEM-UP project
The renovation of Brogården in Alingsås is a pilot project and is part of a major ongoing study called BEEM-UP[11]. The project is mainly funded by the European Union, having the purpose to "demonstrate the economic, technical and social feasibility of retrofitting in social or public housing in the residential sector", but it also seeks to "reduce heating energy demand by at least 75%, while ensuring a comfortable and healthy living environment" and to "Investigate the replication potential through the European housing stock". The project was initiated in January 2011 and spans 48 months.

Three pilot sites are investigated and renovated in BEEM-UP: Brogården in Alingsås, Sweden, one in Delft, the Netherlands and one in Paris, France. These have been evaluated in terms of LCA and LCC but the social aspects are more or less left out of the evaluation[6].

11 BEEM-UP (2013) Building Energy Efficiency for Massive Market Uptake

Lower Reference: No retrofit

The lower reference is regarded as the building before retrofitting. In Figure 4, two of the buildings can be seen to give an idea of the area. The condition of the houses was bad. The brick façade was literally falling off, the discharge pipes needed to be changed, as well as roofing insulation, drainage and ground insulation. The balconies were a major thermal bridge. The windows were of bad shape and needed changing. The energy demand, accounting all types of energy uses, was 216 kWh/m^2, year[10].

Figure 4: A sample picture of Brogården before renovation[9].

It was, as already mentioned, assumed that the lower reference building looks and functions as the original drawings show. This means that there is still insulation in the attic, the façades are not broken, the windows are not leaking and the discharge pipes are still in good shape. Furthermore, the building needed to be simplified in order to make the analyses possible to perform. The resulting simplification is visualized in Figure 5. The building interior was not considered.

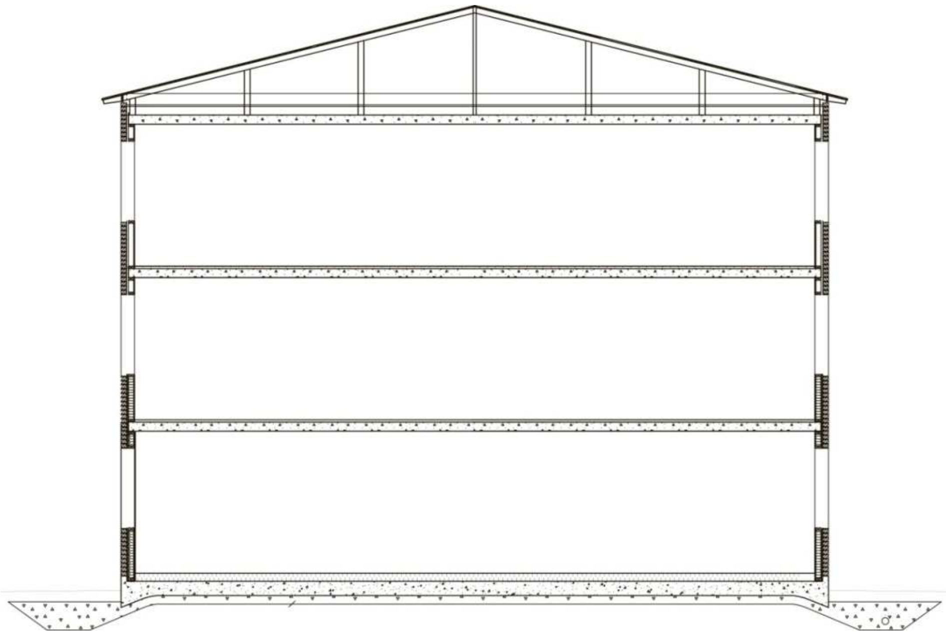

Figure 5: A section of the lower reference after simplifications. The internal walls, both load bearing and sectioning, have been removed, and a cellar wall was removed and replaced by a mirror of the opposite wall. The balconies which were going into the building have been disregarded but are analyzed as thermal bridges in the ecological analysis.

Upper Reference: Extensive retrofit

The actual renovations performed of Brogården were made to mimic the aesthetic look of the previous façade, as can be seen in Figure 6. Even though the new façade material is not made of brick, the pieces seek to resemble a brick façade. The tiles are however a lot bigger than the original bricks, and are placed in a different pattern. This recognition of the buildings original expression is relevant for the social sustainability as will be brought up in the chapter *Social sustainability analysis.*

Figure 6: House K after extensive renovations.

The retrofitting of Brogården started 2008 with a pilot building and the whole process was finished in 2014. As a result of the retrofitting the energy consumption was decreased to 50 kWh/m^2 annually, excluding household electricity. At the same time the rents increased with 27% and the tenants were made to pay for their hot water and household electricity leading to a total increased cost for the tenants of 310 SEK/m^2 annually[8]. A 60 m^2 apartment would then have gone from costing 5740 SEK per/month to 7290 SEK/month.

Tenants had to move out for around ten months and 46% did not come back. The reason could be that[3]:

- They found another place where they would rather live,
- They did not want to move a second time,
- They found the new rent to be too high or
- They already had plans to move.

The evacuation period and tenants moving out are relevant issues for social sustainability and one of the reasons to investigate a renovation alternative that does not demand evacuation.

The upper reference is in this thesis considered as the most extensive and well performed refurbishment feasible for Brogården and is for this reason used as an upper reference. The upper reference was simplified similarly to the lower reference, and the result is shown in Figure 7.

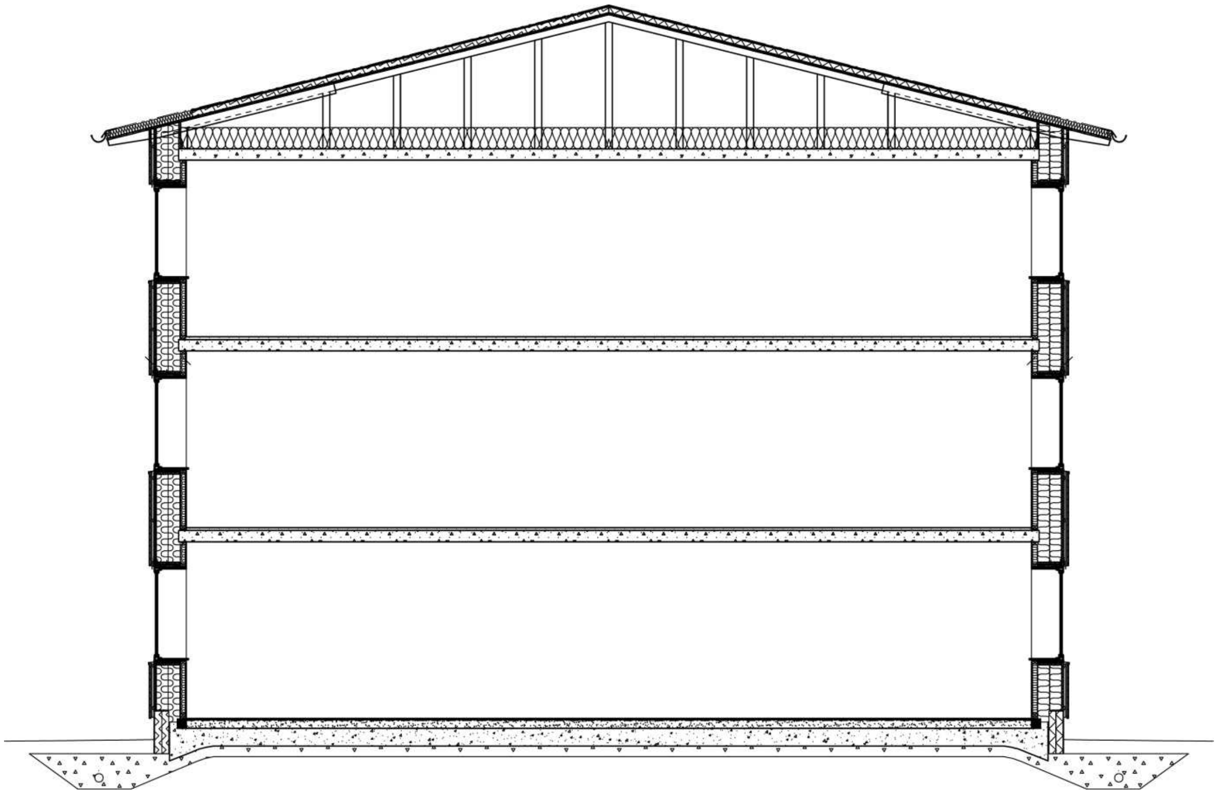

Figure 7: A section of the building under observation as the upper reference case. Similar simplifications as performed for the lower reference have been conducted.

The greenhouse suggestion

There were several reasons for choosing a greenhouse as a retrofit alternative. First, it is an action not demanding evacuation since the greenhouse is a pure addition to the building. Also, the rents were estimated not having to increase drastically which means a continued affordability for the tenants. A greenhouse also provides a number of benefits, such as a common space and possibility of a higher degree of self-sufficiency. There are also thermal comfort related reasons such as extending the warmer seasons in the greenhouse and in this way increasing quality of life for tenants.

The greenhouse suggestion is however not a suitable alternative in some cases and here are a few important parameters:

- The building entrances should not be facing only this façade
- The façade should face south for maximum benefit
- The space needed should not obstruct already built or claimed areas
- The space needed should not interfere with roads that cannot be redrawn
- The greenhouse geometry should not obstruct views from neighbors

The idea with the greenhouse is for tenants in the building to have the possibility to use it freely, providing a space for social interaction. It could also function as a magnet to create community ties between people in more houses than just the connected building.

Geometry and orientation of the greenhouse
To be able to find a suiting geometry for the greenhouse a literature research has been conducted to find previous examples. Parameters also taken into consideration when shaping the greenhouse have been:

Orientation: Maximum solar irradiation is desired, which is why the greenhouse should be oriented towards south.

No rounded shapes: Rounded shapes are by experience more expensive and complex.

Air flows: A problem with greenhouses is that the hot air rises and is collected at the top of the greenhouse where it is ventilated away. By sectioning the greenhouse air volume horizontally, air pockets are created. This makes the air flows more easily controlled and the heat is also more distributed which is desirable. Air convection inside the greenhouse is complex, which was sought to be mitigated by choice of geometry.

Inclination of surfaces: The greenhouse roof adopts the same inclination of its roof as the adjacent building's roof.

Space desired in the greenhouse: Four meters was assumed as a reasonable width for social activities such as farming or a table with chairs[4].

Space to open windows or have balconies: Approximately two meters will leave the possibility of adding balconies on second and third floor.

PCM placement: The PCM should be placed where the solar irradiation reaches its maximum and/or where the air temperature is highest.

Feasible load bearing structure: The chosen shape is considered to be feasible to construct. It is also assumed to be relatively cost efficient due to the second parameter in this list.

The work with designing the greenhouse has been focused on quickly coming up with a reasonable geometry to be able to put most of the effort on analysis and evaluation.

The greenhouse suggestion is a building addition which adds a function to the building unit, but also changes the amount of surface claimed by the building. The greenhouse suggestion is not a refurbishment or retrofitting of the building, but rather a building addition with thermal benefits. In Figure 8 the greenhouse suggestion is illustrated in a 3D view, and in Figure 9 the greenhouse section, including the building wall, is positioned next to the reference cases to illustrate the differences between the alternating cases' wall compositions.

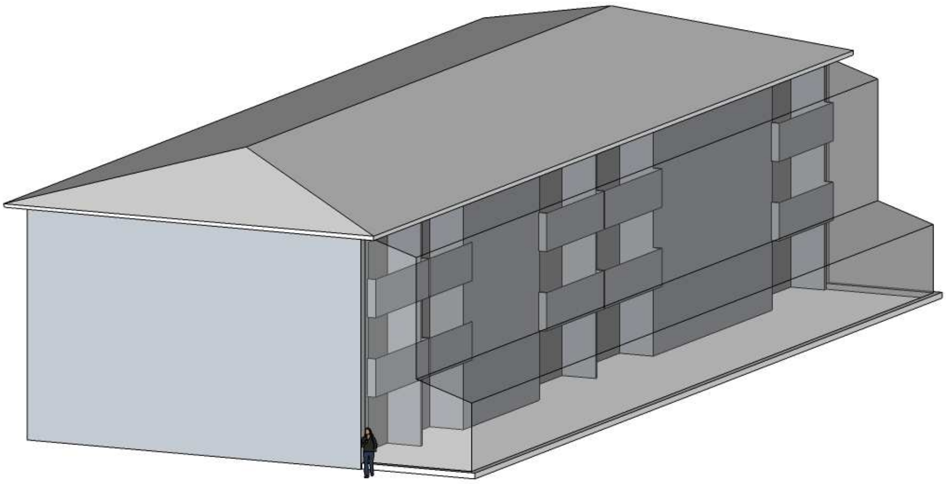

Figure 8: A visualization of the greenhouse suggestion.

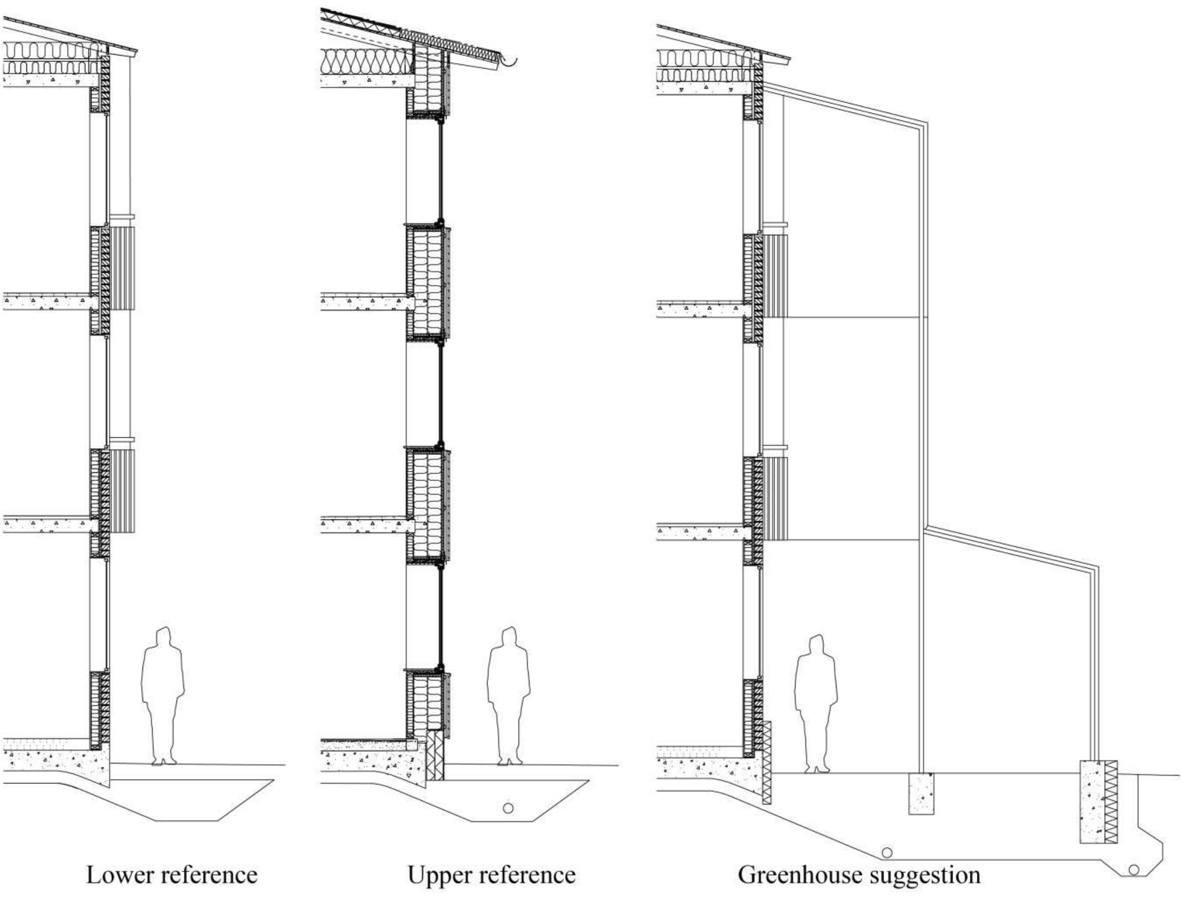

Figure 9: The sections of each case for comparison. The upper reference has balconies too but these have been excluded from the ecological sustainability analysis and are for this reason not visualized here.

Juridical implications and restrictions
Adding to the built structure in this way might be easy and not very problematic on a constructional level but it does bring other consequences. After reviewing current laws and regulations, the greenhouse suggestion was considered a feasible building alteration under certain conditions, such as:

- Tenant dialog and approval
- Tenant commitment and engagement
- The building addition cannot be closer to property border than 4.5 meters, if not acquiring permission from affected neighbors.
- The greenhouse needs a building permit and approval

The reviewed juridical matters can be read in its extent in *Appendix A*.

3. THEORY

The following chapter provides the relevant theoretic background as an orientation in key topics within the thesis. The addressed topics are the properties and applications of Phase Change Material, and a summary of the discussion on social sustainability as seen in the literature.

Phase Change Materials

PCMs show promising properties for thermal energy storage applications. There is virtually no material that does not have the ability to change phase but even so, the term PCM refers to a limited range of materials when used in building physics contexts. The key aspect is to find materials whose heat of fusion, i.e. the energy needed for melting and which is released at solidification, is much larger than the specific (sensible) heat capacity. The most common materials known as PCMs are either waxes or salts. Waxes can generally handle more melt-freeze cycles within its life time but do not have as high thermal capacity as the salts, whereas salts display phenomena that affect their long term stability in a negative way[12].

Types of PCM
The classification of PCMs divides them into the following three categories:

1) *Organic PCMs* which most commonly are types of paraffin. Their main advantage is operational stability, both from a thermal and a chemical standpoint, as they sustain their properties better over several melt-freeze-cycles, display little or no undercooling and are less corrosive. However, they could potentially catch fire if temperatures reach their ignition temperature. These temperatures are normally in the range of 110-170 ℃, and are thus not an issue under normal operational conditions[13,14].

2) *Inorganic PCMs* like salts or metallic compounds. The big benefit that these display is a larger Thermal Energy Storage (TES) capacity, both from a higher heat of fusion and a higher thermal conductance within the material. The disadvantages, though, are that they experience phase segregation, corrosion and are in that way harder to rely on for long-term applications.

3) *Eutectics* are combinations of two or more PCMs. Their melting points depend on the fractions of the added materials and are commonly optimized for as low melting point as possible, which is when the two share the same melting point. Is this so called eutectic point is not found, it would imply the possibility for both the liquid and the solid state being present in the mix and would give the PCM two melting points instead of one [15, 16, 17].

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[12] Khudhair, A.M. Farid, M.M. (2003) A review on energy conservation in building applications with thermal storage by latent heat using phase change materials.
[13] Rubitherm Technologies GmbH. (2013) Data Sheet RT10.
[14] Rubitherm Technologies GmbH. (2013) Data Sheet RT35.
[15] Tyagi, V.V. and Buddhi, D. PCM thermal storage in buildings: A state of art.
[16] Zalba, B. et al. (2003) Review on thermal energy storage with phase change: materials, heat transfer analysis and applications.
[17] Kauranen, P. Peippo, K. Lund, P.D. (1991) An organic PCM storage system with adjustable melting temperature.

Properties of PCMs
A helpful list of important thermophysical properties of PCMs was presented by Tyagi and Buddhi[15]. These properties are important to consider when selecting a PCM:

Thermophysical properties

i. *Melting temperature in the desired operating temperature range.*
ii. *High latent heat of fusion per unit volume so that the required volume of the container to store a given amount of energy is less.*
iii. *High Specific heat to provide additional significant sensible heat storage*
iv. *High thermal conductivity of both solid and liquid phases to assist the charging and discharging energy of the system.*
v. *Small volume change on phase transformation and small vapor pressure at operating temperature to reduce the containment problem.*
vi. *Congruent melting of the phase change material for a constant storage capacity of the material with each freezing/melting cycle.*

The phase transition
The main parameter is the amount of energy a PCM can store and at what temperature this phase change happens. All of this information can be included in an enthalpy distribution diagram, as the one in Figure 10. The phase transition temperature lies at 9-10 °C, but it is not exactly the same for melting as for cooling. Additionally, the diagram displays the maximum energy that is stored per temperature step during melting and that is released during cooling. Not displayed in the diagram is that the total energy stored over the entire transition is nearly 200 kJ/kg whereas the sensible (specific) heat capacity is 2 kJ/kgK – or almost factor 100 smaller[13]. For comparison, the sensible heat capacity of water is 4.2 kJ/kgK[18].

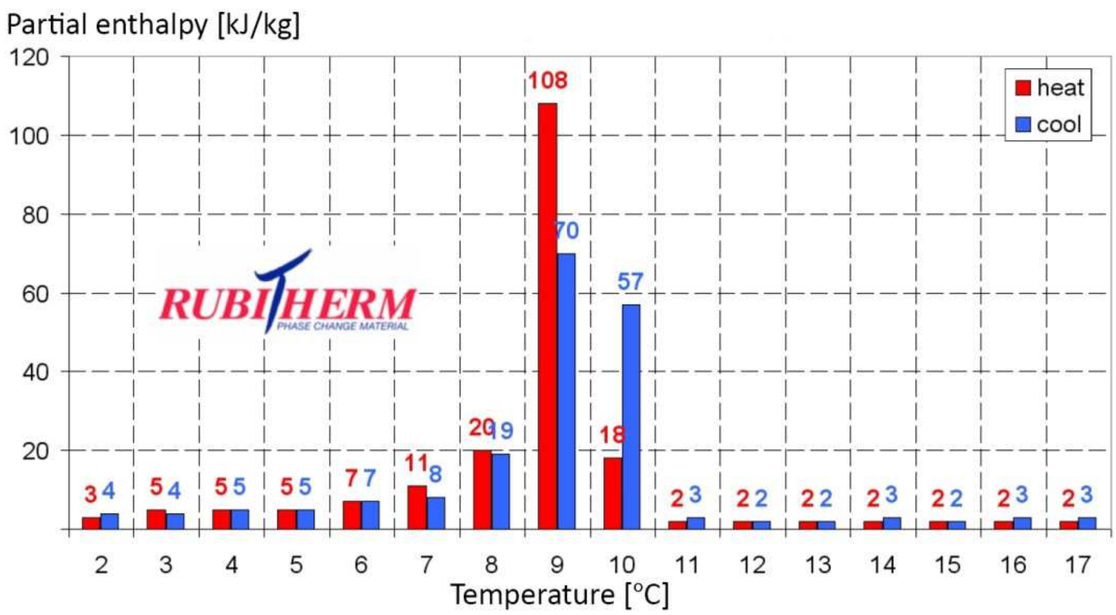

Figure 10: A typical partial enthalpy distribution for a phase change. Each bar shows the latent heat released or stored per 1K temperature step. The red bars signify heat stored during melting and the blue bars signify the heat released when freezing. This particular PCM is a type of paraffin from the German manufacturer Rubitherm[13].

[18] Petersson, Bengt-Åke (2009) Tillämpad byggnadsfysik, Upplaga 4:1.

Building applications

In building applications, the phase change typically goes from solid to liquid and back. The temperature at which this transition occurs, i.e. the melting point, needs to be in a relevant range so that the PCMs are actually forced to change phase by the fluctuations in the air temperature. The efficiency of TES is heavily influenced by the choice of melting point. For indoor applications, a melting point 1-3 °C above the mean temperature in the area where it is to be introduced was found to be the optimum[19]. Already at 3 °C off optimum, the heat storage capacity is reduced by 50%[17].

The physical placement of PCM is crucial for the effectiveness of TES. Zalba et al[16]. and Tyagi and Buddhi[15] presented comprehensible reviews of the state of the art for using PCM in building applications, from which a summary of two themes, which are present in both papers, follow below.

One reoccurring theme is impregnating or including PCM in building elements or blocks such as wallboards, masonry bricks, concrete etc. The immersion of PCM is mainly done by either impregnating the pore space with liquid PCM or encapsulating PCM in plastic microbubbles that are mixed in at the wet stage of the production, granted that there is one. Advantages with this principle are that the PCM element is a direct replacement of something that would be installed anyway so that there is no visual effect of them, and there is a chance that irradiating heat would hit the PCM which could then store the heat immediately. On the negative side, there is a limit to how high the PCM content can be for the element to fulfil its other requirements, such as structural stability, which limits the amount of heat that can be stored.

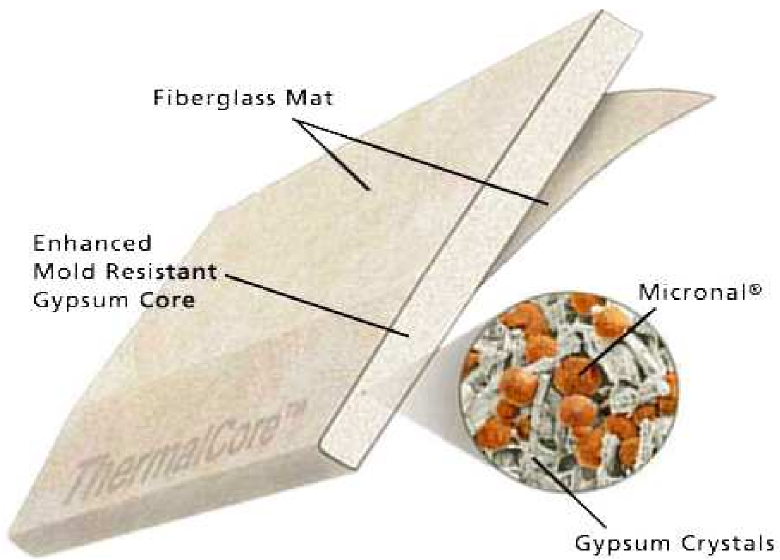

Figure 11: The principle construction of a PCM plasterboard[20]

Another major theme is placing PCM where their access to solar irradiation and moving air is maximized. PCM shutters are good examples of this, as are PCM rods in ventilation. Typically, the PCM is kept pure and simply encapsulated in metal casing with cross section that are circular (rods) or rectangular (as in chilled beams). The employment of these types is most suitable outside the main living areas and outside the views of the users of a building, since they are probably considered less appealing by most people. Their main advantage is the added efficiency as compared to many other types of PCM application, which come from the increased surface area, the reduced thermal resistance between the PCM and the heat medium, and the unchanged heat capacity per volume.

[19] Kauranen, P. Peippo, K. Lund, P.D. (1991) A multicomponent PCM wall optimized for passive solar heating.

[20] National Gypsum. Thermal CORE™.

Social sustainability in current research

A literature study was conducted to provide a definition of social sustainability, describe the state of the art as well as challenges with assessing social sustainability on a community level. Key words for the research have been: social sustainability, social sustainability indicator, SDI, sustainable development indicator, sustainable community and sustainable housing.

Three spheres of sustainability

Sustainable development has grown into a well-known and widely used concept. Three principles from the evolution of this concept are particularly important for the reasoning that founded this thesis. They are illustrated in Figure 12. The first principle traditionally visualizes Sustainable Development with three overlapping circles, three spheres of sustainability; the environmental, the social, and the economic sustainability. This approach communicates the need for positive development in all spheres for true sustainable development to be achieved. The second principle displays concentric circles. This approach communicates how the economic system is part of the social system, which is a part of the ecological system in its turn. The third principle regards weak contra strong sustainability; weak sustainability demands that the sum of development in the three spheres is positive for sustainability to be achieved, whereas strong sustainability does not allow positive development in one sphere at the cost of another[21].

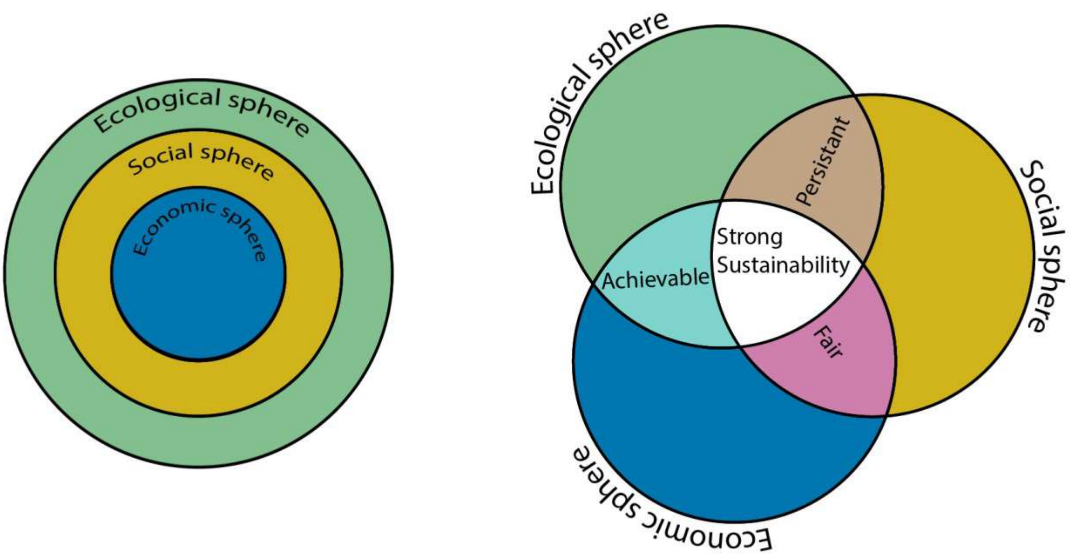

Figure 12: The overlapping circles visualization and concentric circles visualization of sustainability.

The social sphere

The field of social sustainability is relatively new. Even though the social aspects of sustainability were brought up in the Brundtland commission report in 1987, this sphere has been neglected the same amount of attention as the other two [22]. The field of site specific urban social sustainability was found to have been left relatively unexplored. The social sphere ought to be as important as the other two spheres, only our economic system lets us use simpler tools of assessing the economic and environmental spheres. Most research within social sustainability has been conducted within the last two decades simultaneously by a range of authors creating a range of different ideas and definitions of social sustainability[23, 24, 25].

[21] Mak, MY. Peacock, C.J. (2011) Social sustainability: A Comparison of Case Studies in UK, USA and Australia.
[22] Brundtland, G. H. (1987). Our common future: The world commission on environment and development.
[23] Ghahramanpouri, A. Lamit, H. Sedaghatnia, S. (2013) Urban Social Sustainability Trends in Research Literature.
[24] Bramley, G. Brown, C. Dempsey, N. Power, S. (2011) The Social Dimension of Sustainable Development: Defining Urban Social Sustainability.
[25] Bramley, G. Power, N. (2009) Urban form and social sustainability: the role of density and housing type.

The imagined development process of the social sustainability sphere can be explained as follows. First of all, it is needed to identify and define what definitions are associated with social sustainability. Second, it is necessary to distinguish parts and structure of the sphere. Third, to put up a framework for the sphere fundamental structure. Fourth, to create a tool for assessing the sphere for different community levels including testing and feedback iteration[26]. As will be seen further on, the process of defining what social sustainability is and distinguishing the fundamental structures has come quite far but needs acceptance from more researchers around the world to reach consensus.

A possible problem regarding the understanding of social sustainability is misinterpretation of the word *social* since it is a notion that varies in meaning between different contexts. Furthermore, the links between the social sphere and the other spheres are weak[26].

Definition of social sustainability
The broad definition of social sustainable development could be *"the maintenance and improvement of wellbeing of current and future generations."* This definition, however, is a bit too broad and multidimensional to grasp the extent of the application. Mak and Peacock try to conclude a social sustainability definition in several steps from various pieces of literature. They describe how the discourse regarding social sustainability has shifted from a more traditional view, treating implementation of equity, reducing grade of poverty and ensuring livelihood, to more immeasurable matters such as identity and social networks. More recently the discourse has turned towards being focused *"... on social networks, community contribution, a sense of place, and community stability and security."*[21].

