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A qualitative and life cycle-based study of the energy performance gap in building construction: Perspectives of Finnish project professionals and property maintenance experts

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ABSTRACT

The significant share of buildings from total energy consumption across the world has been mentioned and emphasized very well by several scholars. In this regard, there have been major developments and improvements in the expertise of developing and designing buildings to be adequately energy efficient. However, the recent studies show that there is still a considerable deviation between the intended and actual energy consumption of the completed buildings. Hence, this exploratory study aims to discover the origin of success and failure in achieving energy efficiency in building construction projects with a life cycle perspective and based on viewpoints of key participants in the project and constructed building's operation. To do so, 21 semi-structured interviews were conducted with Finnish project professionals representing client, design/planning experts, contractors and building operation/maintenance experts. Both thematic analysis and content analysis methods were employed for analysing the obtained research data. The findings reveal a set of challenges/barriers and solutions/enablers which account for failure and success of achieving energy-efficient buildings. The obtained results contribute to the existing body of knowledge and practices on achieving energy efficiency in building construction projects.

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Building construction; building energy consumption; construction management; sustainability; energy performance gap

Introduction

The significant role of buildings in global energy consumption has been recognized very well by the research community. According to the previous studies, buildings almost account for the 40% of the whole energy consumption in the world (e.g. Laconte & Gossop, 2016). This fact, in turn, has triggered the research community and regulatory bodies in the built environment sector to ponder about the causes and also the possible solutions. In the European Union, the Energy Performance of Buildings Directive (EPBD) was implemented to guarantee that new buildings would be much more energy efficient than those built in the past (Directive 2010/31/EU).

In this regard, there have been also major developments and improvements in designing energy-efficient buildings. An example of these developments is the theoretical and practical advancements in building information modelling, energy simulation and calculation methods, and use of hybrid energy systems. However, other studies show that there is still a considerable deviation between the energy consumption target, specified in the design phase and the actual performance of constructed building in terms of energy consumption. Laconte and Gossop (2016) stated the actual energy consumption of buildings is usually two or even three times bigger than the design intentions.

The mentioned deviation, which is called the performance gap, can be seen as one of the major obstacles in developed and developing countries which are trying to transform their built environment sector into carbon neutrality era. Such performance gaps have been observed in existing buildings, building retrofit projects and new construction (e.g. Mahdavi et al., 2021). The gap exists both between simulated and actual performance and between the target set by regulations vs. the actual performance (Zou et al., 2018). Even buildings certified to be energy-efficient often consume more energy than their conventional counterparts. While energy certificates can serve as a good indication of energy efficiency at a design level, they do not show whether the building is performing as well as it is supposed to. To take into account the actual use of the

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building and its practical performance, energy efficiency should be examined through the lens of energy consumption targets that have been set for each specific building and type of energy. Thus, the performance gap between the targeted and actual energy consumption provides a useful look at energy efficiency on a practical level.

The performance gap increases the operation cost of the building in its life cycle which negatively affects both the building owner and users. Higher energy consumption will increase the carbon footprint of the building, while incorrectly dimensioned or operated systems can also negatively impact the indoor air quality and temperature conditions within the building. Considering the negative impact of the performance gap, it is imperative to study this phenomenon in an in-depth manner. In this regard, there have been a few studies conducted to address the barriers of energy efficiency in building construction projects (Häkkinen & Belloni, 2011; Liang et al., 2019; Qian et al., 2015). However, it seems that adopting a life cycle perspective and addressing all the involved disciplines in building construction projects has been almost overlooked. Consequently, there is currently very limited research-based knowledge on the barriers and solutions of energy efficiency through the lens of different disciplines involved in phases of project life cycle.

In order to the fill the mentioned knowledge gap, this study aims to explore and overcome the challenges and barriers of achieving energy efficiency in building construction projects. The resultant article is structured in six sections. The next section includes the theoretical background on the subject under study, which is followed by the explanation of the data collection and analysis process in the Methodology section. Then, the obtained results are presented and discussed. Finally, the conclusions are stated.

Theoretical background

Previous research on barriers and enablers of achieving energy efficiency in building construction projects

Barriers/challenges

Despite the environmental and even economic benefits of energy-efficient buildings, many new buildings end up consuming more energy than necessary. There are many reasons for this issue, ranging from the technical and regulatory level to knowledge and psychology. In this regard, there have been a few studies, which are explained and discussed in the following.

Häkkinen and Belloni (2011) performed the literature review and surveyed and interviewed Finnish experts on sustainable buildings. They found that the major barriers to sustainable building relate to steering mechanisms, economics, lack of client understanding, process and underpinning knowledge, including access to methods and tools. In addition, Frei et al. (2017) reviewed many energy performance gap studies and noted that the causes of the energy performance gap can be linked to three life cycle phases of the building: (i) design and planning (poor early design decisions, uncertainty in energy modelling, oversizing of systems), (ii) construction and commissioning (economy over design, poor commissioning) and (iii) operation (equipment issues, user interaction, change of building purpose). Moreover, interviews by Dadzie et al. (2018) revealed that in Australia, many barriers to energy renovation relate to the financial side, such as the cost of sustainable technologies, perceived poor payback period, unreliable energy-savings projections and hidden costs of renovation. Existing design and age of buildings also serve as barriers. Demolish-and-build is perceived to be a more economical alternative to retrofitting of existing buildings.

Furthermore, based on a Norwegian survey of property owners, consultants and property managers in 2018, the greatest barriers to building's usability and lifetime value creation were found to be the bad decisions made in the early-phase planning (Boge et al., 2018). Avoiding moderate investments in the early stage often requires substantial investments at a later stage to remedy. Not solving the issues in the early stage may even result in irreversible problems in the operation phase.

