Exploring Decision-Making Factors for Energy Efficiency Retrofit in Building Portfolio

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Abstract

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Building Energy Efficiency Retrofit (BEER) is essential for energy conservation and emission reduction. Despite advancing knowledge of the benefits and available solutions, the current BEER projects are considerably limited. One difficulty in promoting BEER is the complexity of the decision-making process. Decisions are made at different stages to evaluate hundreds of energy efficiency measures involving multiple stakeholders with conflicting interests, especially those who manage building portfolios. This dissertation aims to evaluate factors to help industry professionals and policymakers establish a comprehensive decision-making approach when considering BEER projects in commercial and institutional buildings. This dissertation first ranked stakeholders' priorities toward a set of factors across the United States using Analytic Hierarchy Process. The study also introduced some critical dimensions of context in energy efficiency, including physical (e.g., geographical region), functional (e.g., industry sector), and social contexts (e.g., leadership position). The results showed no significant disagreement between public and private institutions or between executives and non-executives but more considerable differences among climate zones and industry sectors. Second, this research explored the decision-making processes of BEER projects at the University of Washington. Using semi-structured interviews, document review, and the Causal Loop Diagram approach, the study identified the cause-and-effect relationships among factors. The research suggests that initiating corrective actions to increase organizational commitment, government support, use of technology, and funding will drive more BEER investment in higher education institutions. Finally, this dissertation brings together empirical studies worldwide that examined the factors influencing energy efficiency improvements. A total of 30 factors emerged from a systematic literature review of 42 peer-reviewed articles, categorized into economic feasibility, team process, technical practicality, institutional characteristic, governmental policy, occupant impact, and environmental impact. The study discussed how geographical regions, building types, and country's economic classifications impact the building stakeholders' perceptions about energy efficiency. The findings from this dissertation highlight that the promotion of energy efficiency in buildings will necessarily imply a further effort to contextualize the research and point out the so-called non-energy benefits from the implementation of BEER.

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Chapter 1. INTRODUCTION

1.1 DISSERTATION SUMMARY

One of the most notable ways to reduce energy consumption as part of climate change mitigation is implementing building energy efficiency retrofit (referred to later in this document interchangeably as BEER, energy retrofit, or retrofit). The building sector is responsible for 40% of the total energy consumption in some developed countries and a related emission of 40% of total greenhouse gas emissions (EIA, n.d.). While the trends and policies regulating the construction of new buildings to meet specific energy performance standards or net-zero energy are essential, a significant number of existing building stock often need upgrades from having high energy intensities and out-of-date codes. Therefore, retrofitting the existing inefficient buildings can substantially reduce the energy footprint of the building sector.

While the selection process of retrofit programs has been improved through existing decision-making frameworks that balance the building performance with the owner's objectives, they are mostly limited to the case of retrofitting a single building or similar building types. Due to the complexity of retrofitting multiple buildings with different characteristics and stakeholders' requirements, this dissertation will develop a decision-making framework suitable for building portfolio retrofit to make large-scale energy retrofit implementation possible. More specifically, it is critical to better understand the contexts and factors that influence retrofit decisions in commercial and institutional buildings to improve energy retrofit decision-making, which is the focus of this dissertation. This dissertation attempts to address the following research questions (Q):

Q1: What are the factors and contexts that could influence the decision to implement energy retrofit?

Q2: How do factors that influence energy retrofit compare among different contexts?

Q3: How do stakeholders rank the importance of the factors that influence energy retrofit?

Q4: How do factors that influence energy retrofit interrelated?

Q1 is addressed by conducting a literature review to identify factors influencing decisions to retrofit performed in multiple iterations. The first effort was documented in Medal and Kim (2017), then followed by a pilot study that resulted in 15 factors under five criteria (Medal et al. 2021). Ultimately, a systematic literature review was conducted to synthesize existing empirical studies worldwide examining factors that influence energy efficiency retrofit. A total of 30 factors emerged and were categorized under seven criteria: economic feasibility, team process, technical practicality, institutional characteristic, governmental policy, occupant impact, and environmental impact. It was observed that there are specific circumstances that impact energy retrofit decisions, referred to in this dissertation as context, that emerged across studies but have not been sufficiently recognized to understand a complete picture of the decision process. Building upon a grounded theory of context in organizational behavior by Johns (2006), a conceptual framework of energy efficiency context is developed and composed of three dimensions: physical (characteristics of the building site and the surrounding built environment), functional (institutional purposes of the building or building occupants), and social (influences of individual's roles or group interaction). Some critical context dimensions were introduced in Chapters 2 and 4, such as climate zone, geographical region, portfolio size, industry sector, ownership type, country's economic classification, leadership position, and job roles.

Q2 is addressed in Chapter 2 and Chapter 4. In Chapter 2, the study explored the impact of some context dimensions in energy efficiency toward factor prioritization using a case study of building stakeholders of commercial and institutional buildings in the US. The physical context is tested by comparing the stakeholders’ judgments managing different portfolio sizes of buildings located in various climate zones across the US. The functional context is examined by comparing the stakeholders’ judgments from different ownership types and industry sectors. Lastly, The stakeholders’ judgments with varying roles of decision and leadership positions were compared to observe the social context's impact. The study found no significant disagreement between public and private institutions or between executives and nonexecutives. However, larger magnitudes of weight differences about factors were observed mainly among diverse climate zones and industry sectors. In Chapter 4, the study explored other dimensions of energy efficiency context based on previous empirical studies worldwide that are qualitatively coded. The physical context is tested by comparing the identified factors influencing energy efficiency retrofit across different geographical regions and the country’s economic classifications. The functional context is tested by comparing the factors across various building types. The study observed differences regarding factors that influence energy retrofit decisions in all contexts. Moreover, the study identified gaps in research areas about perceptions toward BEER investment that may contribute to the variations of decision criteria across contexts. For example, more studies should be conducted in developing countries and building types other than commercial offices to clarify the context impact on stakeholders’ retrofit decisions.

Q3 is addressed in Chapter 2 by applying Analytic Hierarchy Process to rank the relative importance of decision-making factors in energy retrofit of 236 experts across the US. The results show that economic feasibility is the most important criterion (37.4%). Economic-related factors were also the most important among 15 factors: payback period, lifecycle cost, and funding mechanism. However, the remaining 62.6% of criteria weight is shared among technical practicality (20.1%), occupant impact (17%), institutional characteristic (13.7%), and environmental impact criteria (11.8%), respectively, which highlighted the importance of not neglecting non-economic factors in developing strategies to promote BEER projects.

Q4 is addressed using in-depth semi-structured interviews of facilities managers in the education sector and secondary data from relevant reports and policy documents. The University of Washington was used as a case study. The content analysis of the data identifies decision factors, and their interactions are depicted in a causal loop diagram that shows cause-effect relationships. Three main loops related to economic feasibility, occupant impact, and technical practicality were highlighted as the most significant concerns in the United States (US) case study. The workflow of this dissertation is illustrated in Figure 1.1. Overall, this dissertation suggests future studies to continue developing contextual thinking of energy retrofit by clearly defining the study settings when designing the research.

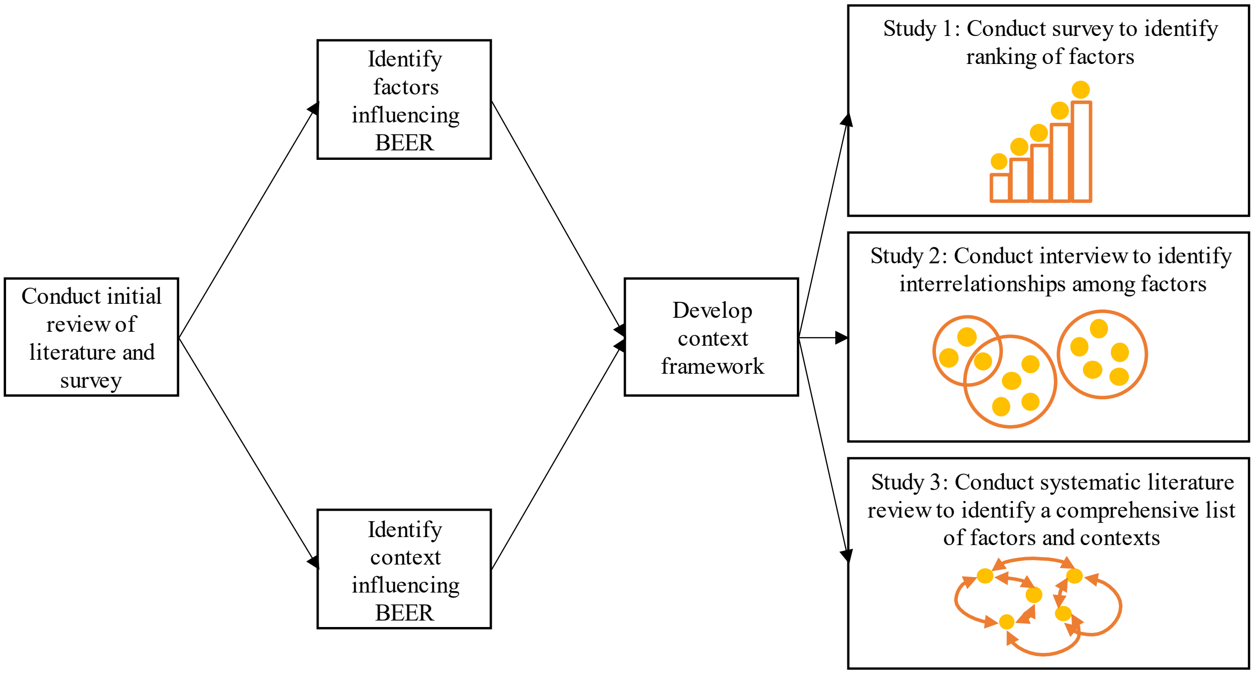

Figure 1.1 Dissertation workflow.

1.2 DISSERTATION FORMAT AND SCOPE

This dissertation follows a publication-based approach, where the research questions are addressed through separate publications. Chapters 2, 3, and 4 represent three independent studies published or under review by various academic journals when finalizing this dissertation. Table 1.1 summarizes how four research questions previously mentioned in Section 1.1 are addressed and outlines the objectives, scopes, methods, and study sizes. The author requests that all references in these chapters use the final journal citation rather than referencing this dissertation document. The dissertation appendices include IRB approvals for conducting the study and additional details about data collection and analysis results.

Table 1.1 Summary of research questions, objectives, scopes, methods, and study sizes.

Topic	Research Question	Objective	Scope	Method	Study Size
Chapter 2 (Paper 1)	Q1, Q2, Q3	Identify the rankings of decision factors in different contexts	Commercial and institutional buildings in the US	Analytic Hierarchy Process	236 industry professionals and policymakers
Chapter 3 (Paper 2)	Q1, Q4	Investigate the interrelationships among decision factors	University of Washington's academic buildings, dorms, offices, and hospital	Semi-structured interviews (mental models) and Causal Loop Diagrams	6 facility managers
Chapter 4 (Paper 3)	Q1, Q2	Examine a comprehensive list of factors and contexts influencing decisions to implement energy retrofit	Worldwide research publications	Systematic literature review	42 peer-reviewed articles

1.3 DEFINITION OF TERMS

This section defines terms that are used frequently throughout the document to ensure a common understanding. While some terminologies are specific to the study topics, some others may seem to be common knowledge, although it can have specific interpretations in this dissertation.

- Building energy efficiency retrofit (also referred to as energy retrofit or retrofit): Renovation of parts of an existing building that involves energy conservation measures to improve the building energy performance, such as higher energy efficiency or decrease energy demand.
- Building portfolio: Building stock containing multiple buildings of various types and functions in a country, region, municipal area, or estate.
- Context: Circumstances, conditions, or situations that affect the implementation effort of building energy efficiency retrofit and the relationships between its influencing factors.
- Setting: A unique condition of a building and its surroundings. This is a term that helps to explain context.

- Decision criteria (or criteria): A set of factors that are grouped based on shared principles that are important in making energy retrofit decisions.
- Decision factor (or factor): An influence that contributes to the decisions of building energy efficiency retrofit.

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Chapter 2. AHP MODEL FOR PRIORITIZING DECISION FACTORS OF ENERGY RETROFIT FOR FACILITIES PORTFOLIO MANAGEMENT

Final draft of:

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ABSTRACT

Improving building energy efficiency is critical to securing a more sustainable future. In this paper, an analytic hierarchy process method was used to systematically highlight the importance of the decision factors and context that affect the prioritization of expert decisions to implement energy efficiency retrofit. This study surveyed 236 facility management experts in the United States (US) to obtain a consensus about the priorities of five decision criteria and 15 factors to retrofit. Additionally, a cross-context comparison was conducted to examine differing perceptions of retrofit as a function of physical, functional, and social contexts. The three most important factors across all US respondents were payback period, life-cycle cost, and funding mechanism. In contrast, the least considered factors were CO_2 emissions, educational programs, and demand pressure. This study revealed that there was no significant disagreement between public and private institutions as well as between executives and non-executives. The larger magnitudes of the weight differences were mainly observed among diverse climate zones and industry sectors. Findings are relevant to regulators when proposing initiatives to increase energy efficiency adoption.

KEYWORDS: energy efficiency, building retrofit, decision analysis, analytic hierarchy process, facilities portfolio management, context

2.1 INTRODUCTION

In the United States (US), more than $279 billion in building retrofit investment opportunities exist across all market segments, which could yield more than $1 trillion in energy savings over the next ten years (The Rockefeller Foundation 2012). Without substantial retrofit implementation, it will be challenging to reach the global building sector's target to improve the energy intensity per square meter (m^2) by 30% by 2030 (based on 2015 levels) as set forth in the Paris Agreement on Climate Change in 2015. Their study also found that nearly 10% of US emissions could be reduced, and 3.3 million jobs could be created if all retrofits were successfully implemented. Given that the US contributes 97.5 quadrillion BTUs (17%) to the world's total primary energy consumption, improvement of US building energy efficiency will make significant contributions to global energy savings.

Energy efficiency in the building sector has generally been improved in recent decades through the implementation of mandatory administration controls, economic incentives, and public participation in voluntary schemes (Shen et al. 2016). In the US, mandatory standards include the 2012 International Green Construction Code and the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) 189.1-2011—Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings, both of which contain requirements to increase the environmental and health performance of buildings. An example of an established incentive is the Energy Policy Act of 2005, which offers tax deductions to businesses for the costs of improving the energy efficiency of commercial buildings. Various voluntary schemes are also promoted, such as the energy-efficient building labels of Energy Star for Homes and Energy Star Portfolio Manager, as well as Leadership in Energy and Environmental Design certification.

Despite the known benefits of building retrofitting, implementation is slow. Many independent studies discuss the gap between the opportunities for cost-effective energy efficiency investment and the levels seen in practice (Sathaye and Murtishaw 2004; Sorrell et al. 2000). Reasons for slow implementations have been identified as inflexibility in the redesign due to technology compatibility restrictions (Evonne Miller 2008), uncertainty in economic markets and financing (Koslow 2009), and interruption of existing occupant activities (Evonne Miller 2008; McCunn et al. 2018; Milam and Snow 2013). Furthermore, building maintenance-related projects also compete with other capital investment opportunities (Kim et al. 2019), often making the retrofits less prioritized.

Accordingly, existing literature has focused on investigating motivations and challenges in selecting and implementing building energy efficiencies (Achtnicht and Madlener 2014; Jagarajan et al. 2017; Kontokosta 2016; Wilson et al. 2015; Xu et al. 2015). Jagarajan et al. (2017) identified barriers—such as financial resources, green building professionals, policy support, green development quantification, green awareness, communication, internal leadership, and green material and technology—that affect the implementation of successful green retrofit projects. Nevertheless, most of these works are still limited to assessing the contributing factors of energy efficiency in certain building types, such as offices (Kontokosta 2016), residential (Achtnicht and Madlener 2014; Wilson et al. 2015) and hotels (Xu et al. 2015). Other studies have taken into account the possible role of different stakeholders and geographical regions in retrofit investment decisions (Chan et al. 2017; Menassa and Baer 2014). For example, Menassa and Baer (2014) found that conflicting stakeholder requirements were the primary barrier in implementing sustainable retrofits. However, all stakeholder categories (owners, tenants, facility managers, designers, and environmental compliance managers) agreed with the main motivations to save energy, which is to comply with the government regulations and reduce costs. Additionally, Chan et al. (2017) identified broad consensus and perception differences on barriers to green technology implementation in the construction industry, according to stakeholder's position, profession, experience, and country.

Decision-makers who are managing multiple types of buildings with different characteristics encounter additional challenges in prioritizing retrofit projects. There is a growing body of literature, although limited, on retrofit decision-making for facilities portfolio management. For example, Pacheco-Torres et al. (2016) identified building heterogeneities across portfolios. Hessami et al. (2019) analyzed strategies for the optimal allocation of energy retrofit resources in a portfolio of buildings based on financial and environmental performance goals. Carli et al. (2017) noted that there is a clear gap in the research literature for defining optimal energy retrofit strategies for facilities portfolio management based on performance outcomes. The magnitude of important drivers and barriers to retrofits was found to be different by building portfolio, institution type, and level of expertise (Medal and Kim 2020). This study adds to this growing body of literature by holistically assessing the impact of social, physical, and functional contexts for prioritizing building retrofits for a portfolio of buildings.

2.1.1 *Research questions*

A better understanding of building contexts is expected to increase our insight among previously isolated perspectives that can be used to guide future empirical work. It is also hypothesized that decisions would differ depending on a building's physical, functional, and social contexts. To test this theory, the objectives of this study were to (1) evaluate the importance of criteria and factors affecting energy retrofit decisions in the US, and (2) explore the differences in perspective regarding decision criteria and factors between various physical, functional, and social contexts. Therefore, the following research questions guided this study:

- What are the most important decision criteria and factors in retrofit decision-making that is common across the different contexts in the US?
- How are the decision criteria and factors different among physical (e.g., between single and multiple building portfolios), functional (e.g., between technology and healthcare sectors), and social (e.g., between building owners and third-party stakeholders) contexts?

2.1.2 *Methodological background*

Various methods are used for multi-criteria decision-making (MCDM) in the building and construction disciplines (Arroyo et al. 2016; Kabak et al. 2014; Li et al. 2017; Seddiki et al. 2016). The growth of publications related to decision-making using AHP stands out from other MCDM techniques. The present study used an analytic hierarchy process (AHP)-based decision analysis approach because it allows decision-makers to systematically analyze complex decision-making problems by breaking down the main problem into simpler subproblems (Aragonés-Beltrán et al. 2014). Additionally, the detailed analysis of priorities between factors forces decision-makers to carefully reflect on their project priority approach, which results in better knowledge of the problem. Literature has shown a broad application of AHP for understanding decision problems in construction. The AHP can be applied to identify different stakeholder perceptions of delay causes in build-operate-transfer projects (Budayan 2019), important school facility aspects to improve project realization (Rogulj and Jajac 2018), and factors affecting the implementation of new construction technologies in differing countries (Sepasgozar et al. 2018).

The AHP method has also been successfully used in various studies in the field of building, sustainability, and energy. The AHP was used to prioritize factors such as in selecting intelligent building systems (Wong and Li 2008), retrofit strategies of energy-efficient heating, ventilating, and air conditioning (HVAC) system (Woo and Menassa 2014), indicators of governance model in megaprojects (Li et al. 2019), and optimal retrofits considering conservation compatibility of a historic building (Roberti et al. 2017). Earlier studies also employed AHP to provide a basis for embedding multi-objective optimization into the decision-making on energy retrofit solutions (Shao et al. 2014) and assess the effects of energy infrastructure revitalization on non-residential public buildings (Kljajić et al. 2016). Due to the complex nature of decisions related to energy retrofit implementation, the AHP method is applied in this paper to evaluate stakeholders' perspectives in different contexts in the US on the relative importance of criteria and factors of energy retrofit decisions.

2.2 RESEARCH METHODOLOGY

A systematic literature review was conducted to identify the decision criteria and factors, as well as context groups. A pilot study and survey questionnaire were performed to assess the priorities of criteria and factors using the AHP method. Finally, a comparison of judgments made between various context groups was evaluated using descriptive statistics.

2.2.1 *Factor identification*

The initial efforts for compiling the list of relevant factors were documented in Medal and Kim (2017), and the decision factors were adopted to investigate the factor interrelationships in a higher education institution context (Kim et al. 2019). Based on these previous studies, the key factors affecting the decision to implement an energy efficiency retrofit were categorized into five criteria: economic feasibility, technical practicality, occupant impact, institutional characteristic, and environmental impact.

An independent follow-up pilot study was used to identify any discrepancies and protocols in the research instrument in developing the AHP survey questionnaire. Three facility management and building sustainability experts, who were managers and executives managing different offices and multiple academic buildings, participated in the pilot study. All participants had over 30 years of experience in facility planning or management, and their diverse background was intentional to ensure that the final decision factors represented the opinions of various experts and were suitable for different contexts. Pilot study participants received an invitation to take the online survey and participate in a follow-up interview to obtain feedback. The main discussion topics included the survey length, question rewording, instruction clarity, factor identification, terminology interpretation, pairwise comparison, and stakeholder background. A final list of factors and a description of each is given in Appendix 1.

2.2.2 *Theoretical context*

Building upon context theory from Johns (2006), this study explored contexts specifically for energy efficiency retrofit in buildings to illustrate how a contextualized view of energy retrofit contributes to a better understanding of the phenomenon. The context classification for energy retrofit consists of physical, functional, and social contexts that were initially proposed in Medal and Kim (2020). The physical context is concerned with how the physical condition of the built environment may be associated with the evaluation of energy retrofit. This context includes portfolio size. For example, retrofitting multiple buildings require a different level of effort than retrofitting a single building. A portfolio of buildings with varying property types also has different energy use intensities to consider. Decisions for energy efficiency initiatives can also vary by geographical regions. This study compared the priorities of factors made between (a) single building stakeholders and multiple buildings stakeholders, and (b) stakeholders in different US climate zones: cold/very cold, mixed-humid, hot-humid, hot-dry/mixed-dry, and marine (PNNL 2015), to investigate the impact of physical context on retrofits.

The functional context categorizes how company ownership and building functions affect retrofit decisions. Salvia et al. (2019) advised that the selection of an energy efficiency initiative depends on whether the property is privately or publicly owned. For example, Delmas and Montes-Sancho (2011) showed a differentiated effect of the policy implementation of renewable portfolio standards between investor-owned utilities, which respond more to policy implementations, as compared to publicly owned utilities. Others have observed the impact of different industry sectors when a retrofit is being considered (Bernstein and Russo 2011). A study by Gliedt and Hoicka (2015) found that education and healthcare building sectors are most aggressive in terms of implementing and achieving energy efficiencies motivated by financial return on investment. This study compared the priorities of factors made between (a) public-owned entities and private-owned entities, and (b) stakeholders of different industry sectors (Russell 2018): technology (electronics, information technology, telecommunication), healthcare (healthcare services, medical equipment and services, pharmaceuticals, biotech), consumer discretionary (e.g., education services, hotels, storage facilities, retail), energy (energy equipment, nonrenewable energy, alternative energy), producer durables (e.g., machinery, construction, transportation, engineering, and contracting services), financial services (e.g., banks, insurance, real estate), and utilities (e.g., electrical, gas, water, telecommunications), to investigate the impact of functional context on retrofits.

The social context highlights a crucial understanding of the "who" variable in a context (Johns 2006). Occupation, personal values, and other professional and personal parameters of the retrofit decision-makers can provide a good explanation of the social context. Professional influence can be reflected by a decision-making role and leadership position or title, whereby the energy-related expertise of the stakeholders can influence the way retrofit investment is evaluated. In this study, the decision-making role is further categorized by the building owner and the third-party. Building owners refer to the subject matter experts who directly manage the building operations and maintenance or participate in selecting energy efficiency measures or other building upgrades. Examples of job titles that fall into the building owner category include building facility managers, property owners, real estate managers, operation managers, and investors. A third-party refers to the subject matter experts who indirectly participate in the building upgrade decisions by providing services to help organizations make energy efficiency or other building upgrades. Stakeholders in the third-party category comprise policymakers, consultants, academic researchers, project developers, and vendors. Additionally, comparison based on professional influence or leadership position was previously seen in Reinsberger et al. (2015), who compared judgments between founders of renewable energy initiatives and other energy experts. Moreover, personal characteristics, such as individual beliefs about energy issues, have been found to influence decision-making in retrofit investments. This study compared the priorities of factors between (a) building owners and third-party stakeholders, and (b) executives (e.g., CEOs and executive directors) and non-executives (e.g., managers and engineers) to investigate the impact of social context on retrofits.