In an article written by B. Boström[27], the author divides the theorization contribution to the social sustainability sphere into four categories:

1. Those that discusses social sustainability in relation to other articles.
2. Those that relate social sustainability to different perspectives of social sciences, such as “social movement theory”, “notions and temporality”, etc.
3. Those that seek to explore the notion *social*.
4. Those who seek to describe social sustainability by stating a framework of important aspects or factors.

Through the many contributions, the key themes of social sustainability have varied, from paper to paper and over the years, and it has thus been difficult to conclude which expression of social sustainability is fundamental. Some even mean that the definition of social sustainability is temporal, and shifts depending on the current cultural context, thus needing to be explored continuously[27]. However, the understanding of the social sphere increases in the literature and key concepts are outlined. Kevin Murphy has, through extensive studies and literature research, formulated four *"Pre-eminent Concepts of the Social Pillar"*: Equity, Awareness for sustainability, Participation and Social cohesion[26]. Here, the word *pillar* has the same meaning as the previously used word *sphere*.

The social sustainability implications might also differ depending on perspective (individual, community, society, planner, etc.). The needs of the perspective owner are in focus, and since the needs are not necessarily the same for every perspective, the social sustainability implications are also different[28]. “For example, planners seek compact urban patterns, revitalization, infill development, and less automobile dependence. Homebuilders want to avoid a shortage of developable land, unfair development costs, and limits to providing housing types desired by homebuyers”[29]. This thesis addresses the perspective of the community and the individual, in the quote before referred to as *Homebuyers.*

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[26] Murphy, K. (2012) The social pillar of sustainable development: a literature review and framework for policy analysis.
[27] Boström, B. 2012. A missing pillar? Challenges in theorizing and practicing social sustainability: introduction to the special issue.
[28] S. Vallance, H. C. Perkins, J. E. Dixon (2011) What is social sustainability? A clarification of concepts.
[29] Godschalk, D.R. (2004) Land use planning challenges - Coping with conflicts in visions of sustainable development and livable communities.

Important factors for social sustainability within buildings and communities
A pre-study to gather important factors as a foundation for the social sustainability assessment tool was conducted. Key words were sought to get a deeper understanding of the notion of social sustainability in the built environment. Four papers stating important factors of social sustainability of the built environment were reviewed[21, 30, 31, 32]. The factors were collated and organized into the four pre-eminent concepts of the social sphere previously mentioned. Duplets have been merged. The following list of factors emanated from the four papers.

Equity

- Adaptability of development to the changing needs

Mobility

- Accessibility
- Convenience, efficiency & safety for pedestrian & public transport users
- Convenience, efficiency & safety for drivers

Access to societal functions

- Accessibility to schools, health and other services
- Proximity to business activities
- Access to work
- Provision of public facilities
- Access to open space

Health and comfort

- Health, quality of life and well-being
- Ability to fulfill psychological needs

Safety and security

- Secure and friendly neighborhood
- Safety
- Security (from crimes)

Justice

- Fair distribution of income
- Social justice: inter- and intra-generational

Housing provision

- Provision of accommodation for different income groups
- Sufficient number of housing
- Great variety of green and quality housing

Housing stability and quality

- Design, size and comfort

Provision of employment

- Availability of local employment
- Employment

Awareness for sustainability

The urban environment

- Urbanity
- Townscape design
- Layout of building and streets
- Establishment of different business activities
- Efficient use of land & space
- Sustainable urban design
- Local environmental quality and amenity

Building properties

- Mixed development i.e. various uses within the same building or an area
- Building design in terms of appearance, density, height & mass
- Energy efficiency and waste management
- Provisions to control pollution

Open spaces

- Design of open spaces in terms of appearance, location, size & use of materials
- Attractive public realm
- Provision of open spaces
- Natural and social environment
- Green features (construction related)

Participation

- Community involvement in public decision making
- Active community organizations

- Education and training

[30] Chan, E. Lee, G. K. L. (2008) Critical factors for improving social sustainability of urban renewal projects.
[31] Dempsey, N. et.al. (2011) The Social Dimension of Sustainable Development: Defining Urban Development Social
[32] Maliene, V. Malys, N. (2009) High-quality housing - A key issue in delivering sustainable communities.

- Established technical and hygienic requirements
- Decent housing
- Affordability
- Residential stability (vs turnover)

Building management

- Rehabilitation of repairable building structures
- Management of buildings, facilities & spaces

Social capital

- Social order
- Social networks
- Provision of social infrastructure
- Social capital
- Interactions in the community/social networks

The community

- Community
- Neighborhood
- Compatibility with neighborhood
- Community cohesion (i.e. cohesion between and among different groups)
- Community stability
- Social interaction

Social cohesion

- Demographic change
- Cultural traditions

Sense of belonging

- Sense of belonging, pride and identity
- Sense of community and belonging
- Identity, sense of place and culture

Social inclusion

- Social inclusion (and eradication of social exclusion)
- Social mixing and cohesion

Local vernacular

- Preservation of local characteristics
- Promotion of local distinctiveness
- Preservation of historical structures & features

Assessment methods on an urban community level

The methods found in literature to assess social sustainability on a community level in an urban environment are rather scarce and those found need to gain ground within renovation. The most common tools are different types of Sustainable Development Indicators (SDI) that are specifically developed for the purpose of investigation[7].

Another method of assessing the social sustainability sphere is by conducting surveys or interviews. In this manner it is possible to reach the core of the social structure, namely the people themselves. This type of undertaking, however, is more in the field of sociology than within engineering, showing that sustainability is interdisciplinary and require competence from various types of expertise.

As Thuvander et.al mentions, there are many tools available but there is no tool *"that addresses a complexity that balances material and immaterial values"*. Furthermore there is a lack of tools that have gained a wider recognition for assessing renovation of housing[7].

4. ECOLOGICAL SUSTAINABILITY ANALYSIS

The field of ecological sustainability is one that relates to a multitude of factors such as resource efficiency, emissions of toxins, influence on biodiversity, climate forcing and so on. None is unimportant, but it is possible to argue a higher relevance of certain factors from case to case. This is the situation in this thesis which has led to this principal choice: to only assess energy flows as the measure of ecological sustainability.

Energy simulation procedure

The main steps taken to assess the thermal energy flows are described below. A specific limitation is that the study is only looking at one wall and not the entire building envelope, as a way to keep the study more isolated and focused on the effect of the greenhouse and PCMs.

Energy Simulation Software
COMSOL Multiphysics® version 4.4, further on only called COMSOL, was used for numerical finite-element analyses of the individual thermal bridges and for the full model. These analyses were assisted by hand calculations in MathCAD and data processing in Excel.

Relevant building physics phenomena
A list of influential phenomena, which were not limited by any criteria, was written as an inventory of the physics that was to be simulated. For each stage in the analysis, they will be presented with explanations of how they were defined and introduced.

Simple Model
A small cell-like model was built in COMSOL in which trial-and-error type of investigations were conducted. This way, the effect and definition of each phenomena, physics, and boundary condition could be clearly comprehended.

Stages of the analysis

The procedure of assembling and improving the analysis was divided in four stages as below. Each will get its explanation, relevant phenomena and results in the following chapter.

Thermal Bridges
Initially, thermal bridges were assessed with the purpose of providing input for the later full models, but also for mastering the software.

Full Reference Models
Step by step, the lessons learned in the simple model were introduced to assemble the full models of the reference cases.

Empty Greenhouse
The geometry and measurements of the greenhouse were previously described in the chapter *0The greenhouse suggestion*. This stage also involved defining the influence of the air and the glazing.

Greenhouse with Phase Change Material
The initial pre-study of the literature gave a base for the decision of type and placement of the PCMs. The melting temperature was decided after running simulations of an empty greenhouse. This stage included a parameter sweep of several melting temperatures of the PCM to find the optimal alternative.

Stage 1: Thermal Bridges

Exceptions in the otherwise homogenous wall make-up are called *Thermal Bridges* since they transmit more energy than their immediate surroundings. The output from their simulations, i.e. magnitude of the thermal bridges measured as thermal conductivity, were collected into a lumped model of the wall in the full digital model together with the conductivity from also walls, windows etc.

Material Properties

A list of materials and their properties was established and the same values were used in all simulations. The data in Table 1 comes from different sources; the more common material properties and variables were found in text books and product sheets while the more uncommon ones were found in online sources.

Table 1: Material properties for the Thermal Bridge models.

Material	Density, ρ , [kg/m^3]	Thermal conductivity, λ ,[W/mK]	Heat Capacity, C_p , [J/kgK]
Mineral Wool	29[33]	0.037[33]	0.8[34]
Min. Wool Board	155[35]	0.037[35]	0.8[34]
EPS S80	27.5[36]	0.038[36]	-
Brick	1500[34]	0.6[34]	0.8[34]
Ceramic tiles	1500[34]	0.6[34]	0.8[34]
Wood	500[37]	0.14[37]	1.6[37]
Concrete	2300[37]	1.7[37]	1[37]
Steel, Stainless	7800[34]	20[34]	0.5[34]
Gypsum	800[34]	0.22[34]	0.8[34]
Soil, wet clay	1760[38]	1.5[34]	0.9[38]
Gravel	1500[38]	2[34]	0.9[38]

Sensitivity Analysis

A sensitivity analysis was done on one thermal bridge, namely the one where the slabs that separate two apartments meet the façade. This method investigated the relative influence of factors such as relative tolerance, mesh size, surface resistances and material conductivity. The full list is presented in

[33] Rockwool AB. (2014) Isolerasjälv
[34] Hagentoft, C-E (2001) Introduction to Building Physics.
[35] Rockwool AB. (2014) Väggboard
[36] BEWI Insulation. (2014) BEWI EPS Standard
[37] Burström P.G. (2009) Byggnadsmaterial: uppbyggnad, tillverkning och egenskaper.
[38] Engineering toolbox (2014)

Appendix B – sensitivity analysis of a thermal bridge.

Numerical simulations
The thermal bridges were evaluated by assigning a unit temperature difference over the building envelope and integrating the thermal energy flux over the length of the model. For each thermal bridge, this was done for a representative 1D-flux-case, excluding the actual junction, and one with the entire geometry of the thermal bridge, see Figure 13. The difference between these two gave the magnitude of the thermal bridge. The model of where the façade meets the ground was special since it had to be assured that the size of the soil beneath the house did not interfere with the results. The Full model was built up through a step-wise procedure where one complexity after another was added. This is more thoroughly explained under the chapter *0 Energy simulation procedure.*

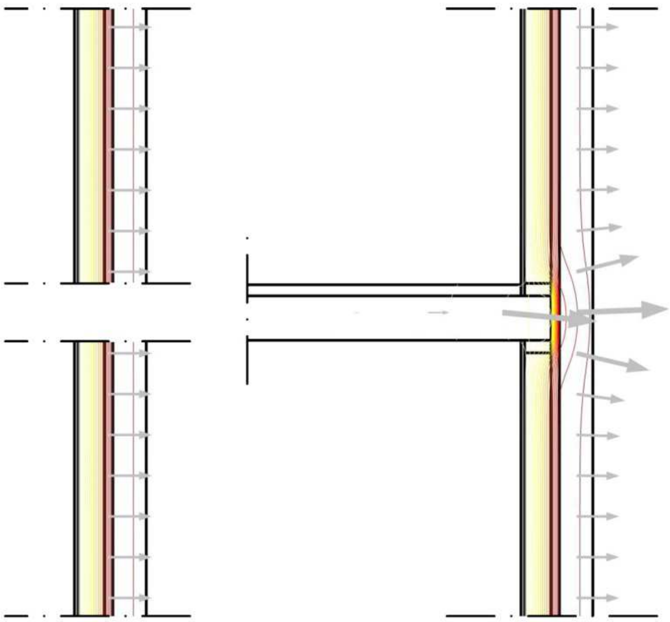

Figure 13: 1D-flux-case and entire geometry of one thermal bridge, exported from COMSOL. Dash-dotted lines indicate adiabatic boundary conditions. The larger size of the grey arrows to the right of the slab in the right picture indicates the increased thermal conductivity in that part of the geometry.

Thermal pillows
The evaluation of the thermal pillow was used by implementing the approach put forward by Angela Sasic in the course Building Physics – Advanced Course on Chalmers[39]. This approach is an adaptation of the master thesis of Nyberg[40], who gathered the methods from the two standards that together describe several calculation methods in a slightly inconsistent way, SS-EN ISO 13370:2007 and SS-EN ISO 10211:2007, and built them into one comprehensive method.

Soil geometry
Under Brogården the ground consists of mainly clay and finer sand. The depth to bedrock is about 30-50 meters[41]. The ground is thus considered to be consisting of homogenous clay for the depth of interest, 23.2 meters. This depth was calculated according to Equation 1.

[39] Sasic, A. (2014) Building Physics: Advanced Course
[40] Nyberg, H. (2011) Thermal bridges at foundations.
[41] Svergies Geologiska Undersökning. Kartgenerator.

Equation 1: By this equation the estimated soil depth for semi-infinity was calculated[40].

INPUT	
Width of the building	$b := 12.44\ m$
Length of the building	$c := 36.668\ m$
Thickness of exterior wall	$d_{w.lower} := 0.238\ m$
CALCULATION	
Characteristic dimension, according to H. Nyberg (2011)	$B' := \frac{b \cdot c}{b + c} = 9.29\ m$
OUTPUT	
Estimated depth of soil for semi-infinity	$2.5 \cdot B' = 23.2\ m$
Estimated width of slab	$0.5 \cdot B' = 4.64\ m$
Estimated minimal width of soil model	$3\ B' + d_{w.lower} = 28.104\ m$

Soil temperature
To mimic a semi-infinitely deep ground, the temperature at the lower boundary of the soil domain was set to be the average temperature for all five years: 6.68 °C. The climate conditions will be further described under the *Full Reference Models* chapter.

Results

It is clear that the building did benefit from the added insulation, see Table 2. The thermal bridge with the smallest improvement between the reference cases is the one where the ground meets the façade and that still showed a reduced heat loss by a factor of two. The other thermal bridges showed an improvement of factor 4 to 10, and the average U-value was improved by 76 %. This was calculated by multiplying the different thermal bridges with their corresponding lengths or areas, and then divided by the total surface area of 283 m^2. 76 % is in agreement with the reported reduction in space heat and domestic hot water of 72 %[11].

Table 2: The calculated magnitudes of the thermal bridges and resulting average U-value.

Analysed Case	Building part	λ [W/mK]	Length [m]	[W/K]	Average U-value [W/m², K]
LOWER REFERENCE	Slab - Facade	0,191	22,2	4,25	1,72
	Ground - Facade	0,190	35,9	6,83	
	Roof - Facade	0,192	35,9	6,88	
	Balconies	0,709	49,6	35,1	
	Windows[2]	3,00 W/ m²K	132 m²	397	
	Façade	0,270 W/ m²K	136 m²	36,9	
UPPER REFERENCE	Slab - Facade	0,0202	71,8	1,45	0,405
	Ground - Facade	0,102	35,9	3,65	
	Roof - Facade	0,0461	35,9	1,65	
	Windows[8]	0,85 W/ m²K	112 m²	95,9	
	Facade	0,0777 W/ m²K	156 m²	12,2	

On the following two pages are isothermal plots of all simulated thermal bridges, see Figure 14 and Figure 15. All points on the same colored line share the same temperature and an increased distance between the lines indicates an increased thermal resistance between them. Also, the grey arrows mark the energy flows at various points in the model, with larger arrows indicating a higher thermal energy flow. Note that the scale factor for the arrows is not necessarily the same for all thermal bridges since they were evaluated in different models.

The isotherms in the lower reference case in Figure 14 are generally closer than those of the upper reference case in Figure 15. This is consistent with the numerical results of the upper reference case having a better thermal insulation than the lower reference case. Also, the sizes of the grey arrows vary more in Figure 14 than in Figure 15. This is consistent with the numerical results of the lower reference case having thermal bridges of a larger magnitude than the upper reference case.

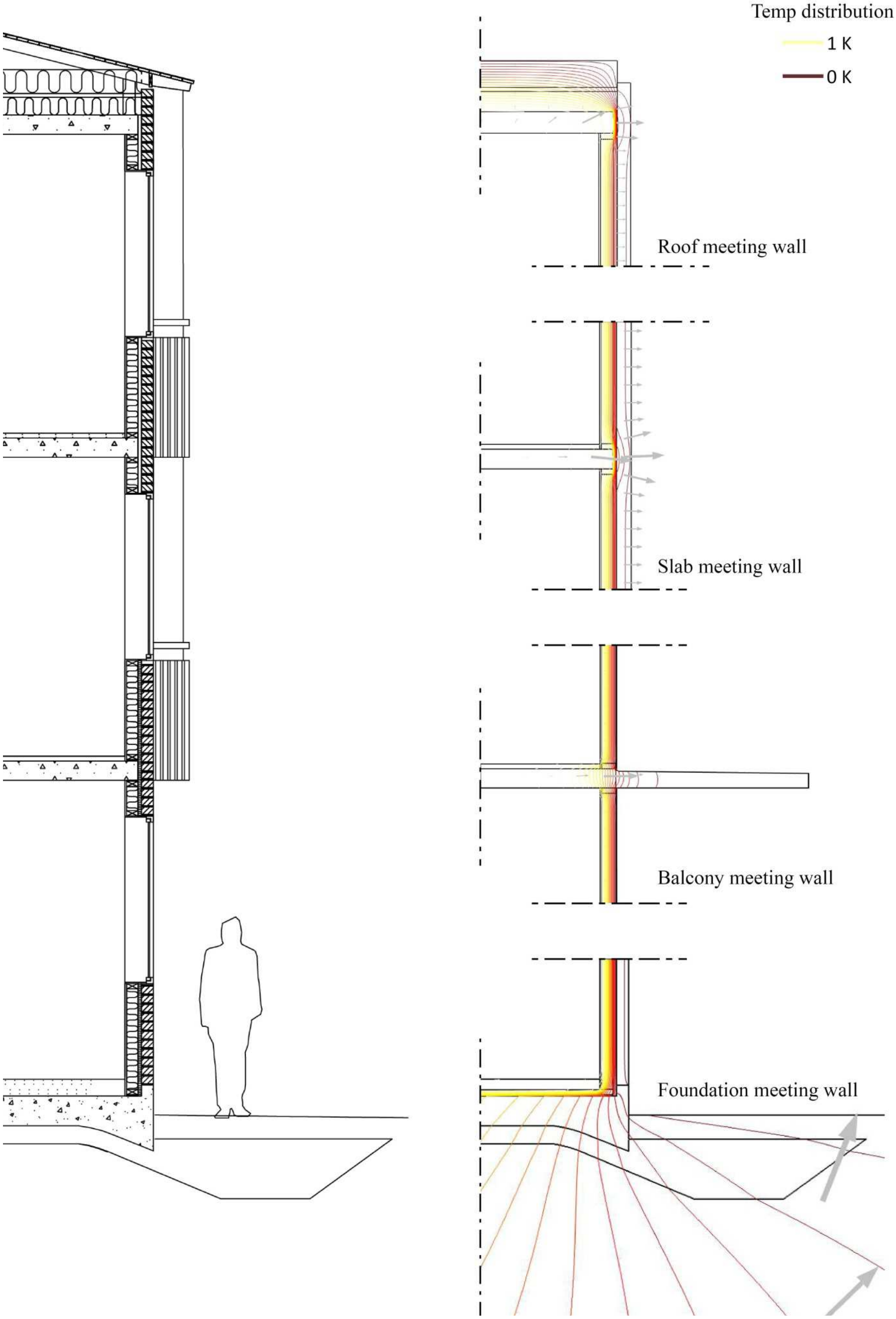

Figure 14: Drawings of the pre-retrofit building and corresponding representations of thermal bridges simulations. The magnitude of the thermal bridges is indicated in the difference in size of the grey flux arrows within each thermal bridge. Thus, it is possible to see that the largest thermal bridges are the ones with the balcony and the foundation.

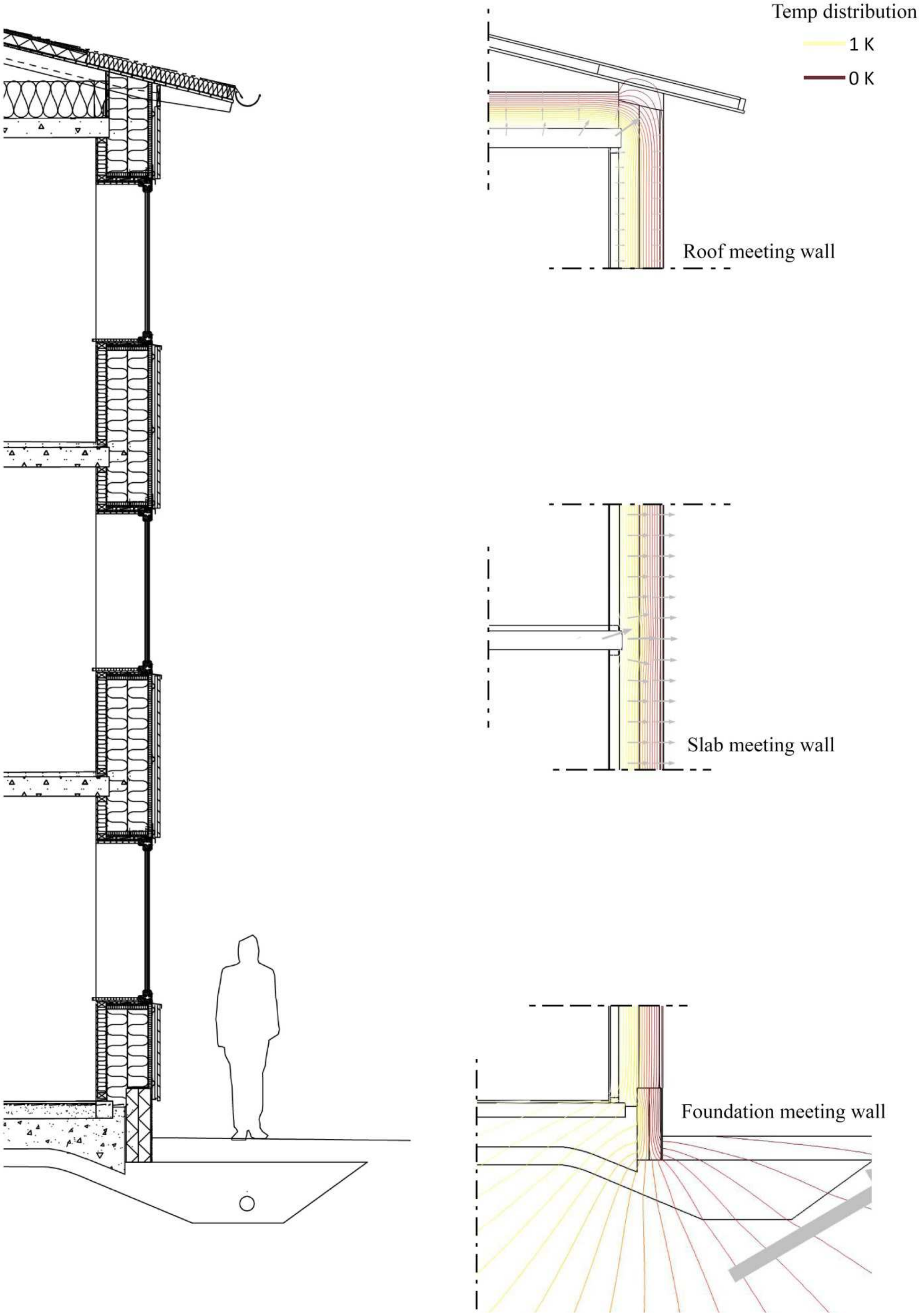

Figure 15: Drawings of the post-retrofit building and corresponding representations of thermal bridges simulations.

Stage 2: Full Reference Models

The simulations in this stage of the analysis begin to regard the final and most developed representation of the reference cases.

Additional Material Properties

The material properties in Table 3 were needed to define the behavior of radiation in the model.

Table 3: Emissivity of a few surface materials

Material	Emissivity, ε , [-]
Brick	0.72[42]
Ceramic tiles	0.93[43]
Soil, wet clay	0.95[42]

U-values of walls

The walls were somewhat simplified. They were divided into one part that holds almost all conductive resistance and one part that holds almost all the active thermal mass. The only layer where the thermal mass was considered was the existing façade brick since in the upper reference case, the ceramic panel is very thin and its thermal mass was therefore disregarded. The layers with the resistance were then lumped into a one meter thick with a λ-value identical to the total U-values presented in Table 2, see Figure 16. Still, the brick is 100 mm thick and has a conductivity that was considered too large to be neglected. To compensate for this, and to make sure that the whole wall had the correct U-value, the resistance of the brick was removed from the total U-value as follows:

Recalculated U-value (Lower reference) $$U_{average} = \frac{1}{{}^{1}/_{U_{tot}} - {}^{d_{brick}}/_{\lambda_{brick}}} = 2.4 \text{ W/m}^2\text{K}$$

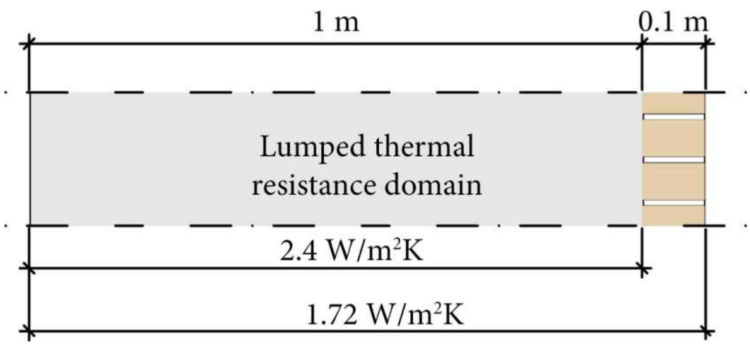

Figure 16. A graphical description of the lumped thermal resistance domain and the brick layer in the lower reference case.

In the upper reference case, the calculated average U-value in Table 2 is used, leaving the wall as a single, one meter thick block.

[42] Infrared Services (2000) Emissivity Values for Common Materials.
[43] Omega Engineering Inc. Emissivity for Common Materials.

Outdoor Air Temperature

Two sources were used for acquiring the climate data for this thesis. The outdoor air temperatures were downloaded from SMHI[44] with a resolution of one hour for the years 2009-2013, as shown in Figure 17.

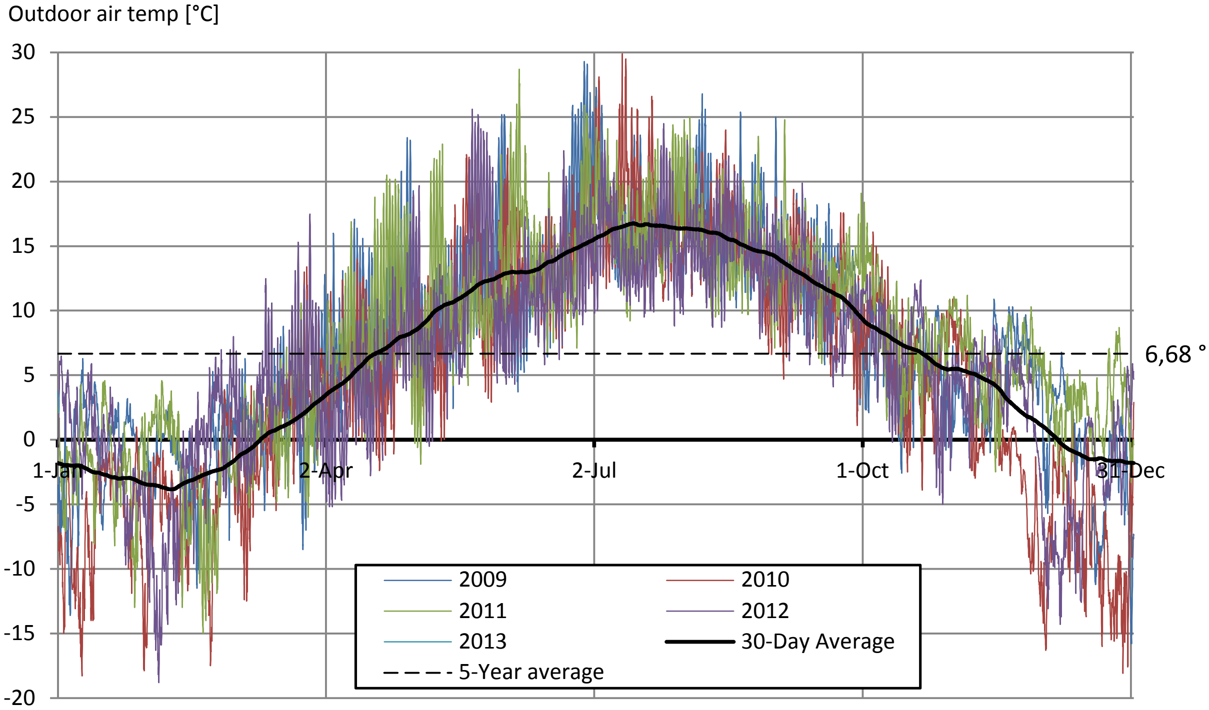

Figure 17: Outdoor air temperatures for 2009-2013, together with running averages for 1- and 30 days and 5- year average. The 5-year average curve was used to determine the length of the heating season.

There is a definition in Sweden called *Heating Season*, which is defined as the part of the year when the outdoor temperature is below 10 °C[18]. At this temperature, the internal heating loads are considered to balance out all heat losses to make the energy balance a status quo. The aim was to make the climate data into a single column of hourly temperatures to import into COMSOL. To this end, the heating season was defined based on the five years in the data series, and the season 2011-2012 was judged representative enough. The reason not to use an averaged season is to keep all the fluctuations in temperature, which are very important for the function of the PCM. Looking at the running average for 30 days over all five years, it was possible to define the Heating Season to be between 2011-09-28 and 2012-05-08, as seen in Figure 18a.

The assembled temperature series is seen in in Figure 18b. Note that the temperatures in the final series sometimes exceed 10 °C. This is a result of using five years for building the average values, but selecting a single season for the applied values.

[44] SMHI. Meterologiska observationer.