In the same year, energy audits of office buildings were done in Brazil to map the issues that lead to problems with energy efficiency and indoor environmental quality (Borgstein et al., 2018). In a result of this effort, 38 failure modes relating to energy performance were encountered. In small buildings, most of the problems were caused by management failure (bad contracts, guidelines without energy performance requirements, lack of proper setpoints and documentation, and high night-time loads). In large buildings, the issues were typically related to improper operation of systems. With the large floor plans, there are also typically too large control zones, where the automation does not work correctly. In both small and large buildings, failures happened mostly due to the operation and maintenance procedures and could be fixed without installing new equipment.

Besides previous research efforts, Liang et al. (2019) surveyed facility managers of commercial buildings in the United States to understand the reasons for the energy performance gap. The primary reasons found for the gap were occupants using more energy than designed, there being more occupants than designed and the failure of energy-efficient technologies. It was speculated that higher than expected occupant energy consumption often results from green building certification or the fact that perceived energy efficiency encourages wasteful behaviour (i.e. the rebound effect). The survey also revealed that facility managers were generally expected to work on improving energy efficiency in their buildings but were not incentivized nor really required to do so. In another study, Willan et al. (2020) examined how various building construction actors talk about the performance gap. The observed discourse indicated that in fear of being held liable for any performance gap, instead of trying to reduce the gap, construction actors instead tend to rationalize the gap as an unavoidable difference between ‘theory’ and ‘reality’. Similar findings were reported by Markus et al. (2022) through exploration of facility managers’ responses to given data and KPIs collected from the buildings they supervise. Unfamiliarity with data-driven methodologies and tools and the aversion to risk in building operations may lead to disinterest in optimal control strategies and deter actionable insights from data-driven building operations analytical approaches. Long-term insights generated through complex computational analyses may seem distant to existing heuristics and experience-based decision-making methods. Hesitancy may especially be faced if the data-based recommendations conflict with existing operating procedures.

Rasmussen and Jensen (2020) noted that alongside the energy performance gap, there are other types of building performance gaps, such as those related to operations and indoor conditions. However, the gaps are often interdependent, with shared causes for the different challenges. On the other hand, closing one performance gap might widen another type of performance gap. Interviews with Danish experts and focus groups revealed that performance gaps should be examined from various viewpoints, as building clients and facility managers may not share priorities. The performance gap was also noted to be project specific, meaning that even different types of facility managers may not perceive the same gap as the most important one.

López-Bernabé et al. (2021) surveyed Spanish hotel owners to find out why the adoption of energy efficiency measures in hotels is so low. While hotel owners considered energy efficiency to be important, the majority of respondents did not know how much energy their buildings consume and what is the cost of energy. Ironically, establishments with appropriate thermal insulation regarded energy efficiency improvement as less important. Perceived good energy performance can thus reduce the interest towards other energy efficiency measures.

The Soft Landings framework is a multi-stage process intended to ensure that the energy performance of buildings is on the intended level. Samarakkody and Perera (2023) examined the barriers to the adoption of the process in Sri Lanka. One important barrier was the lack of interest towards building performance. Another key barrier was the lack of industry standards and that quality certifications are not really adhered to. Other barriers were industry concerns on corruption, procurement challenges, high construction costs, adverse impacts of government changes, lack of appropriate policies and delays in administration and approvals. The inefficiency of the local government and public administrative bodies were seen as the reason for the existence of many of the perceived barriers.

Kazemi and Kazemi (2022) examined the financial barriers to residential buildings’ energy efficiency in Iran. The main barriers were misplaced incentives and distortionary fiscal and regulatory policies as well as unpriced costs and benefits, fear of hidden costs, and a focus on initial cost. Mistaken beliefs in energy efficiency also served as an obstacle. Finally, in a recent study, Too et al. (2023) performed interviews and examined project reports and documentation to reveal a lack of effective handover procedures after the completion of building projects.

Enablers/solutions

While various studies have identified many types of obstacles for energy-efficient construction, those same studies typically also reveal enablers that can help solve the issues and increase the uptake of energy-efficient building solutions. According to Häkkinen and Belloni (2011), promotion of sustainable building requires improving the awareness of clients about the benefits of sustainable building and the adoption of methods for sustainable building requirements management. Designers’ competence and teamwork skills were also important. New tools and services should be developed and utilized.

Li and Yao (2012) recommended establishing stricter compliance and verification systems to guarantee that energy efficiency standards are implemented in practice. There should also be policies to remove structural barriers between construction professionals and all the other stakeholders in creating, operating and using buildings. Increased access to data on actual building performance would help confirm actual energy performance of buildings and the efficacy of any energy efficiency policies. Frei et al. (2017) suggested data collection and monitoring and improved commissioning and management to improve building performance on the operational side. Training, design improvements and better communication between different stakeholders, alongside energy performance contracts were also found important.

According to Boge et al. (2018), a building's usability and lifetime value creation is largely determined by decisions made in the early-stage planning. More resources utilized in early-stage planning will reduce costs and problems later. Just time and attention are often adequate when the issues are addressed early enough. Facility management planning should also be started right at the beginning of construction projects to ensure successful facility management in the operational phase.

In the case of small office buildings, Borgstein et al. (2018) found out that even simple checklists to identify performance failures could be used to improve building performance. As users have more control, the systems should be kept as simply as possible. In large buildings with more complex systems, commissioning and finetuning of operational parameters are needed. Investments into building automation would also improve energy efficiency.

