Building the future, measuring the present

Addressing the energy performance gap in redeveloped office buildings to achieve the Paris Proof targets

Master Thesis
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Management in the Built Environment
Delft University of Technology

"In theory there is no difference between theory and practice. In practice there is."

Albert Einstein

ABSTRACT

The building sector's substantial environmental impact, responsible for 40% of total energy consumption and one-third of CO_2 emissions globally, emphasises the urgency to enhance energy efficiency. While there are potentials for energy savings, there are still challenges that need to be faced. In particular, a significant 'performance gap' exists between the predicted and actual energy usage in buildings. This gap, observed during the operational phase, poses challenges for realising high-performance buildings. The focus of this thesis will be on renovated office buildings, acknowledging their significance in sustainability efforts. A critical aspect of the performance gap is attributed to the operation and maintenance of the energy systems compared to the intended usage. The research will therefore address the critical main research question: *"How can operation and maintenance-related energy performance gap in renovated office buildings be effectively addressed to meet the Paris Proof commitment targets?"* By conducting literature reviews and employing a mixed-method approach, including both qualitative and quantitative methods combined, the study will utilise interviews and a case study, using data from advanced systems. Focusing on the complexities of influencing factors, specifically in operation and maintenance, the research aims to address the energy performance gap. Findings indicate that the main challenges are knowledge gaps among stakeholders due to fragmented collaboration, inadequate commissioning and monitoring, and tuning practices, including the lack of a feedback loop. A strategic roadmap of a restructured redevelopment process is proposed, emphasising enhanced commissioning practices, continuous monitoring, and improved stakeholder collaboration. The strategic roadmap therefore suggests practical steps for addressing the performance gap, fostering more energy-efficient building operations, and aiming for redeveloped office buildings to achieve the Paris Proof standards.

KEYWORDS – Energy Performance Gap – Operation and Maintenance – Renovated Office Buildings – Advanced Technologies – Paris Proof – Strategic Roadmap – Monitoring

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PREFACE AND ACKNOWLEDGEMENTS

This report represents my graduation thesis as part of the Master track Management in the Built Environment at the Delft University of Technology. The research aims to address the disparities between computer-based energy performance predictions during the redevelopment phase and the actual usage in the operational phase of office buildings. The scope is on renovated office buildings aiming at Paris Proof given the problems that could arise when the promised performance is not in alignment with the predictions. In order to achieve this goal, the research evolves with numerous interconnected goals and objectives. Addressing the disparities caused in the operational phase is the initial objective. This involves identifying the gaps that currently exist. To do so, a literature review followed by empirical research is conducted as part of the research.

For this thesis, the personal study targets embrace a multidimensional approach aimed at gaining insights in understanding and addressing the energy performance gap from a development point of view. These targets emerged from an interest in sustainable practices in the built environment. Developing an insightful analytical perspective to examine and classify the factors that contribute to the observed performance disparities is an essential aspect of the personal study goals. The overall goal of this research is to make a contribution to academic understanding and develop an strategic roadmap with the aim of successfully addressing the challenges identified in the findings.

First and foremost, I would want to express my gratitude to my two TU Delft mentors, Queena Qian and Laure Itard, for their invaluable guidance and support during my thesis process. I sincerely appreciate the feedback, interesting insights, and encouragement. This thesis has been greatly shaped by their advice and I have learned to take a step back every now and then in order to achieve further and more successful progress.

In addition, I am grateful to my graduation company Edge, in particularly Constantijn Berning and Imardo de Blok, my internship supervisors. Working on my thesis as part of the development team at this company has been of great value due to the real-world learning environment it provided, helping me to expand my knowledge. Moreover, Edge assisted me in terms of networking for interviewees and getting asses to the case study data, all of which contributed to the development of the strategic roadmap and all the in-between steps. All people involved, including the interviewees, have had their own meaningful insights for this thesis. Finally, my family and friends have been a great motivation throughout the whole process.

Feline Dupuits
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EXECUTIVE SUMMARY

1. Introduction

The building sector accounts for one-third of CO_2 emissions and 40% of all energy consumption, which makes it a significant contributor to global warming. Despite this, it offers substantial opportunities to reduce energy use. In response to climate change, the Paris Proof Commitment has been introduced, with the goal of reducing energy consumption and associated CO_2 emissions in the built environment by two-thirds. Achieving these targets, however, also comes with several challenges. As part of the design phase, energy modelling is essential for enhancing the energy performance, yet there is often a 'performance gap' between predicted and actual energy consumption. Therefore, the research focuses on the energy performance gap (EPG) in renovated office buildings with the aim of meeting the Paris Proof standards. This gap is caused by a number of factors, including those related to building operations. Addressing the causes and challenges is needed to reduce operating emissions, which account for 76% of a building's lifecycle emissions, and to comply with energy efficiency targets. The research explores factors influencing the EPG and future practices needed, specifically those related to the operational and maintenance challenges. It aims to provide deeper insights and propose strategies to improve sustainability and energy performance reliability by addressing the following main research question: *"How can operation and maintenance-related energy performance gap in renovated office buildings be effectively addressed to meet the Paris Proof commitment targets?"* The main question is further subdivided into four sub questions in order to highlight the different aspects.

2. Theoretical background

The EPG arises from various lifecycle phases, including the design, construction, handover, and operational phase. The operational phase, influenced by both occupant behaviour and system performance, incurs the highest energy costs and impacts the comfort for the end user. Six main factors have been identified that influence building energy consumption: building equipment, building envelope, outdoor climate, occupant behaviour, operation and maintenance, and indoor environmental conditions. These can be divided into human influenced factors and technical and physical factors. As part of the human influenced factors, effective operation and maintenance have emerged as being critical for minimising the EPG. Key challenges include inadequate control of HVAC systems, miscommunication among stakeholders, and lack of proactive maintenance. Thereby, the building operators' education levels impacts the energy efficiency. The redevelopment process involves multiple stakeholders. To achieve optimal energy performance, stakeholders must effectively interact to transfer knowledge. Furthermore, in addition to the theoretical NTA 8800, the application of the WEii indicator offers insights into the real-world energy usage. Paris Proof, a high-level WEii score, seeks to increase a building's energy efficiency by establishing practical and actionable targets based on actual energy use.

3. Methodology

In order to answer the main research question, this research employs an explanatory mixed-methods research design that combines both qualitative and quantitative methods. The research process involves three phases: defining the theoretical background, active data collection and preliminary analysis, and synthesising findings to develop a strategic roadmap. Data is gathered through interviews and quantitative analysis of energy performance data from the Edge Olympic case study building. The qualitative aspect involves semi-structured interviews with experts, offering insights into energy

management practices and challenges. Key topics explored include energy performance calculations, causes and challenges, communication and collaboration, operations and monitoring, and future strategies. The aim of these interviews is to get insight into the complexities of energy performance and pinpoint practical approaches for enhancement. The Edge Olympic office building, which underwent an extensive renovation to increase energy efficiency, serves as the case study for the quantitative analysis. The analysis focuses on real-time energy usage data, identifying patterns and inefficiencies. This case study provides empirical evidence and practical examples of how operational and maintenance practices can be optimised. A strategic roadmap covering the redevelopment process is developed as the research's deliverable.

4. Qualitative research

This section analyses the findings from semi-structured interviews with industry experts to address the EPG in renovated office buildings. Figure A provides an overview of the key thematic areas and issues identified in the qualitative research, categorised into main- and subtopics. Each category focuses on specific challenges and insights from expert interviews, showcasing that achieving optimal energy performance is complex and interconnected. To ensure sustainable and efficient building operations, this visual overview highlights the need for dynamic modelling, effective communication, continuous monitoring, and collaboration among disciplines to address the disparity between the predicted and actual energy use.

Calculations & certifications	Causes & challenges	Collaboration & responsibilities	Operations & monitoring	Future strategies
Unsuitability of NTA 8800	Inadequate commissioning & monitoring	Fragmentation in stakeholder collaboration	Inadequate 24/7 real time monitoring	(Seasonal) commissioning
Advantages of WEii indicator for Paris Proof	Complex and impact end-user	Unclear roles and responsibilities	Tuning challenges	Continuous monitoring and tuning
Dynamic modelling & simulations	Operational and maintenance challenges	Enforcement of energy efficiency responsibilities	Operational control and development disconnection	Collaborative contracts
Data driven predictions	Absence of a feedback and learning loop	Earlier interdisciplinary integrations in process	Need for specialization in operations	Effective communication and data utilization
Communication of predictions	Transition and information transfer issues	Awareness gap and misinterpretations	Operational and monitoring costs	Early engagement and training

Figure A: Semi-structured interview topics (own illustration)

5. Case study

The case study of the Edge Olympic office building evaluates the effectiveness of operational practices identified in the qualitative research. The building, which underwent a renovation between 2016 and 2018, encountered initial inefficiencies in energy consumption after delivery, which were addressed through various operational adjustments. Key interventions included seasonal commissioning, real-time monitoring, and segmentation of operational zones to reflect actual occupancy patterns. Through these measures, the building's energy consumption was significantly reduced, bringing the building in line with Paris Proof standards. Between 2019 and 2023, the building succeeded to establish a significant decrease of 34,08%. The enhancements underscore the importance of specialised roles in energy efficiency management when adopting advanced digital building operations. The case study supports the qualitative findings by emphasising the need for specialised operations, feedback loops, and constant monitoring. It also highlights the need of customised approaches for meeting end-user requirements along with specific building characteristics. These insights offer a predictable framework for other renovated office buildings striving to meet high energy efficiency standards.

6. Strategic roadmap

As a result of the both the theoretical background and empirical findings, a strategic roadmap is developed to address the EPG. It offers a structured approach from project initiation to the in-use phase, promoting operational efficiency. The roadmap outlines several stages, each with specific goals and steps:

1. Business case: Establish project scope, performance targets, and stakeholder responsibilities.
2. Design phases: Develop design documents that are focused on energy-efficiency and ensure that the construction adheres with the established targets.
3. Construction: Implement construction practices that are in line with the energy efficiency criteria while maintaining a high level of quality.
4. Pre-handover: Validate the functionality and performance of building systems through extensive commissioning and testing.
5. Handover: Ensure that the operational parties are trained and equipped to maintain the set performance targets after the building has been officially handed over to the client and end user. This also includes a seamless knowledge transfer among the stakeholders.
6. Initial aftercare: During the in-use phase, monitor and improve the building performance by implementing any required modifications.
7. Operational phase: To meet the Paris Proof standards, implement sustainable practices for long-term energy efficiency and continuous improvements, including commissioning and monitoring with feedback loops.

The roadmap stresses the added value of clear stakeholder responsibilities, seamless knowledge transfer, continuous monitoring, and feedback loops. It also emphasises the integration of advanced technologies and data-driven management to optimise energy use. By implementing these strategies, the roadmap aims to improve operational related energy efficiency, supporting renovated office buildings to meet the Paris Proof standards and contribute to broader sustainability goals. The proposed steps provide a guide for stakeholders, encouraging effective collaboration and ensuring accountability throughout the redevelopment process.

7. Discussion

The four main themes identified in the research are categorised in figure B. Each main theme is further divided into subthemes, presenting a framework with the most important aspects for improving energy efficiency. Continuous monitoring and tuning is the first main theme and focuses on utilising real-time data and feedback loops for operational improvements. Second, the integration of cutting-edge technologies and the requirement for specialised roles are highlighted by advanced technologies and specialisation. Responsibilities and incentives emphasise the need of having well-defined tasks and contracts based on performance. Finally, knowledge transfer and trainings stress the necessity of continuous effective transfer of knowledge and profession development.

During the expert panel, key findings included the emphasises for systematic information transfer to avoid energy performance loss during ownership transitions, maintaining a building's "memory" of accumulated knowledge, and tackling conflicts of interests in commissioning processes. In addition to the operational framework, there is an importance of maintaining the strategic and tactical framework. Moreover, the significance of dynamic, data-driven approaches was again emphasised, as were future concerns about privacy issues associated with energy usage monitoring.

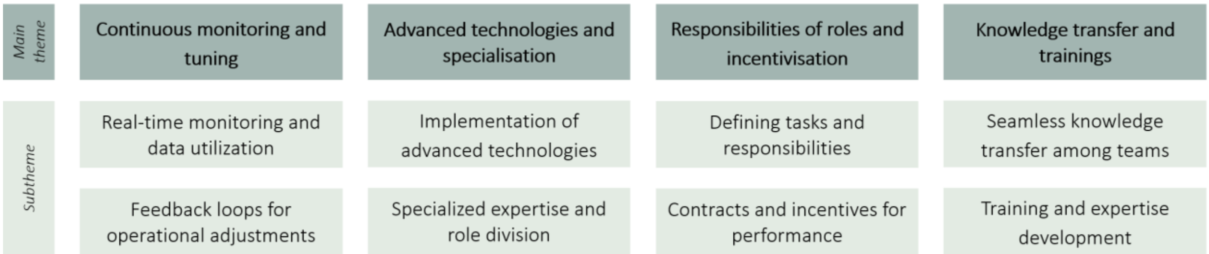

Figure B: Identified main and subthemes (own illustration)

8. Conclusion

In conclusion, this research aims to address the EPG in renovated office buildings. The findings demonstrate that the gap is largely influenced by inefficiencies in operational and maintenance practices that fail to align with the design intent. Key insights from the research questions include:

- Main influencing factors: A building's actual energy performance is influenced by a wide range of factors, from the planning stage to building operations. These can be divided into technical and human-influenced factors, that includes operations and maintenance.
- Operational and maintenance challenges: The main challenges include insufficient commissioning, inadequate monitoring and the absence of feedback loops. The gap between theoretical predictions and practical outcomes can significantly be exacerbated when design, construction, handover, and operating phases are fragmented.
- Responsibilities and collaboration: For energy performance management to be effective, clear roles and responsibilities are required among stakeholders. For this reason, detailed contracts, continuous information exchange, and performance-based incentives are essential.
- Improved operational and maintenance practices: Effective strategies include enhancing collaboration, commissioning, continuous monitoring, using feedback loops, and specialisation in operational tasks. Furthermore, the case study confirms the effectiveness of seasonal commissioning and real-time monitoring in reducing energy use.
- Roadmap: The proposed strategy includes several stages to address the challenges encountered throughout the process. It focuses on continuous monitoring, stakeholder collaboration, effective communication, and training to overcome a fragmented stakeholder approach and preserve the design intent with the final aim of meeting Paris Proof standards.

9. Limitations & recommendations

Due to the reliance on a single case study and ten interviews, the generalisability of the findings may be limited and not fully capture the diverse challenges and strategies across different building types. In addition, time constraints could restrict the depth of the research. Given the focus on smart buildings, the roadmap might not be as useful for buildings lacking cutting-edge technologies. Furthermore, the certification guidelines referred to, such as Paris Proof which uses the WEii, are specific to the Netherlands and may not be applicable elsewhere. As part of the recommendations, future research could encompass a range of building types, including those lacking advanced systems, and explore diverse (re)development structures. Implementing and testing the roadmap in real-world projects is advised to refine its effectiveness and boarder applicability.

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EPG = Energy Performance Gap
RED = Real Estate Developer
CE = Cost Expert
SE = Structural Engineer
BPE = Building Physicist Engineer
AR = Architect
IEA = Installation & Energy Advisor
CL = Client
GC = General Contractor
IN = Installer
DBO = Digital Building Operator
EBSP = Expert Building Systems & Platforms
CM = Commissioning Manager
TE = Technical Engineer
EU = End User

1. INTRODUCTION

1. INTRODUCTION

1.1 Problem statement

In the global context, the building sector stands as a significant contributor to global warming since it is responsible for 40% of total delivered energy consumption and one-third of CO2 emissions (Yang et al., 2014; Ali et al., 2020) (figure 1). At the same time, the buildings sector also offers substantial opportunities for energy savings. In order to address climate change, the Paris climate agreement entered into force in 2016. This legally binding international treaty aims at reducing global greenhouse gas emissions and limiting global warming to well below 2 degrees Celsius above pre-industrial levels, while striving for efforts to limit the temperature increase to 1.5 degrees Celsius (United Nations, 2015). In alignment with these targets, the Dutch Green Building Council (DGBC) has introduced the Paris Proof Commitment. The Paris Proof Commitment, aiming at lowering energy usage in the built environment by two-thirds and corresponding CO2 emissions, has now been signed by 114 market parties. This shows that stakeholders are becoming more conscious and making a commitment to reduce the ecological impact of the building industry, which is critical in the battle against climate change (DGBC, 2023). Improving energy efficiency in buildings is however challenging given that people spend considerable amounts of their time indoors and require energy for heating, cooling, and lighting to maintain a comfortable and healthy environment (Shaikh et al., 2014). Realising the built environment its potential requires therefore an deeper understanding of the influencing factors and a comparative assessment of alternative strategies for energy-savings.

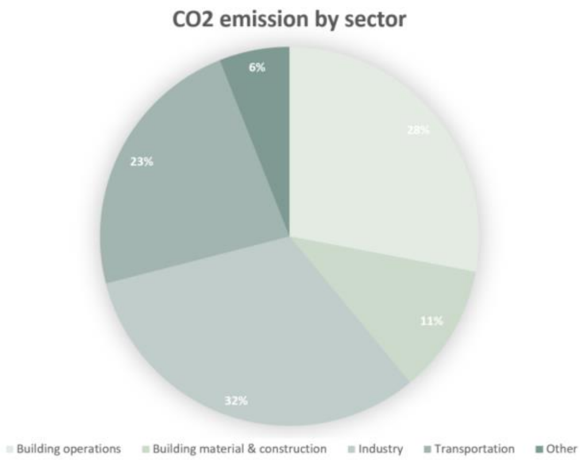

Figure 1: CO2 emission by sector (adapted from Ali et al., 2020)

In order to make the building energy performance more efficient, energy modelling has become an integral part of today's design process. Nevertheless, there is a growing concern within the building industry around the 'performance gap'. Depending on the benchmark, there are two definitions of this term in current literature. In the first definition, the predicted energy consumption during the design stage is compared with the actual energy consumption of a building during the operational phase. In the second definition, the difference between actual measured consumption and the energy-efficient building standard established by authorities is what defines the gap (Zou & Alam, 2020). Since the first definition was largely accepted by previous researchers, it is used in this study. In this context, the predicted performance consists of design assumptions and energy simulation tools while the actual performance consists of energy management, monitoring, occupancy behaviour, and built quality (Menezes et al., 2011). According to previous reports, measured energy use could differ significantly, sometimes even rising to 2.5 times the amount initially predicted (de Wilde, 2014). Given the increased importance placed on addressing environmental challenges and the rising cost of energy, there is an urgent need to reduce this performance gap. Deep renovations, which combine numerous energy-saving methods, have on average a bigger energy gap compared to single renovation measures, despite achieving higher energy savings (van den Brom, et al., 2019). Moreover, it is observed that buildings with higher energy rates consume more energy than predicted, while lower energy rated buildings consume substantially less energy (Cozza, et al., 2020). According to a study by McKinsey and Company, operational activities account for 76% of emissions throughout the typical building's life cycle, with the remaining 24% deriving from the processing of raw materials and construction. Since 80 percent of the building stock that is expected to exist in 2050 is already constructed, it is imperative that the built environment will need to decarbonise both embodied emissions and, more crucially, the emissions from operations of the current building stock (Apel et al., 2022). These results highlight the importance of investigating the gap in renovated buildings. Clients and the general public nowadays expect strict energy efficiency goals and problems could arise when the promised energy performance certificates are not achieved. Therefore, it is necessary to narrow the performance gap between predicted and measured performance in order to deliver high-performance buildings, such as Paris Proof and BREEAM excellent or outstanding buildings, as well as foster change resilience. The maintenance of optimal performance over the course of a building's life and technical adaptation to changing usage conditions depend on this resilience (Fan et al., 2017). Additionally, it is required for innovative building delivery and building operations ideas such as performance-based buildings or performance contracts. These concepts envision users having a working environment with predefined comfort parameters rather than traditional hardware-based systems that may or may not provide such an environment (Fan et al., 2017).

When looking into previous studies, it is notable that a large amount of research has been conducted, highlighting different topics. However, upon closer examination, noticeable gaps emerge when delving into specific areas of consideration. Most studies are focused with designers, suppliers, contractors, occupants, energy managers, and owners as key players, not mentioning the role of developers. The literature review further underscores the global significance of the energy performance gap (EPG) in office buildings, emphasising the various challenges faced in achieving energy efficiency goals. An issue to be addressed is in terms of who is responsible and what method should be applied. There is a challenge faced in making more precise predictions and enhancing energy related operations. In addition, the findings indicate that the gap results from various underlying factors, necessitating appropriate usage of buildings and their service systems and collaboration and a comprehensive understanding among all stakeholders engaged (Zou & Alam, 2020). The identified complexity of this gap is reflected in the operational phase, with the influence of inadequate operation and maintenance emerging as a critical factor. The need for customised strategies developed to the specific challenges faced by office buildings is highlighted, considering factors such as changing occupancy patterns, dynamics in usage, and technological infrastructure. Furthermore, the literature emphasises the potential contribution of advanced control and monitoring systems, such as building energy management systems, in addressing the gap. These technologies offer accurate output data analysis, identification of inefficiencies, and energy model improvement, thereby contributing to new insights. In-use analyses of the building are recognised as valuable tools for enhancing predictions and aligning them with actual usage. In purposing future research directions, there is a specific need for a focused understanding in the complexities of the predictions and the incorrect usage of the energy systems.

The proposed research seeks to delve into the operation and maintenance-related disparities in redeveloped office buildings striving for Paris Proof, given the importance of the accuracy of the energy usage. The final aim is to offer detailed insights and practical strategies for addressing the performance gap, ultimately enhancing sustainability and reliability in the energy performance.

1.2 Research questions

Researching the performance gap is essential for achieving energy efficiency, sustainability, cost savings, occupant well-being, regulatory compliance, and technological innovation. Focusing within the context of existing office building stock holds particular significance for several reasons. First of all, the existing office building stock represents a substantial portion of the built environment. These buildings, in contrast to new ones, have already made an impact on the environment through the design, building, and operational phases. As the buildings are already integrated into the built environment, examining the performance gap in renovated buildings becomes valuable. Secondly, redeveloping existing office buildings presents unique challenges and opportunities since they frequently have diverse usage patterns. Understanding the performance gap in this context is essential to develop specific methods to enhance energy efficiency while maintaining the functionality and comfort of these buildings. To specify the field of research, the scope will be focused on redeveloped office building, aiming at Paris Proof. The high promised energy performance linked to the certification make the accuracy of these energy specifications even more important. Due to the challenge of balancing sustainability with economic constraints and navigating a competitive real estate market, researching efficiency and effectiveness is essential for mitigating financial risks. To tackle the mentioned challenges, this research aims to systematically identify and address the energy performance gap (EPG) of renovated office buildings with the goal of enhancing sustainability and performance reliability (figure 2). Therefore, the main question (MQ) is stated as:

- *How can operation and maintenance-related energy performance gap in renovated office buildings be effectively addressed to meet the Paris Proof commitment targets?*

This research explores various aspects through a set of sub-questions (SRQ). These aim to uncover factors influencing the performance gap, explore the influence of ownership structures, and examine the human influencing factor of operation and maintenance in specific. With the overarching goal to address the EPG, the following sub-questions will be discussed:

1. *What are the main factors influencing the energy performance gap in buildings?*
2. *What are the key operational and maintenance challenges that contribute to disparities in energy performance from predictions?*
3. *What responsibilities do various stakeholders have in relation to the energy performance of a building and what agreements and information exchanges are in place for this purpose?*
4. *What operational and maintenance practices should be implemented to realise Paris Proof redeveloped office buildings?*

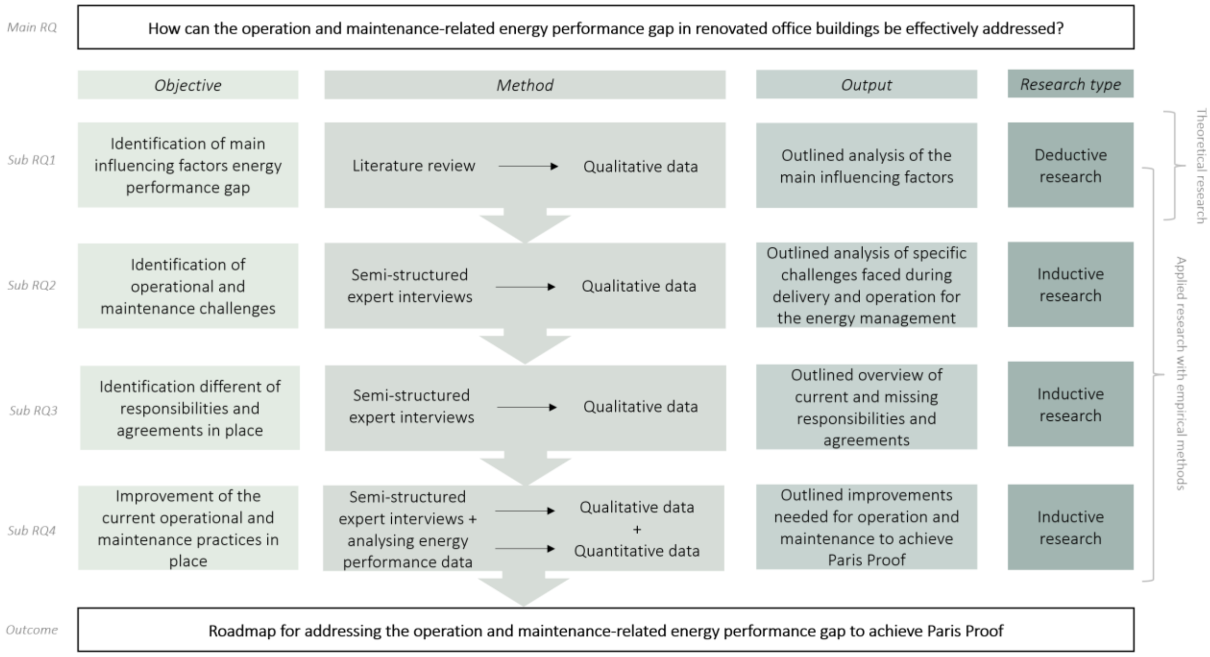

Figure 2: Conceptual framework (own illustration)

1.3 Societal and scientific relevance

The study will take into account societal and scientific reliability and applicability and their complex interactions. From a social point of view, the study recognises that human-influenced factors within the built environment, including operation and maintenance, are varied and dynamic and that building operations can have a substantial impact on energy usage. Developing sustainable solutions that meet the occupant's expectations and societal guidelines requires an awareness of this. In terms of science, the study explores the complexity of energy performance predictions within office buildings. It emphasises the integration of advanced methods, such as data analysis using building management systems and smart meters, to bridge the gap between predicted and actual energy use. By addressing both societal and scientific dimensions, the research aims to provide a deeper understanding of the challenges and opportunities in building energy efficiency, fostering solutions that are both technically robust and socially relevant.

1.4 Structure

The structure of this report comprises several key sections. First of all, the problem statement has been elaborated followed by the research questions. In order to get a better understanding of the EPG, the theoretical background will be outlined in the second section, answering the first sub-research question. Moreover, explanations will be given to the applicable certifications and definitions. Third, the methodology employed will be explained, outlining the research strategy. This includes the aimed data collection, analysis, and research output. Thereafter, the research outcomes will be analysed divided into the qualitative interviews and case study that address the second and third sub-research question, followed by steps that need to be taken, focusing on the fourth research question. This will result in the research findings and roadmap measures. In the final sections, the discussion will be outlined, followed by the research conclusion, limitations, and recommendations.

2. THEORETICAL BACKGROUND

2. THEORETICAL BACKGROUND

This section sets the foundation for the exploration into the main factors influencing the EPG in renovated office buildings. Through a review of existing literature and recent studies, the aim is to collect key insights that influence building energy efficiency during the development process, hand-over, and operational phase. Therefore, the focus will be around the first research question: *"What are the main factors influencing the energy performance gap in buildings?"*

2.1 Literature and market research

2.1.1 Life cycle phases

The EPG could arise from various sources related to the building life cycle phases (figure 3). During the design phase uncertainties are introduced for the practical realisation due to unreliable design specifications and inaccurate simulation tools, contributing to the gap. Secondly, insufficient equipment and materials, along with inadequate building methods, make it challenging to achieve optimal energy performance throughout the construction phase. As the building proceeds toward the handover, the lack of commissioning and therefore sufficient verification for installed systems could cause a deviation from the planned operation. Finally, due to the significant influence that building operators and occupant behaviour have on the total energy consumption, difficulties with inadequately performing energy systems continue to arise in the operational phase (Kallab et al., 2017; van Dronkelaar et al., 2016). Focusing specifically on the operational phase is essential for addressing the challenges and optimise energy over the building's lifecycle since it has a long-term impact. Moreover, the operational phase often incurs the highest energy costs and influences the comfort and productivity of occupants.

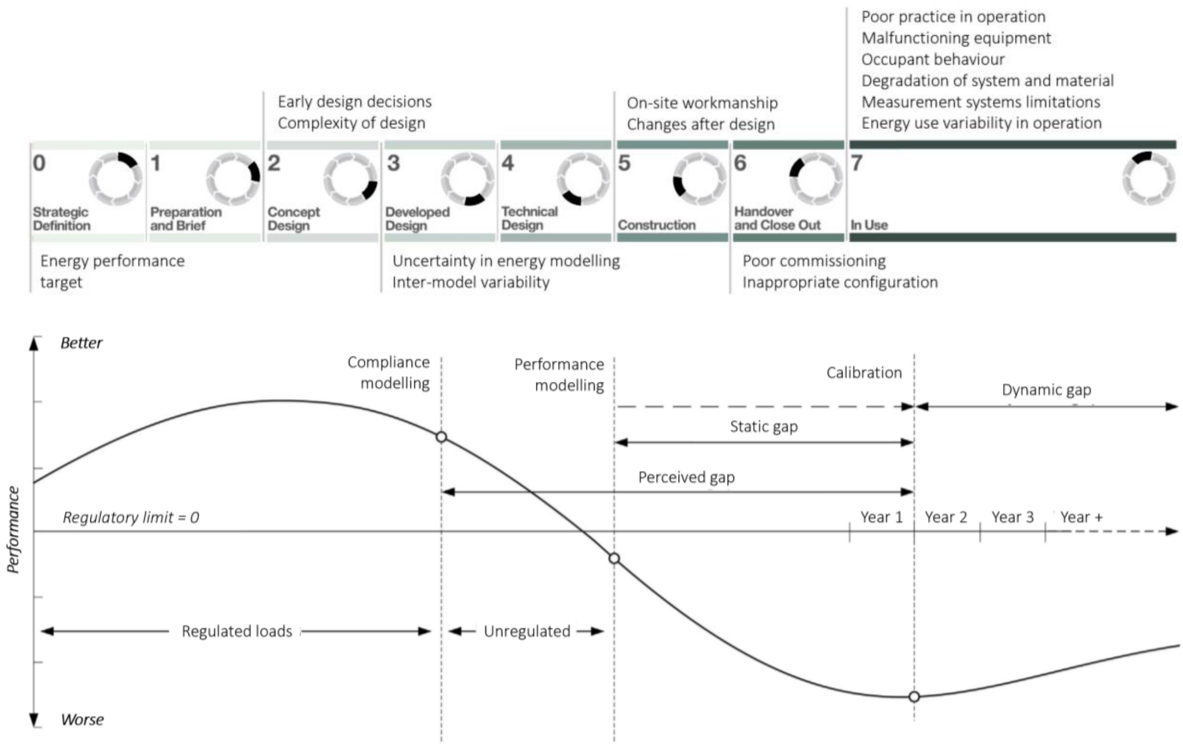

Figure 3: Underlying causes existent in different RIBA stages and S-curve visualisation of performance throughout the life cycle (adapted from van Dronkelaar et al., 2016)

2.1.2 Influencing factors

The computer-based parameters used for the energy performance predictions usually include the building orientation, number of levels, volume, total area of exposed walls, total windows area, wall ratio, floor height, indoor design temp, operating schedule, occupancies, infiltration rate, lighting level, and appliances (Ahsan et al., 2019). Parameters are often used as fixed numbers, however, external factors are dynamic. These factors include occupancy and thermal energy gains, which are important to take into account since they are interlinked and complex. Thermal energy gains include internal heat gains and solar heat gains, generated inside a space and not used as energy for heating, cooling, or hot water. Internal gains are the heat produced by occupants, lighting, and appliances inside offices. Internal gains increase the cooling load in the summer and decrease the amount of heat the HVAC system needs to provide in the winter. Solar heat gains are the thermal energy provided by solar radiation which enters a building through the windows and non-transparent walls and roofs directly and indirectly (Carlander, et al., 2020). Due to the dependence on external influences, it is important to research how this could be effectively managed during the operational phase.

One of the challenges hindering buildings from achieving substantial energy efficiency is a limited understanding of the main factors influencing the use of energy and the challenges coming with those factors (Yoshino, et al., 2017). The main factors influencing the energy consumption of buildings can broadly be categorised into the following six main elements: building equipment, building envelope, outdoor climate, operation and maintenance, occupant behaviour and preferences, and indoor environmental conditions (figure 3).

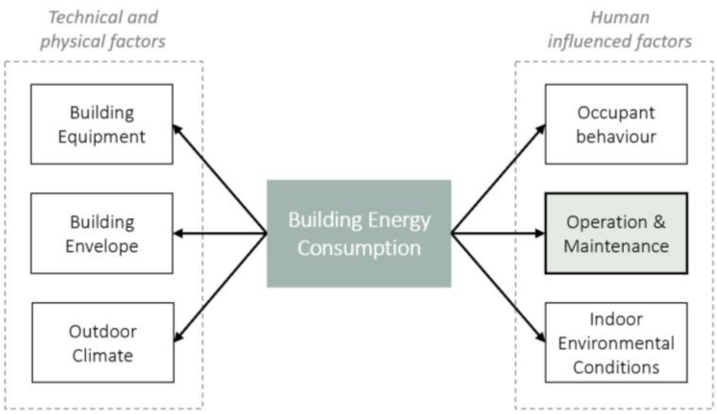

Figure 4: Six influencing factors on building energy use (adapted from Yoshino, et al., 2017)

The building equipment, part of the technical and physical factors, refers to the various systems and appliances within a building that consume energy. This includes HVAC systems, lighting, water heating, appliances, and office equipment. The integration of energy-efficient technologies, the implementation of building automation and energy management systems, and renewable energy sources play crucial roles in optimising energy efficiency (Chen, et al., 2020). The building envelope is a influencing factor by serving as the barrier between the interior and exterior environments. It includes the walls, roof, windows, doors, and foundation of a building. The strategies related to the building envelope are considered passive strategies since they rely on natural processes and design principles to enhance the energy efficiency, without the need for active mechanical systems or constant energy inputs (Sadineni, et al., 2011). The outdoor climate includes the temperature, humidity, solar radiation, and wind speed which are not influenceable, however, it directly affects the indoor energy consumption (Chen, et al., 2020). When looking into the human influenced factors, occupant behaviour encompasses energy use related activities, interactions, and preferences in the building (Ahmed, et al., 2023). The operation and maintenance involve the ongoing activities and management practices to ensure that a building or system operates optimally. This includes the usage, regular inspections, monitoring, and adjustments to enhance efficiency (Piper, 2016). Finally, the indoor environmental conditions cover the thermal comfort, visual comfort, acoustic comfort, and indoor air quality. These conditions affect human health, with research emphasising a direct link between building design, indoor quality, and well-being (Šujanová, et al., 2019). While the three left components in the figure have received the majority of attention in previous research, more recent studies have emphasised the importance of the right three, focusing on the influence of human-influenced factors on energy consumption. This is especially important since the notable gap is often attributed more to human behaviour than to the design of the buildings (Yoshino, H, 2017).

Focusing specifically on occupant behaviour, this factor refers to the actions, preferences, and practices of people within a building that impact its energy usage. This encompasses not just standard actions such as preferred temperature, lighting usage, and appliance usage, but also how occupants interact with the building's energy systems. As shown in figure 5, occupant behaviour can be divided essentially into two categories: occupancy and occupant interactions with building systems including heating, ventilation, air conditioning (HVAC), lighting, appliances, and other energy-consuming equipment (Ahmed, 2023). The interaction with systems, such turning on the light and changing thermostats, plays a crucial role in the actual energy consumption. However, in buildings with a high energy performance that include smart and automated management building systems, the direct impact of occupant behaviour is minimised. Some systems allow users to interact with the system, however in others this is very limited and users are not even allowed to open windows. These automated systems are equipped with advanced sensors and automation that regulate energy consumption, reducing the significance of occupant behaviour and its individual actions (Naylor, et al., 2018). Centralised control mechanisms enable building operators to coordinate and fine-tune energy-consuming components. These technologies are being managed by building operators and react to environmental conditions without relying heavily on individual preferences, resulting in a transitions of the building operations.

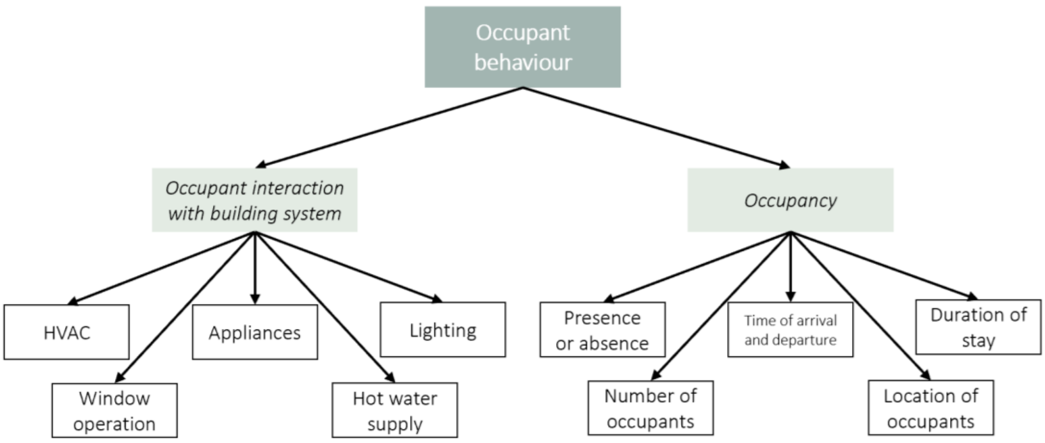

Figure 5: The two main categories of occupant behaviour (adapted from Ahmed, et al., 2023)

2.1.3 Operation & maintenance

Three key factors contributing to uncertainties in energy consumption within buildings are identified by van Dronkelaar, et al (2016). These factors include uncertainties in building modelling specifications accounting for 20%-60%, occupant behaviour accounting for 10%-80%, and operational practices accounting for 15-80% of estimated effects. Focussing on operation and maintenance, it has been researched in case studies that approximately 30% of the energy used was lost due to inadequately maintained and operated building services equipment (Granderson, et al., 2011). According to another research on the key operating parameters of 14 office buildings in Canada, the gap is greatly impacted by poor control of HVAC parameters, such as seasonal heating and cooling temperature setpoints, air handling unit start-stop times, and ventilation rates (Gunay et al., 2019). Additionally, another significant contributor to uncertainty includes the influence of miscommunication among various parties or stakeholders regarding the anticipated performance of the building (Jones, et al., 2015). This is interlinked with the lack of consistent naming of building service components in prediction models and inaccurate predictions of after hour demand, as well as human manual overriding of automatic control systems. Moreover, inaccurate energy control during unusual weather conditions has been identified as a influencing factor (Zou, et al., 2020) (figure 6). In essence, these variables collectively play a substantial role in the challenges associated with accurately predicting and managing energy use in buildings. The Energy Standard 90.1 Appendix G states: "Neither the proposed building performance nor the baseline building performance are predictions of actual energy consumption, due to variations such as occupancy, building operation and maintenance, weather, and the precision of the calculation tool" (Office of energy efficiency & renewable energy, 2020). This statement emphasises the importance of the energy control systems during the operational phase. The control of energy usage in office buildings with advanced systems is largely influenced by its facility management and building operations. According to research in the United States, buildings overseen by facility managers with higher education levels are 13% more likely to implement temperature setbacks (Liang, et al., 2019). Moreover, it has been demonstrated that inefficient building operations across a number of parameters lead to a 49–79% increase in energy use, whereas efficient operations cut energy use by 15–29% (van Dronkelaar, et al., 2016). The operation of the building is influenced by its ownership structure. The type of owner could impact the role of financial, social and moral considerations in decision-making, as well as the influence of such issues from investors. Corporate social responsibility and sustainability goals may be more prominent factors for privately-owned buildings, while investor-owned properties may prioritise financial returns. Moreover, different owner types may have varying regulations and requirements related to energy efficiency (Kontokosta, 2016). The energy certification of green buildings relies on model-based consumption rather than performance-based consumption, which emphasises the need for appropriate facility management to maintain the certification requirements (Liang, et al., 2019). Therefore, the interplay between the operation of facility management practices, building systems and technologies, and ownership types collectively shape the energy efficiency and sustainability outcomes of buildings.

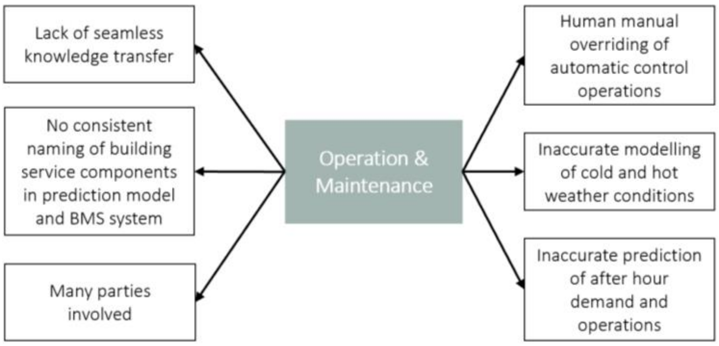

Figure 6: Challenges and causes related to building operation and maintenance (adapted from Zou, et al., 2020)

2.1.4 Office Buildings

The EPG appears in different types of buildings. Addressing this, a review of a previous study by van Dronkelaar (2016) notices a significant difference between predicted and actual energy consumption, with a deviation of +34% and a standard deviation of 55% across a dataset of 62 buildings with different functions, including offices, retail, restaurants and universities. In this dataset, 15% of the 62 buildings studied show a notable pattern in which the actual energy usage is double the amount compared to what was previously expected (van Dronkelaar, 2016). Office buildings are particularly important in the context of sustainability for a number of reasons. First of all, office buildings contain a significant percentage of the non-residential building sector with 32% of the surface area (Economidou., et al 2011). Secondly, office buildings' dynamic and unpredictable occupancy patterns add difficulties to the energy management. This includes the varying end-user, occupancy, and electrical equipment, demanding an effective approach to optimise energy consumption. Moreover, the technological infrastructure embedded within office buildings, including HVAC systems and other energy-intensive equipment, offers a unique potential for sustainable interventions. Finally, the behavioural dynamics in offices offer an effective way to influence sustainable business practices. Based on an analysis of 25 case studies, it is revealed that office buildings have an average deviation of +22% and a standard deviation of 50% between the predicted and actual energy consumption (van Dronkelaar, 2016). Another study, using post-occupancy evaluation, even indicates that the measured electricity use is 70% more than what was expected (Menezes et al., 2011). This emphasises how challenging it is to predict and manage energy use in office environments, where a variety of activities lead to unpredictable energy performance.