2.2.3 *Data analysis*

2.2.3.1 Analytic Hierarchy Process

In this study, the AHP questionnaire was structured as a hierarchy model and designed to let the experts provide relative comparisons between pairs of factors using the AHP scale. A web-based questionnaire was developed using Qualtrics® software that could effectively represent the AHP pairwise questions. The questionnaire was distributed between September and November 2018. Two reminders were sent within a 2-week interval from the first invitation, and another reminder was explicitly sent to respondents who started the survey but had not completed it. The authors invited potential participants by reaching out to members of relevant professional organizations, such as the Association for the Advancement of Sustainability in Higher Education, International Facility Management Association, and Building Owners and Managers Association. Recruitment was through individual emails, event meetings, and advertisements by the facility management organizations. The participants were also encouraged to distribute the survey to their relevant colleagues. The authors directly sent out a total of 494 emails to industry professionals.

The first section of the questionnaire contained general demographic questions intended to understand the background of the respondents and the characteristics of the respondents' organization business portfolio, which were used to evaluate the potential relevance of these different contexts to their judgments. The second section of the questionnaire was the pairwise comparison of each criterion and then the pairwise comparison of each factor in the same category. There was a total of 10 pairwise comparison questions for five criteria and 15 pairwise comparison questions for 15 factors. The factors at the same level were compared using Saaty's 1-9 scale. The interpretation of each number is included in Table 2.1.

Table 2.1 AHP fundamental scale

Intensity of Importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very strong to extreme importance
9	Extreme importance

For example, if a respondent felt *very strongly* that "technical practicality" was more important than "environmental impact," the response would be to select the 7 closer to technical practicality. If a respondent felt *strongly* that "environmental impact" was more important than "technical practicality," the response would be to select the 5 closer to environmental impact. This section also included open-ended questions that allowed respondents the opportunity to further elaborate on the answers for criteria and factor comparisons. After calculating the weights of the factors, the authors checked the consistency ratio (CR) of the matrix to check judgment inconsistencies. If the CR is less than a threshold value of 0.1, then the matrix can be considered as having an acceptable consistency, and the derived priorities from the comparison matrix are meaningful (Saaty 1980). Next, the local priorities were calculated using Saaty's principal eigenvector of pairwise comparison matrices. These priorities are local because they are the priorities of elements in the same level of the hierarchy. Finally, the local priorities were multiplied by the respective group priority to determine the global priority for each factor. All weight and CR values were obtained with the algorithm written in RStudio software. The AHP survey questions are given in Appendix 2.

2.2.3.2 Context priorities

The overall agreement between respondents in different context groups was validated by the intraclass correlation coefficient (ICC) analysis. The data set of criteria and factor weights were analyzed with SPSS® version 26 software to obtain ICC values. The results were then interpreted following Portney and Watkins (2000): poor agreement (<0.5), moderate agreement (0.5 – 0.75), good agreement (0.75 – 0.9), and excellent agreement (>0.9). The priorities of each criterion and factor were also assessed by evaluating the rankings assigned by different context groups, as well as calculating the variations between each local weight in both criteria and factor level, categorized by three levels: small difference (<5%), medium difference (5% – 10%), and large difference (>10%).

2.3 RESULTS AND DISCUSSION

This section first presents an overview of the survey data collected. Next, based on the total sample of the US respondents, the overall weightings and rankings of factors influencing energy retrofit implementation are discussed in order of criteria importance. Finally, the AHP analysis is evaluated using the multi granularity lens of various groups among physical, functional, and social contexts inherent in a portfolio of facilities, and reviewed additional comments provided by the survey respondents. The implications of the findings are presented concerning strategies for developing building energy retrofit policy.

2.3.1 *Context description of respondents*

A total of 337 surveys were gathered, of which 236 AHP surveys were usable for further analysis (response rate = 48% based on direct individual emails sent). The actual percentage would have been lower if target participants who might have seen the survey advertisements or been referred by other participants were included. However, the authors believe that the sample collected is sufficient and representative of diverse context groups for evaluation.

The demographic composition of the respondents based on context classification is indicated in Figure 2.1. The respondents were categorized into six different context groups. In terms of the respondents' physical context, responses were received from 43 US states, with 62% of respondents living in cold/very cold and marine climate zones combined. About half of the respondents managed a single building, and most of the other half managed multiple buildings (3% of the respondents did not answer the portfolio size question). In terms of respondents' functional context, 62% were affiliated with a public institution, and 68% of the industry sector was represented by the consumer discretionary and producer durables sectors combined. In terms of respondents' social context, 87% were building owner representatives, and 88% of respondents held non-executive positions.

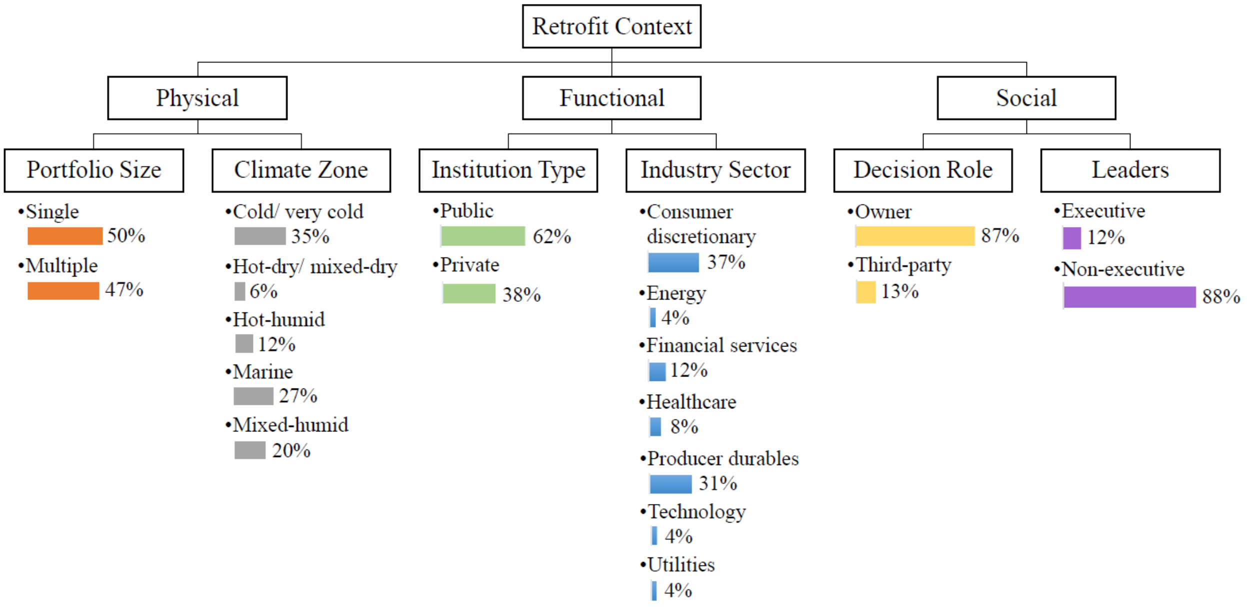

Figure 2.1 Context classification and distribution of survey respondents.

2.3.2 *Relative importance of criteria and factors in total US sample: The consensus*

Table 2.2 presents the weight of criteria and factors in the order of highest to lowest priority. At the criteria level, the results show that economic feasibility was the most important criterion when considering retrofit, followed by technical practicality, occupant impact, and institutional characteristic, respectively. The environmental impact had the lowest weight on priority. All CR obtained for comparisons of retrofit criteria in different context groups were less than 10% (between 1.1% to 9.9%), indicating that all judgments of the participants were logically consistent. Furthermore, the global factor priority for each factor was calculated by multiplying the local factor priority by the respective criteria priority. The results show that four of the top five factors were related to economic feasibility and technical practicality criteria.

Table 2.2 Consensus on priorities of criteria and factors

Criteria	Criteria Priority (%)	Priority by context (%)	CR (%)	Factors	Local Factor Priority (%)	Global Factor Priority (%)
Economic feasibility	37.4 (1)	30.0–40.2	1.8	Payback period	37.7 (1)	14.1 (1)
				Lifecycle cost	37.2 (2)	13.9 (2)
				Funding mechanism	24.9 (3)	9.3 (3)
Technical practicality	20.1 (2)	13.6–25.2	1.9	System compatibility	45.8 (1)	9.2 (4)
				Project integration	33.8 (2)	6.8 (6)
				Site accessibility	20.9 (3)	4.2 (10)
Occupant impact	17.0 (3)	12.0–23.2	0.0	Occupant satisfaction	44.1 (1)	7.5 (5)
				Energy-efficient behavior	36.5 (2)	6.2 (7)
				Educational program	20.0 (3)	3.4 (13)
Institutional characteristic	13.7 (4)	11.7–15.6	0.5	Expert skills	44.5 (1)	6.1 (8)
				Reputation	29.2 (2)	4.0 (11)
				Demand pressure	27.0 (3)	3.7 (12)
Environmental impact	11.8 (5)	8.7–16.8	0.1	Sustainable resources	39.0 (1)	4.6 (9)
				Waste management	34.7 (2)	4.1 (14)
				CO_2 emissions	26.3 (3)	3.1 (15)

ICC assessment shows that respondents had an excellent agreement with the set of important decision criteria and factors to implement energy efficiency retrofits (ICC range 0.960 – 0.997). The confidence level of ICC was 95%, which validates that the values were significant at the alpha level of 0.05. These results indicated that despite considerably large survey samples for AHP, the responses provided by diverse backgrounds were reliable and of good quality. Table 2.3 presents the summary results of ICC assessment based on criteria and global factor priorities.

Table 2.3 ICC assessment of weights by different contexts

Measure	N (N of Items)	ICC Coefficient	95% Confidence Interval of ICC	
			Lower Bound	Upper Bound
Building portfolio	(2)			
Criteria weight	5	0.987	0.872	0.999
Global factor weight	15	0.971	0.912	0.990
Climate zone	(5)			
Criteria weight	5	0.987	0.951	0.998
Global factor weight	15	0.972	0.942	0.990
Institution type	(2)			
Criteria weight	5	0.987	0.873	0.999
Global factor weight	15	0.984	0.951	0.994
Industry sector	(7)			
Criteria weight	5	0.984	0.946	0.998
Global factor weight	15	0.960	0.918	0.984
Decision role	(2)			
Criteria weight	5	0.981	0.809	0.998
Global factor weight	15	0.967	0.901	0.989
Leadership position	(2)			
Criteria weight	5	0.997	0.967	1.000
Global factor weight	15	0.989	0.966	0.996

2.3.2.1 Economic feasibility

The top-ranking of economic feasibility, among other energy retrofit criteria, was also observed in many previous studies (Achtnicht and Madlener 2014; Xu et al. 2015). The most important factor in retrofitting under economic feasibility was the payback period (37.7%). Business practices often compared various retrofit options based on their payback period to make a quick investment judgment regarding the economic impacts of possible energy efficiency projects (Rosenquist et al. 2004). Energy efficiency measures with a shorter payback period provide more attractive incentives to implement the retrofit. Beyond the payback period, there are strategies for a more robust economic analysis for assessing building retrofit options (Kim et al. 2019; Wang et al. 2017). The life-cycle cost was the second most important factor (37.2%), slightly lower than the payback period factor. The use of life-cycle costs to assess financial metrics has been increasing to evaluate building retrofit options (Ham and Golparvar-Fard 2014; Lee et al. 2015; Mauro et al. 2015). Minimal life-cycle cost is favorably emphasized by decision-makers, a process that guarantees long-term cost-effectiveness. The funding mechanism factor was given the least priority among the economic feasibility factors (24.9%). Using available capital or internal funds is the simplest way to finance energy efficiency retrofits. However, tight budget and efforts to obtain internal approval for capital expenditures often inhibit direct financing of energy efficiency upgrades. Thus, economic incentives could improve the investment environment and the project's financial status (Xu et al. 2015). Various financing options must be considered based on debt capacity, creditworthiness, risk level, in-house expertise, and project term (NREL 2013). Likewise, ensuring the continuity of incentive policies, designing more funding channels, and subsidy measures can improve the effectiveness of economic incentive instruments (Shen et al. 2016).

2.3.2.2 Technical practicality

The most important factor in retrofitting under technical practicality was system compatibility (45.8%). As demonstrated by other studies (Xu et al. 2015), available technology determined the economic and environmental sustainability of building retrofits under the energy performance contracting mechanism. Project integration was the second most important factor under technical practicality (33.8%). Project integration looks at synergetic opportunities with other operations and maintenance projects that can overlap with resource conservation measures. Raising the level of awareness and competency of the building management team to capture potential project integration could augment energy efficiency efforts (Kim et al. 2019). Furthermore, identifying more opportunities to integrate projects will reduce the time and increase the ease of implementation, which are essential aspects in evaluating energy efficiency projects (Jollands et al. 2008; Salvia et al. 2019). Site accessibility was ranked last under technical practicality (20.9%). The building or space must be prepared to allow the retrofit activities, which will cause disruptions to daily operations, including potential relocation of occupants.

2.3.2.3 Occupant impact

The most important factor in retrofitting under occupant impact was occupant satisfaction (44.1%). Energy efficiency measures are gaining more attraction as ways to improve occupant-related impact. For example, the recent innovation of high-efficiency lighting has been widely adopted not only to increase energy efficiency (Kim et al. 2019) but also to improve visual comfort (Ikuzwe et al. 2020) and perceived productivity (McCunn et al. 2018; McCunn and Feracor 2018). The second most important factor under occupant impact was energy-efficient behavior (36.5%). Although energy-efficient behavior can be conflicting with comfort and productivity, lack of consideration of occupant behavior in building retrofit decisions may result in an inappropriate selection of energy efficiency measures (Ben and Steemers 2014). The educational program was ranked last among other factors under occupant impact (20%). Educating building occupants and surrounding communities is necessary to encourage energy-efficient behavior and eventually increase the chance that the occupant-independent retrofit measures (e.g., reduction of lighting power density, improvement of envelope properties, and improvement of HVAC system efficiency) achieve the intended performance (Sun and Hong 2017).

2.3.2.4 Institutional characteristic

The most important factor in retrofitting under institutional characteristic was expert skills (44.5%). The lack of technical expertise is one of the main barriers to energy efficiency improvement that should be addressed by multiple stakeholders in the building industry. Such efforts include keeping up with knowledge about energy management and the technical skills of new energy efficiency technologies (Kangas et al. 2018). There is a need for much improved technical expertise to enhance the energy performance of buildings. Training and qualification schemes should ensure that worker qualifications keep pace with the technical complexity of building components. The second most important institutional characteristic factor was reputation (29.2%). An international survey of building experts found that companies were driven to adopt green technologies to obtain good public image (Darko et al. 2017). The demand pressure factor was rated last under institutional characteristic (27%). Energy benchmarking and transparency programs are an example of a policy to stimulate demand pressure. This policy requires publicly sharing energy use data for similar building types and size to boost energy efficiency in buildings (Mims et al. 2017). Furthermore, this policy addresses the institutional characteristic factors by promoting data-driven decision-making and creating long-term market demand. Building owners and managers can identify opportunities to cost-effectively reduce energy, get rewarded if ranked as a high performer with a good reputation, and become more attractive in the market.

2.3.2.5 Environmental impact

The environmental impact was found to be the least important criterion. One explanation was from a state government respondent, who was barred from considering climate change and calculating the environmental impact and noted that although energy projects were still being considered, their acceptance should be due to other positive effects besides environmental factors. Another possible reason this criterion was ranked last is that, in the US, environmental context is included as part of local and state regulations. Consequently, decision-makers give this effect less consideration since a well-established minimum requirement policy is already enforced, as said by one of the survey respondents. The most important factor in retrofitting under environmental impact was sustainable resources (39%), which refers to the sustainable method of using raw materials and other resources to retrofit, including renewable options. The second most important factor was waste management (34.7%), which refers to the availability of building waste management from the retrofit project. CO_2 emissions were rated last among other environmental impact factors (26.3%). This factor mostly ranked last in terms of the global weight among all factors across different retrofit criteria. Finally, the emerging trends of digitalization to improve energy efficiency raised concern about its net environmental impact. The rapid change of many energy management technologies should be followed by policy updates to minimize the environmental impact from its embodied energy and resources for production (IEA 2019).

2.3.3 *Cross-context comparison*

While statistical assessment about the agreement level generally indicated good consensus between context groups, the results do not suggest a deeper understanding of how priorities of different contexts may deviate. Similar to previous studies (Reinsberger et al. 2015; Si and Marjanovic-Halburd 2018), a cross-context comparison was conducted based on weight differences to identify more precisely the variations of judgments and to provide insights of strategies for energy efficiency improvements tailored based on the context. The weight variations of decision factors among different contexts are given in Figure 2.2. The full list of criteria and factor weights for all context groups are shown in the Appendix 3.

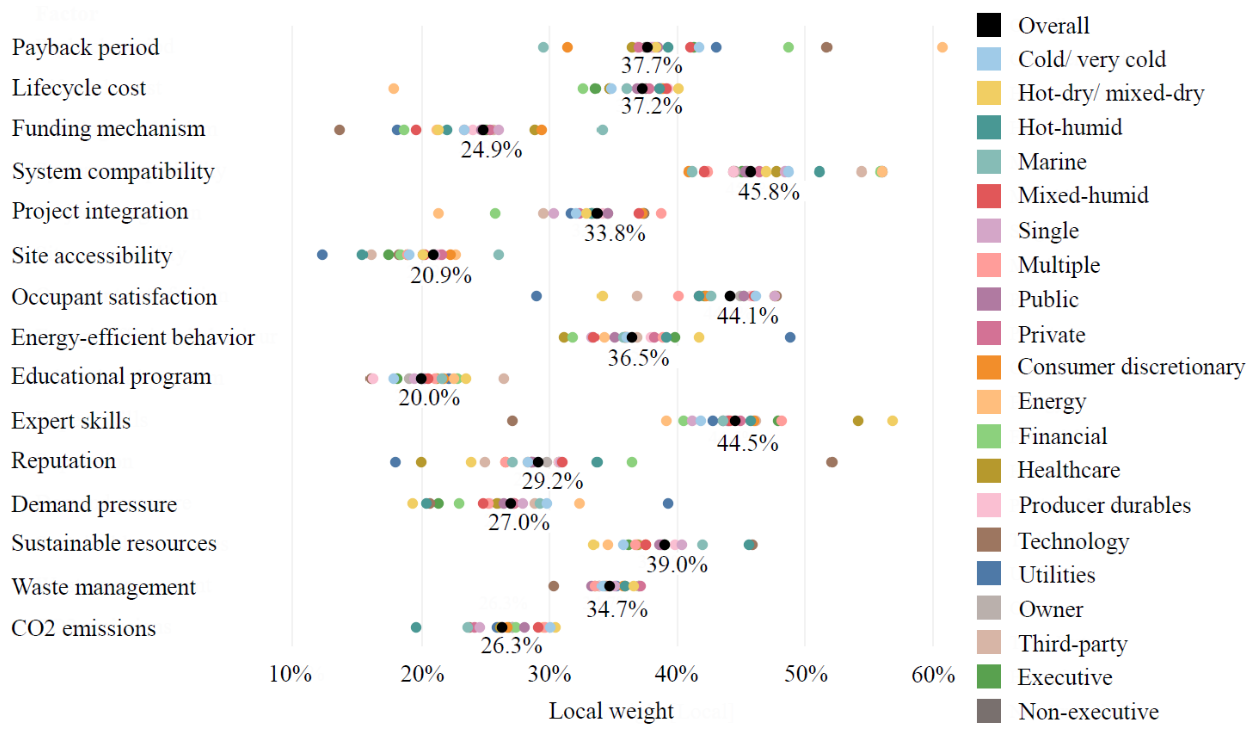

Figure 2.2 Local weights of factors by overall US sample and by different contexts.

There were 35 combinations of context comparisons for each factor. The results showed that most variations between context groups were observed in the payback period, system compatibility, reputation factors, with 22 out of 35 comparisons each indicated medium (5-10%) to the large difference (>10%) on weightings. In contrast, all context groups instead assigned similar importance to waste management factor, with only two comparisons indicated medium difference (5-10%) on weightings, and the remaining comparisons showed small differences (<5%). Table 2.4 summarized the context groups that assigned the highest weight regarding the relative priority of each criterion and factor. The comparison of criteria and factor weight between context groups are provided in the Appendix 4. The following paragraphs discuss the comparisons focusing on those with a medium and large difference.

Table 2.4 Context group assigning the highest local weight (%)

Criteria and Factor	Physical Context		Functional Context		Social Context	
	Building Portfolio	Climate Zone	Institution Type	Industry Sector	Decision Role	Leadership Position
Economic feasibility	Multiple (37.3)	Hot-humid (39.9)	Public (37.2)	Consumer discretionary (40.1)	Third-Party (40.2)	Executive (38.7)
Payback period	Multiple (38.1)	Cold/ very cold (41.8)	Public (38.4)	Energy (60.7)	Owner 38.2)	Executive (41.3)
Lifecycle cost	Multiple (38.6)	Hot-dry/ mixed-dry (40.1)	Private (37.7)	Producer durables (39.3)	Third-Party (37.3)	Non-executive (37.5)
Funding mechanism	Single (26.0)	Marine (34.1)	Private (25.3)	Consumer discretionary (29.4)	Third-Party (25.6)	Executive (25.1)
Technical practicality	Multiple (21.2)	Hot-humid (24.6)	Private (21.3)	Utilities (25.2)	Third-Party (20.6)	Executive (20.6)
System compatibility	Single (48.5)	Hot-humid (51.2)	Private (46.5)	Utilities (56.0)	Third-Party (54.4)	Non-executive (45.5)
Project integration	Multiple (38.7)	Mixed-humid (37.1)	Public (34.5)	Technology (37.4)	Owner (34.5)	Executive (37.4)
Site accessibility	Single (21.1)	Marine (26.0)	Private (21.6)	Energy (22.6)	Owner (21.5)	Non-executive (21.0)
Occupant impact	Single (19.5)	Mixed-humid (20.0)	Public (18.8)	Financial (23.2)	Owner (17.8)	Executive (17.1)
Occupant satisfaction	Single (47.7)	Cold/ very cold (46.1)	Public (45.2)	Technology (47.8)	Owner (44.9)	Non-executive (44.1)
Energy-efficient behavior	Multiple (38.8)	Hot-dry/ mixed-dry (41.8)	Private (38.2)	Utilities (48.9)	Third-Party (36.8)	Executive (39.8)
Educational program	Multiple (21.1)	Hot-dry/ mixed-dry (23.5)	Public (20.2)	Financial (22.8)	Third-Party (26.4)	Non-executive (20.0)
Institutional characteristic	Single (13.6)	Hot-dry/ mixed-dry (15.5)	Private (14.7)	Energy (14.8)	Third-Party (15.6)	Non-executive (14.0)
Expert skills	Multiple (48.1)	Hot-dry/ mixed-dry (56.8)	Private (44.9)	Healthcare (54.1)	Third-Party (46.2)	Executive (47.9)
Reputation	Single (30.9)	Hot-humid (33.8)	Public (28.8)	Technology (52.1)	Owner (29.9)	Executive (30.8)
Demand pressure	Single (27.9)	Cold/ very cold (29.9)	Private (27.2)	Utilities (39.3)	Third-Party (28.8)	Non-executive (27.1)
Environmental impact	Multiple (12.8)	Hot-dry/ mixed-dry (16.7)	Private (12.4)	Technology (16.8)	Owner (11.8)	Executive (11.9)
Sustainable resources	Single (40.4)	Hot-humid (45.7)	Private (38.7)	Technology (45.8)	Owner (39.0)	Non-executive (39.0)
Waste management	Single (35.1)	Hot-dry/ mixed-dry (36.5)	Private (37.1)	Healthcare (35.9)	Third-Party (36.9)	Executive (37.0)
CO_2 emissions	Multiple (29.7)	Hot-dry/ mixed-dry (30.5)	Public (28.1)	Energy (29.6)	Owner (27.1)	Non-executive (27.1)

2.3.3.1 Priority according to the portfolio size

The comparison of judgments between building portfolio groups resulted in small to medium differences, as shown in Figure 2.3. Respondents who manage multiple buildings were more concerned about the need for expert skills (48.1%) compared to those managing single building (41.2%), which was expected since retrofitting multiple buildings is more complicated and thus requires more experts to conduct such improvements. Multiple building group also had stronger opinions regarding the relative priority of project integration and energy-efficient behavior (38.7% and 38.8% by multiple buildings group, compared to 30.4% and 33.3% by single building group, respectively). This perception may indicate that integrating energy efficiency measures with other renovation investments and improving energy-efficient behavior is more challenging in diverse building portfolios but would be critical to the project success. In contrast, respondents who manage single buildings assigned more weight of importance to system compatibility and occupant satisfaction (48.5% and 47.7% by single building group, compared to 42.5% and 40.1% by multiple buildings group, respectively). This finding is similar to the previous study (Medal and Kim 2020), were occupant satisfaction was more important for respondents who managed single buildings than those who managed multiple buildings.

