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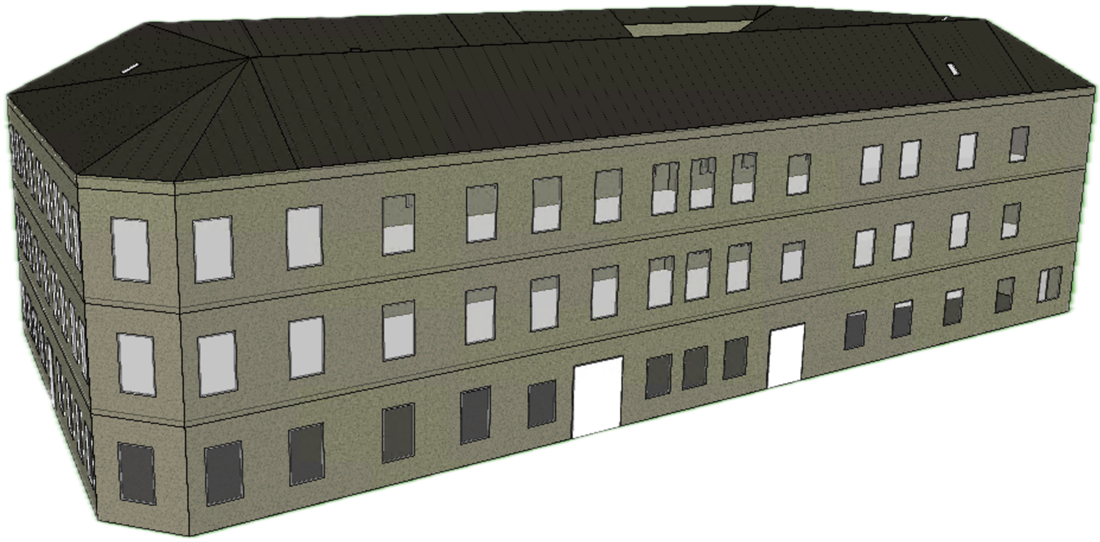

Organizational Decision-Making and the Implementation of Energy-Efficiency Measures

A Socio-Technical Analysis Using Attic Insulation as an Analytical Case

Master's thesis in Design and Construction Project Management

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Cover: IDA ICE model of the case building

Gothenburg, Sweden 2026

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Abstract

Despite increasing regulatory pressure and growing awareness of sustainability, many technically feasible energy-efficiency measures are not implemented within the existing building stock. This thesis investigates the organizational, technical, and economic factors that influence decision-making regarding such measures. Supplementary attic insulation is used as an analytical case study, based on a building at Sankt Eriksgatan 4 in Gothenburg.

A mixed-methods approach was applied, combining a literature review, seven semi-structured interviews with professionals in the Swedish real estate sector, building-energy simulations in IDA ICE, and profitability calculations. The simulations evaluated the effects of supplementary attic insulation, moisture-related risks, and the cost of mitigation measures.

The simulations also indicate high relative humidity levels in the attic both before and after insulation. Moisture mitigation is therefore necessary, not only as a consequence of the proposed measure but also to address an existing risk. When the costs of insulation and dehumidification are included, the combined investment has an estimated payback period of 10.27 years, an annual return of 9.75%, and a 50-year return on investment of 387%.

The interview findings demonstrate that technical feasibility and long-term profitability alone are insufficient to ensure implementation. Budget constraints, strict return requirements, uncertainty regarding future building use, split incentives, organizational inertia, and insufficient knowledge integration were identified as important barriers. At the same time, increasing energy prices, internal sustainability targets, and regulatory requirements were identified as key drivers.

The study concludes that the implementation of energy-efficiency measures depends on the interaction between technical performance, economic conditions, organizational structures, institutional pressure, knowledge-sharing practices and the ability to manage uncertainty. Strengthening these organizational conditions can help property owners transform technical and economic potential into practical implementation.

Keywords: Energy-efficiency, decision-making, renovation, attic insulation, simulation, profitability.

Acknowledgments

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We would like to express our sincere gratitude to all individuals who contributed to the completion of this thesis. Firstly, we would like to thank Dimosthenis Kifokeris, our supervisor at Chalmers University for all the support and insights throughout the process.

Furthermore, we would like to thank our supervisors at Higab, Maria Lindström and Daniel Lanz for their support and provision of valuable documentation for the study.

Lastly, we are thankful for all the participants who shared their time, experiences and perspectives with us. Your valuable contributions were essential to the completion of this research and have generated insights that we hope will advance a broader understanding of the subject in the future.

Erik Vansvik & Saga Nilsson Ermler
Gothenburg, June 2026

List of Abbreviations and Acronyms

Below is the list of abbreviations and acronyms that have been used throughout this thesis listed in alphabetical order:

ERH	Equilibrium Relative Humidity
EMC	Equilibrium Moisture Content
EM	Moisture Content
MVHR	Mechanical Ventilation with Heat Recovery
KM	Knowledge Management
SECI	Socialization, Externalization, Combination and Internalization
EU	European Union
ROI	Return On Investment
SMHI	Swedish Meteorological and Hydrological Institute

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1
Background

Energy-efficiency is a central policy objective within the European Union (EU) and its member states. The EU has set a target to reduce energy consumption by 32.5% by 2030, together with a primary energy consumption target of no more than 1,483 million tons of oil equivalent. This was based on projections made in 2007 and was later adjusted following the withdrawal of an EU member state (Eurostat, 2025). Similarly, Sweden aims to reduce energy use per heated floor area in residential and non-residential buildings by 50% by 2050, relative to 1995 levels (Palm and Reindl, 2016; SOU 2008:110).

The residential and service sectors account for approximately 40% of Sweden's total energy use in 2024. Significant potential for further energy savings remains, particularly within the housing sector (Energimyndigheten, 2025a; Palm & Reindl, 2016). When energy-efficiency is addressed within the housing sector, attention must be paid to the existing building stock, as it will remain the largest source of housing in the coming decades. Achieving national and EU energy targets therefore requires reduction in energy use within existing buildings. According to Sweden's national strategy for energy-efficient renovation, which was developed in response to the EU Energy Efficiency Directive, approximately 75% of existing buildings will require renovation by 2050 (Palm & Reindl, 2016). The growing need to renovate the existing building stock provides an opportunity to improve energy-efficiency, align with national energy and climate goals, and create suitable accommodations (Palm & Reindl, 2016). Energy consumption in society is strongly connected to greenhouse gas emissions. Improving energy-efficiency and reducing energy demand can therefore contribute to lowering emission levels (Nair et al., 2017; RISE, n.d.). This remains relevant even when renewable energy sources are used, since energy production and distribution still result in a certain degree of climate impact (RISE, n.d.). Furthermore, improved energy-efficiency can provide several benefits. A better and more stable indoor climate can increase comfort and well-being for occupants, while investments in energy-efficiency measures may also increase property value. In addition, lower energy use can reduce operating and maintenance costs, decrease climate and environmental impacts, and reduce the load on the electricity grid (Boverket, 2024).

Europe's existing building stock offers significantly greater potential for energy-efficiency improvements through renovation and retrofitting than newly constructed dwellings, which already comply with higher energy performance standards. Although new construction continues to expand, the existing building stock still constitutes a substantial share of the built environment in many developed countries and will continue to dominate in the coming years (Meijer et al., 2009). This underscores the need for efficient renovation strategies to enhance the performance of existing buildings while sustaining the continuous development of renovation measures.

A statistical report commissioned by the Swedish Energy Agency indicates that real estate owners and their organizational practices can significantly influence building energy consumption. This influence may arise from implementing stricter energy requirements in procurement processes, as well as from active energy management and operational optimization of building systems (Energimyndigheten, 2025b). However, despite the recognized importance of energy-efficient renovation, the implementation of cost-effective measures remains limited due to a wide range of barriers (Carlander & Thollander, 2023).

1.1 Problem Statement

Despite increasing political pressure, technological development, and growing awareness of sustainability and energy-efficiency, many technically feasible energy-efficiency measures remain unimplemented in the existing building stock. It is especially evident in situations where measures have the potential to reduce energy demand and operational costs (Blomqvist et al., 2022; Carlander & Thollander, 2023). The discrepancy between viability and actual implementation suggests that decision-making regarding energy-efficiency measures cannot be understood solely through technical or economic evaluations.

Previous research has extensively investigated technical performance, energy savings, environmental impact and financial profitability of energy-efficiency measures. Research has also increasingly acknowledged the importance of organizational and managerial challenges influencing the implementation of energy-efficiency measures (Carlander & Thollander, 2023).

However, despite the increasing interest in energy-efficiency in recent years, research on decision-making related to energy-efficiency remains limited (Klöckner & Nayum, 2017). This indicates that the relationship between technical-economic feasibility and organizational decision-making remains insufficiently explored. As a result, limited understanding of how organizational structures, internal work processes, institutional pressure, strategic priorities, uncertainty and knowledge integration influence renovation-related decision-making within property-owning organizations.

Understanding this discrepancy is important, particularly considering the significant role of the existing building stock in achieving national and European energy and climate targets. Therefore, further research integrating technical-economic assessments with organizational and socio-technical perspectives is needed. A broader understanding of these factors may help explain why profitable and technically feasible energy-efficiency measures are not always implemented in practice.

1.2 Case Introduction

This study investigates a case building located at Sankt Eriksgatan 4 in the center of Gothenburg. The attic of this building, together with its associated input data, serves as the reference case for the analysis. It represents a realistic scenario in which the implementation of supplementary attic insulation is considered. The building, built in 1810, has a total heated floor area of 2548 m^2. Additionally, there are three activity levels, where the first floor is shared industrial activity and a restaurant, while the second and third floors are classified as round-the-clock care.

Figure 1: The case building of Sankt Eriksgatan 4 (Higab, n.d.).

The property owner of this building is Higab, which has owned and managed it since 1991. Higab is a publicly owned real estate company responsible for managing a large portfolio of culturally and historically significant buildings in Gothenburg. Managing these older properties presents considerable challenges, particularly due to their age and the strict regulations governing permissible alterations. The company's interest in this project is to develop a solid basis for decision-making, both for the specific project and for similar projects in the future.

1.3 Aim and Research Question

This study aims to investigate the organizational, technical, and strategic factors that influence decision-making on implementing technically feasible energy-efficiency measures. By identifying and evaluating these factors, the study seeks to address existing knowledge gaps and contribute to a broader understanding of the current situation, the challenges that still persist within the industry, and potential areas for improvement. Furthermore, it aims to provide insight into the barriers and drivers shaping the sector in its present state, as well as highlight practices that could support the transition towards a more sustainable society.

Increased knowledge may help property-owning organizations refine and evaluate current working methods, improve knowledge integration, and identify gaps in the decision-making process for energy-efficient renovation alternatives. Additionally, it is expected to provide industry-relevant perspectives that may encourage organizations to critically reflect on their capacity to influence the development, evaluation and implementation of energy-efficiency measures. Furthermore, the study aims to identify both enabling and limiting organizational practices that influence decision-making, with the intention of supporting organizations in developing more effective approaches to energy-efficient renovation measures.

The main research question of this study is as follows:

- *Which factors influence organizational decision-making when technically feasible energy-efficiency measures are not implemented despite their potential?*

Additional sub-questions are investigated to address the main question:

- *Which factors constitute the primary barriers and drivers influencing decision-making processes related to the implementation of energy-efficiency measures?*
- *Which organizational practices and structures contribute to the development and implementation of energy-efficiency measures?*
- *To what extent can profitability be achieved through attic insulation, when accounting for risk mitigation measures, based on the case study of Sankt Eriksgatan 4?*

1.4 Limitations and Delimitations

This study is constrained by several limitations. Furthermore, several delimitations were necessary to ensure a manageable and focused scope of inquiry. Consequently, these factors may have affected the study's outcomes and the extent to which the findings can be generalized.

In terms of limitations, the building's character poses a challenge, as necessary blueprints are not always available and assumptions and comparisons with other buildings from approximately the same time had to be made. The study is further constrained by the limited time frame of the thesis project, which was conducted over 20 weeks.

Furthermore, the delimitations are restricted to the Swedish context as the interviewed companies are Swedish. This study also focuses on the Swedish climate, more specifically conditions of the Gothenburg region. Only the specific project building and the related attic dimensions are investigated. The profitability calculations do not include labor costs for either the mitigation measures. Additionally, the maintenance costs for the mitigation measures are not considered. The energy and electricity prices used in the study are based on district heating costs and fixed electricity contracts collected during a specific time period. As energy prices fluctuate over time, using price data from another period may yield different outcomes. Additionally, the economic assumptions used in the study are based on an organizational perspective and reflect conditions relevant to companies rather than private households. The study focuses solely on the multistory rental buildings.

1.5 Ethical Consideration

Since this report includes insights from participating companies and professionals, ethical considerations were important throughout the research process. The interviewees were informed about the purpose of the study, the general themes of the interviews, and how the collected material would be used. Participation was voluntary, and interviews were recorded only with respondents' consent.

Careful consideration was given, in consultation with the interviewees, to determining what information could be included in the report. To encourage transparency and reduce the risk of respondents withholding relevant information due to concerns regarding corporate representation or marketing, both the companies and interviewees have been anonymized throughout the report. Furthermore, no direct quotations are attributed to individual respondents in order to ensure that no statements can be linked to a specific company or person.

The collected material was used only for the purpose of this thesis and was handled with care during transcription, analysis, and reporting. By applying this approach, the study aimed to protect the respondents while also enabling a broader and more accurate representation of the empirical findings.

1.6 Sustainability

From a sustainability perspective, this thesis contributes to efforts across all three dimensions: social, economic, and environmental.

From a social perspective, the study contributes by deepening understanding of how energy-efficient buildings can reduce energy demand, thereby creating more cost-effective living conditions for both tenants and property owners. The study also highlights the importance of cooperation and clearer allocation of responsibilities between tenants and property owners to enable long-term, sustainable, and energy-efficient solutions. In addition, the study contributes to social sustainability by raising awareness of how energy-efficiency measures can be evaluated and implemented to promote long-term building quality and sustainable living conditions for future generations.

From an economic perspective, the study identifies several barriers in the real estate sector related to short-term economic prioritization and organizational decision-making. By increasing understanding of these barriers, the findings may support organizations in developing more effective working practices and decision-support systems that reduce energy demand, lower operational costs, and improve long-term competitiveness.

Environmentally, the study contributes by addressing barriers limiting the transition toward more energy-efficient building stocks. Since existing buildings account for a significant share of both energy consumption and climate impact, there is considerable potential for improvement. By investigating the organizational and institutional factors hindering the implementation of energy-efficiency measures, the study may support the development of strategies that contribute to reduced energy consumption, lower greenhouse gas emissions and a more sustainable built environment.

1.7 AI Disclosure

Generative AI tools were used during the preparation of this thesis to support linguistic refinement, improve readability, discuss the formulation of interview questions and explore additional perspectives during the research process. The tools were primarily used as a writing and reflection aid, for example to identify possible angles, improve clarity and reduce the risk of overlooking relevant viewpoints during discussions between the authors.