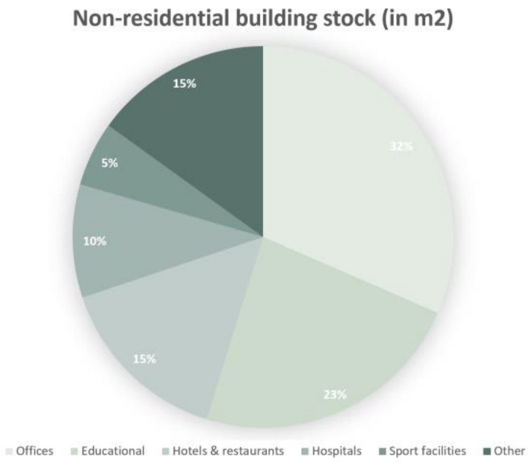

Figure 7: Non-residential building stock in m2 (adapted from Economidou., et al 2011)

In the quest for enhanced energy efficiency in office buildings, the improvements needed can be categorised into three core areas: building change, organisational change, and behavioural change (figure 8). Changes in the building characteristics consist the physical attributes including the design of structures and technical aspects. In terms of renovations, this aspect is focused on changing building components and technical systems since the building structure and main envelope already exists. Building components include insulation improvements and window and door replacements (Chen et al., 2020). Improvement of the technical aspects encompass the adoption of energy-efficient technologies and systems, ranging from upgraded appliances to the integration of renewable energy sources. These changes contribute to the optimisation of the generation, distribution, and utilisation of energy resources. Organisational changes entail reorganising practises and controls within organisations to emphasise and promote energy efficiency. Establishing efficient energy management systems and promoting a sustainable culture collectively contribute to a more energy-conscious environment. In addition to the technological and organisational aspects, behavioural changes seek to improve sustainable energy usage by reducing it (Ruparathna et al., 2016). These three core values are dynamic and interlinked with one another and to the building operations. The building characteristics have an impact on the overall energy consumption and provide direction to energy certifications. This includes technical changes which is associated with the building equipment and envelope. Building changes requires organisational support for effective implementation and both depend on behaviour, which includes operational changes, to create a culture that encourages improvements. This interdependence emphasises the value of a comprehensive strategy, recognising that actual improvements in energy efficiency depend on organisational, behavioural, and technical changes integrated into a cohesive plan.

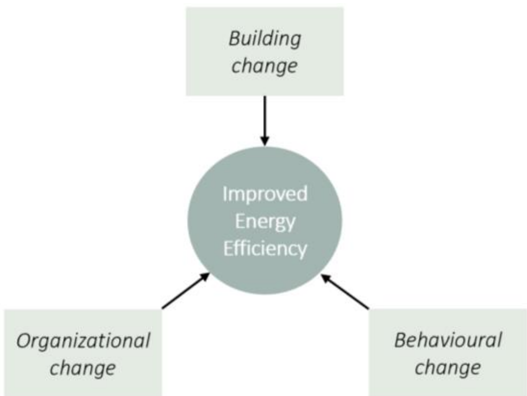

Figure 8: Paradigms for energy performance improvement in existing buildings (adapted from Ruparathna et al., 2016)

2.2 Process and stakeholders

In order to understand the challenges that emerge during the operation and maintenance, insights into the whole redevelopment process are needed. The initial phase, known as the front-end, plays a pivotal role in shaping the delivery process and the subsequent in-use phase of the redevelopment. During the front-end phase, various stakeholders, including developers, contractors, architects, engineers, advisors, and urban planners collaborate to conceptualise and plan the project, negotiating agreements regarding design specifications, sustainability objectives, construction methods, and building materials. Effective communication is crucial to safeguard compliance with the project's objectives and specifications. Decisions and agreements made during the front-end phase influence the operational and maintenance practices during the in-use phase. Challenges such as missing agreements, unclear definitions, a lack of responsibilities and enforcement, broken knowledge transfers, absent stakeholders, insufficient motivation, and ineffective monitoring and tuning can all contribute to the EPG. Zou & Alam (2020) therefore emphasise the critical importance of addressing various factors to effectively bridge the EPG observed during operation and maintenance (figure 9). Several key considerations to enhance energy management practices and ensure optimal energy performance throughout the project lifecycle are highlighted. First of all, the study emphasises the need of establishing strong motivations for the involvement and active participation of all stakeholders, as clear incentives motivate actively contributing to the implementation of sustainable practices. Secondly, emphasis should be placed on maintaining consistency in the naming of building service components within both the prediction model and the building management system in order to ensure accurate comparisons between predicted energy consumption and actual energy usage. Third, the importance of seamless knowledge transfer between stakeholders is pointed out in order to support the effective implementation of energy management strategies. The introduction of energy monitoring and tuning operations for post-occupancy allows stakeholders to quickly identify and correct inefficiencies, resulting in enhanced energy efficiency and lower operational costs. In addition, prediction methods must be updated on a regular basis to accurately reflect changing conditions. This will help ensure that the methods used, including models, continue to be applicable and useful for forecasting energy performance and identifying areas for improvement throughout the project lifecycle (Zou & Alam, 2020).

Another study confirms the importance of including operational control and management for facility management into the integrated design processes (Min, et al., 2016). After facility management integration in the design phase, there is a need of continuous improvement and proactive maintenance which include preventive and predictive maintenance. This draws attention to deliberately strengthen the role and level of expertise of facilities managers at the organisational, industrial, and national policy levels. A case study in the research has demonstrated that proactive maintenance focused on continuous improvements could result in a 36% improvement in energy performance.

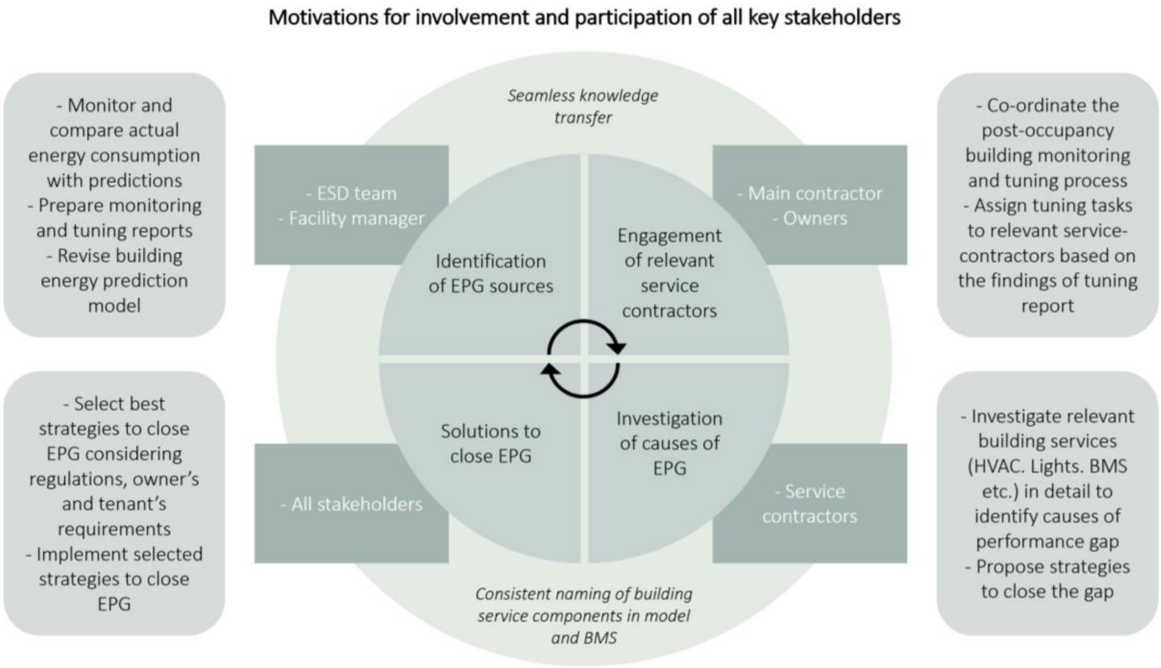

Figure 9: Strategic framework for closing the EPG (adapted from Zou & Alam, 2020)

2.3 ISSO 107

For the purpose of maximising the performance of climate installations in buildings from the commissioning stage to the final handover for management, ISSO Publication 107, "Commissioning Process for Climate Installations and Handover to Management", provides a guide. Focusing on bridging the gap between the design, realisation, and management phases of building projects is a crucial aspect of ISSO 107. It acknowledges that many of challenges with building installations can be traced back to the handover phase, when the original project team disengages and the new management teams take control. In order to prevent a decline in building performance, the guide specifies the need for clear communication, complete documentation, and the precise division of maintenance and management tasks. Furthermore, the ISSO 107 clarifies that a one-size-fits-all strategy is not practical for addressing the difficulties caused by the variety of buildings and their management (Stichting ISSO, 2017).

Using a structured choice framework, the ISSO-publication 107 has three separate classes of quality assessment, known as "toetsingsklassen",that correspond to different testing scopes and quality levels. Class C represents a sufficient quality level that maintains the standard delivery procedure while setting the standard slightly higher than current practices. Subsequent to this, class B is more strict and aligns with the quality level expected in sustainable management and maintenance, extending beyond the conventional delivery approach. Finally, class A is intended for large or complex installations, where quality assessment and the process are elevated to the highest level. It takes up the commissioning process's guiding principles and requirements and prioritises quality control across the whole project lifecycle, from programming to management. The different classes are intended to meet the different needs of customers in terms of quality level preferences based varying quality level preferences that clients may have based on how the buildings are to be used or the ownership situation, as well as the changing complexities and sizes of projects.

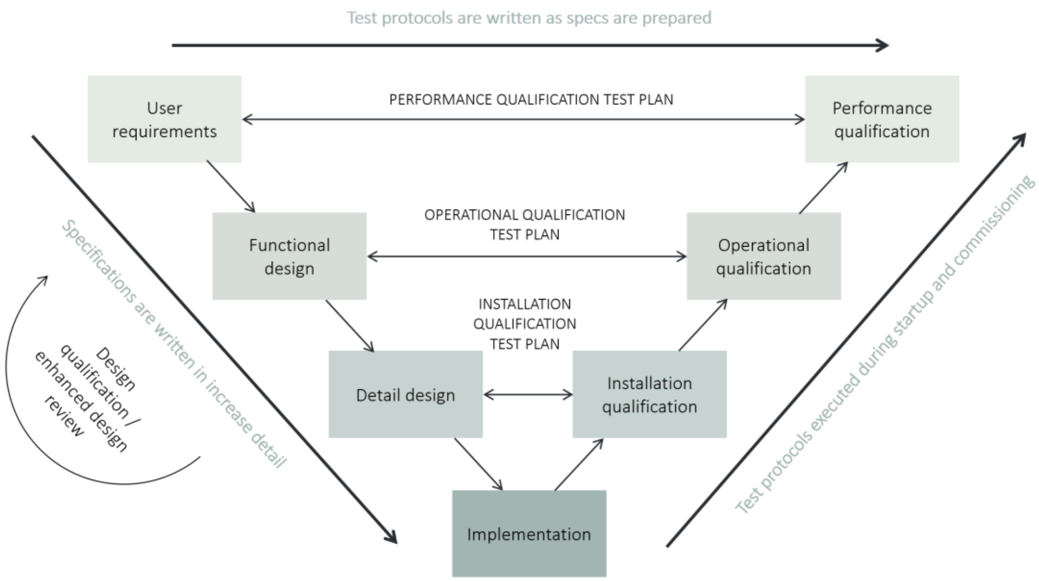

Figure 10: V-model for tests (adapted from ISSO 107, 2017)

While traditional handover procedures usually focus on the physical transfer of a building, the ISSO 107 emphasises a systematic approach to commissioning. Commissioning is an important ongoing process which verifies and ensures the adequate functioning of installations from its design phase to beyond the warranty period, through advanced verification steps (Stichting ISSO, 2017). In order to guarantee that buildings not only achieve but also maintain their targeted energy performance levels, this entails extensive testing, documentation, and climate adjustments to meet predetermined performance standards. Figure 10 illustrates a systematic approach to quality assurance during the development of climate installations, starting with the user requirements and moving through design qualification, functional and detailed design, and on to implementation. It emphasises the need for test protocols at various stages of the process.

2.4 Methods

Focusing on the energy performance, a greater understanding of where and how energy is used in a building, as well as which measures have the biggest effects on energy usage, can be gained by using several methods for calculating the energy performance of a building during both its design and operating phases. During the design phase, the NTA 8800 serves as a method for determining the energy performance of buildings. When in use, sensors and building energy management systems can locate possible energy-saving opportunities and analyse the energy efficiency and economic viability of proposed energy-saving methods. However, it is challenging to reflect actual building energy use and possible savings in the real world since the built environment is complex and influenced by a wide range of independent and interconnected variables. Models are a simplification of reality, using parameters with set standards that ignore certain processes (van Dronkelaar, 2016).

Building energy management systems can be used to monitor and control data regarding energy use, analyse consumption patterns, and optimise energy efficiency (figure 11). Given that heating, ventilation, and air conditioning (HVAC) systems, use the majority of the electricity consumed by buildings, it is crucial to include this data in the analysis of energy efficiency and identify areas of inefficiency. This involves locating weaknesses in the way the HVAC is operating and identifying timeslots with energy inefficiencies. A case study of a Houston office building demonstrates the effectiveness of data analysis and self-organising maps in identifying potential energy savings of up to 4.6%. Energy managers can find more energy savings by using machine learning and time series analysis methods (Talei et al., 2023). Another study shows that post-occupancy evaluations in office buildings can improve the energy model's accuracy within 3% of the actual energy consumption (Menezes et al., 2011). Moreover, Taal et al., (2020) demonstrated 25% annual primary energy savings on the thermal energy plan at the Hague University of applied Sciences in Delft by correcting isolated faults using automated fault detection and diagnosis methods (Taal & Itard, 2020).

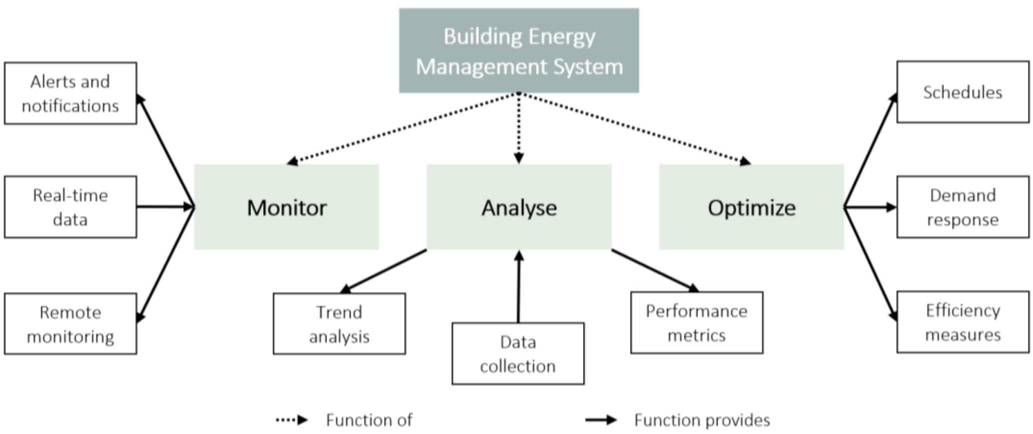

Figure 11: Characteristics of Building Energy Management Systems (own illustration)

2.6 Certifications and definitions

Interestingly enough, it has been shown that buildings with higher energy ratings use more energy than predicted, whereas buildings with lower energy ratings use substantially less (Cozza et al., 2020). Therefore, high performance certified buildings are more likely to contribute to an EPG, making it an important field of research. Furthermore, when sustainable certificates are awarded to buildings, it is even more crucial that these energy performances are achieved and maintained following delivery. This research will therefore focus on a highly certified office building, which will be explained in the case study section 3.3. In an era marked by rapid developments in sustainable building practices, certifications and standards are evolving significantly. This progression emphasises the need to comprehend these definitions with clarity. Misunderstandings become more common as many methods and definitions exist, such as BREEAM, BENG, Paris Proof, and the WEii indication. In order to effectively deal with the complexity of sustainable development, it is therefore essential to have a solid understanding of these methods and their definitions. The following section reviews the main certifications and methods that have shaped the sustainable building sector, providing insight into their definitions. Deeper analysis of these concepts demonstrates that they are not only set as benchmarks for environmental performance but also serve as catalysts for innovation and progress within the built environment.

2.6.1 NTA 8800

Focusing specifically on the energy performance, the NTA 8800 serves as a method for determining the energy performance of buildings, aligning with the EU's Energy Performance of Buildings Directive (EPBD). According to the NTA 8800:2024 terms and definitions 3.58, the energy performance of a building is defined as: ‘the sum of the use of fossil fuels converted into primary energy for heating, humidification, fans, cooling, dehumidification, hot tap water and the total auxiliary energy used, minus any (building-related) energy produced on your own plot, for example, converted into primary energy, for example solar power and electricity supply from building-related combined heat and power installations.’ In contrast to setting energy performance standards, NTA 8800 provides a mandatory framework for determining compliance with such standards. It is applicable to all building types, both new and existing structures, and subject to energy performance criteria in building standards. NTA 8800 expresses energy demand and primary energy use expressed in kWh/m2·y, with renewable energy given as a percentage. Operating within the regulatory framework of the Netherlands, it is designed for public use and follows predefined user profiles and building usage scenarios. This standardised method of system and building usage is intended to reflect average behavioural patterns, climate conditions, and occupancy rates. The determination procedure focuses solely on building-related measures. Non-building-related energy usage, which includes energy used for appliances, computers, machines, and other non-building-related purposes in buildings are not included in the calculations (NEN, 2024). The decision-making method offers a benchmark. To ensure that various structures are comparable to one another, the calculation is based on an average situation. As a result, depending on energy management, user behaviour, external factors, and the location of the building, the actual energy use for building-related measures may differ significantly from the predicted energy usage in practice. Additionally, NTA 8800 covers solely building-related data and excludes user-specific energy usage.

2.6.1.1 Energy labels

Within the framework of evaluating and improving the energy efficiency of buildings, energy labels stand as a well-known instrument, providing a standardised measure of the building-related energy consumption. The NTA 8800 calculation method is integral to determining the energy label, calculating the energy performance based on both the physical characteristics of the building and its fixed installations (Rijksdienst voor ondernemend Nederland, 2024). While this method aims to offer a consistent basis for comparison across buildings, it inherently lacks the detail to reflect the actual, varied energy consumption within buildings (NEN, 2024). This perspective is further emphasised by the disclaimer associated with the energy label, which clarifies: ‘The energy label provides insight into the standardised building-related energy use and not into the actual energy use of the users of this building. Therefore, the annual energy use on the energy label may not correspond to the information on the annual energy bill of this building’ (DGMR, 2018). This disclaimer highlights that labels are based on standardised, building-bound energy use rather than actual user consumption, indicating that the building's annual energy performance might not align with the energy label's annual energy usage. Acknowledging this disclaimer is essential since it underscores supplementing building-focused energy measurements to the generalised insights from energy labels using the NTA 8800 method. Adding a supplementing strategy not only increases the overall value of energy labels but also improves their use in encouraging improvements in energy efficiency by bridging the gap between the standardised energy performance measurements and actual energy consumption patterns.

2.6.1.2 BREEAM

In the field of sustainable building certifications using the NTA 8800, the BREEAM (Building Research Establishment's Environmental Assessment Method) is also recognised as a standard model (BREEAM-NL, 2023). This method is widely utilised to categorise both new and renovated buildings based on their environmental performance. The Dutch version of BREEAM, known as BREEAM-NL, uses an evaluation and rating system to assign five star ratings to buildings, each representing a different degree of sustainability achievement: Pass (>30%), Good (>45%), Very Good (>55%), Excellent (>70%), and Outstanding (>85%). BREEAM-NL evaluates sustainability using approximately seventy parameters in nine key categories, including a building's lifecycle and its relationship to the environment. These categories, shown in figure 12, include: management, health, energy, transport, water, materials, waste, land use, and ecology and pollution (BREAAM-NL, 2023). The energy performance in the BREEAM certification is calculated as part of the energy category with the ENE01 criteria, which is a mandatory criteria to achieve at least BREEAM excellent. Usually the ENE01 criteria is being calculated using the NTA 8800 method, depending on the specific BREEAM guidelines and project requirements. In contrast to many certification programmes that primarily focus on energy usage, BREEAM-NL adopts a extensive strategy, taking into account a building's broader impact on its surroundings and the well-being of its occupants. The Dutch Green Building Council (2022) reported that BREEAM-NL has a notable impact on the Dutch real estate market with over 20 million square metres, or roughly 3,000 football fields' worth of floor area in 2021. There has been a growing recognition within the industry of the importance of sustainable building practices ever since with currently more than 1,200 utility buildings with BREEAM-NL certificates.

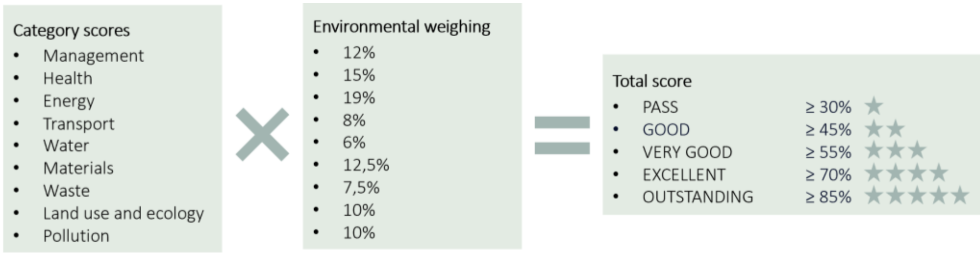

Figure 12: BREEAM category scores (adapted from BREEAM-NL, 2023)

BREEAM has a number of measures that a building must meet to achieve a certain certification score. As part of the management category, several criteria relate to transferring, securing, and maintaining the energy performance (BREEAM-NL, 2023). These include performance assurance of installations (MAN 1), user manuals (MAN 4), knowledge transfer (MAN 9), and ease of maintenance (MAN 11), all of which were also met in the Edge Olympic case study, as explained in section 3.3.1 (table 1). Achieving a higher BREEAM score goes hand in hand with meeting multiple criteria from different categories. Focusing on transferring, securing, and maintaining energy performance, BREEAM serves as a means to achieve certain energy performance objectives. However, the BREEAM certificate remains based on theoretical approaches, requiring additional methods to align actual performance with objectives.

Criteria	Theme	Mandatory from	Function
MAN 1	Performance assurance of installations	≥ BREEAM Pass	Encouraging and appreciating insight into the energy performance of the building and that measures have been taken to minimize building-related energy use.
MAN 4	User manuals	≥ BREEAM Excellent	Encouraging the provision of a building manual for the non-technically proficient user of the building to enable them to understand the building and use it efficiently.
MAN 9	Knowledge transfer	≥ BREEAM Outstanding	Encouraging informing users and visitors about sustainable construction.
MAN 11	Ease of maintenance	-	Encouraging the design of a building and its installations that can be easily maintained throughout their entire lifecycle.

Table 1: BREEAM Management criteria (adapted from BREEAM-NL, 2023)

2.6.1.3 BENG

The NTA 8800 moreover offers calculations to determine a building's energy label and confirm adherence to the BENG standards (NEN, 2024). BENG, standing for nearly zero energy buildings, represents a compulsory computational method utilised to assess the energy efficiency of both new and existing buildings. All factors influencing building-related energy usage, including the building envelope, heating, ventilation, cooling, insulation, solar heat gain, lighting, and the presence of solar panels, are integral to the BENG calculation. Additional appliances, such as computers and refrigerators, are not included in the calculation according to criteria specified in the Building Decree. BENG calculations are conducted against three key indicators: BENG 1 evaluates the structural energy efficiency, measured by the maximum energy requirement in kWh per m^2 of usable space annually; BENG 2 assesses the maximum annual primary energy consumption per m^2 of usable space; and BENG 3 determines the percentage of energy consumption generated by renewable sources. Data related to these parameters are divided into three categories throughout the BENG calculation process. The general data includes building type, utilisation function, and whether the structure is new or existing. The technical features indicate the presence of systems for tasks such as ventilation, cooling, heating, and energy generation. Finally, structural aspects include size, air permeability, insulation value, and shading (DWA, 2023).

The BENG standards replace the previously used energy performance coefficient (EPC). The main distinction between the two is that BENG demands compliance with four criteria instead of to a single one. A poorly insulated building could be compensated for with technical installation measures when using EPC, whereas this is not possible with BENG. Compared to EPC, the criteria are less abstract, thereby making it clear which measures affect each requirement. BENG is strongly aligned with sustainability objectives, supporting the shift to renewable energy sources and contributing in the effort to battle against climate change. BENG offers a more future-proof foundation for building design and construction by anticipating future energy efficiency standards and technology improvements. The initial concept underlying BENG, known as "Trias Energetica", offered more guidance on how to achieve energy-neutral buildings. BENG 1 includes reducing energy demand, BENG 2 includes using finite (fossil) energy sources as efficiently as possible, and BENG 3 includes utilising energy from renewable sources (Archidat, 2021). BENG places a strong emphasis on energy efficiency in building design, however, operational challenges including operational and maintenance practices have not been given enough consideration. While BENG emphasises energy efficiency in building design, it may not sufficiently consider operational factors such as operational and maintenance practices. This oversight poses a risk of a performance gap between predicted and actual energy usage in BENG-compliant buildings, ultimately undermining its effectiveness in achieving energy efficiency targets.

2.6.2 WEii indicator

When in use, the WEii (Werkelijke Energie Intensiteit Indicator) indicator measures the actual energy intensity of a building over time, reflecting its real energy performance. Its main objective is to measure a building's actual energy consumption while taking into account factors such as operational practices, occupancy patterns, and weather conditions. WEii provides information on a building's actual energy usage, which could be used to identify areas for improvement and enhance energy-saving strategies. A straightforward instrument to improve building sustainability to Paris Proof criteria is the WEii Energy Compass. Through a series of steps, the WEii Energy Compass demonstrates the most efficient route for utility buildings to achieve their targeted level of ambition by combining the energy label and the WEii score. For each building type, seven classes of energy efficiency are distinguished, including Paris Proof (table 2). The numerical value of WEii is used to divide buildings into these classes. In this categorisation the WEii classes' limitations are expressed in kWh/m^2. The highest score is WENG standing for ‘Werkelijk Energieneutral’, meaning truly energy neutral (TVVL & DGBC, 2023).

Building type	WENG	Paris Proof	Very efficient	Efficient	Average	Inefficient	Very inefficient
Ground-based home	0 kWh/m^2	35 kWh/m^2	55 kWh/m^2	90 kWh/m^2	140 kWh/m^2	170 kWh/m^2	-
Apartment	0 kWh/m^2	45 kWh/m^2	65 kWh/m^2	100 kWh/m^2	150 kWh/m^2	180 kWh/m^2	-
University	0 kWh/m^2	70 kWh/m^2	90 kWh/m^2	125 kWh/m^2	225 kWh/m^2	380 kWh/m^2	-
Gym	0 kWh/m^2	70 kWh/m^2	90 kWh/m^2	140 kWh/m^2	245 kWh/m^2	435 kWh/m^2	-
Office	0 kWh/m^2	70 kWh/m^2	100 kWh/m^2	150 kWh/m^2	230 kWh/m^2	330 kWh/m^2	-
Hospital	0 kWh/m^2	100 kWh/m^2	135 kWh/m^2	185 kWh/m^2	315 kWh/m^2	500 kWh/m^2	-
Hotel	0 kWh/m^2	110 kWh/m^2	140 kWh/m^2	210 kWh/m^2	375 kWh/m^2	640 kWh/m^2	-
Restaurant	0 kWh/m^2	200 kWh/m^2	270 kWh/m^2	415 kWh/m^2	695 kWh/m^2	1075 kWh/m^2	-
Swimming pool	0 kWh/m^2	210 kWh/m^2	300 kWh/m^2	430 kWh/m^2	765 kWh/m^2	1365 kWh/m^2	-

Table 2: Upper limits in kWh/m2 of the WEii classes (TVVL & DGBC, 2023)

This indicator, expressed in kilowatt hours per square meter per year (kWh/m² · year), is determined by starting with a conversion of the energy consumption of different carriers, such as electricity, gas, and heat, into a uniform measure of kWh. By using specific conversion factors, this step harmonises disparate energy inputs into a similar framework. Subsequently, the calculation includes weighing factors for each energy type, adjusting for environmental impact and providing a nuanced assessment of energy consumption. The total of these corrected values presents an overview of the building's energy consumption. By dividing this total consumption by the usable area of the building, the energy intensity can be calculated and displayed in a statistic that shows the energy consumption per square meter (figure 13). This intensity indicator is essential for evaluating efficiency and identifying areas that require improvements. To guarantee that the WEii accurately reflects operational energy consumption, it is crucial to account for exclusions, such as energy used for charging electric cars which is an activity unrelated to the building's functioning. Given the numerous uncertainties associated with the user-related component, this is beneficial for offering an energy performance guarantee. If the excluded energy function occupies a certain part of the building's floor area and the energy consumption of this energy function is excluded, then the corresponding floor area needs to be excluded as well (TVVL & DGBC, 2023).

$$WEii = \frac{E_{in;ci} - E_{uit;ci} - E_{uitgesl;ci} + E_{cor;verw} - E_{cor;prod}}{A_g}$$

WEii	The Actual Energy intensity indicator [kWh/m2 • year]	$E_{cor;verw}$	The weather correction for space heating [kWh/year]
$E_{in;ci}$	Energy supply per year for energy carrier ci [kWh/year]	$E_{cor;prod}$	The weather correction for local generation by PV panels [kWh/year]
$E_{uit;ci}$	Energy return per year for energy carrier ci [kWh/year]		
$E_{uitgesl;ci}$	Corrections regarding excluded energy use [kWh/year]	A_g	Usable area [m2]

Figure 13: WEii calculation (TVVL & DGBC, 2023).

2.6.2.1 Paris Proof

In order to achieve the set sustainability ambitions and targets, Paris Proof has been introduced by the Dutch Green Building Council (DGBC). Paris Proof is the second highest WEii score established for various building types. As part of the Sustainable Renovation Delta Plan, the initiative aims to make the built environment Paris Proof by 2040. This includes cutting building energy use by two thirds compared to the currently average, with goals set for various sectors including offices, supermarkets, and healthcare facilities. By 2025, the annual consumption of existing office buildings should not exceed 70 kWh per square metre. In order to achieve the climate change goals of the Paris Agreement, these targets are essential. While the initiative sets ambitious energy consumption targets for existing buildings undergoing renovation, it also establishes standards for newly constructed buildings to ensure they meet stringent energy efficiency criteria from the outset. Unlike generic targets, Paris Proof is based on actual energy usage data, providing a practical and actionable framework for achieving sustainability goals. By focusing on real-world energy measures, energy efficiency measures are not just theoretical but practical and achievable. When establishing Paris Proof, the monitoring process plays an important role. Monitoring involves the methodical gathering of building energy usage data, which provides insight into actual energy consumption patterns and identifies opportunities for improvement. Building compliance with Paris Proof standards and energy performance ratings are determined using this data as a basis. Using actual data promotes a more comprehensive approach to building design and operation as well as increased responsibility among stakeholders. Additionally, it increases credibility and transparency, promoting trust among stakeholders and fostering the broader adoption of sustainable building practices (DGBC, 2023).

2.7 Conclusion

In addressing the first sub question, *'What are the main factors influencing the energy performance gap in renovated office buildings?'*, this section explored the theoretical background that clarifies the complex and interrelated factors contributing to the discrepancy between predicted and actual energy performance. Through a review of literature, studies and methods, this section identifies the key influencing factors, shedding light on the complexities inherent in achieving optimal energy efficiency as shown in figure 14. In the core of these factors are inefficiencies that occur throughout a building's whole lifecycle, from the beginning phases of design to its final phase of operation. The framework demonstrates how substantial uncertainties in energy performance outcomes are introduced by unreliable design specifications, inadequate construction methods, and a lack of accurate verification of installed systems during commissioning, underscoring the gap.

The operational phase of a building's lifecycle emerges as a critical area of concern. The need of developing strong operational and maintenance procedures is underscored by the fact that inadequate operational practices and maintenance protocols can result in significant energy inefficiencies. The dynamic and unpredictable occupancy patterns of office buildings add to the complexity of this phase, making it more challenging to effectively manage and predict energy consumption. Additionally, the technological infrastructure within office buildings is identified as an important factor. Achieving energy efficiency requires these systems to be integrated and managed effectively, however, inefficiencies arise when these systems are not optimally managed. Miscommunication among the stakeholders involved in the design, construction, hand-over, and operational phases moreover leads to misaligned expectations and outcomes. This includes issues such as unclear definitions of responsibilities and broken knowledge transfers, contributing to inadequate monitoring and tuning operations. In order to address the challenges identified by the influencing factors, effective strategies are needed. In view of this strategy, the adoption of Paris Proof emerges as a practical and helpful approach in addition to currently used certification since it sets clear, actionable targets based on actual energy usage. By focusing on real-world consumption patterns, Paris Proof promotes the implementation of sustainable practices and technologies that directly impact the building's energy efficiency. This approach provides a practical pathway for enhancing the operational efficiency.

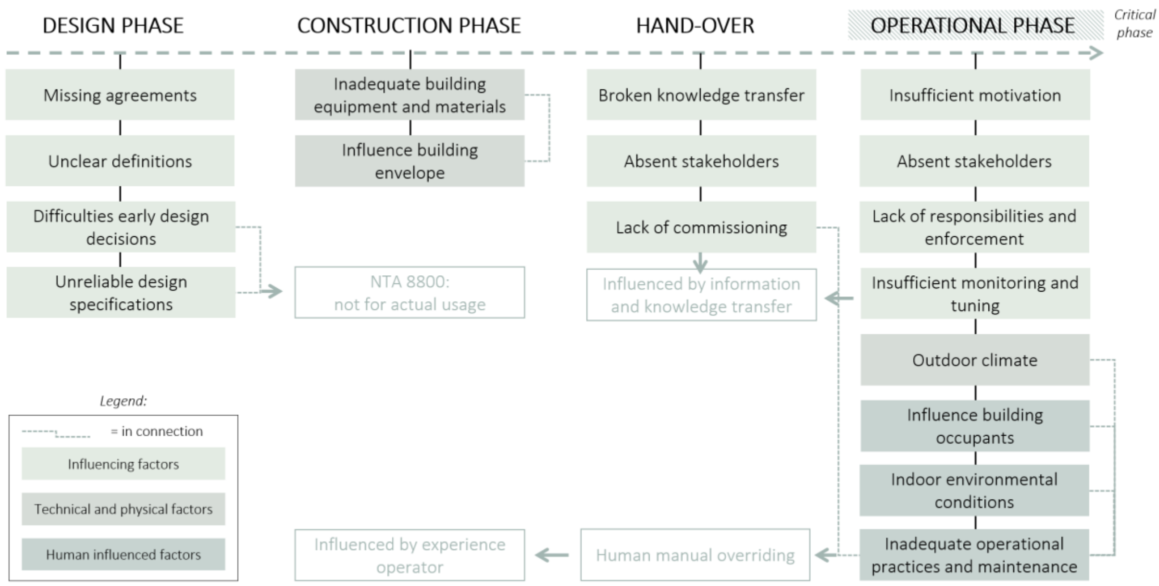

Figure 14: Theoretical framework (own illustration)

3. RESEARCH METHODOLOGY

3. RESEARCH METHODOLOGY

3.1 Research design

The research methodology that will be used in this study is an explanatory mixed-methods research study, combining both qualitative and quantitative methods to address the EPG, thereby improving energy efficiency (figure 15). The explanatory nature aims to go beyond describing the identified phenomenon and seeks to explain the underlying causes and relationships contributing to the gap. Given the complexity of the gap, the research attempts to provide an understanding of the problems and possible solutions by connecting qualitative insights with quantitative data. After conducting theoretical research, applied research will be done to address the challenges faced and to develop practical strategies. This will be done by using empirical methods which involves data collection from semi-structured interviews and building energy management systems.

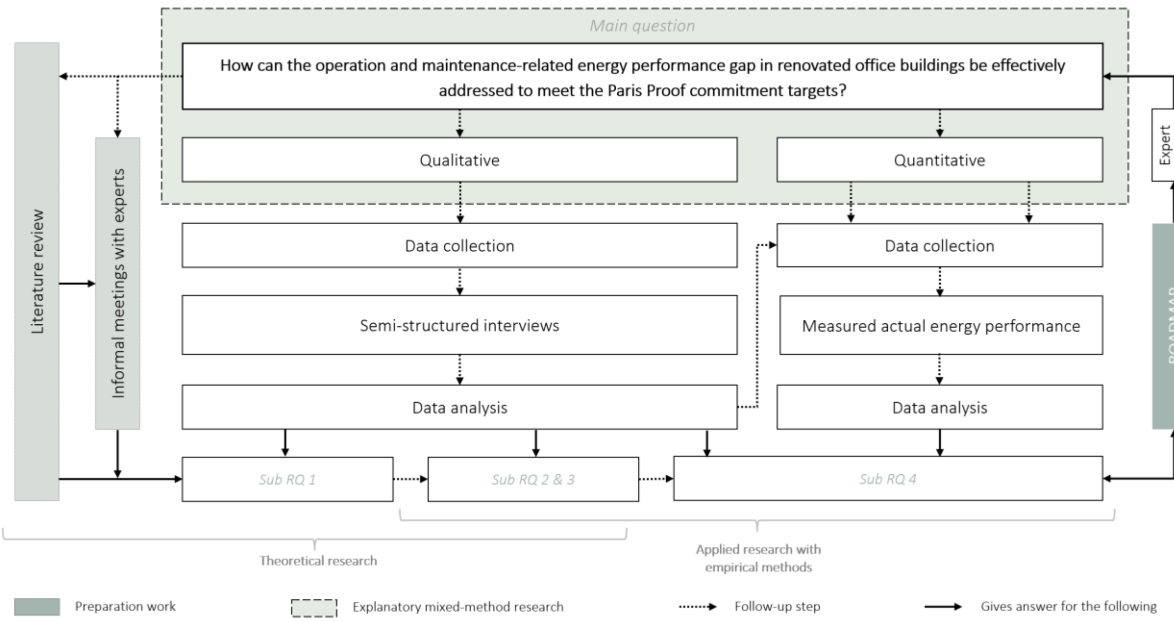

Figure 15: Explanatory mixed-methods research (own illustration)

The research design is presented in three sequential steps, each corresponding to a distinct phase of the research process. Starting with the first phase, part of define and design, a theoretical background is established to develop the further research. A particular focus is put on the first sub-research question which investigates the theoretical foundations of the EPG. As part of the research design, a case study is selected based on its relevance to the research topic. This phase, which includes selecting interviewees who can offer insightful information on the building's road towards improved energy performance, is crucial for setting the foundation for the research. In order to answer the other sub-research questions, a data collection plan is implemented, taking into account the applied aspect of the research. The next phase involves active data collection and preliminary analysis. Expert interviews are the first step in this data collection process, as it enables an understanding of the operating and maintenance procedures. The following research question, which investigates the challenges of energy performance within the operational setting of the building, are directly informed by this phase. A first review of the gathered data reveals the complications, laying the groundwork for a deeper examination. The qualitative data is enriched by quantitative data, aiming at improvements for the current operational and maintenance practices in place by looking into a case study that has undergone such interventions. In the third phase, the research synthesises the collected information and develops conclusions and a strategy. To understand the subtleties of operational and maintenance efforts towards Paris Proof achievement, the interviews and the case study combined entail a deeper analytical investigation into the data. The development of the roadmap aims to provide strategic guidance to address the EPG in office buildings based on the findings from the analysis. The main research question is directly addressed by the synthesis of findings, resulting in an understanding of the areas of challenges and the approaches by which operational practices should be modified for improved energy outcomes. By conducting an experts panel with four interviewees, the aim is to evaluate the effectiveness and accuracy of the proposed strategy and to offer insights into additional enhancements. The conclusion provides a set of recommendations to address the research problem and suggest directions for further study, aiming to offer a useful guide for comparable buildings.

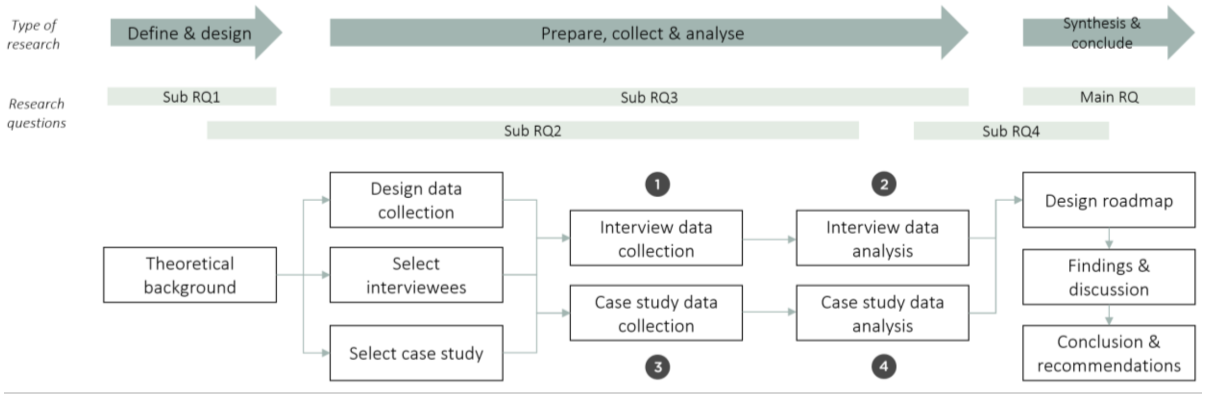

Figure 16: Research methodology framework (own illustration)

The whole process of comparing the energy predictions to the actual outcomes can be seen as a loop. In addressing the operation and maintenance-related challenges, the scope will be focused on three main points in the process loop (figure 17). The input consists of the design phase, including design parameters and computer-based data used for the energy predictions, followed by the construction, functioning as the basis. The second aspect focuses on the information transfer and implementation of services and installations provided during delivery, recognising their substantial impact on efficiency in energy management. The third and last focus is on the output, exploring the operation and maintenance of the energy systems in usage. Through examination of these core points, the research aims to understand the impact of implemented steps, identifying any factors that are presently missing in the output, and thus are essential to include in the input or output. In the end, strategies will be developed to address the gap in terms of the effective practices during the operational phase.

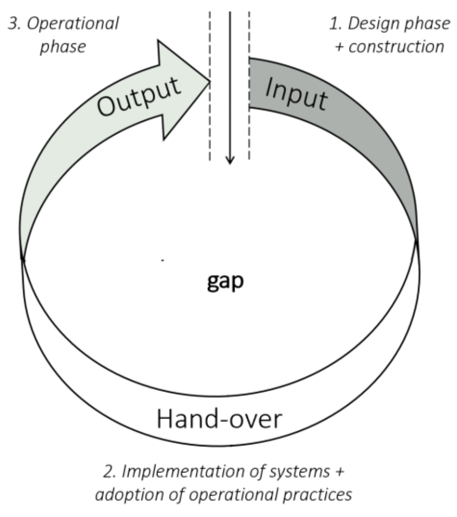

Figure 17: Input vs output energy loop (own illustration)

3.2 Qualitative interviews

3.2.1 Data collection techniques

Qualitative data will be gathered, using semi-structured interviews in order to gain additional insights into a building its energy management and how it affects the performance gap. The approach for the qualitative data is mostly inductive since it starts with a question, followed by observations using interviews to obtain results that will be used to develop the roadmap. Prior to the data analysis, information will be gathered from literature reviews and informal meetings with different experts, including three real estate developers and a smart solution manager. The knowledge obtained will provide a basis for the follow-up steps needed for developing the roadmap. The data analysis is characterised by a dual focus on first the qualitative data after looking into the quantitative dimensions. Semi-structured interviews will be done with 10 different experts in the field of energy efficiency and the EPG in the built environment. Prior to the interviews, a human research ethics checklist and a data management plan have been made to protect the participants. This also includes an informed consent letter to inform the participants about the research and to get approval for using the anonymised insights (Appendix 12.2). After gaining knowledge about the whole development process form developers, different people are selected all with different focuses in the whole process, as shown in table 3. These people have been selected based on their field of focus. As a result, the experts have varying levels of involvement in different phases and responsibilities, enabling them to provide diverse insights. The interviews will be recorded using Microsoft teams to write out the transcripts. These interview transcripts are primary data and will be analysed using ATLAS.ti and Excel as tools. The goal of this research is to find the gaps and patterns that are critical for understanding and addressing the issues presented by the performance gap in office buildings. The integration of different perspectives will provide nuanced insights into possible causes and facilitates the formulation of effective strategies to improve energy efficiency.