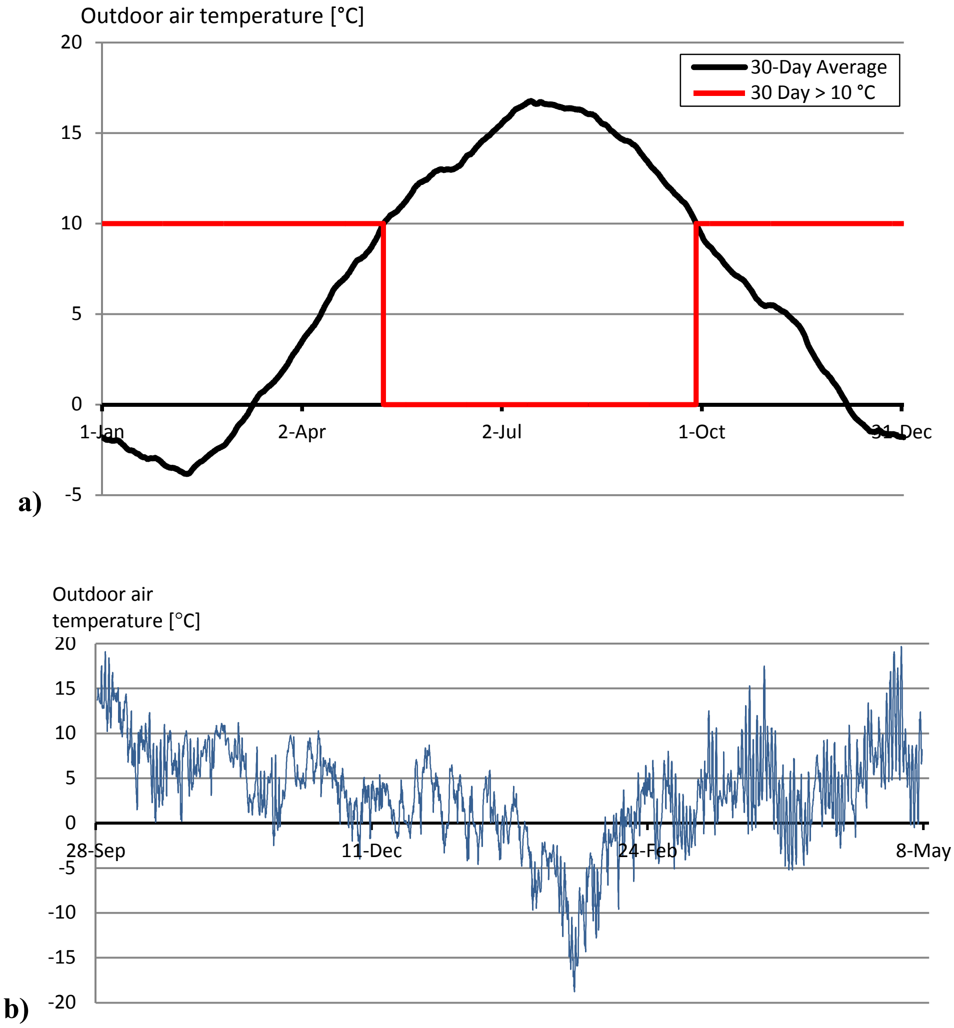

Figure 18: a, defining the Heating Season as September 28th – May 8th based on when the 5-year rolling average temperature for 2009-2013 is below 10 degrees Celsius, and b, the outdoor air temperature series for the selected Heating Season 2011-2012.

Radiation

Next to transmission and convection, radiation is the third mechanism of heat transfer that is commonly considered in building physics.

Direct and diffuse radiation

The values for radiation were acquired by using Meteonorm version 6.1. Meteonorm is a software that computes irradiation data based on measurements by weather stations and satellites and interpolates the data series to fit any place on earth. The extracted data included direct radiation effect perpendicular to rays; diffuse radiation effect on horizontal and vertical surfaces; cloud coverage; and sun angle in azimuth and inclination.

The direct radiation was reduced projecting its directional vector in 3D onto the 2D plane shown in the sections in Figure 9. Total reflection of the irradiation was neglected as a further simplification.

Night sky radiation

The long-wave radiation exchange with the sky was defined by three parts; Surface emissivity, view factors and the temperature of the sky. Hagentoft presents a model for deciding the temperature during a clear night[34]. However, since the simulations will be performed during the day, a continuous temperature sequence had to be established. The method will only be described for horizontal surfaces, but it was done in the same way for the vertical surfaces. From the graph presented by Hagentoft, a linear function was constructed to describe the relation between outdoor air temperature and clear sky temperature, and this was computed for all time steps. Then, the fraction of the sky that was covered by clouds was taken from the Meteonorm simulations, and the applied, effective, sky temperature was decided by a linear interpolation between the temperatures of the air and the clear sky. An illustration is presented in Figure 19. The effective sky temperature reaches closer to the air temperature the more clouds there were.

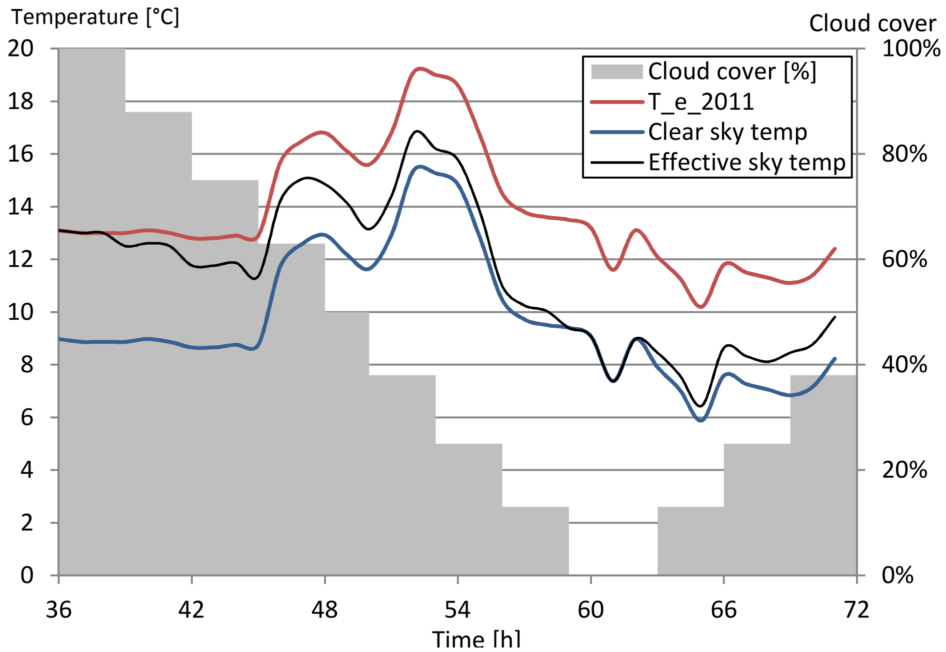

Figure 19: Relation between cloud cover and temperatures of the air and the clear sky, respectively, and how these influence the applied, effective sky temperature. When the cloud cover is 100%, the effective sky temperature is exactly the measured outdoor air temperature, and when the cloud cover is 0%, the effective sky temperature is exactly the calculated clear sky temperature.

View factors

The method for choosing view factors was made almost as simple as possible. The choices of view factors for the radiation exchange between the sky and the various elements in the building envelope were made by considering the ground outside the greenhouse to be an infinite horizontal plane without any other objects on. This gave a view factor towards the sky of *1.0* for horizontal surfaces (the ground inside the greenhouse), a view factor of *0.5* for vertical surfaces (the walls of the façade and the greenhouse), and a slightly higher view factor of *0.6* for the slightly inclined surfaces (the greenhouse roof parts).

Results

The reductions in energy flow between the reference cases correspond well with the reduction in U-value previously presented of 76 %. As shown in Figure 20, the simulated energy flow went down from 29.2 to 8.4 MWh/a,   a reduction by 71 %. This also corresponds very well with the results reported by Alingsåshem, i.e. a reduction of 72 %[11], although their results also contained the domestic hot water use. To acquire these numbers, the total energy flow was integrated as *Normal Conductive Heat Flux* on the inside of the façade wall, i.e. towards the indoor air.

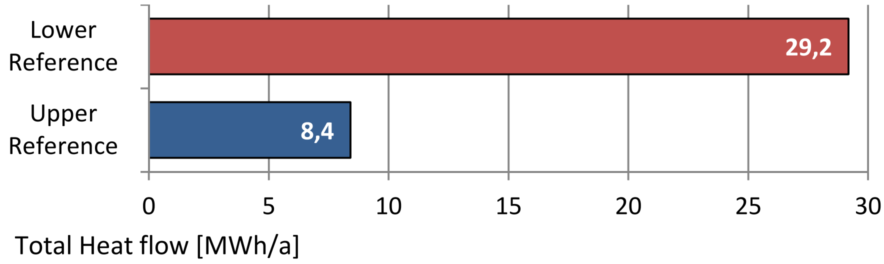

Figure 20: The size of total heat flows for the two reference cases, over the entire façade wall. The simulations resulted in a reduction by 71%, which is very close to the results reported by Alingsåshem - 72 %[11].

These results are an important checkpoint in the whole modeling and simulation process. Since the simulated results correspond so well with the measured results by Alingsåshem, this gave a confidence in the accuracy of the simulations and it was possible to proceed to the next stage in the analysis.

Stage 3: Empty Greenhouse

Since the main challenge in this stage was to define the greenhouse properly, a finite element model was developed step by step to ensure control and feedback for each addition. The first step was defining the geometry of the greenhouse and tuning a mesh, after which came assembling material properties, defining temperature boundary conditions and finally introducing radiation-related boundary conditions.

Greenhouse

The two most influential parameters for the greenhouse suggestion are air movements and how the glass panes allow radiation to pass.

Glazing properties

The greenhouse glass reduces the solar radiation by reflection and absorption, which is measured in the so called G-value. The used value 0.*76* was taken from a product sheet after recommendation from a manufacturer, namely Pilkington, and was simply multiplied with the solar effect [W/m^2] at the points where it hits surfaces inside the greenhouse[45]. Also, the emissivity was defined as *0.92*[42].

Fluid dynamics

The movement of the air is influencing how fast energy is transported through the greenhouse and the temperature distribution in the air volume. However, simulating it is very complicated and demands a lot of time for both running the simulations and for making sure that they are under control. As a way to simplify the fluid dynamics, the conductivity of the air was increased to simulate the convective heat transfer. For this, the whole greenhouse was considered as an air gap using a model for air gaps presented by Hagentoft[34], see Figure 21. Note that this is not a perfect method since it is not intended for such large air gaps, and there are certainly a number of extra phenomena and mechanisms that come into play between 8 cm and 400 cm, but it was found to be a useful starting point.

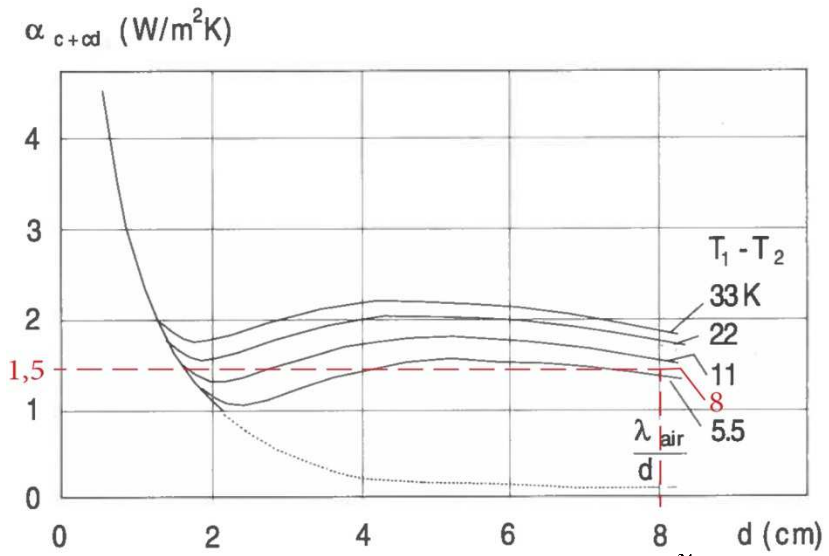

Figure 21: The graph to determine the heat transfer coefficient, α, in a vertical air gap[34]. This model was the starting point for determine the thermal conductance of the air in the greenhouse instead of using CFD simulations.

[45] Pilkington (2015) Datablad Pilkington K Glass™ N.

Interpreting the graph gave the thermal transfer coefficient, by using 8 cm as a starting point since it is as large as possible, and taking 8 K from glancing at the simulation results:

$$\alpha(8K, 8\,cm) = 1{,}5\ \ \mathrm{W/m^2K}$$

Inverting gives the resistance $$R = \frac{1}{\alpha} = \frac{1}{1{,}5 * \mathrm{W/m^2K}} = \frac{2}{3}\,\mathrm{m^2K/W}$$

This can be recalculated into the conductivity $$\lambda_{airgap} = \frac{d}{R} = \frac{2\,m}{\frac{2}{3} * \mathrm{m^2K/W}} = 3\ \mathrm{W/mK}$$

However, higher air movements than that of an air gap were anticipated and a higher conductivity of the air was thereby needed to properly represent that. But the question was: How much more is feasible? A parametric sweep was conducted to investigate the effects of altering λ_{airgap} , see Figure 22 where an excerpt from the investigation is presented.

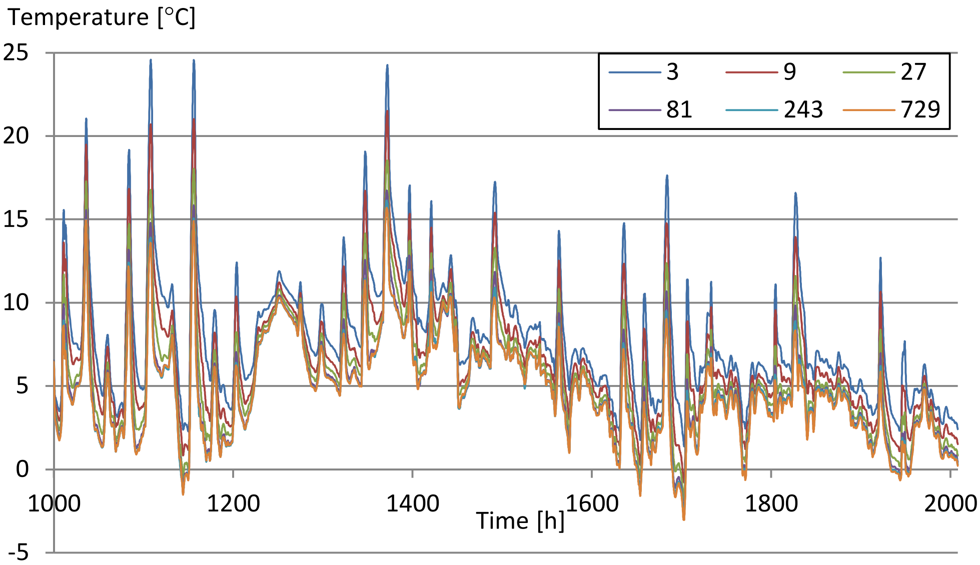

Figure 22: Variations in average temperature in the greenhouse during slightly more than one month, for a number of different values of λ_{airgap}. The conductance influences temperature but does not change the shape of the fluctuations considerably, which was expected.

Clearly, the conductivity has no revolutionary influence over the greenhouse air temperature, but is scaling the temperature down as the conductivity goes up. So what does this mean for the melting temperature of the PCM that will be introduced in the greenhouse? To answer this, the average air temperature for the entire season was calculated, see Figure 23. Upon viewing the graph, it is possible to realize how the plateau after λ_{air}=81 W/mK indicates that no or a very small part of the thermal resistance lies in the air. That is a bit too extreme but in the right direction. Leading from this, the chosen value was: 27 W/mK.

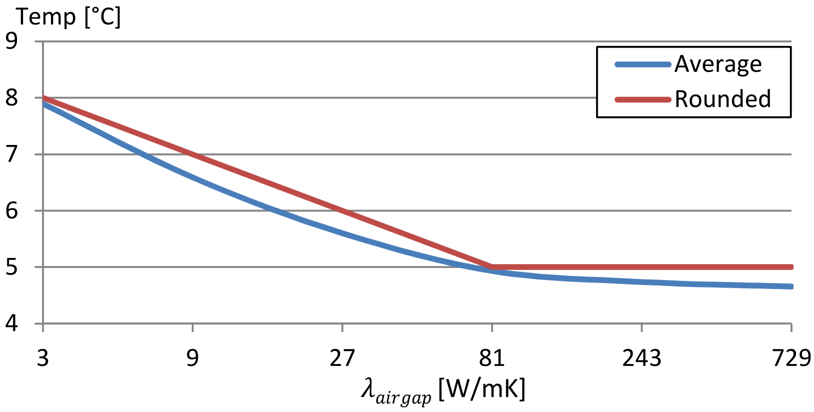

Figure 23: Sensitivity to variations in air conductivity, on a logarithmic horizontal axis. After 81 W/mK, even a huge increase in conductance has very little influence over the average temperature. That implies that all the thermal resistance in the model lies somewhere else than in the air after that point.

Extraction of external irradiation

A particular simplification was made to handle the influence of the radiation in the model. After all radiative boundary conditions had been defined and applied to a greenhouse model without PCMs, the external irradiation was extracted from the greenhouse by integrating the incoming energy over the on wall and the floor individually. The energy that hit those surfaces were made into two separate lists and introduced into the model as heat sources. This was done in order to fit a larger number of simulations in the ruling time frame, and in this way allow for testing more melting points of the PCM.

Results

As expected, the energy savings from adding a greenhouse to the building is notable but not as large as for the Upper Reference case. The simulations show a reduction in total energy flows by 32 %, see Figure 24. Keep in mind that the word *Total* means that *Total energy flow* is not displaying the energy flows for the 1 meter (out of the plane of the drawings) deep section that the COMSOL model represents, but rather the total length of the façade.

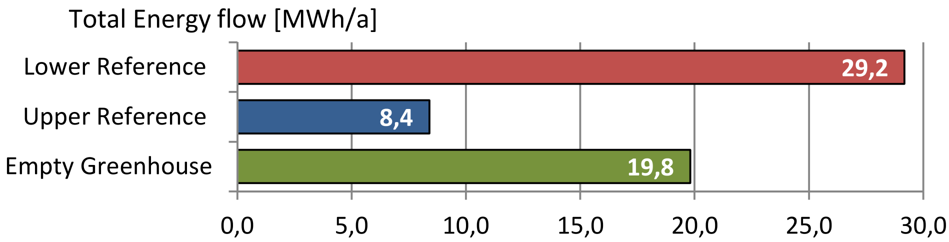

Figure 24: The size of total energy flows for the two reference cases and the empty greenhouse. Adding an empty greenhouse to the lower reference building gives a simulated energy reduction of 32 %.

Figure 25 shows how the greenhouse experiences a significant temperature increase compared to the outdoor air temperature. The annual average air temperature is 3.3 °C outdoors (during the defined heating season) and 6.8 °C in the empty greenhouse. This is reasonable since the greenhouse captures solar radiation and heats its air volume with it. This effect is emphasized in Figure 26 below, where the time scale has been reduced to only three days.

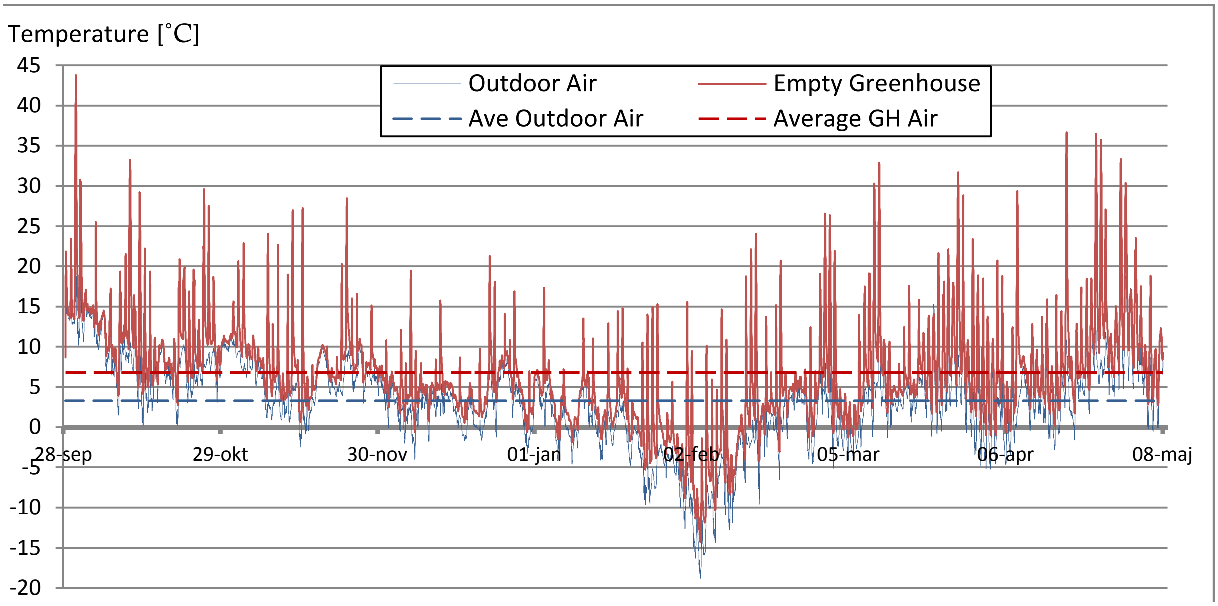

Figure 25: Outdoor air temperature and average air temperature in empty greenhouse. The greenhouse gives substantially higher temperature peaks than the outdoor air, suggesting that the greenhouse can in fact trap radiation also in the computer model.

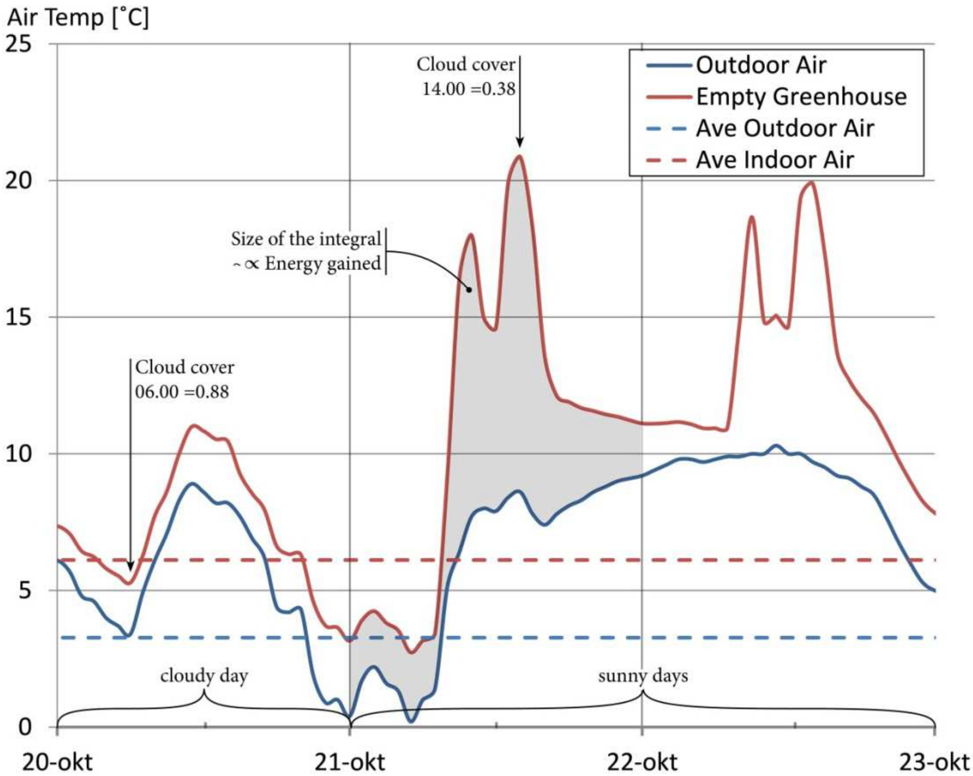

Figure 26: An excerpt from Figure 25 of three days in late October. The first day displays an upward shift of the temperature curve for the greenhouse, whereas the other two days display remarkable temperature peaks. This is a result of the increased irradiation and lower cloud cover during the last two days. The temperature difference between the outdoor air and the air in the greenhouse is roughly proportional to the energy gain from the greenhouse.

Stage 4: Greenhouse with Phase Change Materials

In this fourth and final stage of the analysis, the PCM was introduced into the model and its melting temperature was defined.

Phase Change Materials

The virtue of having PCMs in the greenhouse is threefold from an energy use point of view. Partly, it could reduce the overall energy consumption by adding thermal resistance and reducing the temperature difference over the envelope. Also, it could decrease the maximal heating power demand by raising the lowest temperature in the greenhouse air.

Choice of type of PCM
Based on the outdoor climate statistics and the response of the greenhouse presented earlier, suitable PCM products can be chosen and further used in the full numerical building physics model. However, the following limitations of products to choose from have been made:

- Due to their longevity and robustness, only organic PCMs were considered.
- Due to financial feasibility, only commercially available products were considered.
- Due to their presence in literature, only products from Rubitherm were considered.

Melting temperature
The air temperature of the greenhouse defines which melting temperature is desired for the PCM. Based on the findings of Kauranen, Peippo and Lund described in the *Theory* chapter[19], the first guess for melting temperature was set to 1-3 °C above the average air temperature in the empty greenhouse. That means somewhere between 8-10 °C. Still, though, the average temperature in a greenhouse is fluctuating significantly over the year so there will always be days and periods when all the PCMs will stay entirely in the same phase.

The PCM Rubitherm RT10[13] was found suitable for a basis of the parametric sweep. Its partial enthalpy distribution, see Figure 10, was digitalized as an *Interpolation Function* in COMSOL. To save calculation time, the function was simplified by reducing all enthalpy steps except for the main peak to the lowest value. Also, all the temperature steps were parameterized to be functions of the melting temperature 10 °C. See Figure 27 below. A parametric sweep then tried different values of this melting point, from 4 to 18 °C to find the optimal one for this case.

Other properties
Besides the phase change specific properties, also general thermal properties are necessary to know for the simulations. Table 4 presents those.

Table 4: Summary of PCM material properties

Material	Density, ρ, [kg/m^3]	Thermal conductivity, λ, [W/mK]	Heat Capacity, C_p, [kJ/kgK]
Phase Change Material	880[13]	0.2[13]	2-108[13]

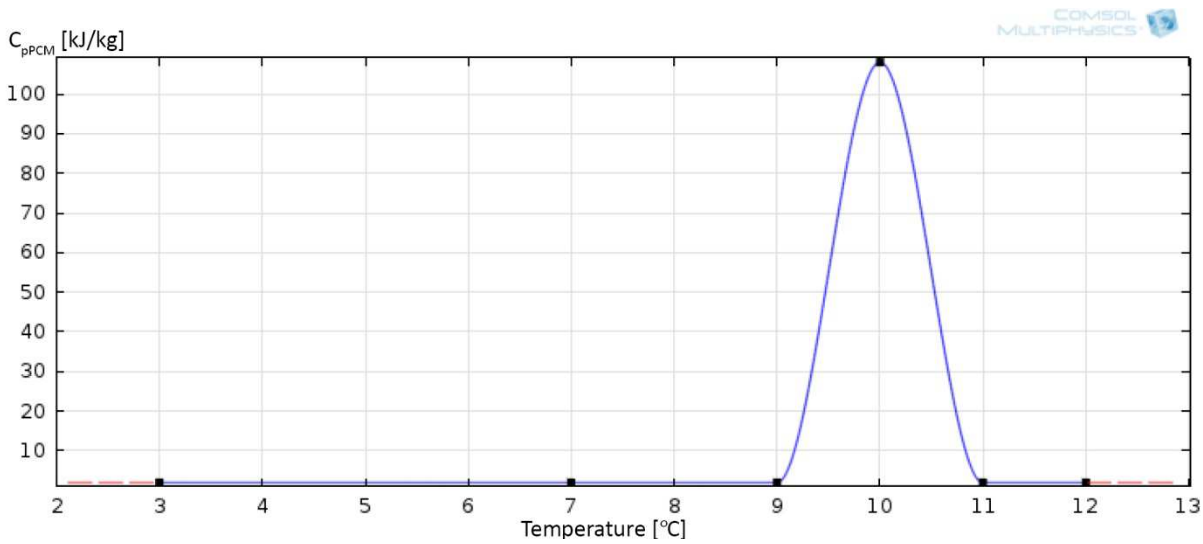

Figure 27: Digitalized, parameterized and simplified partial enthalpy distribution for RT10, that the parametric sweep was based on. The entire invariable region has been contained in a two degrees wide temperature region. Also, the difference between heating and cooling has been removed.

Implementation of PCM in greenhouse

The choice of placement of the PCM in the greenhouse was mainly based on two aspects. First, the stratification of air leading to a higher temperature at higher points in each air volume which led to the decision of placing a number of rods at elevated points. They are relatively thin to have a large surface area per cross section area. The paraffin was considered to be contained in a thin metal tube with high thermal conductivity property, whereby this tube was disregarded in the model. The second aspect is how the sun falls on the surfaces in the greenhouse, which led to the decision of applying PCM immersed in bricks as the flooring of the greenhouse. This also gave a quite large volume of PCMs since it could be used without having to consider shading effects like with the rods. The PCM rods and the flooring are marked green in Figure 28, below.

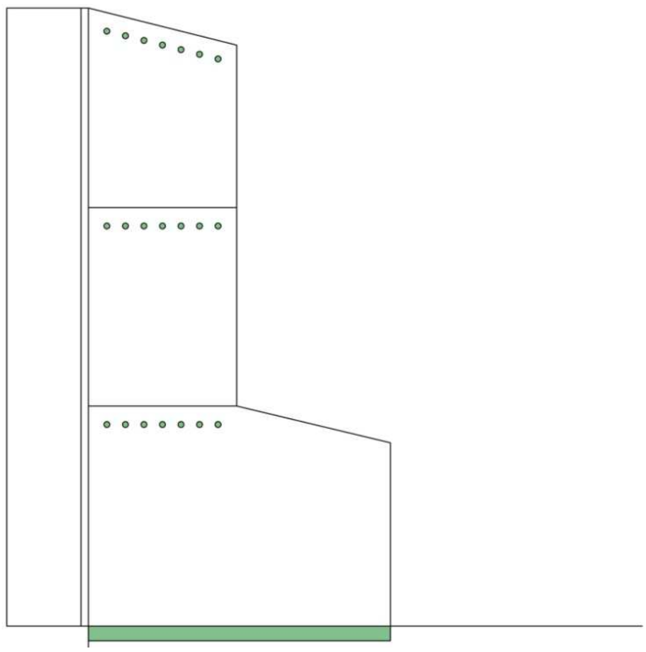

Figure 28: The positioning of the PCMs as elevated rods and flooring in the greenhouse. Note that this figure shows the geometry of the numerical model and does as such not display a correct representation of thicknesses of wall and glass etc.

Model visualization

To better explain the model setup, Figure 29 shows a sample picture of the final COMSOL model, from the greenhouse case with PCM. Parts of the soil domain have been cropped since it is very large. The picture shows the temperature at a certain point in time and for a single PCM alternative. It shows how the lowermost air volume has the highest air temperature, which is a result of irradiation hitting the floor of the greenhouse and not only the façade, as is the case for the two upper air volumes. A keen eye can also notice that the temperature in the PCM rods is slightly warmer than the surrounding air. This indicates an ongoing cooling which the PCM delays due to its increased thermal inertia.