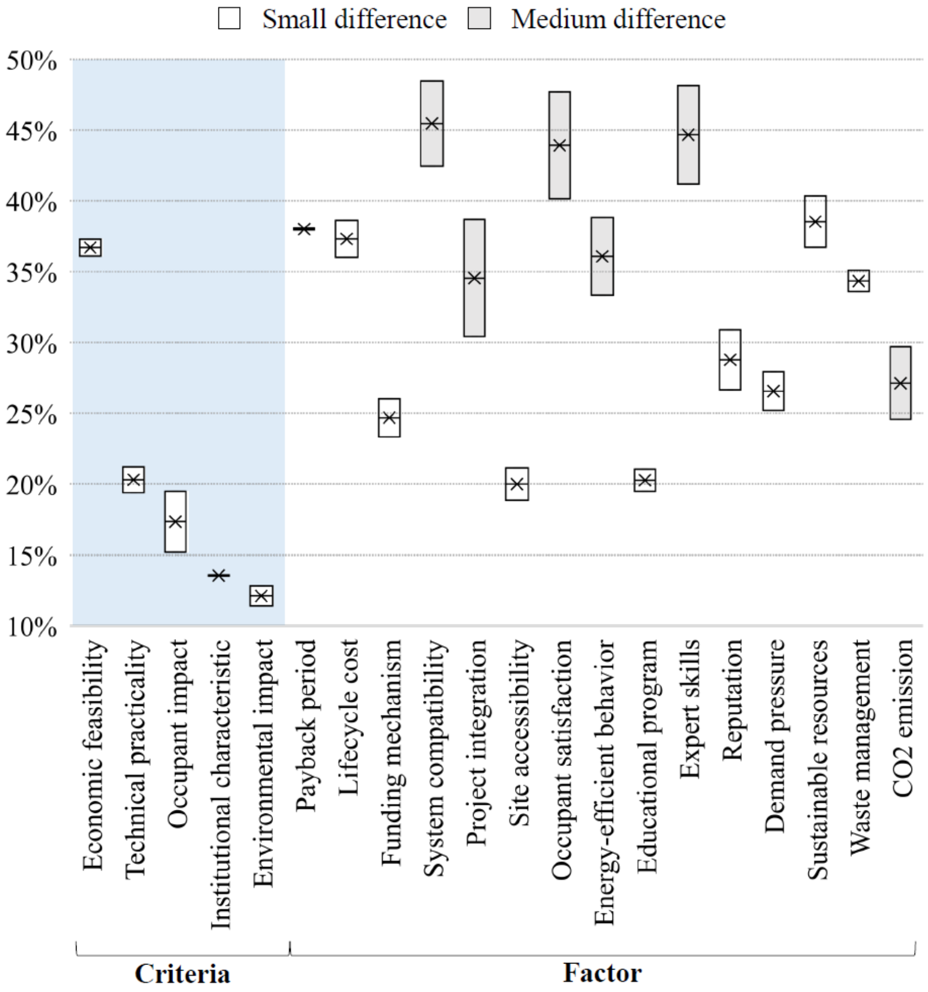

Figure 2.3 Weight differences between single building and multiple buildings groups.

2.3.3.2 Priority according to the climate zone

The comparison of judgments between climate zones showed small to large differences, as shown in Figure 2.4. Respondents from different climate zones were seen to hold varying opinions on the importance of factors such as funding mechanisms, expert skills, and CO_2 emissions. Under economic feasibility, the funding mechanism was assigned the second most important factor by the marine climate group, compared to four other climate groups that placed the funding mechanism as the least essential economic factor. The most considerable difference regarding the importance of this factor was observed between the marine climate group (34.1%) and the mixed-humid climate group (19.6%). Respondents from marine climate were dominated by Washington state, followed by Oregon and some California respondents, all of which are within the top 10 rankings in the 2019 State Energy Efficiency Scorecard, as reported by the American Council for an Energy-Efficient Economy (ACEEE 2019). This scorecard ranks all US states on 33 metrics regarding their clean energy leadership, such as by adopting ambitious state carbon goals, energy efficiency codes, and robust financial incentives. On the other side, three-in-four respondents from mixed-humid climate were identified to be the states ranked within the bottom 30 of the same scorecard. The relatively higher weight of importance for CO_2 emissions by the hot-dry/mixed-dry climate group (30.5%), which is dominated by California and Arizona in our study, might be explained by the fact that the respondents' increase awareness on the negative impact of CO_2 emissions. The survey was taken just a few months after the 2018 wildfire season in California, which released 68 million tons of CO_2, equivalent to the annual emissions produced by generating enough electricity to power the entire state for a year (U.S. Department of the Interior 2018). Furthermore, California and Arizona are two of the 27 states demonstrating climate leadership through the adoption of energy efficiency resource standards that set targets of energy savings for citizens and businesses from energy efficiency measures (ACEEE 2019). Additionally, it was observed that respondents from a hot-dry/mixed-dry climate assigned high importance of expert skills (56.8%) compared to other climate groups' assessments. This strong opinion on expert skills that is dominated by California respondents is relevant with a recent report on energy efficiency jobs in the US, which ranks California as the state with the highest employment in energy efficiency (E4TheFuture and E2 2019). The report also shows that close to 60% of jobs in California are in the HVAC sector, a substantially higher proportion compared to careers related to efficient appliances and lighting, building materials and insulation, and other energy efficiency jobs. Climate characteristics play a substantial role in exploring HVAC retrofit strategies in buildings (Papadopoulos et al. 2019; Rackes and Waring 2017), which entails significant energy saving potentials but requires a relatively complex approach. There are, however, some obvious limitations on further exploring the relationship between decision factor priorities and geographical locations according to climate zones. Additional research should be done to possibly explain these findings at the micro-level, such as if different building code stringency, training program robustness, and financial incentives offered by specific local and state governments, may contribute to different decision priorities.

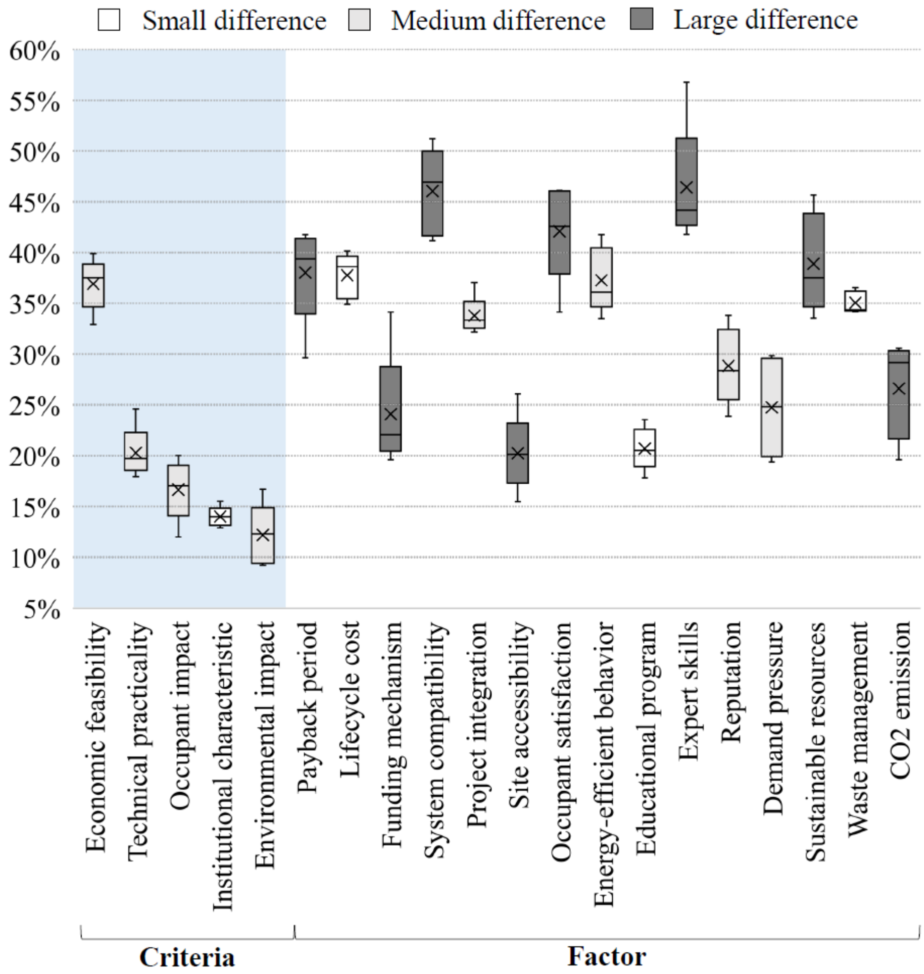

Figure 2.4 Weight differences among climate zone groups.

2.3.3.3 Priority according to the institution type

Interestingly, the segmentation of professionals regarding their institution types in this study sample did not affect most factor rankings. Figure 2.5 shows that there were only small differences in the magnitude of the weightings assigned between public and private institutions. Although, it is worth mentioning that public institution ranked payback period as the most important factor, compared to a private institution that prioritized life-cycle cost as the most important factor. This finding indicates the tendency of institutions to prioritize different metrics when evaluating the economic feasibility of energy efficiency projects. Another study reported that the surveyed Finnish professionals from the private and public sectors had different perceptions regarding energy efficiency (Virkki-Hatakka et al. 2013). While acknowledging different opinions are beneficial, revealing the shared understanding of the decision factor priorities that is found in this study is also critical to establish common goals and accelerate the energy efficiency efforts.

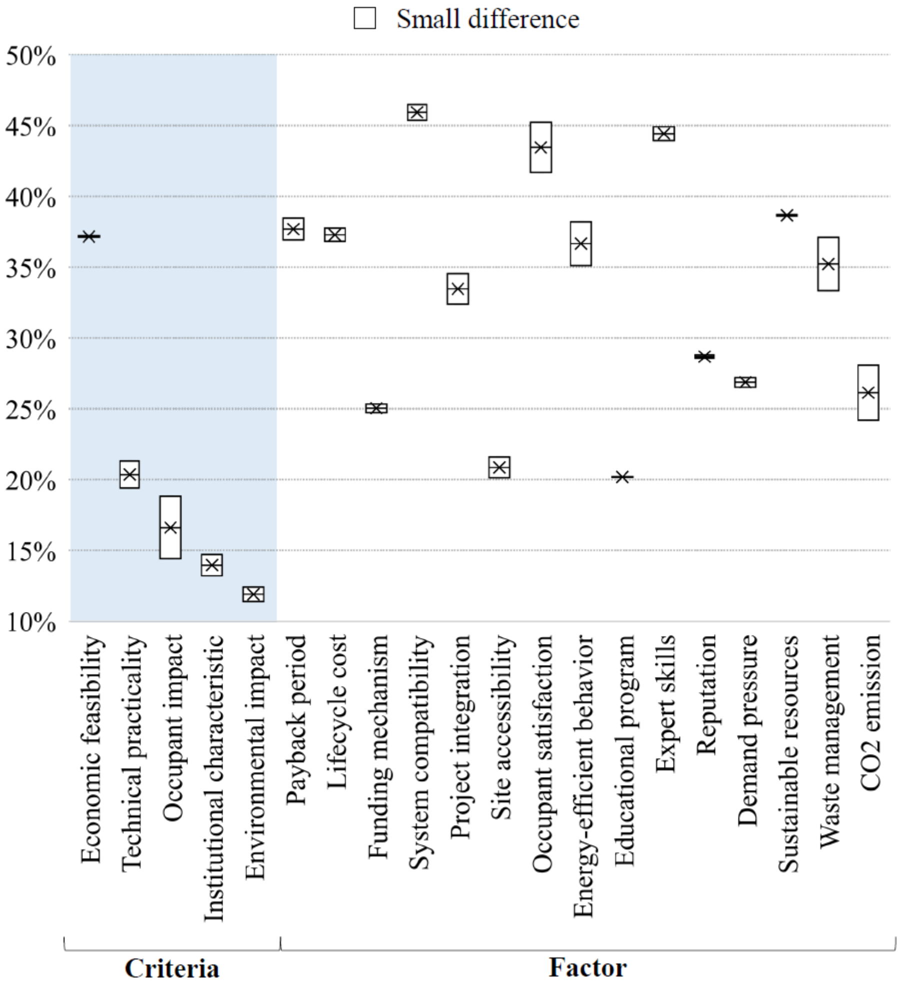

Figure 2.5 Weight differences between public institution and private institution groups.

2.3.3.4 Priority according to the industry sector

The comparison of judgments among industry sector groups resulted in small to large differences, as shown in Figure 2.6. The respondents from the healthcare sector placed the highest weight of importance on expert skills (54.1%) and waste management (35.9%), compared to six other industry sectors. Healthcare facilities such as hospitals operate around the clock using energy-intensive medical equipment. This sector is also a significant source of contamination, making waste management during building operations even more critical to minimize environmental impacts. The healthcare sector has unique characteristics, such as inspections and strict medical licensing requirements, that often take priority over opportunities for energy efficiency improvements. Nevertheless, medical facilities must follow strict building standards, such as air quality regulation, to avoid microorganism infection (Singh et al. 2017). Healthcare facilities tend to have a longer-term view when considering upgrades and are seeing energy efficiency more as strategies for energy resilience. Obtaining the right expertise to perform energy efficiency projects in healthcare buildings is critical to ensure minimal disruption of continuous operations and adherence to health-specific regulations.

Producer durables and energy sectors hold different opinions on the most important economic feasibility factor. The producer durables sector placed the highest weight of importance on life-cycle cost (39.3%). While other context groups assigned relatively minor differences of concern to all three economic factors, the energy sector identified that a payback period is more significant (60.7%) than life-cycle cost (17.8%) and funding mechanism (21.2%). Respondents from producer durables sector are mostly from private construction, engineering, and contracting services, indicating preference of using life cycle cost analysis as a decision-making tool for evaluating the economic performance of building projects over its entire life. Conversely, respondents from the energy sector suggest that they tend to rely on the payback period as a metric to help make technology selection.

Technology placed the highest weight of importance on occupant satisfaction and reputation, compared to six other industry sectors. While all other context groups ranked expert skills as the most important technical practicality factor, the technology sector placed reputation as the most important factor (52.1%). This finding is in line with the fact that the technology sector also assigned the highest weight for occupant satisfaction (47.8%) among other industry sectors. These employers realize that pro-environment policies and practices help them attract and retain employees in the highly competitive and fast-growing technology field (Grossman 2019). Under the environmental impact, the sustainable resources factor was given the highest priority weight by the technology sector (45.8%). High technology corporations manage large data centers that are energy-intensive for storing, processing, and analyzing data, as well as keeping the servers from overheating. Thus, it is no surprise that the technology companies have been dominating as the largest US renewable energy procurers for 2019, according to Renewable Energy Buyers Alliance deal tracker. This sector must contribute to a more-resilient and less-volatile future by powering its facilities with renewable energy.

Utilities sector group were most concerned about system compatibility (56%) compared to other context groups. The qualitative data of this survey supported this judgment as a respondent from the utilities sector highlighted that any new technology must be reliable and easy to maintain, especially for application to a large number of buildings and when the knowledge levels of the building management teams vary. Another respondent from the utility sector stressed the need to maintain existing building standards, so system compatibility is an undermining factor. The utility sector group also had strong opinions regarding the importance of energy-efficient behavior (48.9%) and demand pressure (39.3%). This finding is understandable as many utility companies are trying to reduce the peak loads on their system to avoid or minimize having to invest in new infrastructure, which can be more costly. One of the most effective ways to shift or to reduce the peak demand on electrical load is to implement efficiency measures. The influence of efficiency measures is maximized when appropriate behavioral strategies are in place. Sun and Hong (2017) found that savings from energy conservation measures with strong occupant interaction, such as the use of natural ventilation, are significantly affected by occupant behavior, where buildings occupied by "energy spenders" could use more than twice the energy of "energy savers." This finding suggests the importance of providing accurate information to decision-makers so that they form realistic expectations and continue to educate the occupants to improve the actual energy savings.

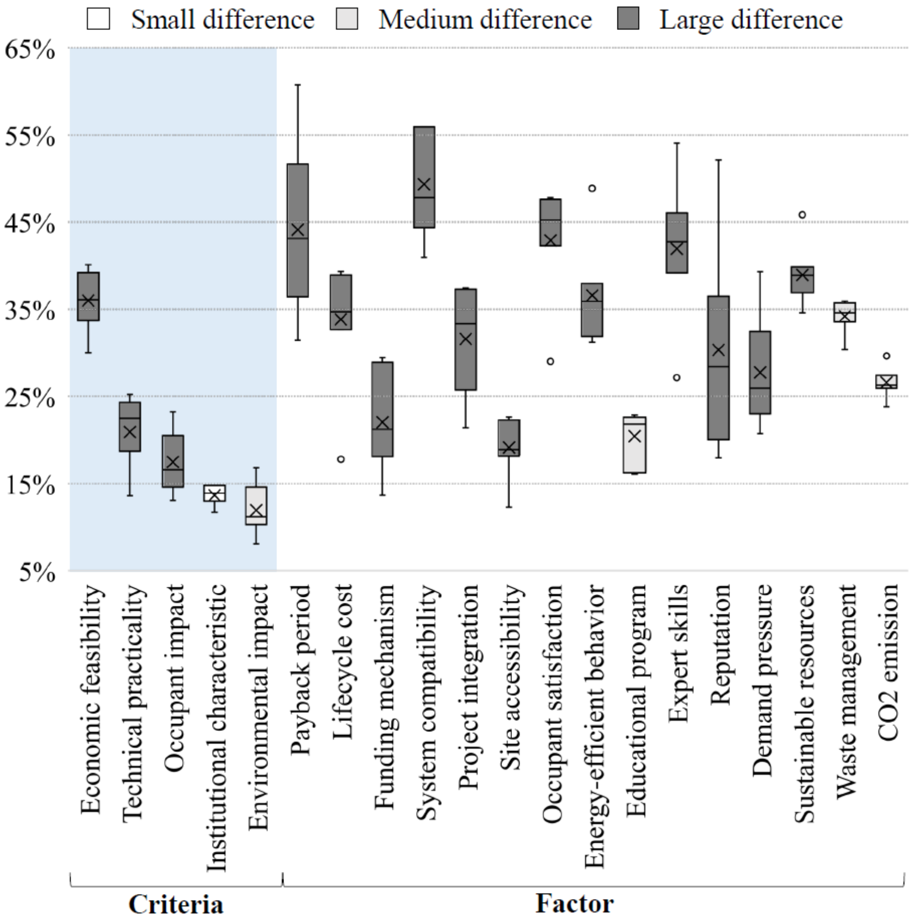

Figure 2.6 Weight differences among industry sector groups.

2.3.3.5 Priority according to the decision role

The comparison of judgments between the building owners and third-party groups resulted in small to medium differences, as shown in Figure 2.7. Respondents from the third-party group were more concerned about system compatibility (54.4%) and educational programs (26.4%) compared to the assessments provided by the building owners group (44.5% and 19.1%, respectively). The higher importance of these factors by the third-party group could come from a reflection of their personal experience about the services provided, such as the technical consulting process to select efficient technologies and in developing the training and educational materials for the building workforce. A survey respondent also cited the importance of system compatibility because some companies limit the software options for security purposes, which reduces the number of integration options. While both building owners and third-party respondents identified occupant satisfaction as the most critical factor under occupant impact, the building owner group assigned higher priority weight for this factor (44.9%) than the third-party group (36.8%). One explanation came from a survey respondent who was a high-end country club owner revealed that their primary goal focused on member safety, comfort, and building esthetics. The cost was rarely the determining factor in making changes, but the budget for energy retrofit often competes with other projects that improve the club experience. An example given by this decision-maker was the consideration of upgrading parking lot lights; they said they would consider using energy-efficient technologies, but only if they fit the design layout. Thus, they tried to tie in energy savings only when it had a positive impression on the members. The greater concern of occupant satisfaction factor by building owners could also be explained by the fact that owner representatives directly interact with the tenants and are more aware of the day-to-day experiences of the tenants. A respondent from the building owner group of a performing art organization highlighted an example that illustrated why building owners are more attuned to occupant satisfaction. Although their nonprofit organization has limited resources, they must fulfill their mission while satisfying their occupants, such as through adequate controls on temperature for both the musicians and their instruments. The building owner group also assigned a higher weight on-site accessibility factor (21.5%) than the third-party group (16%), which could be explained by the fact that the owners better understand the ramifications of how the tenant could be directly impacted by the retrofit activity. Ultimately, it is the owner's job to assess the business continuity while the facility is under renovation and logistically how actual retrofits will occur.

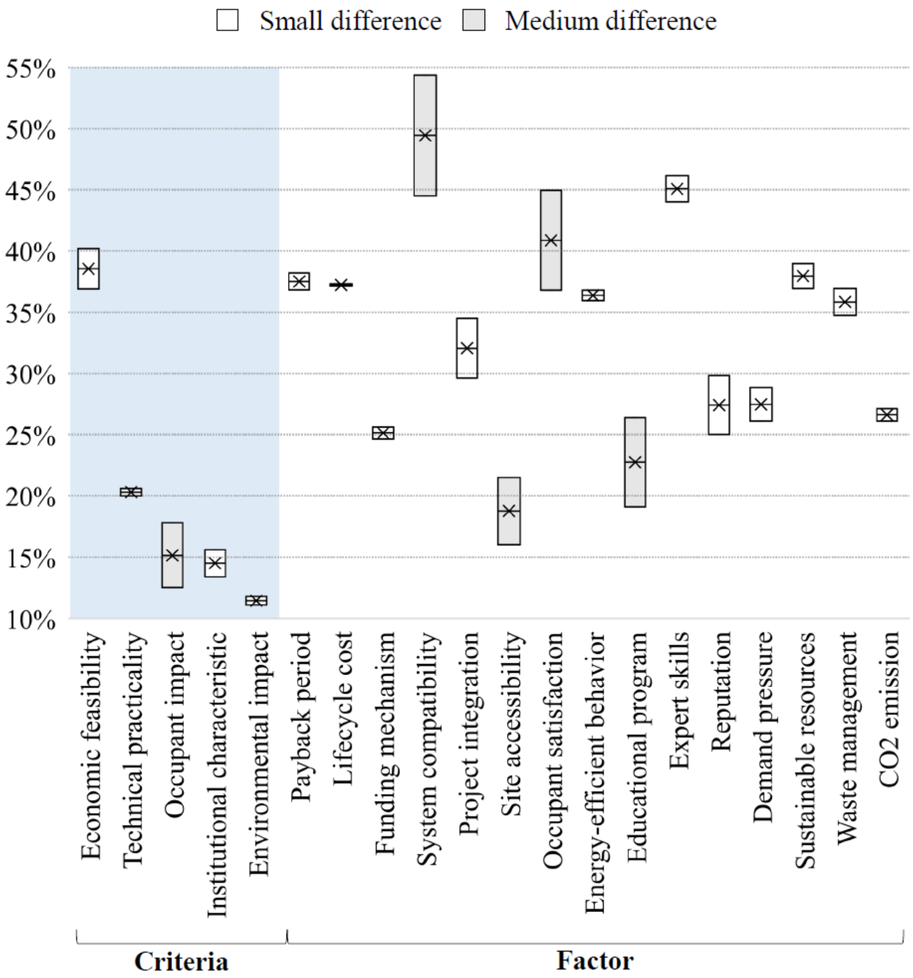

Figure 2.7 Weight differences between building owner and third-party groups.

2.3.3.6 Priority according to the leadership position

The comparison of judgments between the executives and non-executives resulted in mostly small differences and one medium difference, as shown in Figure 2.8. Some respondents in the non-executive position reported in the survey that occupant satisfaction is an important factor to retrofit in their personal view, but they mentioned that it was sometimes undervalued by their organization. The AHP results found no major disagreement, although this perception is reflected as non-executives had slightly stronger opinions regarding the importance of occupant satisfaction (44.1%) compared to the executives (42.1%). Under the criteria of institutional characteristic, demand pressure was given higher weight by non-executives (27.1%) than the executives (21.4%). This finding is in line with a previous study that reported a significant obstacle to energy efficiency to be gaining top management support for upgrades (Siemens 2010). When the executives value the energy efficiency improvements to gain sustainability reputation, some selective organizations were seen to firmly committed to sustainability beyond the government regulations. According to the qualitative survey data, a government agency overseeing seaports and airports was committed to being the most energy efficient; besides, a manager from the healthcare sector stated that their parent company has corporate goals regarding sustainability that sometimes outweigh payback. Conversely, the survey also reported that energy upgrades were not favored in an upscale library facility by the administration and a community-elected board of trustees in an affluent community.