Interview	Role	Company
1	Digital building operator	Specialised in building intelligence management and smart building operations
2	Managing partner & manager installation advise	Consultancy in sustainable and energy-efficient building and infrastructure solutions.
3	Managing partner & program manager digital	Consultancy in sustainable and energy-efficient building and infrastructure solutions.
4	Project leader & installation advisor	Consultancy in sustainable and energy-efficient building and infrastructure solutions.
5	Head of smart solutions	Real estate developer
6	Data science specialist	Energy management and developer data services
7	Expert in building physics and sustainable construction	Consultancy and engineering firm
8	Engineer and advisor in building physics	Consultancy and engineering firm
9	Energy manager	Independent consultant involved in energy management, energy policy and energy savings
10	Program manager and certification manager	Specialised in making the built environment more sustainable and focused on the development and management of green building certification systems.

Table 3: Interviewees selection (own illustration)

3.2.2 Data analysis

The development of the semi-structured interview questions is represented in topics, offering the opportunity to highlight different viewpoints and to respond to the areas of expertise. Prior to the empirical phase, a literature review has been carried out, which served as a foundation for the identification of the five topics for empirical research. Throughout this examination, several unsolved issues related to energy management and the EPG emerged as the focus of attention. In order to clarify and address the complexity involved in operations and maintenance within the context of energy efficiency, further study is necessary in these areas. Moreover, these topics aim to support the development of the roadmap. The questions in the interviews will therefore be focused on different phases and stakeholders. The literature review has highlighted various challenges related to the energy management practices with notable understanding and implementation gaps. The following topics have emerged as important areas with the need of further research: calculations and certifications, causes and challenges, communication and collaboration, operations and monitoring, and future strategies. The objective of the empirical research is to investigate these topics in-depth, using qualitative semi-structured interviews to analyse the complexity within each area and address the EPG.

First of all, it is important to get an understanding of the current energy performance calculations in place. The last couple of years, technical progress has led to developments in the field of calculation methods. These developments have resulted in the implementation of new methods for calculation as well as related energy performance certifications (Dutch Green Building Council, 2022). An understanding of the energy performance calculation process and potential enhancements is crucial in light of the numerous technological innovations. Secondly, various causes and challenges have been identified through the literature review, such as operational practices, not specified responsibilities, and broken knowledge transfers, contributing to the EPG. Understanding the specific challenges faced in energy management is essential for developing an effective roadmap. Interviews with experts can provide context on the obstacles encountered, providing insights into areas where improvements are most urgently needed. Third, collaboration and responsibilities have emerged as an important topic influencing the redevelopment process, including energy efficiency aspects. This involves acquiring more knowledge about current feedback, training, and guidelines in place. Miscommunication and lack of collaboration among involved parties can hinder effective energy management efforts (Zou & Alam, 2020). Therefore, this topic is interlinked with causes and challenges. Deeper insights are needed to understand the underlying reasons for broken communication and to imply strategies in the roadmap for fostering collaboration among building the stakeholders. Interviews with experts can identify these barriers to communication and collaboration, as well as best practices for fostering effective partnerships. Feedback mechanisms are essential for improving energy models. There may be limitations in existing feedback mechanisms that need to be addressed. Another topic highlighted by the theoretical research is the importance of the operational phase and monitoring energy consumption patterns to identify inefficiencies and optimise performance. Experts in the field of building operations can offer valuable perspectives on the current state of monitoring technologies and practices within buildings. According to the literature, building operators their skills and knowledge have significant impact on energy management operations (van Dronkelaar, et al., 2016). The various demands of building operators might not be sufficiently addressed by the existing training programmes. Experts can shed light on the particular training requirements for building operators. By exploring the challenges and limitations of existing operations and monitoring, interviews can help develop more advanced and effective operational and monitoring strategies. Finally, it is essential to develop future strategies for driving continuous improvement in energy practices. The interviews can provide valuable insights and help anticipate opportunities in the creation of innovative solutions to address the EPG. When analysing the main topics, five different subtopics divided into three statements, will be formulated for each topic, giving context to the topics. These statements are based on the interview outcomes and summarise the most important findings. The statements aim to go more in-depth and identify interconnectedness between the topics (figure 18).

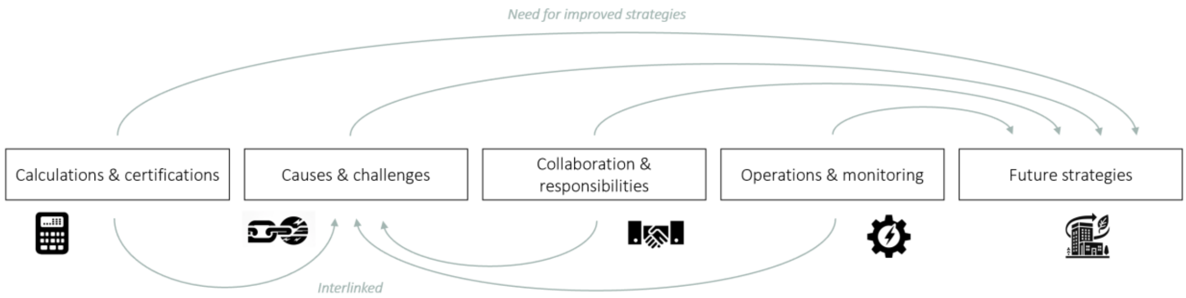

Figure 18: Semi-structured interview themes (own illustration)

3.3 Case study

3.3.1 Data collection techniques

In the context of quantitative data, an energy building performance data analysis will be done based on monitored data of a renovated office building. The quantitative case study involves an empirical inquiry that investigates a project within its real-life context over several years, ensuring an examination of long-term trends. The case study methodology allows for flexibility in selecting data collection methods to suit the research purpose, emphasising the significance of conducting a thorough, unbiased investigation over a sustained period (Priya, 2021). Prior to the analysis, case study criteria have been listed in order to evaluate the effectiveness and compliance with the research target. The criteria provided in table 4 will guide the assessment of the building's characteristics in energy efficiency and sustainability. The selected case study is the in 1990 constructed Edge Olympic office building, situated in the Amsterdam Zuidas area in the Netherlands (figure 19). Edge Olympic underwent a significant transformation from 2016 to April 2018, after being commissioned in 2015. The renovation modernised its appearance and included Cradle2Cradle, which is a sustainable design principle that encourages creating products with a positive environmental impact. A two-story sustainable timber structure on top that is intended for open work areas with visible wooden structures is a noteworthy addition. In order to maximise space while adhering to zoning regulations, two office stories are constructed above an adjacent parking area and floor-to-ceiling windows replaced the previous narrow with larger ones. The renovation includes high-tech features, increasing the building its automation based on sensors and systems (de Architekten Cie, n.d.). Due to the implementations, the building its energy label improved from label G to label A+++, meeting the mandatory requirement put in place as of January 2023 (Rijksdienst voor ondernemend Nederland, 2024). Moreover, it is BREEAM Excellent certified, standing for Building Research Establishment's Environmental Assessment Method, which is the world's leading method for assessing the sustainability of projects in the built environment and sets the standard for best practice in sustainable design (BRE Group, 2023). Nevertheless, not all the energy efficiency targets set where immediately achieved after completion. The case study has gone through the process of improving its energy efficiency by adjusting the operations and monitoring with the aim of achieving Paris Proof. Since the operational challenges had to be tackled to make the operations more efficient, this case study is of added value to the interviews for developing the roadmap.

Edge Olympic	Criteria	Reason
✓	Renovated office building	The theoretical background emphasised the importance of addressing the energy performance gap in renovated office buildings
✓	Sustainability certifications	There is an importance of maintaining compliance with the promised certification when the building is in use
✓	Smart building technologies	Smart technologies represent the forefront of energy management, enabling real-time adjustments and optimisations that directly influence a building's energy consumption and operational efficiency.
✓	Energy consumption data	Quantitative data on energy consumption after renovations provide empirical evidence of the effectiveness of energy efficiency measures, allowing for objective analysis of outcomes
✓	Operational adjustment and monitoring	The collection and analysis of operational data form the basis for informed decision-making, enabling the identification of inefficiencies and the implementation of targeted improvements
✓	Comparison of theoretical and practical usage	A before-and-after analysis is foundational for measuring the energy performance gap, providing a clear picture and identifying areas for further improvement.
✓	Paris Proof	Striving to meet the Paris Proof criteria illustrates a commitment to achieving some of the highest standards in energy efficiency, setting a commendable example for the industry.

Table 4: Case study criteria (own illustration)

3.3.2 Data analysis

The data analysis will be done using building energy management systems that offer monitoring, analysing, and improvement. When analysing the data, the focus will be on heating, cooling, and electricity usage. Real-time energy usage, derived from an investigation into the data, plays a crucial role in identifying patterns and their credibility. Importantly, this analysis helps to provide insights into possible errors in the way the energy systems are being managed. By addressing these gaps in knowledge, the research aims to provide a more holistic and accurate framework for developing a strategy to improve the energy efficiency in office buildings.

A crucial step is collecting quantitative data, which captures important aspects of the building its energy performance. Based on the knowledge obtained during literature reviews and semi-structured interviews with experts in different professions in this field, this process involves collecting information related to the expected and actual energy performance. The approach applied is deductive, starting with a theoretical understanding of the gap, followed by a hypothesis formulation and the collection and analysis of data for confirmation. The data needed to get insights into the energy predictions consist of the BENG indicator, as explained in section 2.6.1.3, and will be gathered from a project of the development company Edge. The data that will be analysed includes the energy consumption of the heating, ventilation, and air conditioning (HVAC) systems, lighting, pumps, and tap water. The six-year measurement period of the data will guarantee a detailed examination of long-term trends and patterns.

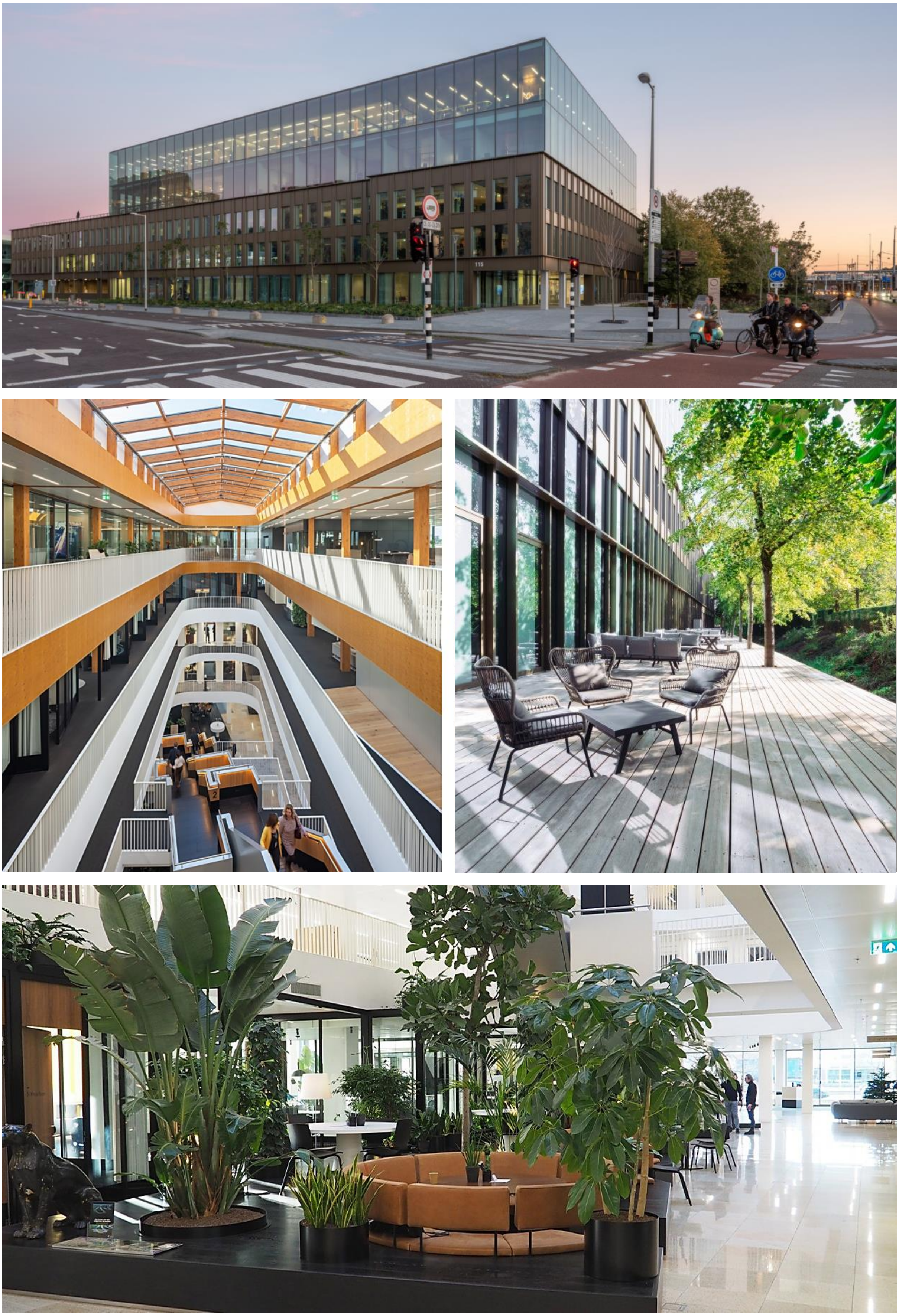

Figure 19: Edge Olympic (Edge, 2018)

3.4 Research output: strategic roadmap

3.4.1 Deliverables

The challenges identified in the literature review Emphasise the need to obtain an overview of the entire redevelopment process and to reconstruct a roadmap with clear steps and measures. A roadmap enables stakeholders to anticipate in advance to potential complexities that could arise at different phases of the project lifecycle. Therefore, the strategy for addressing the EPG involves implementing a roadmap that spans from the initiation of a development process to the operational phase during the building's occupancy. This roadmap encompasses several key elements, including establishing agreements among involved parties, which define roles, responsibilities, and energy performance targets. By understanding the interconnectedness of various activities and agreements related to the energy management, stakeholders can proactively address issues, ultimately enhancing the overall energy efficiency. Moreover, having a strategic roadmap facilitates alignment among all parties involved since it gives direction towards common goals. This alignment is particularly crucial in complex projects where multiple parties with different expertise and priorities are involved. To ensure compliance with the agreements made, the roadmap incorporates enforcement measures for the agreed-upon targets. This serves as a mechanism to uphold accountability and encourage adherence to energy performance standards. Additionally, the roadmap aims to include previously overlooked stakeholders, ensuring their contribution to energy efficiency goals. Particularly during the operational phase of the building, the roadmap emphasises the importance of training and continuous monitoring of energy performance. These efforts should help ensure that energy-saving practices are effectively implemented and maintained throughout the building's lifecycle. The aim of the roadmap is to contribute to reduced disparities while also strengthening the overall reliability of computer-based predictions and their practical applications, facilitating more efficient and sustainable redevelopments for office buildings. A structured framework helps prioritise tasks, allocate responsibilities, and track progress against predefined milestones by including monitoring. Ultimately, the aim of the roadmap is to improve collaboration among stakeholders, fostering a shared understanding of roles, expectations, and responsibilities. In order to validate the effectiveness of the proposed roadmap, the research findings and the roadmap will be tested in an expert panel. This gives participants the opportunity to suggest enhancements or additional insights and challenges that are not sufficient addressed.

3.4.2 Dissemination and audience

Finally, the research concludes by providing recommendations for diverse stakeholders, aiming to facilitate the effective implementation of the roadmap and the practical addressing of identified disparities in energy performance, specifically strategies related to the operation and maintenance. These recommendations are aimed at key players in the building industry, including developers, building operators, contractors, installation engineers, building physics engineers, and advisors for improving the energy efficiency in their projects. Moreover, it is aimed at improving the energy efficiency for building owners and renters who benefit from decreased energy costs and improved user experience. The research output, in terms of deliverables, is a combined document that captures the breadth and depth of the research findings. These include an review of the literature in the theoretical background, an analysis of the empirical findings, and finally the strategic roadmap outlined.

4. QUALITATIVE RESEARCH

4. QUALITATIVE RESEARCH

4.1 Semi-structured interviews

In this section, an analysis of outcomes from semi-structured interviews conducted with industry experts is presented, focusing on thematic areas essential for to addressing the EPG in renovated office buildings. Prior to the semi-structured interviews, the following five topics have been formulated in order to get deeper insights into the EPG: calculations and certifications, causes and challenges, communication and collaboration, operations and monitoring, and future strategies. Each topic emphasises significant findings around the complex nature of the EPG as explain in section 3.2.2. This empirical research is important for a number of reasons. It highlights the current approaches and energy performance practices in place, including their strengths and limitations. It points out areas where adjustments are required and highlights systemic issues with the industry's approach to building design, operation, and maintenance. Additionally, the semi-structured interview opens the door for the development of practical strategies and solutions that should be applied throughout a building's lifecycle to guarantee performance efficiency. Together, the topics addressed aim to answer the second and third research question. The second question looks into the key operational and maintenance challenges that contribute to disparities and third questions researches the responsibilities of various stakeholders in relation to the energy performance, including the types of collaboration. Moreover, the fourth sub question will be addressed by examining what operational and maintenance practices should be implemented to realise Paris Proof office buildings. The final sub question will be supplemented in the fifth section by looking into the case study. As outlined in the methodology, ten interviewees have been selected to provide insight into the different topics. The semi-structured interviews enabled the interviewees to go deeper into their specific field of knowledge, resulting in five subtopic for each main topic which are again divided and phrased into three statements (figure 20). Appendix 12.7 provides an overview of the topics for each interviewee, along with a more detailed explanation of the outcomes for each topic.

Calculations & certifications	Causes & challenges	Collaboration & responsibilities	Operations & monitoring	Future strategies
Unsuitability of NTA 8800	Inadequate commissioning & monitoring	Fragmentation in stakeholder collaboration	Inadequate 24/7 real time monitoring	(Seasonal) commissioning
Advantages of WEii indicator for Paris Proof	Complex and impact end-user	Unclear roles and responsibilities	Tuning challenges	Continuous monitoring and tuning
Dynamic modelling & simulations	Operational and maintenance challenges	Enforcement of energy efficiency responsibilities	Operational control and development disconnection	Collaborative contracts
Data driven predictions	Absence of a feedback and learning loop	Earlier interdisciplinary integrations in process	Need for specialisation in operations	Effective communication and data utilisation
Communication of predictions	Transition and information transfer issues	Awareness gap and misinterpretations	Operational and monitoring costs	Early engagement and training

Figure 20: Semi-structured interview topics (own illustration)

4.2 Interview topics

4.2.1 Calculations and certifications

Calculations and certifications are fundamental in predicting energy performance, setting benchmarks, and ultimately guiding the redevelopment process towards energy efficiency. This topic presents the obstacles and innovations in accurately calculating energy use as well as the shift to more dynamic, data-driven methodologies, as shown in table 5. This topic brings to light several critical aspects. The NTA 8800 method, while providing a standardised approach, faces criticism for its inability to adapt to the unique attributes of each building. The rigidity of the fixed parameters used for calculating the energy performance are not suited to predict the actual usage. This has frequently been brought during the interviews as expressed in the following quote by an expert in building physics and sustainable construction: *"An NTA 8800 calculation is a first rough calculation that shows whether Paris Proof is feasible and whether if it likely that the limit value will be met. However, I think there will be a discussion about the need to calculate it more accurately using supplementing methods."* This emphasises the need for additional methods such as the WEii indicator. The WEii indicator is praised for displaying actual energy use, providing a reliable measure for assessing the energy efficiency of a building as also stated by the interviewed data science specialist: "*The aim of the WEii indicator is to ensure that we can express measured consumption on the meter in a very simple way".*

Furthermore, dynamic simulations emerged as a promising avenue for generating more accurate energy performance predictions by accommodating specific building characteristics. However, the high costs and intensive labour required present obstacles to their widespread application. The current state of technology is moreover characterised by complexity, making it challenging to translate into a understandable language. This highlights the need for the implementation of smart prediction and monitoring frameworks, such as digital building twins, that can estimate real-world energy use more accurately. There is a growing recognition of the importance of shifting towards data-driven predictions, leveraging extensive data collection on energy usage and building characteristics. As the most frequently mentioned aspect, it was addressed by all interviewees except of one. Innovations in AI and machine learning offer potentials in making predictions more accurate and effective. This highlights the growing importance of actual energy usage data and reduced value of theoretical calculations. The crucial function of post-occupancy monitoring, which stresses a paradigm shift of ongoing monitoring and tuning to maintain and improve a building's energy performance over the course of its operational lifespan. Communicating energy performance targets as understandable values also emerges, with a preference for conveying a spectrum of potential scenarios over single-point estimates. This approach encourages the communication of a range, acknowledging the inherent variability and uncertainty in forecasting the building its energy consumption. The need for effective communication, also in terms of definitions and methods, is emphasised in the following quote of an engineer and advisor in building physics: *"Different parties have different definitions and expectations. It is chaotic in the energy sector right now since everyone has their own tools and methods*." This examination of the "calculations and certifications" topic therefore reveals the shortcomings of existing approaches while also outlining future directions for technological developments that will enable more reliable evaluation and management.

	Calculations & certifications	Interviewees									
Subtopic	**Insights**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Inadequacies of NTA 8800	Criticised for its inability to adapt to the unique characteristics of each building due to using fixed parameters in calculations.			■			□	■	■		■
	Not suitable for calculation actual energy performance		■	■	■		■	■	■	□	■
	Cannot stand alone and additional calculations based on actual usage are necessary.		■	■	■		■	■		■	■
Advantages of WEii	Based on actual energy consumption as measured at the meter, offering a concrete and metric for assessing the performance.	■		■		■	■	■		■	□
	A certification process that is increasingly recognised in the market.		□					■	■	■	
	The WEii indicator makes it possible to calculate Paris Proof and issue a certificate		□	■	□		■	■		■	
The role of dynamic simulations	Represents a promising solution for more accurate energy performance predictions.	■	■	■	□	□			□		□
	They allow for ongoing adjustments and improvement and can anticipate on non-standard building characteristics		■					■	■		
	Their high cost and (specific) labour-intensive nature pose barriers to widespread adoption.							■		■	□
Shift towards data-driven predictions	Data-driven models are more accurate and less resource-intense.	■	■	■	■	■	■	■		□	■
	The integration of AI and machine learning could revolutionise how energy consumption is estimated.	■		■	■		□	■			
	Shift towards data-driven predictions improve the implantation of feedback and learning loops	■	■			□		□			
Communication of energy performance predictions	The necessity of communicating a range of potential scenarios rather than a single energy use to stakeholders is emphasised.	□	■			□	□	■	■	□	
	The need of translating energy usage into understandable quantities, such as the quantity and type of equipment.					■	■	■	□		
	The importance of knowledge sharing from the person who made the prediction to the operator.	□	■		□		■			□	

■ *Directly addressed* □ *Indirectly addressed*

Table 5: Calculation & certification

4.2.2 Causes and challenges

The topic "causes and challenges" is central to understanding the EPG and delves deep into the root issues contributing to the disparities. It is necessary to comprehend the causes in order to develop effective strategies to mitigate it. The analysis of the interviews reveals a series of interconnected issues and the multifaceted approach needed to address the issues (table 6). Central to these findings is the observable gap between theoretical models and the real-world outcomes observed due to information transfer issues. This gap primarily arises from a lack of integration between the expertise of those conducting energy calculations and the practical insights of those responsible for monitoring actual energy use, leading to a scenario where theoretical knowledge fails to be translated into practical application. This is addressed by all interviewees and confirmed in the following quote of a data science specialist: *"There is a need to bring theory and practice closer together. I now see in the built environment that they exist in two completely separate worlds. People who are calculating on buildings have a lot of insights into how systems should behave and people who are measuring do not use the theoretical foundation of how they should interpret the monitor."* This transition is marked by inadequate information and responsibility transfer. As a result, crucial insights into the building's intended functional design are lost, leaving operators and tenants failing for efficient energy usage. This problem is compounded by the uncertainty in user profiles during the early phases of design, when estimations on potential occupants make energy use predictions difficult as stated by an installation advisor: *"It is a challenge that the user profile may still be uncertain at the beginning of the process and that not enough can be said about it because it is not certain which tenant will be involved or what determines what exactly is expected from the user."* The influence of tenant fit-outs and plug loads combined with this uncertainty makes disparities in energy use more challenging. Energy forecasts are further distorted from reality when average usage patterns are relied upon in simulations, which fails to reflect the dynamic nature of actual occupancy.

	Causes and challenges	Interviewees									
Subtopic	**Insights**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Issues transition and information transfer	There's a knowledge gap from design to operation, due to operators lacking critical information about energy systems.	■	■	■	■	■	■	■	□	■	■
	There is an absence of early involvement of the operational team before the hand-over	■			□	■	■		□	□	
	The increasing complexity of building systems and technologies can lead to challenges in operation in the absence of trainings	■			■	■	■		■	■	
Complexity and impact end-user	There is a complexity of modern buildings due to the advanced systems	■	□		■		■	□		□	□
	The unpredictable tenants/end-users make the energy predictions and final operations more challenging	□			■					■	
	As a result of high variability in occupancy, (incorrect) manual interventions in system settings occur.	■			■		□			■	
Operational and maintenance challenges	There is a frequent issue where building systems are either set incorrectly or manually overridden	■	□	■	□	■	■	□	■	■	■
	The increasing complexity of modern building systems often leads to operational challenges	■				■	□			■	
	There is a notable gap in the knowledge transfer and training from those who design/install to those who operate systems	■	□	□	■	■	■		■	■	■
Absence of a feedback and learning loop	The lack of feedback loops between the design, construction, and operational phases of building projects.	■	□	□	■	■	■		□		
	Once buildings are constructed and operational, there's generally a lack of ongoing monitoring that integrates feedback	■				■	■				□
	There's a significant divide between those who design, those build, and operate, resulting in segmentations	■	□		□	■	■				
Inadequate commissioning and monitoring	Buildings are not always commissioned effectively, leading to inefficiencies in systems.	■		□	■	□	■				
	The lack of sufficient monitoring post-construction could lead to operational inefficiencies	■		□	■	■	■			□	■
	There is an absence of a clear benchmarks. Comparing with previous years is not a good indication if those were inefficient						■				■

■ *Directly addressed* □ *Indirectly addressed*

Table 6: Causes & challenges

Changes during and after construction without consistent oversight contribute to operational practices that deviate from the original design intent. A notable lack of knowledge among building operators and maintenance staff regarding the building's energy systems and their optimal operation often results in inefficiencies. This includes adjustment in manual settings made by people who do not have a deep understanding of the systems, leading to operational decisions that misalign with design intentions. Moreover, the lack of a feedback and learning loop have been identified as challenges. The industry's segmented approach, which is characterised by separated management in design, construction, and operational phases, restricts the feedback loop that is necessary to improve future projects. This lack of continuous improvement is reflected in the commonly inadequate commissioning of buildings, which allows unidentified inefficiencies to continue. The recognised absence of effective monitoring systems and a suitable performance benchmark results in operational inefficiencies since errors are not identified.

The reliance on static norms, guidelines, and contractual incentives misaligned with long-term efficiency goals also discourages the adoption of tailored, innovative solutions. While less frequently mentioned and not included in table 6, it is an important aspect to keep in mind. This conflict of interest is best illustrated by maintenance contracts that favour frequent service calls over effective operation and prioritise short-term fixes over long-term improvements. Collectively, these challenges highlight the complex interplay of variables causing the EPG. A holistic approach is needed to address these problems. It should establish clear communication and knowledge transfer over the whole project lifecycle, realign incentives to favour sustainability and long-term energy efficiency.

4.2.3 Communication and responsibilities

Building upon the analysis of challenges and causes, this section delves into communication and responsibilities. This topic overlaps with the previously discussed issues, underlining the interconnection of challenges within the sector. To begin with, a fragmentation in stakeholder collaboration throughout the development process has been identified. The building delivery from developers to building operators marks a pivotal phase, however, frequently signifies the end of developers' active involvement. The hand-over highlights a critical gap in the transfer of essential information regarding the intended design intent, which can lead to a significant loss of crucial knowledge about the building's operational practises if not adequately addressed. As a result, operators and end users are left without the necessary information to optimise energy use effectively. Furthermore, adjustments made throughout the fit-out process and an overall lack of continuity in oversight could cause difficulties when transitioning to the operational phase. Secondly, it has been noted that roles and responsibilities with regard to the energy performance often suffer from clarity. This got specifically attention in view of the changing tasks for the building operator, requiring a division and clarification of responsibilities. Without a clear understanding of these roles, overlaps and gaps can occur, hindering effective energy management. This is related to the need of enforcement of responsibilities. While roles may be documented, the practical application and adherence to these defined roles are frequently not adequately supervised or controlled in practice. This suggests the need for contracts and incentive systems that not only outline expectations but also impose consequences for non-compliance.

In addition, the need of the integration of interdisciplinary expertise before the hand-over became evident from the interviews. Buildings as complex systems requiring a blend of knowledge areas to ensure optimal performance, including those of the building operators and data science specialist prior to operational phase. Interviewees highlighted the importance of bringing together diverse perspectives to anticipate potential issues that could affect a building's energy performance post-renovation. In practice, this interdisciplinary collaboration can lead to better-informed decisions about the building’s energy management. Finally, a significant awareness gap has been mentioned among key actors, particularly building owners and operators. This lack of awareness is often the result of inadequate guidelines and inconsistent communication, leading to misunderstandings that directly impact the operational phase. This awareness gap could also negatively impacts the end-user as stated by a data science specialist: *“The problem is often exacerbated by the fact that the building owner* *and/or users are not aware of the potential misery that may exist within their building. Due to lack of monitoring, they may not even realise that there could be a problem, let alone that they actually have one. So, I always refer to it as the difference between the headache and the paracetamol. The vast majority of the Netherlands actually suffers from latent headaches, but they don't feel them because there is no awareness due to the lack of proper monitoring and no frame of reference."*

It becomes evident that the cooperation and communication needs to be improved. In order to close the gap, it is necessary to involve certain stakeholders earlier in the process than is currently standard practice, as well as to extend their involvement into the in-use phase of the building lifecycle. These changes aim to ensure alignment of knowledge and intentions from the design and construction phases through to the operational phase, thereby minimising the loss of important information.

	Communication & responsibilities	Interviewees									
Subtopic	Insights	1	2	3	4	5	6	7	8	9	10
Stakeholder collaboration	There is a fragmented approach in collaboration among the key stakeholders in the design, construction, and operation.										
	Stakeholders often have varying objectives and expectations from a project, which can lead to conflicts and inefficiencies										
	Collaboration shouldn't end once the building is constructed; it should extend into the operational phase										
Unclear roles and responsibilities	The ambiguity surrounding the roles and responsibilities of different stakeholders regarding energy performance.										
	There is a need of dividing the tasks of the building operator into two roles										
	Unclear roles lead to confusion in communication, resulting in misalignments in expectations among team members										
Enforcement of energy efficiency responsibilities	A need for more explicit enforcement of responsibilities related to energy targets.										
	Specifying requirements and consequences in contracts.										
	Implementation of a rewarding and fining system										
Interdisciplinary integrations early in development process	The need for integrating interdisciplinary expertise early in the building design process is emphasised.										
	Coordinating efforts among various disciplines requires significant management and oversight										
	When various disciplines work together from the beginning, the project can achieve increased risk management and efficiency										
Awareness gap and misinterpretations	A general lack of awareness among stakeholders, specifically owners and building operators, is noted.										
	There is a need on clear guidelines, and consistent communication.										
	The different terms used and complex/technical nature of information can lead to misinterpretations										

Directly addressed *Indirectly addressed*

Table 7: Communication & responsibilities

4.2.4 Operations and monitoring

The topic of "operations and monitoring" reveals insights into how the management of energy systems directly influence a building's energy performance. This area is crucial for understanding the operational gap, underscoring the potential for optimising energy efficiency through improved operational strategies and monitoring technologies. Recurring aspects are the critical role of data collection, feedback loops, and the seamless flow of information throughout the project lifecycle. The experts point to ineffective 24/7 monitoring practices, including the improper commissioning of systems for seasonal variations and a failure to adjust settings based on actual building usage. The experts also draw attention to the tuning challenges that arise from the absence of effective feedback loops and benchmarks as noted by a digital building operator: *"There is a missing feedback loop in the monitoring of data. The energy data appears on a dashboard that nobody looks at and nobody does anything with."* Current practices in monitoring can lead to missed opportunities to refine and optimise building performance because they do not adequately utilise data patterns that reflect actual energy use.

Another area of focus is the disconnect between the development phase and operational control of building projects. Building operators often lack a thorough understanding of a building's intended operational strategies, which results in operational inefficiencies. A key step towards increasing energy efficiency is the practice of using data to support the transition to a digital twin model. Nevertheless difficulties still exist, particularly in bridging the gap between the design intent and the operational control by building operators and maintenance teams. As previous mentioned, the parties often have a lack of an in-depth understanding of the building's intended operating strategies, which might result in operational inefficiencies with respect to the building's intended functioning. This could lead to temporary solutions that might take care of immediate comfort concerns, however in the long run, they could cause increased energy inefficiencies and more significant issues. These inefficiencies complicate by the lack of documenting operational adjustments and maintaining records. In case when energy data is collected, it is often ignored, wasting opportunities to optimise building efficiency based on real time trends. This kind of oversight makes it more challenging to locate inefficiencies and address their underlying causes. These problems have been discussed by the smart solution manager, stating the following: "*The biggest factor for the energy performance of a smart building is the operations. The tricky part is, of course, is that those who really make the design and ultimately deliver and build the project have a lot of expertise, but at some point, they deliver a project and then they take of their hands of it and it's a very different party that ultimately takes over those operations. That is much more customer-oriented; they get calls and they go into a conversation to ultimately solve a problem for that customer but they do not know which knobs and settings they need to turn to actually solve the problems. As a result, they make wrong adjustments which seem to temporarily solve the problem, however, eventually lead to much bigger problems with respect to energy use and user comfort. If you create an imbalance somewhere, you are also going to have problems elsewhere, and if they solve those, then at some point the whole building becomes inefficient. Officially, the building operator should keep all adjustments in documentation but that often does not happen."* In this situation, enhanced specialisation is required in the responsibilities regarding to building operations and monitoring. It is suggested to make a distinction between operational tasks, which refer physical operations such as repairs and adjustments, and performance monitoring tasks, which includes evaluating and optimise building efficiency from remote.

The interviews reflect an industry-wide challenge of balancing the costs associated with operations and monitoring against the potential long-term energy savings. There is an emphasis on the broader industry challenge of prioritising long-term efficiency gains and performance improvements, which often require upfront investment over immediate financial savings. Both the digital building operator and smart solutions manager mention the solution of integrating the operational costs into the service costs since the service costs will decrease due to improved efficiency. This goes hand-in-hand with giving guarantees. The alignment of contractual motivations with the goal of achieving optimal energy performance, however, presents a challenge. Current contractual structures, which tend to Emphasise maintenance and short term fixes over performance, can detract from efforts to enhance energy efficiency. The annual reconciliation of energy use further accentuates the need for precise metering and transparent billing practices, where tenants may either be compensated or charged extra based on their energy consumption. This process, combined with the allocation of budgets for user-specific energy consumption, underscores the importance to provide accurate management segmented building's energy use.

	Operations & monitoring	Interviewees									
Subtopic	Insights	1	2	3	4	5	6	7	8	9	10
Inadequate 24/7 real time monitoring	Ineffective monitoring practices, including inadequate (seasonal) commissioning.	■	■	■		■	■		□	■	□
	Failure to adjust settings according to actual needed use, resulting in operational inefficiencies.	■	□	■		■					□
	Often there is a lack of awareness about the performance issues and the need for monitoring	■	□				■				□
Tuning challenges	The absence of effective feedback loops and a benchmark in leads to missed opportunities for optimising performance	□	■	□	□	■	□		■	■	■
	The challenges of setting building operations to match the theoretical energy models used during the design phase	■	□	■		■					■
	The lack of documentation of previous systems adjustments made					■	□			□	
Operational control and development disconnection	Building operators often lack an in-depth understanding of the building's intended operation, resulting in inefficiencies	■	■	■	■	■	■	□	■		■
	Lack of continuous commissioning	■		□	■	■	■				
	Need for early involvement of the operational teams pre-handover	■			■	■					
Need for specialisation in operations	Need for specialised roles due to complexity building systems, where operations extend beyond traditional maintenance	■	■	□	□	■			□		
	The evolving role of building operators suggests a division between performance monitoring and operational duties.	■	■			■			□		
	Clarification of responsibilities and tasks, including guarantees	■	□	■	■	□	□				
Operational and monitoring costs	The challenge of prioritising long-term efficiency gains and performance improvements over short-term financial savings.	■	■			■		■			■
	Postponing/avoiding energy efficiency costs and monitoring by building owner/end users	■			□	■	□	□			
	The incorporation of the commissioning and monitoring costs should be incorporated in the service costs	■				■	□				

■ *Directly addressed* □ *Indirectly addressed*

Table 8: Operations & monitoring

4.2.5 Future strategies

Strategies for addressing the EPG incorporate human knowledge, technology, and strategic management. The need of training, efficient monitoring, and ongoing improvement procedures is emphasised by this topic. When combined, these aspects have the potential to make a significant effect on guaranteeing the energy performance and fostering effective building operations.

Within the analysis, an emphasis is placed on the multifaceted strategies essential for bridging the gap.

The insights from interviews reveal a focus on integrating commissioning activities into construction planning and ensuring effective post-delivery operation. The strategy emphasises early involvement of commissioning managers, effective testing of building systems before handover, and continuous (seasonal) commissioning to adapt buildings to actual usage patterns. According to the first interviewee, commissioning can cut considerable energy savings: *"The digital building operator must focus on scope and urgency to achieve effectiveness in solving operational issues. Without altering the hardware, or changing pumps or anything, the digital building operator can achieve 30-40% energy savings through commissioning. Also, commissioning should be done once every quarterly season."* Commissioning facilitates detailed continuous maintenance, providing more targeted advises and interventions for the end-user. It has been stated by the energy advisor that monitoring and fine-tuning can optimise the energy consumption by 20-25%. Monitoring and tuning include learning from previous mistakes or successes by using a feedback loop in the follow-up process and future projects as highlighted by all the interviewees. This strategy encourages building operators and other stakeholders to place priority on energy efficiency in their operations. Ensuring strong communication and collaboration is central to this approach as stated by the digital building operator: *"Building physics consultants, installation- and energy advisors, installers, and commissioning managers often conduct advisory processes, but afterwards, they are no longer involved in the building to verify if the advice is followed and to make any improvements. What the digital building operator should do is keep these parties in the loop, so that even after they have given their advice, they actually continue to participate, ensuring the building operates as designed."* Achieving the targets requires strong collaboration as well as the translation of operational practices into understandable concepts. A collaborative contract, such as a consortium, consisting of the building operator, contractor, installation- and energy advisor, and installer is recommended to share collective responsibility for a guaranteed energy performance. This cooperative strategy promotes a common mindset towards and efficiency and performance goals through contractual commitments. By financially rewarding energy savings and penalising excess use, the implementation of incentive and penalty systems through bonus-malus arrangements serves as a motivational tool that encourages energy-efficient practices. Furthermore, delegating phase-specific tasks helps ensure that the integrity of energy performance assurances are maintained throughout the project, from initial design to post-construction. This requires early engagement and training for the continuous involvement of the digital building operator, commissioning managers and installation advisors. By employing machine learning and other advanced technologies, buildings could operate as intended, even as use patterns and environmental conditions change. This underscores the value of continuous oversight and fine-tuning of building settings post-construction.

Using data from comparable projects to inform design and operational strategies is highlighted as a method for enhancing the accuracy of energy performance predictions. Process oversight helps sure that all decisions made at all phases of the project lifecycle, from detailed engineering and construction to the initial design phase, are thoroughly evaluated for its impact on energy. This systematic approach safeguards that goals for energy performance are continuously fulfilled at every level. In addition, it is stressed that maintaining energy performance over a building's lifecycle depends on the documentation and transfer of the design intent and technical solutions to operational parties. Training for experts enhance the management and understanding of energy performance from a certified viewpoint. An important addition to these strategies is the certification of actual energy use, as indicated by the Paris Proof initiative. This certification offers a measurable objective that is in line with broader sustainability initiatives by serving as a benchmark for actual energy consumption. Making energy consumption data more understandable for end users aligns with the Paris Proof goals, promoting measurable energy efficiency goals. Encouragement of energy-efficient practices is achieved through involvement of users with smart apps and trainings.

	Future strategies	Interviewees									
Subtopic	Insights	1	2	3	4	5	6	7	8	9	10
(Seasonal) commissioning	Early involvement of commissioning authorities, effective testing of building systems before handover	■	□	■	■	■	■				
	Continuous seasonal commissioning in the operational phase to adapt buildings to actual usage patterns.	■		□	■	■					
	Using data-driven strategies for continuous commissioning is seen as a key part of future operational strategies	■				□	□	□			
Continuous monitoring and tuning	Ongoing tuning and monitoring to ensures that buildings remain efficient and adaptable	■	■	■	■	■	■	■	■	■	■
	Implementing effective feedback and learning loops based on information from monitored data	■			■	□	■				
	The use of advanced technologies and analytics tools to analyse data collected from various building sensors is emphasised	■		□		■	■				
Collaborative contracts	Contracts with clear responsibilities, ensuring committed to achieving the goals.	□	■	■	■	□			□		□
	Setting up a consortium of key stakeholders for meeting the energy targets		■	■	■						
	Implementing bonus-malus where operating parties have to pay when exceeding budget and receive if they stay in the limits	□	■	■	■						
Effective communication and data utilisation	Strengthen communication between key stakeholders	■	■	■	■	■	■	■	■	■	■
	Make energy data understandable and actionable for all stakeholders	□	■		■	□		■			
	Use data insights from comparable buildings to inform decisions	■	□	■			□				
Early engagement and training	Integrate building operators and commissioning managers before hand-over to ensure a deep understanding of the goals	■	□		■	■	□		■	■	■
	Implement trainings for the operating parties on the design intent		■			■		□			
	Implement workshop and manuals for the end users about the building's energy performance goals		■		□		■				

■ *Directly addressed* □ *Indirectly addressed*

Table 9: Future strategies

4.3 Interconnectedness main- and subtopics

The interconnectedness in figure 21 represents how the various aspects addressed are interrelated and influence one another. This concept is visually demonstrated through connection lines between different main- and subtopics. The interconnectedness of the main- and subtopics reveal the recurring importance of commissioning and monitoring, feedback and learning loops, stakeholder collaboration, and effective communication. These aspects are crucial across the multiple main topics. First of all, inadequate commissioning and monitoring is addressed as part of the "causes and challenges" and is subdivided in the "operations and monitoring". Moreover, as part of the improvements needed, the need for (seasonal) commissioning and continuous monitoring and tuning are stated as subtopics as part of the "future strategies". Second, in order to address inefficiencies, the feedback and learning loop are essential. The lack of such a loop in "causes and challenges" hinders ongoing improvements and results in recurring operational inefficiencies as part of the "operations and monitoring". A strong feedback loop in "operations and monitoring" makes sure that information gathered from real-time monitoring guides improved procedures and is therefore covered by the “future strategies”. Third, stakeholder collaboration is essential in both “collaboration and responsibilities” and “future strategies”. Fragmentation in collaboration results in inefficiencies and the loss of important information. Ensuring alignment and commitment to energy efficiency targets is made possible by effective collaboration, clearly defined roles, and earlier engagement of operational parties. Finally, all of the major subjects are connected to the importance of communication. It facilitates the clear communication of energy performance targets in “calculations and certifications”. In “causes and challenges”, it addresses the information gap between theoretical models and real-world outcomes. Roles and responsibilities are defined in “collaboration and responsibilities”, while in “future strategies” it ensures effective communication through the different stages, ongoing stakeholder engagement and alignment. Additionally, some quotes can be categorised under different main topics. As an example, the digital building operator stated the following: *“The building operator and maintenance parties are the ones who control the energy systems. The companies involved in development pay less attention to the operational phase. The building manager does not understand about how the building was conceived and such. The maintenance party often sets up the building systems once, thereafter it has to figure out for itself how to operate most efficiently. There lies an error in thinking as simulations assume for example average work patterns which are entered, and in practice there are peaks and troughs in usage that cannot be standardly inputted. Monitoring and tuning are needed for this.”* This quote addresses multiple aspects, including the fragmentation in stakeholder approach and the need for specialised operations as part of “collaboration and responsibilities”, and the need for continuous monitoring and tuning based on real time data as part of the “future strategies”.