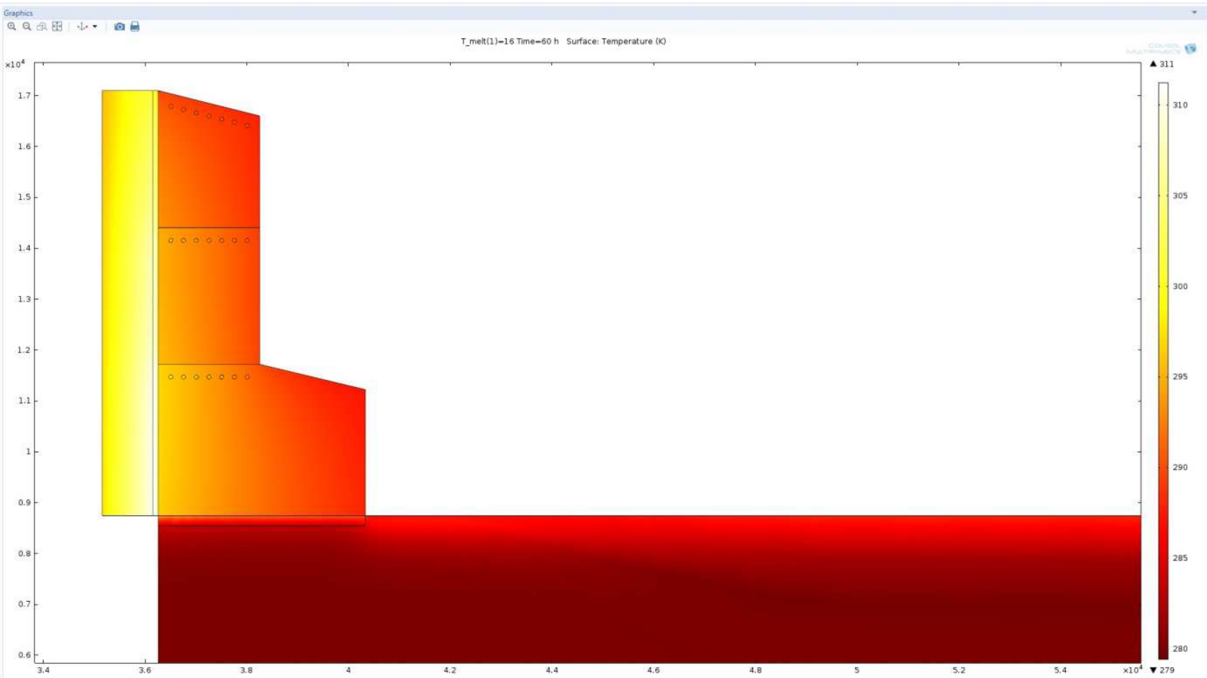

Figure 29: A screenshot from the energy simulations showing temperature gradients. Brighter colors show higher temperatures.

Results

The temperature response changes when PCM is introduced into the model. As is shown in Figure 30, some of the temperature fluctuations were weakened by the PCM. At higher temperatures, the PCM with a higher phase transition temperature was more active, and vice versa for lower temperatures. This is reasonable. However, it is strange that the valley between the two temperature peaks on October 21st displays a deeper valley for PCM 12. It probably should not be activated to store energy when coming down from 18 to 14 °C. The reason behind this response could be a higher time delay than expected in the system, so that not all the PCM 12 had melted during the first peak, and it kept storing energy even after the first peak.

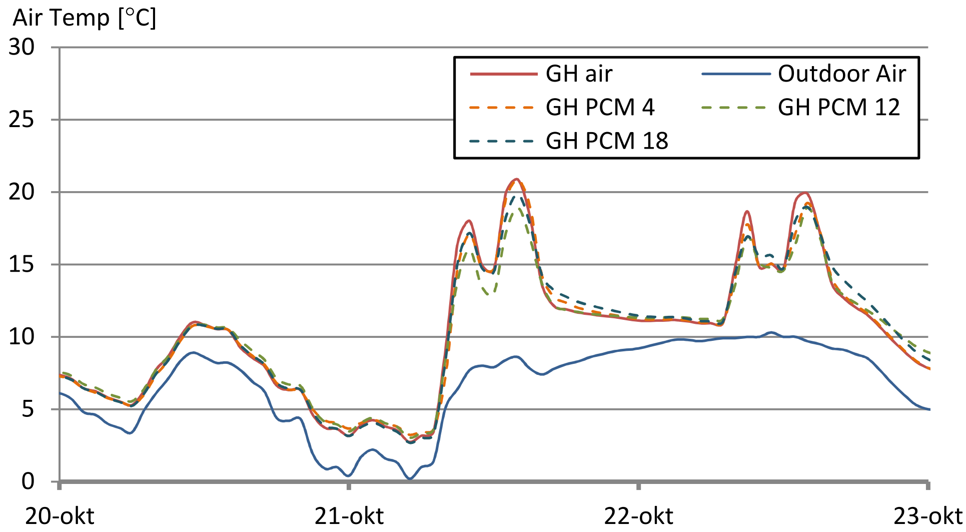

Figure 30: Temperature variations in the greenhouse for PCM phase transition temperatures of 4, 12 and 18 °C. The effect of the PCM is visible but no version of transition temperature shows to be the overall best choice.

Energy flows

After establishing that the simulations gave reasonably accurate results, how do the simulated cases behave in terms of energy use? The magnitudes of these are presented in Figure 31. It is clear that the PCM had little, if any, effect on the energy consumption, which was not really expected. This called for assessing other variables to decide which PCM was most fitting and beneficial to use, see Table 5.

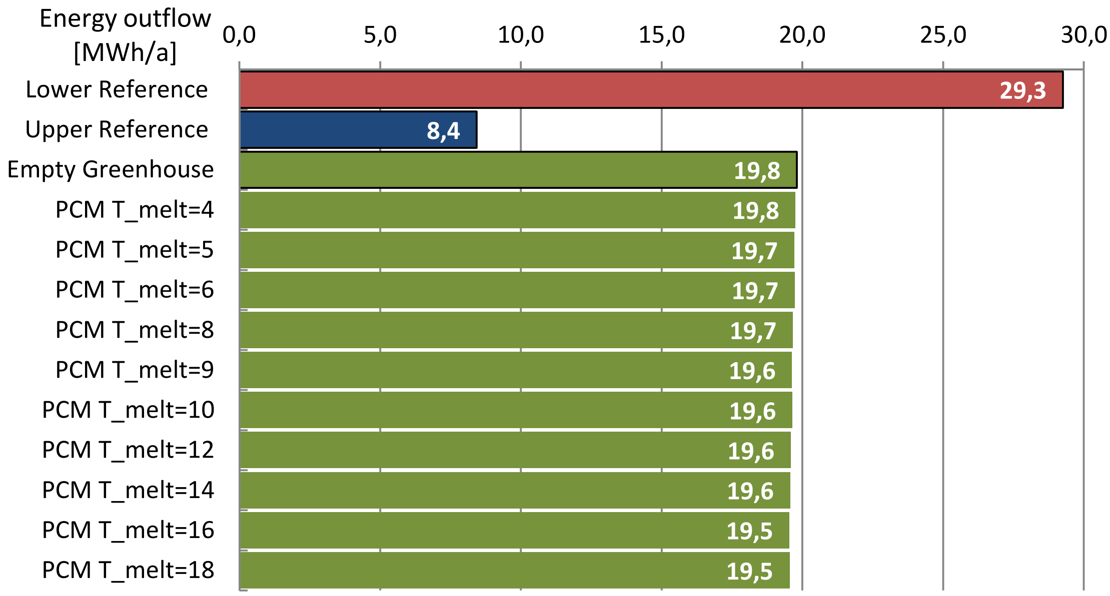

Figure 31: Total energy flows for the simulated cases. Adding PCM to the greenhouse makes a very small difference in terms of total energy losses since only around two percentage points separate the empty greenhouse from the best simulated alternative of PCM.

Table 5: Energy flows, Heating season hours and Degree-hours for the analyzed variations of greenhouse with PCM. Best results in each variable are marked in deep orange.

	Empty GH	GH PCM 4	GH PCM 5	GH PCM 6	GH PCM 8	GH PCM 9	GH PCM 10	GH PCM 12	GH PCM 14	GH PCM 16	GH PCM 18
Heat flow [kWh/ma]	618	550	549	550	548	547	547	546	545	**544**	545
Ratio	100%	89,1%	88,9%	89,0%	88,7%	88,6%	88,6%	88,3%	88,2%	**88,1%**	88,2%
Deviation	13,5%	1,12%	0,873%	0,988%	0,663%	0,502%	0,535%	0,248%	0,131%	**0%**	0,040%
Heating season [h]	4026	4066	4077	4104	4149	4124	4061	3936	**3916**	3936	3950
Ratio	100%	101,0%	101,3%	101,9%	103,1%	102,4%	100,9%	97,8%	**97,3%**	97,8%	98,1%
Deviation	2,81%	3,83%	4,11%	4,80%	5,95%	5,31%	3,70%	0,511%	**0%**	0,511%	0,868%
Degreehours [kKh]	23,9	23,7	23,6	23,5	23,2	23,0	**23,0**	23,0	23,2	23,4	23,6
Ratio	100%	99,2%	98,6%	98,1%	96,7%	96,2%	**95,9%**	96,3%	97,1%	97,8%	98,4%
Deviation	4,22%	3,34%	2,75%	2,26%	0,794%	0,272%	**0%**	0,316%	1,15%	1,97%	2,532%
Optimization	13,4%	7,71%	7,27%	7,53%	7,06%	5,82%	3,96%	**0,944%**	1,22%	2,48%	3,42%

Selecting phase transition point

In addition to measuring energy flows, also *Heating Season* and *Degreehours* were selected to be calculated and assessed. The *Heating Season [h]* shows how many hours the temperature is colder than 10 °C in the greenhouse air. *Degreehours [Kh]* shows the temperature difference between the indoor and greenhouse air, multiplied by the time step, and summarized for the whole simulation. Since the time step is one hour, this was simply the sum of all temperature differences. Still, no consistent winner was found since different transition temperatures for the PCMs were shown to be most optimal in different categories. This means that some kind of combined assessment or optimization was needed to fixate a single value. To this end, the *Ratio* was calculated in percentages of the result of the empty greenhouse suggestion. Also, the *Deviation* was calculated as the difference between the current ratio and the best one in every variable. When the Deviation from each variable were added to each other, and the deviation from Total energy outflow was divided by 2.1 to give it a higher importance than the other two, the value for *Optimization* was acquired. As can be seen on the last row of Table 5 and in Figure 32, PCM 12 is the best option.

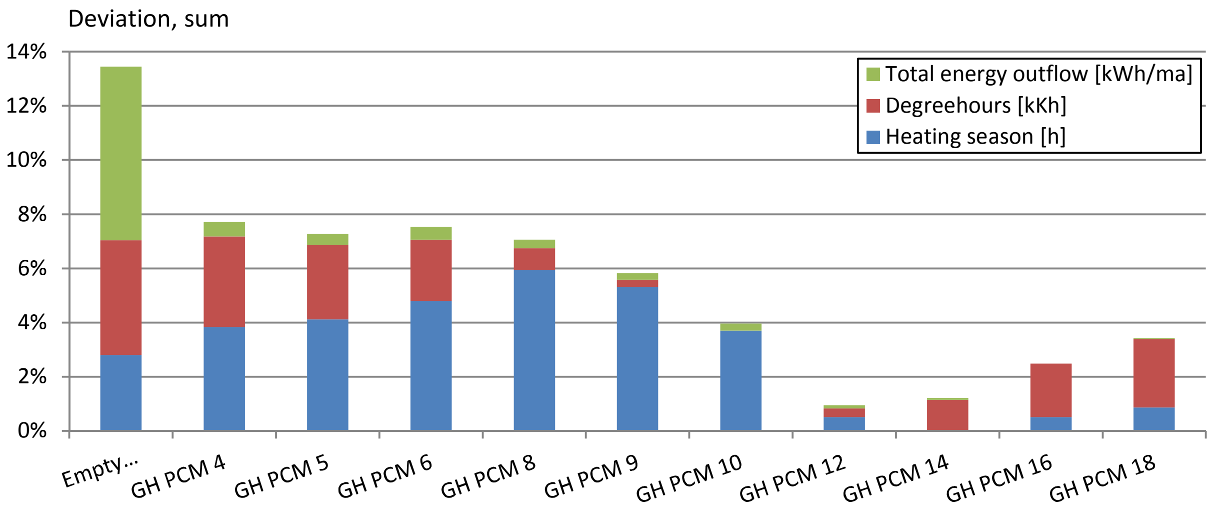

Figure 32: The sum of deviations from best case versions. The alternatives 10, 14 and 16 are all missing one color in their columns, since they were the optimal choice in one category each. PCM 12 is the overall most optimal case.

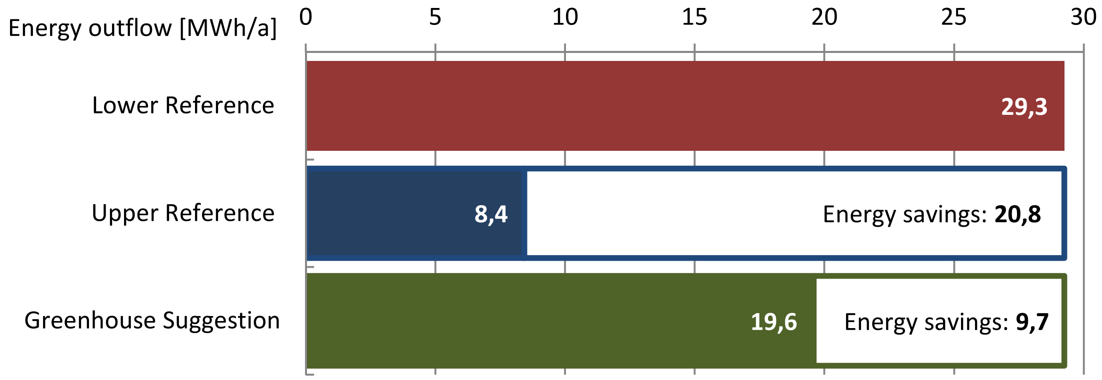

Figure 33: Final energy outflows from the three cases. The upper reference case shows energy savings of 71 % and the same number for the greenhouse is 33%.

The final result indicates that the greenhouse is pretty good but, being a small action, its benefit is rather limited, see Figure 33. The Upper Reference reduces energy flows by 71.3 %, and the same number for the greenhouse suggestion is 33.1 %. Still, the smoothing effect of the PCM can be clearly seen in Figure 34 below. The temperature peaks above the melting point 12 °C are all reduced by 1-2 °C when the PCM is included. The valleys after those peaks, when the PCM can be assumed to be charged with some energy, are all shallower by roughly 1 °C. Additionally, the cold period before midday the 21st shows no significant effect of the PCM, which is probably because the PCM has not been activated – it is all in its solid phase. All this indicate a reasonable behavior of the PCM, albeit slower and of smaller magnitude than expected.

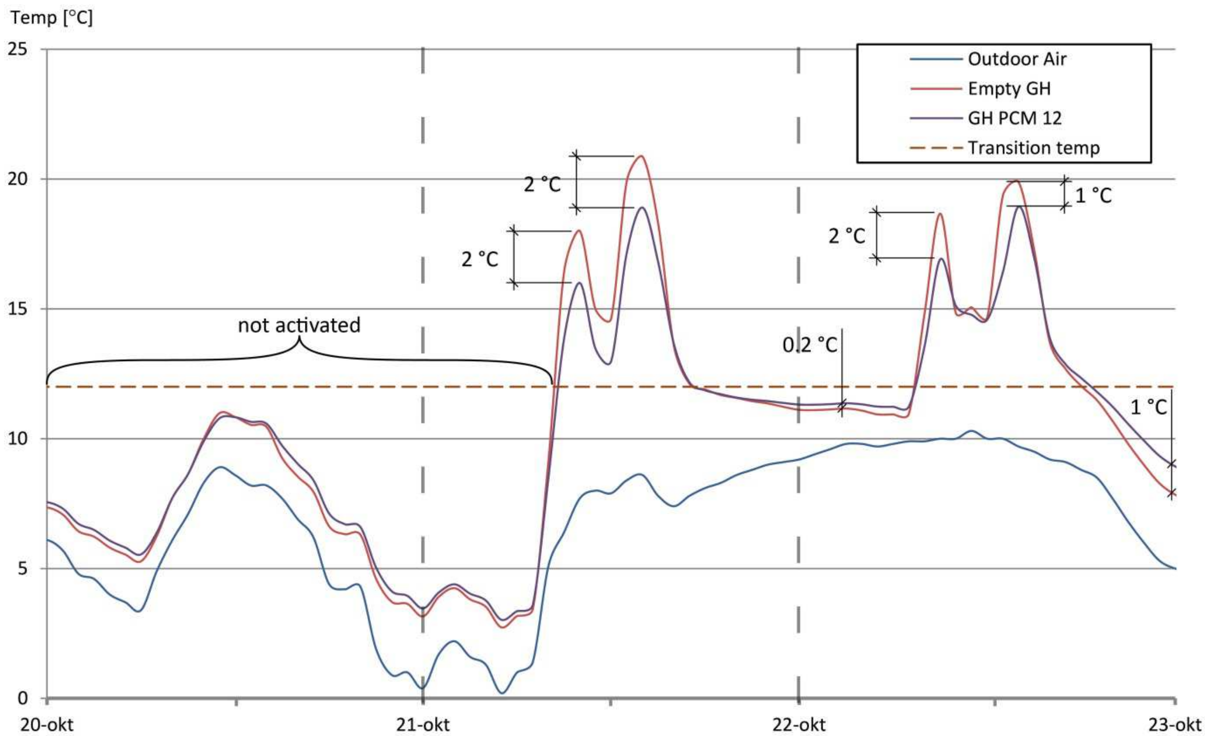

Figure 34: Air temperature outdoors and in greenhouse with and without PCM, as well as PCM transition temperature for three days in October. During the days before the temperature has gone above 12 °C, the PCM has not been activated and there is no significant difference between the temperature of the empty greenhouse or that of the greenhouse with PCM. Once the temperature has risen above 12 °C, the temperature variations in the greenhouse with PCM are noticeably dampened.

Discussion

One source of uncertainty was the limitation to not include CFD in the simulations. This could have affected not only the effective conductivity of the air, but also the surface resistances if the air velocity would have been significantly changed. If the velocity would have been increased, it might have increased the convective heat transfer beyond the level that was used in the simulations which would have reduced the energy savings from the greenhouse suggestion. Increased air flows could also have reduced the surface resistances at the PCM rods which could have given the whole system a quicker response and utilized the PCM better.

Another large source of uncertainty was the properties of the existing materials. The exact fabrication was unknown, as well as possible degradation or damages, moisture content, and alterations. All of these could influence the results to the better or worse, and the lower reference case is most sensitive to this.

An additional source of uncertainty is the influence of moisture in the air in the greenhouse. Would it have been great enough to cause deterioration of the façade? Would it have forced itself into the interior of the building? Would it have had an effect as a heat medium and given the air flows an increased role in the heat transfer. All of this is unknown now.

However, the most important improvement of the simulations would be studying the whole energy system of the building to be able to say something about total energy consumption. Certainly, the greenhouse suggestion would look worse in this type of analysis since the three unimproved walls, roof and ventilation losses would be accounted for. Assuming that transmission losses account for 40% of the energy consumption of the building, and that the studied façade accounts for about 25% of the total transmission resistance of the building envelope, the energy reduction of 33% on the studied façade translates to only 3 % (0,4*0,25*0,33) total energy savings. This is remarkably lower and probably within the range of minor indoor temperature adjustments of behavior changes.

It would have been very interesting to extend the ecological analysis to also include a Life Cycle Assessment of some other major issues. Climate forcing and embedded energy are two such issues which directly come to mind and that would render the Upper Reference less beneficial in comparison to the Lower Reference due to its more extensive retrofitting actions. Without any kind of lifecycle perspective, or without considering other issues than energy use, it is hard to call this analysis a sustainability analysis. Perhaps the energy is not really a problem, perhaps the district heating system of Alingsås has access to large amounts of excess heat from industries that would otherwise be ventilated away. We do not know anything about that without broadening the scope and considering the context. However, efficiency in energy and material use is generally very important and could be considered to be one of the basic virtues in sustainable building. Only in extreme cases could a reduction in energy use be considered unfavorable.

The amount of PCM seems to be too small since a bigger response and influence of them was expected. This might also derive from a low thermal conductivity in the PCM itself, which should slow down the uptake and release of energy.

A question for the future is how useful PCMs are in applications when the air temperature varies much. With the same transition temperature for all the PCM, the PCMs will be inactive during large parts of the season. If instead PCMs with multiple transition temperatures had been chosen, the number of hours without active PCM would be much smaller, but at the price of even less volume and even less thermal capacity available on a given day.

This raises the issue of introducing active systems into the PCM in greenhouse configuration. It is imaginable that a better regulation of heat transport between PCM and air could improve the usefulness of the PCM considerably. Perhaps, an insulated TES-tank including PCM that is connected to a system with water as a heat medium could prove to be a feasible alternative.

5. ECONOMIC SUSTAINABILITY ANALYSIS

This chapter explains the analysis of economic sustainability measured in Payback Period.

Choice of method
The desired output from this chapter was a single comparative value for each of the studied cases. The BEEM-UP project used total LCC per treated floor area as the value for economic sustainability[6], and Alingsåshem used a special kind of economic prognosis[8] that is similar to the Discounted Payback Period method. LCC was not used in this analysis since the limitations for the work as a whole would have made it misleading. The assumption that the state of the building was as good as on original drawings, i.e. without problems with façade bricks or the discharge pipes, would have overlooked that the lifespans of the cases varied greatly in reality and is a large reason behind the need for retrofitting in the first place, and the Upper Reference would have been wrongfully judged. The payback period was instead chosen and computed to find when the investment alternatives can be paid back by the increased income and decreased costs derived from the investment. Generally, a shorter payback period is more economically sustainable since this allows for replacement of resources more quickly.

Payback Period Analysis

The Payback Period Analysis was used to calculate when the investments had paid themselves off. Investment costs were put as an immediate negative post and discounted annually by the direct economic effects of the investments, such as increased rents or reductions in energy consumption and maintenance costs. Exponential functions including interests, inflation and increases in energy prices were applied to recalculate future expenses and incomes during a given amount of years to the economic spectrum of today, i.e. recalculating into the present value. The acquired value is the remainder of the initial loan which was taken to pay for the investments in year 1. This gave one variation per retrofit case and both were plotted as curves in Figure 36.

Input to the analysis

The input to the analysis consists of two parts. Immediate input that occur only once, such as investments, purchases or sales, and annual input that occur every year, such as income from rent or the costs of maintenance, interest rates and supplies.

Investments
The lower reference is considered to have paid itself and does not have an investment cost.

For the upper reference the cost declared by Alingsåshem in their report was used. This number was by their estimation 426.15 Million SEK for all buildings in the Brogården area. The total amount of BOA is 19 278 m^2 [8], and for the building under observation the BOA is 1187.1 m^2. This provides a number for the investment for the investigated house in the upper reference of 26.24 Million SEK. The money is for the scenario borrowed and a fixed interest rate of 2.84%[8] on the loan as used by Alingsåshem was applied in the calculation.

The cost of the greenhouse was provided by a greenhouse production company situated in Belgium called Deforche[46]. Their calculation did not include foundation or building site equipment like water or office during production. Their prize was added to a calculation made in a building production cost calculation tool provided online by Svensk Byggtjänst, where the total production and material cost of

[46] Deforche, e-mail contact, 2014-12-02.

the greenhouse suggestion was calculated[47]. The total investment cost of the greenhouse suggestion was calculated to 1 963 000 SEK. Similar to the upper reference case the money was borrowed and the interest rate fixed on 2.84%.

Alingsåshem included an increased property value as a result from the investment in their calculations. It was, however, considered too unsure to estimate the increased property value of the greenhouse, which was the reason to exclude this parameter from the entire analysis.

Annual input
The following five costs and expenses are reoccurring every year, although not necessarily in the same amount every year.

Energy costs
The energy model in the ecological analysis provided the amount of energy savings from the greenhouse suggestion relative the modelled lower reference wall. These savings were then brought into the economic calculations, relying on a correspondence between the model and real measured values. For the reference cases, the measured energy costs from Brogården were used.

Maintenance costs
The lower reference has an increasing maintenance cost which was interpolated from the estimated running costs calculated by Alingsåshem. After the last input value the maintenance cost increased with the internal rent.

The maintenance cost of the upper reference was taken from Alingsåshem and BEEM-UP and was interpolated between the three input values of 2014, 2025 and 2030[8]. After the last input value the maintenance cost increased with the internal rent.

The maintenance cost of the greenhouse suggestion was assumed to be paid for by the tenants in the building and surrounding buildings using the greenhouse for gardening. A fee for using the seed beds was designed to cover cleaning and maintenance. For this reason, an analysis was performed to investigate the impact of varying fee amount and space for seed beds in the greenhouse. Other than this, the same maintenance cost used in the lower reference case was used since no maintenance related renovations were included in the greenhouse suggestion.

Seed beds - analysis of space and fee
Using pallet rims is convenient when wanting to divide space in farming lots, see Figure 35. They can also be moved around if wanting to modify the use of space in the greenhouse. A pallet rim has the measurements 1,2 x 0,8 meters.

Figure 35: Pallet rims used as seed beds[48].

[47] Svensk Byggtjänst. Byggkalkylatorn.
[48] Richardsson, A. (2012) [Figure]

A part of the greenhouse area is needed for paths and functional surfaces but the greenhouse should also provide opportunity for other social activities. The amount of seed beds, and what income they would provide were brought up in Table 6. It was considered that an amount of 105 seed beds, covering 100,8 m^2 was reasonable, leaving around 40 m^2 for other uses. Furthermore, 400 SEK per year was considered to be a reasonable fee for using a seed bed. This provides an annual resource of 42000 to cover maintenance and cleaning.

Table 6: An analysis of the seed bed rent and generated income. The most probable alternatives are outlined based on surface desired for other activity than gardening, expected demand for gardening and will of paying for using the seed beds.

Greenhouse surface [m^2]	144							
Surface for seedbeds [m^2]	14,4	28,8	43,2	72	86,4	100,8	115,2	129,6
	Amount of seedbeds							
Fee [SEK/seed bed, year]	15	30	45	75	90	105	120	135
20	300	600	900	1500	1800	2100	2400	2700
50	750	1500	2250	3750	4500	5250	6000	6750
100	1500	3000	4500	7500	9000	10500	12000	13500
200	3000	6000	9000	15000	18000	21000	24000	27000
300	4500	9000	13500	22500	27000	31500	36000	40500
400	6000	12000	18000	30000	36000	42000	48000	54000
500	7500	15000	22500	37500	45000	52500	60000	67500
600	9000	18000	27000	45000	54000	63000	72000	81000

An estimation of cleaning and maintenance costs was performed, shown in Table 7, to see if the resources accumulated from the seed bed fees covers maintenance costs. Cleaning is accounted for during the warm season of the year when the greenhouse is probable to be used in higher extent. It was found that the fee is sufficient to cover the costs. The exceeding money is used to pay back the investment.

Table 7: Estimated costs of cleaning and maintenance.

Warm season, weeks	26
Hours of cleaning per week	2
Cost per hour	300
Total	15600
Repairs 10% of fee income	4200
Sum of costs	19800
Fee income	42000

Rent increase

Rent increase for the lower reference used the same principle as used in the calculations performed by Alingsåshem, which was a yearly rent increase by 2.5 %.

The rent increase in upper reference used the same values as used by Alingsåshem which was 1264 SEK per month and household after retrofitting and a yearly rent increase of 2.5 % after that.

To estimate by how much the rent could increase for the greenhouse suggestion, an expert within rent negotiation was contacted, namely Hyresgästföreningen[49]. Constructing a greenhouse along an entire

[49] Hakenmyr, P. (Negotiator, Hyresgästföreningen) Interview.

façade is not a common renovation method but could resemble refurbishing for the tenants to have an external patio with qualities for social interventions. How much tenants are willing to pay for a specific quality or increased standard needs to be investigated for each case.

The technical life span of the greenhouse was an important factor. This estimation was necessary to know how long time the tenants would have to pay back for the greenhouse suggestion. When Deforche performed the investment calculations they assumed a life span of 50 years.

The increase of rent depends of what circumstances the actual case was facing. If there was a community interested in gardening or farming that had requested the greenhouse, it would be more feasible to put a higher rent. But if constructing the greenhouse suggestion without any interest from the tenants it could be argued to not increase rents at all.

Hyresgästföreningen considered the construction of a greenhouse as an improvement of living qualities and would have approved a rent increase by 75 SEK ± 35 SEK per month and household. 75 SEK per month and household was the rent increase used for the calculations.

Taxes
The building addition of a greenhouse has no inflict on yearly governmental tax. This is because a greenhouse is by Skatteverket, the Swedish taxation agency, defined as “ekonomibyggnad”, economy building, which is exempt from taxation[50].

[50] Skatteverket. (2014) Ekonomibyggnad.

Results

The graph in Figure 36 illustrates the variations in remainder of the loan. The initial negative step of the investment is clearly visible, as is the exponential nature of the variations following year one. It can be seen that the greenhouse suggestion would be paid back during the 18th year and the upper reference during the 15th year. This can be compared to the analyses that Alingsåshem conducted, in which the Upper Reference is profitable after 10 years.

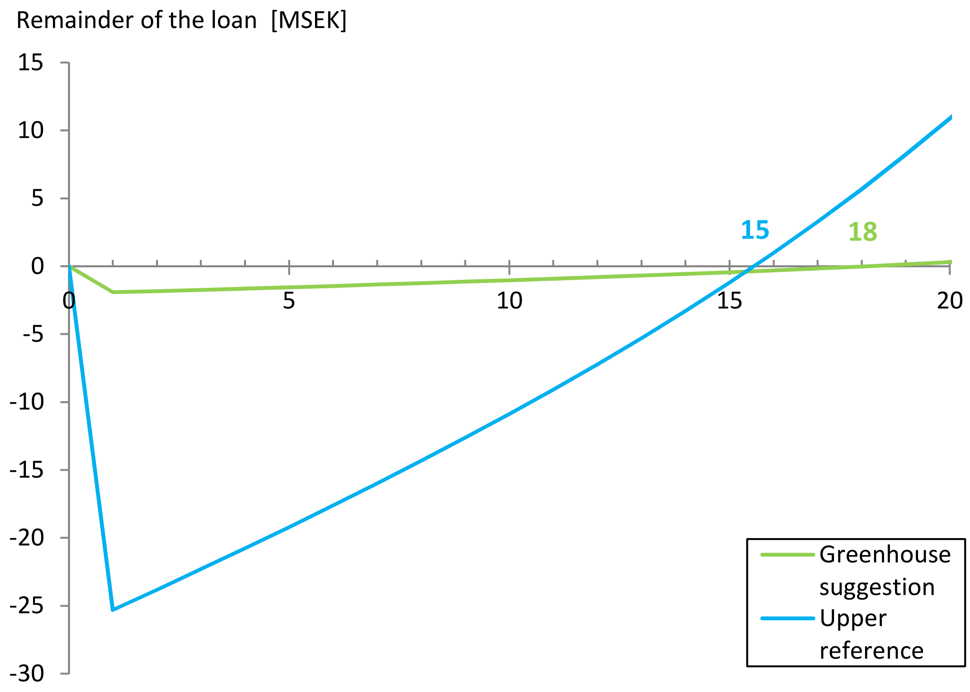

Figure 36: The accumulated profit of investment.

The values in Table 8 were brought into the comparing chapter *7 COLLECTED RESULTS*.

Table 8: The results that are brought into the comparing analysis.

	Upper reference	Greenhouse suggestion
Payback Period [years]	15	18

Discussion

A variable of concern is the level of rent increase for the greenhouse suggestion. The building landlord would likely have increased rents until profitability could be ensured, if the greenhouse suggestion was to be constructed in reality.

The economic sustainability assessment compares two real cases with a fictive case. This is problematic in terms of energy use. The economic calculations account the real energy use for the lower and upper references, whereas the energy use is modelled in the greenhouse suggestion. Since the energy model only measures the energy flow over one wall it is impossible to know how well the modelled outcome corresponds to the real energy flow over the wall of the lower reference.

The costs of the greenhouse suggestion could change if the concept would go to mass production. If constructing a larger number of greenhouses of similar type, a company in Sweden could be contracted to lower transportation costs. Also, if producing the same type of elements, the investment cost for the individual greenhouse could become lower.

If the calculations would have included the increased property value of the retrofitting, they would probably have a more similar result to those of Alingsåshem for the upper reference case.

6. SOCIAL SUSTAINABILITY ANALYSIS

This chapter explains the process of assembling a tool to assess social sustainability early in the planning process of renovations. The tool is then applied to assess social sustainability of the studied cases and evaluated.