AI-generated suggestions were not used as independent sources of information. All theoretical content, empirical interpretations, simulation results, calculations, and conclusions were developed, reviewed, and verified by the authors against relevant literature, collected data, and project-specific material. Any AI-generated text was critically assessed, modified, and integrated only where considered appropriate.

The responsibility for the research design, data collection, analysis, interpretations and conclusions remains entirely with the authors.

2
Methodology

This study applies a mixed method approach by combining qualitative and quantitative methods through a literature study, interviews, calculations and simulations. A mixed methods approach was considered suitable since the study aims to examine both the technical and economic performance of the proposed measure, as well as the organizational and practical factors that influence its implementation. According to Johnson and Onwuegbuzie, mixed methods research is useful because it combines the strengths of qualitative and quantitative approaches while reducing the limitations associated with using only one method (Johnson & Onwuegbuzie, 2004). Similarly, Creswell and Plano Clark emphasizes that mixed methods research can provide a more comprehensive understanding of complex research problems by integrating different types of data (Creswell & Plano Clark, 2018). In this study, the qualitative parts, consisting of the literature study and interviews, provide contextual understanding and insights from both company representatives and external experts. The quantitative parts, consisting of calculations and simulations, provide numerical results that support the technical and economic evaluation. By combining these methods, the study enables triangulation, in which findings from different sources can be compared and used to strengthen the credibility and validity of the results (Jick, 1979).

2.1 Literature review

The literature review was conducted to identify existing research on the subject, establish a theoretical foundation, and support the development of the analytical framework used in this study. According to Snyder, 2019, literature reviews are useful for synthesizing previous research and creating an overview of existing knowledge. Snyder also emphasizes that literature reviews should follow a clear methodology in order to improve their quality, transparency and trustworthiness. Therefore, the literature review in this study was conducted in a structured manner, using defined databases, keywords and selection criteria (Snyder, 2019).

The sources were obtained from various scientific databases, including Scopus, Web of Science and Google Scholar. Keywords used in the search for articles were **Renovation, Attic, Humidity, Insulation, Sustainability, Energy-efficiency**. The publication year was also used as a filtering criterion, with a focus on more recent studies. The final selection consisted mainly of papers published between 1993 and 2026, with one older source from 1974 included due to its relevance to the topic.

Careful consideration was given to the use of older sources as some information may be outdated. In several cases older information was therefore compared with more recent sources before being used in the report. After the articles had been identified they were assessed to determine their relevance to the thesis. This was mainly done by reading the abstracts and skimming the full texts. Once relevance had been established, key findings were presented and used to support the study's theoretical foundation and analysis.

2.2 Interview study

To conduct the interview study, relevant companies and individuals were identified through an initial mapping of major Swedish real estate companies. These companies were subsequently evaluated based on their relevance to the study and their potential to contribute meaningful insights. Relevant employees were then identified to facilitate direct contact. Interview participants from Higab were recommended internally and included in the final selection.

Furthermore, the invitation emails were prepared to outline the study's aim and the general themes of the interviews. Participants were offered the option to conduct the interview either remotely or in person, depending on geographical considerations. Invitations were primarily distributed directly via email. In total, seven interviews were conducted, including three representatives from the same company who held different professional roles and contributed insights from their previous work experience.

Role	Type of company
Energy Analyst	Private property organization
Energy Strategist	Private property organization
Unit Manager	Publicly owned property organization
Project Manager	Publicly owned property organization
Technical Property Manager	Private property organization
Energy Efficiency Specialist	Private property organization
Energy Engineer	Publicly owned property organization

Table 1: Description of the respondents' roles and organizations

The interview questions were developed by analyzing the intended outcome of the interviews. This ensured that all questions had the potential to generate relevant and useful results for the study. Semi-structured interviews were chosen because they provide a balance between structure and flexibility. The use of an interview guide ensured that the same central themes were covered in each interview, while the format still allowed follow-up questions when relevant. This made it possible to collect comparable data from different respondents, while also gaining deeper insight into their perspectives and experiences. Kallio et al. (2016) state that semi-structured interviews are a commonly used qualitative method and that a systematically developed interview guide can strengthen the relevance and quality of the collected data (Kallio et al., 2016).

2.2.1 Transcription and thematic analysis

All interviews were recorded with the consent of the interviewees. The audio recordings were reviewed in parallel with the transcriptions generated using the Microsoft Teams transcription function. To ensure familiarity with the data, the transcripts were read multiple times while listening to the recordings, allowing for an in-depth understanding of the material.

The analysis of the collected material was conducted using an inductive approach, meaning that themes and coding were derived from the data. An inductive approach ensures that the findings are derived directly from the data rather than forcing a predetermined result. It further captures important aspects of the material and allows new themes and patterns to emerge that might not have been expected. It further indicates that the material is coded by developing themes for each sentence or paragraph. Moreover, the text segments and themes are further grouped into broader themes (Azungah, 2018).

The selection of relevant information was guided by the study's research questions, so only data that contributed to understanding the research aim were coded. The material was divided intentionally to generate more themes in the initial stage. These themes were subsequently reviewed against the full transcription through an iterative process and refined, merged, or reduced where necessary. This ensured internal coherence within the themes as well as distinctions between them. This process was repeated for each interview. Thereafter, themes that appeared across multiple interviews were grouped together in order to identify similarities and deviations within the dataset.

2.3 Simulations

The simulations will provide data reports from two scenarios with and without the renovation measure to see the effects and assess the risks that need to be taken into account. The results will be foundational for assessing whether this project/case could be beneficial and how the organizational work process affects the potential of renovation measures. The renovation measures added to the case will be added in varying dimensions to fully get the picture of when or if it can be economically profitable in terms of reduced energy consumption.

Scenarios:

- No supplementary insulation
- Supplementary insulation (SI) in the floor construction - changing parameter insulation thickness

For the simulations, the IDA ICE 5 (IDA Indoor Climate and Energy) tool, developed by EQUA, was used. It is a building simulation tool used to model and evaluate a building's energy performance, indoor climate, HVAC systems, and control strategies. The tool enables detailed simulations of how a building is expected to perform in practice, supporting decisions related to energy-efficiency, comfort, system design, and optimization (EQUA, n.d.).

2.3.1 Measurements

In order to create the model, measurements have to be made of the building. The drawings provided for the building are scanned from the physical originals and do not retain a functional scale. Adobe Acrobat Reader 2020 was therefore used to scale the PDF drawings for measurement purposes. This was done by first measuring a known distance, then calibrating and setting the scale. After this, the measurement tools in the PDF reader was used to extract the relevant measurements. Additional measurements that were not provided by the "case/project" will therefore be estimated or assumed based on available knowledge and information from external sources.

2.3.2 Input in Simulation tool

Material
After creating the model using the measurements from the available drawings, specific data had to be entered regarding the building elements. Firstly, the slab was changed in order to be more accurate with the case building. The information of these designs was provided to us by the case company. The appropriate material was then chosen from the database included in IDA ICE.

The case building, as stated, was built in 1810, which means its elements were constructed according to that time's standards. Due to the lack of documentation regarding the building, assumptions will be made in accordance with the construction standards of the time period. Firstly, the roof construction is a low-pitched gable roof and uninsulated. It is covered with both standing-seam metal roofing and sheet-metal cladding on three roof slopes, and clay tiles in five different formats on the remaining slopes. The roof consist of metal sheets or clay tiles that are supported and fastened to the wooden roof construction. Under the main metal roof, a thin sheet metal flashing 0.6 mm thick is installed. A wooden ridge board is installed along with a wind-barrier felt. The exterior walls consist of solid masonry constructed to a 1.5-brick thickness using Danish-format bricks, corresponding to a wall thickness of 382 mm, including mortar. The wall is fully solid without cavity or insulation. Both the interior and exterior surfaces are finished with lime-based plaster, with the exterior having a thicker layer. The building contains a timber floor structure without insulation.

Following is the construction of the exterior walls in the order from interior to exterior:

Material	Thickness [m]
Lime, Sand	0.008
Brick	0.114
Mortar	0.012
Brick	0.228
Lime, Sand	0.02

Table 2: Exterior Walls Materials and Measurements

The next change was in the structure of the roof construction from interior to exterior, the measurements and structure were found in the blueprints:

Material	Thickness [m]
Wood	0.03
Air vertical 45	0.048
Tiles (roofing) clay	0.02

Table 3: Roof Construction Materials and Measurements

Furthermore, the floor structure was adjusted between the top floor and the attic. The information provided was that the structure is made of wood, and above it is a layer of bricks two units thick. The wood structure is inserted as a homogeneous material in the model with a $\lambda - value$ adjusted to 0.07 $W/(m\,K)$ based on data of a similar construction provided by Rockwool, with the assumption that the building is old (Rockwool, n.d.). The structure is displayed from interior to exterior:

Material	Thickness [m]
Wood Structure	0.1
Brick	0.108

Table 4: Floor Construction Materials and Measurements

Ventilation system parameters
The ventilation system parameters were taken from the actual building and it was equipped with a supply and exhaust air system without heat recovery with assumed constant air volume (CAV).

Heating and cooling
Parameters for the heating and cooling systems were provided by the building's energy performance certificate. Heating is provided to the building by district heating, and as this report does not consider cooling, no cooling for ventilation was included. The heating demand is regulated by the minimum operative temperature for thermal comfort, which is 20°C and was applied for all areas (Boverket, 2018). To achieve this operative temperature, the setpoint temperature in IDA ICE was set to 21°C.

Occupancy load
The number of people varies depending on the activity within the building. The restaurant and industrial activity were assumed in the design occupancy load factor in consideration of fire safety (Boverket, 2018). The restaurant was based on a fac-

tor of 1.0 (people/m^2), and the area was determined by deducting the area for loose fittings. The level of industrial activity was in the same occupancy class as offices and was therefore assumed to use the same load factor, 0.1. The round-the-clock care was not similar to any of the activities mentioned in the document and numbers were instead taken from the value of the number of people in residential apartments by Boverket which was 1.42 people per room (Boverket, 2017).

Lightning
Since only facility electricity is included in the energy use of a building, lighting is assumed to cover corridors, stairwells, and common areas. According to Sveby, an installed lighting power density of $4\,W/m^2$ can be assumed for these areas. The total area of facility lighting was calculated to be $791.75\,m^2$, which corresponds to approximately 396 lamps of 8 W each (Sveby, 2013).

Equipment
When estimating the equipment for the industrial activity, it was assumed to serve a similar function to an office because there is a lack of data for the specific industrial activity. Equipment was then estimated to $12\,W/m^2$ during the day and $2\,W/m^2$ during the night, which was calculated according to the schedule. The same estimations were made for the restaurant with $500\,W/m^2$ for the kitchen and $47\,W/m^2$ for the rest of the area during the day. During the night, it was estimated at $50\,W/m^2$ and representatively $6\,W/m^2$ during the night. For the care activity, there were no usage data for the appliance, and therefore assumptions were made that it had approximately half the electrical power demand of the industrial activity. This resulted in an estimated value of $6\,W/m^2$ during the day and $1\,W/m^2$ during the night.

Airtightness
ACH (air changes per hour) is the unit used to measure airtightness, representing unintentional air leakage through the building envelope, modeled as wind-driven flows (EQUA Simulation AB, n.d.). As no measure was available for the case building, a value of 1.5 ACH was assumed based on typical values for older buildings with relatively poor envelope sealing of 1.0 -2.0 (HVAC Systems Encyclopedia, n.d.). The attic operates in different conditions than the indoor zones, as it is highly thermally connected to the outdoor environment and has significantly higher ventilation rates. The ACH is based on a study in which ventilation rates were measured in the attic of 10 different houses over a two-week period. The average of these measurements was 11.22 ACH, which was used for this study (Møller et al., 2019)

Extra energy and losses
For the generator efficiencies for standard plant and ideal heaters and coolers, district heating was selected for both heating and domestic hot water.

Thermal bridges
The treatment of thermal bridges in the model is based on the standard SS-EN ISO 14683:2017, which provides simplified methods and default values for estimating linear thermal transmittance (Ψ-values) in building constructions. According

to the standard, thermal bridges should be accounted for by adding a linear heat-loss term proportional to the length of each junction and its corresponding Ψ-value, contributing to the overall transmission heat transfer coefficient. In this study, the building envelope is uninsulated. As a consequence, the relative impact of thermal bridges is reduced compared to insulated constructions, since the contrast in thermal resistance between adjacent building elements is smaller. Following the guidance of the standard, which allows the use of simplified methods and adapted values when detailed information is not available, the Ψ-values used in the model have been adjusted accordingly.

The following are the values for the thermal bridges:

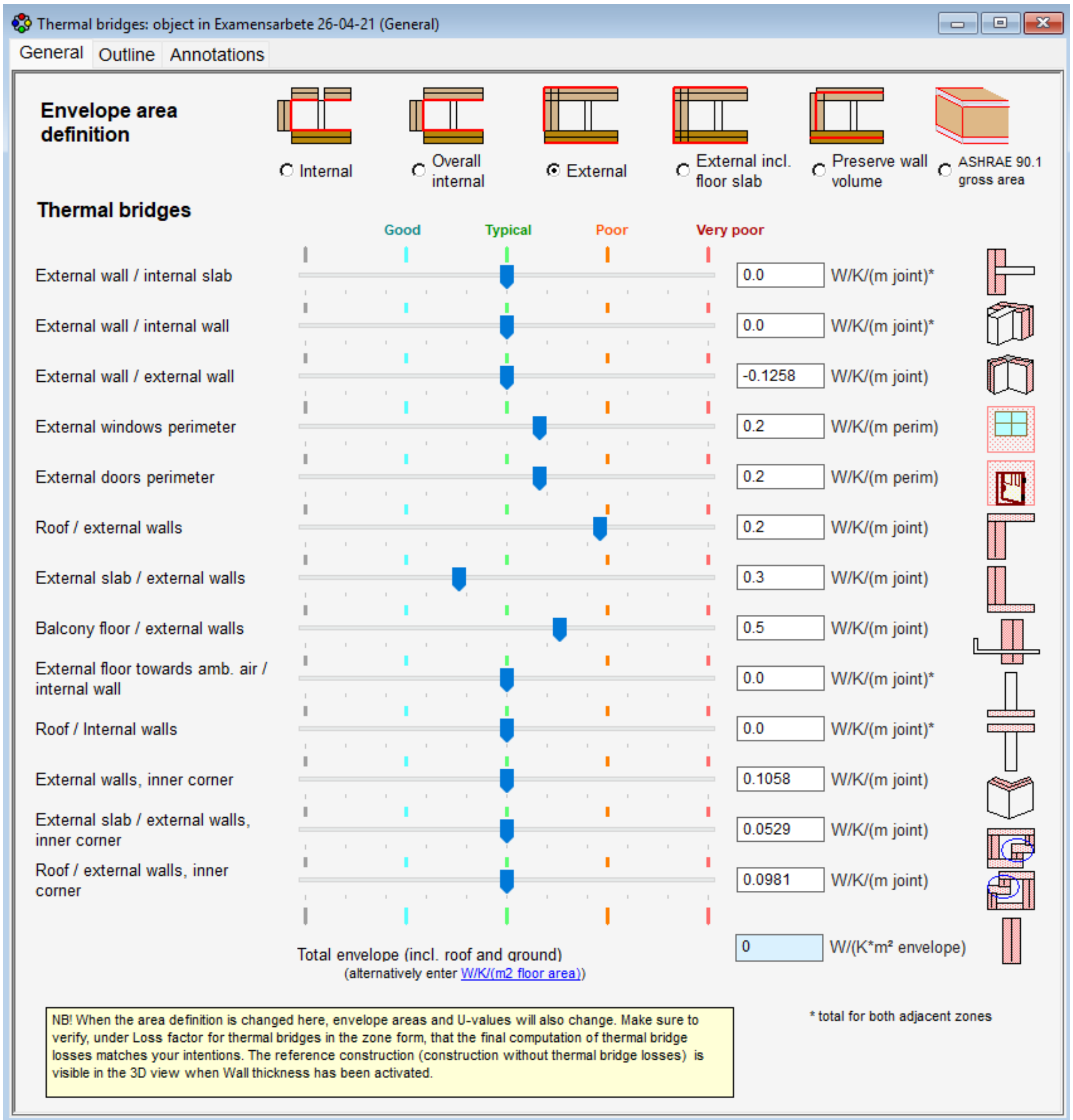

Figure 2: The values of thermal bridges in IDA ICE.