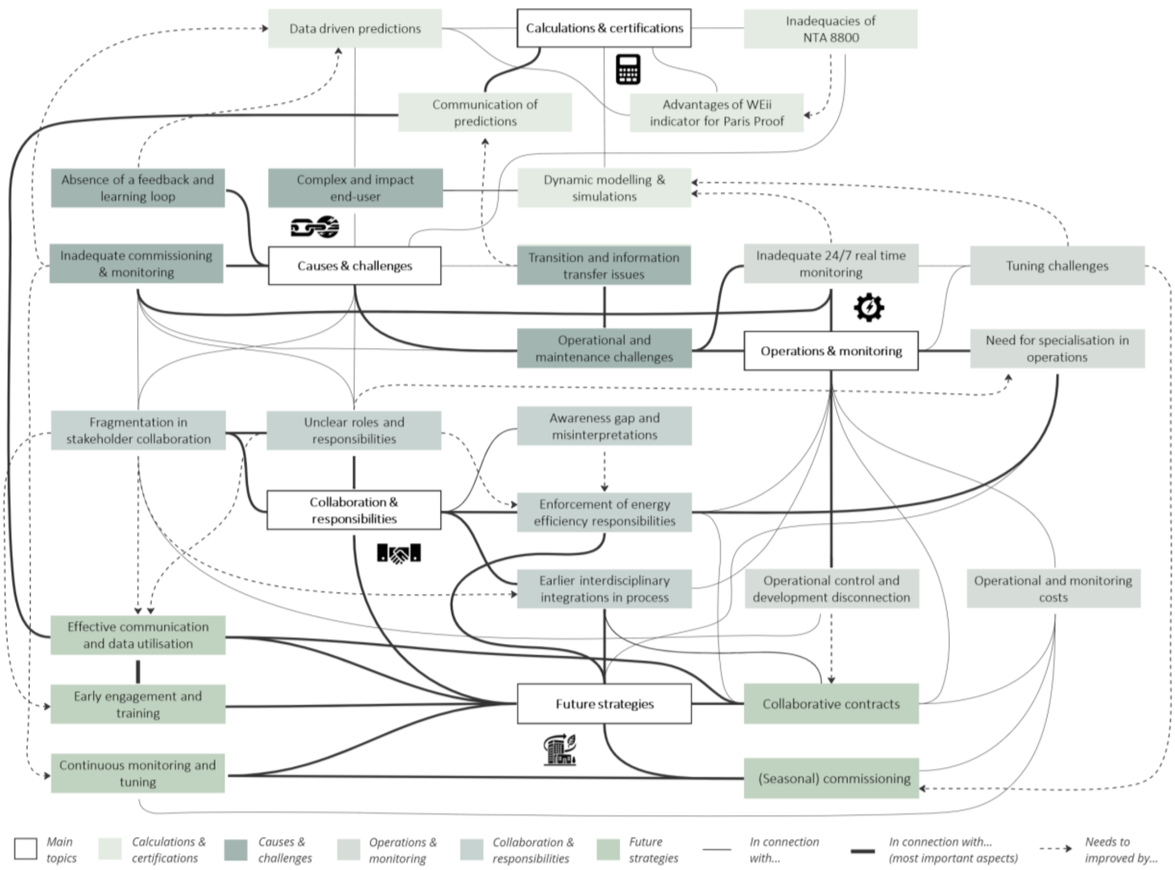

Figure 21: Interconnectedness topics (own illustration)

4.4 Conclusion

In concluding the qualitative empirical research, the aspects addressed by the different experts can be categorised in different interconnected topics and statements (figure 21). The analyses followed by the findings provide an overview of the factors influencing the gap, highlighting critical operational, communication, and strategic shortcomings that, unless addressed, continue to contribute to the EPG. The topics of "causes and challenges" and "operations and monitoring" particularly address the second sub research question: *"What are the key operational and maintenance challenges that contribute to disparities in energy performance from predictions?"*. Experts frequently pointed out the lack of effective 24/7 real-time monitoring and the absence of a feedback loop as significant challenges to maintaining predicted energy efficiencies. As a result, tuning issues have been identified, requiring the need for specialised operations. Moreover, operational inefficiencies are compounded by disconnected processes before hand-over and operational controls after handover, and an absence of a data feedback loop to inform better operational practices (figure 22). The causes and challenges are interconnected with the third topic and sub question, focused on the different stakeholders involved. In addressing the third sub research question*: "What responsibilities do various stakeholders have in relation to the energy performance of a building and what agreements and information exchanges are in place for this purpose?"*, "communication and responsibilities" emerged as a critical topic. The findings underscore a fragmented approach to stakeholder collaboration, where unclear roles and responsibilities contribute to inefficiencies. Improved enforcement of energy efficiency responsibilities and early interdisciplinary integration in the process are emphasised. Collaborative contracts that clearly define roles and establish a framework for effective information exchange should serve as the foundation for these. Better energy efficiency outcomes may additionally be achieved by raising awareness among all stakeholders and promoting active engagement throughout the building's lifecycle.

With regard to the fourth research question *"What operational and maintenance practices should be implemented to realise Paris Proof redeveloped office buildings?",* this research proposes a shift toward more integrated and continuous monitoring approaches. The need for enhanced collaboration and specialisation in operational roles to ensure proper adjustment and tuning of building systems has emerged as an essential factor in improving energy efficiency. The implementation of seasonal commissioning and utilisation of data for continuous monitoring and tuning based on feedback- and learning loops are recommended to align operational practices with the Paris Proof initiative's benchmarks. Digital twins that incorporate machine learning and AI can further enhance the accuracy of operational adjustments (figure 23). The interviews analysis indicated that a paradigm shift is essential, emphasising the need for effective communication, ongoing stakeholder engagement and training, and contractual incentives. This aligns with the interconnectedness scheme which stresses the significance of collaboration and responsibilities, future strategies, and effective operations and monitoring to address the root causes and challenges of the EPG. As the industry faces several challenges, the implementation of strategies covered is crucial for realising Paris Proof office buildings. There is a call for action to improve energy efficiency, which will not only reduce operational costs but also contribute to the broader sustainability goals.

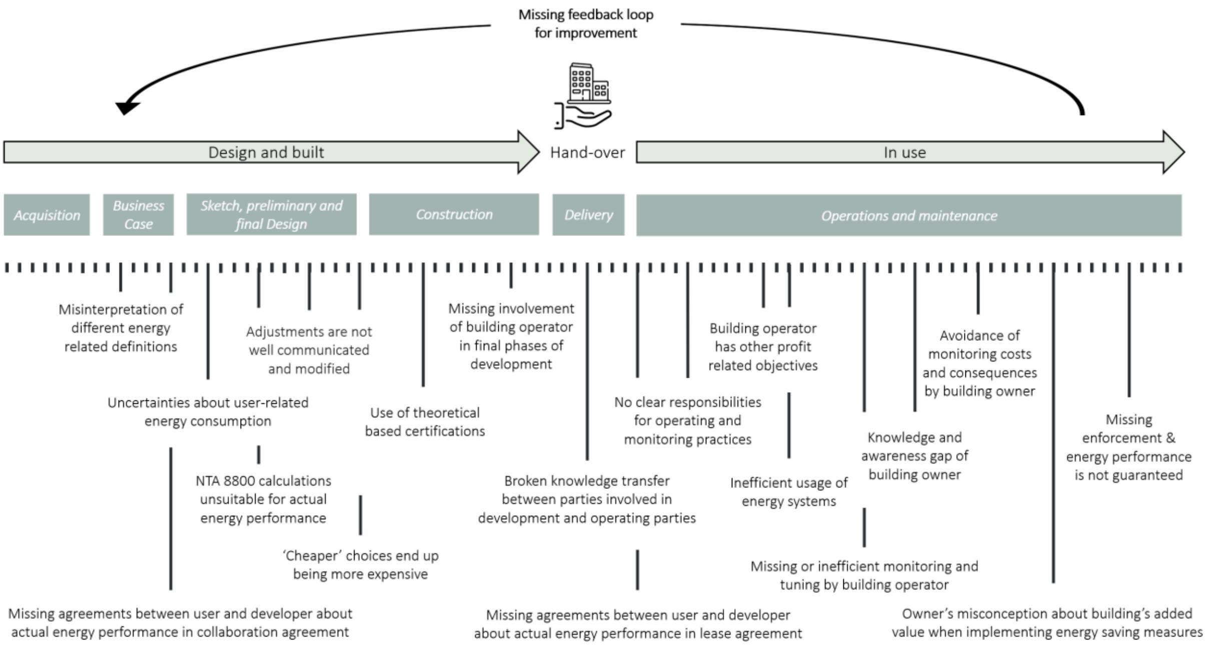

Figure 22: EPG causes and challenges (own illustration)

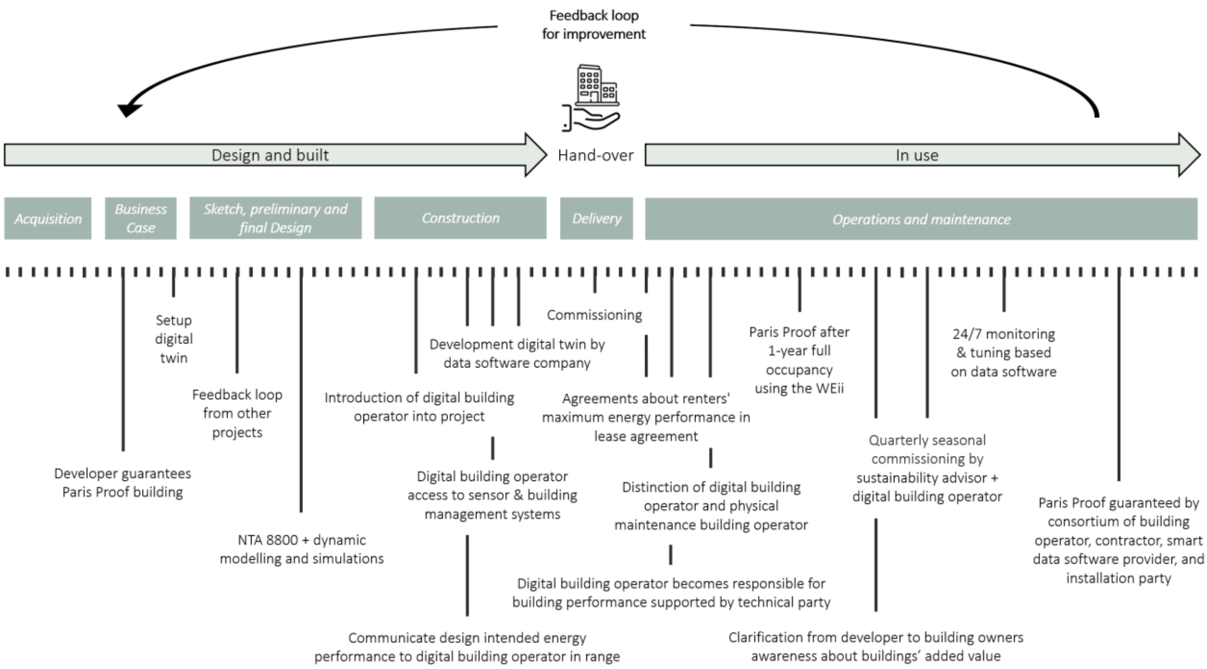

Figure 23: EPG improvements (own illustration)

5.
CASE STUDY

5. CASE STUDY

5.1 Case study approach

The case study seeks to validate if the interview results can be substantiated through real-world implementation. The outcomes identified in the operations and maintenance will be therefore compared with the causes and challenges of the qualitative research. Secondly, by looking into the steps taken in the case study and their impact on the energy consumption, the effectiveness of the operational practices will be examined. Moreover, the case study will research if the adjustments made comply with future challenges mentioned in the interviews or that strategies can have a strengthened effect on one another. The redeveloped Edge Olympic office building started its construction in October 2016 and was delivered in May 2018 (Edge, 2018; de ArchitektenCie, n.d.). The building has a total floor area of 11.185 m^2, predominantly comprising office spaces, alongside areas designated for meetings, a restaurant, and sporting activities. The Paris Proof limit for office building is set on 70 kWh/m^2, however, Edge Olympic has a limit of 81 kWh/m^2 due to the additional functions that contain other values as shown in table 10. The first whole year of operational use was 2019, during which construction activities deviated from the design intent. After identifying the inefficiencies, an digital building operator got involved into the project, being supported by technical parties and supplied with the energy data by a company specialised in smart building platforms.

Function	Specifics	Floor area	Paris Proof limit
Meeting function	Meeting function other	1405 m2	70 kWh/m2
Meeting function	Restaurant	590 m2	200 kWh/m2
Sports function	Sports accommodation	60 m2	70 kWh/m2
Office function	Office	9130 m2	70 kWh/m2
		Total: 11185 m2	*Total: 81 kWh/m2*

Table 10: Floor area and Paris Proof limits (adapted from TPex, 2023)

To determine the causes of the inefficiencies in the operations, a detailed analysis based on the monthly energy consumption is an essential first step. A closer look into the data and influencing components provides information about the energy consumption before modifications in the operations and monitoring compared to the outcomes afterwards. At this level, there may also exist a considerable positive and negative EPG that balance each other out resulting in an overall disparity that is sometimes very close to zero. Moreover, certain months might operate more inefficiently compared to other months due to seasonal circumstances. The quantitative that that will be analysed therefore consist of monthly energy consumption, divided into the electricity usage and heat usage from the start of 2018 to the end of 2023. The excel, included in appendix 12.10, provides information about the usages cumulative per year in yellow, the usages per half year in orange, and the usage compared to other years, both monthly and cumulative, to identify improvements made. Additionally, information is provided about the costs and electricity use during office hours and other hours. The most important information for the analysis is summarised in table 11, providing information about the energy per year in kWh divided in months. This information enables the calculation of the WEii indicator since it provides information about the building-related and user-related energy consumption combined. However, the BENG calculations used for the theoretical analyses are solely based on building-related energy consumption, making the data unsuitable for comparison. Therefore, the data to be analysed will focus on the energy consumption from the first year of full occupancy in 2019 to the most recently monitored data from 2023, seeking to identify changes due to the involvement of the digital building operator.

5.2 Data analysis

Edge Olympic, as being a smart building, is equipped with electrical and mechanical systems, building management systems, sensors, IT systems and environmental information. The systems provide real time data, giving insights into the electricity and heat usage. Moreover, the data gives information about the outdoor environmental conditions, including sun hours, temperature, and rain, that all influence the operational adjustments needed to optimise the indoor environment. As demonstrated in table 11 and figures 24, the total energy consumption in February 2023 was 77,42% higher compared to that in May of that same year ($(\frac{74.488 - 132.157}{132.157}) \times 100\%$). The outdoor environmental conditions are continuously changing throughout the year and need to be taken into account for internal needs and operations. During the winter months, the proportion of total energy usage attributed to heating significantly increases, while the average electricity usage decreases during these periods (figure 25). Due to varying circumstances every year, the WEii indicator includes a correction factor. This correction factor has multiple advantages. By accounting for the specific weather conditions of the measurement year, the energy performance is evaluated more accurately. It ensures a fairer comparison between buildings, as temporary climatic deviations do not unduly influence the energy performance score. Additionally, buildings can be compared year after year, even as weather conditions vary, which ensures consistent monitoring and benchmarking (TVVL & DGBC, 2023).

Month	2018	2019	2020	2021	2022	2023
January	151.349	160.315	134.138	118.426	129.221	125.134
February	149.028	148.073	105.525	104.100	114.845	132.157
March	98.830	137.239	87.753	93.140	87.507	100.012
April	86.824	123.170	87.441	82.780	81.491	76.555
May	89.421	124.445	78.865	76.251	80.899	74.488
June	88.251	109.721	79.861	69.984	73.268	71.114
July	67.830	107.870	79.874	76.671	79.115	85.221
August	63.151	116.490	65.053	78.966	77.163	113.001
September	39.019	122.500	66.748	107.459	78.685	90.800
October	44.531	143.931	122.849	117.505	102.035	129.617
November	58.249	136.791	140.745	112.564	112.336	110.031
December	28.784	179.243	156.215	130.119	117.727	127.437

Table 11: Total energy per year in kWh divided in months (adapted from TPex, 2023)

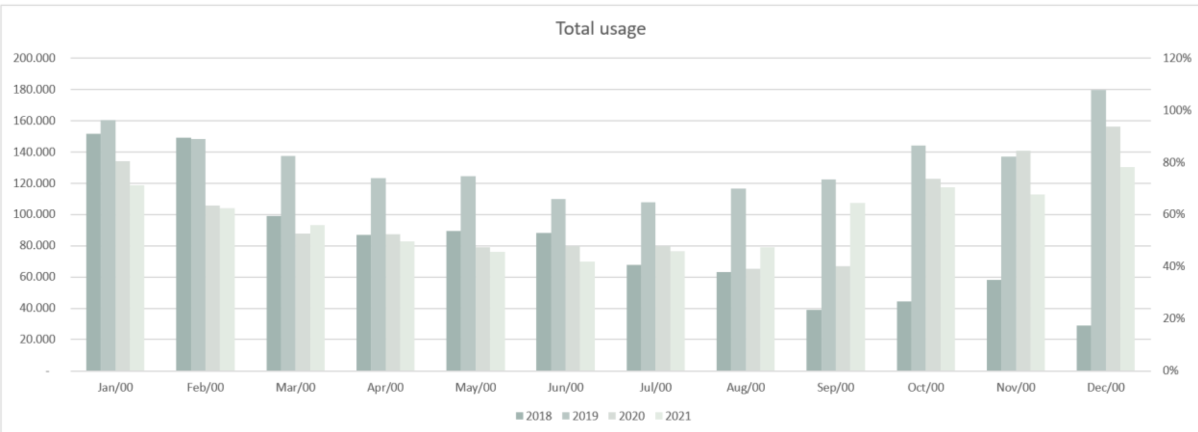

Figure 24: Total energy per year in kWh divided in months (adapted from TPex, 2023)

When looking into the influence of the involvement of the digital building operator, significant improvement have been made. After delivery the building systems where set with a 24/7 character due to the 24/7 occupancy of merely a single tenant. As a result of inefficient operational settings, the entire building operated on these time slots since the building systems were not divided into separate controlled zones. Given the multi-tenant usage, the implementation of separate zones is needed as all other tenants aside from a single one adhere to regular office hours. The lack of fragmentation in zones and operational timeslot resulted in a total cumulative usage of 1.609.788 kWh in 2019. With a corrected usage of 110,32 kWh/m^2, the Paris Proof limit of 81 kWh/m^2 was not achieved. After the involvement of the building operator, several changes had been made, including seasonal commissioning, real time monitoring, feedback loops, fragmentation of zones, and changing the 24/7 character. By making the previously running 24/7 systems more efficient, the operating timeslots had been divided into normal office hour and extended timeslots. The normal office hours range from 08:00 to 18:00 wherein the energy consumption of systems, including lighting, HVAC and pumps, are set automatically. During the extended office hours, set from 06:00 to 08:00 and 18:00-20:00, the systems reflect the real time occupancy based on the sensors. Consequently, the indoor conditions are optimal set during office hours and efficient used in extend hours. In addition, exceptions can be made for zones with unusual circumstances. These interventions resulted in an decreased cumulative usage of 960.014 kWh in 2020, 777.875 kWh in 2021, 797.667 kWh in 2022, and 837.497 kWh in 2023. These values are corrected according to the Paris Proof norms, which includes the deduction of kWh used for EV-Box charging stations for electric cars. As shown in table 12, the total kWh of the EV-Box charging stations increased over the years from 2021 to 2023 with 26 additional chargers, thereby impacting the correction factor of those years. As a result of the adjustments made in the operations, the corrected use for was 67,54 kWh/m^2 in 2021, 69,76 kWh/m^2 in 2022, and 72,72 kWh/m^2 in 2023, complying with the Paris Proof norms.

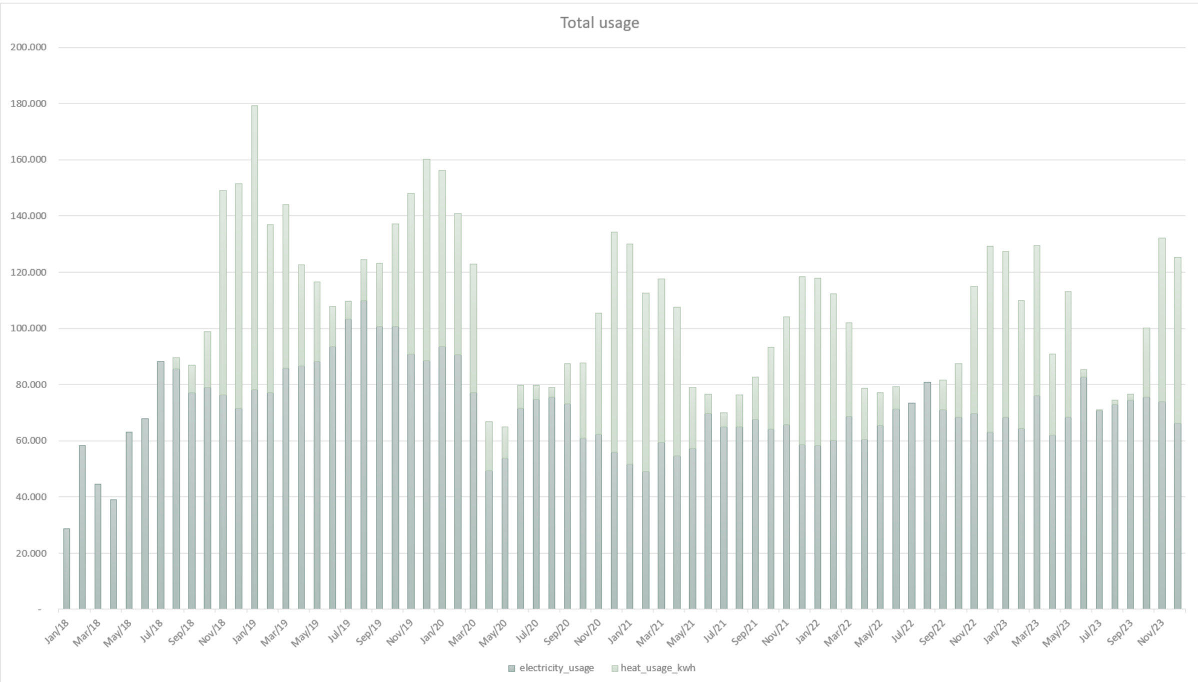

Figure 25: Total energy per year in kWh divided in electricity and heat (adapted from TPex, 2023)

Year	Electricity	Heat	Total	Total EV chargers	Correction factor	Corrected usage	kWh/m2	
2019	1.103.553	506.124	1.609.677		0,7893348	1.270.574	110,32	Start
2020	839.179	366.168	1.205.347		0,7964631	960.014	83,36	Operations
2021	727.412	440.563	1.167.975	-80.044	0,6660029	777.875	67,54	Paris Proof
2022	810.432	323.859	1.134.291	-106.449	0,703229	797.667	69,76	Paris Proof
2023	847.963	376.613	1.224.577	-121.947	0,6839071	837.497	72,72	Paris Proof

Table 12: Total corrected energy per year in kWh (adapted from TPex, 2023)

It is important to note the possible influence of COVID-19 on these outcomes. The pandemic led generally to reduced occupancy and operational intensity in office buildings in 2020 and 2021, which may have contributed to a reduced energy consumption (Ministerie van Algemene Zaken, 2024). Nevertheless, the energy usage remained around the same level after the last lockdown at the end of 2021 with the operations continued to be optimised. These results highlight the significant impact of operational adjustments in maintaining energy efficiency even as building usage patterns stabilised post-pandemic. By adjusting the operations to the design intent and implementing continuous monitoring and tuning, the building's energy efficiency can be improved, ultimately achieving the Paris Proof standards.

5.3 Case study comparison with qualitative research

Through a comparison analysis of the Edge Olympic case study results and the qualitative findings from the semi-structured interviews, the aim is to get a deeper understanding of the challenges and strategies related to the EPG in renovated office buildings. The key subtopics from the qualitative research that directly align with the case study findings include inadequate commissioning and real-time monitoring, tuning challenges, and the need for specialised operations. These problems were particularly notable in the case study, as initial 24/7 system setups failed to consider the diverse operational needs of the multi-tenants, resulting in operational inefficiencies.

The interview outcomes highlighted the importance of effective monitoring and integrating feedback loops. The case study's improvements, which included enhancing energy efficiency through real-time monitoring and modifying operating hours in accordance with actual consumption, closely correspond with the approaches suggested by the experts. Another common topic is the requirement for specialised operations. The involvement of a digital building operator with expertise in smart building management systems was essential in the Edge Olympic case study to enable accurate operational improvements, including the segmentation of operational zones and the distinction in normal and extended operating hours. This validates the results of the interviews, which show that specialised roles are necessary to manage complex building operations. By providing real-time operational data and involving operational teams in continuous improvement processes, the case study demonstrated practical applications of previously proposed strategies, as shown in figure 26. In addition to the findings from the interviews, the case study emphasises the need of unique adjustments needed for the specific characteristics of this case study. Every building functions differently, being influenced by the needs of the end users. Due to the multi-tenant character of Edge Olympic, the zoning and specifications in time slots were essential in the optimalisation of the energy efficiency. Therefore the case study not only validates certain challenges and strategies identified through qualitative research but also demonstrates tailored practical approaches for improving the energy efficiency in a specific renovated office buildings. Furthermore, the case study emphasises shortcomings faced in comparing the theoretical BENG calculations to the actual energy outcomes using the WEii indicator. Since the WEii incorporates both the building-related and user-related energy consumption, the BENG cannot be used as a benchmark due to the focus on solely building-related consumption. This emphasises the need for incorporating the user-related part into the calculations, along with splitting the user-related and building-related consumption in the data metering.

The variations between qualitative and quantitative studies in this context arise primarily due to the temporal focus of the case study versus the interviews. The case study's focus on the in-use phase enables an analysis of operational adjustments and their impact on energy consumption. The operational inefficiencies identified in the case study were only addressed after one year of occupancy. This contrasts with the qualitative research from the interviews, which considers all phases of the building lifecycle, from the initiation. This broader perspective includes earlier phases, wherein potential energy performance issues can be pre-emptively addressed. These insights are crucial for preventing operational inefficiencies before they manifest during the in-use phase.

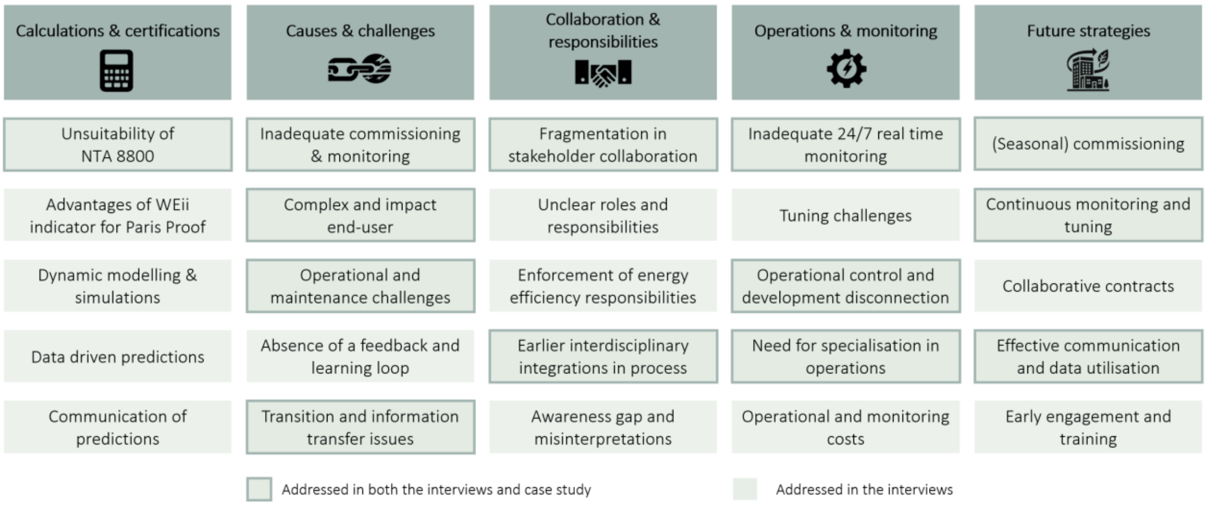

Figure 26: Case study comparison with qualitative research topics (own illustration)

5.4 Conclusion

Based on the case study analysis conducted, insights have been obtained regarding the operation and maintenance inefficiencies of a renovated office building in its practical contexts. This section specifically addressed research question four: *"What operational and maintenance practices should be implemented to realise Paris Proof redeveloped office buildings?"* Thereby, it draws attention to the challenges and effective strategies for aligning real-world energy usage with the Paris Proof standards.

The Edge Olympic case study highlights the critical function of real-time monitoring, consumption zone segmentation, and flexible operating approaches in reducing the energy consumption. By conducting a monthly analysis of energy usage along with implementing required operational improvements, the building succeeded to establish a significant decrease of 34,08% (($\frac{72,72 - 110,32}{110,32}$) x 100%) in energy consumption from 2019 to 2023. Targeted operational improvements, including the implementation of zoning and timeslots, real-time adjustments based on occupancy and environmental conditions, and seasonal commissioning procedures, were put into place to achieve this. The main results of the case study include the imperative requirement for advanced digital building operations that incorporate real-time data analytics to continuously optimise energy consumption. The engagement of the specialised role of the digital building operator was needed for managing the demands of the multi-tenant setting and carrying out the specific modifications required. The operational challenged and improvements suggested in the semi-structured interviews have been successfully validated by this case study. The energy related process demonstrates the inefficiencies problems that could arise when current practices in place are adhered, as well as the added value of applying the practical applications in a real-world situation.

The successful reduction in energy consumption in operational practices to meet Paris Proof standards within Edge Olympic serves as a replicable model for other renovated office buildings with similar characteristics. The generalised take aways of the case study include dividing the building into different zones based on usage and occupancy, adapting operating hours based on actual occupancy, and engaging specialised roles in energy management. Additionally, implementing commissioning and real-time monitoring is emphasised for continuous optimalisations. By doing so, other office buildings can adopt similar methods to improve energy efficiency, particularly in multi-tenant environments. Nevertheless, it should be noted that implications can be better prevented than cured by implementing the proposed strategies in the roadmap from the start.

6. STRATEGIC ROADMAP

6. STRATEGIC ROADMAP

6.1 Introduction

The renovation of office buildings provides challenges, nevertheless also opportunities in achieving energy efficiency as identified in the research. The analysis from the theoretical and applied research, summarised in figure 27, highlights the main challenges in operational efficiency. This section of the thesis presents a strategic roadmap that aims to offer stakeholders a detailed approach to effectively tackle and overcome these obstacles, ultimately leading to the redevelopment of Paris Proof buildings. This roadmap is essential for directing the redevelopment process from initiation to completion, ensuring that it is in line with sustainability objectives. Thereby, this section addresses the main research question: *"How can operation and maintenance-related energy performance gap in renovated office buildings be effectively addressed to meet the Paris Proof commitment targets?"* In order to meet the Paris Proof standards for office buildings, it suggests essential adjustments to operations and maintenance practices. This involves a shift towards utilisation of seasonal commissioning, more integrated and continuous monitoring approaches with feedback loops, and strong communication and knowledge sharing.

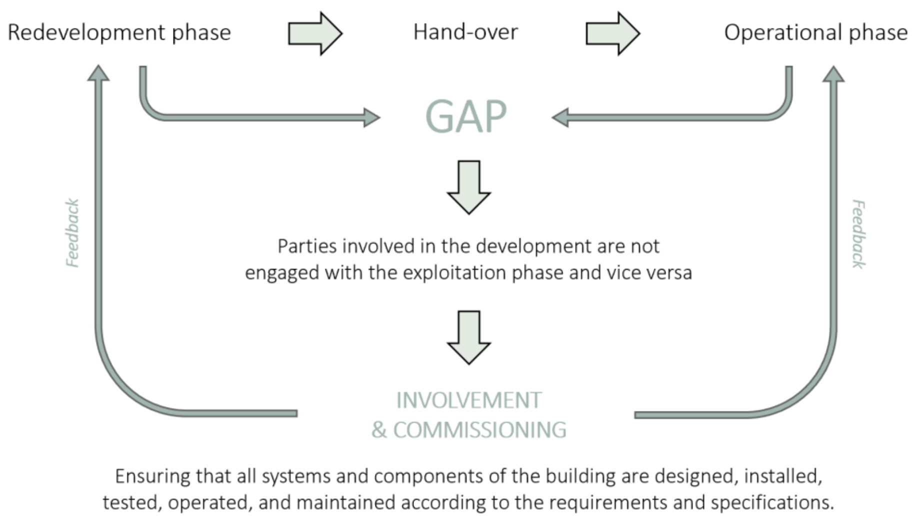

Figure 27: Challenges in operational efficiency

This roadmap outlines the actions required to improve energy efficiency and offers a structured approach for carrying out these steps. These steps include guidelines, predefined targets, roles and responsibilities, contracts and incentives, and compliance with the targets. By using separate outlined stages, it strives to be adaptable for varying projects and evolving energy efficiency technologies and processes. Finally, the strategic roadmap aims to show that structured preparation and implementation may greatly increase energy efficiency in office building, offering an adaptable framework for projects that are similar to the case study.

6.2 Stages strategic roadmap

STAGE 1: Business case

Goal: Establish project scope, performance targets, contractual agreements, and clear stakeholder responsibilities.

Steps initial phase:

1. Stakeholder kick-off meeting:
    - Organised by the RED, this meeting brings together the stakeholders involved, known as the 'design team', to discuss the project's vision, objectives, and the significance of energy performance targets.
    - RED (and CL, which could be the developer) outlines the project's investment and business case.
    - RED, BPE, and IEA present case studies and lessons learned from similar projects.
2. Define project objectives and performance criteria:
    - BPE and IEA develop a clear set of energy performance criteria based on regulatory requirements and the client's sustainability goals.
    - AR provides preliminary designs, incorporating inputs from BPE and IEA for energy-efficient features.
    - RED established framework for the project with input from CE.
3. Roles and responsibilities agreement:
    - The roles and responsibilities are outlined with the expectations from each stakeholder, arranged by the RED with documented agreements signed by all stakeholders in the design team.
4. Energy performance targets:
    - Input from the CE to the RED on financial implications.
    - RED proposes specific energy performance targets.
    - AR integrates these targets into mass studies and sketch design proposals.
5. Legal definitions:
    - CL (which could be the developer) reviews and approves the definitions, ensuring all terms are clearly defined and understood.
6. Collaboration tools and processes setup:
    - RED sets up digital collaboration tools to be used throughout the project, including a project management platform for document sharing, communication, and scheduling.
    - BPE establish benchmarks and metrics to be used for measuring energy performance, integrating them into the project energy management tools.

Key stakeholders: Real Estate Developer (RED), Cost Expert (CE), Structural Engineer (SE), Building Physicist Engineer (BPE), Architect (AR), Installation & Energy Advisor (IEA), and (Client (CL)).

Deliverables:

- Meeting notes and action items from the kick-off meeting.
- A project brief, including agreed and defined energy performance criteria.
- Project collaboration platform among all stakeholders.
- Sketch design concepts with integrated energy-efficiency features based on mass studies.
- Concept of how the energy management of a project will broadly be organised.

By the end of stage 1, all stakeholders should have a clear understanding of the project's direction, their individual roles, and the collaborative effort required to achieve the energy performance targets set for the redevelopment of the office building.

STAGE 2: Sketch, preliminary, final and technical design

Goal: To develop energy-efficient design documents, ensuring the construction complies with the energy performance targets established in stage 1.

Steps:

1. Design development:
    - BPE is in the design team responsible for the energy performance.
    - AR develops the design based on the design principles, integrating feedback from BPE and IEA to ensure energy efficiency is a core component.
    - BPE conducts detailed simulations to model the building's thermal performance, daylighting, and energy consumption.
    - IEA suggests sustainable energy systems and materials that align with the energy targets.
2. Stakeholder collaboration and design review:
    - Regular design meetings are held where the RED and CL review progress and provide input.
    - GC and IEA provide practical insights on construction feasibility and systems installation.
3. Energy modelling and performance analysis:
    - BPE updates the energy model based on design and construction inputs.
    - IEA evaluates energy systems' performance through modelling, proposing optimisations to AR and RED.
    - Development of digital twin by EBSP.
4. Finalising design documents:
    - AR prepares final design documents, incorporating all feedback.
    - BPE and IEA validate the final design against energy performance targets.
    - RED gives energy performance guarantee by including a consortium consisting of the GC, DBO, IEA, and IN. All parties have individual responsibilities in this consortium.
    - Contracts are drawn up by RED, with legal terms reviewed by a legal team, outlining energy performance obligations and establishing the groundwork for the following phases, particularly regarding compliance and enforcement.

Key Stakeholders: Real Estate Developer (RED), Cost Expert (CE), Structural Engineer (SE), Building Physicist Engineer (BPE), Architect (AR), Installation & Energy Advisor (IEA), Client (CL), General Contractor (GC), and Installer (IN).

Deliverables:

- Finalised design documents with detailed plans, specifications and a construction schedule.
- Energy modelling outputs and performance simulation reports.
- Legal contracts with energy performance requirements.
- Signed agreements on roles and responsibilities.

At the end of the stage 2, the project transitions to construction with a complete design that integrates energy efficiency and performance targets, preparing for a construction process that upholds these standards.

STAGE 3: Construction

Goal: Implement the construction phase in accordance with the finalised design documents, focusing on maintaining the energy efficiency standards set out in the design phase to meet or exceed the energy performance targets.

Steps:

1. Construction oversight:
   - RED has a controlling role over the GC and asks questions.
   - GC ensures that construction practices align precisely with the finalised design documents, maintaining oversight of the building's energy performance targets. GC takes responsibility for the design and therefore the energy performance.
   - GC is tasked with the management of day-to-day construction activities, while the BPE and IEA act as on-site advisors, confirming that construction methods and material choices sustain the energy efficiency goals.
2. Quality assurance and compliance:
   - Intermediate checks on energy performance are systematically conducted by the BPE during key construction milestones to ensure quality assurance.
   - IEA verifies that all installations and systems adhere to stringent energy efficiency standards and practices.

Key Stakeholders: Real Estate Developer (RED), Structural Engineer (SE), Building Physicist Engineer (BPE), Architect (AR), Installation & Energy Advisor (IEA), Client (CL), General Contractor (GC), and Installer (IN).

Deliverables:

- Compliance checklist for use during construction, with specific energy efficiency metrics.
- Progress reports and updates on construction against energy efficiency targets.
- Documentation of all changes made during construction, with justifications and impact assessments on energy performance.

By the end of stage 3, the building is prepared for commissioning, with construction completed in alignment with the energy performance targets, ensuring the building is ready for its pre-handover.

STAGE 4: Pre-handover

Goal: Validate the installation, functionality, and performance of building systems to ensure they meet or exceed the design intentions and energy efficiency targets.

Steps pre-commissioning:

1. Pre-commissioning checks:
   - Early involvement of the DBO by getting introduces into the project one year before handover and having access into building management systems a half year in advance.

- Before formal commissioning begins, the GC and CM perform pre-commissioning checks to verify that installations align with the design specifications.
- The DBO ensures that the building management systems are properly set up and ready to collect data for the CM and EBSP.

2. Installation verification:
   - TE and BPE inspect and verify the installation of building systems, especially those related to energy use.
   - IEA reviews system manuals and verifies that all energy-related equipment is accounted for and installed according to the manufacturer's specifications.

Steps commissioning activities:

3. System testing and tuning:
   - CM leads the commissioning process under direction of GC, systematically testing each system to ensure it functions according to the design intent.
   - DBO, provided with data by EBSP, monitors systems operation through the building management systems and is assisted by CM in fine-tuning operations for optimal energy efficiency.
4. Documentation and digital twin development:
   - DBO collaborates with EBSP to develop a digital twin of the building, simulating its performance and establishing a baseline for future operations.
   - BPE assists in interpreting data and integrating findings into a living document for the building's operations.
5. Contract review and energy benchmarking:
   - IEA and CM review energy performance contracts and benchmarks established in the business case and design stage to ensure compliance and set expectations for operation.
   - RED confirms whether the building meets the pre-handover targets and prepares for the eventual handover to the CL.
6. Occupant engagement planning:
   - IEA plans for occupant engagement by creating educational materials on energy-saving features and operational guidelines.
   - RED and CL define roles for ongoing occupant communication to ensure users understand and support the building's energy efficiency goals.

Steps finalisation before handover:

7. Completion of as-built documentation:
   - AR and GC prepare as-built drawings and documentation, reflecting any adjustments or deviations made during construction.
   - BPE ensures that the as-built documentation reflects the actual energy performance capabilities.
8. Operational and maintenance training:
   - CM coordinates with IN and DBO to conduct operational and maintenance training sessions for the operating team.
   - Training materials include troubleshooting guides, maintenance schedules, and energy efficiency best practices.

9. Final energy performance report:
    - IEA compiles a final energy performance report, including data from the commissioning process, to present to the RED.
    - BPE and DBO validate the report, ensuring that it accurately reflects the building's performance and readiness for handover.

Key stakeholders: Real Estate Developer (RED), Structural Engineer (SE), Building Physicist Engineer (BPE), Architect (AR), Installation & Energy Advisor (IEA), Client (CL), General Contractor (GC), Installer (IN), Digital Building Operator (DBO), Expert Building Systems & Platforms (EBSP), and Commissioning Manager (CM).

Deliverables:
- Verified and tested building systems ready for operation.
- A commissioning report detailing findings and any corrective actions taken.
- As-built documentation and digital twin model for ongoing building operations.
- Operational and maintenance manuals and training records for the operating team.
- Energy performance report as a benchmark for the building's operational phase.

By the end of stage 4, the building is prepared for handover with proven systems in place to ensure it operates at the envisioned energy performance level. This sets the stage for a smooth transition to daily use while maintaining high energy efficiency standards.

STAGE 5: Handover

Goal: Officially transfer control of the building from the project team to the client and their operational team while ensuring the energy performance is understood and can be managed effectively.

Steps handover planning and execution:
1. Final inspections:
    - The CM conducts final inspections with the GC, TE, and BPE to ensure all systems operate as intended.
    - The CL is being informed about inspections to get confirmation that the energy systems are operating as intended.
2. Documentation delivery:
    - The GC and IN present as-built documentation, including detailed schematics and specifications of all energy-related systems and installations.
    - The GC and IN prepare a detailed handover package with all manuals, warranties, and service agreements for the building's energy systems.
3. Energy management system handover:
    - The RED and IN facilitate the transfer of the energy monitoring tools to DBO and EBSP.
    - The DBO and EBSP demonstrate the functionality of the BMS to the whole operating team, ensuring they understand data interpretation and system controls.