Liang et al. (2019) noted that to reduce energy consumption in buildings, facility managers should be incentivized to do so, for example, through rebates based on saved energy. The need for continuous energy consumption monitoring was highlighted. Energy performance targets and contracts would be useful for energy efficiency. Influencing the occupants' behaviour was also found to be important. Proper commissioning procedures and continuous monitoring as a way to achieve energy efficiency was also proposed by Mikhail et al. (2023). Knowledge of energy consumption at each moment of time allows finetuning of setpoints and system start times. Buildings should be designed with variable occupation in mind, so that the building energy systems can adjust to non-uniform occupation of spaces and distinguish between occupied and unoccupied hours.

Willan et al. (2020) suggested that in addition to energy performance targets, there need to be incentives for companies to take responsibility for those targets. This could be realized through public procurement contracts that encourage collaboration and innovation, instead of focusing on accountability. Markus et al. (2022) noted that improving energy efficiency should be a key role of building operators and facility managers. This includes short- and long-term interventions to controls and equipment maintenance to continually improve building energy performance. Education of the operational staff is required so that there is enough understanding to apply insights obtained from data-driven methods, especially if such actions contradict existing operating procedures. Rasmussen and Jensen (2020) emphasized a multi-disciplinary view of building performance gaps. When solving one issue (e.g. energy performance), care should be taken to avoid worsening other issues (e.g. indoor air quality).

López-Bernabé et al. (2021) reported that information-based policy instruments such as labels, energy audits and feedback on bills would be useful to increase energy efficiency adoption in the hotel industry. Lower HVAC system prices and labels with additional monetary information on the impact of efficiency improvement would increase interest in energy efficiency. Mandatory energy efficiency standards would increase adoption among those who generally choose cheaper and low-quality equipment. Samarakkody and Perera (2023) proposed the application of the Soft Landings (SL) framework to reduce the building performance gap in Sri Lanka. the existence of a significant performance gap serves as a motivator to implement SL. To enable the use of SL, there need to be available building environmental assessment methodologies and certifications. Clients and facility managers need to be educated on the gap and the framework. Other enablers are increased valuation of cross-disciplinary collaboration and good practices followed by market leaders.

Providing more financial options through loan financing, grants, subsidies and fiscal incentives were recommended as solutions to increase the uptake of energy efficiency measures in Iranian buildings (Kazemi & Kazemi, 2022). Better regulation as well as training and information programmes were also recommended. Accounting for the negative environmental costs of fossil fuel supply chains would make energy-efficiency a more economically feasible choice.

Research gap

A large number of different barriers for energy efficiency have been identified in past studies, with corresponding solutions to enable improved building performance. The issues vary country by country and by building type. In some regions, the problems relate mainly to facility management procedures, while elsewhere the issue might be inadequate enforcement of regulations or lack of communication and proper performance incentives. However, it is clear that the energy performance gap can result from decisions and actions made in each stage of the construction process and that various professionals have different views and priorities on the issues. This study sets out to provide a comprehensive view of the issue in the Finnish construction industry by separately looking at each phase of the construction process and by involving professionals specifically responsible for each of those phases.

Methodology

Research design

This study aims to explore and overcome the challenges/barriers of achieving energy efficiency in building construction projects. Due to the existence of literature related to the topic under study, the deductive approach was adopted (Saunders et al., 2019). Consequently, literature study and semi-structured interviews were selected as the data collection methods. The exploratory purpose of the research seemed to justify the selection of the semi-structured interview as the data collection method, and thematic as well as content analysis as the data analysis methods (Saunders et al., 2019). The next step was defining the context and selecting the sampling method. Building construction and renovation projects were selected as the focus of the study. In terms of the building type (construction category), the interviewed professionals' latest project represented constructing or renovating residential buildings, institutional buildings (i.e. school and hospital) and commercial buildings (i.e. shopping mall and office building). Regarding the sampling method, a combination of quota sampling and purposive sampling method was utilized in this study through which the research team defined four groups of interviewees including client project manager, contractor project manager, design manager, and maintenance experts and targeted at least five interviewees in each group. According to the data collection possibilities and available time as well as resources, the goal was to interview at least five people in each interviewee group. Then, the research team filled each quota by intentionally choosing individuals (i.e. interviewees) who was in the possession of relevant knowledge and experiences related to the quota and the research topic.

Data collection

Following the selection of the sampling method, the protocol and questions of the semi-structured interviews were formulated. The developed questions aimed to the explore the causes behind the energy performance gap in building construction projects based on the viewpoints of different project parties and their representatives, involved in different phases of project life cycle. The action was theoretically justified through the findings of the study conducted by Rasmussen and Jensen (2020), suggesting that performance gap should be examined from various viewpoints. The interview protocol and questions can be seen in the Appendix.

The developed interview protocol and questions were piloted in the first three interviews to seek feedback from the interviewees. Since there was neither negative feedback nor any changes in the interview protocol and questions, the first three interviews, which had been conducted with piloting purpose, were also considered valid to be analysed in the data analysis stage.

Then, 21 semi-structured interviews were conducted in Finland with project professionals representing client, design/planning experts, contractors and building operation/maintenance experts. The interview panel was consisted of three individuals of which the first one was the leading researcher (i.e. main author of this article), the second one was a native Finnish speaking member of the research team (the second author of this article) who asked the main and follow up questions in Finnish language, and the third member of the interview panel was a colleague with a background in building energy efficiency. The interviews were audio recorded based on the obtained consent from the interviewees.

Demographic information of the interviewees

Figure 1 shows the gender, age group and experience of the interviewees. In addition, Table 1 shows interviewees' discipline, role and their latest project's type, budget, and duration.