2.4 Insulation of the Attic

When simulating scenarios with added insulation in the attic floor structure, the insulation thickness was increased incrementally in steps of 100 mm. The existing brick layer was first removed and replaced with lightweight insulation. An initial thickness of 100 mm was applied and simulated, after which the process was repeated in successive increments up to a total insulation thickness of 600 mm.

2.5 Calculations

The manual calculations were carried out after the simulations had been completed. They were based on the most commonly used heating sources in Gothenburg, with cost estimates calculated across the full range of typical price variations. This will demonstrate whether a price range exists in which the renovation becomes financially viable, taking into account both the initial investment and the ongoing operational costs.

The energy cost was received from Göteborg Energi, which is the local district heating provider in Gothenburg. The cost used was based on the mean cost for larger multi-family dwellings. Thus, the price used was 0.793 SEK per kWh (Göteborg Energi, 2026b). The cost for the electricity was also received from Göteborg Energi from the same category, which is used for the calculations of the operational costs for the dehumidifiers. The cost used was 0.93 SEK per kWh, which was based on the fixed electricity contract from Göteborg Energi, 2026a, the retrieval date was in the middle of April 2026.

The market for suitable dehumidifiers for operation in the building's attic climate conditions was thoroughly searched. A variation of fifteen different models was found to be suitable, meaning they can operate at lower temperatures. The variation of dehumidifiers was exclusively sorption and thermal dehumidifiers. Of these, eight were found to be economically and technically feasible and were subsequently used in the study. The investment cost was then calculated to the volume of the attic. The relevant information was found on the respective product's website through the product specification. Afterward, a mean value of the investment cost was calculated in order to cover the full range of products.

Based on the simulated relative humidity levels in IDA ICE and an assumed critical relative humidity threshold of 65% RH found in the literature review. This threshold corresponds with the limit for fungal growth. As humidity is not always above the threshold, adjustments are needed to more accurately reflect the dehumidifiers' operating power. The average consumption per square meter was found from a manufacturer's product specifications. This was $3.5\,\mathrm{SEK/m^2}$ for thermal dehumidifiers and $7\,\mathrm{SEK/m^2}$ for sorption dehumidifiers (TrygghetsVakten, n.d.) (Trygghetsvakten, n.d.).

The insulation price had to be calculated for the area and amount needed. This was done by first finding the price of the same type of insulation from different manufacturers. The specific insulation material used was rock wool and there were two main manufacturers in Sweden. When the price was calculated for each product, a mean value was calculated and used to determine the cost and profitability.

When calculating profitability with regard to operational and investment costs, three methods were used in determining the profitability. These were *Return On Investment* (ROI), *Payback Period* and *Yearly Return*. The payback period measures how long it takes for the initial investment cost to be recovered through generated savings or profits. ROI evaluates the profitability of the investment in relation to its cost, providing an indication of the overall financial return. Since ROI is strongly influenced by the chosen time horizon, it has been calculated over three different periods: 1 year, 10 years, and 50 years. This allows both short-term and long-term profitability to be assessed and compared.

2.6 The Synthesis of Results

After the literature study, interviews, calculations and simulations had been conducted the results were compiled and analyzed together in a synthesis. The purpose of the synthesis was to compare and connect the qualitative and quantitative findings in order to obtain a more complete understanding of the studied measure. The quantitative results from the calculations and simulations were used to assess the technical and economic performance, while the qualitative findings from the interviews were used to understand practical, organizational and decision-making related factors. By combining these results, the synthesis made it possible to evaluate whether the measure was technically and economically feasible and which factors may influence its implementation in practice.

2.7 Validity and Reliability

The validity and reliability of this study were considered in relation to the mixed-methods research design where interviews, literature, simulations and calculations were combined. The use of several research methods strengthened the validity of the study by enabling triangulation because of the qualitative findings from the interviews could be compared with the technical and economic results from the simulations and calculations. This reduced the risk of relying on a single source of evidence and contributed to a broader understanding of the studied problem.

For the interview study, validity was supported by using a semi-structured format, which ensured that the same main themes were addressed in all interviews while still allowing follow-up questions. The interview questions were continuously refined during the project as the understanding of the topic developed. This made later interviews more precise and relevant, although it may have affected the consistency between interviews. The reliability of the qualitative analysis was strengthened by reviewing the transcriptions together with the recordings, reading the material several times, and applying the same general coding and thematic analysis procedure to each interview.

The validity of the simulations and calculations depends on the accuracy of the input data and assumptions used. Since complete documentation for the case building was not available, assumptions had to be made regarding construction materials, airtightness, thermal bridges and attic ventilation. Similarly, the profitability calculations were based on selected energy prices, product costs and operational assumptions which may vary over time. Therefore, the quantitative results should be interpreted as estimates under the selected conditions rather than exact or universally applicable results. However, by documenting the assumptions and calculation steps, the study's transparency and reliability were strengthened.

3

Theory

The theoretical framework will guide the analysis and interpretation of the study through different theoretical lenses. This provides a broader understanding of the subject from multiple perspectives throughout the thesis.

3.1 Knowledge Management Theory

This theoretical foundation provides a lens for analyzing how knowledge is created, transferred and embedded within organizational structures.

Knowledge Management (KM) is based on a clear difference between information and knowledge. According to Baskerville and Dulipovici, 2006, organizational knowledge can be defined as information embedded in routines and processes that enable action. This definition shows that knowledge is not only structured data or stored information, it is also information that has been understood, given context and built into the organization's ways of working so that it can be used to take action. Knowledge is described as a human quality that resides in individuals' minds and requires identification, interpretation, and internalization. At the same time, knowledge extends beyond individuals and becomes a part of organizational routines, structures and norms. Furthermore, knowledge is dynamic and context-dependent and not static as it evolves through interaction, interpretation and application(Baskerville & Dulipovici, 2006; Wiig, 1997). Castaneda & Ramírez Rojas support this by describing knowledge sharing as a social process through which individual knowledge becomes available to others and can be used by the organization. They also state that knowledge sharing supports decision-making and organizational performance and that organizational conditions such as culture, training, strategic clarity, and IT support influence whether knowledge sharing occurs effectively (Castaneda & Ramírez Rojas, 2024).

In the KM literature, knowledge is multidimensional and there exist different forms that each require different management approaches. There are several important distinctions to make.

- **Know-what versus know-how**: Meaning factual knowledge versus practical skills.
- **Tacit versus articulated (explicit) knowledge**: This is experience-based and difficult to formulate knowledge versus codified and transferable knowledge.

- **Professional versus firm-specific knowledge**: transferable expertise versus organization-specific knowledge.

These distinctions are important because they show the different governance mechanisms and management practices. Tacit knowledge requires social interaction for transfer, while articulated knowledge can be stored, distributed and reused through formal systems. Similarly, firm-specific knowledge can create a source of competitive advantage, whereas professional knowledge can be acquired externally (Baskerville & Dulipovici, 2006; Nonaka & Takeuchi, 1995).

A very common way to observe knowledge creation and conversion in KM is the "Knowledge Spiral" and the SECI model created by Nonaka and Takeuchi, 1995. Central to their framework is the distinction between tacit and explicit knowledge shown above, where tacit knowledge is personal, experience-based, and difficult to formalize, while explicit knowledge is articulated, codified, and transmitted in systematic language. Organizational knowledge creation occurs through the conversion between these two forms. **Figure 3** describes four modes of knowledge conversion: Socialization, Externalization, Combination, and Internalization (SECI) (Nonaka & Takeuchi, 1995).

Although several foundational contributions to KM originate from the 1990s, the distinction between tacit and explicit knowledge remains central in current KM research. Recent studies continue to emphasize that tacit knowledge is experience-based, contextual and difficult to formalize, while explicit knowledge can be codified and transferred through documents, databases and formal systems. Current research also shows that organizational culture, strategic clarity, training and information technology influence how knowledge is shared within organizations, although tacit knowledge remains more dependent on social interaction and trust than explicit knowledge (Castaneda & Ramírez Rojas, 2024; Pasipamire, 2025)

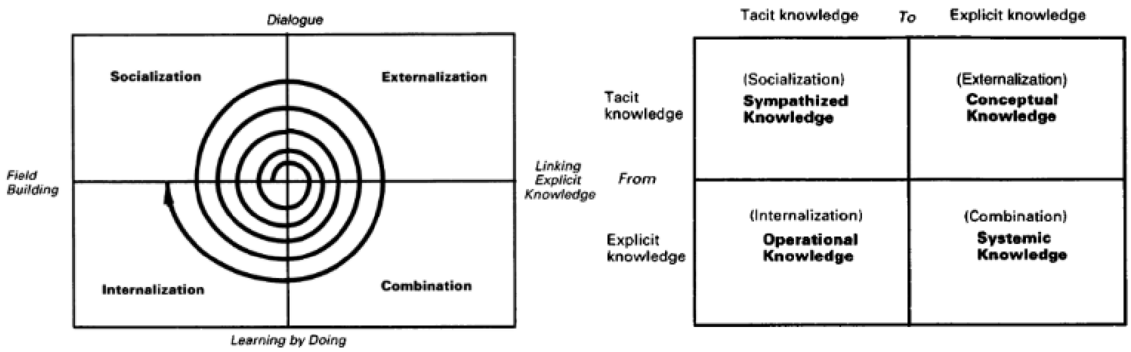

Figure 3: Knowledge spiral and contents of knowledge created by the four modes (Nonaka & Takeuchi, 1995).

Tacit insights regarding customers' preferences and expectations may at first exist as intuitive, experience-based understanding within individuals. Through socialization, such experiential knowledge is shared among team members through interaction and dialogue. In the externalization phase, these insights are expressed and translated into explicit concepts, such as a formalized new product idea or design specification.

This conceptual knowledge then guides the combination phase, where different parts of explicit knowledge are integrated. The new product concept may direct the systematic integration of the newly developed and existing component technologies to construct a prototype. During internalization, this systemic knowledge is applied in practice. Employees learn through implementation, testing and production activities, transforming documented procedures and technical designs into operational know-how required for large-scale manufacturing. Explicit knowledge thus becomes internalized as tacit competence embedded in routines and skills(Nonaka & Takeuchi, 1995).

The process does not end there however, experience-based operational knowledge created from production and use often starts a new cycle of knowledge creation. Users' tacit experiences that are gained through the use of a product can be shared, leading to improvements and new innovations. Therefore, the SECI process functions as a continuous and dynamic knowledge spiral rather than a linear sequence. The knowledge spiral represents a dynamic and expanding process in which individual tacit knowledge is converted, amplified and institutionalized across increasing ontological levels. Through SECI cycles, knowledge grows in scope and complexity, enabling organizational learning and innovation. The spiral shows both the transformation between tacit and explicit knowledge and the expansion of knowledge across organizational boundaries see **Figure 4** (Nonaka & Takeuchi, 1995).

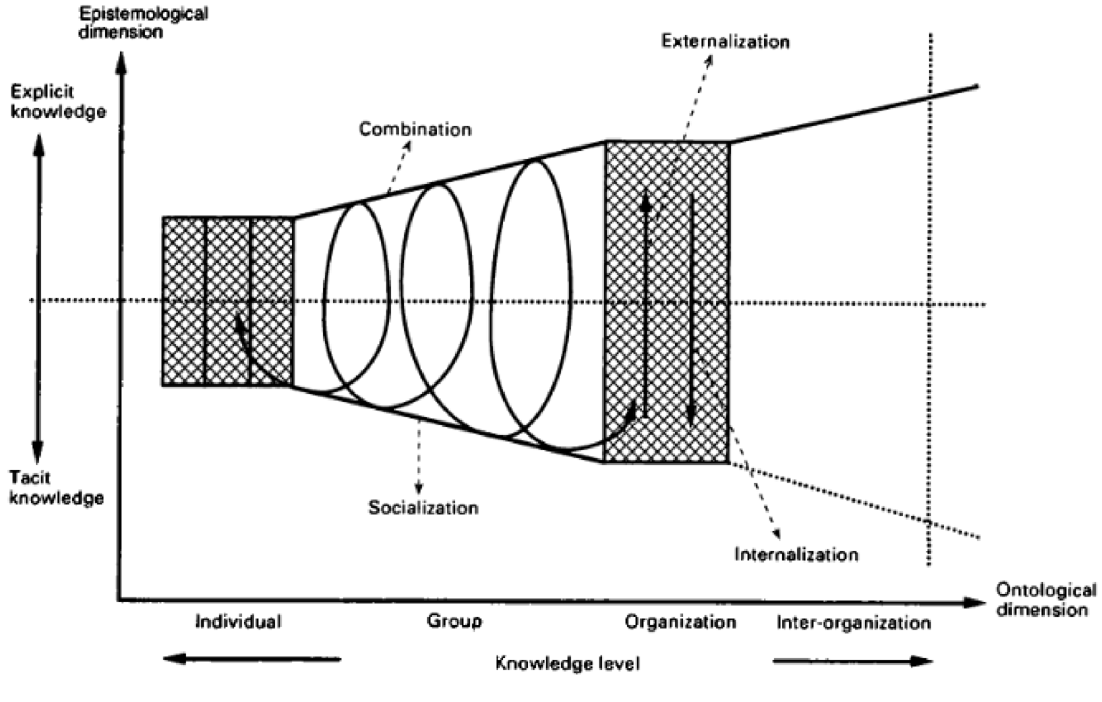

Figure 4: Spiral of organizational knowledge creation (Nonaka & Takeuchi, 1995).