Steps training and knowledge transfer:

4. Operational training sessions:
    - The CM and IN lead training sessions for the operating team, focusing on system operations and maintenance procedures.
    - The IEA provides energy efficiency workshops to the end user and manuals that incorporate the energy performance targets.
5. Transfer of energy performance knowledge:
    - The BPE and IEA organise sessions to transfer knowledge of the building's energy model and expected performance, ensuring the operating team can manage and maintain efficiency.
    - Documentation and training materials are handed over, and Q&A sessions are conducted to clarify any uncertainties.

Steps legal and administrative closure:

6. Rental agreements and energy clauses:
    - RED finalises any rental agreement, incorporating energy elements that outline expectations for energy performance and responsibilities. This moreover includes a bonus-malus system and the incorporation of the operation and monitoring costs into the service costs.
    - Consortium consisting of the GC, DBO, IEA, and IN serves as an incentive wherein they have to pay for inefficiencies and get rewarded when achieving the targets. All parties have individual tasks and responsibilities for achieving the set energy performance goals.
    - Legal sign-off is obtained from both RED and CL on all contractual agreements related to the building's energy performance.
7. Official handover:
    - An official handover is held, marking the transfer of the building to the client. If feasible, the RED keeps the building in its own portfolio for 2-3 years, implementing the buy and hold strategy, in order to safeguard the energy performance. This event includes presenting the energy performance certificates and any recognition for sustainability achievements.

Steps post-handover support:

8. Aftercare services planning:
    - The CM, IEA, and BPE discuss with the CL the aftercare services, setting up schedules for periodic reviews and audits to ensure long-term energy performance.
    - RED sets expectations for the initial aftercare phase, emphasising the importance of ongoing monitoring and engagement.
9. Establishing communication channels:
    - A communication channel between the project team and the operational team is established for post-handover support.
    - The EU is introduced and provided with contact information for support by the DBO regarding energy management.

Key stakeholders: Real Estate Developer (RED), Client (CL), Building Physicist Engineer (BPE), Architect (AR), Installation & Energy Advisor (IEA), General Contractor (GC), Installer (IN), Digital Building

Operator (DBO), Expert Building Systems & Platforms (EBSP), Commissioning Manager (CM), Technical Engineer (TE), and End User (EU).

Deliverables:

- Completed building ready for occupancy with all energy systems tested and operational.
- As-built documentation
- Operational manuals and workshops tailored to the client's needs.
- A fully trained operational staff equipped to maintain energy performance standards.
- Rental agreements with energy conditions.
- A clear contractual framework that includes provisions for maintaining energy efficiency.

By the conclusion of stage 5, the building is officially operational, with the operational team fully equipped and knowledgeable about maintaining and improving the building's energy performance, and with all necessary documentation and tools transferred. This ensures a smooth and informed transition into the in-use phase while upholding energy efficiency and performance.

STAGE 6: Initial Aftercare

Goal: Monitor the building's initial operational performance to ensure it adheres to energy performance targets set in the design intend and optimise where necessary.

Steps commissioning and ongoing evaluation:

1. Post-occupancy commissioning:
   - The CM coordinates post-occupancy commissioning activities, ensuring that the building systems are optimised for actual occupancy patterns.
   - The DBO, with support from the EBSP, leverages the building management systems to fine-tune operations and manage energy use effectively.
2. Performance data analysis:
   - The IEA collects and analyses performance data provided by the DBO and EBSP to ensure that energy consumption aligns with predictions.
   - The TE reviews the initial performance data and compares it against the predictions of the energy model.
   - The IEA and/or DBO follows a training to become authorised to give Paris Proof certification based on the WEii.

Steps building management and optimisation:

3. Continuous monitoring and feedback Loop:
   - The DBO establishes a continuous monitoring program for real-time tracking of energy consumption, setting up alerts for deviations from expected performance.
   - Feedback on energy performance is communicated from the DBO and EBSP to the RED, IEA, and the CL for transparency and lessons.
4. Energy efficiency training and engagement:
   - The IEA conducts sessions with EU to explain the building its functioning and promote energy-efficient behaviours.

Steps documentation and cost management:

5. Documentation of energy performance:
    - The DBO maintains detailed records of energy performance, documenting all adjustments and outcomes for future reference.
    - The CM ensures that all operational changes and their impacts on energy performance are well-documented.
6. Cost control and service charges:
    - The RED/CL reviews energy costs against service charges to identify any discrepancies and opportunities for cost-saving measures.
    - The GC and IN remain available to address any system inefficiencies that may impact operational costs.

Steps handover to full occupancy:

7. Extended ownership support:
    - The RED preferably remains the owner for the first 2-3 years or provides extended support during the initial aftercare to assist the CL with any issues related to building performance.
    - A defined support period is agreed upon, after which the client assumes full responsibility for building operations.
8. Guidance for sustainable operation:
    - The IEA develops a sustainable operation guide to maintain and improve energy performance.
    - EU is provided with easy-to-understand guides and tips for contributing to the building's energy efficiency.

Key stakeholders: Real Estate Developer (RED), Client (CL), Building Physicist Engineer (BPE), Installation & Energy Advisor (IEA), General Contractor (GC), Installer (IN), Digital Building Operator (DBO), Expert Building Systems & Platforms (EBSP), Commissioning Manager (CM), Technical Engineer (TE), End User (EU)

Deliverables:

- A fully commissioned building fine-tuned for initial occupancy patterns.
- Operational adjustments documentation.
- A detailed data set of early-stage energy performance.
- Training materials and engagement strategies for occupants.
- A framework for ongoing cost management related to energy use.
- Sustainable operation guides.

At the end of stage 6, the building's early performance is well-understood and optimised, providing a strong foundation for long-term energy efficiency. The operational team is fully capable of managing and maintaining the building's systems, and the end users/renters are engaged to contribute to the building's sustainability goals.

STAGE 7: Operational phase

Goal: Establish sustainable operational practices and routines to ensure the building continues to meet its energy performance targets over the long term and adapt to any changes in technology or occupancy.

Steps long-term monitoring and maintenance:

1. Seasonal commissioning:
   - The CM oversees seasonal commissioning to adjust the building's systems for changing weather patterns and occupancy rates, ensuring optimal energy performance year-round.
   - The DBO uses the building management systems to implement seasonal adjustments based on data analytics provided by the EBSP.
2. Long-term data analysis and reporting:
   - The IEA works with the DBO to analyse long-term energy data and generate detailed reports on the building’s performance.
   - The DBO reviews these reports to track the building's performance against the initial energy models and identify trends or areas for improvement.

Steps continuous improvement and engagement:

3. Continuous performance improvement:
   - The TE collaborates with the IEA and DBO to implement technological upgrades and renovations that can further enhance the building’s energy efficiency.
   - The CL and RED evaluate and approve recommended improvements to ensure they align with financial and sustainability goals.
4. Feedback and learning loop:
   - The IEA sets up a feedback mechanism for occupants to report any discomfort or suggestions related to the building’s energy systems, creating a responsive environment for continuous improvement.
   - The DBO and EBSP monitor occupant feedback and adjust systems accordingly, fostering an adaptive operational approach.

Steps certification and compliance:

5. Paris Proof certification and compliance:
   - The IEA leads the effort to obtain or maintain Paris Proof certification by implementing necessary updates and ensuring ongoing compliance with its standards.
   - The IEA and/or DBO is authorised to give Paris Proof certification based on the WEii.
6. Regular audits and training:
   - Regular energy audits are conducted to ensure the building remains compliant with energy performance targets and to identify new opportunities for energy savings.
   - Training for the operational team is updated to incorporate the latest energy management practices and technologies.

Steps ongoing support and communication:

7. Building management support system:

    - The RED establishes a support system for building management that includes regular check-ins with the operational team, including the CM and DBO, to ensure continued performance optimisation.
    - A dedicated channel for technical support from the EBSP and TE is maintained to address any system issues promptly.
8. Stakeholder meetings:
    - Regular stakeholder meetings are held to review the building’s energy performance, discuss potential improvements, and foster a sense of shared responsibility for the energy performance.
    - The RED, CL, and DBO co-organise these meetings, with input from the IEA, to ensure transparency and collaborative engagement.

Key stakeholders: Real Estate Developer (RED), Client (CL), Building Physicist Engineer (BPE), Installation & Energy Advisor (IEA), Digital Building Operator (DBO), Expert Building Systems & Platforms (EBSP), Commissioning Manager (CM), Technical Engineer (TE), End User (EU).

Deliverables:

- Seasonal commissioning reports and long-term energy data reports
- An established routine for seasonal commissioning and data-driven system adjustments.
- A strategy for ongoing improvements, integrating new technologies and responding to feedback.
- Documentation and records necessary for maintaining or achieving Paris Proof certification.
- A community-focused approach to energy management, engaging stakeholders and occupants in the process.

After completing stage 7, the building should perform efficiently as well as being adaptive to changes, supported by an active operational team who are invested in the building’s long-term sustainability and energy performance.

6.3 Proposed roadmap implementations

In contrast to the existing fragmented process, a more overlapping approach to stakeholder involvement has been recommended in the strategic roadmap. The roadmap redefines the role of the outdated role of the building operators. The digital building operator is primarily concerned with the implementation and management of building management systems, playing a key role in the collection and analysis of energy usage data. Important enhancements further involve the inclusion and extended involvement of specialised roles. Experts in smart building systems are integrated to make sure that the digital building operator building has access to performance analytics and data-driven management for the digital building platforms. These experts bring expertise in cutting-edge technology and platform management. In order to ensure that systems and installations operate as intended, the commissioning manager's role has become increasingly important over time.

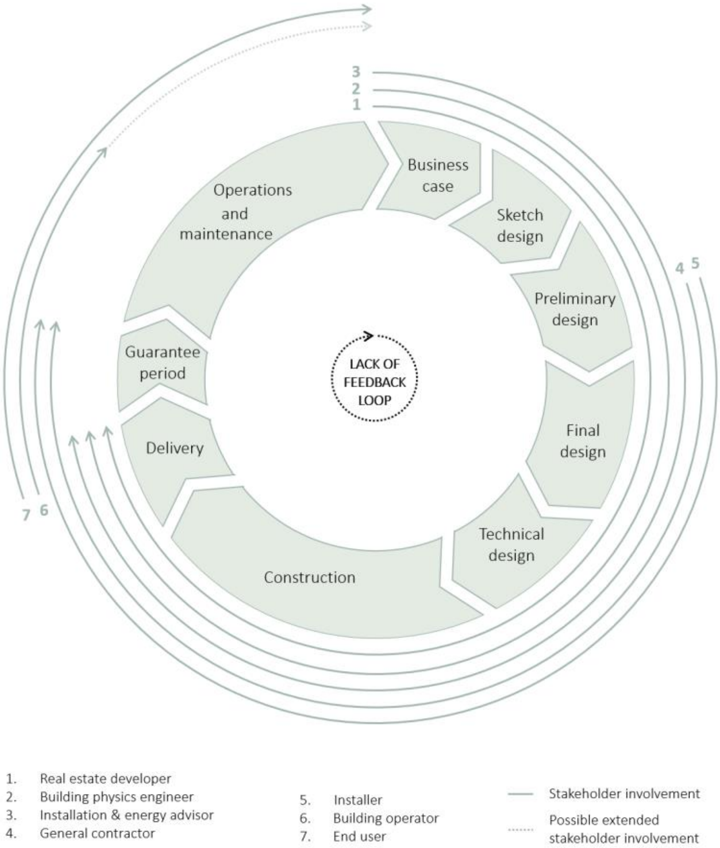

Figure 28: Currently organised stakeholders involvement (own illustration)

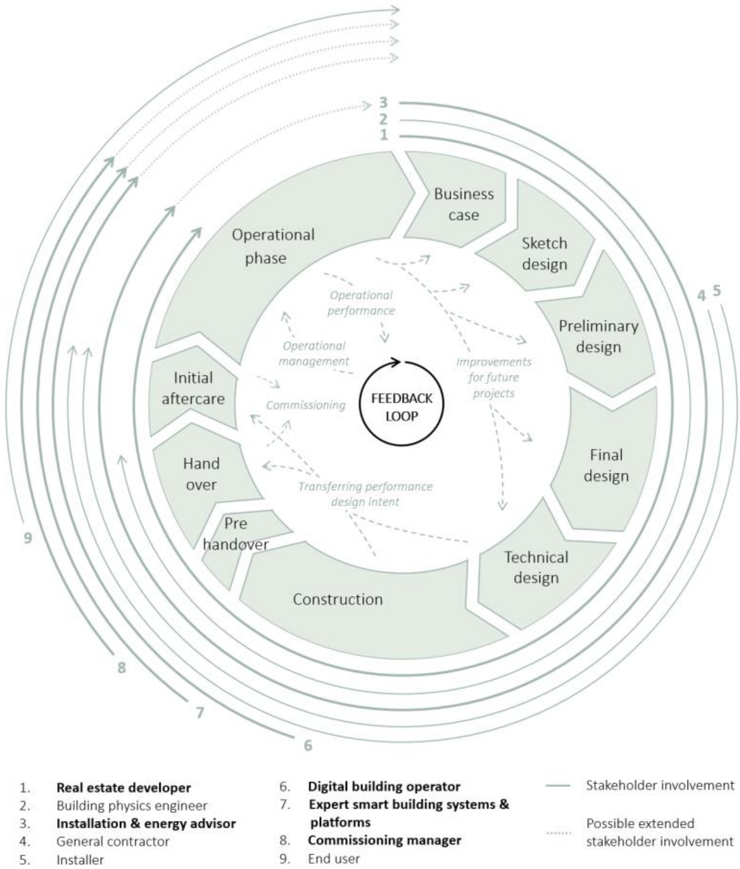

Figure 29: Improved organised stakeholder involvement (own illustration)

Another addition is the extended involvement of stakeholders through the pre-operational and initial aftercare phases. While being fragmented in current practices, the roadmap proposed more overlap between the phases as shown in figure 28 and 29. These stages are essential for enhancing the sharing of knowledge and optimising building operations and maintenance. Pre-operational involvement includes steps such as system commissioning and performance verification, while the initial aftercare phase focuses on monitoring the building's performance against its energy targets to ensure that the operations comply to the needs. The emphasises on a seamless transition knowledge between phases moreover facilitated well-defined roles and responsibilities. This makes the stakeholders aware of their impact on the building's energy performance and their contribution to achieving Paris Proof standards.

6.4 Conclusion

In concluding the strategic roadmap, this section addresses the main research question: *"How can operation and maintenance-related energy performance gap in renovated office buildings be effectively addressed to meet the Paris Proof commitment targets?"* First of all, a redefined involvement structure is proposed in order to comply with the suggested strategies, as shown in figure 29 compared to figure 28. The recommendations provided in the roadmap are aimed at enhancing current energy related practices throughout all stages since the overall process impacts the outcomes of the final operational phase. Finally, the steps are targeted at fulfilling the stringent criteria needed to obtain the Paris Proof certification.

The introduction of pre-handover and seasonal commissioning ensures that building systems are finely tuned to operate optimally also under varying seasonal conditions, contributing to maintaining consistent energy performance throughout the whole year. Implementing continuous monitoring systems which utilise advanced technologies is needed for real-time data analysis. Real-time data makes immediate adjustments to optimise inefficiencies in energy usage possible as they arise. Additionally, clear redefined stakeholder responsibilities are crucial, especially in the operational team. Collaborative contracts and robust communication ensure ongoing engagement and accountability, making energy performance guarantees possible. Moreover, training for operational teams on the design intent ensures that teams are well-equipped to manage building systems efficient. This includes providing and integrating feedback loops into the operational framework for continual improvement real-time data. The strategy intends to achieve high energy efficiency in renovated office buildings by implementing these strategic changes into maintenance and operation procedures. The proposed roadmap, summarised in figure 31, provides structured steps to achieve Paris Proof criteria, functioning as a guide for all stakeholders participating in the redevelopment process. The most important steps that need to be prioritised are displayed in bold since they are identified as having the most significant impact on energy efficiency.

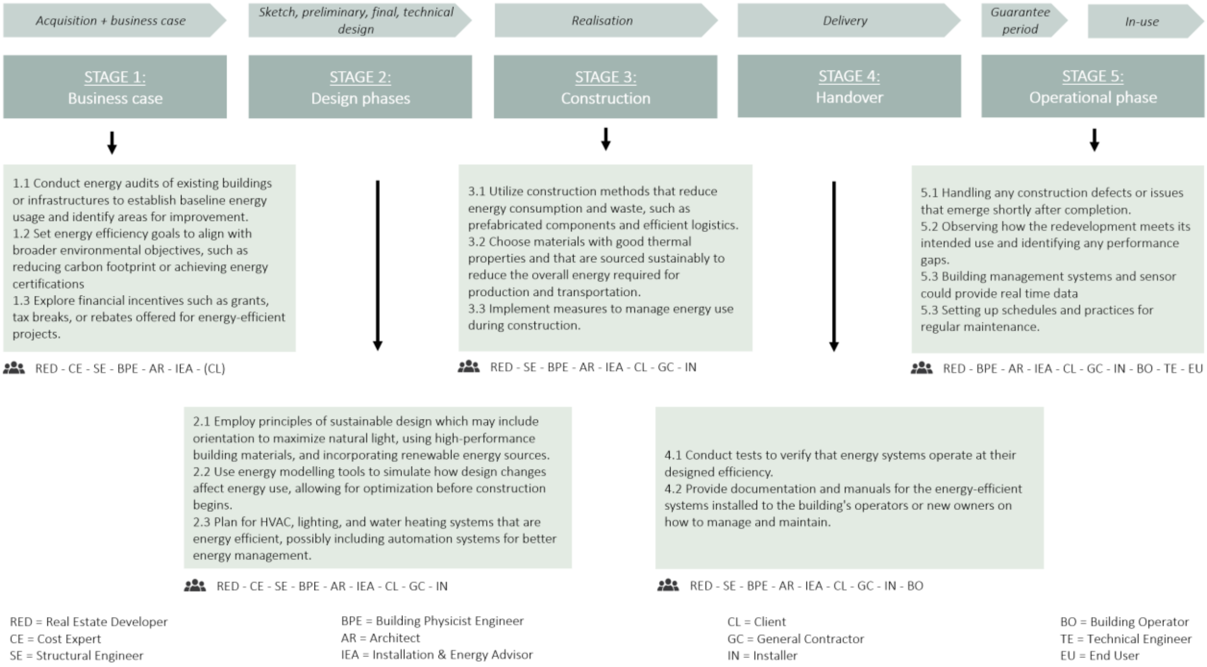

Figure 30: Currently organised redevelopment process (own illustration)

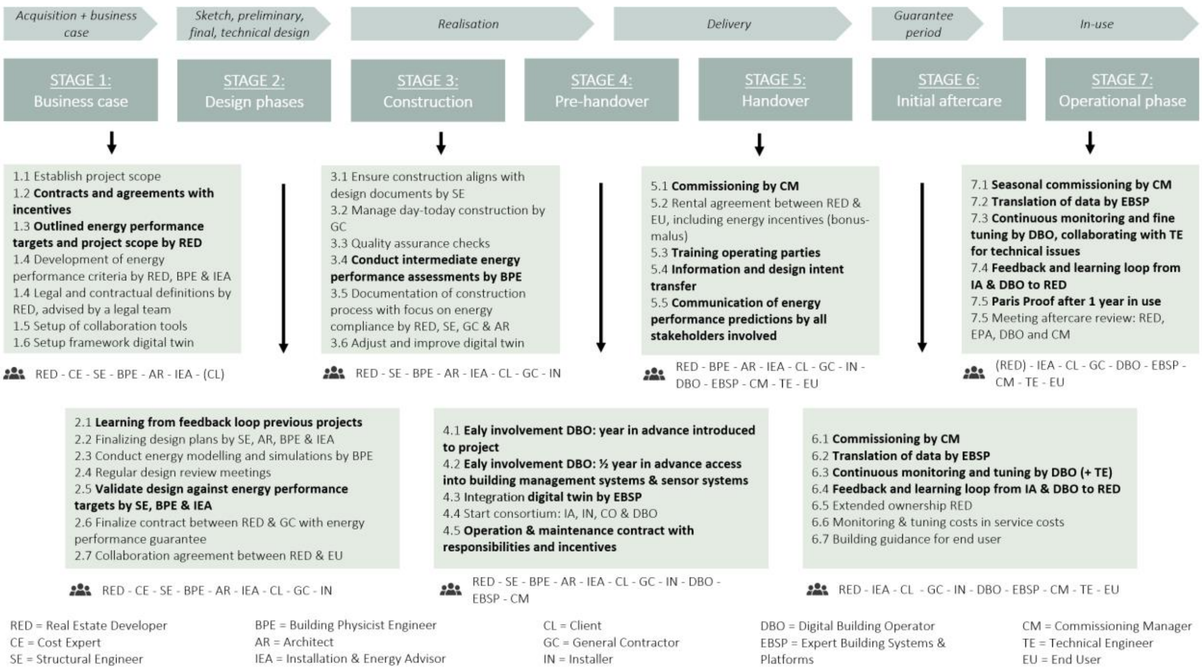

Figure 31: Strategic roadmap proposed redevelopment (own illustration)

7. DISCUSSION

7. DISCUSSION

7.1 Different perspectives interviewees

When analysing the interview findings it is noticeable that while the interviewees highlight the same overarching challenges, the focus on different phases or specifics within those challenges is being influenced by their knowledge and expertise. For instance, the digital building operator emphasises the operational phase and gives priority to integrating advanced technologies and real-time data to improve operational efficiency. On the other hand, building physics specialists and engineers emphasise the importance of the first stages of design and construction, thereby more focusing on the calculations and processes upfront. Experts in data science advise employing machine learning and advanced analytics to improve both energy consumption forecasts and accurate improvements needed, directing the decision-making. Installation advisors concentrate on the tangible aspects of system configuration, emphasising the importance of correct implementation to achieve designed energy efficiencies.

Despite the differences between these viewpoints, the experts collectively draw attention to the complexity of the current challenges. Each interviewee contributes a piece of the puzzle to the understanding of how various stages of the building lifecycle affect the EPG in the operations, highlighting the need of a strategy that includes ongoing collaboration as well as communication between all sectors. This synthesis of perspectives points out that interdisciplinary collaboration helps ensuring that theoretical design intents are more effectively implemented in practice.

7.2 Generalisation of the findings

This discussion will synthesise findings across the research to present main- and subthemes with a focus on operations and maintenance, reflecting back on the strategic roadmap. Four main themes have been identified in the research outcomes, highlighting underlying causes, current challenges, and focus areas for addressing the EPG effectively (figure 32). The four main themes, all subdivided into subthemes are as followed: “continuous monitoring and tuning”, “advanced technologies and specialisation”, “responsibilities of roles and incentivisation”, and “knowledge transfer and trainings”.

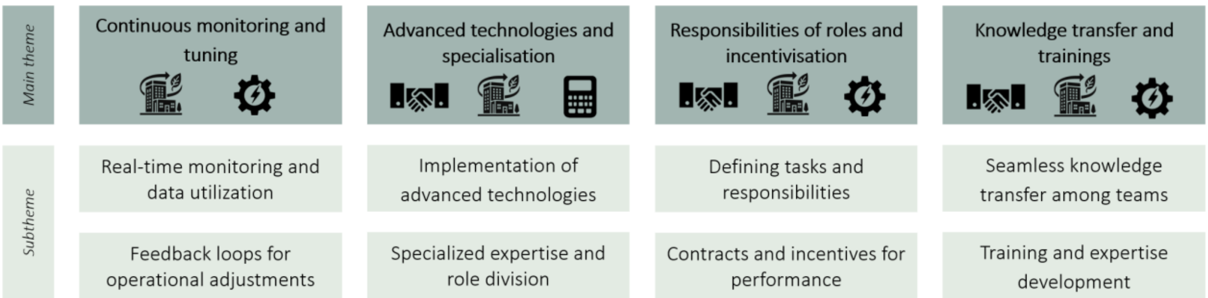

Figure 32: Identified main and subthemes (own illustration)

7.2.1 Continuous monitoring and tuning

In order to make sure that buildings function as planned, "continuous monitoring and tuning" emerges as a key concept. The findings address the specifics of how both of these approaches could help improving efficiency. "Real-time monitoring and data utilisation" and "feedback loops for operational adjustments" are the two subthemes that together constitute this main theme.

Subtheme: Real-time monitoring and data utilisation

Real-time monitoring relies on the capacity to collect and evaluate actual energy consumption data. Sensor-equipped data collecting systems enable the quick identification of mistakes and disparities between the performance of the building as intended and as obtained, thereby offering essential data for effective energy management. Using real-time data has several benefits since it helps to understand the dynamics of buildings by providing an overview of previous collected data in addition to recording the current performance. The process of continuously gathering data is essential for creating a foundation for future advancements. Furthermore, a benchmark must be used in order to serve as an indicator of reference for building operators to identify inefficiencies.

Subtheme: Feedback loops for operational adjustments

Data alone, however, is not sufficient enough to close the performance gap. Data becomes valuable when it translated into useful feedback loops. These loops are cyclical processes where decisions on operational adjustments are made based on data and the results are monitored and supplied back into the system as new data. This cyclical process ensures that the operations team is continuously informed about the building's performance to make timely decisions. Feedback loops are essential for converting data into workable operational practices. This may entail making necessary repairs to malfunctioning equipment, modifying HVAC system control settings, or planning preventative maintenance to prevent energy waste. By implementing these interventions, procedures are regularly improved in order to meet the predefined energy efficiency targets.

7.2.2 Advanced technological integration and specialisation

The second main theme, "advanced technological integration and specialisation", focuses on how cutting-edge technologies and the need for specialised professional roles could help transforming the field of building management and therefore energy efficiency. The theme emphasises the importance of incorporating digital tools such as digital twins, machine learning, and artificial intelligence into both the structural and the functional design of buildings. In parallel, the theme also explores the evolution of specialised roles within the field of building management. This calls for a separate division of responsibilities between the roles of the physical and digital building operators.

Subtheme: Implementation of advanced technologies

One significant technical development in the field of building operations and management is the emergence of digital twins. By using data from numerous sensors located throughout the building, a digital twin is a virtual model that replicates the real building and simulates its systems and operations in real time. Moreover, it can incorporate AI algorithms to implement predictive maintenance and machine learning to automatically adjust operational parameters in real-time for optimal based on learned experiences from collected data. For instance, to optimise energy consumption and space usage, the digital twin leverages data from occupancy sensors. These provide important insights into building performance that could inform operational decisions. By implementing these cutting-edge technology, building operations can be optimised for increased sustainability, efficiency, and condition adaptability. Moreover, more accurate forecasting are made achievable, improving compliance with the set targets.

Subtheme: Specialised expertise and role division

A specialised approach to building management is highlighted by the distinction in roles between a digital and physical building operator. The digital building operator's responsibility is to optimise building performance by utilising data from advanced digital systems. Real-time data is analysed by the digital building operator to make sure that the building operates well, anticipates on repairs needed and adjusts to changing circumstances. Using extensive analytics and simulations from digital twins and other intelligent building systems, decision-making is centred on data management, system optimisation, and performance monitoring. On the other hand, the tangible aspects of building management need to be handled by the physical building operator. The physical care and hands-on maintenance of the building are part of this function. In order to make sure that the physical features of the building correspond with the insights from the digital strategy, the physical building operator is in charge of putting the tasks suggested by the digital analytics into practice. A more targeted and efficient method of managing the digital and physical facets of building operations is made possible by this division, fostering an organised approach that makes use of both data-driven insights as well as helpful on-the-ground activities, as explained more detailed in section 7.3.

7.2.3 Responsibilities of roles and incentivisation

Based on the research findings, the third main theme of "responsibilities of roles and incentivisation" is formulated, focusing on enhancing energy performance in building operations through clear role delineation and incentivisation mechanisms. This theme can be specified in the following subthemes: “defining tasks and responsibilities” and “contracts and incentives for performance”, providing deeper insights.

Subtheme: Defining tasks and responsibilities

For building operations to be efficient and effective, it is imperative that all stakeholders' roles and responsibilities are clearly defined. It guarantees that all participants are aware of their specific duties and how they fit into the building's overall energy efficiency objectives. Having distinct role descriptions helps avoid responsibility overlaps, which can result in inefficiencies or overlooked tasks. Moreover, it facilitates a more seamless coordination among various parties, resulting in more systematically operations towards achieving energy efficiency.

Subtheme: Contracts and incentives for performance

To further drive the energy performance of buildings, the introduction of contracts and incentives aligned with performance criteria is essential. Contractual responsibilities can specify required performance standards that the parties concerned must meet, such as energy consumption goals or sustainability benchmarks. Additionally, incentive strategies can be implemented to reward stakeholders for meeting or exceeding these targets. This approach not only fosters ongoing enhancements in energy efficiency but also aligns the interests of all stakeholders with the overall objectives. Contracts and incentives could provide recognition, financial rewards, or other advantages in order to promote compliance and proactive involvement in energy-saving measures.

7.2.4 Knowledge transfer and trainings

The main theme "knowledge transfer and trainings" explores how effective communication and educational strategies within building management can significantly influence energy efficiency outcomes. This theme addresses the critical need for “seamless knowledge transfer among teams” and “staff training and expertise development”.

Subtheme: Seamless knowledge transfer among teams
Effective knowledge transfer between stakeholders is essential to prevent gaps in information and ensure that everyone involved is using the same energy management strategy. Transparency on energy-efficiency measures, technology advancements, and operational strategies keeps essential information from getting lost and helps to adopt a cohesive approach. This seamless knowledge sharing not only improves collaboration but also maximises the application of energy-saving techniques in various disciplines.

Subtheme: Training and expertise development
Achieving high levels of energy efficiency requires training operational staff in the latest energy management methods operations. Continuous professional development ensures that staff are up-to-date with the best practices and regulatory requirements. Expertise is essential to efficiently manage the building's energy use and operational effectiveness. Alongside professional training, creating trainings and manuals for end-users is also important. These manuals should provide clear instructions on the building its functioning and raise awareness. Moreover, it provides users with an understandable translation of energy consumption and thus understanding of certain energy objectives.

7.3 The role of the building operator

The evolution of smart buildings, characterized by their integration of advanced technologies, IoT devices, and data analytics, necessitates a re-evaluation and specialisation of the building operator role. Traditional building operator responsibilities encompass a broad range of tasks, from monitoring building systems and managing energy use to maintaining and doing repairs (figure 33). However, as buildings become increasingly complex and data-driven, the scope of these tasks become more diverse, leading to the need for a more specialised approach with distinct responsibilities and expertise required for the digital building operator and the physical building operator and maintenance as shown in figure 34.

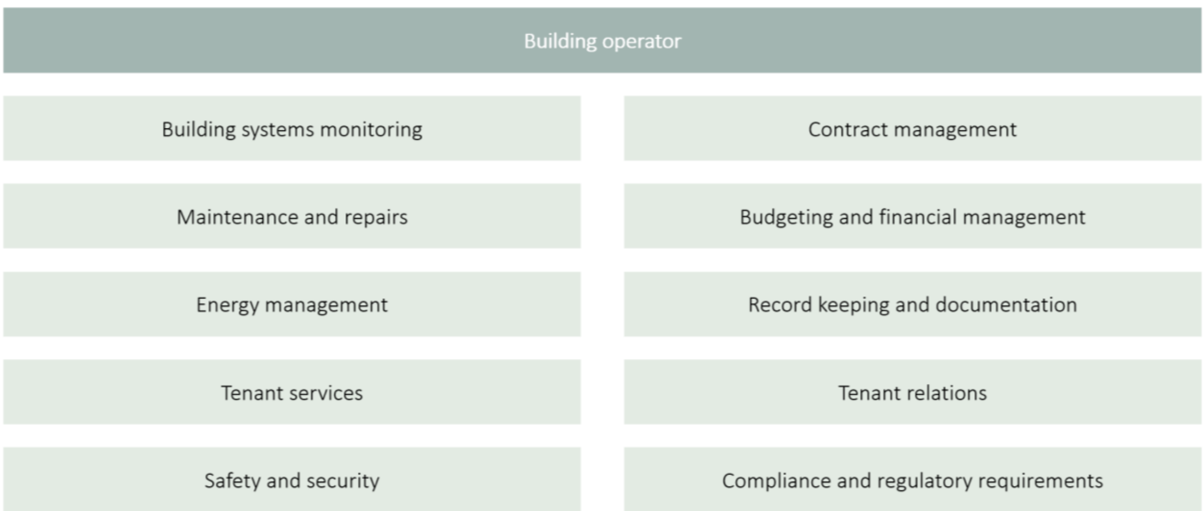

Figure 33: Traditional tasks building operator (own illustration)

The introduction of smart technologies in buildings has significantly increased the complexity of data related to building operations. This data, when analysed and utilised effectively, can greatly optimise energy efficiency and improve tenant comfort. The role of the digital building operator emerges as a specialised position focused on leveraging this data to achieve these outcomes. While the digital building operator focuses on data and processes, the physical presence and intervention of a building operator remain crucial. The tangible aspects of building maintenance, security, and tenant services cannot be fully automated or managed remotely, requiring a physical building operator.

Digital building operator → process & operations	Building operator and maintenance → physical
24/7 remote monitoring and control	Routine inspections and maintenance
Data analysis and optimization	Equipment repairs and troubleshooting
Alarm management and troubleshooting	Emergency response and resolution
Performance reporting and analysis	Physical security and safety checks
Tenant communication and support	Site supervision and coordination
Vendor and contractor coordination	Documentation and reporting

Figure 34: Division of tasks building operator (own illustration)

7.4 Contextualisation within existing literature

The findings from this thesis build upon and strengthen the theoretical background laid by prior research into the factors influencing the EPG. This contextualisation incorporates viewpoints from energy efficiency experts' interviews and contrasts them with the literature's outcomes, as described in section 2.7. A key similarity is the acknowledgment of the operational phase as pivotal in determining a building's energy efficiency, aligning with the emphasis on operational practices and maintenance protocols discussed in the theoretical background (section 2.1.3). Van Dronkelaar et al. (2016) identified uncertainties in building modelling and the significant influence of operational practices. This research further underscores the transition of operational practices and the critical role of continuous monitoring and feedback mechanisms in addressing the uncertainties effectively. Moreover, the interviews revealed that real-time monitoring and feedback loops are essential in order to adapt operations to actual building performance, thereby optimising energy efficiency over time. This aligns with previous findings by Granderson et al. (2011), who pointed out the energy losses due to inadequately operated and maintained building systems.

Nevertheless, there are also differences in the focus points, particularly in the application and impact of advanced technological integrations such as digital twins. While Chen et al. (2020) emphasises the integration of energy-efficient technologies and systems, the finding from the interviews point to a more nuanced application, where digital twins enhance operational decision-making by offering detailed, real-time data about building performance in addition to supporting energy efficiency. Moreover, the importance of specialised roles in managing these technologies is a less pronounced in the existing literature comparing to outcomes of the interviews. The insights offers a deeper understanding of how the building operations should be cooperated and contribute to a more specified approach to efficient energy management, highlighting the need for a blend of technological and human factors. Whereas literature, such as the study by Yoshino et al. (2017), categorises main influencing factors in a broader context, this research specifically focuses on the impact of operations and maintenance on the energy efficiency. The interviews focus on the potential for minimising this impact through automated systems, data management and centralised control, suggesting a shift towards controlled operations and less occupant-dependent energy management strategies.

7.5 Expert panel and feedback proposed strategy

The EPG's challenges identified in the theoretical and applied research are addressed in several stages in the proposed strategic roadmap. In line with the findings on communication and responsibilities, the business case stage addresses issues raised in the theoretical background and interviews by placing a emphasis on defined roles, responsibilities, and energy performance targets. As pointed out in the interviews, the design phase should ensure that energy efficiency is a core element, incorporating feedback and encouraging interdisciplinary collaboration. Oversight during construction facilitates adherence to energy performance objectives and the design intent. Intermediate checks ensure that systems are set correctly, which corresponds to continuous monitoring needs. As part of the pre-handover stage, experts highlight the early involvement of operating parties, system testing, and tuning, which is in line with effective commissioning. During the handover, the operating team's training and knowledge transfer are the key priorities, aiming to maintain energy efficiency. Incorporating energy clauses in the agreements promotes ongoing accountability. The initial stage of the aftercare process places a strong emphasis on commissioning and continuous monitoring, which reflects the value placed on ongoing improvements by both the interviews and case study. The operational phase, which reflects a trend towards data-driven approaches, modifies systems for year-round optimal performance through seasonal commissioning and utilises data to drive improvements. Maintaining Paris Proof standards in the operational phase aligns with performance-based assessments.

During the expert panel with the interviewed digital building operator, head of smart solutions, program manager digital, and engineer and advisor building physics, several key findings were discussed regarding the proposed roadmap. First of all, it was noted that fragmented information transfer and stakeholder collaboration are evident not only during the delivery but also later on throughout the transition to new ownership. This is evident by the following quote from the digital building operator: *"At the moment the building is sold, or when after a year a maintenance party arrives who has not been involved at all in the design, construction, and operation, in my view, approximately 50% of the available information will be lost."* The loss of overlooked data regarding the energy performance has a tendency to repeat itself with each ownership transition. There should be a dedicated focus on transferring information regarding the energy performance in order to prevent a decrease of energy efficiency over time. The building's energy efficiency may gradually decrease if information about its energy performance is not correctly transferred. Consequently, in response to this challenge, the head of smart solutions mentioned the importance of including a handover manager who regulates the transfer of information. It is essential to make sure that information transfer is done systematically and consistent while taking into account the varying importance levels of internal and external stakeholders. Secondly, the digital building operator compared buildings to a production line, emphasising the significance of preserving its "memory" over the course of its lifespan. This "memory" comprises the information and data that has been gathered over time regarding the operations, maintenance, and systems. Problems occur when this data is misplaced or not shared properly, which can result in inefficiencies and possibly decreased efficiency. Maintaining energy efficiency requires implementing systems to transfer and preserve this information. Third, it was mentioned that often the commissioning does take place, however with the wrong interests, as confirmed by all participants. In many cases, commissioning is carried out simply to obtain check marks rather than tempting to enhance the system's operation. This draws attention to the potential issues brought on by the conflicting priorities of different parties. Furthermore, there is an importance of maintaining the strategic and tactical framework, in addition to the operational framework as stated by the digital building operator: "*What you see is that as soon as a building enters the operational phase, it often loses contact with the strategic and tactical framework. If you want to make a building sustainable in the long term, you need to keep the strategic and tactical parties involved during the operational phase."* Finally, the value of a dynamic and data-driven approach was again stressed, specifically by the program manager digital. However, while not previously emerged during the interviews, potential privacy issues related to monitoring energy usage through sensors were brought up by the engineer and advisor building physics. While these sensors are essential for gathering detailed data on patterns of energy consumption, they also raise concerns about discussions that could arise around the privacy of occupants.

In addition the aspects addressed in the experts panel, gaps in the proposed strategy include the lack of fully covering certain aspects. This involves focusing on minimising user profile uncertainty in the early stages of the design, which makes precise energy use predictions challenging. There is a lack of the integration between their particular energy usage patterns and behavioural dynamics. Although plans for occupant engagement and manuals are included, detailed user behaviour analytics could be emphasised more. Moreover, economic incentives and performance guarantees have a critical role in guaranteeing adherence and encouraging stakeholders to achieve energy-efficiency targets. Long-term goals might be better served by providing additional details on how these incentives are to be structured and enforced. Addressing these gaps would enhance the roadmap's effectiveness in tackling the full spectrum of challenges associated with the EPG in renovated office buildings.

7.6 Conclusion

Through a theoretical review of literature and the collection of findings from expert interviews and the case study, this thesis has investigated the operational related aspects of the EPG in renovated office buildings. Four main themes emerged from the discussions: 'continuous monitoring and tuning', 'advanced technological integration and specialisation', 'responsibilities of roles and incentivisation', and 'knowledge transfer and trainings', each contributing the understanding of energy efficiency in building operations. The integration of theoretical framework and empirical data has expanded upon prior studies. In operational contexts, it has highlighted the critical role of real-time monitoring and the use of advanced systems, moving beyond traditional energy managing. In order to promote efficient energy consumption, this study has also highlighted the significance of well-defined roles and proactive incentive systems. Moreover, it has addressed the need of training and seamless knowledge transfer with the aim of upholding high standards of operational efficiency.

8. CONCLUSION

8 CONCLUSION

8.1 Sub research question 1

In answering the first sub-question of this research, *"What are the main factors influencing the energy performance gap in buildings?"*, an analysis in the theoretical background section has clarified the complexity and interrelation of the factors. Central to the findings is the recognition that a wide range of factors, from the initial phase to building operation, affect a building's actual energy performance. The influencing factors can be broken down into two categories: human influenced factors, which include operations and maintenance, occupant behaviour, and indoor environment conditions, and technical and physical factors, which include climate, building envelope, and building equipment. As a result of a transition in building culture and the adoption of smart buildings, the operational phase stands out as a critical component where inefficiencies tend to arise. Office buildings, with their dynamic and unpredictable occupancy patterns, encounter the challenges in managing energy consumption effectively. Although these buildings' advanced systems are essential for energy efficiency and offer potentials, they frequently fall short when incorrectly managed. This inefficiency can result in significant energy waste and can be linked to inadequate operational and maintenance practices.

The study additionally underscores the critical role of miscommunication among stakeholders across the design, handover, and operational phases. Fragmented knowledge transfers, unclarity in responsibilities, and insufficient operation monitoring and tuning may result in misalignments in expectations. These organisational and communicational challenges not only contribute to the EPG but also make it more difficult to implement energy-efficient measures for improvements.

8.2 Sub research question 2

Understanding the operational and maintenance challenges has been established in the qualitative study by employing semi-structured interviews with industry experts. As a cornerstone of the thesis, the second SRQ is stated as follow: *"What are the key operational and maintenance challenges that contribute to disparities in energy performance from predictions?"*. The results indicate that a significant portion of the disparities can be attributed to inadequate monitoring and the absence of continuous feedback loops. Experts frequently point out that one of the main barriers in achieving targeted efficiency goals is the lack of employing effective 24/7 monitoring. Using these advanced systems is essential for detecting inefficiencies enabling timely adjustments. The absence of robust feedback loops further exacerbates these challenges, leaving operators without the necessary data to make informed decisions regarding energy management.

The transition from theoretical predictions to practical application moreover reveals a disconnection. A gap could occur when theoretical knowledge is not adequately applied in practice due to a lack of integration between the people overseeing energy calculations and those responsible for operational monitoring. This disconnect is most noticeable during handover and continues throughout the operational stages. To compound, there is limited documentation for well-informed decision-making. When systems are being management by people who may not have an in-depth understanding of the design intent and setting, decisions could lead to misalignments. Furthermore, the fragmented approach of the sector, characterised by distinct phases of design, building, and operation, hinders the formation of a feedback loop for continuous development that could improve future projects.

8.3 Sub research question 3

In addressing the third SRQ, *“What responsibilities do various stakeholders have in relation to the energy performance of a building and what agreements and information exchanges are in place for this purpose?”*, it becomes clear that managing the energy performance efficiently relies on the roles and responsibilities among various stakeholders. These stakeholders, including the real estate developer, building physics engineer, advisors, general contractor, installer, digital building operator, expert smart building platforms, and commissioning manager, each have distinct roles that span from the initial phase through to the design, construction and operational phases of a building. In this regard, architects and engineers integrate energy-efficient designs, alongside installation and energy advisors are in responsible for advising and supervising the installation of sustainable energy systems that complement these designs. In order to make sure that building procedures follow predefined guidelines, general contractors supervise the integration of these energy-efficient components throughout construction. Moreover, the operational phase highlights the ongoing responsibilities of the installation and energy advisor, commissioning manager, and building operator to maintain system performance in accordance with design goals. They should also propose improvements in order to constantly optimise energy use based on real-time performance data. The energy management approach centres around comprehensive agreements and ongoing information exchanges that facilitate the sharing of responsibilities. In order to ensure that all parties are legally committed to meeting specific energy standards, legal contracts have the purpose of explicitly specify energy performance requirements. A collaborative environment is facilitated by regular exchanges of performance outputs and digital data platforms. This enables for ongoing improvements and maintains the commitment to the targets throughout the building lifecycle. Essential is the inclusion of performance-aligned incentives in contracts. The purpose of these incentives is to encourage stakeholders to meet the targets, promote proactive approach, and align their activities with overall energy efficiency objectives.