Early in the thesis process it was found that there is a need for a tool to assess social sustainability for the three cases presented in chapter *2 ANALYZED CASES.* It was decided to create such a tool and design it to be deployed in a meeting between expert evaluators. The goal of this tool is to provide a single numerical value of social sustainability to be used for a Pareto assembly for the three spheres of sustainability. As was found in the literature study in chapter *0 Social sustainability in current research,* there is also a need for a simple tool dedicated to assessing only social sustainability in renovation or retrofitting of multi-residential buildings. For the assessment in this thesis it is desired that the tool has a balanced composition, i.e. holistic within the stated boundaries, but still allows a relatively quick assessment of social sustainability. The tool should in this way provide early input in a decision making process, as described in chapter *0 The Tool and the Refurbishment Process.*

Assessment methods
There are as mentioned in chapter *0 Social sustainability in current research* many difficulties with analyzing social sustainability. One of the best ways is to involve the actual people that are concerned by the renovation. The building under observation does, however, not provide a good opportunity for tenant surveys or involvement since the retrofitting of the building is already finished. Additionally, many tenants have moved out because of the retrofitting process and are more difficult to include in surveys[3]. Furthermore surveys and interviews are not done in a quick procedure why the use of indicators was found to be the most viable assessment method for the purpose.

Indicators and certification systems
The building certification systems that have implemented the use of SDIs were found to have the potential of providing a basis for collection of data. Most of them consider only energy consumption, why these were disregarded further investigation. Those having a holistic environmental perspective were found also addressing the social sphere. Four building certification systems that emerged during the literature research were in this way found to bring up indicators relating to social values. These were *BREEAM*, *LEED*, *DGNB* and *Miljöbyggnad*. An analysis to find the relevant indicators was performed.

Indicator and aspect definition
To distinguish the different levels of detail in the attempted social sustainability tool the words *indicator* and *aspect* are used. The word *indicator* is used for a directly measurable issue, for instance window area percentage of the façade. The word *aspect* is used to describe what the indicator affects, which in this case would be daylight and lighting comfort. The certification systems use indicators and these are brought into the assembled tool, defining the aspects and also functions as a guide to how the aspects are assessed.

The Tool and the Refurbishment Process

When used in practice this method of predicting the social sustainability would lie in an early stage of the process. In the refurbishment process, as explained in Byggvägledning[51] and illustrated in Figure 37 below, the meeting would take place in connection with the preliminary reckoning and design phase and/or inventory and information accumulation stage.

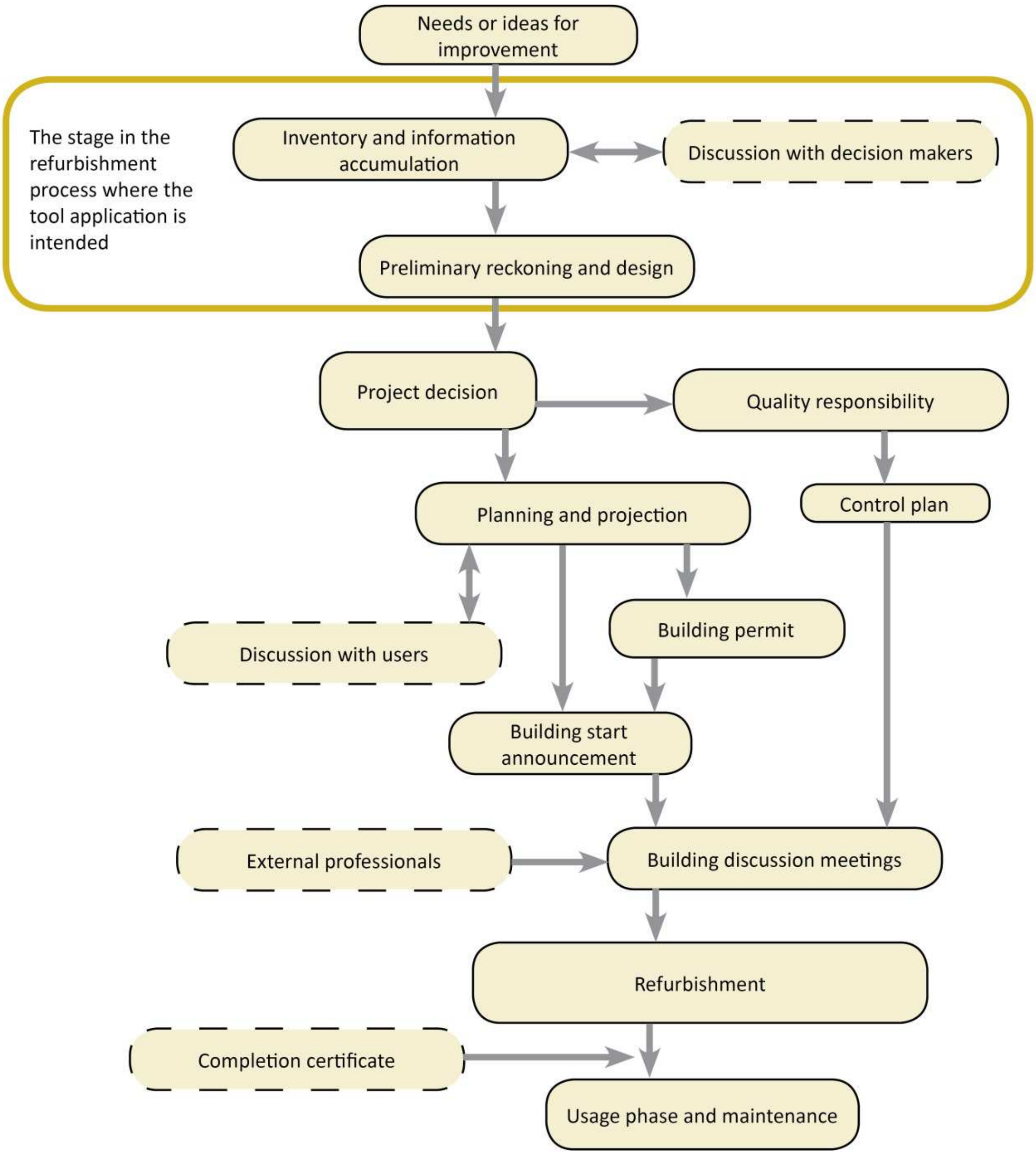

Figure 37: The process of refurbishing translated from Swedish[51]. The rounded yellow rectangle has been added to indicate where in the refurbishment process the tool is intended to be applied.

[51] Nordling, L. Reppen, L. (red.) (2000). Byggvägledning.

Indicator Identification and Selection

Each indicator in the certification systems *BREEAM*, *DGNB*, *LEED* and *Miljöbyggnad* was evaluated against the following three criteria to identify the indicators connected to social issues and the desired use. How the certain indicator was regarded can be read in

Appendix C - Social indicators detection:

- **Physical boundary**. Only aspects or indicators applicable for a single physical building are considered, e.g. not taking into account habitats or access to public transport, which are otherwise important for social sustainability. The physical boundary is the façade of the building. However, the aspect for light pollution is included because of the possibility of façade lighting.
- **Time boundary**. Aspects or indicators should only concern the already constructed building in its usage phase, i.e. aspects or indicators connected to the construction phase, management of the building after construction or disposal of the building are not considered.
- **Social aspects**. The aspects or indicators should inflict social life or the tenants directly, e.g. all indicators of energy consumption are disregarded since these are not important preconditions for social life, while indicators regarding for instance thermal comfort are considered relevant.

When evaluating the indicators according to these criteria, the indicators relevant to social sustainability and connected to process and a larger geographical context get lost. There are for instance a number of indicators in the certification systems regarding user participation in the processes and tenant surveys of different kinds. Although these are very relevant, they are excluded due to the thesis limitations. The implications of this are brought up in the discussion at the end of this chapter.

The following sections of this chapter represent the chronologic procedure of putting together the set of aspects, which creates the foundation of the tool. The first step in this procedure is getting to know the certification tools and identify what indicators connected to social values are used. After this comes structuring and categorization of the aspects and finally the assembling of the tool. The process is illustrated in Figure 38.

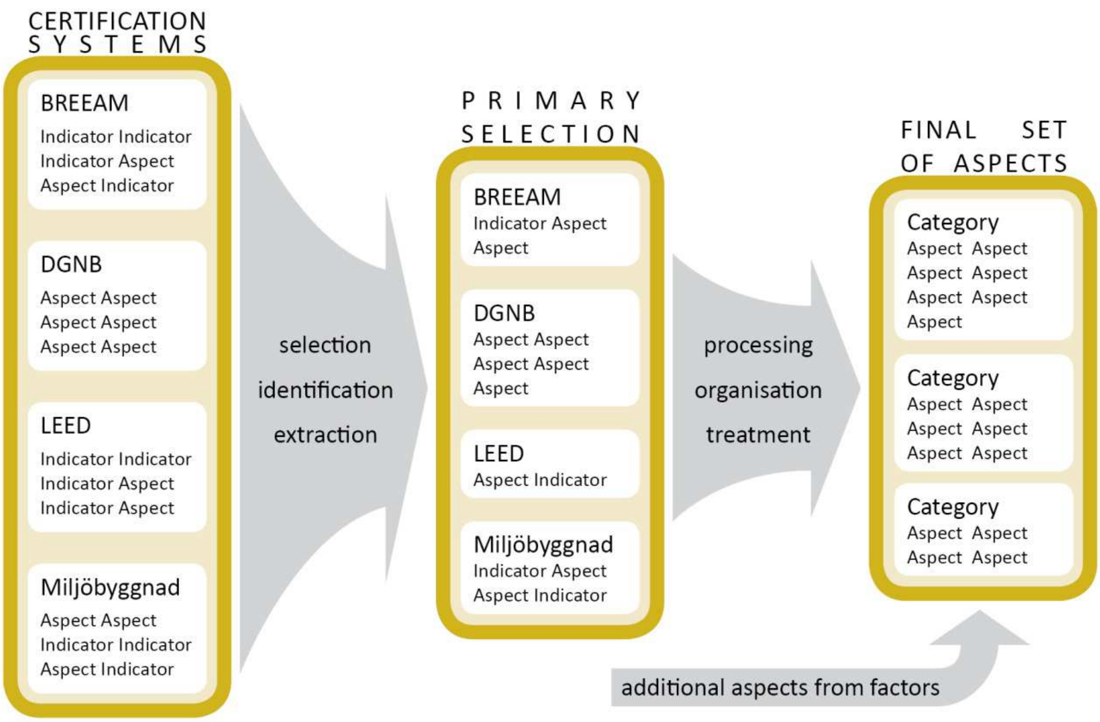

Figure 38: The process of assembling the set of aspects.

BREEAM

This certification system was developed in the UK. *BREEAM* stands for *Building Research Establishment Environmental Assessment Method*. There are several versions of *BREEAM* assessing different types of buildings and processes. The systems are designed to suit the standards of the UK but the *SGBC (Sweden Green Building Council)* has adapted *BREEAM* into *BREEAM-SE* to suit Swedish conditions. This tool is only designed to assess industrial, commercial or office buildings but was still chosen for aspect identification due to the adaption of Swedish standards[52]. *BREEAM* has also come up with a special type of certification tool called *BREEAM communities* for assessing sustainability on a community level. This edition is made mainly to assess neighborhoods and bigger projects[53]. Even though many of the indicators used in this system risk falling outside of the criteria put up for selection, this certification system was chosen for investigation. It was believed the different perspective of the certification system could provide additional indicators important for social sustainability. Yet another edition is called *BREEAM Domestic Refurbishment* and would have been relevant to include in the investigation[54]. This certification system, though, is still too new to be publicly available. The indicators and aspects selected from the two *BREEAM* systems are presented below.

The selected indicators and aspects from BREEAM-SE

- Moisture control
- Lighting comfort
- Daylight
- Occupant thermal comfort
- Acoustics
- Indoor air and water quality
- Avoidance of hazardous substances
- Pedestrian and Cyclist facilities
- External light and noise pollution

The selected indicators and aspects from BREEAM communities

- Housing provision
- Public realm
- Local vernacular
- Inclusive design
- Light pollution
- Cycling facilities

[52] Sweden green Building Council (2011) BREEAM® SE.
[53] BRE Group (2012) BREEAM Communities Manual 2012.
[54] BRE Group. The world's leading design and assessment method for sustainable building.

DGNB

This certification system is fairly new and was developed by the *German Sustainable Building Council* in 2009. It was designed and is used foremost in Germany but has already been applied in other parts of Europe and in Latin America, because of its adaptability. The certification system was created to shape a *"common quality standard based on EU legislation"*[55, 56].

The selected aspects from DGNB

- Flexibility and adaptability
- Thermal comfort
- Interior air quality
- Acoustic comfort
- Visual comfort
- User controllability
- Safety and accident risks
- Accessibility
- Biking comfort
- Ease of cleaning and maintenance

[55] Heincke, Catrin & Olsson, Daniel (2012). Simply green: a quick guide to environmental and energy certification systems for sustainable buildings.

[56] DGNB GmbH. *DGNB System*.

LEED

This certification system was developed by the *U.S. Green Building Council* (USGBC) and is the biggest existing building certification system today, although mostly used in the U.S. Within *LEED* there are several rating systems adapted to different types of buildings. The USGBC do not provide an adaption to standards of other countries but some countries have adapted local *LEED* themselves. It is possible to use *LEED* without adaptation but one will then have to use the standards of the U.S. Since *LEED* certification systems are widely acknowledged it was considered a valuable input for finding aspects. The systems suitable for the social sustainability assessment tool are *LEED for New Construction* and *Major Renovations* and *LEED for Existing Buildings: Operations & Maintenance*[55, 57, 58]. The selected aspects and indicators are presented below.

The selected indicators and aspects from LEED for New Construction and Major Renovations

- Bicycle Storage and changing Rooms
- Light Pollution
- Air quality performance
- Air delivery monitoring
- Ventilation capacity
- Low-emitting materials - adhesives and sealants
- Low-emitting materials- paints and coatings
- Low-emitting materials- flooring system
- Low-emitting materials- composite wood and agrifiber products
- Indoor chemical pollutant source control
- Controllability of systems - lighting
- Controllability of systems - thermal comfort
- Daylight and views - Daylight
- Daylight and views - Views

The selected indicators and aspects from LEED for Existing Buildings: Operations & Maintenance

- Light pollution
- Indoor air quality performance
- Air delivery monitoring
- Ventilation capacity
- Air quality
- Green cleaning
- Controllability of systems - lighting
- Daylight and views

[57] U.S. Green Building Council (2009) LEED 2009 for New Construction and Major Renovations
[58] U.S. Green Building Council (2012) LEED for Existing Buildings: Operations & Maintenance Recertification Guidance.

Miljöbyggnad

This certification system is a fairly new Swedish system which has been used so far only in Sweden. It can be applied to both new and existing buildings as well as many different types of buildings since it considers mainly measurable indicators. It is designed so that no external consultancy is required for assessment. Of this reason this system is not going as deep into the assessments as other systems and socially only considers aspects that connect to comfort and health[59].

The selected indicators and aspects from Miljöbyggnad

- Noise environment
- Radon gas
- Ventilation standard
- Moisture resistance
- Thermal climate in winter
- Thermal climate in summer
- Daylight
- Phasing out dangerous substances
- Removal of dangerous substances

[59] Sweden Green Building Council. (2011) Miljöbyggnad.

Processing the Aspects

In this part of bringing the set of aspects together the aspects were structured in terms of assigning every aspect to a respective category. Furthermore the aspects that came up more than once were joined into only one aspect. If an indicator in one certification system happened to be regarded as many indicators in a different certification system these have been regarded as one aspect. The resulting set of aspects can be seen in Table 9.

Table 9: The aspects considered to regard social issues from the previously mentioned certification systems, how they are grouped and from which systems the aspects origin.

Category	Social sustainability aspects	Origin
General	Flexibility and conversion	DGNB
	User controllability	LEED NCMR, LEED BOM, DGNB
	Shared spaces	BREEAM communities
	Accessibility	BREEAM communities, DGNB
	Housing provision	BREEAM communities
	Feeling of safety	DGNB
Comfort	Thermal comfort	BREEAM-SE, DGNB, LEED, Miljöbyggnad
	Indoor air quality	BREEAM-SE, DGNB, LEED, Miljöbyggnad
	Acoustic comfort	BREEAM-SE, DGNB, Miljöbyggnad
	Biking comfort	BREEAM, BREEAM-SE, DGNB, LEED
	Light pollution	BREEAM communities, BREEAM-SE
	Daylight and lighting	BREEAM-SE, LEED, Miljöbyggnad
	Local vernacular	BREEAM communities, DGNB
Health	Phasing out dangerous substances	BREEAM-SE, LEED, Miljöbyggnad
	Radon gas	Miljöbyggnad
	Moisture resistance	BREEAM-SE, Miljöbyggnad
	Ease of cleaning and maintenance	DGNB, LEED BOM

Motivations

The following passage describes every aspect separately, containing a motivation to why it is considered relevant to social sustainability and a short explanation. Each aspect has also been compared to the important factors of social sustainability brought up in chapter *0 Social sustainability in current research*. The factor and aspect correspondence investigation can be read in

Appendix D – Correlation between Factors and Aspects. Some aspects were found to be easier to motivate. The aspects in the categories of *Health* and *Comfort* are not specifically mentioned, but the categories are on the other hand expressed to be involved in important factors.

Accessibility
This aspect relates to social inclusion of current and future tenants and visitors which was found to be an important factor of social sustainability. Accessibility refers to the buildings ability to provide access for different types of disabilities and could involve the existence of thresholds, elevator and ramps when needed, as well as sufficient dimensions of entrances and hallways.

According to Swedish regulations, new construction must fulfil a certain level of accessibility, depending on the type of building. Older buildings, though, have not all been adapted to these regulations. It is stated that when a major refurbishment is performed it is demanded that the building users of need are provided with proper accessibility adjustments, and it is advised to make adjustments as far as possible. Sometimes contradicting these regulations are the requirement of refurbishing with caution to not change the expression of the building. This requirement varies depending on what is stated in the corresponding local plan[60].

Feeling of safety
This aspect found a direct correspondence within the important factors of social sustainability. The origin of the aspect mainly regards the surrounding area of the building but the physical building also enables evaluation of the aspect. A feeling of safety refers to both exposure to crime and risk of accident which on a building level for instance could concern lighting conditions and how overlookable hallways and entrances are.

Flexibility and conversion
This aspect found a direct correspondence to a factor. The aspect refers to the ability of the building to adapt to shifting demands, such as family sizes. The adaptability of the living space is considered to enable tenants to fulfill their needs easier, allowing for tenants to stay longer and not disrupting social structures.

Housing provision
This aspect found a direct correspondence to several factors. It regards affordability of housing, mixed housing and function types as well as housing suiting different income groups. Other implications on a building level could be assuring sufficient housing space and that tenants displaced by development get affordable housing on the new site.

Local vernacular
This aspect relates to the preservation and continuity of architectural expression and local characteristics. It is often defined through local materials or building shapes. The values that are often referred to are keeping in line with the local building tradition, being able to feel identification with spatial surroundings. When regarding the building it is considered beneficial to identify key elements and introduce them in the development.

Shared spaces
This aspect regards the preconditions for social interaction and is influenced by matters like open attractive spaces not claimed by any single individual or apartment. A building implication could be spaces that allow for hosting events, doing physical exercise or creative activities.

The comfort category
A certain level of comfort in the building is a prerequisite for people to want to reside in it. The aspects in this category concerns for instance: the ease of cleaning and maintaining the building, which implies less disturbing of the tenants and healthier living conditions; and the ability to control the indoor climate and lighting provides a higher level of comfort.

[60] Örnhall, Hans (2008). Bostadsbestämmelser 2009.

The health category
Feeling healthy is one of the fundamental prerequisites of quality of life and wellbeing. The aspects in this category bring up the most common occurring problems a building can experience in terms of inflicting health conditions, which are presence of mold, radon and volatile substances.

Additional Aspects

The investigation in

Appendix D – Correlation between Factors and Aspects that was used to in *0 Motivations* was also used to see if there were important aspects missing in the set of aspects. It was found that a range of factors did not have a direct correspondence to the set of aspects. This is mainly due to three reasons:

1. The first reason is that the criteria for selecting the aspects have limited the aspects and thereby removed some that are relevant in other applications.
2. The second reason is that the factors are stated in a global scale, seeking to address the global factors of social sustainability, whereas the aspects are on a building scale. There is a need to transform the scale to be able to understand the implications of the factors for the single building.
3. The third reason is that the aspects do not cover the field of social sustainability sufficiently, failing to address more intangible values.

In Table 10 the factors lacking correspondence within the aspects are collated and investigated further.

Table 10: Factors not corresponding to aspects criteria evaluation.

Accessibility Convenience, efficiency & safety for drivers Convenience, efficiency & safety for pedestrian & public transport users Accessibility to schools, health and other services Proximity to business activities Access to work Provision of public facilities Access to open space Local environmental quality and amenity Urbanity Townscape design Layout of building and streets Establishment of different business activities Efficient use of land & space Sustainable urban design Great variety of green and quality housing Neighborhood Compatibility with neighborhood	These factors are limited by the *physical boundary* criterion.
Rehabilitation of repairable building structures Management of buildings, facilities & spaces Availability of local employment Employment Education and training Community involvement in public decision making Active community organizations Social order Social networks Social capital	These factors are limited by the *time boundary* criterion.

Fair distribution of income Social justice: inter- and intra-generational Residential stability (vs turnover)	These factors are limited by both the *time boundary* and the *physical boundary* criteria.
Sense of belonging, pride and identity Sense of community and belonging Identity, sense of place and culture Building design in terms of appearance, density, height & mass Energy efficiency and waste management	Not restricted by any criteria

In Table 10 it is possible to see that the factors in the lowermost row have not been represented by any aspect and fulfil all the limiting criteria. This group of factors was then considered to be a valuable input to the tool. The first three are very similar and it was considered appropriate to regard them as one aspect with the unitized name: *Sense of belonging*. On a building level scale this aspect would imply that living in the building should spur feelings of identity, pride and a sense of belonging. This could be in terms of a recognizable building shape or building performance giving the building character and recognition in the neighborhood or city. This aspect is similar to *Local vernacular* but the difference is that *Local vernacular* can also mean striving for a more homogenous and/or traditional building character. The last two factors, *Building design in terms of appearance, density, height & mass* and *Energy efficiency and waste management,* can find correspondence to this additional aspect or the category *Comfort.*

The final set of aspects evaluating social sustainability is presented in Table 11.

Table 11: Final set of aspects

Category	Aspect
General	Accessibility
	Feeling of safety
	Flexibility and conversion
	Housing provision
	Local vernacular
	Shared spaces
Comfort	Acoustic comfort
	Biking comfort
	Ease of cleaning and maintenance
	Daylight and lighting comfort
	Indoor air quality
	Light pollution
	User controlability
	Thermal comfort
Health	Phasing out dangerous substances
	Moisture resistance
	Radon gas
Additional	Sense of belonging

Identification of the Experts

The process of assembling the final tool and defining the method for evaluation is presented in the following passage. Figure 39 below clarifies the procedure.

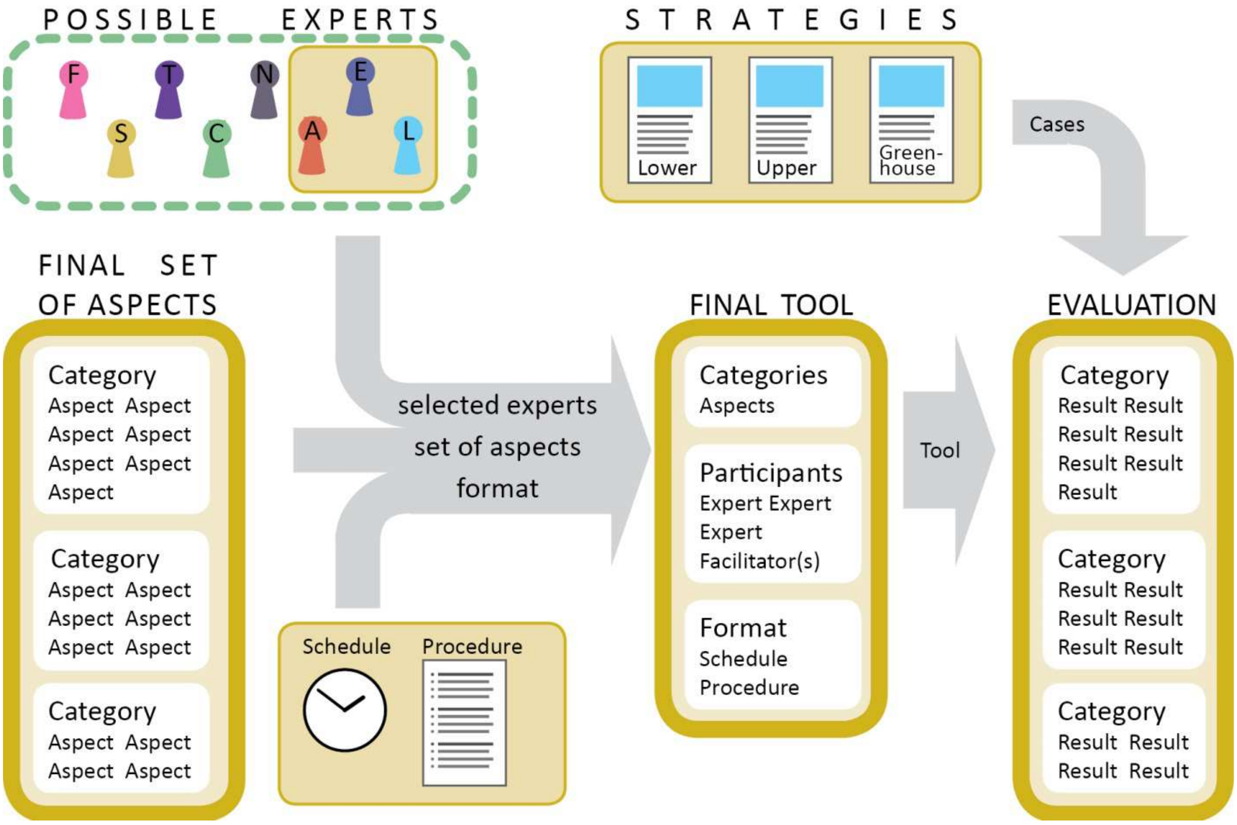

Figure 39: The process of assembling the final tool and finding method for evaluation.

The aspects need to be evaluated by knowledgeable and experienced professionals, here called experts, since the evaluation is not an inherently quantitative process. An investigation of possible experts was conducted to estimate which of them would be suited for this type of evaluation, and to give input on whom to invite to the actual evaluation meeting, which is presented in coming chapters.

The fields of expertise involved in the design of the refurbishment of Brogården were distinguished: building architects, architects working with renewal plan and program, landscape architects, construction and energy engineer, HVAC engineer, electricity engineer, fire engineer[8].

The architects working with renewal plan and program, and landscape architects are delimitated by the aspects, and matters of fire regulations are delimitated by the initial thesis limitations, whereby these roles were disregarded. Involving too specific roles might risk shifting the evaluation out of the tool focus. Of this reason the different engineering expertise were merged into one engineering role. Those affected by the building alteration were also considered as experts on the specific object and are stated in the left column and the external experts in the right column in Table 12.

Table 12: The experts of the building alteration process presented.

Affected experts	External experts
Tenants	Architect
Building caretaker	Engineer
Landlord	
Adjacent houses and neighbors	

The roles were matched towards the aspects which they were considered mastering. In this way the experts were assigned a range of aspects on which they were thought to provide knowledge, see Table 13.

Table 13: The aspects and which experts might have a greater influence for them presented.

Aspect	Expected expert familiarity
Accessibility	Architect
Feeling of safety	Tenant, landlord
Flexibility and conversion	Engineer, architect
Housing provision	Tenant, landlord, architect
Local vernacular	Tenant, architect, adjacent houses and neighbors
Shared spaces	Architect, landlord, tenant
Acoustic comfort	Architect, engineer
Biking comfort	Landlord, architect, tenant
Ease of cleaning and maintenance	Landlord, building caretaker
Daylight and lighting	Architect, engineer
Indoor air quality	Engineer
Light pollution	Tenant, architect, adjacent houses and neighbors
Thermal comfort	Engineer
User controllability	Landlord, tenant, engineer
Phasing out dangerous substances	Architect, engineer, building caretaker
Moisture resistance	Engineer
Radon gas	Landlord, building caretaker, engineer
Sense of belonging	Architect, tenant, adjacent houses and neighbors

The number of times the different experts appeared along with how many times they appeared alone on an aspect was counted, see Table 14.

Table 14: The number of times the experts appear for different aspects.

Expert	Times appearing	Times alone
Architect:	11	1
Engineer	9	3
Landlord:	7	0
Tenant:	8	0
Building caretaker:	3	0
Adjacent houses and neighbors:	3	0

As Table 14 displays, the architect and the engineer roles appear alone on aspects and should be represented in the expert group. Only two aspects were not influenced by the architect or the engineer, and the only expert that was represented on those two was the landlord. These three roles should be represented on the social sustainability evaluation meeting as a minimum for this format to be fulfilled. It was considered beneficial to have an uneven number of experts since that enables simple majority decisions.

If wanting to involve more meeting participants, a tenant representative is the most valuable role to involve for the assessment, as this role appeared eight times. After this, going into more detailed engineering expertise, such as an engineer within the fields necessary for the specific building would be most valuable. The building caretaker came up three times but is considered to share the landlord's point of view in most occasions. The adjacent houses and neighbors also came up three times and were regarded as less important for the assessment as they are indirectly affected by the building alterations.

When the actual experts are to be invited, it makes sense to consider the specific conditions of the case at hand and ensure that the desired area of expertise is covered by the experts. For a renovation of a housing building, it is valuable if the Engineer is also experienced in matters of building physics, material emissions and comfort. In the same way, it would be valuable to employ an Architect whose portfolio contains similar project to the one under observation.

Outcome of the analysis

The outcome of the expert identification suggested that an engineer; an architect; and someone representing the ownership perspective, i.e. landlord, should be present on the evaluation meeting. The experts that participated in the conducted evaluation meeting are presented in chapter *0 Conducted Evaluation Meeting*.

Social Sustainability Assessment Tool

This tool is a defined method and format of conducting an assessment. The set of aspects could also be interpreted as a checklist without the assessment but conducting the evaluation should also provide comparable input for decision making. The result of the assessment should be more or less replicable if the conditions are the same, all the while depending on the background and current state of the participants. This is mitigated by having at least three experts on the meeting. A hand out of the tool can be read in *Appendix E – Social Sustainability Assessment Tool*.

Grading

When it comes to defining how the aspects would be graded, a few important frames for the grading system were distinguished, and are stated below.

The tool is intended to be applied for assessment of refurbishment alternatives in an early stage of the decision making process, implying that there is not necessarily extensive information about the refurbishment alternatives available. It was thought to be relevant to give this uncertainty room in the grading system since it was considered difficult to make a detailed assessment in an early stage. This promoted a simple grading system with few grade steps.

In the balance of the tool, i.e. holistic within the stated boundaries, many aspects are involved and all aspects are not necessarily affected by every refurbishment alternative, which needs to be represented in the grading system.

As the tool assesses refurbishment it needs to account for both a positive and negative change in the ruling, i.e. if the refurbishment alternative implies an improvement or a worsening of the specific aspect. It is not possible to use this relative type of tool for evaluation in new construction projects.