3.2 Institutional Theory

In Chapter 8 of The SAGE Handbook of Organizational Communication (John C. Lammers & Mattea A. Garcia, 2013), institutionalization is described as the central process within institutional theory, referring to how institutions establish and reinforce patterns and behaviors across the organizational field. Furthermore, institutional theory is structured around three fundamental concepts: legitimacy, rational myth and isomorphism. Legitimacy refers to the social acceptance gained through adherence to regulatory and normative organizational policies, together with cognitive norms and expectations. In strongly regulated environments, legitimacy constitutes an important organizational resource, as external expectations and institutional pressure shape organizational behavior, encouraging conformity. To attain legitimacy, organizations adopt rational myths aligning their practices to establish these norms and expectations. Over time, these alignments will spread across organizations, seen as standards within an organizational field (John C. Lammers & Mattea A. Garcia, 2013). The last fundamental concept is isomorphism, describing how organizations tend to gradually mimic according to structure, working practices and expression. These changes are less driven by effectiveness or competition but rather as a result of institutional pressure and the need for legitimacy (John C. Lammers & Mattea A. Garcia, 2013; Pirrolas & Correia, 2025). Since legitimacy plays an important role in competition and acceptance, organizations tend to adopt similar practices, which contributes to organizations becoming increasingly alike in how they operate (Pirrolas & Correia, 2025).

While traditional institutional theory mainly focused on stability and conformity, viewing institutions as rational systems shaped by rules and routines, the development of neo-institutionalism during the 1980s emphasized that institutions are influenced by power, conflict, and changing norms. Unlike traditional institutionalism, neo-institutionalism recognizes that institutions are not always rational or stable and that individuals within organizations can actively shape and transform them (Hwang, 2023).

Institutional inertia is a concept within institutional theory that explains how established and institutionalized routines shape organizational behavior over time and make organizational change difficult. A central aspect of institutional inertia is that organizations often struggle to explore and adapt to new working practices and changes as established and institutionalized routines tend to persist over time, even after major or rapid changes. These established routines continue to influence how new practices are understood, utilized and implemented within an organization. It can therefore hinder an organization's ability to adapt to new practices, structures and changes both in the short and long term (Aksom, 2022).

3.3 Bounded Rationality

The concept of bounded rationality was originally developed by Herbert A. Simon. The theory explains that human decision-making is influenced not only by goals and external conditions but also by cognitive limitations. Rationality depends on factors including the knowledge people possess, their ability to understand and predict consequences, manage uncertainty and recognize when they lack relevant information. Human rationality is therefore bounded by mental limitations. People cannot access all available information, often lack the time to gather and evaluate all relevant data, and are not capable of analyzing every situation perfectly. In addition, uncertainty about the future makes it difficult to determine the objectively best decision (Simon, 2000).

Even if Herbert A. Simon developed the theory of bounded rationality long before today's advanced technology and data accessibility, the theory remains highly relevant. As discussed in Bounded Rationality: Managerial Decision-Making and Data, the increasing availability of data does not eliminate uncertainty or guarantee fully rational decision-making. Instead large and complex amounts of information can exceed human cognitive capacity making it difficult for managers to interpret, evaluate and effectively use all available data. Consequently decision quality remains limited by cognitive constraints, reinforcing bounded rationality and satisfaction behavior rather than fully optimal decision-making (Pittenger et al., 2023). Additionally, the article emphasizes that access to data alone is not sufficient to improve decision-making. For data to create value organizations and managers must possess data literacy, analytical competence and the ability to interpret and communicate data effectively.

3.4 Theory Synthesis

The theoretical perspectives complement each other by explaining organizational behavior, knowledge processes and decision-making from different but interconnected perspectives. KM theory focuses on how knowledge is created, shared and embedded within organizational structures and routines, while institutional theory explains how organizational behavior and practices are shaped by institutional pressures, legitimacy, norms and established routines. Through concepts such as isomorphism and institutional inertia, institutional theory further explains why organizations tend to adopt similar practices and why established routines may persist over time, making organizational change difficult.

Bounded rationality complements these perspectives by explaining how cognitive limitations, uncertainty, and limited information-processing capacity influence organizational decision-making. While KM focuses on knowledge creation and institutional theory emphasizes institutional structures and pressures, Bounded rationality explains why organizations may still struggle to fully utilize available knowledge and make optimal decisions. Together, the theories provide a broader understanding of how knowledge, institutional structures, routines and human limitations influence organizational behavior and organizational change.

4
Literature Review

This chapter presents a literature review that aims to establish the theoretical foundation of the thesis. The review examines existing research, standards and technical studies relevant to the subject area, with the purpose of providing an overview of current knowledge and commonly applied methodologies. In general, the review of the literature serves as a basis for the methodological choices and analysis presented in subsequent chapters, ensuring that the work is grounded in established scientific and technical knowledge.

4.1 Renovation Decision Process

Renovation processes are often initiated due to technical refurbishment or maintenance needs, such as façade deterioration, poor indoor climate or other building-related deficiencies, rather than energy-efficiency being the primary trigger. This means that energy-efficiency improvements are often treated as secondary considerations within broader renovation projects (Palm & Reindl, 2016). Furthermore, they show that energy-efficiency in Swedish residential renovation is shaped by established renovation practices and by decisions made during the planning and design phase. Similarly, the European Comission describes renovation decisions as being triggered by factors such as maintenance, repair needs, available budget and building shortcomings (European Comission, 2019). Furthermore, Palm and Reindl state that it is the planning and design phase of a project that the most critical decisions about renovation measures are made. Once this phase is completed and procurement begins, the contractor mainly follows the predefined design. This means that energy-efficiency measures must be integrated early, otherwise they run the risk of not being implemented later in the process (Palm & Reindl, 2016). A report by Reindl supports this when explaining that since key decisions regarding renovation measures are made early in the planning and design phase, energy-efficiency measures need to be integrated at an early stage to avoid being excluded later in the process. Furthermore, Reindl emphasizes that building professionals and other actors involved in the early renovation phase influence which energy-efficiency measures are ultimately implemented (Reindl, 2020).

The existing building infrastructure such as HVAC shafts, ventilation systems, and district heating connections can significantly influence what renovation measures are considered feasible. This is due to the costly nature of these elements, thus renovation planning usually is adapted to the existing infrastructure. Professionals commonly rely on practical experience and previous used solutions when deciding what measures to implement. Measures that have worked in earlier projects are often reused without extensive analysis of their effectiveness in the specific building (Palm & Reindl, 2016).

4.2 Barriers for Energy-Efficiency

Several barriers to the implementation of energy-efficiency measures are addressed in the literature. The most discussed barriers were economically related, including investment costs, payback periods, limited access to capital, hidden costs and perceived financial risks (Carlander & Thollander, 2023; Meijer et al., 2009; Nair et al., 2017). Furthermore, low energy prices can reduce motivation for investments since the potential savings are considered too small to justify renovation measures (Nair et al., 2017). Behavioral and organizational barriers, including inertia, resistance to change and fear of new technologies are further highlighted (Carlander & Thollander, 2023). In addition, a lack of knowledge, technical competence and experience with energy-efficiency technologies are repeatedly identified as a major obstacle to implementation (Carlander & Thollander, 2023; Meijer et al., 2009). Sustainable renovation is also frequently constrained by weak financial incentives and the fact that many building products and solutions are primarily designed for new construction rather than renovation contexts. This challenge is further compounded by limited practical experience in the sector and a lack of well-established best practices. In addition, renovation projects are characterized by significant variability in building conditions and project contexts, which makes it more difficult to assess and select appropriate renovation measures. While this complexity may create opportunities for innovation and tailored solutions, it also introduces additional uncertainty as measures are not universally applicable across different buildings. Misconceptions about the cost-effectiveness of energy-efficiency measures may further hinder their implementation despite evidence that many such measures are economically viable (Meijer et al., 2009; Nair et al., 2017).

Furthermore, risks are identified as a major reason for the non-implementation of energy-efficiency measures and can be divided into three categories. The first category is external risks and reduction in electricity prices. The second category consists of business risks related to individual business economics and financing. The final category is technical risks, which involve concerns regarding technical performance and reliability (Carlander & Thollander, 2023). One could argue that many of these perceived risks are closely interconnected with the barriers mentioned, since uncertainties regarding economic outcomes, technical performance, organizational capabilities, and future conditions may discourage stakeholders from investing in energy-efficient measures.

4.2.1 Split Incentives

The split incentive dilemma between the landlord and the tenant is a known phenomenon. It refers to situations where the party responsible for investing in energy-efficiency measures is not the same party that benefits from the resulting energy savings. In rental buildings, property owners are typically responsible for financing upgrades such as insulation or heating system improvements, while tenants benefit from reduced energy costs through lower utility bills. As a result, landlords may lack incentives to invest since they do not directly receive the financial savings, while tenants are often unwilling to invest in buildings they do not own (Aydin et al., 2026; International Union of Property Owners, 2024). This phenomenon has therefore been identified as a major barrier to increasing renovation rates and improving energy-efficiency within the existing building stock (Aydin et al., 2026; Carlander & Thollander, 2023; International Union of Property Owners, 2024; Meijer et al., 2009).

To overcome this dilemma, the International Union of Property Owners (UIPI) (International Union of Property Owners, 2024) emphasizes the importance of institutional and policy-based solutions, arguing that market-based financial incentives alone may be insufficient to encourage the implementation of energy-efficiency measures. Suggested solutions include regulated rent adjustments linked to renovation investments, cost sharing between landlord and tenant, public subsidies, tax incentives and legal frameworks supporting renovation while protecting tenants from excessive rent increases. The article particularly emphasizes that both landlords and tenants should benefit from energy-efficiency measures in order to create stronger incentives for implementation (International Union of Property Owners, 2024).

4.3 Organizational decision-making

The organizational structure and resource allocation processes may influence how sustainability initiatives and energy-efficiency measures are implemented within organizations. Organizational structures can be either centralized or decentralized representing approaches of how decision-making and resource allocation are managed within organizations. Centralized resource allocation supports knowledge-sharing, organizational standardization and organizational control, which may strengthen long-term sustainability work and improve consistency across projects (Solberg, 2024).

On the other hand, decentralized structures may provide flexibility and adaptability by enabling decisions to be adjusted to local conditions and project-specific requirements. This structure may therefore be beneficial in situations where rapid adaptation and operational flexibility are important factors (Solberg, 2024).

Furthermore, proactive organizational behavior refers to working practices that initiate to improving current situations rather than passively adapting to the present circumstances. Meaning that organizations aim to take action, reduce uncertainty, integrate improvements, and identify opportunities. Proactive behavior is associated with improved organizational effectiveness, innovation, leadership and working performance. Rather than challenging established routines or seeking new opportunities, less proactive individuals tend to adjust themselves to existing circumstances and respond to change only when necessary (Crant, 2000).

4.4 Supplementary Insulation

Ventilated cold attics have traditionally been a good building practice in Nordic countries (Hansen et al., 2020). Due to increased energy-efficiency demands, measures for improvement must be implemented. Supplementary insulation in cold, ventilated attics is a simple and profitable measure to tackle this issue. It has the ability to be implemented on a large scale and thus can significantly contribute to reducing the energy use of a building or across a company's building stock (Hamid et al., 2023). Supplementary insulation is possible in two different ways. Insulating the roof of the building to make the attic itself insulated, or the floor (slab) in between the attic and the (living space) room beneath, which reduces the heat transfer between the two spaces (Meuwissen Gerritsen, n.d.).

According to the Swedish Energy Agency in older single-family houses approximately 15% of all heat losses go through the attic and the roof. Therefore, additional insulation is a relatively simple and profitable solution (Energimyndigheten, 2022). The research by (Hamid et al., 2023) shows that there is a clear reduction in heat losses by transmission through the roof after installation of additional insulation. On the other hand, they also state that in terms of an entire building, this reduction of energy losses is relatively small. However, this performance can be further improved through additional measures such as air sealing, the use of radiant barriers, installation of mechanical ventilation with heat recovery (MVHR), and the replacement of windows. When combined with these measures, attic insulation can reduce energy use by up to 70% (Hamid et al., 2023).

4.5 Humidity in Attic

Damage caused by moisture in attics has increased in Sweden during recent decades as a consequence of thicker insulation to the layer between the attic and the living space. This measure compromises the hygrothermal performance of the attic. Due to the insulation, the outer construction is subjected to a decrease in temperature which subsequently leads to a higher relative humidity, which in turn increases the risk of condensation (Hagentoft & Kalagasidis, 2010; Hansen et al., 2020; Harderup & Arfvidsson, 2013). Another source of condensation is that during calm, warm nights with clear skies, radiative heat losses can lower the temperature of the roof construction below the dew point of the outdoor air entering the attic. As a result, condensation may occur increasing the moisture content of the roof structure (Hagentoft & Kalagasidis, 2010; Harderup & Arfvidsson, 2013). Roppel and Lawton, 2013 states that much research points to the leading cause of moisture issues due to high humidity is the transfer of moist indoor air into the attic space from the humid indoor spaces. However, in coastal regions with a marine climate, the dominant source of moisture could be the outdoor air instead (Forest & Berg, 1993; Roppel & Lawton, 2013)

Climate predictions for Sweden indicate a warmer and more humid climate, which may also increase moisture-related problems in attics (Nik et al., 2012). In Sweden, absolute humidity varies seasonally and can reach levels up to three to four times higher during the summer than in winter according to the Swedish Meteorological and Hydrological Institute (SMHI, n.d.). Fluctuations in humidity levels may increase the difficulty and complexity of mitigation measures, as such measures must be capable of adapting to varying environmental conditions, including temperature, ventilation and absolute humidity. Furthermore, SMHI states that the annual mean of absolute humidity has shown an increasing trend over a 68 year period from 1951 to 2019, as illustrated in Figure 5. This can reduce the effectiveness of ventilation-based mitigation measures as the drying potential of the outdoor climate decreases with higher levels of moisture.

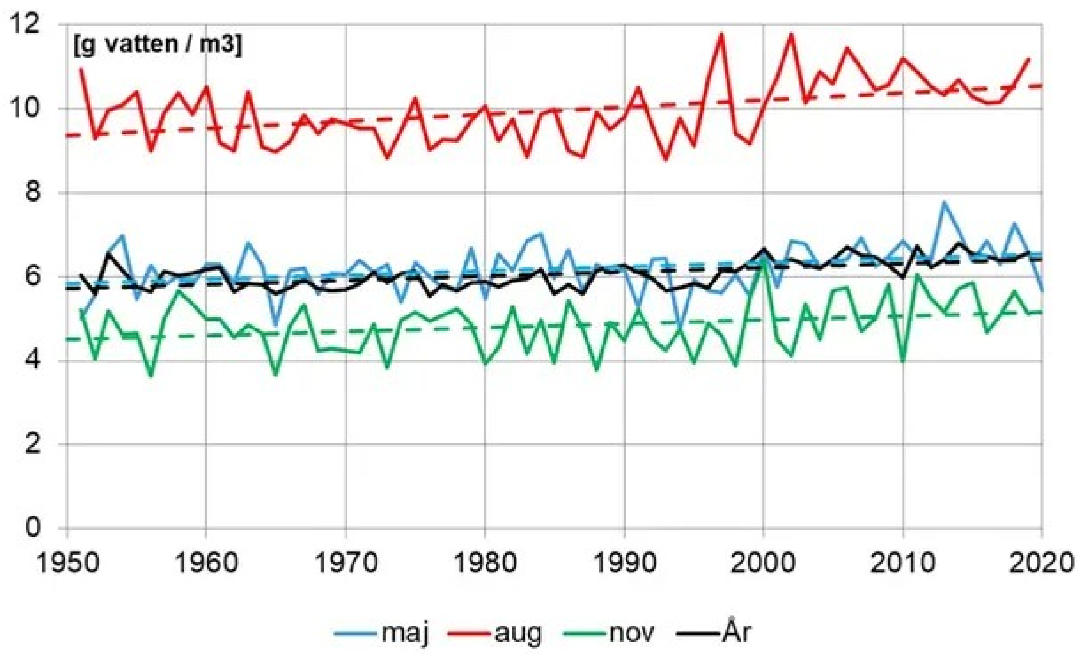

Figure 5: Observations of absolute humidity. Mean monthly and annual values for ten Swedish measurement stations at 06:00, 12:00, and 18:00 UTC (SMHI, n.d.).