8.4 Sub research question 4

Finally, the fourth SRQ looks into: *“What operational and maintenance practices should be implemented to realise Paris Proof redeveloped office buildings?”* Both from the qualitative research and case study findings, it is evident that several strategic shifts are crucial. Enhancing collaboration and specialisation in operational tasks is crucial for effective building system adjustment and tuning. This includes using data from advanced systems for ongoing monitoring and modification based on feedback- and learning loops to match operating procedures with the benchmarks set by the Paris Proof effort, as well as implementing seasonal commissioning.

The Edge Olympic case study serves as an example of how seasonal commissioning, real-time monitoring, and operational adjustments turn out to be successful. Significant energy reductions were made possible by reorganising operating hours and zoning for multi-tenant use, bringing the building's energy use in line with Paris Proof standards. This real-world example shows how specialised operations and tailored strategies can significantly reduce the energy performance gap. Additionally, the qualitative research underscores the need for a paradigm shift towards operational frameworks that are more dynamic and data-driven, including digital twins that use AI and machine learning to improve the accuracy. The insights gathered emphasises the necessity of effective communication, ongoing stakeholder engagement, and training, along with the alignment of contractual incentives to promote energy-efficient practices throughout the lifecycle of a building. Collectively, these findings suggest the need for an effort to incorporate cutting-edge technologies, promote interdisciplinary collaboration, and enforce an operational and contractual framework to realise Paris Proof office buildings. These approaches not only aim to maximise energy efficiency but also support broader sustainability goals.

8.5 Main research question

In conclusion, this research aims to address the main research question: *"How can operation and maintenance-related energy performance gap in renovated office buildings be effectively addressed to meet the Paris Proof commitment targets?"* The findings indicate notable EPGs, largely attributed to inefficiencies in operational and maintenance procedures that fail to align with the design intent. In order to achieve Paris Proof requirements, a structured strategic roadmap has been created to overcome these inefficiencies and align operational processes with energy performance targets. The roadmap developed involves a redefinition of responsibilities and roles and more integrated stakeholder involvement. In order to guarantee that building systems are optimally adjusted to both seasonal changes and actual operating conditions, this strategy includes the introduction of pre-handover, initial aftercare, and seasonal commissioning. Furthermore, the implementation of continuous monitoring and feedback systems enables immediate modifications, immediately correcting inefficiencies. Another key aspect of the proposed improvements involves enhancing stakeholder collaboration and communication. This aims to ensure that all involved stakeholders, ranging from developers to digital building operations, have a shared understanding and commitment to the building's energy targets. The roadmap, summarised on the following page, additionally underscores the added value of trainings to guarantee that all operational teams are fully equipped to manage and maintain building systems effectively, thus sustaining the design intend and compliance with Paris Proof standards.

The strategic roadmap comprises several stages, each with steps aiming for renovated office buildings to meet their energy performance targets:

Stage 1: Business case

- Align stakeholders on vision and objectives.
- Define and document project objectives, performance criteria, roles, and responsibilities.
- Establish clear energy performance targets and legal terms.

Stage 2: Design development

- Develop and refine energy-efficient designs and conduct performance simulations.
- Ensure stakeholder input through regular reviews.

Stage 3: Construction

- Align construction practices with designed energy standards and perform compliance checks.
- Verify installation and energy efficiency standards adherence.

Stage 4: Pre-handover

- Conduct system tests and tuning to ensure operational efficiency.
- Develop digital tools for ongoing performance monitoring and finalise documentation.

Stage 5: Handover

- Inspect systems and conduct final verifications.
- Train operational teams and transfer essential energy management knowledge.

Stage 6: Initial aftercare

- Optimise systems based on actual occupancy patterns and perform continuous monitoring.
- Adjust operations based on performance data and document outcomes.

Stage 7: Operational phase

- Implement seasonal commissioning.
- Continuous data driven system improvements, integrating new technologies and responding to feedback.
- Documentation and records necessary for maintaining the Paris Proof standards.

9. LIMITATIONS & RECCOMMENDATIONS

9. LIMITATIONS & RECCOMMENDATIONS

9.1 Implications of future strategies

1. One single case study: The research relies on a single case study to investigate the EPG and associated challenges in renovated office buildings. Although the selected building provided valuable insights, this limited focus may not reflect the broader range of challenges faced across different types of buildings, regions, or ownership and tenant structures. The findings may thus lack generalisability to other contexts.
2. Limited interviewees: Interviews were conducted with ten participants, potentially affecting the representativeness of the data. Although participants were chosen for their expertise in energy management and building operations, their insights may not fully capture the diverse challenges and strategies present in different building types or organisational structures. A larger and more varied group of interviewees provides a wider range of perspectives and experiences, enhancing the research's applicability.
3. Time constraints: Due to the limited research period of a few months, the research has the potential to go more in depth on specific topics. A longer timeframe could offer deeper insights into the aspects of the EPG and how to address these.
4. Focus on smart buildings: The roadmap addresses buildings equipped with smart and advanced technologies. Consequently, the strategies may be less applicable to buildings lacking these systems, making it challenging to adapt the recommended practices. Future research should consider alternative strategies for buildings with limited technological capabilities to address the EPG across a broader range of building types.
5. Certification guidelines: The study references existing certifications such as Paris Proof and WEii which are set in the Netherlands. These standards and tools are not globally known and may undergo changes over time. Adapting to new guidelines might require additional steps not covered in the current roadmap.

9.2 Recommendations

1. Diversify of building types: Conduct research on additional types of buildings, including newly built office buildings and those not used for offices, such as retail, healthcare, and educational buildings. This could offer valuable insights into EPGs related to varying building functions, occupant behaviours, and challenges. Further insights could be obtained by focusing on buildings without advanced energy management systems in order to pinpoint particular problems and feasible solutions for improving energy efficiency in situations with less resources.
2. Different (re)development structures and cooperations: The research can be expanded by investigating how different companies or regions employ varied development structures and cooperation agreements, affecting energy management practices. Such agreements determine how stakeholders share information, coordinate responsibilities, and collaborate on energy efficiency strategies
3. Implement and test the roadmap: Implementing and testing the strategic roadmap in a real-world project gives the opportunity to evaluate its practical applicability. This will provide concrete feedback on its effectiveness in reducing the EPG and could offer opportunities for refining the roadmap to make it more suitable for varying contexts.

10.
REFLECTION

10. REFLECTION

10.1 Research topic in master track

When I started my research process, I was particularly interested in the theme of energy transition within the building sector due to its critical role in sustainability. Recognising the need for increased sustainability practices and the potential for energy savings in renovated office buildings motivated me to delve deeper into exploring this crucial aspect. By focusing on the EPG in the built environment, my graduation thesis aligns with the "Management in the Built Environment" master track as part of the broader curriculum of the MSc in Architecture, Urbanism, and Building Sciences at TU Delft, particularly within the chosen graduation lab of energy transition. The central concept of my thesis is its dedication to enhancing the built environments' sustainability and efficiency, a goal that has grown in significance over time in the management track. By examining operational and maintenance challenges along with developing a strategic roadmap to reduce them, this thesis is focused on addressing the EPG and applying management concepts to building science. The master program's integration of practical management solutions, including providing the possibility of conducting my research within a company, demonstrates the connection between academic research and practical application. By applying scientifically confirmed approaches and promoting sustainability and efficiency in urban development, the research advances the field of a sustainable built environment and supports the educational goals of TU Delft.

10.2 Research design

The initial phase of this thesis involved a review of excising literature, which revealed significant operational inefficiencies and discrepancies between predicted and actual energy performance in renovated office buildings. This awareness impacted the need for a restructured process approach and contributed in the development of a strategic roadmap. These findings had an impact on the further research design, which focused on optimising maintenance and operating procedures. By employing a combination of both qualitative and quantitative methods, including expert interviews and a case study analysis, the study provided greater understanding of current challenges. This approach influenced the recommendations, narrowing them on important areas such as enhancing stakeholder collaboration, commissioning, energy monitoring and tuning. The development of the recommendations, in turn, influenced following phases of the research. The dynamic process between the formulation of recommendations and the ongoing improvement of research goals ensured that the roadmap was supported by empirical findings and in line with practical needs.

10.3 Research process

When evaluating the effectiveness of the used methodology, several aspects of the approach now stand out as being particularly valuable in conducting my research. For example, the interviewing method functioned as intended, supporting the reliability and consistency of the qualitative data collected. Notably, a potential problem of experts declining to participate was taken into consideration in advance, nevertheless, all approached experts agreed to participate immediately, streamlining the data collection process and enriching the research with diverse expert insights without delay. The analysis of the interview data brought to light the evolutionary nature of research methodologies. At first, the analysis revealed less specific results that gave a general idea of the subjects covered. Recognising the need for deeper insight, a more detailed second analysis was conducted. The progressive approach ensured that the findings improved the quality and application of the conclusions for each subject and each interviewee.

As part of the research approach, the case study had an important role in understanding the practical aspects of the EPG in renovated office buildings. However, obstacles where identified when accessing the data needed. The access to the necessary data took longer than expected, influencing the planned schedule and forcing a focus of shift in order to other sections of the thesis. After receiving the detailed data gathered over multiple years, unexpected insight where noted into aligning theoretical predictions with practical outcomes. This disconnection demonstrated the frequently overlooked difficulty of translating theoretical models into practical settings, making it not feasible to define the EPG in this particular case study. It nevertheless managed to offered a valuable lesson in the limitations and potential adaptations needed in energy performance research. All in all, I discovered that while a structured approach needs to be established in advance of a research process, it is also important to allow flexibility to account for unforeseen circumstances.

10.4 Research planning

The planning of my research involved a structured timeline that spanned several key milestones, each essential to the development and completion of the thesis (appendix 12.6). My graduation preparations was initially planned to start in September until February with the actual graduation, including the internship, from February until June. To dedicate more time to my thesis, I decided to start my internship earlier in November. This early involvement with the company improved the understanding and foundation of my thesis and enabled me to learn the company's organisational culture and operations earlier.

After the preparatory phase (P2), I immediately started the applied research, which involved conducting semi-structured interviews. This step was more time-consuming than expected, especially the tasks of transcribing and coding the interviews. I experienced the period from the midterm to the green light presentation (P3 to P4) as more stressful, as it involved translating all research findings into coherent and understandable outputs. The specific feedback to my P3 presentation helped to set structured targets for this phase. This feedback had an important impact in giving my work a systematic approach, directing the last phases of my thesis, and ensuring that the outcomes were not only insightful but also methodically presented. It helped me to focus on a specific sections and tasks without focussing on others at the same time. This systematic timeline and the adjustments made along the way were important in accommodating the complexities of the research.

10.5 Research results

The academic and societal value of the thesis primarily lies in its contribution to the knowledge on sustainable building practices. Academically, the research aims to address the EPG, shedding light on operational inefficiencies and providing an understanding of the factors contributing to the disparities. The development of a strategic roadmap grounded in empirical data enhances the scholarly discussions around energy efficiency and sustainability in the built environment and aims to create awareness. Through an examination of the energy efficiency improvements made to an existing project, the case study seeks to project direct implications for similar projects. However, it should be noted as done in section 9.1 that the scope is especially focused on redeveloped office building equipped with smart technologies, limiting the application to other developments. Also, some of the methods used, including Paris Proof, are introduced in the Netherlands and not known world-wide.

Ethically, all participants were informed in advance and voluntarily contributed to the research, ensuring the confidentiality and accuracy of the data used. This ethical commitment supports the research's credibility and is consistent with larger social principles that support individual rights. The research results aim to significantly contribute to the subject of sustainable building management by providing valuable insights and actionable strategies by publishing the report the TU Delft repository.

10.6 Research feedback

Assessing the transferability of the results from my graduation project, it becomes evident that the topic is concentrated on a specific area within the built environment. The focus on EPGs in renovated office buildings is a niche yet crucial aspect of building science, which can sometimes be less accessible to those not familiar with the field. In order to mitigate this and improve understandability, the literature research intends to establish a foundation that would be comprehensible to a wider audience, regardless of their expertise. Moreover, in developing the strategic roadmap, a comparisons with existing and proposed practices in the field is provided with the purpose of giving more insights. By aligning the new insights with familiar concepts and practices, the transferability of the results are enhanced, making them applicable and valuable for a broader audience.

10.7 Personal reflection

Reflecting back on my journey through this graduation research, I notice that I have been deeply enriched in experience and knowledge, both academically and personally. Undertaking a project wherein I was in charge of the direction and planning taught me lessons about structured working, developing strategies to keep track of progress and determining what needed to be done next. Initially, the wide scope of the EPG made it challenging for me to define a focused direction for my thesis. Nonetheless, through engaging in informal meetings and conducting literature reviews, I learned the importance of narrowing down my focus to specific areas that required deeper investigation. The interview phase of the research was especially rewarding, as it not only validated many theoretical aspects I had studied but also enriched the research with new insights. In terms of gathering data, this phase was remarkable since it allowed for direct interaction with the topic and determined the direction of the study. The most demanding and challenging part of the research was transitioning from P3 to P4, as I had to thoroughly synthesise all of the data and clearly translate the conclusions into recommendations. Despite the pressure, this phase proved to be the most rewarding. As I worked through and presented the findings of the research I had been invested in for so long, I experienced a sense of accomplishment. This project was not just about gaining knowledge in the field of energy efficiency but also about discovering my own capacities and resilience in managing and executing a significant academic research.

11.
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11. REFERENCES

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12. APPENDIX

12 APPENDIX

12.1 Informed consent letter

Date

Dear participant,

You are being invited to participate in the thesis research titled ‘Building the future, measuring the present’. This study is being conducted by Feline Dupuits, a master's student in Management in the Built Environment at TU Delft. The research is being carried out in collaboration with the graduation internship company Edge.

The thesis research focuses on improving the energy efficiency of buildings, particularly addressing the gap between predicted and actual energy performance during the operational phase of energy-neutral office buildings. The aim of the research is to tackle the challenge of the energy performance gap by identifying operational-related issues. The ultimate goal is to develop a roadmap implemented during the design phase and extending to post-completion monitoring, aiming to address the identified gap. The study will take approximately 45 minutes, during which I will seek your insights and experiences in this field, starting with the identification of problems and challenges, followed by improvement needed.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions. I assure you that your data will be handled with care, and it will be stored on a secure server with an additional password for enhanced security. In the processing of the interview, only your function will be mentioned; further personal information will be fully anonymised, including any projects and other companies that may be mentioned.

If you have any questions about this research, please feel free to contact me: Feline Dupuits. If you wish to participate in this study, would you please complete and sign the attached statement?

Kind regards,
Feline Dupuits

	Yes	No
(1) I have read and understood the study information dated [*DD/MM/YYYY*], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
(2) I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
(3) I understand that participating in this study means that my answers will be kept and that the audio material (or its editing) and other collected data will be used solely for analysis and scientific presentation and publications.	○	○
(4) I understand that the stored data is kept under a code and processed anonymously	○	○
(5) I agree that my responses, views or other input can be quoted anonymously in research outputs	○	○
(6) I understand that the research outcomes and final thesis will be published in the TU Delft repository	○	○
(7) I hereby give separate permission that the anonymized data may also be used by other researchers in the future.	○	○

I have read this form or the form and I agree to participate in the study.

______________________ ______________________ ______________

Name of participant Signature Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

________________________ ________________________ ______________

Name of researcher Signature Date

12.2 Semi-structured interview questions

Introduction and background:

- Can you briefly describe your role and responsibilities?
- What is your expertise in the field of renovated office buildings and the challenges associated with achieving Paris Proof energy performance?

Calculations and certifications:

- How familiar are you with the concept of the energy performance gap, i.e., the difference between the expected energy performance in buildings compared to the actual?
- How is the energy performance of buildings currently calculated theoretically? What methods are used and how does this work?
- Which certifications currently play a significant role, and how are they awarded?
- To what extent do energy-related certifications influence the process of implementing energy efficiency measures?
- From your perspective, what do you consider to be the main factors influencing the energy performance gap? Do you see more challenges in renovated office buildings?

Causes and challenges:

- In your opinion, what is the main cause and/or challenge in achieving the set energy performance goals?
- To what extent do you think incorrect operations of energy systems and monitoring have a negative effect on energy performance and contribute to the performance gap? If so, what problems have you observed?
- Can you provide examples of current operational practices related to the management of energy systems?
- Can you share specific examples where incorrect operational or monitoring practices have led to energy inefficiencies in a building?

Collaboration and responsibilities:

- How would you describe the collaboration and influence of different parties (e.g., building operators, developers, owner, tenants, energy supplier) involved in the energy performance of a building and how is this currently organised?
- Based on your experience, how well are the energy performance goals (Paris Proof) and expectations communicated and understood by different teams involved in managing and monitoring the energy of buildings? Do you encounter problems in collaboration?

Operations and monitoring:

- Are the energy performances of buildings currently monitored? If so, how often does this happen and for what purposes is it used?
- Are there specific tools or technologies used to identify deviations from expected energy performances? Are any tools or technologies missing?
- Is there a monitoring or feedback system in place for identifying and correcting energy performance problems?
- How are lessons from practice integrated to improve future energy performance and achieve Paris Proof?
- Are there currently trainings provided related to energy efficient use of energy systems?
- Do you think there is a need for more specialised training in this area?

Future strategies:

- Are there existing guidelines from development to use phase to address energy-efficient operational practices?
- Are these guidelines effectively implemented? What is missing and what needs to be improved?
- Given your expertise, what strategies would you propose to effectively address the energy performance gap with respect to operational and monitoring practices?
- What recommendations would you make with regard to the development of a roadmap including the role of specific stakeholders?
- Are there emerging practices or technologies that you believe can significantly improve energy efficiency in the management and maintenance of buildings?

12.3 Data plan

As outlined, this research will be based on semi-structured interviews combined with a case study of a renovated office building, using data on energy consumption that has been collected for a minimum of one year. The method starts with a review of the literature, delving into the collection of information already existing to develop an in-depth understanding of the variety of factors influencing the performance gap. As part of the empirical research, qualitative semi-structured interviews will be constructed, using ATLAS.TI and Excel for the coding and analysing. Subsequently, quantitative data collection will focus on data about energy consumption and efficiency. To collect this data, advanced technologies such as sensors, smart meters, and building energy management systems will be used. Data collected from various sources for this research are accurately cited in accordance with APA 7th edition guidelines, enhancing the findability and credibility of the utilised sources. Regarding availability, the thesis reports will be published in the TU Delft repository as the research is a thesis affiliated with the Technical University of Delft.

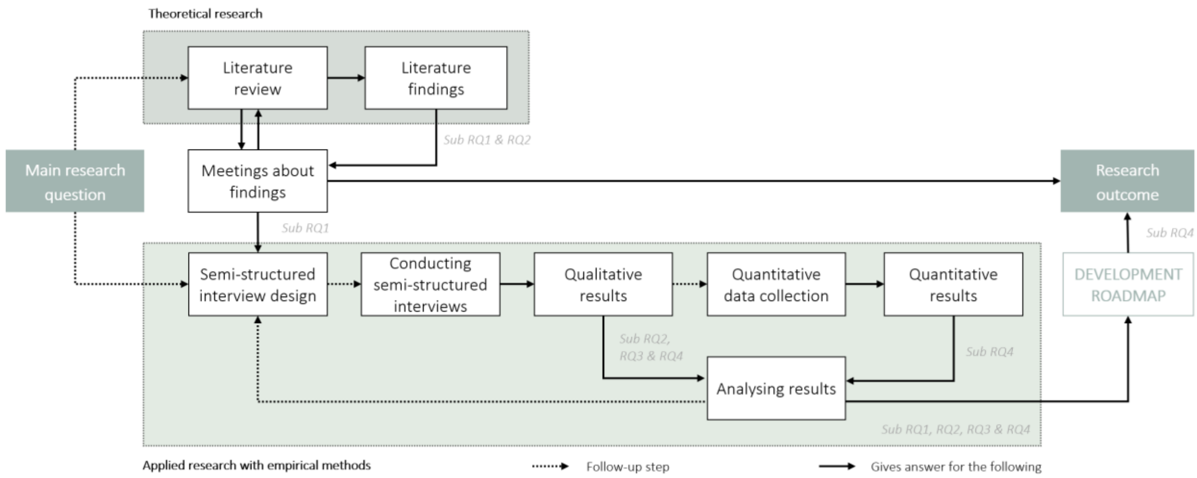

Figure 35: Research process from the research question to the research outcome

12.4 Ethical considerations

This thesis involves a research, employing a two-phase approach incorporating qualitative and quantitative data collection. The ethical considerations are guided by principles aimed at safeguarding the rights and well-being of all involved parties. Prior to data collection, informed consent processes will be implemented, ensuring participants understand the research's purpose, potential impacts, and their right to withdraw. Moreover, steps will be taken to safeguard privacy, including anonymising and aggregating data to prevent the identification of individuals. Maintaining the integrity of the research requires a strong commitment to accurate and high-quality data. A key component will be transparent reporting that addresses any constraints or uncertainties related to the data. Efforts will be made to mitigate potential biases in both quantitative and qualitative data throughout analysis and interpretation, once they are acknowledged. An essential component of this research's ethical approach is transparent reporting. The procedure of integrating data will be explained, enhancing the credibility and reproducibility of the results. Findings will be communicated back to the people involved, fostering a collaborative relationship that extends beyond the research framework.

12.5 Goals and objectives

This explanatory mixed-methods research aims to address the disparities between computer-based energy performance predictions during the redevelopment phase and the actual usage in the operational phase of office buildings. The scope is on renovated office buildings aiming at Paris Proof given the problems that could arise when the promised performance is not in alignment with the predictions. In order to achieve this goal, the research evolves with numerous interconnected goals and objectives. Addressing the disparities caused in the operational phase is the initial objective. This involves identifying the gaps that currently exist. To do so, an literature review is conducted as part of the research. This literature review will provide the foundation for comprehending the current state of the performance gap. Moving forward, the research aims to analyse the main factors that contribute to the observed performance disparity. This entails an analysis and classification of the many factors impacting the disparities, including incorrect energy management. The analysis will specifically be focused on the operation and maintenance since it is impactful for the energy efficiency. Certifications, including BREEAM-NL and Paris Proof, will be used as a benchmark. As a standardised indicator prominently displayed on buildings, these labels communicate expected energy performance to various stakeholders. They serve as a translation between theoretical energy models and real-world outcomes and foster transparency.

12.6 Main milestones

The whole process is structured through five phases, divided into 5 P's, to systematically develop the research. The first phase, which starts with P1, entails a literature analysis to identify the research gap and understand the global relevance of the energy performance gap. The literature review emphasises the challenges during the operational phase, with a particular focus on challenges related to operation and maintenance. Moving on to P2, a crucial milestone is reached with the formulation of research questions focusing on disparities between energy performance predictions and actual usage in redeveloped office buildings. Sub-questions delve into influencing factors and operation and maintenance-related disparities. In addition, a key component of P2 is the research methodology, which uses a mixed-method approach to combine qualitative and quantitative techniques. In this phase the Paris Proof redeveloped office building is selected as the case study. Based on the available data of the case study, the data collection and analysis will be developed. As shown in figure 36, the actual research starts after P2 since the preparatory work has been done. The P3 phase is dedicated to progress evaluation, ensuring that the working method aligns with the requirements for the subsequent P4 phase. A data plan describes the FAIR-compliant handling and distribution strategy for research data. Ethical considerations include informed consent, privacy safeguards, and transparent reporting to ensure the integrity and protect the rights and well-being of all parties involved. The use of a mixed-method approach in the research methodology represents a significant milestone, incorporating qualitative and quantitative methods. The case study, using advanced technologies serve as an important source for the data collection. An important milestone to be reached is the completion of the study output, which includes findings from the literature review and case study, an analysis of contributing factors, and development of practical strategies. Transitioning to P4, the research is finalised into a document with the P5 including the final presentation. The research plan, clarified in the conceptual framework and data loop, is strategically designed across the 5 P's to deliver valuable insights and practical strategies for effectively addressing the energy performance gap in Paris Proof redeveloped office buildings.

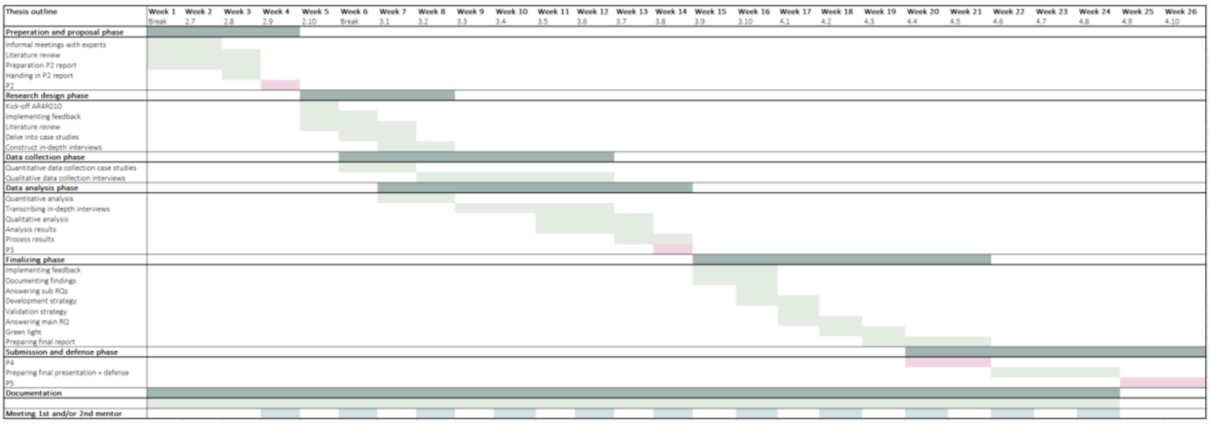

Figure 36: Research schedule

12.7 Analysis interviews

12.7.1 Calculations & certifications

Quotes:
Interviewee 2: BENG does not match the actual energy consumption, and this is where most projects fail. Promises are made based on tools that are not intended for this purpose. When it comes to energy consumption, you need to critically consider when to use which tools. And if we're talking about actual energy consumption, yes, you then need to deploy different tools. So, you need to use tools that help you set up an energy model and define the entire user profile.

Interviewee 2: Regarding terms like energy-neutral, climate-neutral, CO2-neutral—these concepts are often used indiscriminately without assigning the correct value; for BENG energy-neutral, yes, that's only possible, you can never monitor it. So in that sense, I am happy with Paris Proof because it concerns the actual energy consumption on the meter. And I also advocate for agreeing on values upfront that can indeed be monitored.

Interviewee 2: You can never pinpoint the last decimal in a theoretical model, and there will always be some discrepancy. Yes, these are all assumptions that might disappoint in practice.

Interviewee 3: If the energy calculation for a building is 0 kWh/m² and the requirement is 70 kWh/m², then Paris Proof is achievable with 20-25 kWh/m² and also with 40 kWh/m².

Interviewee 3: Paris Proof has a significant advantage in that it is very concrete and looks at the actual energy consumption on the meter, unlike the theoretical calculation of BENG and how energy-efficient the building is, since BENG is not really a good predictor of energy.

Interviewee 3: A problem is actually the fixed standards and guidelines and the programs of requirements.

Interviewee 4: So everything we calculate at the front end is an estimation, but that's not yet Paris Proof. In that methodology calculated, that's the expectation of what it should be, but a building is Paris Proof when the meter actually shows it when in use.

Interviewee 4: So the connection between the digital building model and the ambitions and how the building actually performs in terms of technology, because technology has grown so exponentially in buildings in recent years, partly due to the sustainability drive. The knowledge that is always required for this, from the initial process to exploitation

Interviewee 6: The NTA 8800 is the methodology for BENG requirements. Well, if you use that method to estimate your energy usage, you will completely miss the mark, so we definitely need a model at the forefront that can make realistic predictions about energy usage.

Interviewee 6: The WEii (actual energy intensity indicator) aims to ensure that we can express measured consumption on the meter in a very simple way.

Interviewee 7: A BENG calculation is a very crude methodology that is not really intended to predict actual energy consumption. But from that result, we could see such a large gap between the threshold for Paris proof and the result of that calculation, we said, well, we don't need to make complicated simulations; this will probably be fine.

Interviewee 7: These calculations should be given less priority, and more should also be put on monitoring and adjusting and improving. If you focus more on that, those very expensive calculations and simulations at the beginning, which are now too complicated and expensive, are also not necessary.

Interviewee 7: A BENG calculation is a first rough calculation that shows it's going to be close, whether you will meet the threshold value, yes, then I think a discussion will arise about whether we need to calculate it more precisely.

Interviewee 7: A BENG calculation for your environmental permit application, and that is really a standardised methodology to arrive at a certain score or a certain number which has something to do with energy. But those are all tools that are not really made to predict real reality.

Interviewee 7: I think if you collect enough data about energy use and you link it nicely to properties of buildings and what kind of user is in it, at some point we will get to the point where we don't even need to make a simulation; we can just ask based on that data, I have this building and maybe linked to all those developments with AI and such, you could just write in Google rules, I have this building with this user, what will my energy use be approximately?

Interviewee 7: Look, in that sense, the BENG calculation is also based on a publication that already consists of 1000 pages. So it's not all nonsense, so to speak, but a lot of parameters are kind of fixed, so the calculation assumes the standard user who you can hardly adjust in that calculation. Look, such a dynamic simulation, then you can adjust things as you want. Usage times, the number of people in a building, that kind of stuff, but in a BENG, all of that is fixed, so that's not a variable.

Interviewee 7: But how can we use such a calculation to also make a prediction about what will actually happen in reality? What you will eventually read on your energy meter—with these kinds of issues, we have been engaged much longer, but because the software we use for that is so labour-intensive as I might describe, and often expensive too. It also takes a lot of time for developers like Edge or other parties, who are quite cautious in using that kind of software. Really, yes, dynamic simulations to make that prediction, especially since it's about tens of thousands of euros for such a calculation. So, we are still a bit looking for how we can make a prediction but also keep time expenditure limited.

Interviewee 7: We never want to communicate just one number, but always, yes, calculate different scenarios so that you also make it clear to a client about where it will approximately fall between.

Interviewee 8: A building is designed based on general principles and guidelines, and it is usually unknown how the building will be used, with which fabrics, which systems, which air handling unit, and what capacity. Each building is unique and does not meet the same guidelines and principles.

Interviewee 9: BENG or NTA 8800 is a fine tool, but yes, our argument has always been that you need to use it together, it cannot stand alone. You need to consider it along with the actual energy use, and by looking at both, you can also learn something about how your building truly performs.

Interviewee 9: WENG, therefore, is a WEii score of zero. Then you set it to actual neutral in that sense, and following that is Paris Proof, which for an office is 70.

Subtopic	Insights	Mentioned by Interviewee 1
Inadequacies of NTA 8800	The interview does not explicitly discuss the inadequacies of NTA 8800 calculations directly. However, it mentions challenges in energy performance predictions and the gap between expected and actual energy usage, implying a critique of current standards and methodologies.	No
Advantages of WEii	The interview explicitly discusses the transition of Olympic from 105 kWh/m² to 68 kWh/m², illustrating the building's achievement of Paris Proof standards and emphasising the focus on actual energy consumption data and improvements to achieve these standards.	Yes
The role of dynamic simulations	The interview details the use of data-driven approaches and continuous commissioning to adjust building operations to real-time data, which aligns with the concept of using dynamic simulations or models to predict and improve energy performance.	Yes
Shift towards data-driven predictions	The interview extensively discusses the utilisation of real-time data, monitoring, and digital twins for building operations and energy management, emphasising a significant Shift towards data-driven predictions and operations for optimising energy performance.	Yes
Communication of energy performance predictions	The interviewee discusses the communication and analysis of energy usage data, including the sharing of this data with stakeholders (e.g., for ESG reporting) and the use of data for operational decisions. While not directly addressing the Communication of energy performance predictions, the practices mentioned suggest a nuanced approach to sharing and utilising energy performance data.	Indirectly

Subtopic	Insights	Mentioned by Interviewee 2
Inadequacies of NTA 8800	The interviewee discusses the limitations of current tools like BENG and EPC for accurately predicting real energy consumption, emphasising that these tools show normed energy use rather than actual usage, which often leads to discrepancies in energy performance expectations vs. reality.	Yes
Advantages of WEii	The interviewee does not explicitly discuss the concept of Paris Proof. However, the importance of actual energy consumption data and focusing on achieving real energy consumption targets, rather than just meeting theoretical standards is mentioned. The interviewee points out that actual consumption is what matters and should be the basis.	No
The role of dynamic simulations	The necessity of using advanced tools that closely mimic real-world conditions and energy consumption patterns is highlighted, as opposed to relying on standardised calculations that may not accurately predict actual energy use.	Yes
Shift towards data-driven predictions	The interviewee discusses leveraging real data for monitoring and predicting energy consumption, emphasising the shift towards a more data-driven approach in energy performance assessment and the potential benefits of using detailed energy models and user profiles for more accurate predictions.	Yes
Communication of energy performance predictions	The interviewee emphasises the importance of clear communication about energy performance and expectations, especially the need to understand the limitations of predictive tools and the importance of setting realistic expectations based on detailed analysis and actual data.	Yes

Subtopic	Insights	Mentioned by Interviewee 3
Inadequacies of NTA 8800	The interviewee discusses the gap between simulation and reality, noting that all simulations tend to produce different outcomes. The importance of what is input into models (garbage in, garbage out) is emphasised, highlighting the limitations of current standards and tools in accurately predicting real energy use.	Yes
Advantages of WEii	The Paris Proof model is mentioned as a benchmark for project evaluations, focusing on achieving real energy consumption targets. This model is contrasted with the theoretical and normative standards like BENG, suggesting that Paris Proof's focus on actual metered energy use offers a more accurate and achievable standard for buildings.	Yes
The role of dynamic simulations	The interviewee describes dynamic simulations as essential for optimising building energy performance but also acknowledges the challenges in bridging the gap between simulated outcomes and actual building performance. The discussion implies an acknowledgment of the value of dynamic simulations while also pointing out their current limitations.	Yes
Shift towards data-driven predictions	The conversation heavily features the use of digital twins, AI, and data analytics for monitoring and predicting building performance, indicating a significant Shift towards data-driven predictions. The interviewee's role in digital program management and the focus on data utilisation for energy optimisation directly support this theme.	Yes
Communication of energy performance predictions	This subtopic is not explicitly mentioned. However, the importance of accurately communicating and setting realistic expectations around energy performance is mentioned.	No

Subtopic	Insights	Mentioned by Interviewee 4
Inadequacies of NTA 8800	Discusses the gap between simulation and reality, emphasising the importance of real data over theoretical models for predicting energy performance, and the challenges of adapting these standard approaches to individual building characteristics.	Yes
Advantages of WEii	The focus is on achieving real, measurable energy consumption targets. While Paris Proof is not directly mentioned, the emphasis on real-world energy consumption is mentioned, advocating for more realistic and achievable standards.	No
The role of dynamic simulations	Mentions the potential of using detailed models and data for predicting and managing building performance, suggesting an appreciation for dynamic simulations, though noting the industry's current limitations in fully utilising such technologies.	Indirectly
Shift towards data-driven predictions	Strongly advocates for a data-driven approach in energy management and building operations, emphasising the role of digital models, AI, and analytics in achieving energy efficiency and reducing the performance gap.	Yes
Communication of energy performance predictions	Not explicitly discussed, however, the connection between the digital building model and the ambitions and how the building actually performs in terms of technology is emphasised	Indirectly

Subtopic	Insights	Mentioned by Interviewee 5
Inadequacies of NTA 8800	The interviewee did not specifically address criticisms of NTA 8800 calculations.	No
Advantages of WEii	Paris Proof was directly mentioned, highlighting its significance in aiming for real energy consumption targets and the importance of monitoring to achieve this. The approach focuses on actual metered energy usage, offering a more accurate metric for assessing a building's energy performance.	Yes
The role of dynamic simulations	While not explicitly mentioned, the emphasis on the need for accurate monitoring and data-driven adjustments suggests a tacit endorsement of the kind of detailed modelling that dynamic simulations could provide, especially in terms of optimising building operations to actual conditions.	Indirectly
Shift towards data-driven predictions	There is a clear shift toward data-driven predictions through the discussion of monitoring and the use of data analytics for energy performance. The importance of detailed energy data for both building-bound and user-bound energy considerations is emphasised, highlighting the move towards leveraging data for energy performance estimation.	Yes
Communication of energy performance predictions	The need for clear communication about energy performance, especially the challenges in managing expectations around energy use, is implied through the discussion on the discrepancies between projected and actual energy consumption. While not directly addressed, the emphasis on monitoring and data suggests a nuanced approach to communication.	Indirectly

Subtopic	Insights	Mentioned by Interviewee 6
Inadequacies of NTA 8800	Directly addresses the limitations and inaccuracies of models like NTA 8800, indicating that they often result in an overestimation of energy use, which leads to a discrepancy between expected and actual energy consumption.	Yes
Advantages of WEii	The discussion on focusing on actual energy consumption and the mention of the WEii indicator advocated for real consumption metrics.	Yes
The role of dynamic simulations	The role of dynamic simulations is not mentioned explicitly. The discussion is more focused on the inadequacies of existing models.	No
Shift towards data-driven predictions	Emphasises the shift towards using real data for monitoring and prediction, including the development of software to analyse smart meter data for insight into building performance, indicating a strong move towards data-driven energy performance predictions.	Yes
Communication of energy performance predictions	Discusses the importance of communicating realistic expectations and the actual functioning of systems to users and maintenance teams by touching on the communication aspect by highlighting the gap between design intent and operational reality.	Yes

Subtopic	Insights	Mentioned by Interviewee 7
Inadequacies of NTA 8800	Interviewee 7 noted the limitations of BENG calculations, emphasising that they are not designed to accurately predict real-world energy consumption. The standardised methodology, while useful for certifications like BREEAM, does not adapt well to the unique characteristics of buildings, leading to discrepancies between predicted and actual energy use.	Yes
Advantages of WEii	The focus on actual energy consumption measured at the meter is praised, distinguishing Paris Proof from more theoretical models. This approach provides a more realistic assessment of a building's energy performance.	Yes
The role of dynamic simulations	Dynamic simulations offer a promising solution for accurate energy performance predictions by being adaptable to specific building characteristics. However, the high cost and labour-intensive nature of these simulations limit their widespread use. Interviewee 7 expresses concern over the practicality and affordability of dynamic simulations for stakeholders like developers.	Yes
Shift towards data-driven predictions	Leveraging extensive data on energy usage and building characteristics could allow for accurate predictions without complex simulations. The potential for AI and machine learning to predict energy consumption is highlighted as a future direction that could offer both accuracy and efficiency.	Yes
Communication of energy performance predictions	Interviewee 7 stresses the need to communicate a range of potential energy use scenarios to stakeholders, rather than a single one, acknowledging the inherent variability and uncertainty in energy performance predictions.	Yes

Subtopic	Insights	Mentioned by Interviewee 8
Inadequacies of NTA 8800	Discusses the complexity and the limitations of the BENG calculations and how these standards do not fully account for real-world energy use, highlighting the need for dynamic and more comprehensive modeling approaches to accurately predict building energy performance.	Yes
Advantages of WEii	The advantages of WEii calculations for Paris Proof are not mentioned. The interviewee points out the lack of a strict definition and challenges in applying it in practice due to its focus on real consumption, which cannot be predicted accurately at the design stage.	No
The role of dynamic simulations	Shortly highlights the importance of dynamic simulations for more accurate predictions but notes the industry's hesitancy due to the high cost and complexity, as well as a general lack of demand for such detailed analysis in the planning stage.	Indirectly
Shift towards data-driven predictions	The interviewee does not mention the Shift towards data-driven predictions, however highlights the current reliance on BENG and the need for a broader approach that accounts for actual energy use.	No
Communication of energy performance predictions	The interviewee points out the challenges in communicating energy performance expectations due to varying definitions and expectations of what constitutes energy neutrality or efficiency, suggesting a need for clearer communication and understanding among all stakeholders.	Yes

Subtopic	Insights	Mentioned by Interviewee 9
Inadequacies of NTA 8800	The interviewee discusses the mismatch between theoretical energy use calculations, such as those done for BENG, and actual energy consumption. The current standards are not sufficiently aligned with real-world energy usage, indicating a fundamental issue with the fixed parameters used in these calculations.	Yes
Advantages of WEii	The interviewee mentions the need for focusing on actual energy use, and suggests a positive view towards approaches like Paris Proof that Emphasise real energy consumption.	Yes
The role of dynamic simulations	The interview does not explicitly mention the role dynamic simulations. However, he/she mentions the increasing complexity of buildings in modern buildings, emphasising expertise and knowledge sharing.	Indirectly
Shift towards data-driven predictions	The development of the WEii certification and discussions around actual energy use suggest a shift towards more data-driven approaches in energy performance assessment. By focusing on the actual energy consumption and developing certifications around it, there's an implied advocacy for leveraging real-world data over theoretical predictions.	Yes
Communication of energy performance predictions	There is an indirect mention of the challenges in communicating energy performance, especially in the context of establishing a common understanding and language around actual energy use versus theoretical predictions. The development of WEii and discussions around its implementation suggest a need for better communication and standards in energy performance predictions.	Indirectly

Subtopic	Insights	Mentioned by Interviewee 10
Inadequacies of NTA 8800	The interviewee discussed the gap between theoretical energy predictions and actual consumption, emphasising that current standards like BENG don't align well with real-world energy use. The conversation also touched on the complexities of such calculations and the need for adjustments to more accurately reflect actual energy consumption.	Yes
Advantages of WEii	WEii's emphasis on actual energy consumption was mentioned in the context of creating more sustainable buildings. The interviewee highlighted efforts to develop and manage green building certification systems that focus on actual energy use, reflecting a positive view towards Paris Proof-like standards that prioritise real-world energy performance over theoretical models.	Indirectly
The role of dynamic simulations	While not directly mentioned, the need for predictive tools that can offer realistic forecasts of energy use was implied. The conversation suggested an understanding of the limitations of current predictive models and a desire for methods that better account for actual building operations and user behaviour.	Indirectly
Shift towards data-driven predictions	The discussion around certifications based on actual energy performance and the development of new methods to assess real energy use indicates a shift toward data-driven approaches and predictions in energy performance assessment.	Yes
Communication of energy performance predictions	The need for clear and accurate communication about energy performance expectations was indirectly mentioned.	No

12.7.2 Causes & challenges

Quotes:
Interviewee 1: The unpredictable usage is the plug load of the tenant. A guarantee cannot be given blindly without making agreements to know what needs to be monitored.

Interviewee 1: Until the building is delivered and fully fit out, many things have changed in the structure now from different parties of development, thus the design, build, operate, and maintain phase, you see at that moment that these phases barely overlap. The companies involved in development tend to pay less attention to the operational phase. The manager really doesn't understand anything about the building and how it was conceived and such matters. But what a maintenance party often does is set up the building once and then it has to figure out for itself how to be most efficient. And there lies a mistake. Simulations assume average work patterns for example, which are entered, and in practice, you just have peaks and troughs in usage and so on, so there is always a wider spread.