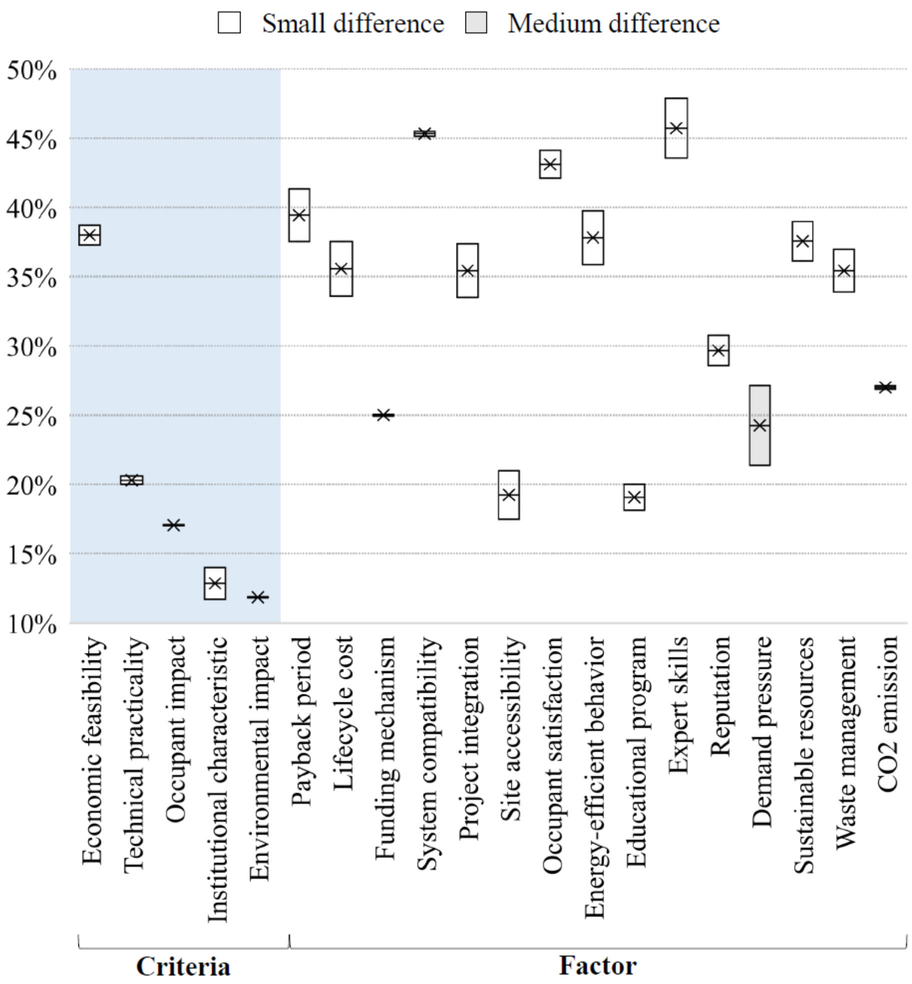

Figure 2.8 Weight differences between executive and non-executive groups.

2.4 CONCLUSION

This study investigated factors affecting the decision-making process to implement energy efficiency retrofit projects. More specifically, this study surveyed 236 facility management professionals from 43 US states and segmenting them in terms of various physical, functional, and social contexts to examine the impact of context to differing perceptions about energy efficiency investments.

Overall, as much as 37.4% of the criteria found to be important in affecting decisions to implement energy efficiency retrofit related to economic feasibility; this was followed by technical practicality (20.1%), occupant impact (17.0%), institutional characteristic (13.7%), and environmental impact (11.8%). The most important factor under economic feasibility to be considered in energy efficiency improvements was the payback period. The most important factor under technical practicality was system compatibility, while occupant satisfaction was the most important factor occupant impact and expert skills factor was the most important factor under the institutional characteristic. Last, the most important factor under the environmental impact was sustainable resources.

The results of criteria and factor weight comparisons further indicate that the magnitude of the decision priorities is different for some professionals among their peers in other context groups. Regarding physical context, respondents managing single building hold stronger opinions about the importance of occupant satisfaction, while the multiple buildings group emphasize project integration more than the single building group. More substantial perception differences were found in terms of diverse climate zones, with respondents from the hot-dry/mixed-dry climate hold significant importance on expert skills compared to four other climate zones. Regarding functional context, public and private institutions indicated a strong agreement by assigning similar importance across all decision factors. The most significant differences in factor weighting and ranking between the respondents were observed among industry sectors. The energy sector assigned a much higher weight on the payback period. The technology sector emphasized the importance of reputation, and the utilities sector emphasized system compatibility in their retrofit decisions. Regarding social context, third-party respondents were more concerned about system compatibility, and building owners placed more weight for site accessibility compared to the judgment provided by the third-party group. Perceptions, according to leadership roles, are rather indifferent to almost all factor weightings, although non-executives assigned a relatively higher weight of importance for demand pressure than the executives to play a role in energy efficiency implementation. There are more variations of weights that were observed based on cross-context comparison and discussed in this study, which contributes to the understanding of expert perceptions regarding retrofit decision-making of different backgrounds in the US.

The methods and results presented in this study are subject to some limitations that call for future research. First, the hierarchical framework and the decision factors were identified based on literature research and evaluated by experts that may still not cover the diverse context groups proposed in this study. Therefore, the survey allowed space for the respondents to provide more information regarding their judgments and if more factors should be considered in the framework. Future research may involve more experts at the pre-survey stage in redefining decision factors to address concerns in more extensive settings; therefore, more decision factors could potentially be added. Additional research may develop hierarchy levels into other vital details, such as in addressing actual field difficulties in retrofitting, evaluating technologies that represent an excellent economic value, identifying methods that are easy to apply, and identifying reliable retrofit processes. Second, this study acknowledges the limitation of the AHP method that relies on expert judgments to identify the important decision factors. Nevertheless, the number of respondents for this study was considerably large and was selected through professional organizations. The survey findings indicated a favorable consistency ratio to ensure the reliability of the judgments. Future studies may consider other multi-criteria decision-making techniques to test whether similar findings are observed. Third, the factor prioritization identified in this study may be specific to the US and, to some extent, may represent the views of other developed countries with mature government policies in improving energy efficiency in buildings. This work can be extended by conducting similar studies to examine the different perceptions of decision factors in other countries and the potential energy efficiency measures, especially that have distinctive government regulations and adoption rates of energy efficiency retrofit from the US. In any case, this study extends prior research by Si and Marjanovic-Halburd (2018) on the impact of country context on different stakeholder priorities, where the U.K. emphasized economic performance compared to China that was more concerned with technical performance. Finally, the AHP approach evaluates the important decision factors by considering that all factors were independent. In fact, there may become correlations among the factors. Thus, future research may be directed towards evaluating the factor relationships.

The success of improving energy efficiency in buildings requires a holistic understanding of the decision context. This study provides a high level of understanding of how the retrofit criteria and factors are prioritized, as well as how the weightings and rankings might change in different contexts. This study provides insights on two aspects influential to that understanding: (a) the determination of quantitative weights and ranking of factors affecting the implementation of energy efficiency retrofits in buildings; and (b) the weights themselves, along with the meaning and implications. This study offers several practical implications. The hierarchical framework can compare both quantitative and qualitative decision criteria, which provides a good representation of complex building energy efficiency issues. Building stakeholders could benefit from these structured criteria and factors in conversations with other stakeholders, as well as applying the AHP to clarify the organization's priorities. The successful implementation of energy efficiency programs depends on channeling measures to a targeted group of end-users and building synergies with other measures or programmers. The policymakers in the US could use the identified weights and ranks of important decision factors to take the necessary actions that lead to more significant energy retrofit improvements.

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Chapter 3. UNDERSTANDING FACILITY MANAGEMENT DECISION MAKING FOR ENERGY EFFICIENCY FOR BUILDINGS AT A HIGHER EDUCATION INSTITUTION

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ABSTRACT

Education buildings, as the third highest consumer of energy in the United States, provides significant opportunities to lower greenhouse gas emissions by increasing energy efficiency (EE). Higher education institutions (HEIs) campuses exhibit multiple favorable but unique attributes, including access to capital, multiple stakeholders involved with differing needs, and control of heterogeneous buildings that are energy intensive, such as laboratories, medical research facilities, sports facilities, and food services. There is a great opportunity to conserve energy by retrofitting these buildings. The decision to retrofit involves many stakeholders and also many factors that are interrelated. This study aims to understand the decision-making processes in EE projects at a higher education institution, particularly the exhaustive list of factors that facilities managers consider when making decision and their interrelationships. Using in-depth semi-structured interviews of facilities managers and secondary data from reports and policy documents, a case study at a large higher education institution is conducted. The content analysis of the data identifies decision factors that are categorized into five major categories: economic feasibility, environmental impact, institutional characteristics, occupant impact, and technical practicality. Interactions among factors are depicted in a causal loop diagram that shows cause-effect relationships. Three main loops highlight the major concerns—economic feasibility, occupant impact, and technical practicality.

KEYWORDS: energy efficiency, higher education, building retrofit, decision making, causal loop diagram

3.1 INTRODUCTION

In the United States (US), the building sector accounted for about 41% of primary energy consumption in 2010 (U.S. DOE 2011). According to the 2012 Commercial Building Energy Consumption Survey, the US has around 389,000 education buildings, with a total floorspace of 12,239 million square feet (1,137 million square meters) (EIA 2016). Education buildings consume approximately 2,238 trillion Btu, equivalent to an energy cost of over $16.8 billion a year—the third highest after office buildings ($30.8 billion) and mercantile buildings ($22.7 billion). Therefore, the potential gain from energy efficiency (EE) opportunities within the educational sector is significant.

EE strategies can be evaluated during the design stage and implemented in new buildings or applied to existing buildings. Retrofitting existing buildings could make a greater contribution to reducing energy consumption and improving sustainability than constructing new green buildings because new construction only adds or replaces a small portion of the existing building stock, fewer than the many existing inefficient buildings. Therefore, a more significant opportunity exists to conserve energy in existing buildings.

Many of the existing buildings, built before 1980, were constructed without stringent guidelines for EE (Gultekin et al. 2014). Today, advanced building technologies and regulatory building codes already mandate many EE strategies for new construction. While industry references and standards exist (e.g., [ASHRAE 2011; ASHRAE 2018; PNNL 2011]) on building energy auditing for identifying appropriate retrofits, stakeholders frequently face challenges related to implementing retrofits (Sutherland 1991). Some of those challenges include work in occupied buildings (Kim et al. 2017), integration and compatibility with existing building systems (Koslow 2009), lack of experience (Polzin et al. 2018), and financing (Heijden 2015). Benefits, when properly executed, include energy savings, a better indoor environment, improved occupant comfort and satisfaction, and improved rental rates (Ardente et al. 2011; Fuerst and McAllister 2009; McCunn et al. 2018; Noris et al. 2013). Therefore, many studies indicate that despite multiple challenges in conducting building retrofit projects, more opportunities and benefits come from such projects (e.g., [Koslow 2009; Miller and Buys 2008; Ungureanu and Fülöp 2014]).

Higher education institutions (HEIs) pursue environmental sustainability through physical operations, research, public outreach, inter-university cooperation, partnerships with government, non-governmental organization and industry, and ecological literacy (Wright 2002). Physical operations on campus include efforts related to resource conservation, recycling and waste reduction, and operation and maintenance of heterogeneous buildings. Physical EE retrofits are complemented by engaging occupants to influence energy-efficient behaviors through education, demonstration, and research (Krasny 2015). HEIs provide an ideal platform and testbed for understanding how decisions are made for evaluating and selecting energy-efficient retrofits. Campuses typically include clusters of heterogeneous buildings, typical of large owners or cities seeking to scale up retrofit opportunities. It is common to have multiple stakeholders involved with differing needs. These characteristics make it generalizable to other contexts.

Although efforts have been made to understand the decision-making process in building energy use (e.g., [Albatici et al. 2016; Jones and Bogus 2010; Kamari and Kirkegaard 2017; Kontokosta 2016; Zavadskas et al. 2008]), it is still unclear what factors are concurrently considered in the decision making of a large institution. The interrelationship between factors, particularly in the context of an HEI, has not been fully explored. This empirical study aims to provide an understanding of the decision-making processes of facilities managers and other relevant decision-makers in designing and executing EE projects, particularly understanding (1) the exhaustive list of factors considered to make decisions and (2) the interrelationships among those factors. The setting of this study is an HEI, the University of Washington (UW) in Seattle, Washington.

3.2 BACKGROUND

3.2.1 *Energy use and efficiency opportunities in buildings*

Various EE opportunities can be considered depending on the context-specific energy demand. In addition, different solutions may exist when evaluating upgrades for single buildings versus multiple buildings. In offices, lighting, computers, and the heating, ventilation, and air conditioning (HVAC) are responsible for more than 70% of electricity consumption (EIA 2016) and therefore are the best categories to target for energy conservation. A study by Hou et al. (2016) identified the market characteristic of commercial building EE retrofit in China. Their results showed that air-conditioning systems in offices require the highest retrofit cost, similar to shopping malls, but have the longest payback period. Overall, a thoughtful policy design is suggested to improve EE opportunities.

Primary energy consumption in the residential sector accounts for 54% in the building sector (U.S. DOE 2011). Demographic, socioeconomic, weather and geography are some of the main factors influencing the energy consumption in residential buildings (Allouhi et al. 2015). For example, heating contributes to 62% of the total energy consumption in Australia, compared to an average of 43% in the US, due to the different climate. EE improvements in residential projects are usually integrated into renovation projects to add value to the property. EE opportunities are not only triggered by the homeowners’ need to save energy but to improve social responsibility and quality of life (Jensen and Maslesa 2015).

Healthcare buildings operate 24 hours a day with sophisticated medical and lab equipment that use a significant amount of energy. Healthcare buildings are the second most energy-intensive commercial-sector buildings, using double the amount of energy per square foot as compared to regular office buildings (Sahamir and Zakaria 2014). Moreover, it is estimated that the hospital industry's current energy use in the US alone causes about $600 million per year in increased health care costs due to increases in asthma, other respiratory illnesses, and hospital emergency department visits (Kaiser et al. 2001). Within medical facilities, lighting and medical equipment contribute the most to energy end uses in hospital facilities (Sahamir and Zakaria 2014).

Identifying EE opportunities for multiple buildings in HEIs is more complicated compared to identifying opportunities in a single building due to different energy consumption characteristics. While the primary goal of university buildings is to support educational services, campus operation also includes servicing academic offices, research facilities, housings, hospitals, restaurants, and sports facilities (Hawkins et al. 2012). These mixed-use buildings create variability of energy use patterns and make retrofit opportunities more challenging yet also attractive. For example, the educational building stock in Italy displayed favorable EE opportunities since a large amount of the buildings require significant renovations to comply with the current national laws (Zinzi et al. 2014). Chung and Rhee (2014) argued that retrofitting existing buildings into low-energy buildings in higher education institutions (HEIs) offers much more benefit than controlling the energy consumption levels. Their argument was based on the consideration of the characteristics of university buildings used by a large number of undefined users and the difficulty of controlling equipment loads and predicting occupancy schedules. Because their source of energy waste is mainly due to predetermined operational control settings and not necessarily due to occupant behavior, retrofit opportunities become more attractive. In fact, Gul and Patidar (2015) found that the shape and magnitude of energy demand profiles are closely associated with the preset heating/cooling systems of the building as opposed to the occupancy profiles. A comparative EE retrofit study in four cities in China found that educational buildings have the lowest retrofit cost compared to shopping malls and office buildings (Hou et al. 2016). Hawkins and Mumovic (2017) found that while the effective carbon reduction intervention varies by building activities and types, the refurbishment scenarios in HEI buildings in the UK showed an average life cycle carbon savings of between 20% and 29%. These studies show that educational buildings have a massive opportunity for energy savings and carbon reduction with reasonable investment costs.

3.2.2 *Decisions and motivations to implement an energy retrofit in academic buildings*

Economic considerations are the main drivers and barriers for energy retrofit implementation in many building types, such as residential (e.g., [Gamtessa 2013]), manufacturing sector (e.g., [Anderson and Newell 2004]), and commercial (e.g., [Hou et al. 2016; Ruparathna et al. 2016]).

Besides economic factors, other considerations such as integrating sustainability efforts with the academic curriculum for educational purposes and demonstrating innovations are other significant drivers for implementing the EE project in academic buildings.

The economic feasibility of retrofitting educational buildings are generally influenced by the building characteristics and investment cost (Ascione et al. 2015; Niemelä et al. 2016; Santoli et al. 2014; Stocker et al. 2015). Niemelä et al. (2016) analyzed the impact of different energy renovation measures on energy efficiency and economic viability in educational buildings in the cold climate of Finland. Their study found that by performing deep renovations such as the installation of new energy efficient windows and dynamic ventilation systems, the proposed nearly zero-energy building (nZEB) requirements can be achieved cost-effectively while significantly improving the thermal comfort and indoor air. Bonomolo et al. (2017) presented a method to select lighting retrofit systems in educational buildings in Italy and found that the daylight analysis can be collectively considered as a factor for optimizing the economic performances. Ascione et al. (2015) discussed the importance of providing incentives for educational building owners as another way to encourage EE investment.

Applying energy conservation measures in university buildings offer educational opportunities that can contribute to raising the general awareness of low-energy buildings (Kim et al. 2018; Sesana et al. 2016). HEIs are increasingly emphasizing sustainability values within the taught curriculum. Sesana et al. (2016) studied the sustainable campus development issues in university communities in Italy and found that involving students, researchers, and other university stakeholders to participate in the EE retrofits can promote engagement and foster creativity. Furthermore, while the immediate financial benefit could be challenging to justify, the teaching staffs at some of the first sustainable schools in Israel were found to have higher satisfaction with their physical work environment (Meron and Meir 2017).

As innovations are the primary goal of HEIs, universities view EEs as a pathway to test innovative technology on campus. For example, a European Union funded project aims to achieve a 50% energy reduction in the region by using university as a living lab to evaluate several innovative retrofit technologies (Ahmed et al. 2017). The advanced technologies considered in their study included vacuum insulated panels, phase change materials tubes, ventilated facade with photovoltaic panels, and electrochromic windows. They noted that scalability and replication is an important factor to consider for future projects. Another study investigated a secondary school in Italy to identify deep energy renovation opportunities in non-residential buildings (Zinzi et al. 2014). The study found that by adding building envelope insulation, new heating and mechanical ventilation systems were able to achieve the energy target reduction while maintaining a comfortable indoor environmental quality. For successful implementation of innovative technology, collaboration among different university departments with partner institutions along with institutional mechanisms was found to be critical (Tan et al. 2014).

3.2.3 *Energy resource conservation measures at the University of Washington*

As one of the largest HEIs in the US, UW is committed to pursuing campus-wide sustainability goals and will play an important role in becoming exemplary of green urban settings. UW’s Seattle campus has over 250 buildings in an urban setting. Of those buildings, Washington State funds about 180 buildings. In 2016, the university has conducted energy audits and analyses for 112 of the largest state-funded buildings, which make up over 11 million square feet in building space, constituting more than 96% of the total square footage (UW 2016). As a result of the audits, 417 potential energy resource conservation measures have been identified, with 30,285 Mg per year of carbon dioxide emissions and $4.4 million per year of utility cost avoidance possible. Those state-funded buildings are managed by Facilities Services, while other non-state-funded buildings at the university are managed by Housing and Food Services, Intercollegiate Athletics, and the Medical Center.

3.3 RESEARCH METHODOLOGY

Figure 3.1 below shows the methodology framework that was adopted to address the research objectives.

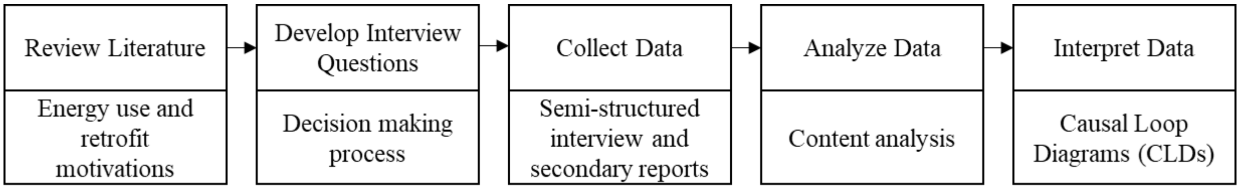


Figure 3.1 The research process

The literature review is summarized in the previous sections and motivated this study to focus on the higher education institution (HEI). The remaining four steps are discussed in the following subsections.

3.3.1 *Interview design and participants*

The interview questions were developed to understand the decision-making process of energy efficiency (EE) retrofits. The interview questions were designed to be semi-structured addressing topics related to personal, procedural, ranking, timeline, and stakeholders involved in retrofit decisions. This is a standard method to elicit causal beliefs and decision strategies (Walker and Bostrom 2014).

The interview instrument had 14 questions under six main topics, as shown in Table 3.1. Topic 1 asks the respondents' role and expertise in energy conservation, especially in the higher education field. Topic 2 through 5 identify the decision-making processes, which include procedural (i.e., planning process, needed information, and impediments), ranking (i.e., determining factors and prioritization strategies), timeline (i.e., duration and frequency of evaluation process), and stakeholders (i.e., people who are involved both internally and externally). Topic 6 captures further feedback related to energy conservation.

Table 3.1 Interview questions

Topic		Questions	
1	Personal	1.1	What is your area of expertise in identifying, selecting, and implementing the energy conservation measures on campus?
2	Procedural	2.1	How do you plan and implement energy conservation efforts?
		2.2	What is the critical information needed during the retrofit identification, selection, and implementation process?
		2.3	How do you quantify energy efficiency measures?
		2.4	What are the impediments of the current practices?
3	Ranking	3.1	How do you shortlist and prioritize the energy retrofits?
		3.2	What are the critical aspects or determining factors of selecting and prioritizing retrofits?
4	Timeline	4.1	What triggers you to implement energy conservation measures?
		4.2	How long does the process take to select and prioritize the retrofits?
		4.3	How often do you perform the energy efficiency retrofit decision process?
5	Stakeholders	5.1	Who is typically involved when selecting, prioritizing, and implementing the retrofits?
		5.2	Ultimately, who is responsible for identifying and implementing the energy retrofits?
		5.3	How do you weigh different stakeholders' input in the decision-making process?
6	General comments	6.1	Do you have any other comments related to the study, which aims to improve the current method of prioritizing energy efficiency retrofits?

3.3.2 *Data collection methods*

This study uses primary data from semi-structured interviews and secondary data from reports and other publicly available documents. A qualitative data analysis approach was employed using ATLAS.ti. The results of the analysis are discussed in Section 4.

The study used a mental model approach that helps to identify knowledge gaps. The mental model has been used to represent people’s perceptions and understanding of various issues and concepts (Olson et al. 2011). This method has been applied in different contexts, such as understanding the non-responder mental models of oil spills (Bostrom et al. 2015). To the authors’ knowledge, there are currently limited studies that have applied the mental model approach in a higher education context, except Olson et al. (2011) that identify misconceptions about campus recycling programs. In addition to the mental model interview, secondary data from a university-wide survey and regional policies were used to increase the depth of information and to validate key findings from the study samples.

3.3.2.1 Primary data

The interview instrument was pilot tested with two UW building coordinators before finalizing the questions. Interviews were conducted with six facilities managers at UW who manage different types of facilities, covering both state-funded and non-state-funded buildings (see Table 3.2). The semi-structured interviews were conducted face to face at the respondent's office and took around 35 to 80 minutes to complete. Four interviews took place in 2016 (August, October, and December), and two interviews took place in May 2017. The respondents are highly experienced individuals who worked at UW for more than ten years.