Fungal Growth in Building Structures

Many different fungal species can cause bio-deterioration in buildings, however only two are considered particularly critical and destructive due to their ability to cause decay of structural timber, *Serpula lacrymans* (dry rot) and *Coniophora puteana* (wet rot). Suitable conditions for fungal growth are moisture rich environments mostly generated from condensation in limited ventilation or stagnant air. Favorable temperatures for growth range between approximately 0 and 25°C, with optimal growth occurring around 21-22°C. However, growth may still be present to temperatures slightly below freezing and up to 30°C although at reduced rates. Above the upper threshold, growth stops, and at temperatures around 37°C, it may lead to fungal death. Similarly, exposure to lower temperatures at -8 and -9°C may lead to the same result.(Elisabeth Gondel, 2025; Singh, 1994).

However, temperature alone does not limit the growth of wet rot, as the potential for fungal growth in building materials is also governed by the availability of moisture, which is commonly described using equilibrium relative humidity (ERH). Below approximately 65% ERH, fungal growth is hindered due to insufficient available moisture. As ERH increases, moisture availability rises, allowing a broader range of fungal species to grow and resulting in increased growth rates. At 100% ERH, water is freely available, creating conditions highly favorable for fungal growth. These fungal species have the ability to grow, settle, and proliferate while posing potential risks to indoor air quality and occupant health (Singh, 1994).

Mold Growth and Moisture Damage
According to Nik et al., 2012 the appearance of mold in attics is an indication of unsatisfactory hygrothermal performance. Due to the predicted increase in humidity in the Swedish environment mold problems in cold attics are declared one of the most vulnerable constructions. Condensation can be absorbed by the roofing material which in many cases is wood, this provides suitable conditions for microbiological growth (Nik et al., 2012; Valovirta et al., 2024). There is increasing evidence that buildings constructed in accordance with current building codes in cool marine climates are experiencing high incidences of moisture-related problems and mold growth in attics. Surveys indicate that approximately 60-80% of single-family houses in the Gothenburg region of Sweden which is characterized by a cool marine climate experience mold growth in attics (Hagentoft & Kalagasidis, 2010; Harderup & Arfvidsson, 2013; Roppel & Lawton, 2013).

For mold development, the minimum ambient humidity requirement is between a relative humidity of 80% - 95%. However, this is also affected by other factors such as ambient temperature, exposure time, and the type and surface conditions of building materials (Roppel & Lawton, 2013; Viitanen et al., 2010). Mold growth typically degrades the quality of the surrounding air by releasing spores and volatile organic compounds. A more advanced stage of moisture related deterioration is material decay, which can pose a serious threat to structural integrity depending on factors such as moisture content, material properties, temperature, and duration of exposure (Viitanen et al., 2010).

4.6 Mitigation Measures

The following section investigates literature regarding different mitigation measures that can be used in order to lower the risk of condensation.

4.6.1 Ventilation

Ventilation of attic spaces may be either mechanical or natural, however the ventilation rate must be carefully balanced to ensure adequate moisture control. Excessive mechanical ventilation can lower attic air temperature and increase pressure differences, potentially enhancing the transport of warm and humid indoor air into the cold attic through air leakage paths. Conversely, insufficient ventilation reduces the drying potential of the attic air, which limits moisture removal, causing humidity related problems (Hagentoft & Kalagasidis, 2016; Harderup & Arfvidsson, 2013).

Recent studies further indicate that attic ventilation cannot be evaluated independently of other design parameters, particularly the airtightness of the ceiling and vapor permeability of the roof. Airflow from the living space has been identified as the dominant moisture transport mechanism, often outweighing diffusion effects. In humid or maritime climates, outdoor air itself may represent a significant moisture source, meaning that increased ventilation can, in some cases, increase rather than mitigate moisture problems. Consequently, a fixed natural ventilation strategy is not always optimal and moisture-safe attic performance depends on a combined consideration of ventilation rate, air leakage control, roof permeability, and climatic conditions (Hagentoft & Kalagasidis, 2016; Richter et al., 2020).

4.6.2 Dehumidifiers

Dehumidifiers are a way to remove moisture from the local environment, as humidity in the air could cause great concerns, especially for the construction sector. It can also be used in order to improve indoor air quality in humid areas as well as reduce the deterioration of building elements. There are many different dehumidification methods available that have the same effect but use different means.

Heating Dehumidification
Heating can be used in the attic with the intention of increasing the temperature and consequently reducing the relative humidity and thus the risk of condensation (Harderup & Arfvidsson, 2013). This is done by heating or circulating hot dry air. The benefits of this method are the low investment and operational costs, the disadvantages with heated dehumidification are the high energy demand, it can also only reduce the local humidity (Wang et al., 2013).

Sorption Dehumidification
A sorption dehumidifier uses a rotating desiccant rotor to remove moisture from the air. As humid process air passes through the rotor, water vapor is adsorbed by the desiccant material. The rotor then rotates into a separate regeneration zone, where heated air removes the accumulated moisture and transports it outside as humid exhaust air. This continuous cycle allows dry air to be supplied to the space without relying on condensation-based moisture removal (DST, n.d.; Slayzak & Ryan, 2001).

5

Empirical Findings

This chapter presents empirical findings for both the semi-structured interviews, the simulations conducted for the case, and the calculations of expenses and savings.

5.1 Interviews

The interview results were analyzed and organized into themes based on recurring patterns of alignment and discrepancy in the respondents' statements. These themes were developed to highlight central patterns within the empirical material and address the research question of the report.

5.1.1 Drivers

The interviews revealed a broad range of drivers influencing the energy-efficiency work, shaped by a combination of external regulatory pressure, internal strategic objectives and economic incentives.

A majority of the respondents, six out of seven, highlighted internal energy and sustainability goals and targets as one of the strongest drivers. These internal goals established strategic direction and guided prioritization and investment decisions, while simultaneously creating continuity in the organizations' energy work.

Furthermore, a common pattern identified across five of the interviews was increasing energy prices as one of the major drivers of organizational development and implementation of energy-efficient measures. The respondents expressing this view were all employed within the organizations' energy departments, indicating that respondents directly affected by energy-related costs perceived rising energy prices as a particularly significant influencing factor. Increasing operational costs contributed to stronger incentives for organizations to optimize building performance by reducing energy consumption, thereby serving as a strong driving force for energy-efficiency initiatives.

Additional external regulations and policy requirements such as EU-related frameworks and governmental regulations increasingly influenced the decision-making was mentioned by five respondents. Taxonomy, CSRD, MEPS and other regulatory requirements were perceived as creating pressure on the organizations, similar to increasing energy prices. The interviewees expressed a strong awareness of ongoing regulatory developments within the sector and emphasized the importance of maintaining a proactive approach to prepare for increasingly stringent regulations.

5.1.2 Barriers

Despite the strong organizational driving forces and increasing interest in energy-efficiency, the interviews identified several barriers limiting the implementation and making the development more difficult. The barriers affecting the implementation of energy-efficiency measures were primarily associated with economic limitations, uncertainty, and split incentives.

Five respondents identified budget constraints and profitability requirements as key factors influencing the prioritization and implementation of projects and energy-efficiency measures. These constraints included strict investment frameworks, required rates of return and long payback periods which were often difficult to justify despite the potential long-term benefits.

In addition, respondents highlighted several other significant barriers, including customer requirements, uncertainty regarding future development plans and limitations related to building use or ongoing maintenance work. For example, planned future renovations or operational considerations were described as reducing the willingness to invest in certain energy-efficiency measures in the present, thereby contributing to delays or, in some cases, non-implementation.

One barrier that directly contributed to non-implementation of energy-efficiency measures was the contractual arrangement between property owners and tenants. Several respondents highlighted the issue of split incentives, particularly in cases where tenants are responsible for paying energy costs. Under such arrangements, property owners often lack sufficient financial incentives to invest in energy-efficiency improvements, because the resulting cost savings primarily accrue to tenants. Conversely, tenants typically have little incentive to invest in renovations or system upgrades extending beyond the tenants' space. This misalignment of incentives creates a deadlock that hinders the implementation of energy-efficiency measures.

Lack of competence was also described as strongly influencing the decision-making process. Three respondents referred to limited innovative culture, reliance on proven methods and insufficient technical understanding among decision-makers including customers or property managers. Competence gaps were perceived as contributing to sub-optimization and difficulties evaluating the full potential in different energy-efficiency measures.

Additionally, administrative and regulatory barriers emerged as a recurring theme. Four respondents identified building permit procedures, procurement regulations, and technical guidelines as factors that may delay, constrain, or hinder the implementation. Furthermore, respondents emphasized that more extensive renovation or energy-efficiency initiatives may trigger additional regulatory requirements, thereby increasing administrative complexity, implementation costs, and overall project uncertainty.

5.1.3 Organizational structures and working processes

The organizational structure and working processes within an organization may play an important role in how the decisions of energy-efficient measures are made and prioritized. Therefore, it is crucial to understand differences in decision-making structures.

A common organizational feature identified by five respondents was the presence of a centralized role with overarching responsibility for coordinating projects, supporting decision-making processes, and overseeing energy-related work across the organization. Furthermore, several respondents described how proposed energy-efficiency measures typically pass through multiple organizational levels before decisions can be made, involving actors such as managers, technical specialists, energy departments, and investment councils. The number and seniority of these decision-making levels were described as increasing in relation to the investment cost and scale of the proposed measure.

Another recurring theme was the integration of energy-efficiency work with planned maintenance and renovation activities. Four respondents specifically explained that organizations actively attempt to coordinate energy measures with already planned renovations in order to improve long-term effectiveness and avoid unnecessary future costs and operational disruptions. This includes combining energy measures with ventilation upgrades, facade renovations, window replacement or other maintenance work.

A key distinction in organizational working processes related to how energy-efficiency measures were identified and initiated where two primary approaches emerged from the interviews: a reactive approach and a proactive approach. The reactive approach was largely driven by existing issues, such as operational deviations, technical problems, or scheduled maintenance requirements, in which energy-efficiency measures were considered part of the necessary corrective actions. The proactive approach, however, involved systematically identifying buildings with high energy consumption, inadequate energy performance, or technical limitations in order to explore potential renovation strategies and energy-efficiency improvements.

An additional distinction identified across the interviews concerned how organizations prioritized and financed energy-efficiency projects. Although the implementation of energy-efficiency measures was largely constrained by budget limitations, as previously discussed, the allocation and management of financial resources differed between organizations. Some organizations operated with a centralized budget covering all energy-efficiency measures, while others allocated smaller, distributed budgets intended for minor-scale projects. Another approach involved first identifying the most suitable energy-efficiency measures and subsequently applying for the necessary funding, which then required approval from higher levels of management. Almost all organizations emphasized that investments and energy-efficiency measures were required to meet predetermined rate-of-return requirements in order to be considered financially viable for implementation, although the specific return thresholds varied between organizations. On the other side a few respondents mentioned the Totalmetodik from Belok as a method used within their organization. This approach involved evaluating packages of measures collectively rather than individually, allowing less profitable measures to be implemented alongside highly profitable projects.

5.1.4 Innovation, competence and knowledge integration

Knowledge sharing and integration, internally and externally, are important aspects of how expertise and experiences stay and circulate within the organization. In many cases from the interviews, the same collaborative platform was mentioned, which was Belok. This is a membership network where companies can access relevant information within the sector. Furthermore, five respondents mentioned that the internal and external integration of knowledge did not have an established system but relied on internal communication and knowledge sharing between colleagues. Some organizations had more formal meetings, seminars and workshops where experiences were shared. The majority lacked fully established systems to efficiently document and store lessons learned from previous projects.

The interviews had a varying approach towards innovation and technological development. Four respondents expressed caution with acting as pioneers and rather rely on proven technologies and established methods. Respondents described a preference for minimizing technical and financial risks prior to the large-scale implementation of new technologies and innovations. This often involved identifying appropriate opportunities to test and evaluate potential solutions through pilot projects or smaller-scale applications. Simultaneously, the respondents described ambitions to improve digitalization, automated monitoring systems, energy data analysis and technical optimization processes. One specifically mentioned ambitions to develop AI-supported systems capable of automatically identifying energy-related deviations in buildings.

5.2 Simulations

We present the results from the simulations, along with pictures of the simulation reports and our own calculations.

There were two types of simulation performed, one without any insulation and the other with insulation of varying thickness. The existing state of the case building is the scenario without insulation in the attic floor structure. Simulation of this scenario serves as the baseline for evaluating the measure. The key points of the measured data from the first simulation in which no insulation is used are shown in **Table 5**.

Energy Demand	261.4 kWh/m^2
Atemp	2558 m^2
Total Demand	668661 kWh/year

Table 5: Energy performance of the building without any measure.

A simulation was conducted to determine the humidity level in the attic before any insulation was installed. This was done in order to determine the baseline of humidity in the attic and to see whether the humidity increases after the measure and to what extent. The following **Table 6** illustrates the relative humidity without any insulation.

Month	Relative Humidity [%]
January	83.4
February	82.2
March	74.9
April	67.8
May	62.2
June	67.3
July	72.3
August	75.3
September	77.8
Oktober	84.1
November	82.9
December	82.9

Table 6: The simulated relative humidity for the attic over one year without insulation.

The next simulation used 100 mm of insulation. The total energy demand of the building and therefore the energy demand per square meter was reduced. The saved energy costs are then calculated with the energy prices, which gave the total savings. **Figure 6** shows the results of the first simulation, where the results from the scenario without insulation are also displayed. The energy demand has been lowered by 9.4 kWh/m^2. The savings amount therefore amounts to 24557 kWh/year, which corresponds to 19474 SEK/year.

21 degree setpoint , 100mm insulation

	Results without Insulation		Results with Insulation			
Energy demand	261.4	kWh/m^2	251.8	kWh/m^2		
Atemp	2558	m^2	2558	m^2		
Total demand	668661	kWh/year	644104	kWh/year		
Savings kWh					24557	kWh
Savings SEK					19474	SEK

Figure 6: Table showing the yearly savings of energy with 100 mm of insulation compared with no insulation.

The simulation for 200 mm is presented below in **Figure 7**, here also the total energy demand was reduced and the economic savings were increased. The energy demand was in this scenario 249.7 kWh/m^2. The saved energy is then 29929 kWh/year, in economical savings this is 23733 SEK/year.