Interviewee 2: The biggest challenge I find in a design process is that you are primarily focused on the building-bound part. So you optimise that, whether it's heating, cooling, lighting. And I can say that we really have that under control together. Afterward, you see that so much happens in the area of interior and equipment that comes along. And yes, we are not involved in that level of detail in all projects, but because of this, energy consumption can completely go off the rails. And then it's often user-related.

Interviewee 2: The developer develops buildings and partly these are of course resold to investors or transferred to investors, and with that, well, the involvement partially ends right there, and then the ball is in another party's court who have no background knowledge about the front end of the project.

Interviewee 2: It's a challenge that at the beginning of the process the user profile might still be uncertain, and not enough can be said about it because it's not sure which tenant will come in or what exactly is expected from the user.

Interviewee 2: But you do miss a piece there, and ideally, you would also monitor the years after delivery, to see how it's running now? What are all those tenants doing in it now? And yes, in my opinion, there's insufficient... that step from delivery to operation? Yes, there's also a certain gap in the sense that, you've been involved as a design team and developing parties for years in that whole process and then you deliver it and in essence it's then suddenly over, yes that. That's also something that occupies us, how can you get more control over that?

Interviewee 2: At some point, a manager becomes the point of contact for a tenant, right? They have to organise everything. Yes, and they often have absolutely no knowledge of the entire pre-process and which choices have been made and what to watch out for, and that's where you see it go wrong. There's just too little knowledge, and as a result, energy consumption ultimately shoots up, right? Because there's no knowledge and you don't know what needs to be driven and insufficient analytical knowledge, like a problem and what could then cause it.

Interviewee 4: Each building has its own DNA and is unique. A multi-tenant building is then structured differently than a single-tenant building.

Interviewee 4: You can simply see that traditionally, a building development process, or actually the entire lifespan of a building, is divided into transactions and transfers of responsibilities between parties.

Interviewee 6: The shelf life of informing people, and well, just half a year later, a while later, most people have forgotten what the instructions were.

Interviewee 6: The city is a bit of the design, and subsequently, there is also the understanding of those who use the operating building, and that is also very important. What I see on the subject side is that there are very smart designs, but they are not busy making a smart installation that is understood by everyone. So they are actually not focused on the goal.

Interviewee 6: Bringing theory and practice closer together. I now also see in the built environment that they are in two completely separate worlds. People who are calculating buildings and have a lot of insights into how systems should behave. And people who are measuring and do not use the theoretical basis for how they should interpret the monitoring.

Interviewee 6: Those perverse incentives can be because it's in the contract that there are maintenance contracts, making a maintenance party benefit from regularly letting faults occur.

Interviewee 6: The problem is often exacerbated by the fact that the building owner and/or users are not aware of the potential misery that may exist within their building. Due to lack of monitoring, they may not even realise that there could be a problem, let alone that they actually have one. So, I always refer to it as the difference between the headache and the paracetamol. The vast majority of the Netherlands actually suffers from latent headaches, but they don't feel them because there is no awareness due to the lack of proper monitoring and no frame of reference. So what you see is that parties have climate complaints and malfunctions and energy use are just compared with how it was last year and how it was two years ago.

Interviewee 6: Maintenance parties come from another building and they are used to dealing with that installation and always with those water temperatures. Well, if such a person comes in and is not instructed what he may and may not do, well then he's going to turn the knobs and make wrong settings because suddenly he's dealing with things he doesn't understand. And then, well, then we're talking about someone who has a network designed there, then it's no longer a service technician, but then it's become a disturbance technician. Then he's just messed everything up and you see that also in a lot of buildings. That people well-intentioned have been turning a knob. But the whole thing is disordered. And well then, then you never see those buildings come back to where they once started.

Interviewee 6: What I see, for example, in monitoring is that people are monitoring but they have no reference frame of what it should have been. They monitor from the time it was renovated and the reference frame is that they look back a year each time, have I gotten a bit better or a bit worse? But they have no reference frame.

Interviewee 6: We are not a sector that is learning, because in our sector there are parties that are designing. There are parties building and there are parties in the operation. There is never any feedback. The party that is on the design side, they never hear how their designs are experienced and how they are running. So I have also analysed a building and then I came across the same design in my time and then I came across the same design error again and they never found out about it because they never measured what the result of their design was.

Interviewee 8: You never ultimately know exactly what the energy consumption in practice is and will be.

Interviewee 9: What you generally see is that there is a lot of energy wastage, meaning that the installations are not functioning optimally or are not optimally adjusted. That the time setpoints and such are not all properly set.

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Subtopic	Insights	Mentioned by Interviewee 1
Inadequate commissioning and monitoring	The interviewee highlighted the significance of continuous commissioning and the need for adaptive operational adjustments based on real-time data. The lack of effective commissioning practices contributes to operational inefficiencies.	Yes
Complexity and impact end-user	The complexity of modern building operations and the unpredictable behaviour of tenants/end-users is addressed. Manual interventions in system settings by occupants contribute to the energy performance gap.	Yes
Operational and maintenance challenges	Discussed the gap in transferring knowledge from the design and construction phases to the operational phase, and the challenge of ensuring maintenance staff are well-informed about energy systems for optimal efficiency.	Yes
Absence of a learning and feedback Loop	Emphasised the importance of a feedback loop to learn from operational data and apply lessons learned to future projects, noting the lack of systematic feedback from operational phases to inform future designs and constructions.	Yes
Transition and information transfer issues	Mentioned the crucial gap in continuity of knowledge from the design and construction phases to the operational phase, affecting the building's operational efficiency due to the lack of critical information about the systems.	Yes

Subtopic	Insights from Interviewee 2	Mentioned by Interviewee 2
Inadequate commissioning and monitoring	It is not directly stated, however, there emphasis on the importance of detailed energy usage projections.	No
Complexity and impact end-user	The interviewee acknowledges the complexity of buildings and the impact of the tenant/end-user. The focus on developing accurate energy models that consider user profiles highlights the challenges posed by the unpredictable nature of building occupancy and user interventions.	Indirectly
Operational and maintenance challenges	The interviewee highlights the challenge of ensuring optimal operation and maintenance for energy efficiency. The importance of transitioning knowledge from the design and construction phases to the operational phase, and ensuring maintenance staff understand the energy systems, is implied through the discussion on the need for ongoing engagement with buildings post-completion to fine-tune energy use.	Indirectly
Absence of a feedback and learning loop	The necessity for a learning and feedback loop is implied through the discussion on the importance of monitoring and adjusting buildings post-occupancy to improve energy performance. The interviewee's focus on utilising data from completed projects to inform future designs and operations suggests an understanding of this gap.	Indirectly
Transition and information transfer issues	The interviewee explicitly discusses the gap in knowledge and intention transfer from the design and construction phases to the operational phase. The emphasis on ensuring that project ambitions are maintained through to operation, and the challenges of ensuring this continuity, particularly in terms of energy performance.	Yes

Subtopic	Insights	Mentioned by Interviewee 3
Inadequate commissioning and monitoring	The discussion on data-driven optimisation and the use of Digital Twins for monitoring suggests an implicit acknowledgment of the challenges posed by inadequate commissioning and monitoring. The focus on ensuring operational efficiency through continuous data analysis implies the need for effective commissioning and ongoing monitoring.	Indirectly
Complexity and impact end-user	Does not address this subtopic	No
Operational and maintenance challenges	Discusses the importance of proper operational and maintenance practices for energy efficiency, particularly highlighting the need for ongoing adjustments based on real building use. This includes the challenges associated with transitioning knowledge from the design and construction phases to operational phases, and ensuring maintenance staff are equipped with adequate knowledge.	Yes
Absence of a feedback and learning loop	Highlights the utilisation of data from completed projects to inform future designs and operations, suggesting an awareness of the absence of systematic feedback loops. The focus on data-driven approaches for continuous improvement implies recognition of the need for better integration of design, construction, and operational phases.	Indirectly
Transition and information transfer issues	The gap in continuity of knowledge from design to operation is directly addressed. There is a need for detailed energy usage projections and understanding the impact of end-users. The conversation on the development and use of Digital Twins for bridging this gap further underscores the challenge of ensuring efficient operation due to insufficient information transfer.	Yes

Subtopic	Insights	Mentioned by Interviewee 4
Inadequate commissioning and monitoring	Interviewee 4 highlights the importance of continuous monitoring and commissioning beyond traditional practices. By utilising Digital Twins and data-driven optimisation, the need for more effective commissioning and ongoing adjustments based on real-time operational data is emphasised, indicating recognition of current inadequacies.	Yes
Complexity and impact end-user	The interviewee directly address the end-user unpredictability and increasing complexity of modern buildings due to sustainability.	Yes
Operational and maintenance challenges	The discussion touches on the gap between the design, construction, and operational phases, particularly highlighting the transition of knowledge and the maintenance of buildings for energy efficiency. The need for detailed energy usage projections suggests recognition of operational and maintenance challenges.	Indirectly
Absence of a feedback and learning loop	The need for a feedback loop through the use of Digital Twins and other tools to continuously adjust and improve building operations based on actual data is emphasised. This approach is seen as a way to bridge the gap, indicating an understanding of the lack of systematic feedback in current practices.	Yes
Transition and information transfer issues	Directly discusses the challenges in ensuring continuity of knowledge and intention from the design and construction phases to the operational phase. The conversation around the development and use of Digital Twins to maintain and utilise the knowledge gathered during the design phase throughout the building's life cycle highlights the critical gap in information transfer.	Yes

Subtopic	Insights	Mentioned by Interviewee 5
Inadequate commissioning and monitoring	The interviewee discusses the importance of monitoring and fine-tuning building systems post-completion to ensure energy efficiency, suggesting an awareness of the challenges related to inadequate commissioning and monitoring. The conversation implies that buildings are not always operated at their optimal efficiency due to these inadequacies.	Yes
Complexity and impact end-user	This challenge is not directly mentioned. The interviewee however expresses the need for detailed energy usage projections and adjustments based on real-time data.	No
Operational and maintenance challenges	The interviewee notes the transition of expertise from construction to operations as a major challenge, highlighting issues related to knowledge and the capability of operational staff to maintain optimal energy efficiency. The distinction between the expertise of those constructing the building and those operating it underlines operational and maintenance challenges.	Yes
Absence of a feedback and learning loop	The interviewee's focus on the use of data for operational adjustments and the acknowledgment of learning from the operational phase to improve future projects addresses the absence of a feedback and learning loop. Using real-time data for continuous improvement suggests an understanding of this issue.	Yes
Transition and information transfer issues	Directly discusses the challenges in the continuity of knowledge and intention from design and construction to the operational phase. The need for detailed documentation and the involvement of operational teams in the commissioning phase to understand the building's energy systems indicates recognition of transition and information transfer issues.	Yes

Subtopic	Insights	Mentioned by Interviewee 6
Inadequate commissioning and monitoring	The interviewee discusses the importance of accurately understanding building performance through monitoring and data analysis. Moreover, the need for a benchmark while monitoring is emphasised.	Yes
Complexity and impact end-user	He/she discusses that the well-though designs are not well understood and communicated to the operator due to the complexity.	Yes
Operational and maintenance challenges	The interviewee notes the challenges related to ensuring buildings operate as intended due to issues in knowledge transfer and the application of theoretical models in practice. This includes the identification of common operational problems such as inefficient control settings and equipment operation, directly linking these issues to the operational and maintenance challenges.	Yes
Absence of a feedback and learning loop	Highlighted by the discussion on the disconnect between design, construction, and operation phases, and the lack of feedback from operational data to inform future designs and practices. This gap underscores the absence of a systematic feedback and learning loop .	Yes
Transition and information transfer issues	Explicitly addressed through the examination of problems in conveying how systems are intended to function ("design intent") from design to operation. The need for detailed documentation and the involvement of operational teams in commissioning phases suggests significant issues in the transition and information transfer, affecting the building's energy efficiency.	Yes

Subtopic	Insights	Mentioned by Interviewee 7
Inadequate commissioning and monitoring	Inadequate commissioning and monitoring is not mentioned. The interviewee did discuss the focus on real-world energy use and Paris Proof standards.	No
Complexity and impact end-user	Acknowledged indirectly by discussing the variability in energy use based on different usage scenarios, emphasising the challenge of predicting energy use due to user behaviour and occupancy variability.	Indirectly
Operational and maintenance challenges	The difficulty in ensuring that buildings are maintained for optimal efficiency is shortly mentioned. The growing need of using data from the operational phase is emphasised.	Indirectly
Absence of a feedback and learning loop	Not explicitly mentioned, but the discussion on the reliance on standardised methodologies like BENG for predictions that don't accurately reflect actual energy use implies a need for better feedback mechanisms to learn from actual building performance and inform future projects.	No
Transition and information transfer issues	The interviewee highlights the need for new methods or calculations that can more accurately forecast real-world performance and ensure this knowledge is effectively passed to operational teams. Moreover, the complexity of too many different terms and the problem of translating expectations into a single number which is not always clear and understandable has been mentioned.	Yes

Subtopic	Insights	Mentioned by Interviewee 8
Inadequate commissioning and monitoring	The interviewee does not explicitly discussing the broader issues of inadequate commissioning or monitoring.	No
Complexity and impact end-user	The interview does not directly address end-user complexity.	No
Operational and maintenance challenges	Explicitly discussed through the challenges of transitioning knowledge from design to operational phases and ensuring that maintenance staff have the necessary knowledge of energy systems, particularly through the use of standardised methodologies like BENG that may not account for actual energy use.	Yes
Absence of a feedback and learning loop	The need for a feedback loop is implied through discussions on the disconnect between design expectations and actual operational energy use, indicating an understanding of the gap in feedback mechanisms to inform future projects.	Indirectly
Transition and information transfer issues	Directly addressed by discussing the need for better integration of design, construction, and operational phases to meet energy-neutral goals. The focus on using BREEAM standards as a benchmark suggests an awareness of the importance of clear information transfer but highlights the need for more accurate tools and methodologies to forecast real-world performance.	Yes

Subtopic	Insights	Mentioned by Interviewee 9
Inadequate commissioning and monitoring	The discussion around the development of norms based on actual energy use, such as the WEii initiative, indirectly touches upon the issue of inadequate commissioning and monitoring.	Indirectly
Complexity and impact end-user	The variability introduced by end-users is acknowledged. The is focus on real-world energy use and the mismatch between energy labels and actual consumption.	Indirectly
Operational and maintenance challenges	The interviewee addresses the problem of building operators changing and setting systems not as intended. Moreover, the disappearance and lack of knowledge is emphasised.	Yes
Absence of a feedback and learning loop	This challenge is not addressed. The initiative to develop a norm around actual energy use (WEii) for Paris Proof is however mentioned.	No
Transition and information transfer issues	Explicitly addresses the challenge of ensuring buildings meet energy-neutral goals and the gap between predicted and actual energy use, indicating issues in the transition and information transfer from design/construction phases to operational phase.	Yes

Subtopic	Insights	Mentioned by Interviewee 10
Inadequate commissioning and monitoring	The interviewee acknowledges the need for continuous monitoring and tuning based on real-world usage to ensure energy efficiency. The mention of initiatives like Paris Proof and WEii highlights the move towards actual energy consumption metrics.	Yes
Complexity and impact end-user	Indirectly discussed through the emphasis on real-world energy use and the limitations of energy labels to reflect this accurately, pointing to the complexities introduced by unpredictable end-users/tenants affecting energy performance.	Indirectly
Operational and maintenance challenges	The interviewee suggests a gap in operational knowledge and maintenance practices that prevents buildings from achieving their intended energy efficiency.	Yes
Absence of a feedback and learning loop	This challenge is not directly mentioned.	No
Transition and information transfer issues	Explicitly addressed through discussions on the need for more accurate methods to better reflect real-world performance, indicating challenges in ensuring the continuity of knowledge and intention from design to operation.	Yes

12.7.3 Communication & responsibilities

Quotes:
Interviewee 1: Building physics consultants, installation advisors, installers, and commissioning managers often conduct advisory processes, but afterwards, they are no longer involved in the building to check if the advice is followed and to make any improvements.

Interviewee 1: The building operator and maintenance parties are the ones who control the energy systems. The companies involved in development pay less attention to the operational phase. The building manager does not understand about how the building was conceived and such. The maintenance party often sets up the building systems once, thereafter it has to figure out for itself how to operate most efficiently. There lies an error in thinking as simulations assume for example average work patterns which are entered, and in practice there are peaks and troughs in usage that cannot be standardly inputted. Monitoring and tuning are needed for this.

Interviewee 2: The developer develops buildings and partly these are naturally resold to investors or transferred to investors, and with that, well, the involvement partially ends right there, and then the ball is in another party's court who have no background knowledge about the front end of the project.

Interviewee 4: But I think we are capable. I don't think so, I'm sure to actually step in from the start and say to us, the building simply has to be Paris proof and have a certain comfort class and a certain circularity. What is the responsibility? This involves a certain investment and make the right choices so that we actually become responsible for this at the start of the design process. Also financially and that can also be extended into the use phase.

Interviewee 4: Well, I believe that someone should remain involved across all the projects, someone who understands the high-level ambitions, the strategy we have together, and the roadmap of the portfolio from Edge, for example, to be able to make the right adjustments when necessary.

Interviewee 4: But that requires a different business model. Unlike developing a building and gradually selling it to an investor during the development process and then handing it over at some point, you really have to remain in the lead during the use phase in those first years and keep a grip on the project, so I would almost say you also need to own it.

Interviewee 4: We are currently mainly focused on the design phase, but we also want to continue to monitor and test this during the exploitation phase and the in use phase.

Interviewee 4: We want to close the circle and really take responsibility through, for example, a consortium. We agree on an annual energy budget that is made available and then we ensure that everything is arranged within that budget. And if things get worse, we will have blisters ourselves and if things get better, we will also benefit from that.

Interviewee 4: Because that contractor also stops at some point. So it is still working in that theoretical phase where the Paris proof requirement is still not visible on the meter. He realises a building. If anything changes, he would then have to make another calculation during the realisation to show that we still meet that requirement, but the question is whether that will be done. But then it is built on buildings, is completed and they are gone, so to speak.

Interviewee 4: There are user instructions, so that is the transfer of the building system, but that does not really end up in the operations of those tenants.

Interviewee 5: The building management company does not have the task to make the energy performance of a building as good as possible. In fact, they are even paid based on maintenance contracts.

Interviewee 5: A traditional building operator is outdated. There should be a split between performance monitoring and building operations because performance monitoring is scalable and more effectively provides insight into where things are going wrong in operations and monitoring. Performance monitoring is about checking whether the building performs and making recommendations to optimise it. This can be done from a control room remotely, but building operations, so actually walking around with a handyman to replace a lightbulb, cannot be done remotely.

Interviewee 6: What you see is that in the transfer of information, what is set up is not conveyed, especially so, so information is transferred about what is set up, but insufficient information is transferred about: 'and this is how it should function,' and that's what we call the design intent.

Interviewee 6: We are not a sector that is learning, because in our sector there are parties that are designing. There are parties building and there are parties in operation. You never find any feedback. The party that is on the design side never hears anymore about how their designs are experienced and how they are running. So I have also analysed a building and then I came across the same design in my time and then I came across the same design error again and they themselves never found out because they never measured what the result of their design was.

Interviewee 6: The problem is often exacerbated by the fact that the building owner and/or users are not aware of the potential misery that may exist within their building. Due to lack of monitoring, they may not even realise that there could be a problem, let alone that they actually have one. So, I always refer to it as the difference between the headache and the paracetamol. The vast majority of the Netherlands actually suffers from latent headaches, but they don't feel them because there is no awareness due to the lack of proper monitoring and no frame of reference. So what you see is that parties have climate complaints and malfunctions and energy use are just compared with how it was last year and how it was two years ago.

Interviewee 7: You may use so many kilowatt-hours per square meter, but many tenants have no idea what that means in practice. You have to make it clear somehow that it's about so many screens, etc.

Interviewee 8: What exactly is the definition of energy-neutral? Different parties have different definitions and expectations. It's a bit chaotic in energy land at the moment as everyone has their own tools and methods.

Interviewee 9: So people don't understand the installations; they simply don't get it at all. A building manager who doesn't really understand how an installation works, but keeps hearing from all his users that it's too cold or too warm, ends up tampering with controls he shouldn't be touching. The knowledge about the installations is gradually disappearing.

Subtopic	Insights	Mentioned by Interviewee 1
Fragmentation in stakeholder collaboration	Discussed extensively, highlighting the fragmentation in the development, operational phases, and the lack of overlap between phases. Emphasises the disconnect between parties involved from design to operation.	Yes
Unclear roles and responsibilities	Addressed through the discussion on the role of building operations and the need for continuous commissioning to adapt buildings to actual demand. The shift towards digital building operations suggests a rethinking of traditional roles	Yes
Enforcement of energy efficiency responsibilities	Explicitly discussed in the context of operational efficiency and commissioning. The focus on data-driven operations to ensure buildings meet energy efficiency goals implies a need for clearer responsibilities and enforcement.	Yes
Interdisciplinary integration early in the development process	The approach to building operations discussed involves a significant degree of integration between various disciplines, from design and construction to operations, suggesting an acknowledgment of this need.	Yes
Awareness gaps and misinterpretations	Implicitly mentioned through the discussion of operations and the adjustments made based on real-time data, indicating a gap in awareness regarding how buildings are used versus how they were designed. .	Indirectly

Subtopic	Insights	Mentioned by Interviewee 2
Fragmentation in stakeholder collaboration	Highlighted through the need for closer collaboration and communication from the project's start to ensure that energy performance targets are met. Emphasises the importance of maintaining a sharp focus on energy targets throughout the project lifecycle.	Yes
Unclear roles and responsibilities	Discussed in terms of ensuring all parties are aware of their roles in meeting energy targets. The interviewee notes the importance of understanding the implications of decisions on energy use and the need for detailed planning from the outset to avoid misalignments and missed targets.	Yes
Enforcement of energy efficiency responsibilities	Addressed through discussions about setting hard targets for energy use and ensuring that these targets are met. The interviewee mentions the use of incentives and penalties (bonus-malus systems) to ensure compliance with energy performance requirements.	Yes
Interdisciplinary integration early in the development process	This statement is not explicitly labelled as such. However, the need of a holistic approach to project management, where technical solutions are aligned with the overarching goals of the project, including energy efficiency is mentioned.	No
Awareness gaps and misinterpretations	Addressed through discussions on the misuse of terms like "energy-neutral" and the need for clearer, actionable definitions that can be monitored and verified in practice. The interviewee emphasises the importance of setting realistic, measurable energy targets to avoid misunderstandings.	Yes

Subtopic	Insights	Mentioned by Interviewee 3
Fragmentation in stakeholder collaboration and communication	The interviewee acknowledges the fragmented approach in collaboration and communication among stakeholders in the design, construction, and operational phases, emphasising the need for integrated efforts and the challenges of current disconnects.	Yes
Unclear roles and responsibilities	The interview touches upon the ambiguity of roles and responsibilities, particularly around the building operator's responsibility, highlighting the need for clearer accountability and expectations across the development process.	Yes
Enforcement of energy efficiency responsibilities	While not directly stated, the conversation implies the necessity of defining and enforcing energy efficiency responsibilities, as seen in the discussion on guarantees and commitments to energy performance.	Indirectly
Interdisciplinary integration early in the development process	Integrating interdisciplinary expertise early in the design process to ensure energy efficiency is a core component from the outset, which aids in identifying potential performance gaps is emphasised.	Yes
Awareness gaps and misinterpretations	The interviewee points out the importance of learning from data of existing buildings to make better designs, indicating awareness gaps among stakeholders regarding energy efficiency definitions and the potential for misinterpretation.	Yes

Subtopic	Insights	Mentioned by Interviewee 4
Fragmentation in stakeholder collaboration	The interviewee emphasises the importance of integrated collaboration among stakeholders throughout the building's life cycle, acknowledging the current disconnects that exist. The discussion reflects on the need for ongoing engagement between developers, engineers, construction teams, advisors, building operators, and maintenance staff to ensure cohesive effort towards energy efficiency.	Yes
Unclear roles and responsibilities	The ambiguity in stakeholder responsibilities in energy performance is pointed out, suggesting a need for clear definitions of roles at every development stage. The idea of shared responsibilities and the challenges of aligning stakeholder expectations for energy efficiency are highlighted.	Yes
Enforcement of energy efficiency responsibilities	The potential for explicit definitions and enforcement of responsibilities related to energy efficiency targets are discussed, including setting these requirements in contracts and the implications for all parties involved. The dialogue covers the need for accountability in meeting energy performance standards.	Yes
Interdisciplinary integration early in the development process	The necessity of involving interdisciplinary expertise earlier in the process to embed energy efficiency as a core design component is mentioned. The interviewee advocates for early collaboration among architects, engineers, and energy specialists to identify and address potential performance gaps..	Yes
Awareness gaps and misinterpretations	Misinterpretation and a general lack of awareness among stakeholders about energy efficiency metrics are identified as barriers. The interviewee suggests the need for clear guidelines and consistent communication to improve understanding and actions towards energy efficiency, highlighting the potential for data and technology such as building information modelling and performance monitoring.	Yes

Subtopic	Insights	Mentioned by Interviewee 5
Fragmentation in stakeholder collaboration	The interviewee acknowledges the fragmentation in collaboration and communication among stakeholders across various phases of building projects, stressing the importance of integrated efforts for energy efficiency and the challenges presented by current disconnections.	Yes
Unclear roles and responsibilities	The ambiguity in roles and responsibilities is not mentioned. However, the interviewee highlights the need of redefined roles for the building operator.	Yes
Enforcement of energy efficiency responsibilities	Discusses the importance of enforcing responsibilities related to achieving and maintaining energy efficiency targets. This includes specifying energy performance requirements in contracts and ensuring all parties understand their roles, albeit indirectly through the emphasis on operational efficiency.	Yes
Interdisciplinary integration early in the development process	The necessity for early interdisciplinary integration is touched upon through discussions on the importance of operational efficiency and the role of various technical and non-technical stakeholders in achieving energy performance goals, suggesting the benefits of collaborative efforts from the outset.	Indirectly
Awareness gaps and misinterpretations	A general lack of awareness and potential misinterpretations around energy efficiency is mentioned, especially in the operational phase. The need for clear guidelines and consistent communication to bridge these gaps is indirectly highlighted through discussions on operational challenges and solutions.	Indirectly

Subtopic	Insights	Mentioned by Interviewee 6
Fragmentation in stakeholder collaboration	The interviewee highlighted the divide between theoretical energy performance calculations and practical energy consumption monitoring. The importance of bringing these worlds closer to each other for effective energy management is emphasised.	Yes
Unclear roles and responsibilities	The ambiguity surrounding stakeholder responsibilities, especially concerning building operators is mentioned. The interviewee discussed the need for a clear transmission of the 'design intent' from the design phase to the operational phase, indicating that while technical aspects are often communicated, how systems are supposed to function is not effectively passed on.	Yes
Enforcement of energy efficiency responsibilities	The enforcement is not explicitly mentioned in these terms. Ensuring that systems function as intended and that monitoring practices are implemented to maintain energy efficiency is however mentioned by specifying requirements and consequences in contracts.	Yes
Interdisciplinary integration early in development process	The interviewee emphasises the importance of integrating monitoring and theoretical design intentions early in the building design process. It is suggested that monitoring should start with the energy data already available (e.g., from smart meters) to establish a reference frame for energy performance, which can then be used to ensure that actual building operations align with the theoretical energy performance predicted during the design phase. This highlights the need for interdisciplinary efforts early on.	Yes
Awareness gaps and misinterpretations	There's a significant focus on the need for better understanding and communication about energy efficiency definitions and the actual energy performance of buildings. The gap in knowledge and awareness among stakeholders, particularly around the actual energy use compared to theoretical predictions is mentioned. This includes a critique of existing models (like NTA 8800, suggesting a broader issue of misinterpretation.	Yes

Subtopic	Insights	Mentioned by Interviewee 7
Fragmentation in stakeholder collaboration	the interviewee does not directly address stakeholder fragmentation in the responses.	No
Unclear roles and responsibilities	The ambiguity surrounding roles and responsibilities is not specfcily addressed through discussions on the difficulty of predicting real-world energy usage accurately.	Indirectly
Enforcement of energy efficiency responsibilities	The interviewee touches upon this particularly when discussing the Paris Proof requirements and the challenges in ensuring that buildings meet predetermined energy use targets in reality. The potential financial implications for not meeting energy efficiency targets indirectly deals with the theme of enforcing responsibilities.	Indirectly
Interdisciplinary integration early in the development process	The need for early interdisciplinary integration is not directly mentioned. The mention of working on dynamic simulations and the potential of leveraging data for predicting energy use is however addressed.	Indirectly
Awareness gaps and misinterpretations	The interview explicitly addresses awareness gaps and misinterpretations, especially in the context of energy efficiency definitions and the expectations set by predictive models versus actual energy consumption. The challenges of communicating energy performance predictions accurately and the importance of setting realistic expectations with a range of scenarios rather than a single one is mentioned. The discussion on the complexity of the BENG calculation and the nuances of achieving Paris Proof certification highlights the issues with misinterpretations and the need for clear communication and guidelines to bridge awareness gaps among stakeholders, including developers, operators, and users.	Yes

Subtopic	Insights	Mentioned by Interviewee 8
Fragmentation in stakeholder collaboration	The interviewee discusses the challenges arising from fragmented collaboration among key stakeholders involved in the building's lifecycle, emphasising the disconnect between design intentions and operational realities due to lack of integrated efforts .	Yes
Unclear roles and responsibilities	The interviewee highlights the ambiguity surrounding the roles and responsibilities of different stakeholders, particularly pointing out the need for clearer delineation of accountability, especially in terms of the building operator's responsibilities for energy performance .	Yes
Enforcement of energy efficiency responsibilities	The need for explicit definition and Enforcement of energy efficiency responsibilities is addressed, suggesting that energy performance requirements should be clearly specified in contracts and that there should be established consequences for not meeting these requirements .	Yes
Interdisciplinary integration early in the development process	The necessity of integrating interdisciplinary expertise early in the building design process is shortly addressed by the interviewee, advocating for the collaboration between energy performance advisors, future building operators, and building system experts from the outset to ensure that energy efficiency is considered a core component.	Indirectly
Awareness gaps and misinterpretations	The significant barrier presented by misinterpretation of energy efficiency definitions and the general lack of awareness among stakeholders is discussed,	Yes

	specifically owners and building operators. He/she notes the importance of clear guidelines and consistent communication to bridge these awareness gaps.	
Subtopic	Insights	Mentioned by Interviewee 9
Fragmentation in stakeholder collaboration	The interviewee highlights the issue of fragmentation shortly, in specific the fragmentation of energy management in the in use phase.	Indirectly
Unclear roles and responsibilities	The interviewee does not mention unclear roles and responsibilities	No
Enforcement of energy efficiency responsibilities	The conversation around the creation of WEii and collaboration with the Dutch Green Building Council (DGBC) on Paris Proof suggests an approach towards clearer Enforcement of energy efficiency responsibilities by defining and using actual energy use as a standard.	Yes
Interdisciplinary integration early in the development process	This statement is not directly mentioned.	No
Awareness gaps and misinterpretations	The interviewee directly addresses the lack of correlation between energy labels and actual energy use, pointing out awareness gaps and the potential for misinterpretation of energy efficiency standards. This discussion underlines the need for clearer guidelines and more consistent communication to bridge these gaps.	Yes

Subtopic	Insights	Mentioned by Interviewee 10
Fragmentation in stakeholder collaboration	There's an indication that challenges remain in ensuring cohesive collaboration and communication among all parties involved in the design, construction, and operational phases of building projects.	Indirectly
Unclear roles and responsibilities	The interviewee notes the difficulty in defining and enforcing responsibilities, especially regarding energy efficiency. There's a need for clearer accountability across the development process, highlighting the ambiguity in roles, particularly about the building operator's responsibility.	Yes
Enforcement of energy efficiency responsibilities	The conversation underscores the need for explicit definition and enforcement of responsibilities for achieving and maintaining energy efficiency targets. Mooij discusses developing methods and goals for projects, like "Paris Proof," based on real energy consumption, advocating for an approach that emphasises actual over theoretical performance.	Yes
Interdisciplinary integration early in the development process	Interdisciplinary integration early in the development process is not directly mentioned	No
Awareness gaps and misinterpretations	There's a focus on pushing for real energy usage as a metric for sustainability, acknowledging that misinterpretations of energy efficiency definitions and a lack of awareness among stakeholders, particularly owners and building operators, pose significant barriers. The move towards using real energy consumption for labelling and certification is seen as a response to the inadequacies of existing models that fail to accurately predict or reflect actual energy performance.	Yes

12.7.4 Operations & monitoring

Quotes:
Interviewee 1: The building operator and maintenance parties are the ones who control the energy systems. The companies involved in development pay less attention to the operational phase. The building manager does not understand about how the building was conceived and such. The maintenance party often sets up the building systems once, thereafter it has to figure out for itself how to operate most efficiently. There lies an error in thinking as simulations assume for example average work patterns which are entered, and in practice there are peaks and troughs in usage that cannot be standardly inputted. Monitoring and tuning are needed for this.

Interviewee 1: In the operational phase, there is too little commissioning.

Interviewee 1: There is a missing feedback loop in the monitoring of data. The energy data appears on a dashboard that nobody looks at and nobody does anything with.

Interviewee 1: Usually, installations are set to manual. They are set without knowledge.

Interviewee 1: The problems are not identified because the technical people say that the pumps are running well. The control system company says: ‘I see no faults’. So, at that moment, you don't see that knowledge of usage is being brought back at the time of the building's commissioning.

Interviewee 2: A lot of attention is paid to rental costs, but service costs are a kind of big unknown.

Interviewee 2: But you miss there a piece, and ideally, you would also monitor the years after delivery, to see how it's running now? What are all those tenants doing in it now? And yes, in my opinion, there's insufficient... that step from delivery to operation? Yes, there's also a certain gap in the sense that you've been involved as a design team and developing parties for years in that whole process and then you deliver it and in essence, it's then suddenly over, yes that. What also occupies us is how can you get more control over that?

Interviewee 3: Place even more emphasis on data, but also on automated data processing and ensuring that data flows through the project, so that you use data from your portfolio to make better designs and to ensure that it continues to grow into a sort of digital twin model.

Interviewee 4: During realisation, but also during operation to actually measure in the building and adjust the installation, both digitally and physically. So actually walking around the building with meters and tests with that knowledge to ensure that okay, well we now digitally measure that the building has a gap, so we know we have to do something about that.

Interviewee 4: So the connection between the digital building model and the ambitions and how the building actually performs in terms of technology, because technology has grown so exponentially in buildings in recent years, partly due to the sustainability drive. The knowledge that is always required for this, from the initial process to exploitation

Interviewee 5: The biggest factor for the energy performance of a smart building is the operations. The tricky part is, of course, that those who really make the design and ultimately deliver and build the project, there's a lot of expertise there, but at some point, they deliver a project and then they take of their hands of it and it's a very different party that ultimately takes over those operations and that's much more customer-oriented. They get those calls and they go into a conversation with such a customer in as tidy a manner as possible to ultimately solve a problem for that customer but they don't know which knobs and settings they need to turn to actually solve the problems. As a result, they make wrong adjustments which seem to temporarily solve the problem but eventually lead to much bigger problems with respect to energy use and user comfort. If you create an imbalance somewhere, you're also going to have problems elsewhere, and if they solve those, then at some point the whole building becomes inefficient. Officially, the building operator should keep all adjustments in documentation but that often does not happen.

Interviewee 5: To make that split between performance monitoring and building operations because performance monitoring is scalable and that's something we want to do on all our buildings, so that we at least see where things are going wrong and what is going wrong.

Interviewee 5: That's the fun part... normally those costs belong to the investor or the owner of the building and indirectly they earn that from the rental income, of course, but now we just integrate the building performance monitoring as part of the service costs so from the service costs, just €3.50 is withheld to do performance monitoring.

Interviewee 5: At the end of the year, the total energy consumption is reviewed and then the tenant may get money back because they did better than expected or they may have to pay extra. That's the model, or you have submeters and then you agree with the tenant that it will settled based on that submeter.

Interviewee 6: What I see, for example in monitoring is that people are monitoring but they have no reference frame of what it should have been. They monitor from the time it was renovated and the reference frame is that they look back a year each time, have I gotten a bit better or a bit worse? But they have no reference frame.

Interviewee 6: Maintenance parties are used to deal with other buildings with settings. Well, if such a person comes in and is not instructed, what he may and may not do, well then he's going to turn the knobs and make wrong settings because suddenly he's dealing with things he doesn't understand. And then, well, then we're talking about someone who has designed a network there, then he's no longer a service technician, but then he's become a disturbance technician. Then he's just messed everything up and you see that also in a lot of buildings. That people well-intentioned have been turning a knob, but the whole thing is disordered. And well then, then you never see those buildings come back to where they once started.

Interviewee 6: Those perverse incentives can be because it's in the contract that there are maintenance contracts, making a maintenance party benefit from regularly letting faults occur.

Interviewee 9: A lot actually goes wrong with modern buildings, and part of that is also in their complexity, right? So buildings are becoming and need to be more energy-efficient, which makes them increasingly complex with a lot of control technology, compartmentalisation, and all sorts of things. And it's precisely because of this complexity that things often quickly go wrong.

Interviewee 9: So people don't understand the installations; they simply don't get it at all. A building manager who doesn't really understand how an installation works, but keeps hearing from all his users that it's too cold or too warm, ends up tampering with controls he shouldn't be touching. The knowledge about the installations is gradually disappearing.

Interviewee 9: Yes, or if something breaks in a very complex installation, a sensor or whatever, it can quickly have major consequences.

Subtopic	Insights	Mentioned by Interviewee 1
Inadequate 24/7 real time monitoring	The interviewee discusses the challenges associated with real-time monitoring, specifically pointing out that while many projects aim for high energy efficiency, the reality often falls short due to inadequate commissioning and the failure to adjust operational settings in response to actual usage patterns. This highlights a significant gap in the continuous, real-time monitoring necessary to optimise building operations and energy use.	Yes
Tuning challenges	Talked about the adjustments in building settings based on actual usage data, which significantly differed from initial settings. Moreover, the interviewee suggests that continuous commissioning and adjustments based on real usage data are crucial but often overlooked, leading to missed opportunities for energy optimisation.	Yes
Operational control and development disconnection	Interviewee 1 notes that building operators often lack a full understanding of the building's operational intent, which stems from a disconnection between the design, construction, and operational phases. This gap can lead to inefficiencies when the operations team does not fully grasp or follow the designed energy protocols.	Yes
Need for specialisation in operations	There's an emphasis on the need for specialised roles within building operations to manage performance monitoring and ensure operational efficiency. Interviewee 1 supports the idea of delineating roles to better manage the complex systems within modern buildings, ensuring that all adjustments are data-driven and based on accurate, real-time performance feedback.	Yes
Operational and monitoring costs	The interviewee does not mention the underlying concern about the costs associated with these operations but mentions that they should be included as part of the service costs. By implementing more efficient operations and monitoring, the service costs will decrease, making money available for this service. As a result, the costs will not be a barrier for the users.	Yes

Subtopic	Insights	Mentioned by Interviewee 2
Inadequate 24/7 real time monitoring	The interviewee discusses the importance of real-time monitoring to track actual energy usage and maintain control over building operations. However, he highlights that traditional benchmarks like BENG do not reflect actual energy use, thus causing a gap in expectations versus reality.	Yes
Tuning challenges	The need for accurate energy modelling tools is emphasised to better predict and optimise building performance based on actual energy patterns. Interviewee mentions that existing tools do not match the reality of energy consumption, which can lead to discrepancies in energy performance monitoring.	Yes
Operational control and development disconnect	The interviewee points out that operators often lack comprehensive knowledge of how buildings are supposed to function, which leads to inefficiencies. This is aggravated by a gap in the transfer of knowledge from the design and construction phase to the operational phase, thus resulting in suboptimal building operation.	Yes
Need for specialisation in operations	There's a discussion about the evolving role of building operators, suggesting a need for a division of duties between performance monitoring and operational tasks. This could ensure more efficient use of energy systems and more responsive adjustments to real-time data.	Yes
Operational and monitoring costs	Interviewee 2 suggests that the current focus in the industry tends to prioritise immediate cost savings over long-term energy efficiency, which affects decisions on operational and monitoring investments. The challenge of balancing upfront costs with long-term benefits is discussed, along with the need for more detailed planning and budget allocation for monitoring to ensure sustainability goals are met.	Yes

Subtopic	Insights	Discussed by Interviewee 3
Inadequate 24/7 real-time monitoring	The interviewee highlights the importance of learning from data in existing buildings to improve future designs, suggesting a need for more comprehensive and continuous monitoring strategies.	Yes
Tuning challenges	Discussed the process of design, implementation, and the focus on energy performance throughout the construction and monitoring phases. Moreover there is an emphasises on the use of digital twins and advanced data analytics to address gaps between simulated and actual building performance.	Yes
Operational control and development disconnection	Discusses the role of digitalisation in enhancing building operations, stressing the necessity of aligning operational control with development phases.	Yes
Need for specialisation in operations	Indicates the evolution of building operations to integrate more specialised roles focused on performance monitoring and data utilisation for operational efficiency.	Yes
Operational and monitoring costs	The Operational and monitoring costs are not mentioned.	No

Subtopic	Insights	Mentioned by Interviewee 4
Inadequate 24/7 Real-Time Monitoring	The interviewee highlights the importance of continuous monitoring to ensure that the building's operations align with its intended performance, but does not discuss specifics about inadequacies in current practices directly.	No
Tuning challenges	The necessity for continual building operations to meet performance targets is discussed, indicating awareness of Tuning challenges. This includes adapting operations based on feedback from energy consumption data to optimise building performance, aligning closely with the concept of effective feedback loops and benchmarks in current monitoring practices.	Indirectly
Operational control and development disconnection	The interviewee discusses the disconnect between the building's intended operational designs and actual operations, stressing the need for building operators to have a deep understanding of the building's systems, which is in line with the Subtopic.	Yes
Need for specialisation in operations	Explicitly mentions the evolving complexity of building systems that necessitates a division between performance monitoring and operational duties. This specialisation ensures that energy systems are not only monitored for efficiency but also operated in a way that aligns with designed energy conservation measures.	Yes
Operational and monitoring costs	The interviewee does not explicitly mention costs related to operations and monitoring, but the context of the discussion implies a concern with the efficiency and effectiveness of operational practices. He/she talks about the importance of accurate simulations and predictions for energy use, which can indirectly impact the building owner's or end user's approach to energy monitoring and efficiency.	Indirectly

Subtopic	Insights	Mentioned by Interviewee 5
Inadequate 24/7 real time monitoring	Interviewee 5 discusses the challenges of building systems, such as HVAC, that are continuously running without efficient monitoring. This results in high energy consumption despite the building having a BREEAM outstanding rating. This indicates a lack of effective real-time monitoring and control over the building operations.	Yes
Tuning challenges	The problem of improper settings adjustments based on specific complaints is emphasised, which can lead to imbalance and inefficiencies in other parts of the system. This reflects a broader issue related to Tuning challenges where settings are adjusted without considering the overall system balance.	Yes
Operational control and development disconnection	The interviewee notes that once a project is handed over, the original project team moves on to new projects, leaving the operational phase potentially lacking in oversight and continuity. This disconnection can lead to operational inefficiencies as those operating the building may not have been involved in its development phase or may lack crucial knowledge about the building's intended operational strategies.	Yes
Need for specialisation in operations	The discussion about different types of maintenance personnel and their varying levels of expertise suggests a Need for specialisation in operations. The interviewee points out that maintenance personnel often address issues based on immediate complaints rather than understanding the holistic needs of building operations, suggesting a division of roles could improve efficiency.	Yes
Operational and monitoring costs	The interviewee talks about the costs being integrated into service charges and how these costs contribute to overall building performance implies concerns about Operational and monitoring costs. The interviewee suggests integrating performance monitoring as a part of the service charges, highlighting the importance of considering long-term efficiency and performance over short-term cost savings.	Yes

Subtopic	Insights	Mentioned by Interviewee 6
Inadequate 24/7 real time monitoring	Describes issues with current monitoring technologies and standards; lack of effective real-time data leading to gaps in energy performance monitoring.	Yes
Tuning challenges	Indirectly discusses difficulties in adjusting systems optimally. The need for improvement based on data is emphasised.	Indirectly
Operational control and development disconnection	Mentions how the theory often doesn't match practical operations due to a lack of continuity and understanding across the phases of building development and operation.	Yes
Need for specialisation in operations	Indirectly emphases detailed responsibilities during the commissioning of installations and systems, and the need of specifying the tasks that must be integrated into construction and operation to ensure building performance meets designed standards.	Indirectly
Operational and monitoring costs	The interviewee does not highlight the economic challenges in maintaining continuous monitoring.	No

Subtopic	Insights	Mentioned by Interviewee 7
Inadequate 24/7 real time monitoring	This is not explicitly discussed	No
Tuning challenges	Not mentioned the Tuning challenges	No
Operational control and development disconnection	Reflects on the gap between the design, represented by static calculations, and operational phases, especially in terms of communicating expectations and results to building operators and developers, pointing towards a disconnection between these phases.	Indirectly
Need for specialisation in operations	Mentions the growing interest in data-driven operations and the potential move towards more specialised roles in monitoring and operations to better use data for energy efficiency, aligning with the Subtopic about the need for specialisation.	Indirectly
Operational and monitoring costs	Talks about the high costs associated with detailed simulations necessary for accurate predictions and the industry's hesitancy due to these costs, reflecting the broader challenge of balancing costs and long-term efficiency gains. However, the low costs of the WEii calculations are also mentioned.	Yes

Subtopic	Insights	Mentioned by interviewee 8
Inadequate 24/7 real time monitoring	The interviewee discusses the challenges related to monitoring systems primarily being handled post-construction by installers rather than the designers or operators themselves. This often leads to discrepancies between the designed energy performance and actual usage due to the implementers' choices during operation	Indirectly
Tuning challenges	The conversation covers difficulties in achieving operational tuning due to the lack of connection between initial design intentions and final building operations. The interviewee specifically mentions the challenge of not being able to predict and adjust for the actual user behaviour and subsequent energy use, which affects the ability to finely tune building systems post-occupancy.	Yes
Operational control and development disconnection	The disconnection between operational control and development is highlighted through the practice of transferring responsibility from designers to builders and then to operators without a comprehensive oversight on how the buildings are operated versus how they were intended to be used.	Yes
Need for specialisation in operations	Interviewee 8 suggests the need for more specialised roles in monitoring and operations to handle the complexities of building performance systems effectively. This includes the division of responsibilities to ensure that someone is specifically tasked with monitoring and adjusting the systems based on accurate, real-time data, rather than having generalists handle complex systems they may not fully understand.	Indirectly
Operational and monitoring costs	The interviewee does not discusses the broader issue of prioritising long-term energy efficiency over immediate cost savings.	No

Subtopic	Insights	Mentioned by Interviewee 9
Inadequate 24/7 real time monitoring	Discussed issues around actual energy usage monitoring, citing examples like the development of norming real energy usage and creating certifications like WEii that ensure accurate data.	Yes
Tuning challenges	Highlighted the need for effective feedback and benchmarks by proposing the integration of real energy use into certification and norming processes, like the development of WEii and merging with Paris proof protocols. This relates to the challenge of not having effective feedback systems in place.	Yes
Operational control and development disconnection	Not directly discussed.	No
Need for specialisation in operations	While not explicitly stated, the importance of specialisation can be inferred from discussions on the creation of certifications and the separation of duties in monitoring real energy usage and operational practices.	Indirectly
Operational and monitoring costs	Not mentioned by the interviewee.	No

Subtopic	Insights	Mentioned by Interviewee 10
Inadequate 24/7 real-time monitoring	Discusses issues with labelling based on actual energy performance rather than expected, suggesting monitoring gaps.	Indirectly
Tuning challenges	Talks about the challenges of predicting energy use accurately and adjusting systems based on real energy use. There is a need to efficiently use energy systems based on accurate data.	Yes
Operational control and development disconnection	Mentions problems with operational inefficiencies due to lack of understanding of building's intended operations.	Yes
Need for specialisation in operations	Not mentioned specifically	No
Operational and monitoring costs	Discusses the costs associated with implementing and maintaining energy-efficient systems, and the trade-offs between short-term costs and long-term gains.	Yes

12.7.5 Future strategies

Quotes:
Interviewee 1: It's crucial to consistently consider the energy consequences and examine each building in detail, reviewing the impact of every decision made at each phase, and weighing these choices. This should start from the very beginning, from the sketch design, through each phase, maintaining focus and continuously verifying. This extends from sketch design to preliminary design to detailed engineering, and also includes supervision during construction and overseeing tests.