Data analysis and results validation

The conducted interviews were transcribed and translated to the English language by the native Finnish-speaking member of the research team. Then, the translated transcripts were reviewed by the leading researcher to identify the challenges/barriers and solutions/enablers of energy efficiency realization in the project and product (i.e. constructed building) life cycle. The extracted research data was then inductively coded (Saunders et al., 2019). Qualitative coding is a process of systematically categorizing excerpts in the qualitative data (i.e. interview transcripts in this study) in order to find themes and patterns. The labels of the codes were data derived by the researcher (Saunders et al., 2019). In result of this effort, 51 codes were generated. These generated codes were then reviewed by the leading

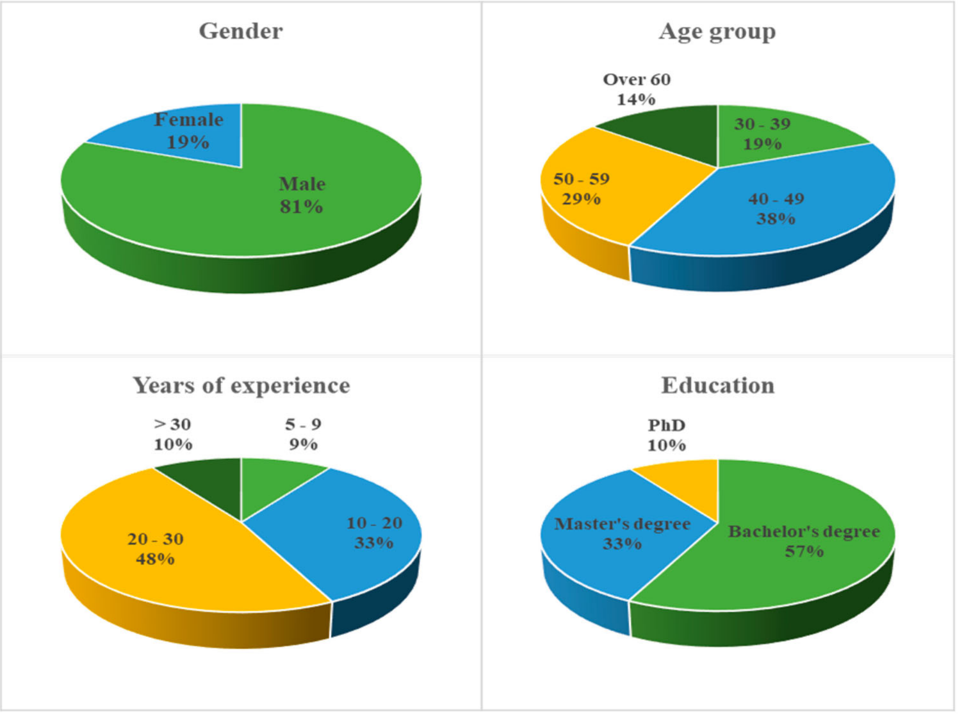

Figure 1. Demographic information of the interviewees.

Table 1. Interviewees' discipline, role and their latest project's type, budget, and duration.

Discipline	Interviewee ID	Role	Last project type	Last project's budget	Last project's duration (year)
Design management	INT 1 (DM)	Geothermal heating design consultant	Building construction	€ 30,000,000	3
	INT 2 (DM)	Principal HVAC designer	Building construction	€ 75,000,000	3
	INT 3 (DM)	CEO	Building construction	€ 140,000,000	5
	INT 4 (DM)	Energy Specialist	Building construction	€ 40,000,000	5
	INT 5 (DM)	Design manager	Building renovation	€ 2,000,000	5
Project management (client)	INT 1 (PMClient)	Project manager	Building construction	€ 150,000,000	4,5
	INT 2 (PMClient)	Site manager	Building renovation	€ 52,000,000	5
	INT 3 (PMClient)	Project manager	Building construction	€ 7,000,000	2,5
	INT 4 (PMClient)	Project manager	Building renovation	€ 10,000,000	2
	INT 5 (PMClient)	Project manager	Building renovation	€ 10,000,000	2
Project management (contractor)	INT 1 (PMContractor)	Design and sustainability manager	Building renovation	€ 80,000	1
	INT 2 (PMContractor)	Project manager	Building construction	€ 40,000,000	5
	INT 3 (PMContractor)	Project manager	Building renovation	€ 1,000,000	1
	INT 4 (PMContractor)	Project manager	Building construction	€ 90,000,000	5
	INT 5 (PMContractor)	Head of Project Business Unit	Building construction	€ 110,000,000	3
Property management	INT 1 (PropertyMgmt)	Service Delivery Manager	Ongoing maintenance of existing buildings	€ 300,000	–
	INT 2 (PropertyMgmt)	Real Estate Manager	Building construction	€ 300,000,000	–
	INT 3 (PropertyMgmt)	Real Estate Manager	Ongoing maintenance of existing buildings	€ 60,000	–
	INT 4 (PropertyMgmt)	Service Unit Director	Ongoing maintenance of existing buildings	€ 200,000	–
	INT 5 (PropertyMgmt)	Chief Strategy Officer	Ongoing maintenance of existing buildings	€ 500,000	–
	INT 6 (PropertyMgmt)	Senior Specialist, indoor air	Ongoing maintenance of existing buildings	€ 200,000,000	–

researcher and two members of the research team who were present in all interviews. In result of this review, 18 out of 51 generated codes were renamed. In result of this effort, the remaining 34 codes were considered valid for thematic analysis. The validated codes were then analysed through thematic analysis to see what themes the data are suggesting. Nine themes were established in result of the thematic analysis. The establishment of the themes was done based on the sameness or similarity of the codes in terms of the meaning and/or title. The challenges/barriers and solutions/enablers representing different codes and themes were listed separately and synthesized based on the similarity or sameness of the title and/or meaning. The results of thematic and content analysis were shown to the interviewees to ensure the interpretations made in the analysis process were valid. The interviewees unanimously approved analysis results (i.e. identified challenges and solutions).