21 degree setpoint , 200mm insulation

	Results without Insulation		Results with Insulation			
Energy demand	261.4	kWh/m^2	249.7	kWh/m^2		
Atemp	2558	m^2	2558	m^2		
Total demand	668661	kWh/year	638733	kWh/year		
Savings kWh					29929	kWh
Savings SEK					23733	SEK

Figure 7: Table showcasing the yearly savings of energy with 200 mm of insulation compared with no insulation.

Next is the simulation for 300 mm of insulation presented in **Figure 8**. There is a slightly decreased demand for energy and thus economic savings in this scenario. The energy demand of this is 249 kWh/m^2 which means total energy savings are 31719 kWh/year. Finally this creates a saving of 25153 SEK/year.

21 degree setpoint , 300mm insulation

	Results without Insulation		Results with Insulation			
Energy demand	261.4	kWh/m^2	249	kWh/m^2		
Atemp	2558	m^2	2558	m^2		
Total demand	668661	kWh/year	636942	kWh/year		
Savings kWh					31719	kWh
Savings SEK					25153	SEK

Figure 8: Table showcasing the yearly savings of energy with 300 mm of insulation compared with no insulation.

The next simulation is 400 mm of insulation which is presented in **Figure 9**. A slight reduction in energy demand is also evident here. The scenario with 400 mm of insulation creates an energy demand of 248.8 kWh/m^2. The energy savings here are 32231 kWh/year and the economical is 25559 SEK/year

21 degree setpoint , 400mm insulation						
	Results without Insulation		**Results with Insulation**			
Energy demand	261.4	kWh/m^2	248.8	kWh/m^2		
Atemp	2558	m^2	2558	m^2		
Total demand	668661	kWh/year	636430	kWh/year		
Savings kWh					32231	kWh
Savings SEK					25559	SEK

Figure 9: Table showcasing the yearly savings of energy with 400 mm of insulation compared with no insulation.

Moving on to the next simulation which was the one with 500 mm insulation shown in **Figure 10**. The performance at this thickness was worse than using a thickness of 400 mm and thus less profitable. In terms of energy demand 248.9 kWh/m^2 is the demand per square meter and the total saving is 31975 kWh/year. 25356 SEK/year is saved.

21 degree setpoint , 500mm insulation						
	Results without Insulation		**Results with Insulation**			
Energy demand	261.4	kWh/m^2	248.9	kWh/m^2		
Atemp	2558	m^2	2558	m^2		
Total demand	668661	kWh/year	636686	kWh/year		
Savings kWh					31975	kWh
Savings SEK					25356	SEK

Figure 10: Table showcasing the yearly savings of energy with 500 mm of insulation compared with no insulation.

The last performed simulation was of 600 mm insulation showcased in **Figure 11**. Similarly to the previous simulation, the profitability is further decreased with the additional insulation. Here 249.1 kWh/m^2 is the energy demand and 31463 kWh/year is saved. This corresponds to 24950 SEK/year.

21 degree setpoint , 600mm insulation						
	Results without Insulation		**Results with Insulation**			
Energy demand	261.4	kWh/m^2	249.1	kWh/m^2		
Atemp	2558	m^2	2558	m^2		
Total demand	668661	kWh/year	637198	kWh/year		
Savings kWh					31463	kWh
Savings SEK					24950	SEK

Figure 11: Table showcasing the yearly savings of energy with 600 mm of insulation compared with no insulation.

The relationship between thickness and energy consumption can be seen in the following figure.

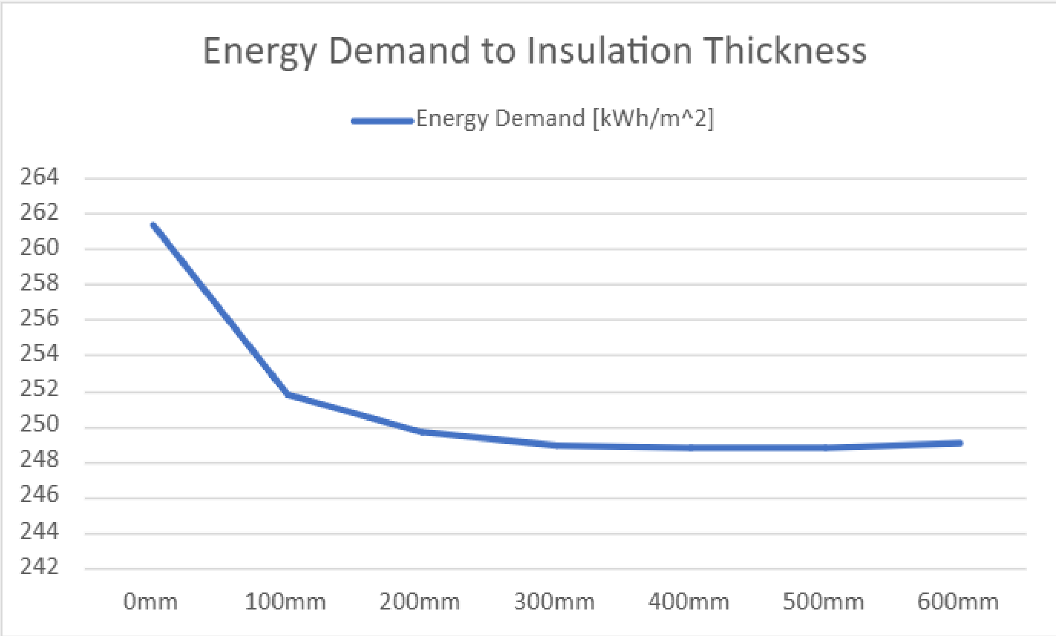

Figure 12: The diagram describes the relationship between energy demand [kWh/m^2] and the insulation thickness [mm].

We can observe that the energy demand only slightly reduces after 200 mm, due to this we decided to use 200 mm as the most optimal scenario for the energy-efficiency.

When the insulation was simulated, we also simulated humidity to determine whether dehumidifiers are needed. The simulation was made with the width chosen previously, which was 200 mm. In the following table, the mean monthly humidity for the attic is shown. This clearly illustrates that the humidity is high throughout the year and especially during the winter. Therefore there is a clear need for dehumidification of the attic space in order to reduce the humidity and as a result reduce the risks associated with high relative humidity.

Month	Relative Humidity [%]
January	88.1
February	87.2
March	79.2
April	70.9
May	64.3
June	69.1
July	74.1
August	77.2
September	80.1
Oktober	87.1
November	86.6
December	87.4

Table 7: The simulated relative humidity for the attic over one year with 200 mm of insulation.

5.3 Profitability Calculations

In this section we present the results of our profitability calculations regarding the dehumidifiers and insulation. We include the investment and operational costs. At the end, we present how these costs determine whether it is profitable to go through with the measure.

5.3.1 Dehumidifier: Product and Operational Costs

The dehumidifiers are based on the fixed electricity contract mentioned in the method chapter and will be applied for the estimated energy required per year as well as the operational assumptions for the energy demand shown in **Table 8**.

Electricity price	Operational cost Sorption	Operational cost Thermal
0.93 SEK/kWh	$3 - 4\,\text{kWh/m}^2 * \text{year}$	$5 - 7\,\text{kWh/m}^2 * \text{year}r$

Table 8: Reference values for the electricity price and operational costs for the dehumidifiers

Based on the aforementioned costs for the sorption and thermal dehumidifiers, respectively, the operational cost of each type can be calculated on a yearly basis.

Area	Operational cost sorption	Operational cost thermal
$852.70m^2$	$5968.90SEK$	$2984.45SEK$

Table 9: Yearly operational costs for the two types of dehumidifiers

The costs of the dehumidifier products are presented in the following table. The results are calculated based on different time spans, 1 year, 10 years and finally 50 years. Some of the dehumidifiers did not have their service life specified and as a consequence those spaces are then empty.

Model	Thermal Dehumidifier	Thermal Dehumidifier	Sorption Dehumidifier	Thermal Dehumidifier
Name	Dehumidifier 1	Dehumidifier 2	Dehumidifier 3	Dehumidifier 4
Price	10995 SEK	17980 SEK	10483 SEK	15689 SEK
Capacity	350 m^3/h	350 m^3/h	250 m^3/h	350 m^3/h
Service Life	50 years	50 years		50 years
Required Amount	4.73	4.73	6.6176	4.73
Investment Cost for the Space	54975 SEK	89900 SEK	73381 SEK	78445 SEK

Table 10: Table of examined dehumidifiers 1 - 4.

Model	Sorption Dehumidifier	Sorption Dehumidifier	Sorption Dehumidifier	Sorption Dehumidifier
Name	Dehumidifier 5	Dehumidifier 6	Dehumidifier 7	Dehumidifier 8
Price	16989 SEK	139330 SEK	87222 SEK	62755 SEK
Capacity	500 m^3/h	3500 m^3/h	1200 m^3/h	600 m^3/h
Service Life				50 years
Required Amount	3.3088	1	1.38	2.8
Investment Cost for the Space	67956 SEK	139330 SEK	174444 SEK	188265 SEK

Table 11: Table of examined dehumidifiers 5 - 8.

The next section will present the cost after a certain number of years. Here, both the cost of the products needed and the operational costs after the number of years are included. The result starts from 1 year, then 10 years,, dehumidifiers 1 to 5 all have relatively similar costs, and lastly 50 years. The calculation is based on the operational cost found in **Table 9** and the investment cost found in **Table 10** and **Table 11**.

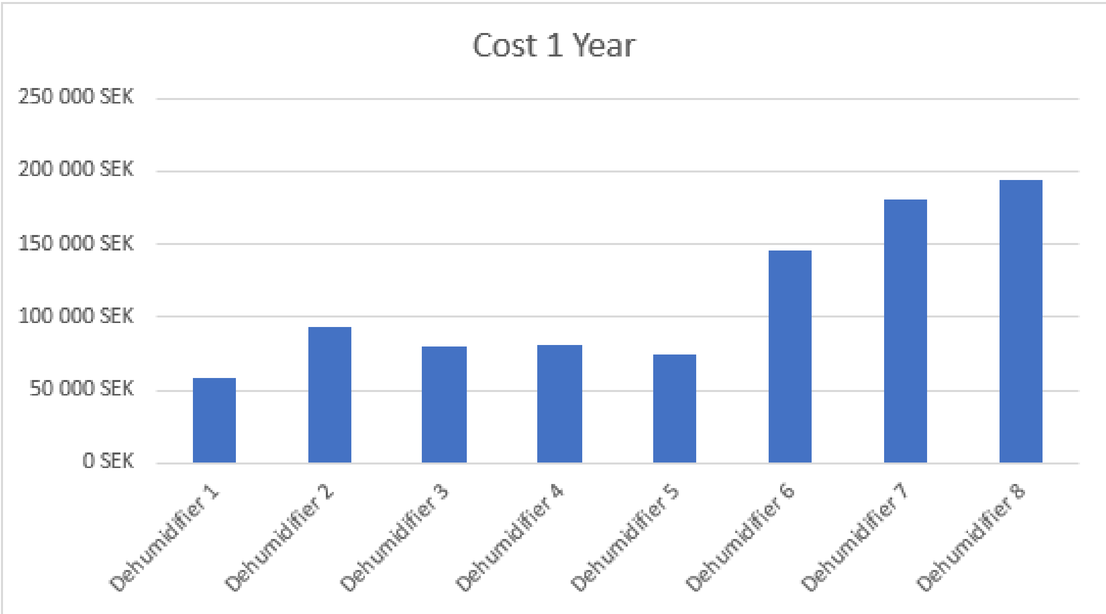

Figure 13: Cost after 1 year of operation, investment and operational costs.

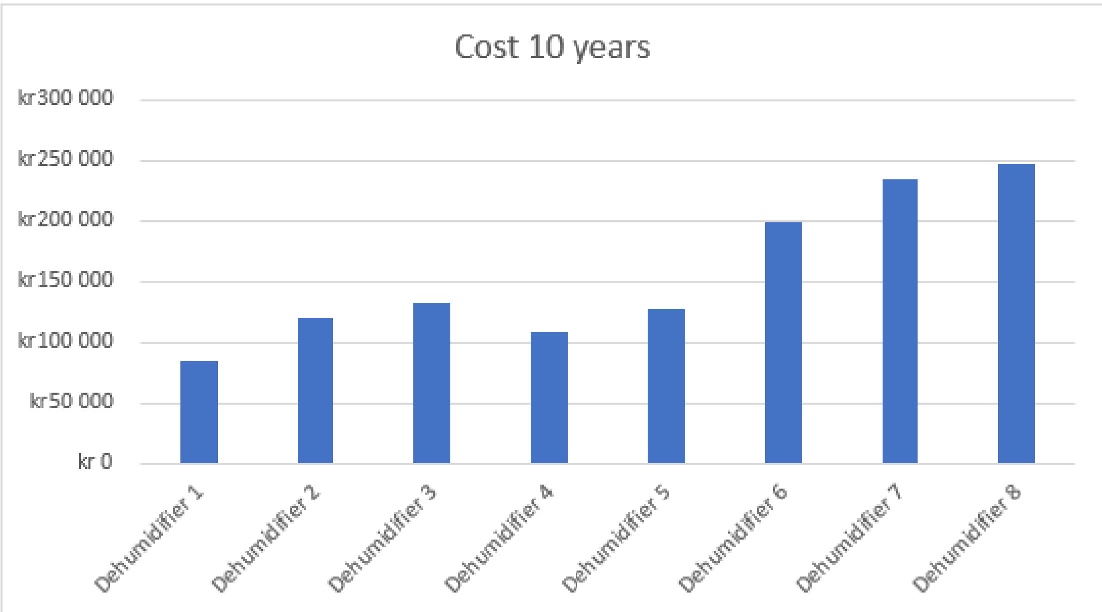

Figure 14: Cost after 10 years of operation, investment and operational costs.

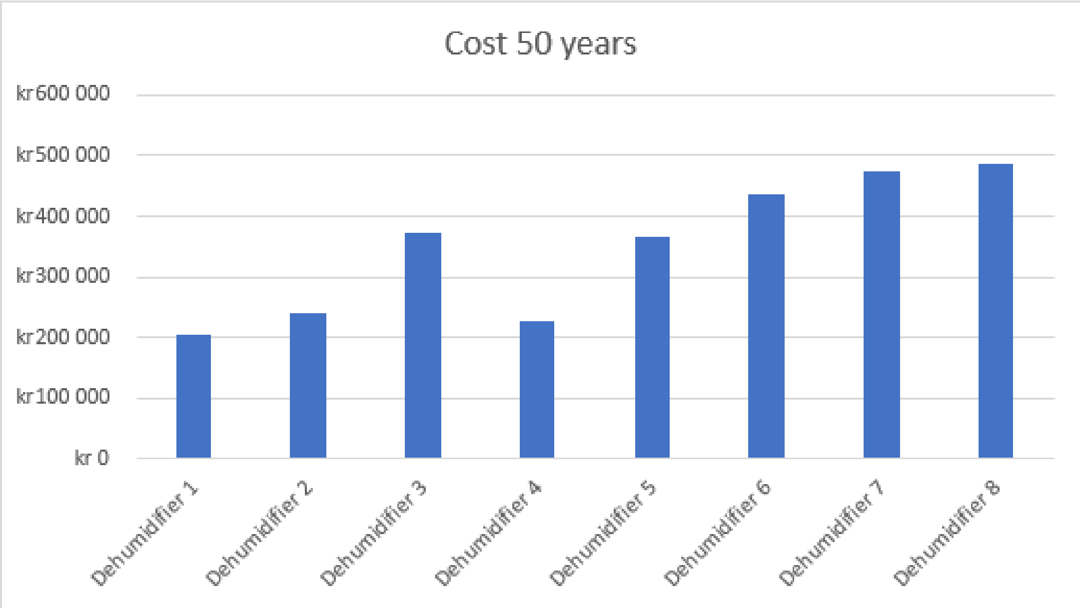

Figure 15: Cost after 50 years of operation, investment and operational costs.