Interviewee 1: Perform continuous commissioning, thus examining the current demands and data-driven information about energy use. The collected data points should guide the maintenance process and facility management.

Interviewee 1: The building operator should be involved beforehand (a year before delivery) so that this party can help steer decisions, and at the moment of hand-over, they become the warranty manager to perfectly tune the building.

Interviewee 1: We actually want to get to know the building much more, about six months to a year in advance.

Interviewee 1: A built trust among all involved parties is important to be able to provide guarantees and rely on the advice of other parties.

Interviewee 1: The digital building operator must focus on scope and urgency to achieve effectiveness in solving operational issues. Without altering the hardware, or changing pumps or anything, the digital building operator can achieve 30-40% energy savings through commissioning. Also, commissioning should be done once every quarterly season.

Interviewee 1: Building physics consultants, installation advisors, installers, and commissioning managers often conduct advisory processes, but afterwards, they are no longer involved in the building to verify if the advice is followed and to make any improvements. What the digital building operator should do is keep these parties in the loop, so that even after they have given their advice, they actually continue to participate, ensuring the building operates as designed.

Interviewee 1: A feedback loop should be created by identifying trends in the data from smart data platforms and making improvements and solutions based on these. All inputs from the digital building operations should already be included in the design, but also the process that we can still improve.

Interviewee 1: A clear step-by-step plan must be documented, so that in new development projects, it serves as a blueprint for managing energy performance, specifying who is responsible for what and when they should be involved in the process.

Interviewee 1: The costs for building performance monitoring should be part of the service charges. By more effective use of energy presentation, money is saved on energy costs, allowing building performance monitoring to be incorporated as a service cost, keeping the total amount the same. This creates a win-win situation where the landlord pays the same service costs but achieves more effective energy performance, and a digital building operator receives the profits from energy savings as a revenue model.

Interviewee 1: Buildings should remain under the management of the digital building operator for longer, at least 2 or 3 years, to achieve energy goals. After this period, it can be demonstrated that the building can function as the design intent was.

Interviewee 1: In the usage phase, a feedback loop is needed on which systems could be set up more efficiently in new buildings to implement and optimise improvements in new projects.

Interviewee 2: We are in a consortium with 'construction company/contractor' and the installer, and as a consortium, we are responsible for the energy budget; thus, from 'real estate company,' we receive an annual energy budget.

Interviewee 2: When there's a firm target in terms of energy consumption and, well, a sort of bonus-malus system, right? That is, if we stay within the energy budget, we have something to distribute among ourselves; if we exceed it, then we all have to contribute.

Interviewee 2: Selling a building with a certain energy promise under the condition that it will be monitored for the next year or two. That is done by the parties involved at the front end, including the developer, installation advisor, installer, and contractor. That ensures, I think, a smoother transition from realisation to operation.

Interviewee 2: It is important to safeguard the overarching Paris-proof ambition and to connect within your organisation to ensure smooth communication, having a kind of translation function between what is the ambition and what that means for the technology.

Interviewee 2: Contracting contractors on hard targets and guarantees so that a conscious mindset regarding energy performance is created.

Interviewee 2: The consortium receives an annual energy budget and a maintenance budget within which the targets must be achieved, and this is done with a bonus-malus arrangement.

Interviewee 2: We must consider everything in terms of fitting within the energy forecast so when there is a firm target in terms of energy consumption and, well, a sort of bonus-malus system, right? In other words, if we stay within the energy budget, then we have something to distribute in the consortium; if we exceed it, then we all have to contribute, and you see that the mindset is much sharper. So the process definitely proceeds differently. And there is much more attention paid to watching if we deviate, then there are consequences.

Interviewee 2: Monitoring a building for a year after delivery or during a year after delivery, then you can fine-tune and optimise energy consumption by 20 to 25% simply by checking how things are currently set up.

Interviewee 2: Of course, the best thing is if you keep buildings under your management, so that you maintain control over the entire operational period as a developer.

Interviewee 2: Selling a building with a certain energy promise under the condition that it will be monitored for the next year or two. That is done by the parties involved at the front end, including the developer, installation advisor, installer, and contractor. That ensures, I think, a smoother transition from realisation to operation.

Interviewee 2: The building operator needs specific training for the specific building and also some coaching directed towards users.

Interviewee 3: You really have to stay on top of it, so besides a very good initial commissioning and following closely during the service period and ensuring system-bound or seasonal optimisation, you must continue monitoring the behaviour and use of the building. Here, machine learning can play a very clear role because once a building is fully optimised during a two-year service period, you really just need algorithms to check if it still operates as per the design intent. The algorithms are trained with machine learning.

Interviewee 3: We predict that the energy volume will be a certain amount, and we have a bonus-malus arrangement with another company for this. So, if they use less energy, we make some money; if they use more energy, they pay a penalty.

Interviewee 3: It's very important that if you give a guarantee, we as installation advisors and commissioning managers want to be involved in all phases of the project, otherwise, we can't guarantee it. When it comes to simulation and calculations, the advisor actively holds responsibility, and when it comes to detailed engineering and mounting, the installer then holds responsibility.

Interviewee 3: What we sometimes do differently is that we split it, saying the user component, we have a certain budget for, and the building component too, and we measure those separately and make them clearly visible. So, you have a more extensive monitoring.

Interviewee 4: Well, I believe that someone should remain involved across all the projects, someone who understands the high-level ambitions, the strategy we have together, and the roadmap of the portfolio from Edge, for example, to be able to make the right adjustments when necessary.

Interviewee 4: The first 2, 3, 4 years after the building has been completed must actually ensure that those ambitions are actually achieved, so that means that you have to stay involved, learn what goes wrong, but also be able to adjust the building to make it perform optimally and the knowledge that we have for that is simply needed.

Interviewee 4: But that requires a different business model. Unlike developing a building and gradually selling it to an investor during the development process and then handing it over at some point, you really have to remain in the lead during the use phase in those first years and keep a grip on the project, so I would almost say you also need to own it.

Interviewee 4: Well, I believe that someone should remain involved across all the projects, someone who understands the high-level ambitions, the strategy we have together, and the roadmap of the portfolio from Edge, for example, to be able to make the right adjustments when necessary.

Interviewee 4: We want to close the circle and really take responsibility through, for example, a consortium. We agree on an annual energy budget that is made available and then we ensure that everything is arranged within that budget. And if things get worse, we will have blisters ourselves and if things get better, we will also benefit from that.

Interviewee 5: Monitoring is just very important, and you really have to make sure that we know in detail what the tenant consumes and what the user uses.

Interviewee 5: The energy performance gap must be visually or demonstrably shown by simulating buildings based on the physical state of the building and predicting what the energy consumption should be in the most optimal situations. This must be compared with the actual performance of a building and conclusions drawn that certain things in the building are not working properly. Based on those data dashboards, the digital building operator must analyse and advise.

Interviewee 5: Developers wash their hands of the project after the hand-over. To secure the energy performance, a performance guarantee must be given. This can be done by keeping the building under management for at least 2-3 years and involving parties, including a digital building operator, who stand guarantee for their own tasks and expertise regarding the energy performance. This way, you can convince the user of the promised product.

Interviewee 6: So it doesn't need to be there permanently, but we have what they call a warranty period, you know, various things are tested during this time, and really there should be a period, especially for buildings that are more complex, where... and I think they do this somewhere in Finland or so I've seen, where for the first three years a senior from the design process continues to be involved to ensure the building is properly regulated.

Interviewee 6: How it's connected so that design intent, in fact, must be put on paper, what the design intent is, it must actually be transferred. Describe the technical solutions and how it should work. You must actually transfer the design intent and then also, it must also be robust.

Interviewee 6: So the challenge with renovations and new construction is that transition is very important in terms of information, giving a clear reference frame of where energy use in all settings of installations should meet, directly implement in your monitoring and that's a reference frame take with you and then you have continuously.. Then you are really, say, really navigating on the right route.

Interviewee 6: One of the first things that I also try to do with monitoring and if I need to look for problems, I first try, what was originally the program of requirements, what were the original settings if they can still be determined. What has changed in the meantime, so that I make a sort of new reference frame of how should this ideally work? And then I just install monitoring to be able to verify my measurements.

Interviewee 6: Prevention is better than cure. Let's learn from that all the buildings that we are now going to tackle that we are now putting down new, that We are going to renovate, that you set them up according to a good process and monitoring right away, so that it actually never can run away in terms of performance and that If it is running away, that people notice in time what is going on.

Interviewee 6: So you ultimately also need a feedback loop, otherwise, we're never going to bring today's problems to light.

Interviewee 6: Transfer the information properly on how it should work so there are parties calculating in the design and they are busy with models and they must transfer this information to the building operator.

Interviewee 6: So it has to do with contracts again that the contracts that we also have in the market now, the contracts that they are more written that the means are described, huh, You have to clean, You must inspect, huh? So You must prescribe what You must do. But we must prescribe more what the result of their activities should be that is, just do maintenance to ensure that there are minimal disruptions and that there are no climate complaints or minimal climate complaints and that your energy performance is within that bandwidth.

Interviewee 6: There is a warranty period, various things are tested out and actually there should be a period, especially for buildings that are more complex that you just have the first 3 years a senior from the design process go along and they will ensure that the building is properly regulated. That everything just, well, that it functions as it was intended and they take that knowledge with them and they take that design intent with them. They understand how it was designed, the principles and they also try to inform the people already, the manager and the maintenance parties of how they should actually act with the building and such a person I think is very decisive.

Interviewee 6: Assign responsibilities to parties that can also influence them. You must impose on the maintenance party that the installation functions perfectly energetically. That it turns off on time and that the efficiencies of the heat pump are good and that the thermal energy storage also functions well. Well then you have peeled that off, then you have the building-bound installations energetically efficient and then you say your user part of Energy. Well then you address the user, then you also write guidelines.

Interviewee 7: We never want to communicate just one number, but always calculate various scenarios so that you also make clear to a client that it will roughly fall between these ranges, but often you see from such a range that it can vary quite a bit, right?

Interviewee 7: There is a bandwidth needed within which the energy performance must fall to achieve Paris proof.

Interviewee 8: It is important to have insight into what those user processes are in the design process. Since that is sometimes still uncertain it is important to establish rules for the use with margins within which the energy consumption must comply.

Interviewee 9: The main argument for me is actually that you just have clear agreements with each other; this is the way we are going to talk about the actual energy efficiency of buildings together.

Interviewee 10: The challenge is to extract what is inside. First with the label you put something in energy-efficient technology. In the operation, the challenge is then to extract what is inside and then you need constant monitoring for that and you need an indicator for that and that's what we call the WEii indicator.

Subtopic	Insights	Mentioned by interviewee 1
(Seasonal) commissioning	Describes the importance of continuous commissioning, driven by data from data points to adapt to actual usage patterns and ensure the building performs as designed post-operation. This includes adjusting building operations based on real-time data and potentially changing requirements like occupancy and weather conditions.	Yes
Continuous monitoring and tuning	Interviewee 1 discusses the practice of continuous commissioning, emphasising data-driven operations where 24,000 data points are collected from buildings to steer maintenance and facility management processes efficiently. They also mention the use of digital twins and AI to manage building operations in real-time based on actual data, ensuring that buildings are adjusted to meet real demands rather than just initial specifications.	Yes
Collaborative Contracts	Although not explicitly discussed in terms of contract structures, there is an implication of collaborative work as Interviewee 1 talks about their role in early stages of building operations to ensure systems are correctly set for actual use and interacting with technical teams and commissioning managers. This suggests involvement in collaborative operational setups, though the specifics of contract forms are not detailed.	Indirectly
Effective Communication and Data Utilisation	Extensively discussed; Interviewee 1 emphasises the importance of using data to drive decisions and the management of buildings. They mention how data from building operations (like occupancy and energy use) is utilised to optimise various services and maintenance tasks. There's also a mention of a system where alerts about building conditions are automatically managed to streamline operations, highlighting effective communication across different stakeholders (maintenance teams, security, etc.).	Yes
Early engagement and training	Interviewee 1 describes their involvement from the early stages of building operations, even before official handover, and stresses the importance of understanding the building and its systems deeply. This ensures they can manage the building effectively from the start, indicating a focus on early engagement and the training of operational teams on the specifics of the building systems they will be managing.	Yes

Subtopic	Insights	Mentioned by interviewee 2
(Seasonal) commissioning	Although not explicitly mentioned as "continuous commissioning," the detailed and ongoing attention to commissioning tasks throughout the project lifecycle suggests an acknowledgment of the need to adapt the building systems continuously to meet actual usage and performance expectations.	Indirectly
Continuous monitoring and tuning	Discussed the importance of monitoring and the role of a consortium in maintaining energy performance. Stressed on actual monitoring versus theoretical models to manage energy use effectively.	Yes
Collaborative Contracts	Mentioned the responsibility shared by the consortium comprising the contractor, installers, and the advisory firm, highlighting collective responsibility for meeting the energy budget and maintaining standards throughout the project lifecycle.	Yes
Effective Communication and Data Utilisation	Stressed on effective communication between project teams and the client to ensure user requirements are met and ambiguities regarding user profiles are clarified, which is crucial for energy efficiency strategies.	Yes
Early engagement and training	Highlighted early involvement in project phases and continuous engagement to ensure the project's energy ambitions are met. Moreover, the need of specific trainings for building operators and coaching for end users is mentioned.	Yes

Subtopic	Insights	Mentioned by interviewee 3
(Seasonal) commissioning	The interviewee highlights the importance of ongoing commissioning throughout all project phases to ensure systems perform according to design intentions. This includes overseeing installation quality and functionality during and after completion.	Yes
Continuous monitoring and tuning	Discusses the importance of data-driven approaches, using digital twins, and machine learning for optimisation. Emphasises the necessity of keeping buildings operating as intended through continuous data analysis.	Yes
Collaborative Contracts	Mentions working within a consortium responsible for a project, which highlights the shared responsibility model in ensuring energy performance goals.	Yes
Effective Communication and Data Utilisation	Highlights the use of data from previous projects to improve future projects and the role of digitalisation in enhancing data flow throughout the project lifecycle.	Yes
Early engagement and training	Not explicitly discussed in terms of training or engaging operators before hand-over.	No

Subtopic	Insights	Mentioned by interviewee 4
(Seasonal) commissioning	Notes the potential benefits of a business model where oversight continues through the use phase, suggesting the need of continuous commissioning. The interviewee mentions the need for commissioning managers pre-hand over, hand-over and in use.	Yes
Continuous monitoring and tuning	Interviewee 4 mentioned the necessity of having commissioning managers who are capable of continuous monitoring and adjustments of building systems to ensure optimal performance. This includes both digital monitoring and physical inspections to address any discrepancies between expected and actual energy performance. The role of technology in real-time data management and system adjustments was emphasised to ensure buildings meet their designed energy efficiencies.	Yes
Collaborative Contracts	The discussion covered the benefits of forming consortiums where multiple stakeholders, including contractors and operators, share responsibility for achieving energy targets. This approach is intended to foster a cooperative environment from the project's inception through to its operational phase, ensuring all parties are equally invested in the building's energy outcomes.	Yes
Effective Communication and Data Utilisation	Stressed the importance of effective communication channels among project teams and the strategic use of data to guide decisions. This involves making energy use data accessible and actionable for all parties involved, including non-technical stakeholders, to foster a common understanding and proactive management of energy goals.	Yes
Early engagement and training	Highlighted the critical importance of engaging operation and maintenance teams early in the project to ensure they have a thorough understanding of the building's energy systems and goals. Training these teams on the specific technologies and operational strategies of the building is crucial for seamless transition to efficient operations post-handover.	Yes

Subtopic	Insights	Mentioned by interviewee 5
(Seasonal) commissioning	The interviewee discusses starting tests and system checks about half a year before completion to ensure systems are operating correctly before full building operations commence.	Yes
Continuous Monitoring and Tuning	Stressed the importance of detail-level monitoring to understand tenant energy use and optimise building performance.	Yes
Collaborative Contracts	Discussed the involvement of different parties during project phases, emphasising the role of initial design and operational teams, however the use of contracts are not directly mentioned.	Indirectly
Effective Communication and Data Utilisation	Highlighted the lack of knowledge transfer and the need for better integration and communication among operators and developers.	Yes
Early Engagement and Training	Emphasised the importance of early engagement, training, and the handover process to ensure the building operates efficiently.	Yes

Subtopic	Insights	Mentioned by Interviewee 6
(Seasonal) commissioning	The interviewee discusses the importance of involving a commissioning authority early in the design phase, integrating commissioning activities in construction planning, and managing commissioning tests and post-handover maintenance. He/she emphasises that for simple installation concepts, a commissioning manager can perform these tasks.	Yes
Continuous monitoring and tuning	Discussed a software for smart meter data analysis that identifies operational inefficiencies for ongoing optimisation.	Yes
Collaborative Contracts	Implied the importance of multi-stakeholder engagement for effective building operations, although not explicitly named.	No
Effective Communication and Data Utilisation	Stressed the necessity for clear communication and the use of data to bridge the gap between design and operation.	Yes
Early Engagement and Training	Indirectly highlighted need of operators to understand the energy goals and operational strategies of buildings and the importance of a guarantee period in order to make this happen. Moreover, he/she mentions the need of instructions for the end users	Yes

Subtopic	Insights	Mentioned by interviewee 7
(Seasonal) commissioning	He/she emphasises a growing interest in data and measurements during the operational phase to understand real-world performance and make informed decisions, reflecting a data-driven approach to managing building systems after they are operational.	Indirectly
Continuous monitoring and tuning	Discusses the importance of collecting data on energy usage and linking it to building properties and user types to potentially eliminate the need for simulations, suggesting reliance on real-world data instead.	Yes
Collaborative Contracts	The interviewee does not mention this subject	No
Effective Communication and Data Utilisation	Emphasises the importance of not committing to a single prediction or number but rather providing a range of scenarios to the client, indicating a nuanced approach to communicating expectations around energy use.	Yes
Early engagement and training	The interviewee indirectly mentions this by mentioning the need of trainings in order to make calculations for the WEii certification and in order to document the data collection correctly	Indirectly

Subtopic	Insights	Mentioned by interviewee 8
(Seasonal) commissioning	The interviewee does not mention (seasonal) commissioning	No
Continuous monitoring and tuning	The interviewee emphasises the shift of monitoring responsibilities to installers and notes that his firm is not involved in post-setup adjustments, highlighting the importance of continuous engagement for sustained energy performance.	Yes
Collaborative Contracts	The interviewee describes his/her involvement in projects from the design phase through to the delivery, which reflects the collaborative effort necessary across different stages of building projects to meet energy goals. He/she does not directly mention collaborative contracts but discusses the importance of roles and responsibilities.	Indirectly
Effective Communication and Data Utilisation	The interviewee points to significant issues with managing expectations and misunderstandings in energy definitions in the building sector. This illustrates the critical need for effective communication and proper utilisation of data to bridge expectation gaps and enhance understanding among all stakeholders.	Yes
Early engagement and training	The need for clear understanding of building use and energy performance expectations from the initial stages of design is discussed, reflecting the importance of early engagement and potentially training of stakeholders to ensure alignment with energy goals.	Yes

Subtopic	Insights	Mentioned by Interviewee 9
(Seasonal) commissioning	No specific mentioned	No
Continuous monitoring and tuning	Discusses the importance of practical measurements over theoretical calculations and highlights real usage measurements in energy management. This ties into continuous optimisation, albeit not explicitly mentioning AI or machine learning.	Yes
Collaborative Contracts	While not explicitly discussed, the interviewee talks about the collective efforts in standard setting and certification in energy management which suggests an indirect reference to collaborative work. However, specifics on contracts or consortium responsibilities are not mentioned.	No
Effective Communication and Data Utilisation	The importance of robust buildings, user understanding, and clear information flow is discussed, which is related to data utilisation for better operational strategies.	Yes
Early engagement and training	Mentions training and certification programs, indicating the engagement of parties in understanding energy performance goals.	Yes

Subtopic	Insights	Mentioned by interviewee 10
(Seasonal) commissioning	No discussion on (seasonal) commissioning	No
Continuous monitoring and tuning	Emphasised steering based on actual energy use data rather than theoretical models. Advocated for ongoing updates to standards to match real-world conditions, highlighting the use of continuous performance data.	Yes
Collaborative Contracts	While not explicitly mentioned, there were references to shared responsibilities in sustainability efforts and the collaborative nature of maintaining standards, suggesting a partial alignment with this Subtopic.	Partially
Effective Communication and Data Utilisation	Detailed the challenges of setting up and regulating systems correctly, user behaviour's impact on energy use, and the consequences of poor communication in system use and settings.	Yes
Early engagement and training	Highlighted problems with knowledge transfer and proper system use post-handover. Discussed the need for early engagement and correct training to ensure operational efficiency and understanding of systems.	Yes

12.8 Results WEii calculation

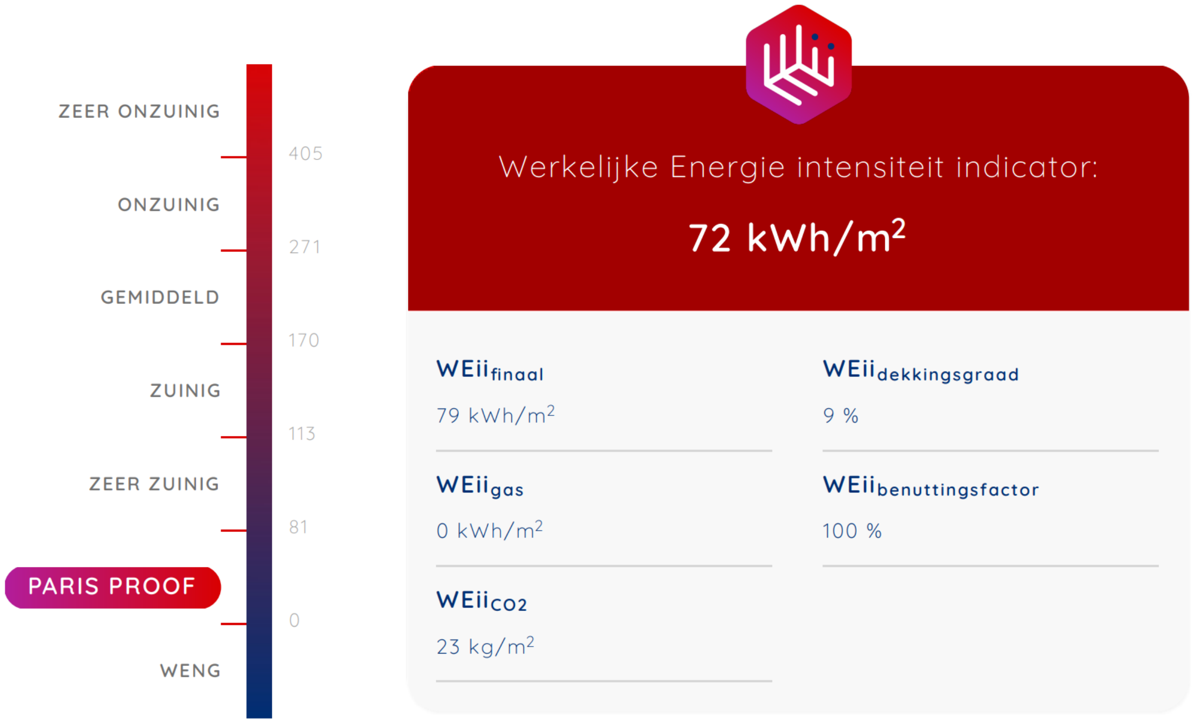

Figure 37: Paris Proof score (WEii, 2023)

Energy consumption

Year	2023	
Electricity	855593	kWh
Neutral Gas	-	m^3
Solid Biomass	-	kg
Hydrogen	-	m^3
Heat	1356	GJ
Cold	-	GJ
Oil	-	ltr
Propane gas	-	ltr

Figure 38: Energy data (WEii, 2023)

Excluded energy

Electricity	Charging station for electric cars	121947	kWh
Electricity	Building-spanning data centre	12802	kWh

Measured solar energy generation

Energy generation		87000	kWh

Energy label

Energy label		A+++	

WEii and reference values

WEii-score		72	kWh/m^2
Reference value Paris Proof	The WEii-score with which the building would comply with Paris Proof	81	kWh/m^2
Average WEii-score reference value	The average WEii-score for a building with the same surface area and the same functional uses as this building		

WEii and reference values

Nearest weather station			Schiphol
Weather correction	Correction of energy use to standard weather conditions	4.623	kWh
WEii without weather correction		72	kWh/m^2

Additional factors

WEii final	The final energy use of the building per m² per year. This is the energy taken from the net plus local generation minus the return to the grid	79	kWh/m²
WEii gas	Actual use of fossil energy sources per m² per year, converted to kWh/m²	0	kWh/m²
WEii CO2	CO2 emission per m² per year	23	kg/m²
Total CO2 emission	CO2 emission factors on WEii.nl	270.405	kg
WEii coverage	Summed over the year, direct use of locally generated energy as a percentage of the final energy use over the same year	9	%
WEii utilization factor	Summed over the year, direct use of local generation as a percentage of total local generation in the same year	100	%

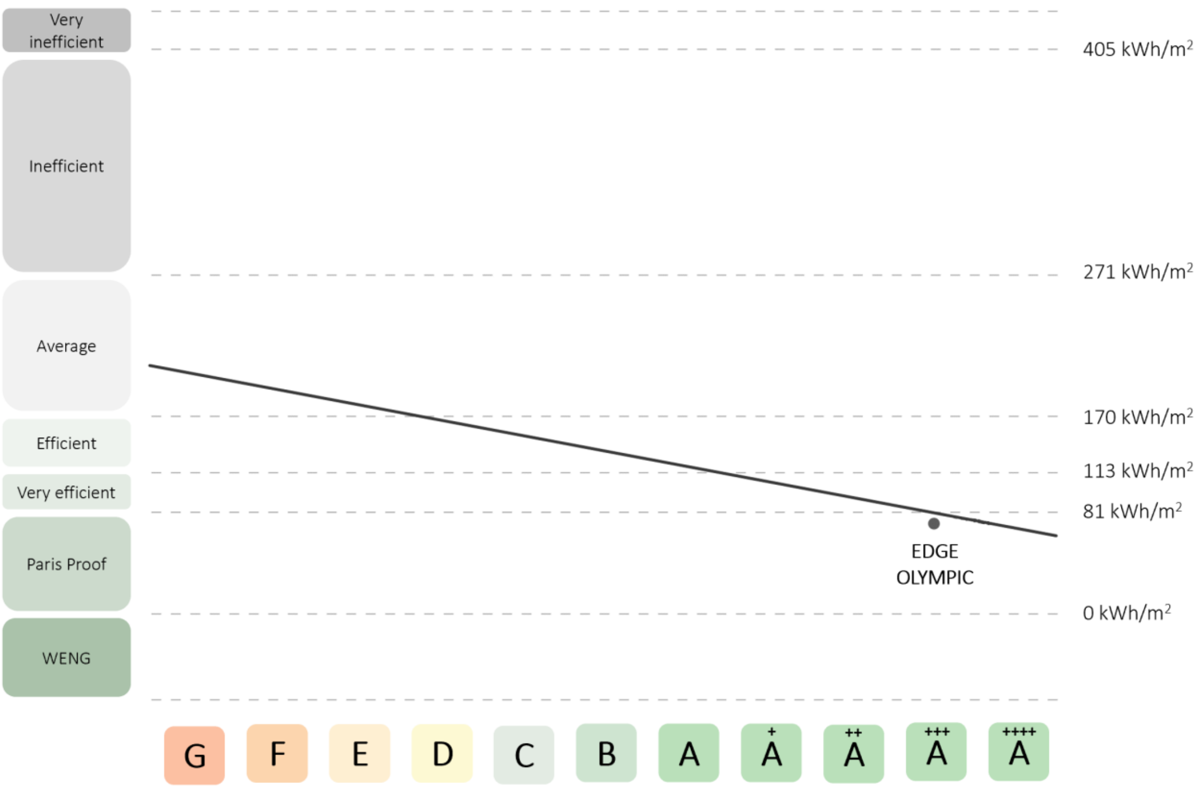

Figure 39: Energy label versus the WEii classes (WEii, 2023)

12.9 Energy performance calculation Edge Olympic

Results	
Primary energy use	[MJ]
Heating	735.212
Hot water	289.382
Cooling	287.333
Humidification	0
Ventilation	443.323
Lighting	1.154.611
Total	**2.909.862**
Electricity production building-bound	-219.819
Withdrawn energy	2.690.043
Exported energy	-2.463.947
Electricity production not building-bound	-233.261
EPtot	**-7.165**
EP;adm,tot	3.076.471
Specific energy performance per m²	0
Calculation Step	
EPtot / EP;adm,tot	-0,002
Satisfies E/E	Yes
Preliminary BENG Indicators	
Energy need [kWh/m² per year]	39,7
Primary energy use [kWh/m² per year]	2,9
Renewable energy [%]	92,1
Ag;total area	11.517.00 m²
Loss:	2.000.00
Electricity production in the area per m²	106.97 MWh/m²

12.10 Actual energy performance Edge Olympic

date	month	eolectricity_usage	electricity_officehours	electricity_otherhours	kwh_cost	kwh_compare_%	kwh_cumm_year	kwh_cumm_year_%	kwh_elec_otherhours_%	heat_usage_kwh	heat_cost	heat_compare_%	heat_cumm_year	heat_cumm_kwh_ear	heat_cumm_year_%
Dec/23	12	66.213	45.671	20.542	7.113	109%	855.593	106%	31%	58.921	8.777		1.368	379.975	117%
Nov/23	11	73.986	57.344	16.642	8.039	109%	789.380	106%	22%	58.171	8.677	223%	1.156	321.053	125%
Oct/23	10	75.427	57.843	17.584	8.187	114%	715.394	106%	23%	24.585	4.210	120%	946	262.882	124%
Sep/23	9	74.360	56.187	18.173	8.061	107%	639.967	105%	24%	2.195	1.490	7%	858	238.297	123%
Aug/23	8	72.960	55.770	17.190	7.915	100%	565.607	105%	24%	1.528	1.143	5%	850	236.102	129%
Jul/23	7	70.725	51.432	19.293	7.627	102%	492.647	108%	27%	389	992	1%	844	234.574	128%
Jun/23	6	82.721	59.187	23.534	8.978	117%	421.922	110%	28%	2.500	1.616	6%	843	234.185	128%
May/23	5	68.275	50.553	17.722	7.416	111%	339.201	108%	26%	44.726	5.320	99%	834	231.685	142%
Apr/23	4	62.131	43.314	18.817	670	108%	270.926	109%	30%	28.669	8.693	93%	673	186.959	129%
Mar/23	3	76.113	58.597	17.516	8.265	119%	208.795	112%	23%	53.504		178%	570	158.290	109%
Feb/23	2	64.416	48.277	16.139	6.975	118%	132.682	112%	25%	45.615	13.276	79%	377	104.786	94%
Jan/23	1	68.266	50.483	17.783	10.688	124%	68.266	117%	26%	59.171	16.943	86%	213	59.171	99%
Dec/22	12	63.049	44.312	18.737	6.474	90%	810.432	111%	30%	66.172	8.649	794%	1.166	323.859	109%
Nov/22	11	69.675	53.111	16.564	7.218	111%	747.383	112%	24%	45.170	6.129	138%	928	257.687	68%
Oct/22	10	68.311	51.774	16.537	7.070	97%	677.708	112%	24%	19.196	3.083	89%	765	212.517	62%
Sep/22	9	70.879	55.310	15.569	7.361	101%	609.397	113%	22%	10.612	2.077	114%	696	193.321	62%
Aug/22	8	80.899	63.113	17.786	8.408	115%	538.518	114%	22%	-	833	0%	658	182.709	61%
Jul/22	7	73.268	54.255	19.013	7.570	105%	457.619	112%	26%	-	833	0%	658	182.709	64%
Jun/22	6	71.392	51.141	20.251	6.749	101%	384.351	112%	28%	7.723	2.214	101%	658	182.709	65%
May/22	5	65.384	48.357	17.027	6.749	118%	312.959	115%	26%	11.779	2.214	71%	630	174.986	64%
Apr/22	4	60.322	42.068	18.254	6.189	116%	247.575	115%	30%	18.363	2.976	52%	588	163.208	65%
Mar/22	3	68.755	51.182	17.573	7.104	101%	187.253	117%	26%	33.280	4.744	64%	521	144.845	72%
Feb/22	2	60.248	44.102	16.146	6.213	86%	118.498	117%	27%	52.088	6.940	92%	402	111.564	79%
Jan/22	1	58.250	40.484	17.766	8.321	80%	58.250	113%	30%	59.477	7.806	84%	214	59.477	76%
Dec/21	12	58.532	41.627	16.905	6.117	81%	727.402	87%	29%	59.894	5.367	80%	1.586	440.563	120%
Nov/21	11	65.625	48.472	17.153	6.889	86%	668.870	85%	26%	38.475	3.742	77%	1.370	380.669	132%
Oct/21	10	64.110	47.389	16.721	6.728	79%	603.245	84%	26%	29.030	3.025	92%	1.232	342.194	140%
Sep/21	9	67.501	52.650	14.851	7.124	78%	539.135	82%	22%	15.279	2.233	83%	1.127	313.164	144%
Aug/21	8	64.833	49.363	15.470	6.824	70%	471.634	80%	24%	11.418	1.669	129%	1.072	297.885	146%
Jul/21	7	64.956	49.370	15.586	6.835	73%	406.801	80%	24%	5.028	1.204	85%	1.031	286.467	143%
Jun/21	6	69.754	54.454	15.300	7.364	85%	341.845	78%	22%	6.917	1.347	61%	1.013	281.439	144%
May/21	5	57.131	41.245	15.886	5.978	80%	272.091	75%	28%	21.835	2.479	111%	988	274.522	147%
Apr/21	4	54.705	40.204	14.501	5.733	80%	214.960	69%	27%	52.754	4.625	199%	910	252.687	144%
Mar/21	3	59.361	46.025	13.336	5.063	73%	160.255	61%	22%	58.144	5.234	112%	720	199.933	126%
Feb/21	2	49.142	35.808	13.334	4.162	59%	100.894	55%	27%	63.422	4.121	116%	510	141.789	126%
Jan/21	1	51.752	35.706	16.046	7.497	60%	51.752	55%	31%	78.367	6.769	96%	282	78.367	125%
Dec/20	12	55.965	40.131	15.834	4.611	70%	838.899	76%	28%	78.173	6.818	103%	1.318	366.168	72%
Nov/20	11	62.355	45.959	16.396	5.157	75%	782.934	77%	26%	43.170	4.121	67%	1.037	287.995	66%
Oct/20	10	60.973	44.502	16.471	5.036	68%	720.579	78%	27%	26.780	2.862	95%	881	244.825	65%
Sep/20	9	73.218	56.536	16.682	6.093	82%	659.606	80%	23%	14.223	1.897	89%	785	218.045	64%
Aug/20	8	75.559	56.508	19.051	6.265	77%	586.388	81%	25%	3.306	1.050	36%	734	203.822	64%
Jul/20	7	74.611	54.014	20.597	6.165	78%	510.829	83%	28%	5.250	1.199	161%	722	200.516	66%
Jun/20	6	71.429	53.484	17.945	5.923	89%	436.218	86%	25%	8.445	1.446	118%	703	195.266	66%
May/20	5	53.913	36.721	17.192	4.417	71%	364.789	88%	32%	11.140	1.653	79%	673	186.821	66%
Apr/20	4	49.441	30.252	19.189	4.008	79%	310.876	95%	39%	17.307	2.128	97%	632	175.681	69%
Mar/20	3	77.123	51.581	25.542	6.348	118%	261.435	108%	33%	45.726	4.318	157%	570	158.374	72%
Feb/20	2	90.685	62.682	28.003	7.468	134%	184.312	119%	31%	50.060	4.652	168%	406	112.648	70%
Jan/20	1	93.627	67.178	26.449	10.820	175%	93.627	120%	28%	62.588	5.617	124%	225	62.588	62%
Dec/19	12	88.448	58.522	29.926	6.167	124%	1.103.664	142%	34%	71.867	6.364	90%	1.822	506.124	272%
Nov/19	11	90.902	64.463	26.439	6.390	119%	1.015.216	143%	29%	57.171	5.211	79%	1.563	434.257	409%
Oct/19	10	100.597	72.172	28.425	7.083	128%	924.314	146%	28%	36.642	3.613	183%	1.357	377.086	1123%
Sep/19	9	100.752	67.254	33.498	7.035	131%	823.717	149%	33%	22.418	2.507	232%	1.226	340.444	2501%
Aug/19	8	110.027	71.624	38.403	7.662	129%	722.965	152%	35%	14.418	1.885	365%	1.145	318.025	8062%
Jul/19	7	103.193	74.075	29.118	7.119	117%	612.938	157%	28%	6.528	1.271	0%	1.093	303.608	0%
Jun/19	6	93.563	61.192	32.371	6.447	138%	509.745	169%	35%	14.307	1.876	0%	1.069	297.079	0%
May/19	5	88.321	61.635	26.686	6.132	140%	416.182	178%	30%	28.169	2.954	0%	1.018	282.773	0%
Apr/19	4	86.747	58.408	28.339	5.997	222%	327.861	192%	33%	35.753	3.544	0%	917	254.604	0%
Mar/19	3	85.843	58.901	26.942	5.948	193%	241.114	183%	31%	58.088	5.282	0%	788	218.851	0%
Feb/19	2	77.036	54.898	22.138	5.162	132%	155.271	178%	29%	59.755	5.412	0%	579	160.763	0%
Jan/19	1	78.235	53.917	24.318	8.765	272%	78.235	272%	31%	101.008	8.621	0%	364	101.008	0%
Dec/18	12	71.509	44.251	27.258	4.697	100%	779.196	100%		79.840	6.201	100%	670	186.070	100%
Nov/18	11	76.383	53.419	22.964	5.091	100%	707.687	100%		72.645	5.710	100%	382	106.231	100%
Oct/18	10	78.856	55.227	23.629	5.256	100%	631.304	100%		19.974	2.115	100%	121	33.586	100%
Sep/18	9	77.157	51.398	25.759	5.112	100%	552.448	100%		9.667	1.412	100%	49	13.612	100%
Aug/18	8	85.476	60.149	25.327	5.701	100%	475.291	100%		3.945	665	100%	14	3.945	100%
Jul/18	7	88.251	58.890	29.361	5.849	100%	389.815	100%		-	-	100%	-		100%
Jun/18	6	67.830	44.072	23.758	4.481	100%	301.564	100%		-	-	100%	-		100%
May/18	5	63.151	37.865	25.286	4.134	100%	233.734	100%		-	-	100%	-		100%
Apr/18	4	39.019	23.046	15.973	4.860	100%	170.583	100%		-	-	100%	-		100%
Mar/18	3	44.531	24.929	19.602	3.599	100%	131.564	100%		-	-	100%	-		100%
Feb/18	2	58.249	29.400	28.849	5.292	100%	87.033	100%		-	-	100%	-		100%
Jan/18	1	28.784	18.447	10.337	4.778	100%	28.784	100%		-	-	100%	-		100%

Table 13: EV-box Energy of charging station in kWh (TPex, 2024)