Based on that reasoning, the aspects in the new grading system are evaluated by giving them a value of -1, 0 or +1. If the retrofit is estimated to have a positive consequence for the aspect it is given a +1. If it is expected to make the situation worse or not good enough it is given a value of -1. If the retrofit does not imply any change for the aspect, or if it is difficult to assess a total outcome of the retrofit, the aspect is given a 0 to show that it has not been accounted for. The original building has the function as the lower reference from which all renovations are compared to, and receives the value 0 for all aspects. It is up to the meeting participants to decide the boundaries between the grades of the evaluation, i.e. decide what is an improvement or deterioration from the lower reference for each aspect and how big a change is needed to not get a 0. Most important is that the refurbishment alternatives are evaluated while using the same frames. If the meeting participants disagree for a certain decision, majority of vote is implemented.

Initially, the aspects are said to be equally important. In a later step, they can receive a weighting as is investigated in chapter *0 Aspect Weighting*.

Meeting Format

The purpose of a strict meeting format is to gain the ability of ensuring consistency, replicability and accuracy in the results.

Preparation
The experts invited should be able to fill the roles identified in chapter *0 Identification of the Experts*, and have relevant expertise for the understanding of the different refurbishment alternatives at hand. The meeting participants should be given information about the goal of the meeting and the existing building beforehand. This should contain a short description and classification of the building. The current state, important issues and describing images are distributed at least one week in advance. This is to create a common understanding of the existing building.

During the meeting the facilitators are to present the different refurbishment alternatives in a neutral way. This means that the refurbishment alternatives need to have been processed so that they give the same type of information on the same level of detail and that they are visualized in a way not promoting an alternative.

Execution
All the experts in the meeting are considered equally important, where all have the possibility to express opinion in a round table discussion and have a vote, which is also equally weighed. One of the meeting facilitators' tasks is to make sure this is realized. The facilitators lead the discussion, keeping them on track and within the time limits, and fills out the meeting evaluation template, see Table 15.

The evaluation has the same limitation as the selection of aspects in chapter *0 Indicator Identification and Selection*, i.e. the evaluation only concerns matters regarding the physical building and no process related issues. Keeping the discussion within the limitation is also part of the meeting facilitators' tasks. In the hand out of the tool in *Appendix E* – Social Sustainability Assessment Tool, there is a guiding section containing questions and statements to help the discussion within each aspect.

Table 15: The tool evaluation template

Category	Aspect	Result: -1, 0, +1	Proposed action of improvement
General	Accessibility Feeling of safety Flexibility and conversion		
	Housing provision Local vernacular Shared spaces		
Comfort	Acoustic comfort Biking comfort Ease of cleaning and maintenance		
	Daylight and lighting comfort Indoor air quality Light pollution		
	User controlability Thermal comfort		
Health	Phasing out dangerous substances Moisture resistance Radon gas		
Additional	Sense of belonging		

Meeting schedule
The meeting is proposed to start with an introduction of the participants if they do not already know each other followed by a presentation of the meeting procedure, the goal of the tool, how the evaluation is performed, the existing building and the refurbishment alternatives, respectively. Each of these exercises should not exceed 10 minutes to keep the focus on the actual evaluation. The evaluation itself should be given one to two hours depending on how many alternatives there are to be considered. The exercise is executed by going through the aspects one at a time and give a ruling for all the refurbishment alternatives for each aspect. A few minutes should be dedicated to discuss the interpretation of the aspect to make sure all participants share the same understanding of the aspect and how to evaluate it. After this, follows a few minutes of discussion to create a stance before voting for how to grade the specific refurbishment alternative. A rough schedule is presented in Table 16.

Table 16: A rough schedule of how the evaluation meeting could be executed.

Time [minutes]	Activity
10	Welcoming and presentation of participants
10	Presentation of the tool
5	Presentation of the existing building
10-20	Presentation of refurbishment alternatives
60-120	Discussion and evaluation of each aspect and alternative
10-15	Feedback and discussion of the meeting outcome

Conducted Evaluation Meeting

The conducted meeting followed the format previously mentioned in chapter *0 Social Sustainability Assessment Tool* and evaluated social sustainability of the two refurbishment alternatives, greenhouse suggestion and upper reference towards the lower reference, presented in chapter *2 ANALYZED CASES*. The meeting participants were provided with the material in *Appendix F – Meeting Preparation Material* one week in advance. The participants were: an architect working with refurbishment of buildings, Kia Bengtson from MA Arkitekter; an engineer, Cecilia Wretlind from White Arkitekter; and Jenny Bengtsson working as communicator for Alingsåshem which is the owner of Brogården. The meeting took about 140 minutes and used the material in *Appendix G – Meeting Execution Material*. The evaluation can be read in Table 17.

Table 17: The result from the social sustainability evaluation meeting.

	Aspect	Upper reference	Greenhouse suggestion
General	Accessibility	1	0
	Feeling of safety	1	0
	Flexibility and conversion	0	0
	Housing provision	0	0
	Local vernacular and aestethic	1	1
	Shared spaces	0	1
Comfort	Acoustic comfort	1	-1
	Biking comfort	0	0
	Ease of cleaning and maintenance	1	-1
	Daylight and lighting comfort	0	-1
	Indoor air quality	1	-1
	Light pollution	0	0
	Thermal comfort	1	0
	User controlability	0	-1
Health	Phasing out dangerous substances	1	0
	Moisture resistance	1	-1
	Radon gas	1	0
Additional aspect	Sense of belonging	1	1

The outcome of the meeting showed that the greenhouse suggestion is questionable in terms of social sustainability, and the upper reference is easier to motivate from a social sustainability point of view, see Table 17. The upper reference does not get any negative results while the greenhouse suggestion receives a negative result for various aspects. How the different aspects were perceived and discussed during the evaluation meeting can be read in chapter *0 Arisen discussions during the evaluation meeting*.

Aspect Weighting

The final passage of this chapter is an analysis and a discussion of a possible weighting of the aspects, see Figure 40. The intention is, however, not to provide a definite weighting of the aspects.

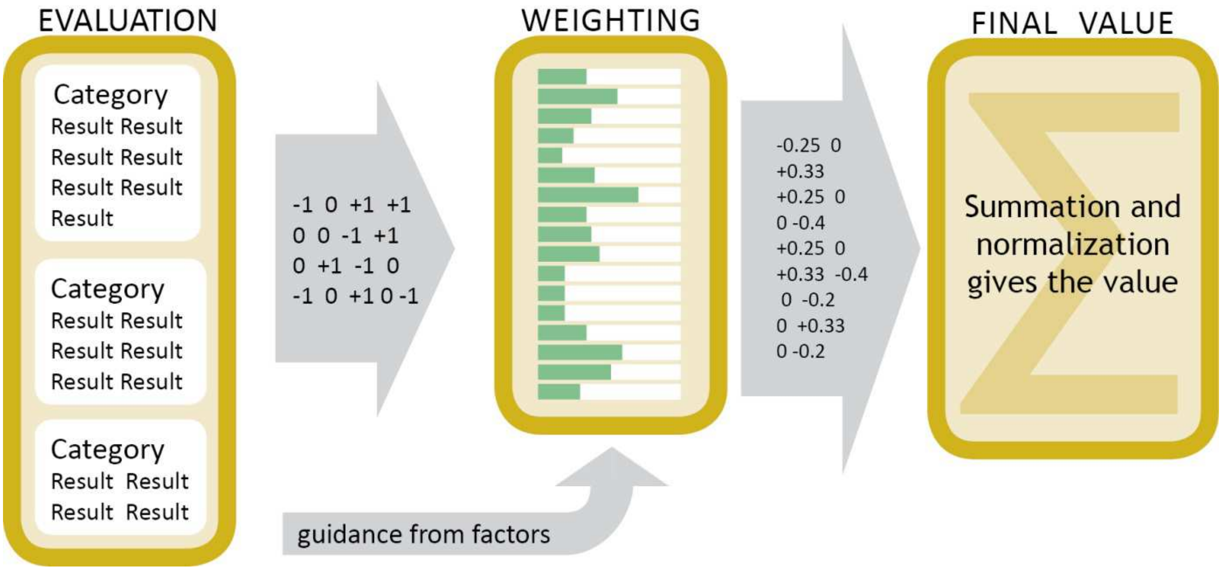

Figure 40: The process of the last phase of designing the tool.

As already mentioned it is important to consider the weighting of the aspects since they do not inflict social sustainability identically. In the different certification systems the issues of assessment are weighted and when extracting aspects into a new system the weighting is taken out of its balance. By weighting an aspect more than another is saying that this aspect is more important than the other.

In the assessed certification systems, the indicators are given values in different weighting systems. In *BREEAM Communities,* for instance, the indicators are divided into five categories that are weighted by the impact of that category. The individual indicators or issues of assessment are also weighted within their category based on a priority of importance of its impact of the overall aim of the category[53]. The other certification systems are weighting their indicators in similar ways. When bringing all the relevant indicators from the different certification systems into a new system, this interfered with the different weighting systems, and a new grading and weighting system was required.

The weighting investigation was conducted to show how different types of weighting systems affect the outcome. Eight different weighting alternatives were investigated. Four of those that were found more viable are presented in Figure 41 and they are explained more in detail below.

***Mean value* weighting system**
The mean value uses the mean value of the summarized values from the certification systems. The number of times the aspect is appearing was in this way taken into account. The additional aspect that are not brought up by the certification systems was here given a value interpolated between the two highest occurring input values.

***Same value* weighting system**
The same value weighting alternative gives all aspects the same importance.

***General category aspects are given the same impact as total other aspects* weighting system**
In the weighting alternative where the general and additional aspects are given the same impact as total other aspects the general aspects are given a greater importance. This weighting system was included in the investigation since the general and additional aspects are more directly linked to social values as described in chapter *0 Social sustainability in current research.*

***Health and comfort categories are considered as one aspect each* weighting system**
The last alternative amplifies the previous weighting alternative giving the general and the additional aspects a significantly higher importance by counting the entire categories of health and comfort as one aspect each. When investigating which factors find a correspondence in the set of aspects in

Appendix D – Correlation between Factors and Aspects, it was also noted that the aspects in the categories *Health* and *Comfort* are not directly addressed by the factors, but the categories themselves find a correspondence. The aspects of comfort and health are then considered to be counted as only one aspect each. Another reason to include this weighting alternative in the investigation was that social sustainability, as found in the literature study in chapter *0 Social sustainability in current research*, rely more on issues related to the aspects in the categories *General* and *Additional aspects* than on the aspects in the categories *Comfort* and *Health*. As was discussed in the meeting evaluation, these are rather prerequisites for social sustainability than an actual measurement of social sustainability.

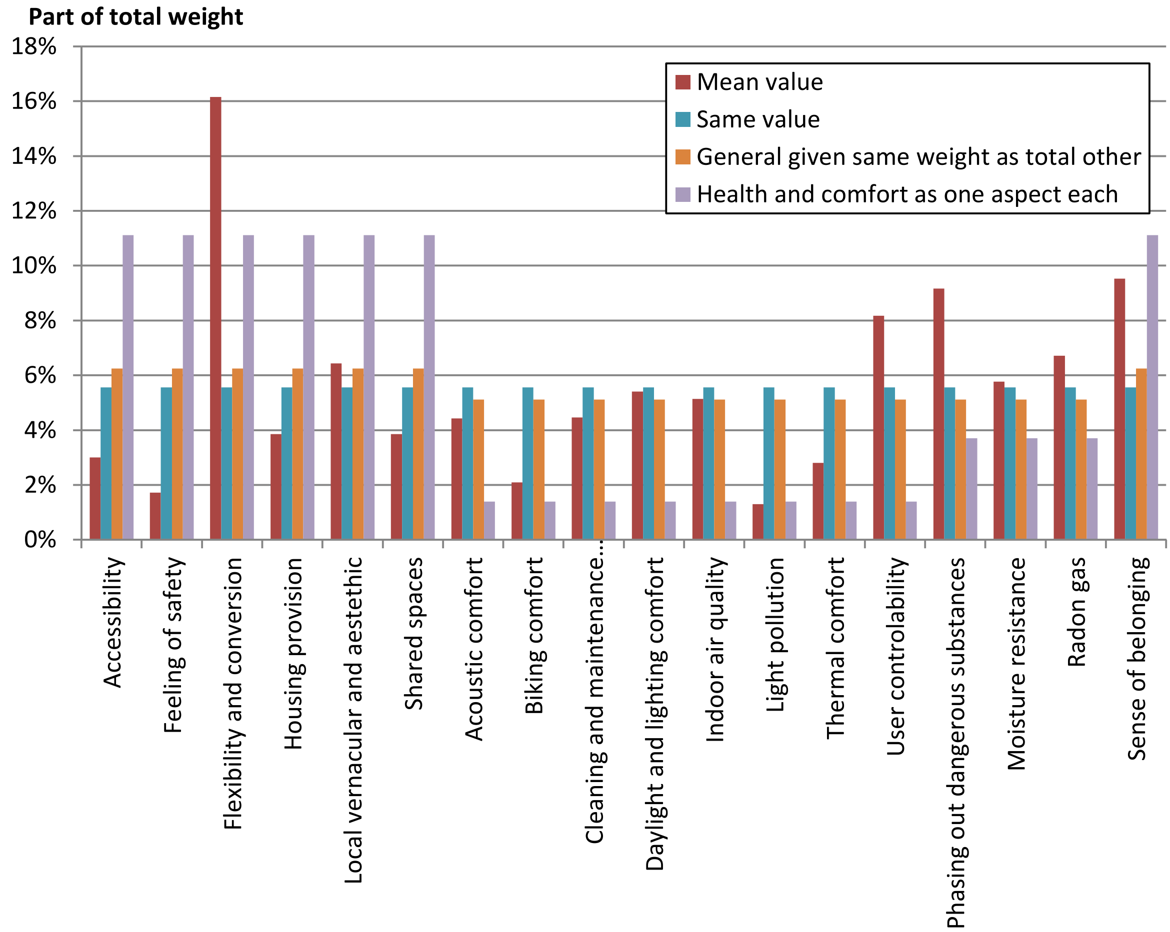

Figure 41: The four weighting alternatives brought into further investigation.

When observing the graph in Figure 41 it becomes clear that the *mean value* weighting system is out of proportion. An occurring problem with this system is that the certification systems are not regarding the same aspects and the weighting becomes distorted when putting aspects with their corresponding weighting from different systems together. For instance the *Flexibility and conversion* aspect is only regarded by *DGNB* but the certification system gives this aspect a very high level of importance providing a high value for the weighting as well.

An additional problem for the *mean value* weighting system is that the certification systems are not designed to account for only social sustainability why the weighting of the aspects can appear strange. For instance the aspect *feeling of safety from crime and accidents* could be thought of as highly important for social sustainability, but this aspect is only brought up by one certification system and given a fairly low weighting and is thus not properly accounted for.

When observing the *same value* weighting system it becomes clear that this system provides an unfair image. The aspects do have a varying degree of influence on social sustainability and some kind of weighting is necessary to show a difference in importance of aspects. For instance, the effect on social sustainability by the aspect light pollution is assumed to be significantly less than the effect of the aspect sense of belonging.

The weighting system *general category aspects are given the same impact as total other aspects* makes the general and additional aspects more important as was suggested in the literature study in chapter *0 Social sustainability in current research*. However, since the *general* and the *additional* aspects are seven in number and the aspects in the categories *health* and *comfort* are 11 in number the difference in weighting from the *same value* weighting system is not significant. It was regarded that the difference ought to be larger than this.

When observing the weighting system *health and comfort categories are considered as one aspect each* the difference in weighting is significantly larger between the categories. Especially the aspects in the category *comfort* are weighted low since this category contains the most aspects. The individual aspects in the category *health* are given a higher importance than the individual aspects in the *comfort* category, also due to the difference in number of aspects in respective category. The aspects in the category *general* are thus weighted as more important.

When going into details observing the individual aspects' relations in the weighting system *health and comfort categories are considered as one aspect each* it becomes clear that this weighting system does not provide a completely fair weighting. The aspects within the same category need individual weighting to show their relative importance.

Although all weighting systems seemed to fail to provide a satisfying weighting of the aspects, one needed to be chosen to be able to provide the single numerical value from the social sustainability analysis. The system that found most support in literature and indirect support from the evaluation meeting was the weighting system of *health and comfort categories are considered as one aspect each*, why this weighting system was chosen.

Weighting Results

When inserting the results from the social sustainability assessment meeting into the weighting system it is possible to see the expected difference regarding social sustainability between the two retrofitting alternatives, see Figure 42 and Table 18.

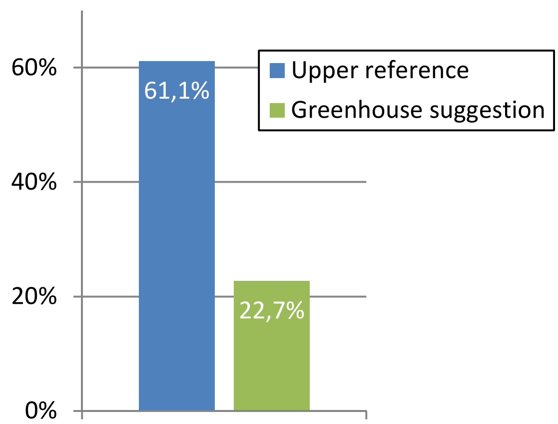

Figure 42: The total social sustainability value for the two alternatives in the weighting system *health and comfort categories are considered as one aspect each*.

Table 18 presents each aspect again with the specific weightings for the two refurbishment alternatives. The summarized percentages at the bottom of the table are brought into chapter *7 COLLECTED RESULTS.*

Table 18: The weighted outcome of the evaluation using the weighting system *health and comfort considered as one aspect each*.

Aspect	Upper reference	Greenhouse suggestion
Accessibility	11,1%	0,0%
Feeling of safety	11,1%	0,0%
Flexibility and conversion	0,0%	0,0%
Housing provision	0,0%	0,0%
Local vernacular and aestethic	11,1%	11,1%
Shared spaces	0,0%	11,1%
Acoustic comfort	1,4%	-1,4%
Biking comfort	0,0%	0,0%
Ease of cleaning and maintenance	1,4%	-1,4%
Daylight and lighting comfort	0,0%	-1,4%
Indoor air quality	1,4%	-1,4%
Light pollution	0,0%	0,0%
Thermal comfort	1,4%	0,0%
User controlability	0,0%	-1,4%
Phasing out dangerous substances	3,7%	0,0%
Moisture resistance	3,7%	-3,7%
Radon gas	3,7%	0,0%
Sense of belonging	11,1%	11,1%
Sum	61,1%	22,7%

The greenhouse suggestion received a significantly lower result than the upper reference. The meeting made one of the main reasons for the low result of the greenhouse suggestion clear: since the greenhouse suggestion was not in place when the tenants first moved in, they are not prepared for the kind of living that this sort of shared space implies. The participants at the meeting suggested that an alteration of this kind might spur conflict and friction between tenants.

The other main reason for the results was the difference in magnitude of the two building alterations. Since the upper reference is an extensive refurbishment strategy, it could affect more aspects than the greenhouse suggestion.

The greenhouse suggestion has weaknesses connected to the categories *health* and c*omfort*, but on the contrary shows potential among the aspects connected to social interaction. The weighting system that has been chosen is favoring the aspects where the greenhouse suggestion performs well, which could be target for criticism. The weighting system chosen was, as previously reasoned, the system that found most support in literature and indirectly from the evaluation meeting. However, in the case of having a weighting system where each aspect is quantified and assessed for an individual weighting, the greenhouse suggestion risks getting a negative result in this evaluation.

Evaluation of the Assessment Tool

Since the tool was created specifically for this master thesis it was considered valuable to conduct a more thorough reflection of this method than the methods used for assessing the other spheres. This motivated emphasizing the evaluation by presenting it in a separate chapter.

Arisen discussions during the evaluation meeting

In many cases the tenant perspective in the greenhouse suggestion provided reason for discussion and uncertainties. The greenhouse suggestion might get different results depending on how the tenants perceive the greenhouse. The greenhouse suggestion brings a significant change, and if the tenants are not included in the decision process, for example, the aspect *feeling of safety* was believed to receive a negative result.

The tenant perspective is also relevant for the aspect *housing provision* where it is important that the building provides what the tenants pay for. The question comes down to what the tenants are willing to pay for when it comes to renovation. If the building instead would be a new construction both alternatives would receive a positive result because of the possibility to choose where to live.

In the aspect *local vernacular* the discussion touched whether the renovation alternatives enhanced or reduced the value of the aspect and it was found that it depends on how to look on the building. In the upper reference effort has been put to maintain the expression of the building but the building parts have been totally exchanged. The greenhouse suggestion keeps the existing walls, which was considered positive despite the façade addition changing the building expression.

In the aspect *shared spaces* both alternatives were considered positive and the greenhouse was considered very positive. The group wanted to contextualize this by giving the alternatives different results.

In the aspect *acoustic comfort* the greenhouse was considered negative because of the risk of sound spreading in the greenhouse volume.

For the aspect of *daylight and lighting* comfort the greenhouse suggestion was believed partly blocking incoming daylight and potential vegetation on ground floor hinders daylight on bottom floor apartments.

When evaluating the aspect of *indoor air quality* the greenhouse suggestion was believed risking spreading air of lower quality and smell from tenants to neighbors. The upper reference was believed to become better in terms of air quality due to the installation of FTX-system.

In the aspect *thermal comfort* the upper reference was believed to become significantly better. In the greenhouse suggestion the greenhouse was believed to improve heat barriers over the adjacent wall but instead causing an unbalance in the interior climate decreasing the thermal comfort.

In the *user controllability* aspect it was believed the upper reference is unaffected even though the FTX-system brings a higher level of controllability. This was due to the ventilation being the same as earlier. For the greenhouse suggestion this aspect was considered becoming worse due to decreased possibility of opening windows.

In the aspect of *phasing out dangerous substances* it was argued that in upper reference all substances contained in the building are known of and taken care of due to the extensive renovation procedure, while in the greenhouse suggestion there might still be a lot of dangerous substances contained in the old building. Same goes for the aspect *radon gas*.

In the *moisture resistance* aspect the greenhouse suggestion was considered a big risk and given a negative value.

Internal Evaluation of the Tool

As a preliminary analysis the method was tested by the authors of the thesis and evaluated. A number of issues were discussed and are stated below.

Evaluation of the tool
The issue of having only +1, -1 and 0 as grading was found problematic since different alternatives can have various degree of influence for an aspect. Having a wider range of grading would solve this problem but would, in this evaluation, face an increasing difficulty of maintaining a consistent evaluation. It could, however, be argued that this type of qualitative analysis could handle a wider grading system.

Even though the tool is limited to only assess the physical building, the area sometimes plays a part in the evaluation, for instance in the aspect *local vernacular*. It would, due to this reason, be beneficial to also involve the building surroundings in the evaluation.

Evaluation of the analyzed cases as alternatives for the assessment
The performed study only investigates two refurbishment alternatives and it would be interesting to perform a study involving several alternatives. The two investigated alternatives are also of very different character and the question was posed if the differences between them are too big, disallowing a proper evaluation. The tool should, however, not make any difference to what alternatives are regarded since the refurbishment alternative is always compared to the existing building.

The amount of input for the different refurbishment alternatives was often too scarce to make a proper judgment. It was also found that there could be room for improvement of the input for the respective alternative.

The potential of the tool
At the moment the tool lacks marketing power to implement it in the building sector. The reason to this is that it still is in a state where it requires some effort to make it complete. It is essential that the work is continued to make the tool viable for application of building companies and other relevant instances.

Social sustainability assessment is requested by many companies and organizations currently and for instance a research group called SIRen (Sustainable Integrated Renovation) has conducted similar investigations[7].

External Evaluation of the Tool

The feedback from the meeting brought up several issues. Some were positive and others identified challenges or problems. Similar to the *internal tool evaluation* in previous passage, the meeting experts experienced that there was often too little input to make a proper decision. It was also stated that the tool rather assess social sustainability preconditions than the actual social sustainability. The systematic procedure was appreciated.

Evaluation of the tool
The set of aspects used in the tool was perceived to have a holistic grasp of the social dimension. However, it was discovered that the tool and some aspects could be interpreted in different ways which is important to prevent by clearer definitions. It is crucial that the meeting participants have a common understanding of the evaluated aspect.

The aspect *flexibility and conversion* was target for criticism. One of the meeting participants argued that flexibility in the apartment is not inducing social sustainability. When living in an apartment and finding the plan suddenly no longer suitable, one would rather move out than to break up walls. The apartment should rather be general, well planned and have similar room dimensions to allow for change of function.

Similar to the previous *Internal Evaluation of the Tool*, a perceived problem with the grading system was the limited amount of grading options. If one alternative is estimated to inflict an aspect far more than any other alternative it could be important to show this in some way.

It was perceived as a weakness to only look at a single building. The context was found important and questions regarding the surroundings of the observed building rose several times. For instance culture and workplaces near the living space was regarded as important issues for social sustainability. At the same time, evaluating a building in this way could bring an overestimation of the importance of the physical building for social sustainability.

The potential of the tool
The meeting participants accentuated that this tool does not measure social sustainability as it occurs to them. It rather measures the prerequisites for socially sustainable development to take place. It was, however, believed that there could be a range of uses for the tool, such as:

- Providing a documentation of the decision process to fall back on further on in a projection. In the building process it is valuable to be able to see why certain decisions were taken.
- Creating a common goal for involved parties and bring the various disciplines together.
- Merging polarized refurbishment alternatives. For this reason the tool could be used to try the most distinct alternatives and see how and what they could benefit from each other.
- A checklist to find where to improve or what is missing in the building for internal control. Checklists are frequently used by companies today, as was stated by one of the experts.
- A base of discussion to ease the communication and process between architect and customer.
- Collating the actual problems with the building.

To make the internal and external evaluations more readable the outcome is summarized and put into a SWOT analysis in Table 19.

Table 19: The table presents a SWOT-analysis of the social sustainability assessment tool.

Strengths	Weaknesses
Holistic approach	Too little input
Systematic procedure	Interpretation differences in aspects
Creates common goal	Grading system not informative
Brings disciplines together	Only looking on a single building
Documentation of decision process	*Flexibility and conversion* aspect is misdirected
Measuring the prerequisites	Tool does not measure social sustainability but rather the prerequisites
	Overestimation of the importance of the physical building

Opportunities	Threats
Use as an internal checklist	The tool lacks marketing (*)
Merging polarized alternatives	SIRen is performing similar investigation (*)
Use in process between architect and customer	How is the work going to be continued for a future development and by whom? (*)
Collating occurring problems	
Social sustainability assessment is requested by many instances currently (*)	

*(*internal identification)*

Discussion

The social sustainability assessment tool was limited to cover only the physical building. However, as was found in the literature study presented in chapter *0 Social sustainability in current research*, social sustainability is achieved mainly by other parameters linked to politics, demography and how the building is run. The physical building can be argued to play a limited part in the overall social sustainability, which was also brought up during the evaluation of the tool in chapter *0 External Evaluation of* the Tool.

The analyzed cases
Since the greenhouse suggestion is a more uncommon type of alteration it might have led to higher degree of uncertainties during the meeting. These uncertainties are necessary to assess if there are additional qualities or risks with the greenhouse suggestion. This could have been mitigated by including an expert experienced within this type of building alteration. At the same time the extensive refurbishment in the upper reference case is a more established type of strategy and it might have been assumed possible to adjust issues along the way in a different way.

The results might have gotten colored by comparing the greenhouse with an already executed renovation. For this reason it would have been better to either compare two non-existing renovation methods, or two existing ones.

The selection of aspects
When looking on a neighborhood scale it would be possible to include important aspects such as mobility. Many of the researched certification tools bring up for instance access to public transport as an indicator. A geographic scale would, thus, be of interest to include in the social sustainability tool.

When regarding process related aspects it is possible to regard equity, social cohesion and participation in a different way, which would be of interest as was found in the literature study in chapter *0 Social sustainability in current research*. The process is also brought up in some of the certification systems, such as management methods of including tenants in the building.

In

Appendix C - Social indicators detection it is possible to see all aspects gone through and how they were regarded, also showing which aspects and indicators could be relevant when setting up different criteria for selecting aspects. More effort of designing the set of aspects and how they are evaluated would be required to reach a satisfying tool for use in practice.

The aspects are sometimes representing several important factors and it could be discussed whether these aspects should be split into several aspects. For example the aspect *housing provision* also regards affordability, but affordability might be of such importance that it deserves to be an aspect.

Weighting of the aspects
The aim of the thesis was not to present a final weighting of the aspects even though it has been shown that the weighting is influencing the evaluation result. In a thorough weighting investigation each aspect would need to be inspected separately, measuring the impact of the aspect on the social sustainability, in a way that assures the possibility of comparing the aspects. This could be in form of tenant surveys, letting those who live in the observed building decide the value of each aspect. Another method could be by linking the weighting with the *pre-eminent concepts and the important factors* of the social sustainability sphere presented in chapter *0 Social sustainability in current research*.

The role of the experts
When performing the evaluation meeting there could be a point to give the expert having a greater knowledge within a certain aspect a higher influence in the ruling of the aspect evaluation outcome. A way could be to let the role with more knowledge for an aspect, have an increased vote weight, for this certain aspect. In the performed evaluation meeting the aspect ruling was discussed and the experts reached a ruling together. A new evaluation meeting would be required to investigate how this change of format would inflict the result.

7. COLLECTED RESULTS

Assessing sustainability is a holistic undertaking. Although each analysis in its sphere calls for a high level of precision to be able to produce a credible result, all results have to viewed and weighed together to be able to predict the preconditions for sustainable development.

The output from the analyses from every sphere of sustainability are brought together to make a comparative analysis. A single result per sphere has been selected that was best describing the output of the respective analysis, see Table 20. Note that the upper reference has the highest performance in all spheres. This was expected since it is a more extensive refurbishment.

Table 20: The output values from each sphere of sustainability and their normalized ratios.

Analysis	Measured issue	Lower reference	Upper reference	Greenhouse suggestion
Ecological	Total energy savings [MWh/year]	0	20.8	9.7
	Normalization	0%	100%	47%
Economic	Payback period [years]	0	15	18
	Inverting [$years^{-1}$]	0	0,067	0,055
	Normalization	0%	100%	83%
Social	Health and Comfort as one aspect each	0%	61.1%	22.7%

Normalization	0%	100%	37.2%

Pareto assembly

Optimization within the building industry has for a long time been about the economic sphere. The goal is often about trying the get as much money at least time possible from a certain project. In more recent years together with energy crises and the various certification tools the environmental sphere has begun to take part. The social sphere, though, has not been measured in a way that allows comparison with the spheres of economy and environment, which is why measuring social sustainability is of interest.

Pareto optimization means that all fields considered are gaining from a certain action. This is contrary to sub optimization when an action has a positive outcome for one certain field but has a negative infliction on the whole picture or in other fields. Applied to the spheres of sustainability, the Pareto optimization could be used in an early stage in building renovation to identify the most important measures and give the possibility to disregard alternatives with less potential on an early stage, not having to involve decision makers.

Quantification and normalization of data

To be able to make a Pareto optimization, it is necessary have quantified and normalized data and to make sure that a higher value signifies a better result. The Pareto-optimization uses the alternatives with the most extreme values to define the normalization span. All other investigated cases will be placed in relation to the values that define the upper and lower limits.

The most potential alternatives are then the one with the longest distance, d, from the origin which is then calculated by using the equation $d = \sqrt{Ecol^2 + Econ^2 + Soc^2}$. $Ecol$, $Econ$ and Soc here represent the three spheres of sustainability[6]. I visualization of how such a Pareto-optimization could look is provided in Figure 43.