After 1 year dehumidifier 1 to 5 all have relatively similar costs while 6 to 8 are larger. Observing 10 and 50 years we see that dehumidifier 1, 2 and 4 outperform the others, additionally those are all thermal dehumidifiers. Due to this we will calculate a mean value based on those three dehumidifiers and since they are all thermal dehumidifiers the operational cost remains the same. **Table 12** show the mean cost of investment for the dehumidifiers.

Dehumidifier	Investment Cost
Dehumidifier 1	$54975SEK$
Dehumidifier 2	$89900SEK$
Dehumidifier 4	$78445SEK$
Mean	$74440SEK$

Table 12: This table illustrates what the mean cost of the three dehumidifiers.

5.3.2 Insulation cost

Here is the mean cost of the insulation material in the attic area presented and shown in **Table 13**.

Thickness	100mm	200mm	300mm	400mm	500mm	600mm
Mean price SEK/m^2	79.9	162.4	228.95	319.9	389.05	473.75
Mean Price SEK	68130.73	138478.48	195225.67	272778.73	331742.94	403966.63

Table 13: Cost of the insulation material over the attic area.

5.3.3 Profitability of the Energy-Efficiency Measure

This section presents three different profitability methods: the payback period, return on investment and annual return. Since the ROI is dependent on the selected time horizon, it has been calculated for periods of 1 year, 10 years, and 50 years. Firstly, the payback period is calculated by dividing the total investment cost by the average annual cash flow. **Equation 5.1** presents the formula for the payback method. The total investment cost consists of the combined costs of the dehumidifiers and the insulation measures. The annual cash flow is determined by subtracting the operational costs from the annual savings.

$$\text{Payback Period} = \frac{\text{Cost of Investment}}{\text{Average Annual Cash Flow}} \tag{5.1}$$

To calculate the investment cost, the mean investment cost of the dehumidifiers presented in **Table 12** is added to the investment cost of the 200mm insulation presented in **Table 13**. The average annual cash flow is then calculated by subtracting the operational costs presented in **Table 8** from the annual savings obtained with 200mm insulation, shown in **Figure 7**. This results in the following:

Cost of Investment:	212918.48 SEK
Average Annual Cash Flow:	20748.93 SEK

Table 14: The calculated cost of investment and the average annual cash flow.

$$\text{Payback Period} = 10.27\,\text{Years} \tag{5.2}$$

The results show that the investment will be repaid after approximately 10 years and 3 months.

Next we calculated the ROI of the investment, it is calculated according to **Equation 5.3**. The gain from the investment varies during the years, as savings have a continuous return annually, but it is calculated by using the previously calculated average annual cash flow and multiplying it by the number of years. The cost of investment is fixed and was also calculated previously. **Table 15** showcase what the ROI is after 1, 10 and 50 years.

$$\text{ROI} = \frac{\text{Gain from Investment} - \text{Cost of Investment}}{\text{Cost of Investment}} \cdot 100 \tag{5.3}$$

Number of Years	ROI [%]
ROI_1	-90%
ROI_{10}	-2.6%
ROI_{50}	387%

Table 15: ROI over 1, 10 and 50 years.

This is the ROI of the investment over the specified years. We can see that it confirms the results from the payback period, in which the ROI after 10 years is close to 0%.

Lastly, there is the yearly return of the investment, this is calculated using **Equation 5.4**.

$$\text{Yearly Return} = \frac{\text{Average Annual Cash Flow}}{\text{Cost of Investment}} \cdot 100 \tag{5.4}$$

$$\text{Yearly Return} = 9.75\% \tag{5.5}$$

As we can see the yearly return on the investment is 9.75%.

To conclude the profitability results we can determine that the investment is economically profitable and after 10 years and 3 months the investment is repaid. **Table 16** shows the profitability results.

Method	Result
Payback Period	10.27 years
ROI_1	-90%
ROI_{10}	-2.6%
ROI_{50}	387%
Yearly Return	9.75%

Table 16: Summarized profitability results.

6
Discussion

This chapter discusses the empirical findings from both the interviews and the technical-economic evaluation of the case study. The findings are first discussed separately from their perspectives, after which they are analyzed in relation to one another. Particular focus is placed on the relationship between technical potential and organizational decision-making processes in order to examine possible discrepancies between feasible energy-efficiency measures and their practical implementation.

6.1 Interviews

The interview findings highlighted several drivers, barriers and organizational structures. The following section aims to interpret these findings in relation to the theoretical framework and previous research presented.

6.1.1 Institutional pressure as a driver for development

The interview findings indicate that the implementation and prioritization of energy-efficient measures in the real estate sector are strongly shaped by the complex interplay between internal and external institutional pressures.

A recurring pattern identified in the interviews was that external pressures, particularly regulatory requirements and increasing energy prices, constitute the most influential driving forces of organizational behavior and strategic priorities. Nair et al. mentioned drivers that further align with the results from this study, highlighting financial incentives and supportive building regulations as factors promoting energy-efficient renovation. Simultaneously, the findings highlighted the internal energy related objectives contributing to shaping the investment decision and long-term planning.

From an institutional theory perspective, these findings suggest that organizational behavior in the real estate sector is strongly influenced by institutional mechanisms that shape how organizations respond to external pressures. The respondents described how increasing regulatory requirements and rising energy prices intensified the focus on energy-efficiency measures. This could be understood through institutional isomorphism where organizations that operate within the same institutional environment gradually adopt similar structure, priorities and working methods in response to shared external pressure and expectations. Consequently, organizations tend to imitate approaches and strategies established within the sector to maintain legitimacy.

At the same time the findings indicate tendencies of institutional inertia. Rather than adopting more innovative or transformative approaches organizations tend to rely on established routines, proven technologies and familiar working methods, a tendency emphasized by the respondents. This further aligns with Carlander and Thollander which mentions inertia and resistance as common barriers. This suggests that organizational change within the sector may remain highly dependent on external pressure(Carlander & Thollander, 2023). In situations where regulatory demands or economic incentives weaken, organizations may have limited incentives to challenge existing practices, resulting in continued reliance on institutionally legitimized solutions.

The interviews further revealed that internal goals, energy targets, and policy frameworks were intended to guide long-term decision-making and organizational development. While these objectives may appear internally initiated it is important to reflect on the possibility that such goals are shaped by external legitimacy requirements according to the institutional theory. As external pressure toward sustainability and energy-efficiency increases organizations may develop internal policies and strategic targets partly in order to demonstrate alignment with societal expectations, regulatory trends and industry norms.

6.1.2 Split incentives and uncertainty

One of the most significant and perhaps the most important issues identified by the interviewees concerns a phenomenon called "split incentives. Despite the increasing energy prices and institutional pressure towards reducing energy consumption the findings remain a recurring and unresolved problem. The issue concerns the contractual agreement between the tenant and the property owner. Mentioned by the respondents was that this contractual form, where the tenant carries the cost for the energy consumption, strictly hinders the property owner from executing energy-efficiency measures for the property, as the economic benefits then primarily benefit the tenant. Under such a contractual arrangement, property owners may have limited financial incentives to invest in long-term energy-efficiency measures despite their technical feasibility and potential societal benefits. Simultaneously, the tenant lacks incentives to invest in improvements expanding beyond their rented space. This therefore suggests that split incentives function as a bottleneck limiting the potential to improve energy-efficiency and minimize energy consumption. Relying on these traditional rental structures and contractual models may significantly hinder the long-term development toward more energy-efficient buildings and sustainable energy consumption.

An additional perspective occurs concerning the opposite scenario where heating and energy costs are included within the rent and therefore remain uncontrolled by the tenant. Tenants may then have reduced incentives to use energy responsibly or actively contribute toward reducing consumption since the operational costs are not directly impacting their individual expenses. This creates another form of incentive misalignment, in which both tenants and property owners may lack motivation to optimize energy use. Both contractual structures may unintentionally reinforce inefficient energy behavior from both perspectives, depending on how operational costs are distributed.

The findings indicate an "error" in these contractual structures and suggest changes in policies and a potential regulatory support system in order to align economic incentives between the tenants and the property owners. Without further adjustments, the organization may continue to face difficulties justifying long-term investments. Regulatory subsidies, or shared saving models, may therefore become important for enabling broader implementation of energy-efficient measures within the sector. The International Union of Property Owners propose several solutions aimed to improve these contractual arrangements. This will thereby facilitate more sustainable decision-making regarding energy-efficiency measures(International Union of Property Owners, 2024).

The interviewees further revealed that uncertainty regarding the future constitutes another major factor influencing organizational decision-making, limiting the implementation of energy-efficiency measures. Several respondents described how uncertainty about future building use, priorities, and renovation strategies affected decision-making regarding the implementation of profitable measures. Even in situations where measures were considered technically feasible and economically profitable, uncertainty regarding future conditions contributed to hesitation or postponement of implementation. These findings can be understood through the perspective of bounded rationality. Decision-makers within organizations operate under conditions characterized by incomplete information, uncertainty, limited predictive capacity, and competing organizational priorities. As described by Simon, organizations are therefore unable to make perfectly rational decisions based on complete knowledge of future consequences. Instead, decisions are often made using simplified assumptions and risk-reducing strategies intended to minimize uncertainty and avoid potentially unfavorable long-term outcomes (Simon, 2000).

When future conditions remain uncertain, organizations may perceive familiar technologies and previously tested approaches as safer alternatives compared to implementing new systems with uncertain long-term performance. Consequently, uncertainty not only affects individual investment decisions but may also contribute to broader institutional inertia within the sector, slowing the adoption of innovative energy-efficiency measures despite increasing external pressure for sustainable transformation. These findings further align with Carlander and Thollander who identified risk as a key factor limiting the implementation of energy-efficiency measures. The barriers described by the respondents can be related to all three categories of risk identified in the literature, suggesting that perceptions of uncertainty continue to play an important role in organizational decision-making (Carlander & Thollander, 2023).

6.1.3 Integration of Knowledge and Innovation

The interview findings indicate that several of the organizations lack structures for integrating innovation and systematically managing knowledge regarding energy-efficiency measures. Respondents describe that valuable experiences and insights often remain project-based and dependent on individuals rather than being formally documented and integrated into organizational processes. As a result, similar evaluations and investigations may need to be repeated across projects despite relevant experiences from previous cases. This may contribute to inefficiencies in both decision-making and project development processes.

From a knowledge management perspective, this suggests limitations within the organization's ability to convert tacit knowledge into explicit knowledge. According to Nonaka and Takeuchi, organizational learning depends on the transformation and integration of tacit and explicit knowledge through the SECI-process (Nonaka & Takeuchi, 1995). However, these findings indicate that knowledge regarding energy-efficiency measures is experience based instead of being systematically shared within the organization. The findings further indicate that much of the knowledge regarding energy-efficiency measures remains experience based within individuals instead of being systematically externalized and shared within the organization. Consequently, valuable competence and lessons learned risk being lost over time.

The interviews highlighted the importance of competence and access to specialized expertise. Several respondents described uncertainty regarding technical performance, moisture risks and long-term profitability, emphasizing the importance not only of possessing relevant competence, but also of recognizing when internal knowledge is insufficient and external expertise is required. Organizations capable of identifying these knowledge gaps may therefore be better equipped to evaluate energy-efficiency alternatives.

Improved knowledge integration and organizational learning could therefore strengthen the organization's ability to implement sustainable energy-efficiency measures. More structured systems for documentation, experience sharing, and cross-functional collaboration may reduce uncertainty, improve decision-making, and increase the implementation of technically feasible measures.

6.1.4 The Impact of Organizational Structures

The organizational structure showed both similarities and differences between the organizations. There are many factors that may affect this outcome among others, size of the organization, long-term or short-term property management, public or private, occupancy type etc. Despite this uncertainty, it is possible to identify several more commonly used practices that could be applied and considered for any organization within the sector to adopt.

The findings indicate that centralized organizational structures may support the implementation and coordination of energy-efficiency measures by enabling broader organizational oversight, standardized decision-making and improved knowledge integration across projects. Several respondents described the presence of centralized roles despite the organization's size, with responsibility for coordinating energy-related work and supporting decision-making. This aligns with Solberg, which argues that centralized structures may strengthen control, long-term sustainability work, and knowledge-sharing between projects (Solberg, 2024). From the interview findings, such centralized coordination also appeared to facilitate the integration of energy-efficiency measures into maintenance plans and renovation projects, potentially reducing the risk of fragmented decision-making and repeated mistakes across projects.

At the same time, the findings suggest that some degree of decentralized decision-making may remain important to adapt solutions to local building conditions and project-specific requirements. This further supports the argument by Solberg that decentralized structures may increase operational flexibility and adaptability (Solberg, 2024). Consequently, the findings may indicate that a combination of centralized strategic coordination together with decentralized local adaptation could represent a beneficial organizational approach for promoting knowledge integration and improving the implementation of energy-efficiency measures within the real estate sector.

Two different approaches to identify opportunities for energy-efficiency measures emerged from the interviews: reactive and proactive approaches. While organizations may use both approaches in practice, the findings suggested important differences in how the opportunities were identified and acted upon. Reactive approaches are often driven by issues as they arise, whereas proactive approaches involve systematically identifying opportunities before problems arise. A reactive approach will likely always be necessary, as future conditions are uncertain and unforeseen events may occur. According to the literature, proactive behavior is associated with reducing uncertainty, supporting the integration of innovation, improving organizational effectiveness, and increasing the likelihood that energy-efficiency measures are considered and implemented.

The interviews revealed notable differences in how organizations allocate financial resources for energy-efficiency measures. Three principal approaches were identified. The first involved distributing predefined budgets to individual properties, giving property managers greater flexibility in allocating resources. The second approach relied on a centralized budget covering the entire property portfolio, allowing resources to be directed toward projects with the greatest potential impact at the organizational level. The third approach differed in that it first identified opportunities across the building stock and then applied for the funding required to implement the selected measures.

Although budget constraints are likely to exist regardless of the allocation model, these approaches may influence how opportunities for energy-efficiency improvements are identified and evaluated. In particular, the approach of first identifying opportunities across the building stock and subsequently applying for funding may allow organizations to evaluate potential measures before financial limitations become the primary consideration. By focusing initially on the technical and strategic potential of different alternatives, organizations may be better positioned to identify measures that generate greater long-term value, even when they entail high upfront investment.