Results

Thematic analysis of the discovered challenges/barriers and solutions/enablers revealed that they represent nine different themes. These themes were: (i) building operation, maintenance and optimization, (ii) building's energy system, (iii) client, (iv) competence development, (v) design, (vi) finance, (vii) information management, (viii) project delivery and (ix) regulatory issues. In this section, the identified challenges and solutions are presented according to their relevant themes.

Challenges/barriers for achieving energy efficiency in building construction projects

Analysing the interview transcripts resulted in the identification of more than 100 challenges for realizing energy efficiency in building construction projects. Among the discovered challenges, 11 of them were mentioned by more than one interviewee. These challenges are shown in Table 2. As can be seen in Table 2, the major obstacles of achieving energy efficiency in building construction projects seem to be rooted in the project delivery model, financial issues and building's energy system. Regarding project delivery, the lack of early involvement of building services designer, contractors and building operation/maintenance people in project definition phase seem to be the key challenges. Concerning financial issues, insufficient budget combined with high initial cost of modern energy systems seem to be the dominant barriers. Finally, the complexity of the modern energy systems and inaccurate calculation of building energy consumption are further challenges for achieving the targeted energy consumption in the operation phase of the new buildings.

Solutions/enablers for achieving energy efficiency in building construction projects

Akin to the identified challenges, there were also some enablers which were mentioned by more than one interviewee. These nine solutions/enablers, representing four different themes (project delivery, building's energy system, building operation, maintenance, and optimization, competence development) were found to be of importance. Table 3 shows these solutions/enablers.

In terms of project delivery, having a life cycle contract, which extends the liability of the party in building operation phase for a sufficient period, can be seen as the most important solution, mentioned by a few interviewees. Life cycle contract, in other words, not only shares the risk and reward in project life cycle, but also in the product (i.e. building) life cycle. In addition to the life cycle contract, involvement of the key project participants (e.g. building services designer and contractors, building operation and maintenance people) in the project definition phase, and early definition of building's end use/end user are the key solutions by the interviewees. The leading author of this article has developed a collaborative project delivery model (featuring the mentioned solutions) for achieving energy efficiency in the building construction projects which will be reported in a separate publication.

In addition to the project delivery area, there were three frequently mentioned solutions representing building's energy system and building operation/maintenance/optimization. As can be expected, the interviewees mentioned that developing guidelines for designing hybrid energy systems for buildings could have significant impact on the high functionality of these systems in building operation phase. Heat pump and thermal borehole field design guidelines were specifically requested. Moreover, appropriate calibration of building energy system and its continuous monitoring and optimization were also found to be key enablers for achieving energy efficiency in building construction projects.

Mapping challenges and solutions of achieving energy efficiency in life cycle phases of building construction projects

Figure 2 shows the relevance of listed challenges and solutions in Tables 2 and 3 to life cycle phases of

Table 2. Most frequently mentioned challenges/barriers by interviewees for achieving energy efficiency in building construction projects.

Theme	Representing challenge/barrier	References (i.e. interviewee ID)
Project delivery	Lack of involvement of HVAC contractors and operation/maintenance people in the project definition and design phase	INT 2 (PropertyMgmt), INT 1 (PMContractor), INT 6 (PropertyMgmt), INT 4 (PMContractor)
	Fragmented (i.e. divided/isolated) procurement, project delivery and maintenance process (multiple contracts) of energy efficient systems & fragmented project organization	INT 1 (PMContractor), INT 2 (DM), INT 5 (PMContractor) INT 1 (PMClient)
	Dominance of low-price criteria in the tendering process for selecting contractors which usually have low capacity to deliver their promises	INT 1 (DM), INT 5 (PMContractor)
Finance	High investment cost of modern energy systems	INT 1 (PMClient), INT 2 (DM) INT 3 (DM), INT 3 (PMClient) INT 4 (PMContractor)
	Insufficient budget for energy efficiency goals	INT 1 (PMClient), INT 3 (PMClient)
	Compromising energy efficiency goals and plans due to the high initial cost and insufficient budget of the project	INT 3 (DM), INT 3 (PMClient)
Building's energy system	Complexity and low efficiency of modern energy systems	INT 2 (DM), INT 2 (PropertyMgmt), INT 4 (DM), INT 2 (PropertyMgmt), INT 4 (PMClient)
	Inaccurate and/or unreasonable calculation of targeted energy consumption of the building	INT 5 (DM), INT 1 (DM), INT 3 (PMClient)
Building operation, maintenance and optimization	Weak commissioning of the building at the beginning of operation phase	INT 5 (PropertyMgmt), INT 4 (DM)
Regulatory Issues	Zoning issues	INT 1 (PMClient), INT 2 (PMContractor)
Client	Client's limited understanding/awareness about modern solutions for achieving energy efficiency in buildings	INT 3 (DM), INT 5 (PMClient)
Competence development	Lack of/limited number of competent maintenance workforce for handling modern and complex energy systems	INT 1 (PropertyMgmt), INT 6 (PropertyMgmt)

Notes: The reference column refers to those interviewees, which mentioned these identified challenges/barriers in the interviews.

building construction projects. As can be seen in Figure 2, most of the identified barriers/challenges and solutions/enablers are related to the project definition and building operation phases.

This finding corresponds to the previous research (e.g. Boge et al., 2018), and highlights the significance of life cycle-based decisions and investments in the project definition phase. Theoretically, this is aligned with the relationship between time and cost of early and late changes in the project. But there are two differences. The first difference here is that instead of the change, the life cycle-based decisions and investments seem to have a relationship with time.