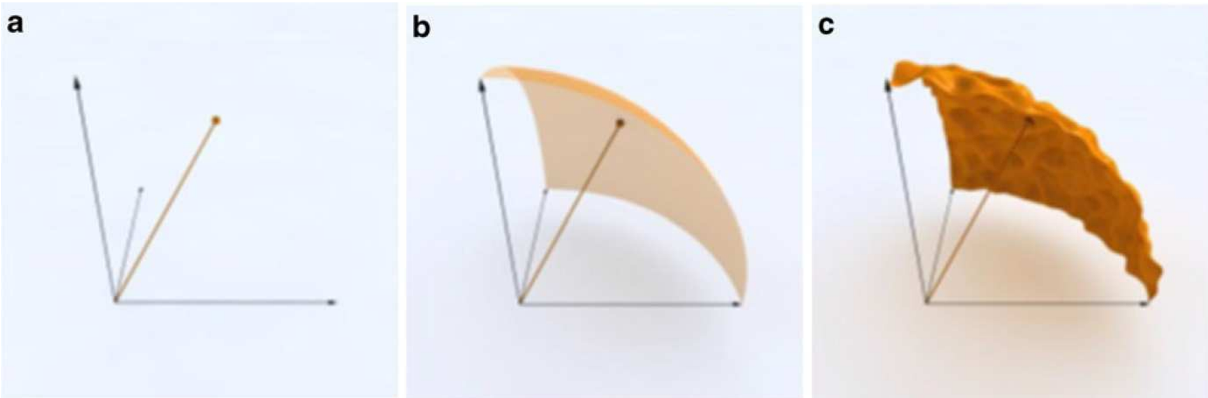

Figure 43: A visualization of the Pareto-optimization plot where different alternatives create a 3-dimensional shape[6].

Pareto assembly results

The normalized data in Table 20 was inserted into a 3-dimensional graph where the distance from the origin was then visualized and measured, see Figure 44. Since the upper reference had the highest performance in all spheres it has the largest distance from the origin. The lower reference had the lowest performance and is of this reason situated in the origin of the graph. The greenhouse suggestion had a positive effect on the building but did not perform as well as the upper reference. When inserting the values from all analyzed spheres into the Pareto assembly, it was found that using Pareto-optimization as method to determine preferable renovation alternatives becomes colorless since too few alternating cases are investigated. The Pareto-optimization method is a better method when analyzing a greater amount of options, whereas three alternatives are better investigated by simple comparison.

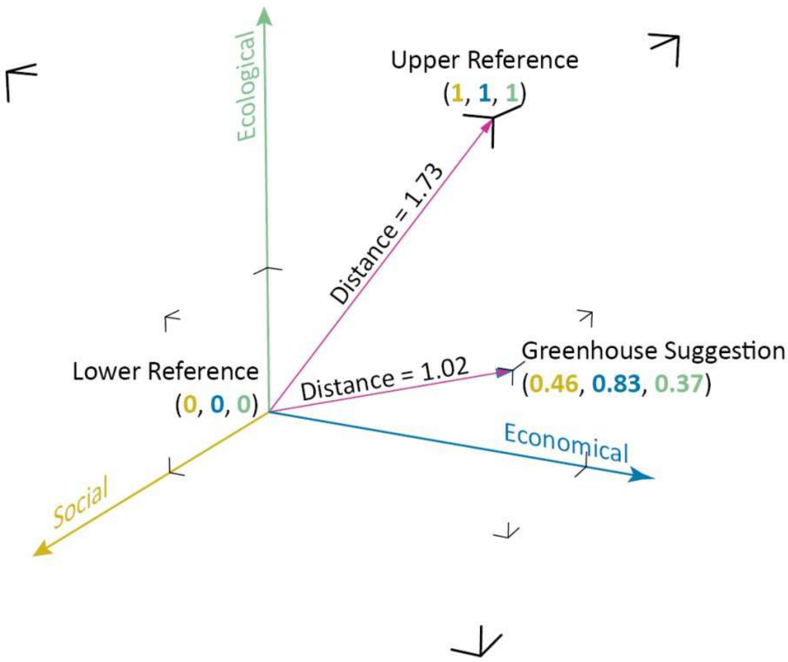

Figure 44: A 3 dimensional Pareto-optimization plot.

Simple comparison

The outcomes from each sphere of sustainability analysis are inserted in Figure 45 for comparison. Upon reviewing the graphs it is possible to see that both retrofitting strategies improve the building performance. The upper reference is considered achieving a better result within all spheres which corresponds to previous suggestions.

Within the ecological sphere the energy savings over the wall are about half for the greenhouse suggestion. This is a remarkably high improvement. As already mentioned, the upper reference in reality reached a passive house standard and it was not expected the greenhouse suggestion would reach the same levels of energy savings. If the greenhouse suggestion would be as a part of a renovation package it could be an interesting building addition.

Within the economic sphere the greenhouse seems to perform reasonably well, mainly due to the difference in investment size of the alternating refurbishments. It could also be investigated what would happen in the greenhouse suggestion case if managing rents in different ways.

Within the social sphere it was previously suggested that the greenhouse suggestion would imply a higher social value but it was found that the alternative induce too many uncertainties. It is also a smaller alteration than the upper reference and do not affect as many aspects in the assessment tool. Furthermore, the weighting system is influencing the outcome and the weighting system needs to be investigated further to ensure a reliable outcome.

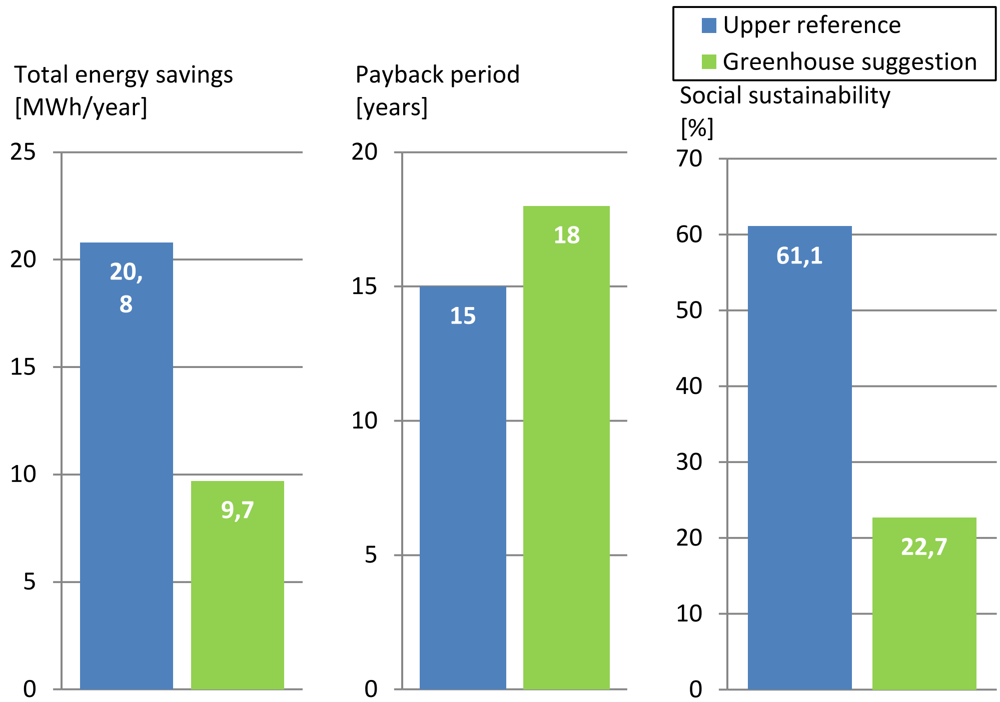

Figure 45: The result of the analyses in all three sustainability spheres. The upper reference case a better alternative than the greenhouse in all analysis: is shows larger energy savings, a shorter payback period and a higher score in the social sustainability assessment.

8. CONCLUSIONS AND OUTLOOK

It was proven to be difficult to find a single quantitative value for sustainability. Although a value was found, this was relating to the references and is not comparable to other assessments unless they use the same references and the same method of assessing each sphere. The method used in this thesis would have resulted differently if having different refurbishment alternatives.

Due to the thesis's limited amount of time it was not possible to assess all important matters in each sphere. The economic sphere could have been more detailed, the ecologic sphere would have benefitted from calculating the total usage of energy and conducting an LCA, and the assessment of the social sphere would have benefitted from tenant surveys to furtherly identify important aspects and further work with defining a fully functional weighting system. The method used for assessing the social sphere is designed so that comparison between different projects is not possible, which is a weakness.

It is still believed, though, that if using methods for analyzing each sphere that are commonly accepted it could be possible to find a single numerical value for sustainability. This is what many of the sustainable building certification systems do, but if conducting one of these assessments it is still not comparable to other certification systems.

It was found that a single numerical value is providing little information on the actual performance of the building alteration than just how well the alteration performs in relation to other alternatives. If one is interested in performing well within ecological sustainability, one would want to see the detailed performance in this specific sphere and vice versa for the other spheres. If having a greater range of alternatives analyzed while using the same methods it could be a powerful way to find the best solution but for a smaller range of alternatives the comparison could just as well be performed directly. Thus, depending on the extent of the desired design procedure of the refurbishment, finding a single numerical value for sustainability for each refurbishment alternative could be useful for future projects.

The assessment
This specific greenhouse suggestion increases the energy performance of the building, but as an energy retrofitting alternative it does not reach far enough. The PCM energy storage was found being of less importance for the energy performance than anticipated. The greenhouse suggestion is not economically optimal due to its longer payback period. It is, however, related to the upper reference investment a small investment which might be easier to handle economically. Furthermore, the greenhouse suggestion is questionable in terms of social sustainability. One of the main reasons is that the greenhouse suggestion was not in place when the tenants first moved in, which means that they are not prepared for the type of life that this type of shared space implies. Since the tenants did not choose to live in a building with such a shared space, this might spur conflicts.

Overall the greenhouse suggestion seems to be an alternative more feasible for a building not in dire need of renovation and could along with a retrofitting package be a valuable asset. It was found that the upper reference scenario is a better suited renovation strategy for the observed building. In a holistic analysis, it is difficult to reach far with a retrofit alternative that does not in its turn have a holistic approach. The

Ecological sustainability
The greenhouse has an impact for the thermal energy flow over one wall. The greenhouse suggestion was found to decrease the energy flow by 33.1% over that façade. This means that renovating with only a greenhouse does not reach far and is not a reasonable retrofitting strategy in terms of energy improvement.

The PCM storage had very little impact on the total thermal energy flow, which contradicted previous suggestions. The ability of TES for day-to-day temperature variations was confirmed. Most likely, the amount of PCMs was too little.

Economic sustainability
In the investigated scenario the greenhouse suggestion pays off later than the alternating renovation strategy. It is not feasible to see the greenhouse as an individual building addition since it does not increase the profit enough. If the greenhouse suggestion would be included as a part of a more extensive renovation package it could be a more feasible renovation strategy, or if investigating a building with higher initial performance. The upper reference is very costly but is more profitable over time.

Social sustainability
In the social sustainability assessment the greenhouse received a low result. By this, it is suggested that the greenhouse makes the preconditions for social sustainability worse. This is contradicting previous expectations. On many occasions the greenhouse suggestion provided reason for uncertainties why this may have led to a negative judgment. It would be required to involve an expert experienced with this type of alteration in the social sustainability evaluation meeting. On the contrary the social sustainability evaluation meeting had beforehand additional information of the upper reference which might have led to a higher result for this renovation strategy. It is an effect of comparing two renovation alternatives where one of them has already been executed. Another reason to why the greenhouse suggestion received a lower result is that there are many risks of social character involved in creating a common area like the greenhouse suggestion for already existing social structures. This can imply difficulties with noise, smell and tension between tenants. If the building would have been a new production along with the greenhouse it would be a different thing since by moving in the tenants have already accepted the greenhouse and the implications the greenhouse brings. The greenhouse could then prove to be of very high social value.

The building certification systems examined for aspect collection do not include all aspects relevant to social sustainability. Using certification systems to assess only social sustainability does not give the whole picture. BREEAM Communities includes many aspects relevant to social sustainability but on a community level involving many buildings, why many of the indicators in the certification systems had to be disregarded.

Social sustainability assessment tool
The attempted social sustainability assessment tool could prove to be a good method to, in an early stage of the renovation decision making process, ensure the prerequisites for social sustainability in the renovation alternatives. It could be used as either a checklist, not following the whole assessment procedure, or used as intended to provide a single numerical value. However, it fails to assess actual social sustainability due to following reasons:

- The tool focus is too narrow and it is necessary to include the whole neighborhood
- The tool is not including process related aspects. It is necessary to involve renovation process and management of the building after renovation.
- The aspects could be more refined, maybe by having a workshop or survey with tenants letting them express what they find important for their individual ideas of social values.
- The weighting of the aspects needs a thorough investigation to find an acceptable way of weighting.

Suggestions for further research

A possible outlook could be to study different types of greenhouse geometries and to evaluate the effect of different greenhouse shapes, for instance by enveloping a whole building in a greenhouse.

Another continuation of the ecological analysis is to include the greenhouse in a package of non-evicting retrofitting actions, such as additional insulation on the roof and around the foundation, upgrading windows and doors, or developing the greenhouse to aid the ventilation system by pre-heating the supply air there. Another alternative could be to introduce an active heat transport system to a TES tank to better control uptake, storage and release of heat.

The convection in the greenhouse is of some significance for the energy modelling. Researching how this can be modeled in a greenhouse in a residential context could be a scope for further investigation.

A continued work with refining the social sustainability assessment tool by widening the scope in terms of process and physical boundaries would be of interest. Within this it would also be valuable to investigate the weighting system of the aspects.

It would have been interesting to include more input data for Pareto assembly in the different sustainability spheres, such as LCA and SLCA.

9. DISCUSSION

This discussion concerns everything outside the individual analysis chapters. For the discussion on the individual analyses and their results, see the chapters *0, 0* and *0,* respectively.

Choice of cases

It turned out troublesome to consider the buildings being in good technical condition since the economic analysis was not able to use LCC properly. However, with accepting the actual state of the real building, either a greenhouse would not have been feasible at all, or another building would have had to be used as a basis for the cases.

It would have been valuable with more cases to compare and that might have been quite easy since the hard part was defining the phenomena and deciding how to model them. However, if those additional cases had brought more phenomena into play, it would have been demanding significantly more time.

Assembly

Regarding the Pareto assembly, it can be discussed how to treat the plot to get the most valuable measure of sustainability. Besides using the distance to the origin as the BEEM-UP project suggested, it would be interesting to investigate meaning and the implications of computing the volume of the box that are created in the plot, see Figure 44. This might better correspond to the idea of strong sustainability since all spheres have a larger influence on the end result.

Overall process

This master thesis has sought to achieve a holistic approach on assessing sustainability. This has demanded various efforts and resulted in a difficulty of reaching a depth within each sphere. In this sense, the thesis would have benefitted from further limitations in the topic to instead focus on one or two key issues of the main goal. Had only an ecological analysis been performed, then it would probably have been possible to consider the entire building and maybe also moisture which would have given more useful results in that field. Had only a social analysis been performed, then the neighborhood and the entire process could have been included in the tool.

The largest value for science and society is seen in the social process and method. This holds the largest potential for future development since it is most sought for in the literature, most novel and seems most needed in practice today.

The question arose how shallow an analysis can be while still providing a valuable outcome?

Everything should be made as simple as possible, but not simpler.
-Albert Einstein

The impression from the analyses conducted in this thesis is that they are not deep enough to create a holistic understanding of the sustainability implications for the retrofit alternatives. They are giving indications, though, both for the sustainability implications and for possible improvements of the retrofit alternative.

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APPENDICES

Appendix A - Juridical implications

First of all a building addition requires a building permit since it changes the expression of the house according to PBL, chapter 8. Furthermore, the addition cannot be closer to property boarder than 4.5 meters unless affected neighbors concur with the changes. The building addition can neither obstruct roads for communication or emergency vehicles, parking lots, accessibility and other important functions without it being possible to meet these requirements.

In PBL chapter 3:1 and 3:10 and PBL 2 §2 it is constituted the importance of considering the nature and the cultural values. The building should be transformed in an aesthetical way, changing it carefully to regard technical, culture historical, environmental and artistic values. For this matter it can be argued that the greenhouse changes the building expression but at the same time conserves the original façade that would otherwise most likely be exchanged by a new type of façade with additional insulation. It can be argued that adding the greenhouse preserves the culture historical values and the original character. The façade in other million housing programs has in comparison sometimes changed drastically when refurbishing and adding external insulation. In PBL 2 §2 the social dimension is mentioned and the importance of good living environment, good environmental conditions and long term efficient use of space and water, energy and resources is brought up[61].

The building addition in relation to the tenants is also important to discuss. The tenant opinion is ruling whether or not a greenhouse like this can be built. According to Swedish law the building owner needs a majority of votes from the tenants to go through with a construction which would make a change for the collective, e.g. a new building for recycling. But when the change involves a single tenant the change must also be granted by the tenant[62]. This is influential for the greenhouse suggestion since the change suggested affects all tenants, for instance in the individual apartment when opening a window to let fresh air in towards the greenhouse. It could thus prove to be a difficult juridical matter.

According to BÄR 4.5 sound pollution penetrating the building envelope can be a problem for old buildings. A greenhouse would in this case be beneficial, shielding off a proportion of exterior noise.

[61] Örnhall, Hans (2008). Bostadsbestämmelser 2009
[62] Hyresgästföreningen igen

Appendix B – sensitivity analysis of a thermal bridge

Below is the full list of simulations for the sensitivity. The, occasionally, large amount of decimals stem from a desire to find out how small the deviation was, not to give influence to a deviation in the tenth decimal place.

Noteworthy is that the largest deviation was found when increasing the conductivity of the mineral wool board, since this is the main insulation material in the junction in that thermal bridge.

Table 21: Sensitivity analysis for the Slab-Facade thermal bridge in the Lower Reference case

Version		Result [W/mK]	Ratio	Deviation
Start		0,1914	*100%*	0%
Rel tolerance 10^-3 --> 10^-5		0,1914	*100,00000000087%*	0,000000000871%
Min mesh 10mm --> 5mm		0,1914	*99,98%*	-0,016%
Min mesh 10mm --> 20mm		0,1915	*100,0318%*	0,0318%
Measuring flux on the outside surface of the facade		0,1914	*100,000000494%*	0,000000494%
Scale factor --> 273		0,1914	*99,99999999903%*	-0,000000000966%
Sweep r_si	5	0,1885	*98,47%*	-1,53%
	7	0,1914	*100,00000000034%*	0,000000000340%
	9	0,1934	*101,00264%*	1,00264%
	11	0,1947	*101,7%*	1,7%
	13	0,1958	*102,3%*	2,3%
	15	0,1966	*102,7%*	2,7%
Sweep r_se	11	0,1886	*98,52%*	-1,48%
	13	0,1902	*99,37%*	-0,63%
	15	0,1914	*100,00000000042%*	0,000000000416%
	25	0,1881	*98,26%*	-1,74%
Sweep λ_minull Board	0,036	0,1880	*98,231%*	-1,769%
	0,037	0,1914	*100,00000001266%*	0,000000012657%
	0,04	0,2012	*105,1%*	5,1%
	0,044	0,2135	*111,5%*	11,5%
	0,05	0,2303	*120,3%*	20,3%
Sweep λ_minull	0,036	0,1919	*100,2%*	0,2%
	0,037	0,1914	*100,00000001266%*	0,000000012658%
	0,04	0,1901	*99,317552%*	-0,682448%
	0,044	0,1885	*98,456896%*	-1,543104%
	0,05	0,1862	*97,263832%*	-2,736168%

Appendix C - Social indicators detection

This appendix shows the detection of relevant indicators which determine the aspects in the social sustainability assessment tool. The indicators have been given a remark to show how they have been regarded. This could be used if commencing a widening of the tool scope to include neighborhood scale and/or process related indicators.

BREEAM communities

Step	Category	Name	Remark
1: Establishing the principle of development	Governance	Consultation plan	Time boundary, physical boundary
	Social and economic wellbeing	Economic impact	Time boundary, physical boundary
		Demographic needs and priorities	Time boundary, physical boundary
		Flood risk assessment	Physical boundary
		Noise pollution	Physical boundary
	Resources and energy	Energy strategy	Not social aspect
		Existing buildings and infrastructure	Not social aspect
		Water strategy	Not social aspect
	Land use and ecology	Ecology strategy	Physical boundary
		Land use	Physical boundary, not social aspect
	Transport and movement	Transport assessment	Physical boundary
2: Determining the layout of the development	Governance	Consultation and engagement	Physical boundary, time boundary
		Design review	Physical boundary, time boundary
	Social and economic wellbeing	Housing provision	Affordability, equity
		Delivery of services facilities and amenities	physical boundary
		Public realm	Relevant to social cohesion
		Microclimate	physical boundary
		Utilities	Physical boundary
		Adapting to climate change	Health
		Green infrastructure	Physical boundary
		Local parking	Physical boundary
		Flood risk management	Physical boundary, not social aspect
	Land use and ecology	Water pollution	Physical boundary, not social aspect
		Enhancement of ecological value	Physical boundary
		Landscape	Physical boundary, not social aspect
	Transport and movement	Safe and appealing streets	Physical boundary

		Cycling network	Physical boundary
		Access to public transport	Physical boundary
3: Designing the details	Governance	Community management of facilities	Physical boundary, time boundary
	Social and economic wellbeing	Local vernacular	Relevant to health and comfort
		Inclusive design	Relevant to equity
		Light pollution	Relevant to health and safety
		Training and skills	Physical boundary and time boundary
	Resources and energy	Sustainable buildings	Physical boundary,
		Low impact materials	Not social aspect
		Resource efficiency	Not social aspect
		Transport carbon emissions	Not social aspect
	Land use and ecology	Rainwater harvesting	Not social aspect
	Transport and movement	Cycling facilities	relevant for health and comfort
		Public transport facilities	physical boundary

BREEAM – SE

Category	Aspect	Relevant aspects identification
Management	Commissioning	Not social aspect
	Construction site impact	Time boundary, Physical boundary
	Building User Guide	Time boundary
	Moisture control	Health
Health and Wellbeing	Daylight	Health
	Occupant thermal comfort	Comfort
	Acoustics	Comfort
	Indoor air and water quality	Health and comfort (air quality)
	Lighting	Feeling of safety, health
Energy	CO2 emissions	Not social aspects, physical boundary
	Low or zero carbon technologies	Not social aspects, physical boundary
	Energy sub metering	Not social aspects, physical boundary
	Energy efficient building systems	Not social aspects, physical boundary
Transport	Public transport network connectivity	Physical boundary
	Pedestrian and Cyclist facilities	Affordability, equity and communications
	Access to amenities	Physical boundary
	Travel plans and information	Physical boundary
Water	Water consumption	Not social aspect
	Leak detection	Not social aspect
	Ware re-use and recycling	Not social aspect
Waste	Construction waste	Not social aspect
	Recycled aggregates	Not social aspect
	Recycling facilities	Not social aspect
Pollution	Refrigerant use and leakage	Not social aspect
	Flood risk	Physical boundary
	NOx emissions	Physical boundary
	Watercourse pollution	Not social aspect
	External light and noise pollution	Relevant for health issues
Land Use and Ecology	Site selection	Time boundary, Physical boundary
	Protection of ecological features	Physical boundary
	Mitigation/enhancement of ecological value	Physical boundary
Materials	Embodied life cycle impact of materials	Not social aspect
	Materials re-use	Not social aspect
	Responsible sourcing	Not social aspect
	Robustness	Not social aspect
	Avoidance of hazardous substances	Relevant for health issues
Innovation	Exemplary performance levels	not Social aspects, physical boundary
	Use of BREEAM Accredited Professionals	not Social aspects, physical boundary

DGNB

Theme area	Criteria definition	
Ecologic quality	Life cycle impact assessment - emissions environmental effects	Physical boundary, not social aspect
	Life cycle assessment - primary energy	Physical boundary, not social aspect
	Demand for drinking water and wastewater production	Physical boundary, not social aspect
	Land use	Physical boundary, not social aspect
Economic quality	Building related cost in the life cycle	Time boundary
	Flexibility and conversion ability	Relevant for equity and comfort
Sociocultural and functional quality	Thermal comfort	Relevant for comfort
	Interior air quality	Relevant for comfort
	Acoustic comfort	Relevant for comfort
	Visual comfort	Relevant for comfort
	User participation	Relevant for equity
	Outdoor quality	Physical boundary
	Safety and accident risks	Relevant for health
	Accessibility	Relevant for equity
	Biking comfort	Relevant for health and equity
Technical quality	Fire safety	Relevant for health
	Ease of cleaning and maintenance	Relevant for health and comfort
	Decommissioning and dismantling friendliness	Time boundary
Process quality	Strategies & Controlling	Time boundary
	Quality of management	Time boundary
	Systematic maintenance management	Time boundary
	Resource management	Time boundary

LEED for Existing buildings and Operations Management

Category	Aspect	Remark
Sustainable sites	LEED certified design and construction	Not social aspect
	Building exterior and hardscape management plan	Not social aspect
	Integrated pest management, erosion control	Time boundary
	Alternative commuting transportation	Time boundary
	Site disturbance - protect or restore open habitat	Physical boundary
	Stormwater control	Physical boundary
	Heat island reduction - nonroof	Not social aspect
	Heat island reduction - roof	Not social aspect
	Light pollution reduction	Relevant for comfort
Water efficiency	Minimum Indoor Plumbing fixture	Not social aspect
	Water performance measurement	Not social aspect
	Additional Indoor plumbing fixture	Not social aspect
	Water efficient landscaping	Not social aspect
	Cooling tower water management	Not social aspect
Energy and atmosphere	Energy efficiency best management practices	Not social aspect
	Minimum energy efficiency performance	Not social aspect
	Fundamental refrigerant management	Not social aspect
	Optimize energy efficiency performance	Not social aspect
	Existing building commissioning-investigation and analysis	Not social aspect
	Existing building commissioning-implementation	Not social aspect
	Existing building commissioning-ongoing commissioning	Not social aspect
	Performance measurement. Building automation system	Not social aspect
	performance measurement-system level metering	Not social aspect
	On-site and off-site renewable energy	Not social aspect
	Enhanced refrigerant management	Not social aspect
	Emissions reduction reporting	Not social aspect
Materials and resources	Sustainable purchasing policy	Not social aspect
	Solid waste management policy	Not social aspect
	Sustainable purchasing - ongoing consumables	Not social aspect
	Sustainable purchasing - durable goods	Not social aspect
	Sustainable purchasing - facility alterations and additions	Not social aspect
	Sustainable purchasing - reduced mercury in lamps	Not social aspect
	Sustainable purchasing - food	Not social aspect
	Solid waste management - ongoing	Not social aspect

	consumables	
	Solid waste management - durable goods	Not social aspect
	Solid waste management - facility alterations and additions	Not social aspect
Indoor environmental quality	Minimum indoor air quality performance	Relevant for comfort
	ETS control	Physical boundary
	Green cleaning policy	Relevant for health
	Indoor air quality management program	Relevant for comfort
	Outdoor air delivery monitoring	Relevant for comfort
	Increased ventilation	Relevant for comfort
	Reduced particulates in air distribution	Relevant for health
	Indoor air quality management for facility alterations and additions	Relevant for comfort
	Occupant comfort - occupant survey	Time boundary
	Controllability of systems - lighting	Relevant for comfort
	Occupant comfort - thermal comfort monitoring	Time boundary
	Daylight and views	Relevant for comfort
	High performance cleaning program	Relevant for health
	Custodial effectiveness standard	Relevant for health
	Purchase of sustainable cleaning products and materials	Relevant for health
	Sustainable cleaning equipment	Relevant for health
	Indoor chemical and pollutant source control	Relevant for health
	Indoor integrated pest management	Relevant for health
Innovation in operations	Innovation in operations	Physical boundary
	LEED accredited professional	Physical boundary
	Documenting sustainable building cost impacts	Physical boundary
Regional priority	Regional priority	Physical boundary

LEED for New Construction and Major Renovations

Sustainable sites	Construction Activity Pollution Prevention	Not social aspect
	Site selection	Time boundary
	Development Density and Community Connectivity	Physical boundary
	Brownfield Redevelopment	Not social aspect
	Alternative transportation - Public Transportation Access	Physical boundary
	Alternative transportation - Bicycle Storage and changing Rooms	Physical boundary
	Alternative transportation - Low-emitting and fuel efficient vehicles	Physical boundary
	Alternative transportation - Parking Capacity	Physical boundary
	Site development - Protect and restore habitat	Physical boundary
	Site development - Maximize Open Space	Physical boundary
	Stormwater - Quantity control	Physical boundary
	Stormwater - Quality control	Physical boundary
	Heat Island effect - Nonroof	Not social aspect
	Heat Island effect - Roof	Not social aspect
	Light Pollution Reduction	Relevant for comfort
Water efficiency	Water use reduction	Not social aspect
	Water efficient landscaping	Not social aspect
	Innovative wastewater technologies	Not social aspect
	Water use reduction	Not social aspect
Energy and Environment	Fundamental Commissioning of Building Energy systems	Not social aspect
	Minimum Energy Performance	Not social aspect
	Fundamental Refrigerant Management	Not social aspect
	Optimize energy performance	Not social aspect
	On-site renewable energy	Not social aspect
	Enhanced Commissioning	Not social aspect
	Enhanced Refrigerant	Not social aspect
	Measurement and verification	Not social aspect
	Green power	Not social aspect
Materials and resources	Storage and collection of recyclables	Not social aspect
	Building reuse - Maintenance existing walls, floors and roof	Not social aspect
	Building reuse - Maintain existing interior nonstructural elements	Not social aspect
	Construction waste management	Not social aspect
	Materials reuse	Not social aspect
	Recycled content	Not social aspect
	Regional material	Not social aspect
	Rapidly renewable materials	Not social aspect
	Certified wood	Not social aspect
Indoor environmental quality	Minimum indoor air quality performance	Relevant for comfort
	Environmental Tobacco smoke (ETS) control	Physical boundary
	Outdoor air delivery monitoring	Relevant for comfort
	Increased ventilation	Relevant for comfort

	Construction indoor air quality management plan - during construction	Relevant for comfort
	Construction indoor air quality management plan - before occupancy	Relevant for comfort
	Low-emitting materials - adhesives and sealants	Relevant for health
	Low-emitting materials - paints and coatings	Relevant for health
	Low-emitting materials - flooring systems	Relevant for health
	Low-emitting materials - composite wood and agrifiber products	Relevant for health
	Indoor chemical and pollutant source control	Relevant for health
	Controllability of systems - lighting	Relevant for comfort
	Controllability of systems - thermal comfort	Relevant for comfort
	Daylight and views - Daylight	Relevant for health and comfort
	Daylight and views - Views	Relevant for health and comfort
Innovation in Design	Innovation in design	Not social aspect
	LEED Accredited Professional	Not social aspect

Miljöbyggnad

Aspect	Indicator	Remark
Energy use	Energy use	Not social aspect
Power demand	Heat power demand	Not social aspect
	Solar heating load	Not social aspect
Type of energy	Type of energy	Not social aspect
Noise environment	Noise environment	Relevant for comfort
Air quality	Radon gas	Relevant for health
	Ventilation standard	Relevant for comfort
	Nitrogen dioxide	Physical boundary
Moisture	Moisture resistance	Relevant for health
Thermal climate	Thermal climate in winter	Relevant for comfort
	Thermal climate in summer	Relevant for comfort
Daylight	Daylight	Relevant for comfort
Legionella	Legionella	Physical boundary
Documentation of building materials	Documentation of building materials	Not social aspect
Phasing out dangerous substances	Phasing out dangerous substances	Relevant for health
Removal of dangerous substances	Removal of dangerous substances	Relevant for health

Appendix D – Correlation between Factors and Aspects

The left column of Table D1 below contains the set of aspects (without *Sense of Belonging*). The right column contains the important factors of social sustainability as found in literature in chapter *0 Social sustainability in current research* that found correlation within the aspects. The list on next page contains all factors lacking correspondence within the set of aspects.