Table 3.2 Interview respondents' profile

No	Initial	Position	Unit	Management Coverage	Relevant Experience
1	FM1	Resource conservation manager for facilities services	UW Facilities Services	Facilities services buildings (mostly state funded and some non-state funded)	32 years (15 years at UW)
2	FM2	Capital planning and sustainability manager	UW Housing and Food Services	Buildings for housing and food services (non-state funded)	44 years (17 years at UW)
3	FM3	Operations and maintenance director	UW Medical Center	Medical center buildings (non-state funded)	11 years at UW
4	FM4	Assistant director of campus utilities	UW Campus Engineering and Operations	State-funded buildings for utility services, including a power plant	30 years (21 years at UW)
5	FM5*	Facilities manager	UW Tower	Highrise buildings for management and offices (non-state funded)	28 years (10 years at UW)
6	FM6*	Facilities supervisor	UW Tower	Highrise buildings for management and offices (non-state funded)	35 years (20 years at UW)

* Interviewed in a group.

3.3.2.2 Secondary data

Reports, policy documents, and other related documents were collected to complement primary data from the interviews (see

Table 3.3). The perspectives of occupants were incorporated from the 2014 UW Sustainability Survey which was obtained from the university (UW 2014). The perspectives of policymakers at the university and city levels were incorporated using a climate action plan (CAP) and other policy and practice documents (Seattle City Council 2013; Seattle City Council 2016; Seattle City Council 2018; UW 2009; UW 2012; UW 2018). The secondary data were not intended to represent those stakeholders' perspectives exhaustively but were used to highlight some of their concerns and help link the factors in the interrelationship analysis.

Table 3.3 Secondary data sources

Secondary Data	Source
Occupant survey	*2014 UW Sustainability Survey* (UW 2014)
UW policy and practice	1. *UW Climate Action Plan 2018* (UW 2009) 2. *Executive Order No. 13 on Environmental Stewardship and Sustainability* (UW 2012) 3. *Sustainability Fact Sheet 2018* (UW 2018)
Seattle city policy	1. *Seattle Climate Action Plan 2013* (Seattle City Council 2013) 2. *New Building Energy Bills 2017* (Seattle City Council 2018) 3. *Seattle Energy Benchmarking Analysis 2016* (Seattle City Council 2016)

3.3.3 *Analysis and interpretation methods*

Transcripts of interviews and written documents were analyzed and coded using the content analysis method, employing a qualitative data analysis software, ATLAS.ti. The coding process is an iterative process in which the researchers revisited and recoded the data several times to refine the analysis and ensure correct mapping of quotes into codes. The established codes are named as factors and grouped into several categories.

After the completion of interview and document analysis, the Causal Loop Diagrams (CLDs) were constructed to show cause-and-effect relationships between factors and to understand the factors which become the drivers for change in the system and those which become the stressors of the system. The loops help to explain the complexity of non-linear relationships among the factors and to find potential interventions, if required, to make EE efforts successfully implemented. CLDs have been successfully used in various sustainable development and resource management, such as for environmental management (Ding et al. 2018; Inam et al. 2015), electricity development (Riva et al. 2018), renewable energy adoption (Agnew et al. 2017; Hidayatno et al. 2019) and energy planning in buildings (Caponio et al. 2015; Macmillan et al. 2016).

3.3.4 *Data analysis*

Based on Medal and Kim (2017), the initial factors were listed as a codebook and used during the initial coding process, while still allowing new concepts to emerge from the data. Those factors are categorized into five dimensions: (1) impact to occupant, which includes educational programs, occupant satisfaction, and energy-efficient behavior; (2) impact to the environment, which includes carbon dioxide emissions; (3) support from stakeholders, which includes expert skills, team collaboration, alignment for ranking, sustainable credit, reputation, and demand pressure; (4) economic feasibility, which includes overall building performance, energy savings, financial incentives, and investment costs; and (5) practicality, which includes project integration, building availability, and projects.

In the first iteration, the 17 factors of preexisting concepts identified by Medal and Kim (2017) were used as the initial codebook. Identical factors were then merged, and redundant/duplicate factors were deleted. Finally, 32 factors were identified within those five categories, and the relationship (density) between factors emerged from the analysis. Three additional factors that represent the role of government and one factor that represents the EE activity were added. The factors and their occurrences (grounded) are shown in Table 3.4.

Table 3.4 Factors and their occurrences

Categories and Factors	Interviews					Secondary Data			Totals
	FM1	FM2	FM3	FM4	FM5/ FM6	Occ. Survey	UW Policy and Practice	Seattle City Policy	
Economic Feasibility (EF)									
EF1 - Complexity of funding mechanism	4	3	3		7				17
EF2 - Cost saving	1	1	4		2		1		9
EF3 - Funding	1	1		3	2				7
EF4 - External funding source	2		2	1	2				7
EF5 - Internal funding source	1	2	2	2	2				9
EF6 - Length of funding cycle	2		1						3
EF7 - Life cycle*	1	2	3				1		7
EF8 - Payback/ return on investment	3	4	9				1		17
EF9 - Rebate (incentive)*		4	2		1				7
Environmental Impact (EI)									
EI1 - Carbon dioxide emissions*	1	3		1			1	3	9
EI2 - Energy conservation	3	2	1	5	2	1	1	1	17
EI3 - Sustainable resources		2		3			3		8
EI4 - Waste management								2	2
Institutional Characteristics (IC)									
IC1 - Coordination/ collaboration*					6				6
IC2 - Demand pressure*	2	2		1			2		7
IC3 - External expert skills*	2	3	2	1					8
IC4 - Internal expert skills*	3	4			2				9
IC5 - Organization commitment							6		6
IC6 - Reputation*		1				7	2		14
Occupant Impact (OI)									
OI1 - Educational program*		6		1		1	3		12
OI2 - Energy-efficient behavior*		6		2		5	2		16
OI3 - Expectation						6			6
OI4 - Satisfaction*	4	1			9				14

Categories and Factors	Interviews					Secondary Data			Totals
	FM1	FM2	FM3	FM4	FM5/ FM6	Occ. Survey	UW Policy and Practice	Seattle City Policy	
Technical Practicality (TP)									
TP1 - Completion time	3	2	1	2	6				14
TP2 - Functionality/ reliability			4	8	5				17
TP3 - Monitoring			3		1		3		7
TP4 - Project integration*	4			2					6
TP5 - Regulation and bureaucracy	1	2	1	5	4				13
TP6 - Site accessibility*	1			1	1				3
TP7 - Speed and ease of implementation		3		1	3				7
TP8 - System compatibility	1			2					3
TP9 - Use of technology	4	2	3	2	1		3		15
Government									
G1 - Govt. commitment								8	8
G2 - Govt. EE requirement								7	7
G3 - Govt. support							1	10	11
UW1 - EE Activities	3	15	10	2					30
Totals	47	71	51	45	56	20	30	31	359

*Note: *similar factors identified in Medal & Kim (2017).*

3.4 RESULTS

3.4.1 *Stakeholders and their relations*

Figure 3.2 shows the decision makers’ relationships in EE projects at the university. The executive vice president for finance and administration is responsible for capital planning and development, which manages major project developments such as new buildings and new facilities, and finance and business services, which include energy conservation resource management, minor projects planning and resources, and technology services. The executive vice president works with the provost, who manages planning and budgeting including state funding that is mainly used for state-funded buildings. The Environmental Stewardship Committee is also under the provision of the provost. The resource conservation program and minor capital projects are funded from external sources through rebate programs such as those from Seattle City Light and Puget Sound Energy. In some cases, minor capital projects are incorporated and augmented into major capital projects.

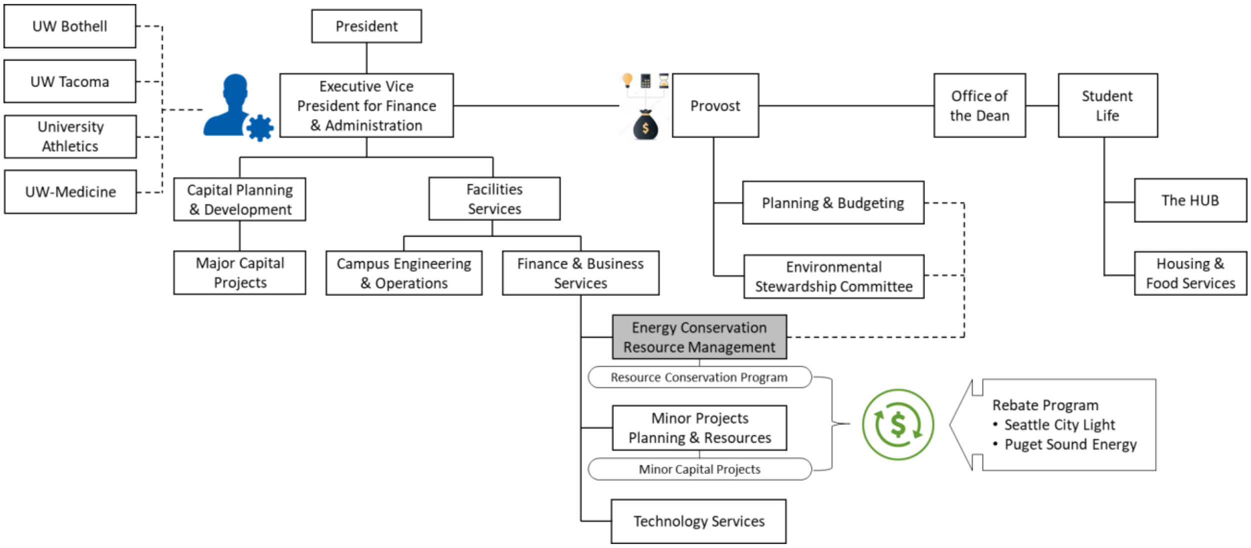


Figure 3.2 Decision makers in EE projects

3.4.2 *Factors considered to make decisions*

In this section, thirty-two individual factors under the five decision categories are described in detail (see Appendix 6 for quotes from interviews).

3.4.2.1 Economic feasibility

In general, there are three types of projects: (1) major capital projects, (2) minor capital projects, and (3) regular maintenance. The source of funding for these types of projects may also differ, which can be categorized into (1) state allocation, (2) major capital renewal safety money, (3) minor capital renewal safety money, and (4) local funds. As a state-university, UW faces the *complexity of funding mechanism* (EF1) issues. For UW Facilities Services, time is often a challenge to get the funding because the bureaucratic process does not get underway until someone makes the decision to fund a project, either at the university level or the city or state level. For a unit that is self-funded like UW Housing and Food Services, the issue is more about the availability of funds rather the process, which basically rests on the decision of the director. For another self-funded unit like the UW Medical Center, the funding is usually not a problem due to the money its services generate. The center has to prioritize maintenance and EE with medical equipment and other capital investments.

The high energy bills and the increase in energy prices are major economic reasons for conducting EE projects. The funding decision also requires the satisfaction of *cost-saving* (EF2) criteria. To date, the resource conservation program at the university has saved $5.6 million from utility costs (UW 2018). *Funding* (EF3**)** for EE projects is an important consideration since all projects involve a budgetary constraint. The money for the projects may come from *internal funding* (EF4) and *external funding* (EF5) sources. In general, the funding schemes and sources vary, depending on the ownership of the buildings (state-funded versus non-state funded) and the types of external funding sources. The *length of the funding cycle* (EF6) differs among different units. UW Facilities Services usually has a biennium funding cycle, which appears in July and lasts for two years, while the UW Medical Center has an eight-year funding cycle. The funding cycle is important because it decides the number, size, and length of projects that can be proposed and executed during each cycle.

In line with the literature (e.g., [Bleyl et al. 2019; Wang et al. 2014]), when deciding to conduct retrofits *life-cycle* (EF7) cost is one of the most important considerations for most respondents. It is more important than the investment cost of the retrofits as long as it is within their budget. While the life cycle is important, the *payback* or *return on investment* (EF9) is also a major consideration in the economic feasibility of retrofit projects. But payback period or return on investment sometimes contradicts with the consideration of the life cycle, especially for a complex and interrelated project that requires substantial capital. Return on investment, commonly calculated using the net present value (NPV) approach, often conflicts with energy conservation, especially in large projects that span multiple years, multiple buildings, and multiple facilities (Wu et al. 2016). The largest energy savings and the largest return on investment cannot be achieved at the same time. Therefore, an optimal tradeoff strategy that dynamically changes in the dimensions of time, building, and technology is needed.

A *rebate* (EF9) is another consideration of the facilities manager when deciding to conduct EE projects. It may come from building retrofits that go beyond building codes or the amount of energy savings generated from the retrofits. However, for UW Facilities Services, there is no tax rebate due to the university's status as a public institution, which does not pay taxes. UW Housing and Food Services and the UW Medical Center can still get rebates because their buildings are not state buildings.

3.4.2.2 Environmental impact

Building energy consumption accounts for more than 20% of Seattle's greenhouse gas emissions (Seattle City Council 2013). The reduction of *carbon dioxide emissions* (EI1) is endorsed at the highest decision maker level at UW. All facilities managers interviewed echo the same in terms of the importance of reducing greenhouse gas emissions, particularly carbon dioxide. Carbon reduction is always the long-term objective of building retrofits because carbon dioxide contributes to climate change. The university has set the target of carbon dioxide reduction in its CAP.

Facilities managers consider the amount of energy consumed as important as the occupants. The city government through its Seattle Energy Benchmarking Dashboard monitors energy consumption. One important aspect of *energy conservation* (EI2) is not wasting energy. The greatest opportunity is to stop wasting heating and cooling to the environment. However, despite its importance both economically and environmentally, the facilities managers do not usually make decisions based solely on energy savings. Respondents also discussed the use of *sustainable resources* (EI3), from shifting to renewable energy such as the use of solar panels to conserving water through rainwater system conservation. However, these efforts can face financial feasibility challenges.

Waste management (EI4) is another important environmental factor. In its CAP, the Seattle City Council (2013) support and expand material exchange and reuse programs and promotes building with salvaged and reclaimed materials. At the university, the contractors who execute the retrofit projects usually handle the waste from those projects. However, for projects owned by UW, Facilities Services has a recycling unit that serves all educational buildings, except UW Housing and Food Services and the UW Medical Center. The unit also provides building waste infrastructure assessment.

3.4.2.3 Institutional characteristic

Coordination or *collaboration* (IC1) among different facility management units within the university is also important in managing the facilities and sharing resources. There is coordination among units at UW, for example, UW Facilities Services manages the most diverse types and a large number of buildings, which require coordination with other units, particularly campus operations and maintenance. UW Tower often works with the Real Estate Office and Campus Engineering and Operations Unit although most of the time they operate autonomously. UW Housing and Food Services and the UW Medical Center are however independent and self-funded entities that mostly self-manage their buildings. Their collaboration is predominantly with students and external entities.

Demand pressure (IC2) is related to the demand from stakeholders, including the occupants, management, and the authorities (city or state). The demand can be in the form of smarter buildings with more data generated from the buildings, energy audits to guide energy retrofit projects on the buildings, what a building can offer to occupants and the city and state require energy use reports to benchmark the performance of buildings (Seattle City Council 2016).

EE projects require both *internal skills* (IC3) and *external skills* (IC4). External skills can be energy engineers or specialists who analyze existing building systems and identify energy waste in those systems through an audit process that they conduct, often using energy analysis software. They can also be subject matter experts in building emission control or energy modeling. Architects, mechanical engineers, and building engineers are often hired by external parties. The degree of involvement of external experts also varies among different units. The UW Medical Center mostly works with external consultants to develop and execute the plan related to the operation and maintenance. The university also has internal experts who have the capability to work on EE projects. For example, there are highly motivated and skilled experts in urban development at the university who can lend valuable insight, skill, and vision. Experienced facilities managers can identify internal resources who have the passion and interest in EE to put together the right people for a particular project. However, the university often requires the services of external experts in many cases due to a limited number of internal resources. The use of tools or software to manage EE activities internally needs to be enhanced to reduce reliance on external experts.

UW shows its strong *organization commitment* (IC5) as a university to continue exploring innovations in conserving energy and help meet the carbon reduction goals. UW Executive Order No. 13 on Environmental Stewardship and Sustainability (UW 2012) provides a foundation of UW commitment as an organization. UW also published its CAP in 2009 and established the UW Environmental Stewardship Committee to provide recommendations for environmental policies at UW and oversee progress in achieving the goals of the CAP. The university commitment is also influenced by geographical locations, given the different energy conservation potentials and strategies due to the climatic regions and supportive local policies.

UW strives to maintain its *reputation* (IC6) as a sustainable university, with awards from Princeton Review's Green College Honor Roll (Princeton Review 2019) and a Gold rating in the Sustainability Tracking, Assessment, and Rating System (AASHE 2018). Reputation is critical to the university. More than 40 of the UW Housing and Food Services buildings are LEED (Leadership in Energy and Environmental Design) certified (UW 2018). The occupants recognize that the Cool School Ranking, Green Honor Roll Award, and LEED Gold certification are very important (UW 2014).

3.4.2.4 Occupant impact

*Educational program*s (OI1) are expected to help foster energy-efficient behavior and to provide an opportunity for occupants to learn and talk to the right people about EE and other sustainability concerns, as mandated in UW Executive Order No. 13 (UW 2012). The educational programs include an energy use dashboard to inform occupants about the energy performance of their space and help them contribute to reducing energy consumption. Hands-on involvement in EE projects is another way to get occupants involved. The UW Campus Sustainability Fund program has awarded more than $2.2 million to over 100 student-led sustainability projects since its start in 2010. The occupants themselves also see that direct engagement in the EE effort on campus is important (UW 2014).

An EE retrofit in a university must be complemented by the supportive behavior of the students, staff, and faculty. The energy dashboard installed in various spaces also encourages an *energy-efficient behavior* (OI2) when occupants compare energy use on electric meters on their floors to each other. Occupants need to have a personal commitment and peer-to-peer pressure to change their behavior to be more energy-efficient behavior. The sustainability survey identified that respondents almost always do their share of saving energy (UW 2014), despite some respondents complaining that some places on campus still keep the lights on when not in use.

The *expectation* (OI3) of the occupants on UW EE efforts is quite high. The sustainability survey indicated that they are conscious of not just their needs being satisfied but also the campus effort to achieve a reputation in sustainability. For example, occupants questioned the university's target of achieving Gold LEED instead of Platinum LEED (UW 2014). These findings indicate the importance of understanding the expectation of occupants, which is in line with extant literature, particularly related to the occupants' perceived comfort (e.g., [Luo et al. 2018; Rinaldi et al. 2018]).

Occupant *satisfaction* (OI4) is a factor that is important when conducting improvements on buildings, which aim to not only improve the comfort in the building but also improve the occupant's productivity. Researchers studied the way perceived comfort can be improved by increasing the occupants' degree of environmental control without increasing energy consumption through a combination of active and passive designs (Lawrence and Keime 2016). McCunn et al. (2018) in a study of a recently renovated space in the administrative building of UW found that occupants' perceived productivity was significantly and positively associated with perceived controllability and affective organizational commitment.

3.4.2.5 Technical practicality

For UW Facilities Services, the project's *completion time* (TP1) of UW can vary from three months to two years, depending on the type and size. It sometimes takes longer to perform the administrative tasks rather than the retrofit implementation due to impediments such as the speed of the process, change of technology, and other barriers. In a building EE retrofit project, time is an important element in the time-building-technology framework (Wu et al. 2016), which dynamically adjusts the three dimensions to optimally control the projects to achieve optimal energy conservation and return on investment indicated by net present value (NPV).

An important technical aspect is how the installed equipment or system can function according to its purposes, how reliable it is to work continuously as demanded, and how safe it is. To maintain its *functionality* and/or *reliability* (TP2), aging equipment needs upgrading or replacing, which is one of the main reasons for conducting an EE project.

In its CAP (UW 2009), the university aimed to install automatic networked metering of all buildings to allow online *monitoring* (TP3) of all energy use. An electronic dashboard can provide immediate behavioral feedback directly to building users and create an energy database of all buildings on all campuses, which is useful to monitor building performance across time and help further improvements. Monitoring is also needed to report building performance to relevant authorities (e.g., US Environmental Protection Agency's Energy Star) as mandated by the federal government and state and city requirements. Monitoring is also required upon completion of a project to ensure that the project delivers reduced energy consumption as promised.

EE projects are often challenging to coordinate, in terms of the project types, their delivery methods and processes, and their commonalities. *Project integration* (TP4) is possible through identifying resource conservation opportunities from regular renovation projects and other maintenance activities. Capturing this opportunity is an evolutionary component that also increases the awareness and competency of the building maintenance unit. Energy conservation measures are not just a series of small tasks at the ground level of maintaining and upgrading facilities, but also about how the manager can coordinate all these activities broadly. Facilities managers should look for opportunities to integrate the EE retrofit projects with other renovation projects when possible.

Another important factor is *regulation and bureaucracy* (TP5). Seattle building and energy codes are the main regulations to comply with when doing EE projects. Exceeding the threshold of code also creates benefits such as rebates, so the technical-related regulatory issue is important for facilities managers. This covers all project aspects, from the procurement process of the projects' materials and equipment to the monitoring and evaluation of the installed system output when it is completed. The bureaucracy in designing and executing retrofit projects takes a great deal of time and committee meetings, so often it takes longer to do the paperwork than to do the actual construction. This may be due to the university's position as a public institution, which is more regulated than the private sector.

The speed and ease of implementing an EE project are affected by site *accessibility* (TP6). Accessibility can be based on the time when the site is accessible for a project, the space since lack of space may create an implementation problem or based on occupancy since an occupied facility often needs to be unoccupied for work to be done safely. Facilities managers stated that the *speed and ease of implementation* (TP7) of the project is important and is often related to the size of the team involved in a project. Speed is also affected by the bureaucratic process. Other factors such as site accessibility, integration with other projects and existing activities, and the use of technology also affect the speed and ease of implementation of the project.

System compatibility (TP8) looks at how the project is compatible with existing systems and facilities. This review can be conducted through a desk evaluation of the facilities by looking at historical records, engineering drawings, studies, reports, commissioning manuals, and other written documentation. It is also important that newly installed retrofits produce similar or better performance than the replaced equipment and do not create unnecessary complexity, for example, due to different types of equipment or systems to be handled by the facilities manager.

As targeted in the UW CAP (UW 2009), the *use of technology* (TP9) is expected to reduce energy consumption. This includes replacing numerous aging and high-horsepower electric motors that drive pumps used for circulating cooling water, condensing water and boiler feed water with modern and more efficient electric motors. The newly installed equipment also carries the technology itself. Newer technology is also expected to require less maintenance and to automate some processes. Technology such as an energy management system or energy use dashboard is deemed important in an EE project, despite the need to train facilities managers in the use and management of the technology to reduce dependency on external parties to operate and maintain the system.

3.4.2.6 Government

Three additional factors were added to the analysis to show the interaction between the university and the City of Seattle and to link the factors through the EE activities at UW.

Seattle is one of the first US cities to declare serious *government commitment* (G1) and deliver real efforts to deal with climate change with its CAP released in 2006 (Seattle City Council 2006) and renewed in 2013 (Seattle City Council 2013). Building energy is one of the three main focuses of Seattle in its 2013 CAP, together with road transportation and waste.

To achieve the emission target, the government set up *EE requirements* (G2) , such as requiring building energy audits for the largest and least-efficient commercial and multifamily buildings to help identify cost-effective improvements, increasing EE standards in the Seattle Energy Code over time, evaluating opportunities for the energy code to focus on total energy performance instead of prescriptive requirements, and phasing in bans on recyclable construction and demolition waste from job sites and private transfer stations (Seattle City Council 2013). Seattle's Energy Benchmarking Program requires owners of non-residential and multi-family buildings 20,000 square feet or larger to track energy use and report benchmarking scores annually to the city (Seattle City Council 2016). The city categorizes buildings by Energy Star scores to help understand the relative performance of buildings, using four categories from poor to excellent.

Despite implementing stringent requirements, Seattle City also provides *support* (G3) through education, information sharing, and tangible incentives. The government realizes that EE improvements need to be financially feasible and attractive. The right package of incentives, financing, and support services can provide an attractive payback period to induce investments in EE. The utility company, Seattle City Light, gives a commitment to energy conservation and the use of renewable sources to provide carbon-neutral electricity. This can be considered an advantage for the university considering only 9% of electricity in the US used in the building sector is generated from renewable sources, while another 75% comes from fossil fuels and the other 16% comes from nuclear generation (U.S. DOE 2011). Through a pay-for-performance (P4P) scheme, Seattle City Light provides incentive payments over time for performance based on verified EE, rather than estimated costs upfront. The scheme simplifies the incentive into a single payment schedule for total energy saved to allow for flexible and creative EE projects and to maximize the incentive for real energy savings. Seattle City Light can have a contract with the P4P participant for up to seven years.

3.4.2.7 UW energy efficiency activities

Another factor included in the analysis is EE activities, which include all types of EE retrofits on building systems related to utility (e.g., steam, electricity, natural gas, compressed air, and water); plumbing; lighting; heating, ventilation, and air conditioning; building envelope; metering; and all other process optimizations or improvements related to energy conservation.