The second difference is that this relationship seems also to be valid not only in project life cycle, but also in the building life cycle. This relationship may look

Table 3. Most frequently mentioned solutions/enablers by interviewees for achieving energy efficiency in building construction projects.

Theme	Representing solution/enbaler	References
Project delivery	Life cycle contract	INT 1 (PropertyMgmt), INT 2 (PropertyMgmt), INT 3 (DM), INT 3 (PMClient), INT 3 (PMContractor), INT 3 (PropertyMgmt), INT 4 (PMContractor), INT 5 (DM), INT 5 (PropertyMgmt), INT 5 (PMContractor) INT 5 (PMContractor), INT 2 (DM)
	Collaborative project delivery models (particularly alliance delivery model)	INT 1 (PMClient), PMContractor INT 2 (PMContractor), INT 3 (DM)
	Involving building services people in the project definition and design phase	INT 2 (PMContractor), INT 2 (PropertyMgmt), INT 3 (PMClient) INT 4 (PMContractor)
	Involvement of client and its representative (consultant) from project definition phase until the end of the project	INT 1 (DM), INT 2 (PropertyMgmt) INT 3 (PMClient)
	Early definition of the use of building and its spaces	INT 1 (PMContractor), INT 3 (PMClient)
Building's energy system	Developing guidelines for designing hybrid energy systems for buildings	INT 1 (DM), INT 2 (PropertyMgmt) INT 4 (PMClient)
Building operation, maintenance and optimization	Appropriate calibration and commissioning of the energy system at the beginning of building operation phase	INT 1 (PropertyMgmt), INT 2 (PMClient), INT 4 (DM)
	Continuous monitoring and optimization of building operation and maintenance by dedicated and competent workforce	INT 1 (PropertyMgmt), INT 3 (PropertyMgmt), INT 4 (DM)
Competence development	Sufficient education, training and number of experts in the area of heat pump	INT 3 (PMContractor), INT 5 (PMClient)

Notes: The reference column refers to those interviewees, which mentioned these identified challenges/barriers in the interviews.

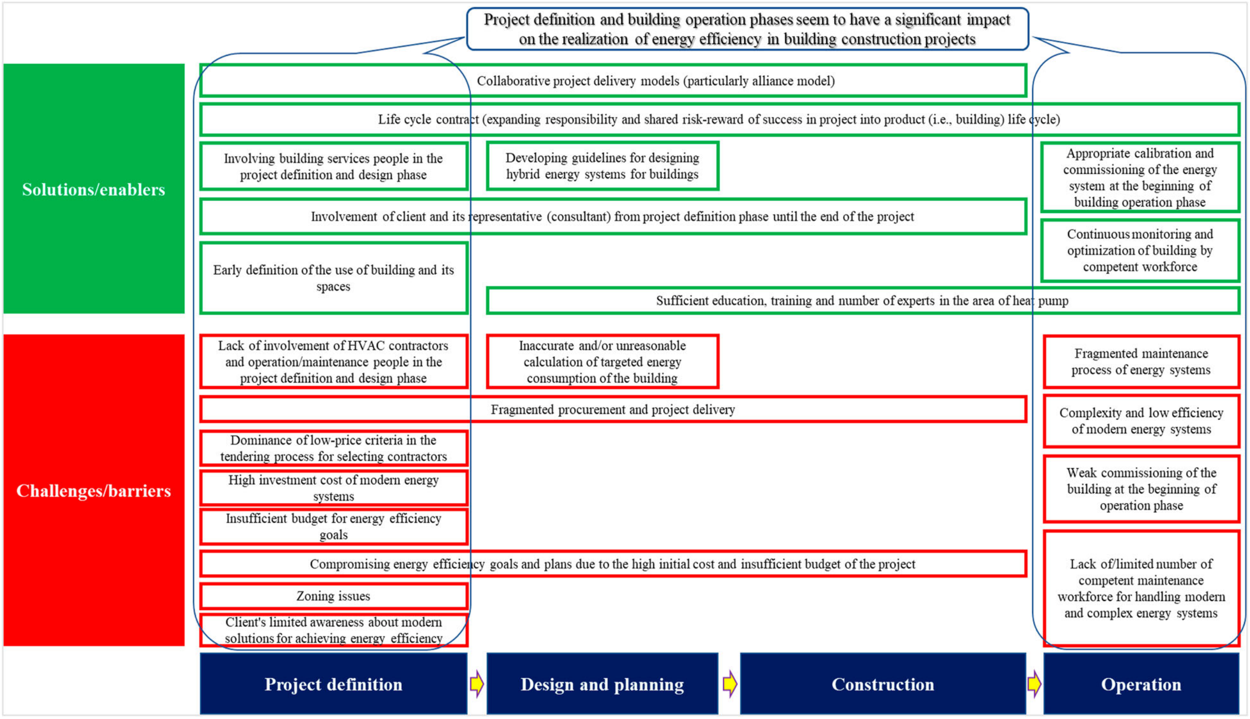

Figure 2. Important barriers and enablers of achieving energy efficiency in different life cycle phases of building construction projects.

something like in Figure 3. According to Figure 3, it can be argued that project definition phase and building commissioning are two important gates which seem to have direct effect on the cost of completing the project and using the building.