From this perspective, a less restrictive budgeting process may support a broader evaluation of potential solutions and reduce the risk of valuable alternatives being rejected due to predefined budget constraints. Such an approach may also create more favorable conditions for innovation, as decision-makers are encouraged to explore a wider range of opportunities before prioritization occurs. Consequently, greater flexibility in the allocation process may strengthen long-term decision-making and improve the organization's ability to identify and implement effective energy-efficiency measures.

6.2 Simulation & Calculation

The results from both our calculations and simulations indicate that installing attic insulation is profitable, even though additional measures would be needed to address humidity issues. The payback period for the investment was slightly over 10 years, which is relatively long, but in the context of a real estate company focused on long-term building management, it is acceptable.

6.2.1 Energy Performance and Moisture Risk

The simulation results shown in **Figure 12** reveal a clear pattern of diminishing returns with increasing insulation thickness, which justifies the selection of 200 mm as the cost-optimal scenario. Moving from no insulation to 100 mm produces the largest single gain, this provides a reduction of 6.6 kWh/m^2 in energy demand. This translates to an annual saving of 19 474 SEK. The step from 100 mm to 200 mm adds a further 4 260 SEK/year in savings at a marginal increase in material cost of approximately 70 350 SEK which is illustrated in **Table 13**. Beyond this point, the benefit of additional insulation deteriorates quickly. The step from 200 mm to 300 mm yields only 1 420 SEK/year in additional savings against an increase in material cost of 56 750 SEK. Increasing thickness further to 400 mm adds only 406 SEK/year for the additional cost of 77 550 SEK. An interesting observation is that the 500 mm and 600 mm scenarios actually perform slightly worse in annual savings than the 400 mm scenario, meaning the additional investment produces no net benefit at all.

This behavior shows that the resistance added by each successive layer is subject to diminishing returns, since heat flux through the assembly is already substantially reduced once the initial layers are in place. Furthermore, as Hamid et al., 2023 notes, the contribution of attic insulation to whole-building energy performance is relatively limited to begin with, which further reinforces the case against overspecifying insulation thickness beyond what the cost analysis supports.

A further observation that strengthens the investment case is that the humidity problem in the attic is not a consequence of the insulation measure itself, but a pre-existing condition of the building. The simulated relative humidity prior to any insulation already ranges from 62% in May to 84% in October, as displayed in **Table 6**, with 7 of 12 months exceeding 75% relative humidity and 5 months exceeding 80%. As both Viitanen et al., 2010 and Roppel and Lawton, 2013 explained the boundary for mold growth is 80%, this makes it clear that the existing building is already at a risk of mold growth before any measure. Important to note is that other factors affect mold development which could be temperature, time and materials, this is also supported by Roppel and Lawton, 2013; Viitanen et al., 2010. Adding 200 mm of insulation raises these levels further. After the insulation the relative humidity ranges from 64% to 88% and 9 of 12 months exceed 75% which can be seen in **Table 7**. This is also aligned with what the literature states as Hagentoft and Kalagasidis, 2010 and Hansen et al., 2020 explain that supplementary insulation lowers the attic temperature, which in turn elevates relative humidity and increases condensation risk. The comparison between the two tables therefore confirms both that the humidity risk is pre-existing and that insulation alone cannot resolve it. This suggests the dehumidifier should not be viewed as an additional cost of the energy-efficiency measure, but rather as a measure already required.

6.2.2 Economic Evaluation of Mitigation Measures

Having confirmed that the humidity problem is pre-existing and that insulation only increases it means that a dedicated moisture mitigation measure is necessary regardless of the insulation retrofit. A method such as ventilation could be used as a mitigation measure, however as Chapter 4.5.1 explains that in humid maritime climates such as Gothenburg, increased ventilation may in some cases increase rather than reduce moisture levels. This is because the outdoor air can contain higher levels of moisture (Hagentoft & Kalagasidis, 2016). As a result of this, dehumidifiers were thus evaluated to be the most appropriate mitigation strategy. Among the eight products investigated, the analysis across the 1, 10 and 50 year time span favored thermal dehumidifiers. Especially, dehumidifiers 1, 2, and 4 were most effective and were all thermal dehumidifiers. This outcome is supported by Wang et al., 2013 who explains that heating-based dehumidification carries low investment costs, while its main disadvantage is higher energy demand. In the context of this attic space, the investment cost advantage of thermal dehumidifiers with a mean of 74 440 SEK compared to sorption investment costs ranging from 67 956 SEK to 188 265 SEK proves to be more profitable over the measured time and the higher operational cost is not enough to offset the higher investment cost. Notably, this is based on the prerequisite of current electricity prices of 0.93 SEK/kWh that we have assumed in the study. Rising electricity prices may influence the choice of dehumidifier, as the associated changes in operating costs can affect the overall profitability of different solutions.

6.2.3 Profitability and Organizational Implications

The calculated payback period of 10.27 years and a 50-year ROI of 387% show good profitability in the long term, moreover the annual return of 9.75% is a good performance against standard financial benchmarks. However, as five respondents highlighted budget constraints and required rates of return are among the most commonly cited barriers to implementing energy-efficiency measures. Some organizations may impose strict internal investment requirements that demand shorter payback periods than the roughly 10-year estimate used here. On the other hand, some organizations apply the Totalmetodik framework developed by Belok. Belok evaluates measures collectively across a project portfolio rather than on individual profitability alone. This is an approach that would allow a measure with a 10 year payback to be implemented alongside higher return projects without being filtered out by a single-project ROI threshold. Furthermore, the profitability results presented in this study should be seen as conservative estimates. The calculations are based on a fixed electricity price of 0.93 SEK/kWh, which reflected the market conditions during the data collection period. Since electricity prices in Sweden have fluctuated widely over time, future increases would improve the investment's profitability by shortening the payback period and increasing ROI. In addition, SMHI data indicates increasing humidity levels which may lead to a higher moisture risk in attics over time. Overall, the profitability model used in this study may underestimate the investment's long-term benefits.

6.2.4 Limitations and Validity

It is important to discuss the study's limitations and the effect our assumptions have had on the results. As with any simulation-based study, the results are subject to a number of assumptions and sources of uncertainty that should be acknowledged when interpreting the profitability findings.

- The building geometry was retrieved from the available drawings of the building, many of these were older and some were from when the building was first constructed in the 1800s. Another issue with the drawings was that the scale was not consistent, to counter this we controlled the scale on known measurements on the drawings.

- The building dates from 1810 and detailed construction documentation was not fully available, the material composition of the building envelope was assumed based on construction standards typical of the period.

- The airtightness of the building envelope was not measured and was instead assumed at 1.5 ACH, based on the typical range for older buildings with relatively poor envelope sealing. The next is for the profitability assessment, the calculations have excluded the installation and maintenance costs for both the insulation and dehumidifiers. Including these in the calculation would extend the payback period.

- The energy and electricity prices are assumed to be fixed and according to the active rates during April 2026. Taken together, these limitations do not change the overall conclusion that the investment is economically viable. However, the results should be seen as indicative rather than exact figures. A more detailed cost estimate, including labor costs, would be needed before making a final investment decision.

- The humidity assessment was based on monthly mean relative humidity values. This provides an overview of attic conditions over the year but may overlook shorter periods with critical humidity levels or a risk of condensation. Consequently, the moisture risk should be interpreted with caution, particularly since mold growth is influenced by exposure time, temperature, material properties and peak humidity conditions.

Together, these findings address the sub-question *"To what extent can profitability be achieved through attic insulation, when accounting for risk mitigation measures?"*. The answer to this is relatively clear based on the results of the study, the combined measure is economically viable with a 10.27 year payback period, a 50 year ROI of 387%, and an annual return of 9.75%. The upfront investment of 212 918 SEK, the 10 year payback period, and the need to combine insulation with dehumidification are all reasonable for a long-term property owner.

6.3 Synthesis and Interpretation of Findings

The combined findings from the interviews, simulations and profitability calculations strengthen the assumption that technically and economically feasible energy-efficiency measures are still not implemented in practice.

The technical evaluation shows that the examined measure can reduce energy demand while remaining economically viable, even when the additional costs of moisture mitigation are included. With a payback period of approximately 10 years, an annual return of 9.75% and a long-term ROI of 387%, the investment appears financially viable from a long-term property management perspective. These results challenge the idea that technically feasible energy-efficiency measures are primarily rejected because they are not profitable. Instead, the findings suggest that organizational and institutional factors also play an important role in whether such measures are implemented.

The interviews support this interpretation by identifying several barriers unrelated to the technical performance of the measure itself. Budget constraints, uncertainty regarding future building use, split incentives and organizational inertia were all described as factors that limit implementation. As a result of this, the study indicates that the existence of technical and economic potential alone is insufficient to ensure implementation. Organizational structures, strategic priorities and institutional conditions determine whether technically feasible measures are executed.

The results also show the importance of uncertainty in organizational decision-making. The case provides a good representation of how organizations are affected by uncertainty and risk when deciding on energy-efficiency measures. In this case, uncertainty should not be viewed as a wall that obstructs implementation of measures, as it can be addressed through appropriate mitigation strategies.

Furthermore, it is essential to emphasize the importance of contractual arrangements and their impact on the implementation of energy-efficiency initiatives. This issue has represented and continues to represent a significant challenge that must be addressed to support organizations´ sustainability development of their properties.

The findings also indicate that institutional pressure drives organizations toward greater focus on energy-efficiency. Regulatory frameworks, sustainability reporting requirements and increasing energy prices were identified as important drivers in the interviews. Due to the influence of external drivers and regulations on decision-making, it is important for organizations to work proactively with these factors rather than merely responding to them when requirements arise. By doing so, the organization can better anticipate future demands, adapt its strategies in time, and ensure that its actions remain aligned with broader societal developments.

Organizational structures may influence the decision-making process, including the effectiveness of decisions and the willingness to explore alternative measures. In addition, it can affect how knowledge is integrated and shared within the organization, thereby contributing to more effective decision-making. Consequently, organizations should continuously evaluate their internal decision-making processes to improve operational efficiency and build a stronger foundation for adopting optimal solutions.

Overall, the combined findings answer the main research question by demonstrating that organizational decision-making regarding energy-efficiency measures is dependent on an interaction between technical feasibility, economic evaluation, institutional pressure, organizational structures and uncertainty. The study therefore suggests that improving implementation rates of energy-efficiency measures requires not only technically profitable solutions but also organizational conditions capable of supporting long-term decision-making, knowledge integration and risk management.

7 Conclusion

The main research question of this study was: *Which factors influence organizational decision-making when technically feasible energy-efficiency measures are not implemented despite their potential?* Below are the sub-questions of the report. The main research question along with the sub-questions were answered in the report and are presented here in the conclusion.

- *Which factors constitute the primary barriers and drivers influencing decision-making processes related to the implementation of energy-efficiency measures?*
- *Which organizational practices and structures contribute to the development and implementation of energy-efficiency measures?*
- *To what extent can profitability be achieved through attic insulation, when accounting for risk mitigation measures, based on the case study of Sankt Eriksgatan 4?*

This thesis has investigated which factors influence organizational decision-making when technically feasible energy-efficiency measures are not implemented despite their potential. By combining interviews, simulations and profitability calculations, the study has shown that the implementation of energy-efficiency measures cannot be understood only through technical feasibility or economic profitability. Instead, implementation is influenced by an interaction between technical performance, economic conditions, organizational structures, institutional pressure, uncertainty, knowledge integration and incentive structures.

The technical and economic evaluation of the case building shows that supplementary attic insulation can reduce the building's energy demand. The results indicate that 200 mm of insulation is the most reasonable alternative, as additional insulation only provides limited additional energy savings. However, the simulations also show that the relative humidity in the attic is high both before and after insulation, meaning that moisture risk must be considered when evaluating the measure. The need for dehumidification should therefore be understood not only as an additional cost associated with the insulation measure, but also as a mitigation measure for an already existing moisture-related risk.

The profitability calculations indicate that the combined investment in insulation and dehumidification can be considered economically viable from a long-term property management perspective. The calculated payback period is approximately 10 years, the yearly return is 9.75%, and the long-term ROI over 50 years is 387%.

These results suggest that the measure has economic potential, even when risk mitigation is included. However, the relatively long payback period may still create challenges in organizations with strict internal return requirements or limited investment budgets.

The interview findings show that profitability alone is not sufficient to ensure implementation. Budget constraints, uncertainty regarding future building use, split incentives, organizational inertia and limited knowledge integration were identified as important barriers. At the same time, increasing energy prices, internal sustainability goals and external regulatory requirements were identified as important drivers. This indicates that organizations are increasingly under pressure to improve energy-efficiency, but that internal structures and decision-making processes strongly affect whether potential measures are implemented.

The study also highlights the importance of organizational learning and knowledge management. Experiences from previous projects are not always systematically documented or transferred within organizations, which may lead to repeated evaluations, uncertainty and inefficient decision-making. Improved knowledge sharing, clearer responsibility structures, and better integration between technical expertise and strategic decision-making could therefore support the implementation of energy-efficiency measures.

Overall, the study concludes that technically and economically feasible energy-efficiency measures require more than positive simulation results and profitability calculations to be implemented in practice. Property-owning organizations need to manage uncertainty, align incentives, strengthen internal knowledge-sharing and develop decision-making processes that support long-term energy-efficiency work. In this way, organizations can improve their ability to transform technical and economic potential into practical implementation and contribute to a more energy-efficient and sustainable building stock.

7.1 Future Research

Based on the research conducted in this thesis, several areas for future study have been identified to support continued exploration of the impact of organizational decision-making and improving the implementation rates of energy-efficiency.

Firstly, future studies could investigate a broader range of building types and organizational contexts. Although the findings provide valuable insights, decision-making processes may differ significantly between public and private property owners, different types of activities such as commercial and residential properties, and between organizations of different sizes. Furthermore, future research could also explore whether the barriers and drivers identified in this study are consistent across different organizational and institutional settings.

Secondly, the issues of split incentives also represent an important subject for future investigation. The findings suggest that incentive misalignment between property owners and tenants remains a significant barrier to implementation. Future research could therefore explore alternative contractual arrangements and regulatory frameworks designed to reduce these incentive conflicts. Such research may provide valuable insights for policymakers and property owners seeking to promote the transition towards a more sustainable and energy-efficient building stock.

A third area concerns the economic evaluation of energy-efficiency measures. The profitability calculations performed in this study focused primarily on investment costs, operational costs, and energy savings. Future research could develop more comprehensive life-cycle economic assessments that incorporate labor and maintenance costs, inflation, and varying energy price scenarios. Sensitivity analyses could further be conducted to evaluate how changes in energy prices and interest rates influence profitability outcomes. Such studies would contribute to a more realistic understanding of the economic uncertainties that decision-makers face when evaluating energy-efficiency investments.

Finally, future research could explore the interaction between digitalization and energy-efficiency decision-making. Additionally, future studies could investigate how improved access to building data, digital twins and advanced simulation tools may influence renovation decisions. Future studies could also examine how organizations utilize digital tools and systems when evaluating energy-efficiency measures and whether these technologies contribute to more effective decision-making processes. This may help identify both opportunities and limitations associated with the ongoing digital transformation of the real-estate sector.

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