3.4.3 *Relationship between factors*

A causal loop diagram represents the interrelationship among individual factors, where the direction of an arrow shows a cause-effect relationship and the plus and minus symbols show the direction of the change (plus means the same direction, and minus means the opposite direction). For example, as shown in Figure 3.3, the relationship between the factor Educational Program (OI1) and the factor Energy-Efficient Behavior (OI2) can be interpreted as follows: the more educational programs the occupants have, the more energy-efficient behaviors the occupants show. The inverse is also true: the fewer educational programs the occupants have, the fewer energy-efficient behaviors the occupants show. A full loop would be either reinforcing (R) or balancing (B) the original change.

In total, 45 reinforcing loops and 13 balancing loops are identified in the causal loop diagram (see Appendix 7 for a complete list). There are several factors that become the main drivers for changes: organization commitment (IC5), government support (G3), use of technology (TP9), and funding (EF3). Conversely, stressors of the system include factors such as occupants' expectation (OI3), CO_2 emissions (EI1) and demand pressure (IC2) are the stressors of the system. Drivers are factors that drive changes in the system in a positive direction, while stressors are factors that trigger the stress responses in the system or changes in a negative direction. Economic feasibility, occupant impact, and technical practicality categories emerged as major concerns showing the role of those factors in driving the systems and are discussed further in sets of relational loops. The relational loops show the interactions between the respective factors within each category as well as with factors from other categories. Other loops and factors that are not closely related are hidden to avoid complexity. The category of institutional characteristics and environmental impacts are less of a concern due to the strong commitment of the university and the city government in promoting EE projects and sustained awareness and practice of all stakeholders in environmental conservation.

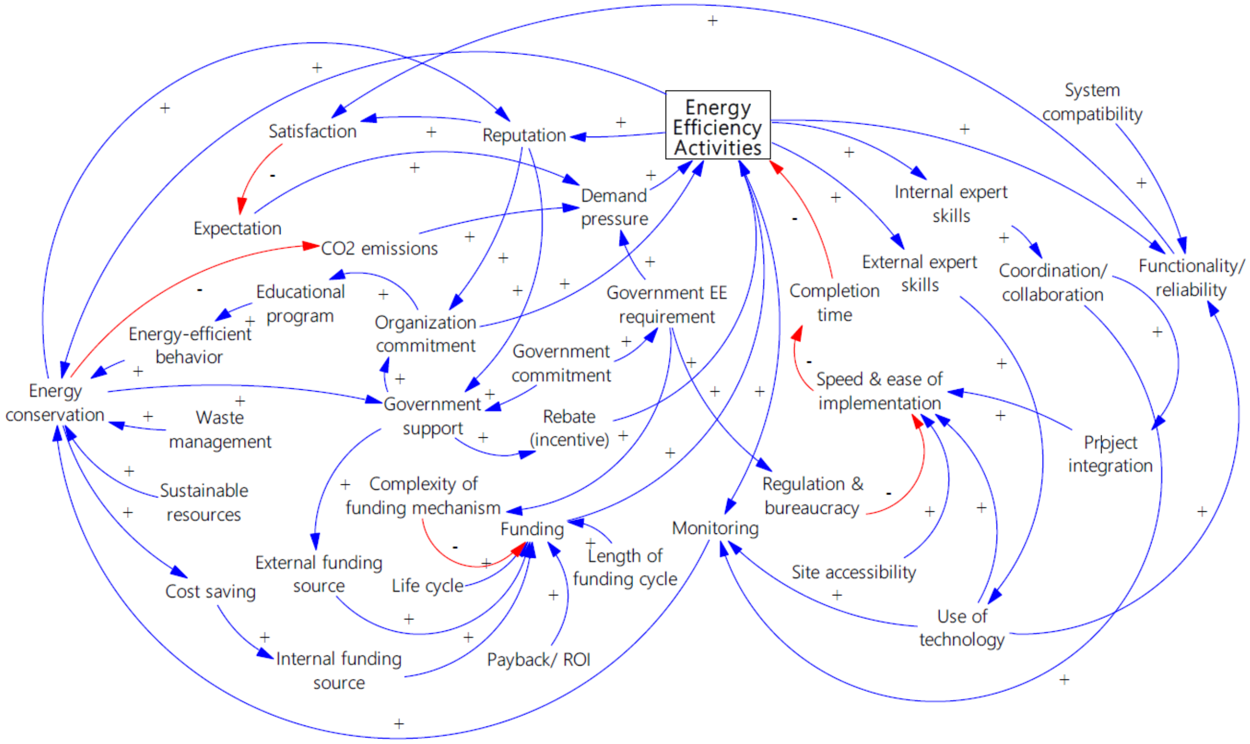
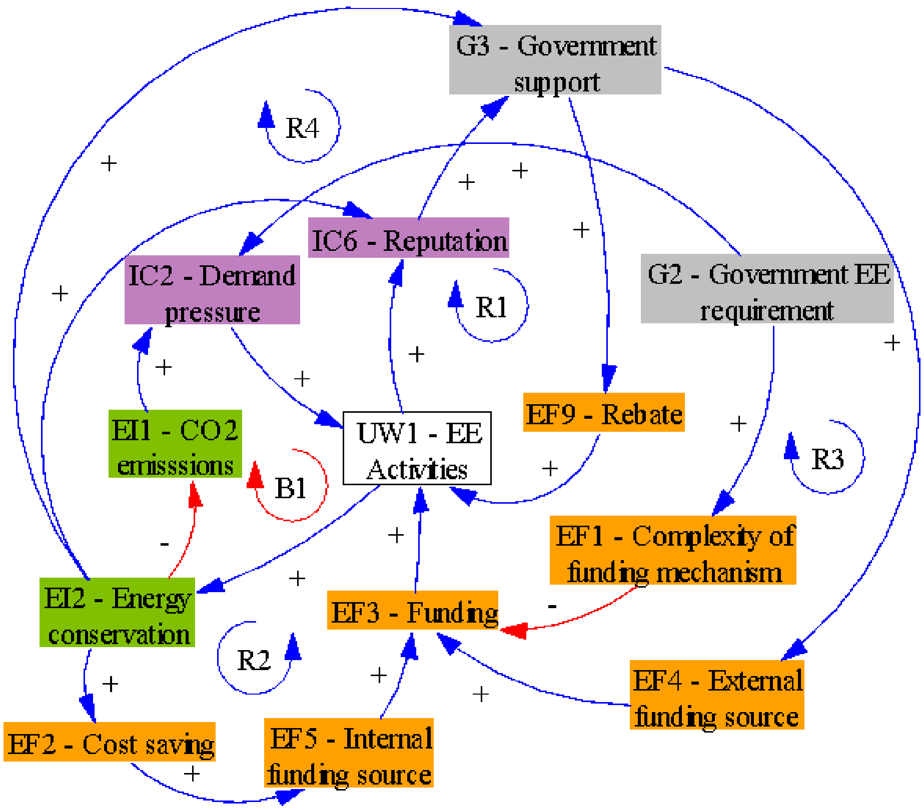


Figure 3.3 Interrelationship among factors

Figure 3.4 shows that government support (G3) affects the availability of an external funding source (EF4) and rebate (EF9), while the decision to provide funding or a rebate is based on the amount of energy conservation (EI2) delivered by a university project and using the complexity of funding mechanism (EF1) set by the government. To deliver the target set by Seattle's CAP, the government sets forth EE requirement (G2) goals, which eventually become a demand pressure (IC2) for the university. The pressure pushes the university to conduct more EE activities (UW1), which conserve energy (EI2) and thereby reduce CO_2 emissions (EI1). The fewer emissions will ease the demand pressure. EE activities are also funded internally (EF5), which will increase when more cost saving (EF2) can be achieved from the increase of energy conservation (EI2). The loops show the important role of government support in driving energy efficiency (EE) to reduce CO_2 emissions and ease the demand pressure, and also the role of funding, which comes from external and internal sources, to drive EE activities.

Similar findings are discussed in other literature. In China, HEIs are less enthusiastic to conserve thermal energy because of the lack of financial incentives and resources (Lo 2013). Although the schools have implemented comprehensive nontechnical energy conservation measures, their investment in technical measures is limited by a lack of funding. Another EE retrofit study of an educational building in Italy shows that the retrofit can be profitable with incentives to make a favorable financial condition (Ascione et al. 2015). Therefore, there is a need for increased government funding (Alam et al. 2019), as well as the removal of the demand that schools assume part of the project cost.



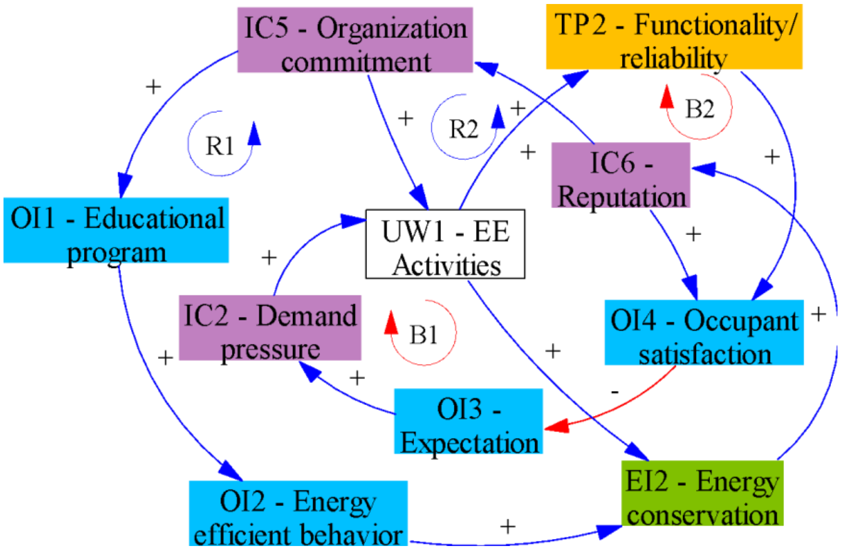
Note:

R1:	The more rebate, the more EE activities, the more reputation, the more government support, the more rebate
R2:	The more internal funding source, the more funding, the more EE activities, the more energy conservation, the more cost saving, the more internal funding source
R3:	The more external funding source, the more funding, the more EE activities, the more reputation, the more government support, the more external funding source
R4:	The more energy conservation, the more government support, the more rebate, the more EE activities, the more energy conservation
B1:	The more energy conservation, the less carbon dioxide emissions, the less demand pressure, the fewer EE activities, the less energy conservation

Figure 3.4 Economic feasibility loops

Figure 3.5 shows several loops related to occupants. Organization commitment (IC5) to provide more educational programs (OI1) to occupants increases the EE behavior of occupants (OI2) and eventually increases energy conservation (EI2) on campus. EE activities (UW1) are driven by organization commitment (IC5) as well as demand pressure (IC2), which is also affected by the expectations of occupants (OI3). The more EE activities (UW1) are conducted, the better the functionality/reliability of facilities (TP2), which then increases occupant satisfaction (OI4). EE activities (UW1) also develop the reputation (IC6) of the university, which eventually increases the satisfaction of the occupants (OI4) and reduces expectations (OI3). The loops in Figure 3.5 shows the role of organizational commitment in energy conservation to build a reputation and satisfy occupant and eventually ease the demand pressure from occupants' expectation.

Masoso and Grobler (2010) in their study in Botswana and South Africa, found that more energy is used during non-working hours (56%) than during working hours (44%) which is due to occupants' behavior of leaving lights and equipment on at the end of the day. Providing the right educational programs can help address the social barriers due to unfamiliar procedures such as inertia, lack of values and interest in energy optimization measurements, and low acceptance of new projects and technologies (Mosannenzadeh et al. 2017). Activities that are dependent on user behavior (e.g., turning off the audio-visual equipment and lights after a lecture finishes, and shutting down computers and monitors when not in use) have the potential to save energy, and a good energy management strategy can raise awareness (Gul and Patidar 2015).



Note:

R1: The more organization commitment, the more educational program, the more energy-efficient behavior, the more energy conservation, the more reputation, the more organization commitment

R2: The more energy conservation, the more reputation, the more organization commitment, the more EE activities, the more energy conservation

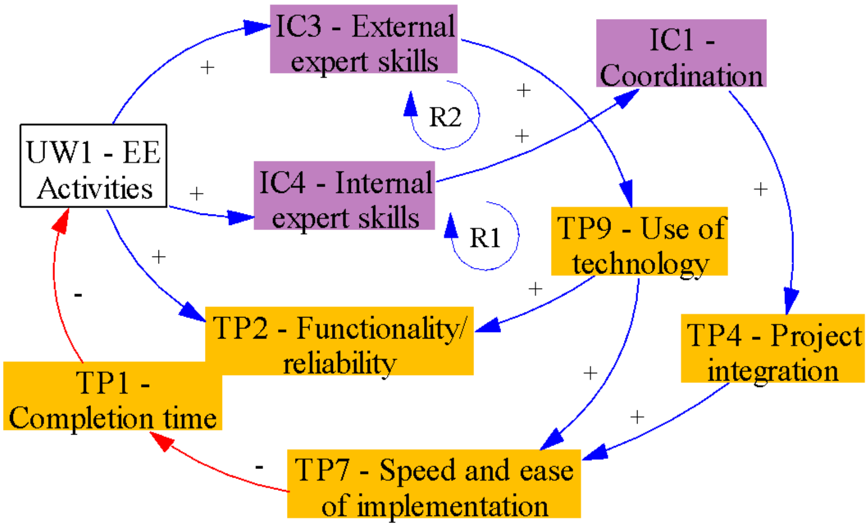
B1: The more reputation, the more occupant satisfaction, the less expectation, the less demand pressure, the fewer EE activities, the less energy conservation, the less reputation

B2: The more functionality/reliability, the more occupant satisfaction, the less expectation, the less demand pressure the fewer EE activities, the less functionality/reliability

Figure 3.5 Occupant impact loops

Other important loops to be described are the loops related to technical practicality (Figure 3.6). More EE activities conducted by the university increase the need for internal expert skills (IC4) and external expert skills (IC3). The more internal expert skills (IC4) are involved, the more coordination (IC1) can be achieved, which improves project integration (TP4). Project integration (TP4) increases the speed and ease of implementation of EE projects (TP7). External expert skills (IC4) also increase the use of technology (TP9), which also increases the speed and ease of implementation of EE projects (TP7) and eventually shortens the completion time (TP1). The use of technology also increases the functionality/reliability of the facilities (TP2) and eventually reduces the completion time of EE projects as well as affects the satisfaction of occupants.

Previous studies addressed similar concerns about the importance of technical practicality. A secondary school in Italy was used as a case study to demonstrate the energy saving potentials of public buildings by integrating the major renovation with the improvement of indoor environmental conditions (Zinzi et al. 2014). Installation of advanced EE technologies in a university building is challenging due to the lack of contractor's experience and knowledge (Ahmed et al. 2017). The study found that effective engagement with the experienced stakeholders at an early project stage is essential to mitigate the risks and benefits associated with the EE technology and intervention strategies. The China Green University Network highlighted the need for technical capability improvement for better EE projects, such as promoting collaborative research, popularizing energy conservation and carbon reduction technology in campus facilities and giving practical demonstrations of green education (Tan et al. 2014).



Note:

R1: The more internal expert skills, the more coordination, the more project integration, the more speed and ease of implementation of EE projects, the less completion time, the more EE activities, the more internal expert skills

R2: The more external expert skills, the more use of technology, the more speed and ease of implementation, the less completion time, the more EE activities, the more external expert skills

Figure 3.6 Technical practicality loops

3.5 CONCLUSIONS

This paper identifies 32 factors that affect the decision making of facilities managers in EE building retrofit projects at an HEI in the US. Facilities managers consider five categories of factors when making retrofits decisions: economic feasibility, environmental impact, institutional characteristics, occupant impact, and technical practicality. Additional factors — the role of government factors and UW EE activities — are also included in the analysis. Complex interactions and interrelations among factors are represented in CLDs that show cause-effect relationships developed from qualitative data obtained mainly from interviews and supported by related documents.

The main driving factors of EE retrofits in HEI buildings are organization commitment, government support, use of technology, and funding. The causal loop diagrams indicated that by initiating more corrective actions through these driving factors, the HEI would be able to satisfy the system's desired level of occupants' expectations, reduce CO_2 emissions, and ease demand pressure.

Despite its richness in findings, the data used in the study is limited to one large university in an urban setting. Future studies can include other HEIs of different sizes and from different geographical locations for comparison. Also, the scope of the work can cover other commercials sectors, which are also among the top three energy consumers in the US — the office and mercantile sectors. The contribution of this study is the formalization of the causal loop diagram based on the grounded theory approach. Our model can be the basis for developing a stock and flow diagram for dynamic simulation of the interrelationship between factors and enable predictions of the system’s behaviors.

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Chapter 4. FACTORS INFLUENCING ENERGY-EFFICIENCY RETROFITS IN COMMERCIAL AND INSTITUTIONAL BUILDINGS: A SYSTEMATIC LITERATURE REVIEW

ABSTRACT

Renovating existing buildings to render them more energy efficient is critical. However, current energy-efficiency efforts in the building sector remain insufficient, and despite the growing literature related to energy efficiency in buildings, context-driven reasons for stakeholders to undertake energy-efficiency retrofits remain less understood. The researchers conducted a systematic literature review to synthesize and consolidate the results of studies worldwide from 2009 to 2020, examining factors and associated contexts that influence building stakeholders' decisions to implement energy-efficiency retrofits. The review involved searching databases and topic-specific journals using multiple keywords and synonyms for energy-efficiency retrofits and decision-making. The initial search yielded 25,093 articles, and 134 articles were further assessed for inclusion and exclusion. Forty-two of those articles met the criteria for inclusion and were examined to evaluate the factors and context associated with the decisions related to energy-efficiency retrofits. Recent relevant research was analyzed, taking into account methodologies, regions, economic development, building types, participant characteristics, and study size. Based on the extensive review of the literature, this study identified 30 factors that can be categorized under seven decision criteria involved in determining retrofits: economic feasibility, team process, technical practicality, institutional characteristic, governmental policy, occupant impact, and environmental impact. The main factors that influenced energy retrofit decisions included life cycle cost, coordination and collaboration, system compatibility, internal value, government commitment, satisfaction and wellbeing, and eco-friendly installation.

Variations regarding factors that influence stakeholders’ perceptions among different regions and building types were also examined. The study found that risk management, technology readiness, and standards and regulations were more significant in countries with developing economies. Conversely, system compatibility, reputation, and political influence were more important in developed economies. The findings from this study provide insights into future research that may guide the development of more context-appropriate strategies that drive stakeholders to implement energy-efficiency retrofits in their buildings.

KEYWORDS: Building portfolio, Context, Decision-making, Energy-efficiency retrofit, Facilities management

4.1 INTRODUCTION

Opinions from building stakeholders about energy efficiency are critical in successfully planning and implementing retrofits in existing buildings. The building sector contributed 20% of global-delivered energy consumption in 2018 (EIA 2019), thereby indicating a need for an international collective effort to reduce energy use in residential and commercial buildings. However, stakeholders’ differing perceptions about what is important creates a barrier that highlights the complexity of renovating existing buildings. Building stakeholders can be classified into two groups: those who participate directly in energy-related processes (e.g., energy manager, building owner, tenant), and those who do not participate directly but have a specific interest in or are affected by the energy management outcomes (e.g., local government, energy auditor, community-based organization) (Li et al. 2017). In addition, the researchers found that the stakeholders’ impact on energy performance occurs at various stages, most notably at the operation and maintenance stage by energy managers and during planning, design, and construction stages by other stakeholders.

Building owners and managers’ perceptions are of particular interest to researchers in understanding the decision processes of retrofitting buildings. This group of stakeholders are the key decision-makers who manage the investment and have a critical role in daily activities. One study suggested that stakeholders who support energy efficiency have attributes associated with a considerable level of knowledge in building energy and sustainability and a solid position of power (Zedan and Miller 2018). In contrast, organizations that do not have a skilled workforce and support from high management are more likely not to pursue energy improvement projects (Valero et al. 2016; Woodroof 2011). Government is also a critical stakeholder that sets energy target policies and programs to encourage building owners to participate in the local and national sustainability agenda (Barnes and Parrish 2016; Liang et al. 2015). Other important stakeholders are the building occupants, who have received much attention from researchers since their characteristics and behavior significantly affect the actual energy performance of the buildings (Zou et al. 2018). Understanding the drivers and barriers regarding energy-efficiency retrofits from these stakeholders’ perspectives is crucial.

The literature on this subject has been growing but is scattered across diverse contexts (e.g., geographic location, building type) and disciplines, making the knowledge fragmented. For instance, Less et al. (2012) argued that the carbon content of electricity varies markedly by geographic area, a factor that should be considered for deep energy retrofit planning. Thus, decision-makers may weigh the concerns about reducing a carbon footprint differently depending on the geographic area. Another study suggested that national incentives are warranted to advance feasible energy retrofits in climates typical of southern Italy (Ascione et al.

2015). This strategy indicates that availability of incentives may be perceived as a driver by stakeholders in one climate but a barrier and a strategy that lacks government support in other climate zones.

Explanations for the gap to energy efficiency should also allow for relative contributions that vary between groups of users and building types. Academic institutions that promote low-energy buildings enjoy increased staff satisfaction with their work environment (Meron and Meir 2017) and improved engagement among the community to foster education and innovation (Ahmed et al. 2017; Sesana et al. 2016). Meanwhile, the American Society for Healthcare Engineering reported that stability and resilience in designs for facilities such as healthcare buildings that respond to disasters, terrorism, and mass casualties constitute critical factors in improving energy efficiency (Carpenter and Hoppszallern 2011). Buildings housing the high-technology sector can consume up to 100 times more energy than do conventional buildings (Naughton 2000). However, energy-efficiency improvements are often overlooked because they are weighed against other capital investments with a payback period of less than a year (Mills et al. 2008). On the other hand, mandatory policy and dedicated financing mechanisms are critical to retrofit government buildings for energy efficiency (Alam et al. 2019). These studies highlighted that each business sector adopts a significantly distinct focus when evaluating energy-efficiency retrofits.

Until now, a comprehensive review of accumulated current scientific knowledge to shed light on the similarities and differences of stakeholders’ views in multiple contexts regarding retrofits was lacking. To fill the research gap, the researchers have herein compiled and synthesized recent academic journal publications that examined factors influencing decisions to implement energy-efficiency retrofits in commercial and institutional buildings. The study will also investigate how perceptions may vary depending on context, including geographical regions, economic development, and building types.

4.2 THEORETICAL BACKGROUND

4.2.1 *Pertinent literature*

Energy-efficiency retrofits in buildings is a complex topic comprised of various aspects from multiple disciplines. This section discusses pertinent literature related to factors influencing energy-efficiency retrofits and clarifies the contribution of this systematic literature review (SLR) beyond the published review papers on the subject.

Many review studies have been conducted on existing retrofitting approaches to improve energy efficiency in buildings. For example, Pombo et al. (2016) reviewed studies on housing retrofits from academic journals, technical journals, books, and reports. They found that passive strategies are the most common retrofitting approaches, but wide variations of their assessment methodologies limited the analysis when trying to compare the results across studies. Ruparathna et al. (2016), when reviewing existing approaches used on improving the energy efficiency of commercial and institutional buildings, found that technological advancement has been the focus of peer-reviewed journal articles from 2000 to 2014, while behavioral changes have been understudied. Ma et al. (2012) reviewed various methodologies and strategies for selecting the best sustainable building retrofits. They found that most of the numerical simulation studies in commercial offices demonstrated improved energy and environmental performance; however, no reported actual energy savings may affect the confidence of building owners to retrofit their buildings. Other literature reviews assessed building energy-efficiency trends in construction material development (Rao et al. 2018), regional policies (Liu et al. 2020), approaches in specific building types (Berg et al. 2017; Lidelöw et al. 2019).

Another group of recent review articles focused on particular aspects of building energy efficiency discussed in this SLR, such as indoor environmental quality and occupant behavior change. For example, a study of peer-reviewed journals from the last 5 years focusing on housing found that retrofitted buildings may pose indoor environmental quality risks, such as a build-up of pollutants, overheating, and noise (Ortiz et al. 2020). The study indicated several risks associated with health and suggested the importance of future research to consider the comfort and health of occupants to establish a better relationship with the retrofitted buildings. Maslesa et al. (2018) identified indicator categories, building types, and assessment methods related to environmental building performance (EBP). Although only five of 69 selected articles examined the nonresidential sector, the study found that environmental impacts in nonresidential buildings were higher. The study called for researchers to pay more attention to EBP studies in nonresidential buildings. Paone and Bacher (2018) reviewed studies related to the impact of building user behavior on energy efficiency and suggested eco-feedback and gamification as some strategies to influence behavioral change. Hashempour et al. (2020) reviewed studies on energy performance optimization of existing buildings that show a growing interest in the multicriteria approach. Similar to a few of the reviews mentioned earlier, the review found that most studies focused on environmental and economic objectives and used residential buildings as case studies. This study indicated a need to pay more attention to social-related factors (e.g., comfort) in the optimization criteria and to expand the research of energy-efficient measures to varying building types and climate conditions.