Discussion

The identified challenges/barriers and enablers/solutions for achieving energy efficiency in building construction projects spotlight some key issues which are discussed here. The identified challenges and solutions are discussed through the lens of their representing theme (mentioned in Tables 2 and 3). In this regard, project delivery is the first focus area here. Project delivery model, through which project organization and processes are formed and managed, has a key role in the success or failure of any project. The detected challenges and solutions under project delivery theme provide a basis to argue that employing the appropriate and compatible project delivery model and contractual framework is of prime importance for the buildings which are designed and built to be highly energy efficient. These identified challenges and solutions imply that

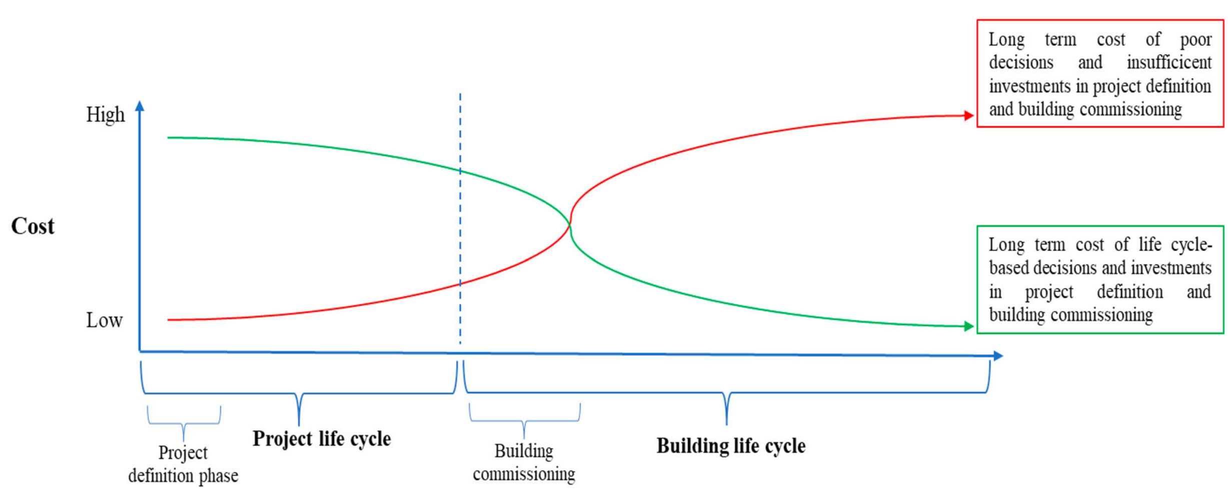

Figure 3. Cost and benefit of poor and wise decisions in the project definition and operation phases.

utilizing traditional delivery models (e.g. design-bid-build) seems to be a major obstacle for realistic and accurate target setting for energy consumption and achieving it in building operation phase. This argument is supported through the fact that the identified challenges/barriers in Table 3 clearly represent the characteristics (e.g. lack of early involvement of key project participants, isolated work, and dominance of low-price criteria) of traditional delivery models like design-bid-build (Moradi et al., 2021; Oakland & Marosszeky, 2017).

In contrary, the mentioned solutions by the interviewees for project delivery area emphasizes the essence of employing collaborative project delivery models (e.g. alliance) which enable early involvement of key project participants, shared risk-reward, joint design and control of projects, mutual trust and competence-based selection of the contractor (Moradi & Kähkönen, 2022). Moreover, the wise choice with the project delivery model can also overcome the mentioned financial challenges in terms of high initial costs for modern energy systems. This can be realized through fair share of risk and reward in the project and product (building) life cycle. This provides a great motivation for client and contractor to justify the high initial costs of modern energy systems with the benefits in the payback period. This includes not only equipment, but also additional design work. Additional investment into design and planning can prevent incorrect system dimensioning, saving money in the procurement and/or operational phases.

The second focus area here is the mentioned challenges related to building's energy system and building operation/maintenance/optimization. These challenges and solutions are again highly rooted in the type of project delivery model and contract. This means that if the building services and maintenance experts are involved in project definition and design phase (which happens in collaborative project delivery), the chance of making better decisions and having highly accurate calculation of building's energy consumption and more functional and cost-effective design of the building's energy system considerably increase (e.g. Boge et al., 2018). This argument can be also supported based on the map of identified barriers and enablers in Figure 3. Besides, when there is a collaborative project delivery model, featuring a life cycle contract, then it seems highly unlikely to miss or neglect proper commissioning and continuous monitoring as well as optimization of building's energy system. This is because contractors are contractually responsible for full commissioning and optimization of building energy system.

The renewal of the maintenance process itself was also called out due to the increased complexity of modern hybrid energy systems. Traditionally the responsibility of maintaining building energy systems has fallen to janitor-type personnel, who have no specific expertise in building energy management. As new systems may involve multiple parallel heating/cooling systems and complicated automation, there is need for both specialist personnel and automated diagnostic tools. The smooth operation of hybrid energy systems requires constant optimization, and merely tuning the system settings during commissioning was seen as inadequate. In addition, the need for updating outdated building maintenance guidelines was brought forward.

Some interviewees also highlighted the missed potential of energy efficiency due to the lack of awareness of available solutions and their actual impact on energy cost. Many types of energy solutions are available on the market, but there has been no systematic review of their joint performance in practice. Detailed monitoring and publication of the results in an open database would provide all market participants and stakeholders a better understanding of available solutions and their expected performance. This could help reduce the energy performance gap while improving the baseline efficiency level.

Many of the observed barriers to energy efficiency seem to be the same as those reported more than 10 years ago by Häkkinen and Belloni (2011) regarding the uptake of sustainable buildings. Thus, clients need to be made aware of the long-term benefits of sustainable solutions that are more costly in the project initiation phase. Teamwork skills must be improved, and new service concepts need to be developed. The longevity of these issues highlights the fact that awareness of the problems is not enough, and active work must be done to fix them.