Table D1: The investigation result of the aspect – factor correspondence.

Aspect	Factor
Accessibility	Social inclusion (and eradication of social exclusion)
Feeling of safety	Secure and friendly neighbourhood Safety Security (from crimes) Ability to fulfill psychological needs
Flexibility and conversion	Adaptability of development to the changing needs Demographic change
Housing provision	Social mixing and cohesion Demographic change Mixed development i.e. various uses within the same building or an area Provision of accommodation for different income groups Sufficient number of housing Affordability
Local vernacular	Preservation of local characteristics Promotion of local distinctiveness Preservation of historical structures & features Building design in terms of appearance, density, height & mass
Shared spaces	Social inclusion (and eradication of social exclusion) Social interaction Design of open spaces in terms of appearance, location, size & use of materials Attractive public realm Provision of open spaces Natural and social environment
Comfort category Acoustic comfort Biking comfort Ease of cleaning and maintenance Daylight and lighting comfort Indoor air quality Light pollution User controlability Thermal comfort	Great variety of green and quality housing Green features (construction related) Green features (design related) Design, size and comfort Established technical and hygienic requirements Decent housing Energy efficiency and waste management Provisions to control pollution
Health category Phasing out dangerous substances Moisture resistance Radon gas	Health, quality of life and well-being

Table D2: The factors that did not find a correlation within the aspects.

Access to societal functions

Accessibility to schools, health and other services

Proximity to business activities

Access to work Provision of public facilities

Access to open space

Mobility

Accessibility

Convenience, efficiency & safety for pedestrian & public transport users

Convenience, efficiency & safety for drivers

Justice

Fair distribution of income

Social justice: inter- and intra-generational

Residential stability (vs turnover)

Building management

Rehabilitation of repairable building structures

Management of buildings, facilities & spaces

Community involvement

Education and training

Community involvement in public decision making

Active community organizations

The Urban environment

Urbanity

Townscape design

Layout of building and streets

Establishment of different business activities

Efficient use of land & space

Sustainable urban design

Local environmental quality and amenity

Social capital

Social order

Social networks

Social capital

Neighbourhood

Compatibility with neighbourhood

Provision of employment

Availability of local employment

Employment

Sense of belonging

Sense of belonging, pride and identity

Sense of community and belonging

Identity, sense of place and culture

Appendix E – Social Sustainability Assessment Tool

Meeting participants

An odd number of meeting participants is promoted since this allows for simple majority ruling. Preferably, one role representing the technical issues, one role representing the functional and aesthetical issues and one representing the owner perspective of the building are present. At least three participants are required and if more nuanced discussions are sought, more participants and roles can be involved such as a tenant representative and an engineer with more detailed knowledge relevant for the building under observation.

Procedure

The meeting participants should be given information about the existing building beforehand if they do not already have the required knowledge. This should contain a short description and classification of the building, including such as the current state and refurbishment goals, important issues for the evaluation and describing images.

During the meeting the facilitators present the different refurbishment alternatives in a neutral way. This means that the refurbishment alternatives need to have been processed so that they give the same type of information on the same level of detail and that they are visualized in a way not promoting an alternative.

All the experts in the meeting are considered equally important, where all have the possibility to express opinion in a round table discussion and have a vote, which is also equally weighed. One of the meeting facilitators' tasks is to make sure this is realized. The facilitators also lead the discussion, keeping them on track and within the time limits, and fills out the meeting evaluation template. The evaluation is limited to regard only the physical building and no process related issues. Keeping the discussion within the limitation is also part of the meeting facilitators' tasks. The meeting guide helps the discussion within each aspect.

The aspects are run through one at a time. For each aspect the different refurbishment strategies get a ruling of -1, 0 or +1. If the retrofit is estimated to have a positive consequence for the aspect it is given a +1. If it is expected to make the situation worse or not good enough it is given a value of -1. If the retrofit does not imply any change for the aspect, or if it is difficult to assess a total outcome of the retrofit, the aspect is given a 0 to show that it has not been accounted for. The original building has the function as the lower reference from which all renovations are compared to. It is up to the meeting participants to decide the boundaries between the grades of the evaluation, i.e. decide what is an improvement or deterioration from the lower reference for each aspect and how big a change is needed to not get a 0. Most important is that the refurbishment alternatives are evaluated while using the same frames. If the meeting disagrees for a certain decision, majority of vote is implemented.

Schedule proposal

Time [minutes]	Activity
10	Welcoming and presentation of participants
10	Presentation of the tool
5	Presentation of the existing building
10-20	Presentation of refurbishment alternatives
60-120	Discussion and evaluation of each aspect and alternative
10-15	Feedback and discussion of the meeting outcome

Refurbishment alternative template

Refurbishment alternative – [Type of Refurbishment]

This alternative involves the following actions:

-
-
-
-
-
-
-
-
-

Image 1: Cross section drawing

Image 2:

Evaluation template

Refurbishment alternative:

Category	Aspect	Result: -1, 0, +1	Proposed action of improvement
General	Accessibility		
	Feeling of safety		
	Flexibility and conversion		
	Housing provision		
	Local vernacular		
	Shared spaces		
Comfort	Acoustic comfort		
	Biking comfort		
	Ease of cleaning and maintenance		
	Daylight and lighting comfort		
	Indoor air quality		
	Light pollution		
	User controlability		
	Thermal comfort		
Health	Phasing out dangerous substances		
	Moisture resistance		
	Radon gas		
Additional	Sense of belonging		

Evaluation Meeting Guide

Below is the set of aspects with a few questions or statements for each aspect to help the discussion in the evaluation meeting. The guide is based on the indicators of the investigated building certification systems.

Accessibility

- There is an accessible emergency egress adapted for all occupants and visitors.
- Is the building accessible for all types of handicap?
- At least one entrance is accessible for all and from there one HWC and elevator.

Feeling of safety

- There is sufficient lighting in communication streaks.
- The communication streaks are overlookable.
- Is there an elevator? (Added after suggestions from the assessment meeting)

Flexibility and conversion

- Surface efficiency, the relation of usable or rentable space and the total area of the building.
- Room height.
- Building depth.
- Square meters per vertical communication.
- Sanitary unit amounts and escape routes.
- Interior walls and construction possibility of rearrangement.
- Estimated flexibility of installations.

Housing provision

- Minimum housing space standard.
- There is a certain amount of affordable rented, social rented and intermediate affordable housing units.
- The affordable housing units are mixed with the other dwellings.
- Assure displaced by development residents get affordable housing on the new site.
- Are the affordable units meeting the future demographic trends?

Local vernacular

- Key elements are identified and introduced in the development.
- Use of local materials?
- Use of local building forms?
- Inclusion or retention of historic elements?
- Use of public art?
- Involving the community in the design of community focal points.

Shared spaces

- The public realm allows multiple uses for different users.
- A mix of uses on the ground floor is encouraged.

Acoustic comfort

- Acoustic situation has been identified.
- Is exterior noise pollution shielded off sufficiently?
- Certain amount of sound absorbing surface materials.
- How is sound of footsteps estimated to improve?
- How is sound of air flow estimated to change?
- Is there a risk of installation sounds?

Biking comfort

- Is there sufficient biking parking?
- Are measures taken for safe walking and biking?
- Is the renovation alternative providing adequate amount of cyclist facilities.
- Amount of bike parking spaces in relation to building floor space.
- Bike parking closeness.
- Theft protection of and secure parking spaces.
- Weather protection for long term parking for certain amount of parking.
- Is there motion controlled lighting?

Ease of cleaning and maintenance

- Are primary parts of structure exposed for maintenance?
- Is outer glass easily accessible?
- Is the flooring tolerant to dirt?
- Dirt trapping zone.

Daylight and lighting comfort

- Room depth.
- View of sky.
- Daylight factor in certain points. Side-light or top-light to ensure daylight amounts.
- How is glare protection handled?
- High frequency lighting.
- Sufficient indoor artificial lighting.
- Outlook and view.
- Window area ratio
- Achieving direct line of sight to outdoor environment for at least 90% of frequently occupied areas.

Indoor air quality

- There is sufficient space between in-flow and out-flow air to avoid mixing.
- Possibility to increase air outlet over stove.
- Level of dangerous substances in indoor air estimation.
- Is there a monitoring system?
- Possibility to open windows in every room.
- Outdoor ventilation in dwelling rooms.
- Air extraction in kitchen, bathroom and WC.
- Possibility to clean ventilation ducts.

Light pollution

- Limited upward light transmission.
- Lights automatically turn off.
- Prevent direct night sky light radiation from lamps.
- Do all non-emergency envelope openings have sky shielding?

Thermal comfort

- Estimated temperature winter and summer.
- Estimated thermal comfort in dwelling rooms.
- How is draft handled?
- Are there risks of radiant temperature asymmetries?
- Floor temperature estimation?
- Are there open able windows?
- Relative humidity estimation.
- Heat source under windows.

- SVF and TF, window-floor ratio.

User controllability
- Is it possible to control daylight and artificial light?
- Temperature controllability (heating and cooling).
- Ventilation controllability.
- Sun screening.
- Glare shielding.
- Ease of use?

Phasing out dangerous substances
- Colors and coatings are approved.
- Using approved systems for limiting substance levels.
- Are there risks of dangerous materials?
- Is impregnated wood utilized?
- Is PCB or ozone damaging substances used?
- Are there existing asbestos and are they capsulated or sanitized?

Moisture resistance
- Securing quality in production.
- Are there increased risks of moist or water damages?
- Has the construction has yet significant longevity?

Radon gas
- In there a presence of radon? Is it handled?

Sense of belonging
- Does the renovation bring characteristics to the building?
- Is there a thought other than technical functions behind the alteration?

Is it possible to feel pride when living with the alterations?

Appendix F – Meeting Preparation Material

Preliminärt schema

10:00	Uppsamling i foajén i forskarhuset
10:10	Välkommnande och presentation av mötesdeltagare Cecilia Wretlind, White Jenny Bengtsson, Alingsås Hem Kia Bengtson, MA Arkitekter Presentation om exjobbet
10:20	Presentation: var befinner vi oss i renoveringsprocessen? Förklaring av randvillkor (vad tittar vi på? En byggnad, ingen process alltså byggnation, boendedialog); Indikatorer och hur de bedöms (+, 0, -); Bedömningsmallar och guide
10:30	Presentation av befintlig byggnad
10:40	Presentation av de två renoveringsalternativen Renoveringsalternativ 1 – full renovering Renoveringsalternativ 2 – växthus
10:50	Social hållbarhet – utvärdering Cirkeltid – diskussion och betänketid ca 2 minuter Triangeltid – beslutsfattning, 1 minut
11:40	Utvärdering av metoden som helhet
12:00	Lunch på Hyllan

Utvärderingsmöte om social hållbarhet i renovering av bostäder

Social hållbarhet har varit ett hett diskussionsämne den senaste tiden. Man har god vana av att mäta ekonomisk hållbarhet och numera även ekologisk hållbarhet i form av energiåtgång eller livscykelanalyser. Den sociala hållbarheten har fortfarande inte kunnat kvantifieras på ett bra sätt; detta är ett försök.

Tillvägagångssätt

Utvärderingen sker i en expertpanel bestående av en arkitekt, en ingenjör och hyresvärden samt en moderator. I en projektering skulle mötet ligga tidigt eftersom utvärderingen handlar om att jämföra en mängd olika renoveringsalternativ för att kunna utesluta de dåliga tidigt. Jämförelsen rör enbart den fysiska byggnaden i ett driftsskede.

På mötet kommer moderatorn presentera de olika renoveringsalternativen. Därefter går panelen igenom varje indikator och kommer fram till hur ramarna för indikatorn bör sättas och vilket utslag den då får, +1 om indikatorn kan förväntas bli förbättrad av renoveringen, -1 om resultatet förväntas bli sämre, eller 0 om renoveringen inte påverkar indikatorn eller om fördelar och nackdelar ”tar ut” varandra. Om panelen tycker olika gäller majoritet.

Värdena summeras senare för de olika renoveringsalternativen och det är det totala värdet som jämförs. En känslighetsanalys görs för att se hur en viktning av de olika värdena inverkar på resultatet.

Mötet avslutas med en diskussion kring utvärderingsmetoden.

Indikatorer

Indikatorerna är filtrerade från miljöcertifieringssystemen BREEAM-SE, BREEAM Communities, LEED, DGNB och Miljöbyggnad. Därtill har ytterligare en indikator lagts till för att gestalta sociala värden bättre. På mötet kommer finnas vägledning om hur indikatorerna kan beaktas.

Generell	Tillgänglighet
	Känsla av trygghet (från brott och olyckor)
	Flexibilitet och omformbarhet
	Boendevillkor, ekonomisk överkomlighet
	Lokal förankring
	Gemensamhetsytor
Komfort	Akustik
	Cykelförråd
	Enkelhet för städning och underhåll
	Dagsljus och ljussättning
	Luftkvalitet inomhus
	Ljusförorening
	Användarstyrning
	Termisk komfort
Hälsa	Hälsovådliga substanser
	Fuktrelaterade hälsoproblem
	Radon
Ytterligare indikatorer	Känsla av tillhörighet

Den befintliga byggnaden - scenario

Huset är ett miljonprogramshus i behov av renovering. Det man vill göra är framför allt energirenovering men det finns stora vinster i att renovera på flera sätt. Man överväger totalrenovering av fasaden men vill också undersöka ett annat alternativ.

Huset är fiktivt men baserat på Brogården.

Huset:

- Byggår: 1971
- Tre våningar
- 18 lägenheter
- Tegelfasad
- Indragna balkonger
- Indragna entréer

Tekniska brister:

- Köldbryggor vid balkonger
- Dragiga lägenheter
- Hög energianvändning
- Dålig ljudisolering

Ytterligare faktorer att beakta:

- Behov av större lägenheter
- Ökad tillgänglighet såsom hissinstallation
- Modernisering av tvättstugor
- Gemensamhetslokaler
- Gestaltningsfrågor – kulturhistoriskt värde





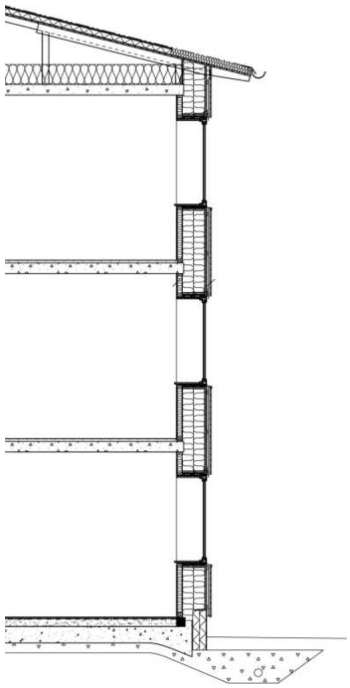
Appendix G – Meeting Execution Material

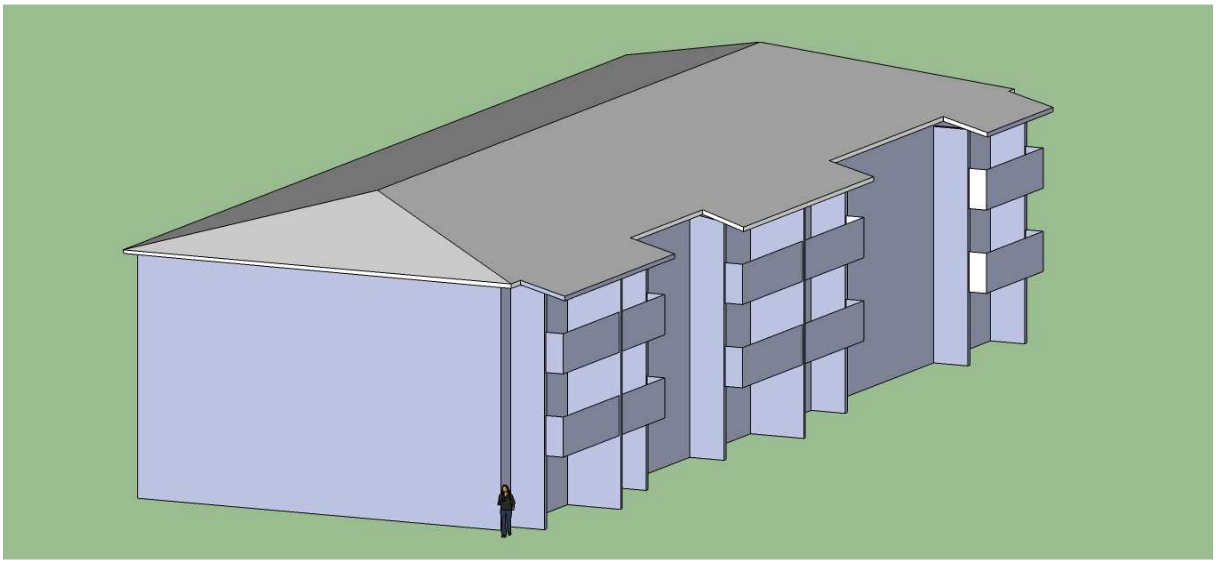
The material in *Appendix F – Meeting Preparation Material* was also available at the meeting.

Renoveringsalternativ 1 – omfattande renovering

Alernativ 1 innebär en omfattande renovering där man:

- isolerar väggar, tak och grund
- ändrar planlösning, större lägenheter
- minskar total mängd lägenheter
- tillgänglighetsanpassar
- moderniserar tvättstugor
- bygger bort köldbryggor
- FTX installeras
- Balkonger byggs om
- Fönster byts

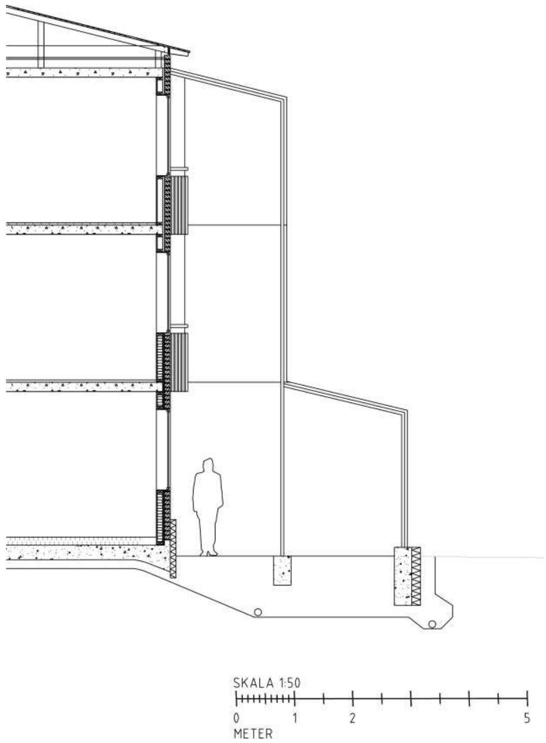


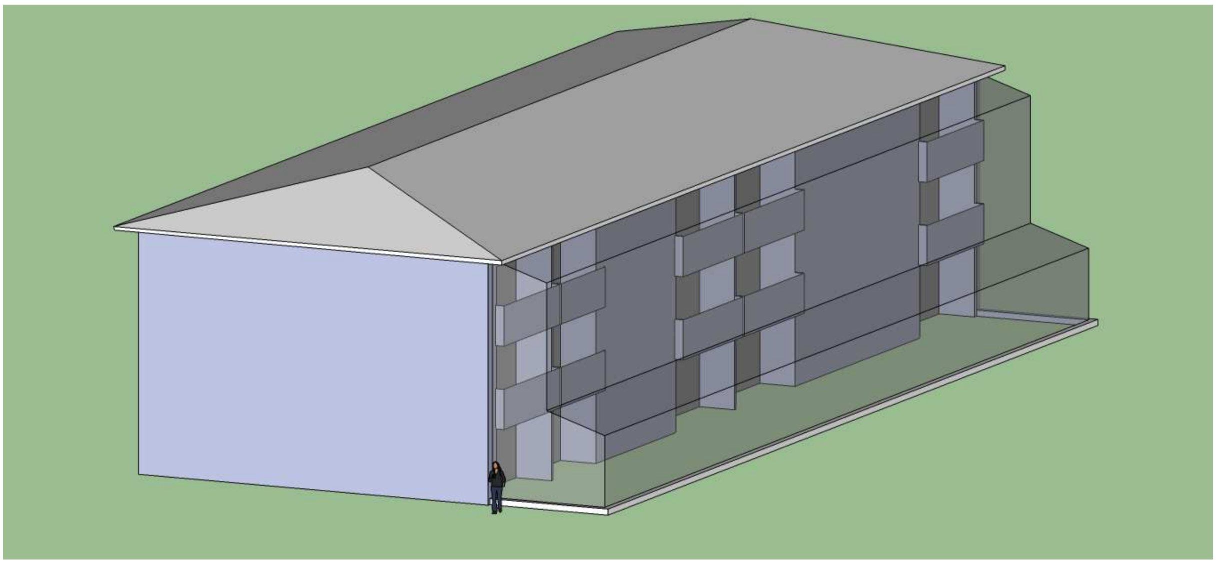


Renoveringsalternativ 2 – Växthus

Renoveringsalternativ 2 innebär ett byggnadstillägg bestående av ett växthus över en hel fasad. Effekterna av det blir att:

- växthuset förväntas minska energiförluster över väggen
- väggen skyddas mot väder och vind
- en gemensamhetsyta skapas
- balkonger kapslas in





Renoveringsalternativ 1 - omfattande renovering

	Aspekt	Resultat: -, 0, +	Förslag på åtgärd
Generell	Tillgänglighet		
	Känsla av trygghet (från brott och olyckor)		
	Flexibilitet och omformbarhet		
	Boendevillkor, ekonomisk överkomlighet		
	Lokal förankring		
	Gemensamhetsytor		
Komfort	Akustik		
	Cykelförråd		
	Enkelhet för städning och underhåll		
	Dagsljus och ljussättning		
	Luftkvalitet inomhus		
	Ljusförorening		
	Användarstyrning		
	Termisk komfort		
Hälsa	Hälsovådliga substanser		
	Fuktrelaterade hälsoproblem		
	Radon		
Ytterligare aspekter	Känsla av tillhörighet		

Renoveringsalternativ 2 - växthus

	Aspekt	Resultat: -, 0, +	Förslag på åtgärd
Generell	Tillgänglighet		
	Känsla av trygghet (från brott och olyckor)		
	Flexibilitet och omformbarhet		
	Boendevillkor, ekonomisk överkomlighet		
	Lokal förankring		
	Gemensamhetsytor		
Komfort	Akustik		
	Cykelförråd		
	Enkelhet för städning och underhåll		
	Dagsljus och ljussättning		
	Luftkvalitet inomhus		
	Ljusförorening		
	Användarstyrning		
	Termisk komfort		
Hälsa	Hälsovådliga substanser		
	Fuktrelaterade hälsoproblem		
	Radon		
Ytterligare aspekt	Känsla av tillhörighet		

Utvärderingsguide

Tillgänglighet
- Är byggnaden tillgänglig för alla typer av handikapp?
- Finns det möjlighet för utrymning för alla typer av handikapp?
- Finns det handikappanspassade toaletter I publika/gemensamma utrymmen?
- Finns det tillgång till hiss?

Känsla av trygghet (från brott och olyckor)
- Är kommunikationsstråken tillräckligt upplysta?
- Har entréer tak och är upplysta?
- Är kommunikationsstråken överblickbara?

Flexibilitet och omformbarhet
- Yteffektivitet, relationen mellan uthyrbar yta och total yta av byggnaden
- Rumshöjd
- Byggnadsdjup
- Antalet kvadratmeter per vertical kommunikation (hiss eller trapphus)
- Antalet sanitära faciliteter
- Innerväggar och möjlighet till omplacering
- Installationernas flexibilitet

Boendevillkor, ekonomisk överkomlighet
- Använda standarder kring minsta tillåtna yta
- Det finns en särskild mängd billigare hyreslägenheter i byggnaden
- De billigare boendealternativen är blandade med andra typer av bostäder
- Möter bostäderna de demografiska trenderna?

Lokal förankring
- Nyckelelement I området är identifierade och implementerade i ombyggnaden
- Används lokala material?
- Bygger man former av samma sort och skala?
- Inkludering eller behållande av historiska element
- Användande av konst i ombyggnaden

Gemensamhetsytor
- De publika ytorna tillåter en varierad användning för olika målgrupper
- En blandning av funktioner finns på bottenvåning

Akustisk komfort

- Hanteras oljud utifrån?
- Används ljudabsorberande material?
- Hur höga är stomljudsnivåerna?
- Hur höga bedöms luftburna ljud vara?
- Hur höga bedöms ljud från installationer vara?

Cykelförråd

- Erbjuds cykelparkering inomhus?
- Tas åtgärder för att göra cykling och gång tryggt och säkert?
- Erbjuds tillräcklig mängd cykelparkering (1 ställ/80-200 m^2)?
- Är cykelparkeringen skyddad mot stöld?

Enkelhet för städning och underhåll

- De huvudsakliga delarna av konstruktionen är tillgänglig för underhåll.
- Fönster är lättåtkomliga för rengöring
- Golvytan är motståndskraftig för smuts.
- Finns det en zon i entrén som fångar smuts utifrån?

Dagsljus och ljussättning

- Kort rumsdjup premieras
- Skyddas byggnad mot bländning?
- Finns tillräcklig mängd artificiella ljuskällor inomhus?
- Utblickbarhet och utsikter
- Hur förväntas dagsljusfaktorn förändras? (Dagsljus på en punkt I byggnaden jämfört med en punkt utomhus)
- Andel av fönster på fasaden
- Uppnå direkt synlinje med utomhus för minst 90% av vistelseytor.

Luftkvalitet inomhus

- Uppnå en naturlig ventilation
- Signifikant avstånd mellan luftföroreningskällor och luftintag
- Signifikant avstånd mellan utflöde och luftintag
- Möjlighet att öppna fönster
- Möjlighet att öka luftuttag över spis
- System för övervakning av luftkvalitet
- Utomhusventilation i vistelserum
- Luftuttag i kök, badrum och WC
- Möjlighet att rengöra ventilationskanaler

Ljusförorening

- Begränsad belysning uppåt
- Automatisk avstängning av belysning
- Alla byggnadens öppningar som inte är utrymmningsvägar har avskärmning mot himmlen

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Termisk komfort

- Hur förväntas inomhustemperaturen påverkas på vintern?
- Hur förväntas inomhustemperaturen påverkas på sommaren?
- Hur förväntas drag förändras?
- Finns det risker för värmestrålande eller köldstrålande ytor?
- Hur förväntas golvtemperaturen inverkas?
- Är fönster öppningsbara?
- Förhållandet mellan golvyta och fönsteryta är låg

Användarstyrning

Hur inverkar renoveringsalternativet på användarkontroll av

- dagsljus och artificiellt ljus?
- temperatur vintertid och sommartid?
- Ventilation
- Solavskärmning
- Bländskydd

Fuktrelaterade hälsoproblem

- Hur inverkar renoveringsalternativet på säkerhet från fuktskador?

Hälsovådliga substanser

- Undviks hälsovådliga substanser i renoveringsalternativet?
- Undviks impregnerat virke?
- Undviks PCB?
- Undviks andra hälsovådliga substanser såsom asbest?

Radon

- Hur förväntas halterna av radon förändras efter renovering?

Känsla av tillhörighet

- Ger renoveringen byggnaden karaktär?
- Tillvaratas den karaktär som huset hade?
- Finns det en uttalad tanke bakom renoveringsalternativet, utöver tekniska funktioner?
- Är det möjligt att känna stolthet över att bo i huset med förändringarna?

Utvärdering

Vilka styrkor har verktyget?

Vilka svagheter har verktyget?

Vilka möjligheter har verktyget?

Vilka utmaningar har verktyget?

Skulle ett sånt här verktyg vara till nytta i planeringsprocessen?

Vad krävs för att verktyget skulle kunnna användas?

Appendix H – Social Sustainability factors

Mak, MY. Peacock, C.J. (2011) Social sustainability: A Comparison of Case Studies in UK, USA and Australia. In 17th Pacific Rim Real Estate Society Conference; 16-19 Jan, 2011 Gold Coast. 14 pages.

Key themes to Social Sustainability

- Identity, sense of place and culture
- Empowerment, participation, access
- Health and safety
- Social capital
- Demographic change
- Social mixing and cohesion
- Well being, happiness, quality of life

[…]

Dimensions to assist Local Communities

- Interactions in the community/social networks
- Community participation
- Pride and sense of place
- Community stability
- Security (crime)

[…]

Significant Success Factors

- Provision of social infrastructure
- Availability of job opportunities
- Accessibility
- Townscape design
- Preservation of local characteristics
- Ability to fulfill psychological needs

Chan, E. Lee, G. K. L. (2008) Critical factors for improving social sustainability of urban renewal projects. Social Indicators Research, 85, 2, 243-256.

Factor 1: Satisfaction of welfare requirements

- Provision for basic needs of disabled, elderly or children with proper access
- Preserving & facilitating social network
- Sense of belongings on community
- Provision of public facilities
- Access to public facilities
- Convenience, efficiency & safety for pedestrian & public transport users
- Provision of accommodation for different income groups
- Security against crimes
- Community involvement in public decision making

Factor 2: Conservation of resources & the surroundings

- Green features (construction related)
- Provisions to control pollution
- Management of buildings, facilities & spaces

Factor 3: Creation of harmonious living environment

- Compatibility with neighborhood
- Layout of building and streets
- Promotion of local distinctiveness
- Rehabilitation of repairable building structures
- Preservation of historical structures & features
- Building design in terms of appearance, density, height & mass

Factor 4: Provision facilitating daily life operations

- Access to work
- Availability of local employment
- Proximity to business activities
- Establishment of different business activities
- Convenience, efficiency & safety for drivers

Factor 5: Form of development

- Adaptability of development to the changing needs
- Efficient use of land & space
- Mixed development i.e. various uses within the same building or an area

Factor 6: Availability of open spaces

- Access to open space
- Design of open spaces in terms of appearance, location, size & use of materials
- Provision of open spaces

Dempsey, N. et.al. (2011) The Social Dimension of Sustainable Development: Defining Urban Development Social Sustainability. Sust. Dev. 19, 289-300

Non-physical factor

- Education and training
- Social justice: inter- and intr-generational
- Participation and local democrazy
- Health, quality of life and well-being
- Social inclusion (and eradication of social exclusion)
- Social capital
- Community
- Safety
- Mixed tenure
- Fair distribution of income
- Social order
- Social cohesion
- Community cohesion (i.e. cohesion between and among different groups)
- Social networks
- Social interaction
- Sense of community and belonging
- Employment
- Residential stability (vs turnover)
- Active community organizations
- Cultural traditions

Predominantly physical factor

- Urbanity
- Attractive public realm
- Decent housing

- Local environmental quality and amenity
- Accessibility
- Sustainable urban design
- Neighborhood
- Walkable neighborhood: pedestrian friendly

Maliene, V. Malys, N. (2009) High-quality housing - A key issue in delivering sustainable communities. Built Environ 44(2):426-430.

- Affordability
- Availability in the market
- Sufficient number of housing
- Great variety of green and quality housing
- Design, size and comfort
- Natural and social environment
- Energy efficiency and waste management
- Secure and friendly neighborhood
- Accessibility to schools, health and other services
- Established technical and hygienic requirements