Overall, none of the existing reviews have combined all existing empirical studies to present a comprehensive list of factors that influence building stakeholders' decisions regarding energy-efficiency retrofits, nor have those factors been assessed in their various contexts—such as their similarities or differences—in order to ascertain how retrofit considerations are affected. Doing so will help identify research gaps still needing to be explored in order to aid stakeholders when making retrofit decisions. In other fields of sustainable energy, literature reviews about stakeholders' perceptions have been conducted to provide insight for policy development, such as factors affecting green building (Darko et al. 2017), sustainable process technology adoption (Fu et al. 2018), and public perceptions of hydropower projects (Mayeda and Boyd 2020). This study will provide a valuable reference for decision-makers when considering energy-efficiency retrofits for nonresidential buildings, particularly commercial and institutional buildings (e.g., hospitals, hotels, offices, schools).

4.2.2 *Context dimensions in building energy-efficiency retrofits*

Contextualizing building energy-efficiency retrofits is essential to understand how and why retrofits happen and whom it involves. For example, understanding context allows researchers to explore whether the results of a study with participants working under a given organizational structure would yield similar findings had the participants worked under another (Rubin et al. 2009). One of the prevalent definitions of context in an organizational behavior study is "situational opportunities and constraints that affect the occurrence and meaning of organizational behavior as well as functional relationships between variables" (Johns 2006). Research about perceptions of energy efficiency is often attributed to contextual conditions, but few studies have discussed this holistically. The influence that context has on retrofit decisions is often unrecognized or underappreciated. When the context is studied, the “contextual features are often studied in a piecemeal fashion, in isolation from each other” (Johns 2006). Besides providing worldwide views based on academic journals, this study will identify, analyze, and report the contextual differences when considering energy-efficiency retrofits.

The context classification in energy-efficiency retrofits, which consists of physical, functional, and social contexts, was initially suggested by Medal and Kim (2020) and further explored by Medal et al. (2021). The physical context refers to how the building’s physical condition and the surrounding environment may be associated with evaluating energy-efficiency retrofits, such as building type, portfolio size, geographical region, and climate zone. The functional context refers to how building owners’ and tenants’ organizational values may affect the evaluation of energy-efficiency retrofits, such as ownership type and tenants’ business sector. The social context refers to how the building stakeholders’ characteristics and preferences may influence decisions related to energy-efficiency retrofits, such as stakeholders’ personalities, job title, and project role. Building upon context theory from Johns (2006), Figure 4.2. shows the contextual framework of the built environment and its connections with factors influencing energy-efficiency decisions (discussed in detail in the Results and Discussion section). This SLR will explore the contextual factors of retrofit decisions based on geographical regions, economic development, and building types.

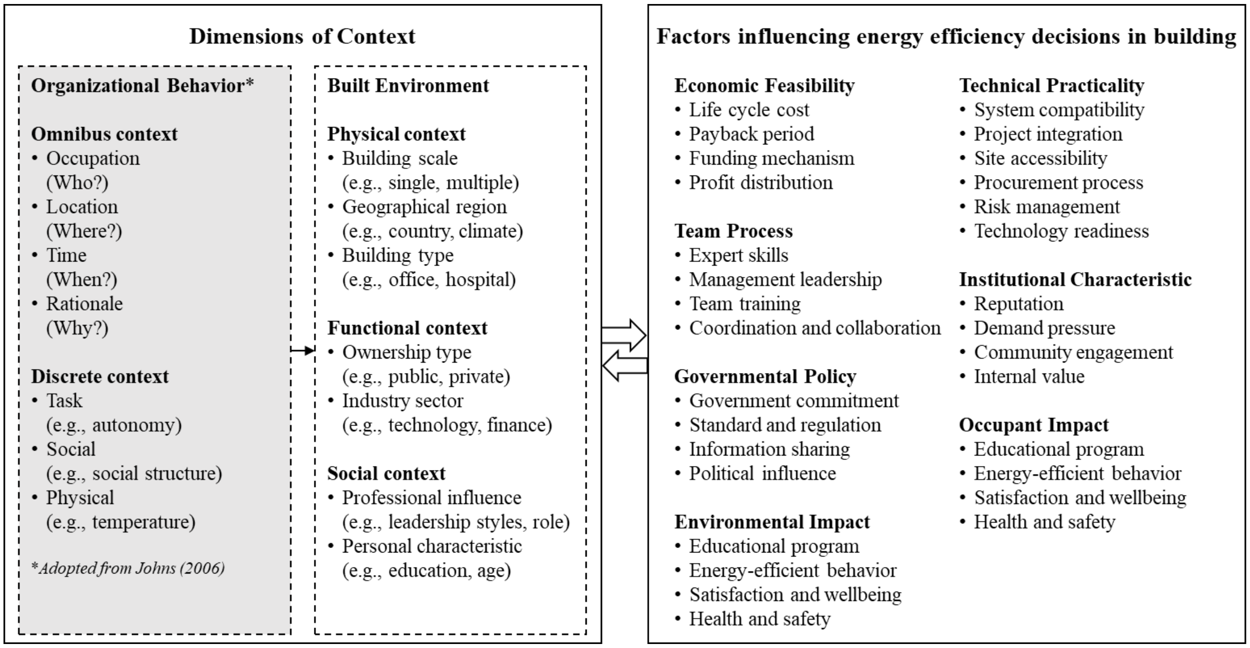

Figure 4.1 Conceptual framework linking context to building energy efficiency.

4.3 METHODOLOGY

4.3.1 *Inclusion criteria*

An SLR was conducted for all research articles published in the English language relevant to decision-makers’ perceptions of energy-efficiency retrofits in buildings during the 12 years from January 1, 2009, to December 31, 2020. In addition, while writing this paper, the researchers used a notification tool available in databases that sent an email on new suggested articles published beyond 2020 based on saved keywords.

Comprehensive criteria for inclusion were developed to identify relevant articles that focus primarily on the perceptions of building stakeholders about energy-efficiency retrofits. They included articles examining assessment criteria to implement various energy-efficiency measures in existing commercial and institutional buildings, such as system upgrades, operations, maintenance optimization, renewable energy installations, and public engagement initiatives. These assessment criteria included the factors affecting the evaluation of energy-efficiency retrofits. Publications on residential buildings were outside the scope of this paper. In addition, this review only includes primary source articles as defined by Colling (2003); thus, commentaries and literature review articles are excluded.

The keywords were designed to identify research articles that included energy-efficiency aspects and perceptions from the building stakeholders. A library scientist at the University of Washington, Seattle, assisted in determining relevant terms and synonyms to ensure a comprehensive search. Boolean operators were used to search for relevant articles (Page 2008). The word ‘AND’ includes all identified keywords, ‘OR’ consists of any of the specified keywords, and the wildcard asterisks allow for identifying plurals and other word suffixes. The following string of keywords was used as the search term for all searches performed: ((Energy OR electricity OR heating OR cooling OR lighting) AND (Retrofit* OR upgrade* OR refurbish* OR renovat* OR “existing building” OR “existing structure” OR “existing buildings” OR “building improvements” OR “building improvement”) AND (Hotels OR hospital OR hospitals OR buildings OR schools OR “non residential” OR “office building” OR “office spaces” OR “office space” OR commercial OR institutional OR campus OR campuses) AND (Conserve* OR conservation OR green OR sustainab* OR efficien* OR “fossil fuels” OR “fossil fuel” OR renewable OR solar OR “energy saving” OR “energy retrofit” OR “energy retrofits” OR “energy use” OR “energy usage” OR “energy utilization” OR “energy consumption” OR “energy upgrade” OR “energy upgrades” OR “energy performance” OR “carbon neutral” OR “low carbon” OR “carbon emissions”)) WN KY AND ({ja} WN DT) AND ({english} WN LA).

4.3.2 *Literature search process*

This SLR adopted a four-step process developed by Khan et al. (2003) to ensure that relevant articles were collected. First, comprehensive searches of seven computerized bibliographic databases were conducted to identify relevant articles: *Engineering Village (i.e., Inspec and Compandex databases), ASCE Library, Environment Complete, JSTOR Sustainability, GreenFILE, and Business Source Complete*. Second, key journals that included publications relevant to the topic were identified to determine if any articles were missed when searching the bibliographic databases. These journals include *Journal of Management in Engineering, Renewable and Sustainable Energy Reviews, Energy and Buildings, Energy Policy, Energy Research and Social Science, Energy, Sustainability, Applied Energy, International Journal of Energy Research, Sustainable Cities and Society*. Third, the reference lists of all the articles that met the inclusion criteria were examined for any citations that could lead to research articles for review. Fourth, all articles that met the inclusion criteria were computed into the Google Scholar database to determine if any articles citing these studies could also be relevant research articles. Citations were further examined for possible pertinent additional articles during the review of the final set of research articles collected.

However, the search of the computerized databases might have missed articles if the article authors used none of the keywords. This limitation was addressed through additional searches of reference lists, key journals, and Google Scholar. Nonetheless, there could have still been missed articles, which thus becomes a limitation of this study. Saturation was achieved when no new studies emerged, but the same articles reappeared across the additional searches.

4.3.3 *Analysis and coding*

All articles collected were initially screened by reading the titles for relevance. Next, the abstracts were examined to categorize the articles to be removed from the SLR and the articles likely to meet the inclusion criteria. Then, the full text of articles was reviewed to determine articles. A total of 25,093 research articles from the database and journal searches were imported into Endnote, and duplicates from all databases were removed. After reviewing the titles and then the abstracts, the remaining 134 full-text articles were assessed for eligibility. A total of 42 articles met the inclusion criteria and were ultimately included in this review.

The qualitative data consisting of 42 articles were thoroughly reviewed to examine the following study characteristics and findings: the geographical region, building type, objective, data collection method, case study and sample size, and participant characteristics. In addition, the articles were examined based on the economic classification of the country where the research was conducted. To determine key factors influencing building stakeholders' decisions to implement energy-efficiency retrofits, the data were qualitatively coded using the *ATLAS.ti* software by following an inductive coding process that allowed themes to emerge naturally from the data (Richards 2020). The initial coding resulted in 658 codes. The next step of the coding process was to adopt preexisting codebooks based on 15 factors grouped under five criteria identified by Medal et al. (2021). For example, codes such as "Loss of significant original building fabric" and "Building conservation compatibility" were recoded as "System compatibility" under the technical practicality criterion. When new themes emerged, the authors added new criteria and factors to accommodate emerging themes that cannot be considered under any preexisting codes. For example, codes such as "Strong school-community partnerships" and "Difficult to organize and coordinate" were recoded as a new factor—"Coordination and collaboration”—under the team process. Finally, the 658 codes were classified under 30 factors and seven criteria associated with energy-efficiency retrofit decisions.

4.4 RESULTS AND DISCUSSION

4.4.1 *Descriptive analysis*

This section focuses on how 42 analyzed articles are distributed over time and explains how relevant and saturated the topic of decision factors is in building retrofits. This section also reports on the article distribution according to publication outlets to show how diverse the subject is in research communities. Next, the distribution of articles based on geographical regions and building types is discussed to illustrate how similar or different the assessment criteria of energy retrofitting are based on physical and functional contexts, as previously described in Section 2. Last, this section summarizes the objectives of the research articles, data collection approaches, case studies, and participant characteristics.

4.4.1.1 Distribution across time

The allocation of research articles within one decade is shown in Figure 4.2. The oldest relevant articles reviewed were in 2011, while the most recent articles were in 2020. Study topic articles increased from 2009 to 2017 and then began a decreasing trend. Most articles were published between 2016 and 2017 (22 articles—52% of total articles in 12 years). Research on the subject began to decrease in 2018 and may decline or stabilize at a low number of publications in the next decade. The general findings of the factors that influence stakeholders’ decisions to retrofit their buildings are similar across diverse regions and building types, as will be discussed in detail in a later section. Moreover, these studies can be used as guidelines in retrofitting decisions in various contexts.

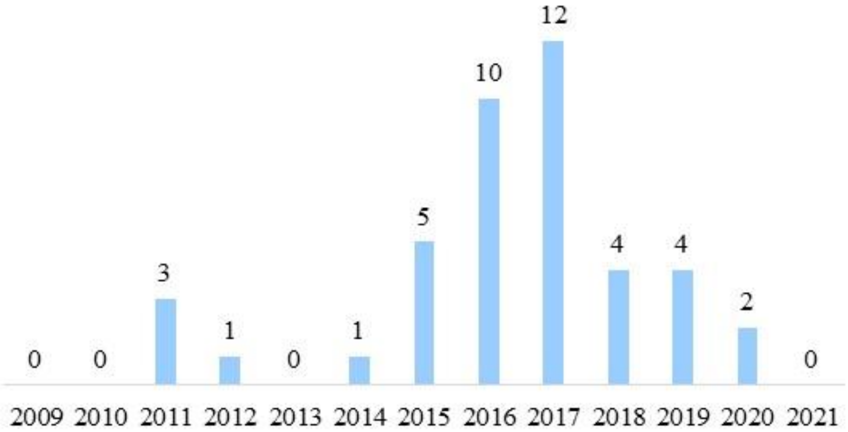

Figure 4.2 Distribution across time between 2009 and 2020.

4.4.1.2 Distribution across main journals

Table 4.1 presents the distribution of articles among scientific journals. Seventeen out of 42 publications are in the journals classified within the Energy subject area (*Applied Energy, Energy and Buildings, Energy Policy, Energy Procedia, International Journal of Energy Sector Management, Renewable Energy,* and *Strategic Planning for Energy and the Environment*). Sustainability and health-related journals (i.e., *International Conference on Urban Regeneration and Sustainability, International Journal of Environmental Research and Public Health, Journal of Cleaner Production, Journal of Green Building, Smart and Sustainable Built Environment, and Sustainable Cities and Society*) represent the next significant portion, with 12 (29%) articles, followed by journals on building, facilities, and construction (19%), engineering (10%), and survey (2%). The dominant journals of the analyzed articles are *Energy and Buildings*, *Energy Policy*, and *Sustainable Cities and Society*, each containing five research articles that were selected for this study. Importantly, this finding reveals that the topic is being addressed in considerably diverse research communities, although predominantly in journals specializing in the Energy subject area.

Table 4.1 Distribution across journals.

Journal	Article	Journal	Article
Applied Energy	1	*Sustainable Cities and Society*	5
Buildings	1	*Renewable and Sustainable Energy Reviews*	2
Energy Policy	5	*Journal of Technology and Design*	1
Facilities	2	*Procedia Engineering*	1
Journal of Architectural Engineering	1	*Structural Survey*	1
Energy and Buildings	5	*Journal of Management in Engineering*	1
Energy Procedia	1	*Renewable Energy*	1
Journal of Cleaner Production	3	*Smart and Sustainable Built Environment*	1
Built Environment Project and Asset Management	1	*Strategic Planning for Energy and the Environment*	1
International Conference on Urban Regeneration and Sustainability	1	*Journal of the American Planning Association*	1
International Journal of Building Pathology and Adaptation	1	*Journal of Construction Engineering and Management*	1
International Journal of Energy Sector Management	1	*Journal of Performance of Constructed Facilities*	1
International Journal of Environmental Research and Public Health	1	*Journal of Green Building*	1

4.4.1.3 Distribution across geographical regions

The articles were coded to denote whether the study area was located within a developed or developing economy, as classified by the United Nations (2019). One study combined developed and developing countries in the study (Si and Marjanovic-Halburd 2018); thus, this article was counted in both categories. Thirty of the studies, (71%), focused on countries with developed economies. The remaining 12 studies (29%) were conducted in developing countries. Distribution of case study locations of the research articles by regions is shown in Figure 4.3. The studies were located in various regions around the world, including the following: Australia, China, Denmark, Egypt, Germany, Greece, Ireland, Italy, Malaysia, Nigeria, Spain, Sri Lanka, Taiwan, United Kingdom (UK), United States (US), Vietnam, and a mix of several European countries that were not named. The country hosting the majority of studies was the US, which appeared in 14 out of 42 articles. China was next, with six articles, then Australia and the UK, each with four articles. Although most articles covered a single region, two articles conducted a multi-country case study to compare the findings among diverse regions, both based on the significant differences and similarities.

Si and Marjanovic-Halburd (2018) found differences in expert opinions about retrofit projects between the UK and China, given their distinctive national contexts. Their case study showed that UK experts emphasize the economic performance of green technology, while Chinese experts place significant importance on technical performance. Tozer (2020) conducted interviews with experts from Stockholm, London, and San Francisco based on their similarities, including their international leadership in carbon governance, leadership heterogeneity, and evidence of leadership in building decarbonization. That study investigated the political effectiveness of implementing decarbonization initiatives. Case studies conducted in multiple countries in Europe were similarly aimed at examining the effect of the identical policies implemented in the countries. Valero et al. (2016) investigated common pan-European challenges in making refurbishment decisions and presented insights regarding a proposed decision-support tool for local administrations. Haase et al. (2015) found similar features amid the practices of rehabilitation of European shopping centers. Thus, the study used three shopping centers in different European countries to define the common drivers of retrofitting European shopping centers.

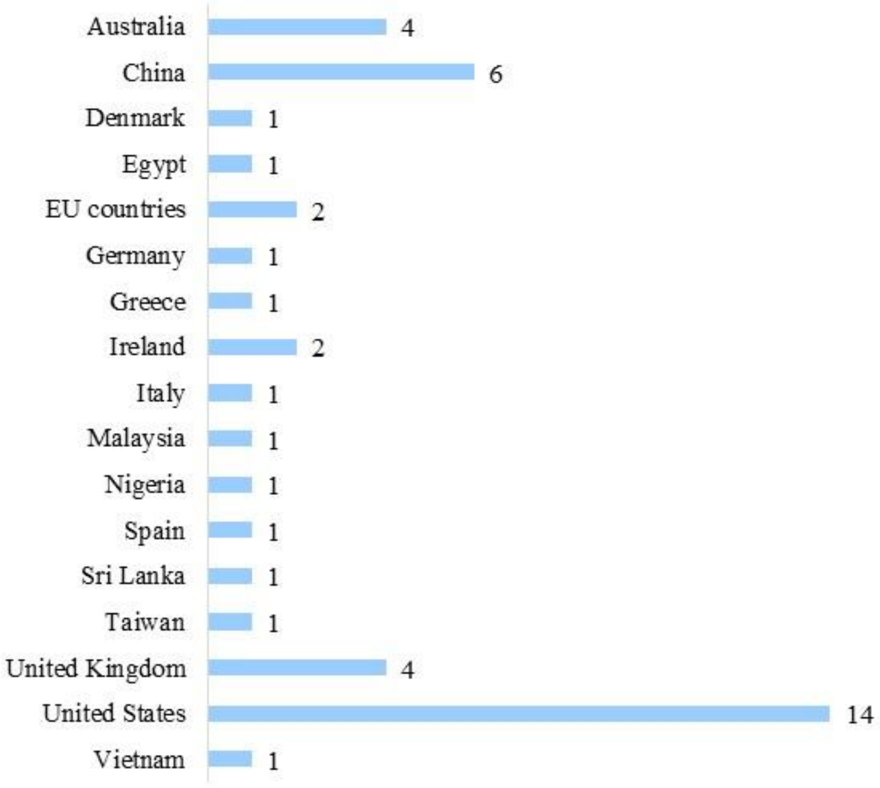

Figure 4.3 Distribution across geographical regions.

4.4.1.4 Distribution across building types

The distribution of articles across building types is shown in Figure 4.4. The buildings used in these case studies can be categorized into eight types: education, health care, lodging, mercantile, office, mixed commercial, historic building, and public facilities. This study partly follows the definitions of building types determined by the Energy Information Administration (EIA) to simplify the classification where possible but keeps some definitions of types of buildings found in the original articles to maintain the particular characteristics of the buildings when being evaluated for energy retrofits. Studies of mixed commercial buildings are identified in 18 articles. These studies either did not specify in detail about the use of facilities or used multiple building types in their research to obtain a consensus about factors affecting retrofit in commercial buildings. For example, Clancy et al. (2017) identified drivers and barriers of energy efficiency by conducting 750 interviews across a statistically representative sample of commercial businesses in Ireland, including retail, hotel, public houses and restaurants, offices, and warehouses and storage. The second most studied building types are offices (9 articles), followed by lodging (5 articles). The articles focusing on hotels focused on the significant energy consumption of this building type. Luxury hotels may spend up to 50% of their expenses on energy (SLEMA 2009) and represent a savings potential of 20% (Karawita and Withanage 2013). Buildings categorized as for education were discussed in three articles, including for public and private schools and higher education institutions. The collected data covered use of the buildings for academic or technical classroom instruction, administration buildings, dormitories, libraries, and teaching hospitals. Public facilities were identified in three articles: one argued that limited studies analyze the implementation of sustainable measures in public buildings (Abdallah et al. 2016), and two explored how fundamental differences in the public sector compared to the non-government sector can present unique challenges to energy-efficiency projects (Alam et al. 2019; Bertone et al. 2018). The historic building was discussed in two articles that represented growing interest in focusing energy-efficiency efforts on historic buildings and emphasizing the value of preserving the structural qualities and aesthetics while still seeking energy efficiency (Lidelöw et al. 2019). Last, a health care building type and mercantile building type were each only used in one article for a case study, indicating the lack of examination about perceptions of energy-efficiency retrofits in these building types. Mohammadpour et al. (2017) focused on examining patient safety during energy-efficiency retrofits of healthcare facilities. Haase et al. (2015) filled the gap of studies in the mercantile sector by understanding the energy efficiency and sustainability issues in shopping centers.

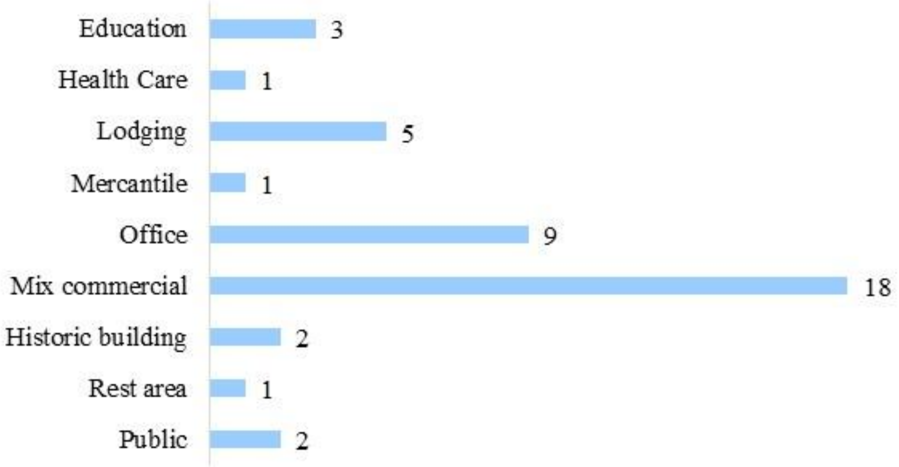

Figure 4.4 Distribution across building types.

4.4.1.5 Overview of research objectives, data collection approaches, and participant characteristics

Table 4.2 summarizes reviewed articles, including the region, building type, objective, data collection, case study and sample size, and participant characteristics. Most of the selected papers had straightforward goals to identify drivers, barriers, and information requirements to implement energy-efficiency retrofits. Some articles used specific building types for a case study, such as shopping centers (Haase et al. 2015), hotels (Xu et al. 2012), and schools (Castleberry et al. 2016). In contrast, other studies focused on the decision factors at different retrofitting phases, such as during the initial intention phase (Liang et al. 2016) and actual project level executions (Fasna and Gunatilake 2019). Factors influencing energy retrofit were also identified in articles that defined the retrofit challenges by focusing on the stakeholders' characteristics. For example, retrofit decisions were examined based on the impact of ownership type, tenant demand, and market competitiveness (Kontokosta 2016) and the interactive effect of participants' experience, knowledge, and roles on sustainable building practices (Nguyen et al. 2017; Zuhaib et al. 2017). Another theme of the selected articles included studies that aimed to comprehensively assess the state-of-the-art methods, processes, and technologies of retrofitting.