Conclusions

This study aimed to explore the challenges/barriers and solutions/enablers of realizing energy efficiency in building construction projects. This was accomplished through a qualitative study of semi-structured interviews. The opinion of project professionals representing client, design, contractor and property management were obtained and analysed. Accordingly, it is concluded that:

- Accuracy of energy consumption estimation (predicted building use and users) has a huge impact on the actual energy performance of the building and therefore building services people need to get involved in the early stages of the project.

- Increasing the awareness of clients about hybrid systems and their life cycle cost and benefits is of prime importance to provide a basis for long-term decisions in the project definition phase.
- Employing traditional delivery models, like design-bid-build seem to be a major obstacle for realizing energy efficiency in building construction projects due to the lack of early involvement of key project participants, isolated work, mistrust, unfair share of risk-reward and dominance of low-price criteria.
- On the contrary, collaborative project delivery models (like alliance) with a life cycle contract (covering risk and reward both in the project life cycle and building life cycle) considerably contribute towards the realization of energy efficiency in building construction projects.
- Project definition and building operation phases seem to have the biggest impact on the realization of energy efficiency in building construction projects.
- Life cycle-based decisions and investments in the project definition phase directly affect the achievement of energy consumption target in the building operation phase.
- To ensure that the building systems work as designed, a proper commissioning process must be performed, but in addition, there must be continuous monitoring and optimization of the systems through the whole operational phase.

This study contributes to the existing body of knowledge on the barriers and enablers of realizing energy efficiency in building construction projects. It also provides practical insights for the relevant project professionals. However, it is acknowledged that the generalisability of the findings could be limited as the limited number of interviews were conducted only in Finland. Moreover, purposive sampling technique which was utilized in this study might have affected the generalizability of the findings. Although the identified challenges in this study are more relevant in Finland, the explored solutions such as collaboration and fair share of risk-reward in project and product life cycle, on the other hand, can be applied in other contexts as well. All in all, similar efforts in other regions are still potential for further research and development in this area.

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Appendix. Interview protocol and questions

Step 1. The interviewer(s) starts the session by explaining the purpose of the interview. This explanation is to be done through reading the following statement:

- This interview is conducted to collect data from project professionals for a research project which aims at exploring and overcoming challenges and barriers of realizing energy efficiency in building construction and renovation projects. The motivation for conducting this research project comes from the latest research findings that *there is a performance gap between the design intentions for energy efficiency of the buildings and the actual performance of the buildings in the operation phase*. The interview will take 45-60 minutes. *The identity of the interviewees and real name of the projects (if mentioned during the interview) will not be disclosed to any third party neither throughout the research nor after that.* Only demographic information of the interviewees (i.e. age, education, experience) and projects (i.e. type, size, duration) will be used in the data analysis and research dissemination without revealing their identity. The interview will be audio recorded for the purpose of transcribing and analyzing the collected data. The interviewee is giving his/her consent for recording the interview by answering the following questions.

Step 2. The interviewer(s) opens the discussion by reading the following statement:

- Now, I will start asking seven questions two of which are related to demographic information.

Step 3. The interviewer(s) asks the following questions from the interviewees based on their discipline:

- ***Questions for the interview with design managers:***

○ **Q1:** What is your educational degree, professional experience and age?

○ **Q2.** What was/is the type, budget and duration of your last/current project?

○ **Q3.** What are the challenges and/or barriers for realizing energy efficiency in the design of new buildings?

○ **Q4.** How do you think these challenges can be overcome?

○ **Q5.** What are the challenges and/or barriers for achieving energy efficiency in the renovation of existing buildings?

○ **Q6.** How do you think these challenges can be overcome?

○ **Q7.** Is there anything which we may have overlooked in our questions, and you would like to say something about it?

- ***Questions for the interview with client project managers:***

○ **Q1:** What is your educational degree, professional experience and age?

○ **Q2.** What was/is the type, budget and duration of your last/current project?

○ **Q3.** What are the challenges and/or barriers in the definition phase of building construction projects which negatively affect the realization of energy efficiency?

○ **Q4.** How do you think these challenges and barriers can be overcome?

○ **Q5.** What are the challenges and/or barriers in the definition phase of building renovation projects which negatively affect the realization of energy efficiency?

○ **Q6.** How do you think these challenges and barriers can be overcome?

○ **Q7.** Is there anything which we may have overlooked in our questions and you would like to say something about it.

- ***Questions for the interview with contractor project managers:***

○ **Q1:** What is your educational degree, professional experience and age?

○ **Q2.** What was/is the type, budget and duration of your last/current project?

○ **Q3.** What are the challenges and/or barriers in the delivery of building construction projects which are designed to be energy efficient?

○ **Q4.** How do you think these challenges and barriers can be overcome?

○ **Q5.** What are the challenges and/or barriers in the renovation of existing buildings which are retrofitted to be energy efficient?

○ **Q6.** How do you think these challenges and barriers can be overcome?

○ **Q7.** Is there anything which we may have overlooked in our questions and you would like to say something about it?

- ***Questions for the interview with property managers:***

○ **Q1:** What is your educational degree, professional experience and age?

○ **Q2.** What was/is the type, budget and duration of your last/current project?

○ **Q3.** What are the challenges and/or barriers of realizing energy efficiency in the utilization phase of the new buildings?

○ **Q4.** How do you think these challenges and barriers can be overcome?

○ **Q5.** What are the challenges and/or barriers of realizing energy efficiency in the utilization phase of the renovated buildings?

○ **Q6.** How do you think these challenges and barriers can be overcome?

○ **Q7.** Is there anything which we may have overlooked in our questions and you would like to say something about it?

Step 4. The interviewer(s) thanks the interviewee for his/ participation in the interview through the following statement:

We truly appreciate your participation in this interview and your insightful responses to our questions.