For example, Mohammadpour et al. (2017) examined current retrofit practices in healthcare facilities focusing on patient safety. Other studies assessed the preferences on various energy reporting, data tracking, and labeling mechanisms available in the market (Christensen et al. 2018) and examined the retrofit decision process by investigating relationships among decision factors (Kim et al. 2019). The remaining articles aimed at evaluating existing buildings with green standards (e.g., (Komolafe et al. 2016; Yang et al. 2018)), proposed a new methodology for optimal retrofit (e.g., (Komolafe et al. 2016; Roberti et al. 2017)), and evaluated new energy-efficiency programs or decision-support tools (e.g., (Zheng et al. 2019)).

Nineteen out of the 42 studies used qualitative methods for data collection, such as interviews, meetings, document review, panel discussions, site visits, focus group discussion, and workshops to assess participants' perceptions. Fifteen articles used a mix of quantitative and qualitative methods. The rarest method used was the quantitative method via survey, which was identified in eight papers. The case study sizes ranged from focusing on a single building case study (Gultekin et al. 2014) to covering the extensive building portfolio of a real estate firm located in multiple cities (Kontokosta 2016). The study with the most participants was Clancy et al. (2017), which was comprised of 750 phone interviews that statistically represented diverse commercial businesses in Ireland. Experts and practitioners who participated in the studies through interviews, focus groups, and surveys worked in the built environment and held extensive experience in building retrofit projects. Professions that were represented included owner representatives (e.g., executives, facility managers, project managers, engineers), contractor representatives (e.g., managers, energy specialists), and consultants (e.g., technical advisors, architects). In addition, some studies required participants to have a particular experience depending on its study objectives. For example, a retrofit investment study of a historic building required perceptions from experts with many years of experience in cultural heritage (Roberti et al. 2017). Another study desired engineering professional participants with knowledge about green building concepts and rating systems when proposing a new energy-efficiency rating system for existing buildings (AbdelAzim et al. 2017). A few studies also included academic researchers for a specific building type (e.g., (Xu et al. 2011)), government officials for public buildings and a regional case study (e.g., (Alam et al. 2019)), and occupants for a customer-centric type of building (e.g., (Haase et al. 2015)).

Table 4.2 Summary of articles examining factors influencing energy-efficiency retrofits in buildings.

No.	Research article	Region	Building type	Objective	Data collection	Case study and sample size	Participant characteristic
1	Woodroof (2011)	US	Education	Identify the key success factors for selecting the best energy consultant for identifying conservation opportunities that do not require equipment upgrades.	Interview	16 school districts that had implemented energy savings programs for more than 2 years.	School district representatives.
2	Xu et al. (2011)	China	Lodging	Develop the critical success factors of EPC for sustainable energy efficiency retrofit of hotel buildings.	Interview; survey	Representatives from 9 different hotels, with 17 professionals for the interview and 91 professionals for the survey.	Engineering managers from hotels, project managers from contractors, academic researchers, energy service companies (ESCOs), governments, and consultants.
3	Zografakis et al. (2011)	Greece	Lodging	Assess the state of the art of practices and technologies of energy-saving and renewable energy sources in hotels.	Survey; information sessions	32 hotels.	Hotel managers.
4	Xu et al. (2012)	China	Lodging	Formulate key performance indicators for the sustainability assessment of energy efficiency retrofit in hotel buildings.	Interview; survey	Representatives from 9 different hotels, with 17 professionals for the interview and 91 professionals for the survey.	Engineering managers from hotels, project managers from contractors, academic researchers, ESCOs, governments, and consultants.
5	Gultekin et al. (2014)	US	Office	Develop an understanding of the process and energy efficiency design strategies used to deliver an energy-efficient deep retrofit project.	Interview; collaboration meetings; document review	An energy innovation center.	Architect, owner's representative, construction manager, MEP designer.
6	Bruce et al. (2015)	Australia	Office	Explore the barriers preventing investment in the reuse of low-grade multi-story building stock.	Interview	Multiple organizations associated with commissioning retrofitting projects and an architectural firm.	Real estate manager, construction manager, developer, architect, asset manager, energy efficiency retrofit advisor.

No.	Research article	Region	Building type	Objective	Data collection	Case study and sample size	Participant characteristic
7	Gliedt and Hoicka (2015)	US	Mix commercial	Examine the decision-making process that leads to energy performance improvements.	Survey	178 professionals representing multiple commercial properties.	Property owners/ managers that have participated in the Energy Star program.
8	Haase et al. (2015)	European countries	Mercantile	Define the drivers of retrofitting shopping centers.	Interview; survey	Three shopping centers.	Customers, tenants, owners, and managers.
9	Liang et al. (2015)	China	Office	Integrate critical success factor analysis with stakeholders in energy efficiency retrofit projects.	Interview; survey	16 experts who were involved in multiple retrofit projects.	Project director, technical specialist, purchasing specialist, designer, researcher, contract manager, contractor, auditor.
10	Yang et al. (2015)	US	Office	Identify the information requirements needed by integrated design teams during advanced energy retrofit design review meetings held in immersive settings.	Survey; discussion; document review	16 professionals for an old building being renovated with meeting spaces, offices, research, and monitoring labs.	Architect, energy modeling expert, integrated design group members.
11	Abdallah et al. (2016)	US	Public	Present an economic and GHG emission analysis of implementing various sustainable measures in rest area buildings.	Site visit; document review	6 rest area buildings.	Facility managers for collecting documents.
12	Andrews et al. (2016)	US	Mix commercial	Examine an implementation problem in regulating the pursuit of energy-efficient reuse of existing buildings.	Interview; focus groups; survey; document review	49 communities for the first survey from Pennsylvania, California, Colorado, Maryland, and Washington. 43 codes officials in Pennsylvania for the second survey.	Municipal officials, regional building officials, building professionals.

No.	Research article	Region	Building type	Objective	Data collection	Case study and sample size	Participant characteristic
13	Barnes and Parrish (2016)	US	Mix commercial	Describe the efforts of a multi-organization collaboration and their demonstration partners in developing a library of case studies that promote and facilitate energy efficiency in the small commercial buildings market and a case study template that standardized the library.	Document review	Multi-organization project team participating in the US Department of Energy's "Better Buildings: Commercial Energy Efficiency Solutions" program.	Lawrence Berkeley National Laboratory; Architecture 2030; City of San Jose, Seattle 2030; District, Pittsburgh 2030; District, Cleveland 2030; District, Arizona State University.
14	Castleberry et al. (2016)	US	Education	Examine factors that may encourage or inhibit a public school district from adopting energy-saving technologies and practices.	Survey	97 survey responses representing 76 different school districts in Oklahoma.	Representatives from the school districts.
15	Hou et al. (2016)	China	Mix commercial	Comprehensively probe into essential aspects associated with existing commercial building retrofit industry.	Interview; site visit; document review	Surveys in 4 pilot cities: Tianjin, Chongqing, Shenzhen, and Shanghai.	Local construction government, commercial building owners, Energy Management Companies, and financial institutes.
16	Komolafe et al. (2016)	Nigeria	Office	Investigate the extent to which green building features are evident in office properties and consequently determine the degree of compliance with green standards.	Interview; site visit	133 office properties, primarily multi-tenants for financial, recruitment, and manufacturing services.	Two users who were dealing with property operations and maintenance in the organization.
17	Kontokosta (2016)	US	Office	Examine the effects of ownership type, tenant demand, and market competitiveness on building energy retrofit decisions in the commercial office sector.	Survey	393 commercial properties managed by CB Richard Ellis, focusing on 19 cities.	Asset managers.
18	Liang et al. (2016)	China	Mix commercial	Reveal the underlying logic of the industry's reluctance to conduct green retrofit by analyzing the behaviors of the building owners and occupiers, who are the direct decision-makers in initiating green retrofit at the initial intention phase.	Interview	19 experts from Hong Kong and Mainland China who have participated in green retrofit projects.	Project manager, designer, facility manager, contract manager, contractor, and third-party consultant authorized by the government to audit projects.

No.	Research article	Region	Building type	Objective	Data collection	Case study and sample size	Participant characteristic
19	Mosgaard et al. (2016)	Denmark	Lodging	Define the constellations of stakeholders that make energy renovations happen.	Interview; site visit	11 stakeholders involved in energy renovation of a small hotel.	Hotel manager, electricians, plumber, local bank managers, energy engineer, board members.
20	Valero et al. (2016)	European countries	Mix commercial	Present the central insights of a new decision-support tool for local administrations developed under a pan-European project upheld by the Climate Knowledge and Innovation Community.	Workshop; interview; meeting	103 interviews with potential tool users across the 9 countries.	Local authorities, service providers (e.g., network operators, ESCOs, construction and refurbishment companies, renewable energy developers, utilities, energy consultancy companies, urban planners or building construction materials' suppliers), citizen representatives.
21	AbdelAzim et al. (2017)	Egypt	Mix commercial	Present the outcomes of a recent study among engineering professionals and academics to propose a criteria-based energy efficiency rating system for existing buildings.	Survey	61 responses from Egyptian engineering professionals.	Engineering professionals who have a background in green building concepts and rating systems or working in a field related to design and construction buildings.
22	Clancy et al. (2017)	Ireland	Mix commercial	Identify the characteristics of commercial companies that are likely and unlikely to engage with energy efficiency actions in the barriers to and drivers of energy efficiency.	Interview; survey	750 phone interviews across a statistically representative sample of commercial businesses in Ireland, including retail, hotel, public houses, and restaurants, offices, warehouses, and storage.	Company representatives.

No.	Research article	Region	Building type	Objective	Data collection	Case study and sample size	Participant characteristic
23	Curtis et al. (2017)	Australia	Mix commercial	Report on a state government program where the uptake of retrofit support program was lower than expected, prompting the program team to consider whether targeting facilities managers rather than building owners might be a better way of delivering the program.	Interview	10 interviews with facilities managers, with the draft of the findings reviewed by the CEO of the Facility Management Association of Australia (FMA).	Facilities managers that are members of the FMA.
24	Ginks and Painter (2017)	UK	Historic building	Investigate how conservation professionals in the UK approach and sanction energy retrofit measures in historic buildings.	Survey; interview; document review	52 survey responses, 7 interviews (4 from England, 2 from Scotland, and 1 from Wales), and 7 local authority databases.	UK conservation professionals.
25	Kim et al. (2017)	US	Office	Identify key adaptive-management strategies during the lighting retrofit process on one floor of an existing office building	Survey; focus group interview	40 occupant survey responses and 6 interview participants.	Real estate managers, occupant representatives, facility services managers who served communication liaisons during the planning, implementation, and calibration of the new system.
26	Masrom et al. (2017)	Malaysia	Mix commercial	Identify the potential barriers and drivers that influence commercial building owners' decisions to implement sustainable refurbishment.	Interview	4 managers from 4 different commercial office buildings.	Building manager, building executive, facility manager, assistant building manager.
27	Mohammadpour et al. (2017)	US	Health Care	Investigate current practices of retrofitting healthcare facilities, with a particular focus on patient safety and energy efficiency	Meetings; phone calls; emails; interview	33 interview participants from 3 healthcare facilities.	Head of the facilities departments, project managers, project engineers, safety experts, energy experts, and the contractor's project managers or engineers.

No.	Research article	Region	Building type	Objective	Data collection	Case study and sample size	Participant characteristic
28	Nguyen et al. (2017)	Vietnam	Mix commercial	Examine the interactive effect of participants' characteristics (experience, knowledge, and roles) on sustainable building practices in conventional buildings.	Interview; survey	7 interview participants and 169 surveys.	Owner representatives (senior executive, division head), constructor (executive, construction manager), designer (architect, division head), construction professionals.
29	Roberti et al. (2017)	Italy	Historic building	Present a methodology that identified a variety of optimal retrofits for historical buildings taking into account energy savings, thermal comfort, and the whole range of conservation compatibility.	Survey	10 Italian experts (2 heritage authorities, 3 conservators, 5 university professors of restoration).	All experts were architects specialized in the refurbishment of historic buildings with many years of experience in cultural heritage.
30	Strachan and Banfill (2017)	UK	Mix commercial	Identify the attributes that professionals consider to be important in selecting energy performance improvement measures and establishing their relative importance.	Survey	13 experts among the membership of a private sector industry-led environmental forum and from public-sector agencies.	Architecture, engineering, and facilities management qualifications with experience within at least one of these sectors: client, guidance, heritage, industry, non-heritage.
31	Tsai et al. (2017)	Taiwan	Mix commercial	Clarify the decision-making considerations of planners for improving the openings of existing buildings.	Survey; interview	A representative for each of the 7 townhouses and 1 condominium.	Government-assigned counselors, designers, and owners proposing retrofitting strategies.
32	Zuhaib et al. (2017)	Ireland	Mix commercial	Assess the attitudes, approaches, and experiences of construction professionals regarding energy-efficient buildings, particularly net-zero energy buildings.	Survey; workshop; interview	90 surveys, 85 workshop participants, and 11 interviews.	Net-zero energy building experts, policy stakeholders, market players for envelopes.

No.	Research article	Region	Building type	Objective	Data collection	Case study and sample size	Participant characteristic
33	Bertone et al. (2018)	Australia	Public	Identify the main challenges and coping strategies for accelerating the retrofitting rate of public buildings.	Workshop; interview; scenario modeling	Interview with experts in the country, including 2 in Brisbane, 1 in Melbourne, and 2 in Perth. Workshops with 15 participants in Queensland and 29 participants in Western Australia.	Champions from the industry sectors, Australian state governments.
34	Christensen et al. (2018)	US	Office	Assess energy reporting, data tracking, labeling preferences, and upgrade decision-making.	Interview	33 interviews representing institutional owners managing large portfolios.	Large scale property owners, investors, and managers. Typical respondents controlled a portfolio of 20-60 office buildings, and all were involved in making decisions related to energy performance and reporting.
35	Si and Marjanovic-Halburd (2018)	UK, China	Mix commercial	Propose default criteria weights based on previously developed criteria tree organized around green technologies' environmental, economic, social, and technical performance.	Survey	25 survey responses from the UK and 29 from China.	Professionals working in the built environment and have experience in building retrofit, mainly with backgrounds from architecture, engineering, planning, and design.
36	Yang et al. (2018)	US	Office	Examine buildings that both had and had not adopted LEED or Energy Star in the New York metropolitan area.	Document review	205 building projects for 273 organizations (102 new construction and 103 renovated buildings) in New York City and the surrounding metro area.	There are directories of office buildings in New York City from a private database, non-profit organization, and a federal agency.

No.	Research article	Region	Building type	Objective	Data collection	Case study and sample size	Participant characteristic
37	Alam et al. (2019)	Australia	Public	Understand how the public building retrofitting barriers are different from existing retrofitting barriers reported in the literature and identify the top barriers and associated coping strategies from the personnel employed within government departments or agencies.	Focus group discussion	2 focus groups in 2 states of Australia where public building retrofitting programs were not successful. 10 and 28 participants for the first and second focus groups.	Senior personnel in a government organization (i.e., director, manager, policy, and program officer) and have at least 10 years of experience in retrofit projects.
38	Fasna and Gunatilake (2019)	Sri Lanka	Lodging	Explore the barriers and strategies that affect the successful implementation of building energy efficiency retrofit in actual project level executions.	Interview	11 respondents actively involved in the selected 2 cases from completed BEER projects in Sri Lankan hotel buildings.	Owner representatives (director-general manager, engineering manager, engineers, senior foreman, foreman, cost controller), contractor (assistant manager), consultant (chief technical advisor).
39	Kim et al. (2019)	US	Education	Understand the decision-making processes in energy efficiency projects at a higher education institution, particularly the factors that facilities managers consider and their interrelationships.	Interview; document review	6 expert interviews from facilities services, housing and food services, campus engineering and operations, an office tower. Secondary data from occupant survey, university policy and practice, and city policy.	Resource conservation manager, capital planning and sustainability manager, assistant director, manager, supervisor.
40	Zheng et al. (2019)	China	Mix commercial	Propose an investment prediction model for large-scale building energy-saving retrofit by considering owners' willingness factors that possess fuzzy attributes and random characteristics.	Survey	100 public buildings in Shanghai, including public institutions, hotels, shopping malls, and commercial offices.	Building owners

No.	Research article	Region	Building type	Objective	Data collection	Case study and sample size	Participant characteristic
41	Jimenez-Pulido et al. (2020)	Spain	Mix commercial	Identify both the demands of the Spanish industry to improve the management of buildings and the contextual challenges on inspections.	Survey; panel discussion	52 experts who completed both rounds of the Delphi consultation.	Senior architects, engineers.
42	Tozer (2020)	UK, Germany, US	Mix commercial	Examine political effectiveness in the implementation of urban decarbonization initiatives	Interview	40 interviews of case studies of urban building low carbon governance in Stockholm, London, and San Francisco.	Representatives from the urban development industry, government, utilities, building owners, and non-governmental organizations involved in building and energy decarbonization.

4.4.2 *Content analysis*

This section discussed themes that emerged as criteria and factors influencing decisions to implement energy-efficiency retrofits.

4.4.2.1 Key factors based on assessment criteria

Based on the SLR of 42 selected articles, this study identified 30 key factors that influence the implementation of energy-efficiency retrofits. These factors can be grouped into seven decision criteria, each of which emerged in multiple articles: *economic feasibility* (EF; 32 articles), *team process* (TPro; 29 articles), *technical practicality* (TPra; 28 articles), *institutional characteristic* (IC; 27 articles), *governmental policy* (GP; 24 articles), *occupant impact* (OI; 24 articles), and *environmental impact* (EI; 17 articles). EF is considered most important and has a strong interrelationship with other criteria, meaning that a change in financial performance can affect the performance of other criteria. EI criterion is mentioned least as an influencer of retrofit decisions. **Error! Reference source not found.** summarizes the total number of articles and the frequency of the assessment criteria being coded. The following sections discuss the primary factors under each assessment criteria that influence retrofit decisions.

Table 4.3 Summary of articles and codes on assessment criteria of building retrofit.

No.	Research article	EF	TPro	TPra	IC	GP	EI	OI
1	Woodroof (2011)		7			1		
2	Xu et al. (2011)	7	8	2	3	1		
3	Zografakis et al. (2011)	2	1	2	2		4	
4	Xu et al. (2012)	2	2		2		1	1
5	Gultekin et al. (2014)	1	2	2	1			2
6	Bruce et al. (2015)	1	1	3	4	2		2
7	Gliedt and Hoicka (2015)	2	1			1	1	
8	Haase et al. (2015)	2	3		1			2
9	Liang et al. (2015)	7	5	11	2	2		1
10	Yang et al. (2015)	2		2				
11	Abdallah et al. (2016)	4					1	
12	Andrews et al. (2016)					4		
13	Barnes and Parrish (2016)	1				4		
14	Castleberry et al. (2016)	4	3		1		1	
15	Hou et al. (2016)		2	1		3		
16	Komolafe et al. (2016)	1		1			10	
17	Kontokosta (2016)	9	1	3	5		1	1
18	Liang et al. (2016)	13	4	1	1	4		2
19	Mosgaard et al. (2016)	2	2	1			1	
20	Valero et al. (2016)	1	5			4		
21	AbdelAzim et al. (2017)			3	1		4	
22	Clancy et al. (2017)		4		2			3
23	Curtis et al. (2017)	3	2	1	1	1		1
24	Ginks and Painter (2017)	1	2	10	5	3		1
25	Kim et al. (2017)		2	1				
26	Masrom et al. (2017)	5	2		2	2	1	2
27	Mohammadpour et al. (2017)							5
28	Nguyen et al. (2017)		4	2	3	1	21	9
29	Roberti et al. (2017)	1		4				1
30	Strachan and Banfill (2017)	5	1	6	2		3	5
31	Tsai et al. (2017)	1		3	1	1		1
32	Zuhaib et al. (2017)	6	10	8	4	7	3	3
33	Bertone et al. (2018)	4	7	1	1	4		1
34	Christensen et al. (2018)	12	2	6	7	1	2	3
35	Si and Marjanovic-Halburd (2018)	5		6	3		4	3
36	Yang et al. (2018)		2					
37	Alam et al. (2019)	14	21	12	11	16		1
38	Fasna and Gunatilake (2019)	3	18	9	3	3		2
39	Kim et al. (2019)	9	3	8	4	4	4	3
40	Zheng et al. (2019)	5		5	2	1		
41	Jimenez-Pulido et al. (2020)	1		10	4	1	1	1
42	Tozer (2020)					3		
Number of codes		136	127	124	78	74	63	56

EF—life cycle cost. Factors related to EF were observed in 32 of 42 articles reviewed (76%) and included life cycle cost, funding mechanism, payback period, and profit distribution. The participants across the literature consistently indicated that energy-efficiency improvements were ultimately made based on financial decisions. The primary factor under this criterion is life cycle cost, covering 74 of 136 codes (54%). The coded statements from the reviewed articles indicated that life cycle cost was seen as a critical measure of success. The high upfront cost of technology installation (Castleberry et al. 2016; Haase et al. 2015; Zuhaib et al. 2017), uncertainty in improving building value and rent (Fasna and Gunatilake 2019; Liang et al. 2016), and financial risks of savings overestimation (Bertone et al. 2018; Bruce et al. 2015) are some barriers related to life cycle cost that hinder retrofit implementation. Participants across the reviewed literature often noted that a retrofit project can be implemented if it can generate an economic return. A retrofit realization can be driven by pursuing affordable retrofitting cost (Tsai et al. 2017) by starting with more minor, simple, low to no-cost improvements (Christensen et al. 2018). Other retrofits requiring significant capital investment can then be considered when financial incentives become available and the affordable retrofit projects prove to be a cost benefit within a short payback period (Christensen et al. 2018). Energy-efficiency investment that can provide attractive economic returns through reduced building energy bills for tenants and higher rents for building owners will drive more implementation of energy-efficiency retrofits (Kontokosta 2016).

TPro—coordination and collaboration. Factors categorized under TPro were mentioned in 29 of 42 articles reviewed (69%) and included coordination and collaboration, expert skills, management leadership, and team training. The primary factor is coordination and collaboration, covering 54 of 127 codes (43%). Some barriers to retrofits discussed regarding coordination and collaboration include lack of quality management system (Hou et al. 2016); weak negotiation power (Liang et al. 2016); the reluctance of energy companies to share data (Valero et al. 2016); lack of trust and good relationships (Woodroof 2011; Xu et al. 2011); potential high coordination cost (Liang et al. 2016); lack of involvement of experts, owners, and occupiers, which leads to conflicting opinions (Bertone et al. 2018; Zuhaib et al. 2017); an unsystematic way of making decisions [54]; and difficulties in establishing communication between parties (Fasna and Gunatilake 2019). Improving the project organization process is a key success factor to effective coordination. Recommendations from the reviewed articles suggest the need to perform project management under internationally recognized systems, communicate the program’s goals and progress across stakeholders through eco-charrette to formulate a shared vision and produce a preventive maintenance plan (Alam et al. 2019; Kim et al. 2017; Xu et al. 2011).

TPra—system compatibility. TPra factors were identified in 28 of 42 articles reviewed (67%) and included system compatibility, risk management, project integration, technology readiness, site accessibility, and procurement process. Under this criterion, the most cited factor was system compatibility, covering 43 of 124 codes (35%). The physical limits on the types of energy-efficiency technologies that can be installed (Ginks and Painter 2017; Jimenez-Pulido et al. 2020; Kontokosta 2016), lack of spare parts for older equipment that requires major disruptions (Curtis et al. 2017), and lack of availability of one-stop solutions (Zuhaib et al. 2017) were some of the main concerns discussed by participants across the studies. Constructability, ease of installation, and functionality of the retrofit technology are critical in fueling stakeholders’ confidence to invest in energy-efficiency improvement (Mosgaard et al. 2016; Strachan and Banfill 2017; Tsai et al. 2017). Evaluating the existing building condition and its environment and improving the inspection processes (Jimenez-Pulido et al. 2020; Liang et al. 2015) should be an essential step to minimize system compatibility issues during retrofitting.

IC—internal value. Factors related to IC—including internal value, demand pressure, community engagement, and reputation—were observed in 27 of 42 articles reviewed (64%). Internal value is mentioned the most, covering 30 of 78 codes under IC (38%). It is well known that companies may not see reducing energy use as a top priority when investing capital. In fact, participants in some studies even perceived energy-efficiency retrofits as work that could harm the value of their organization or building. For example, historic building experts are concerned that retrofits are insensitive toward architectural and cultural aspects (Zuhaib et al. 2017). They could lead to a loss of historical material and might not maintain the building's heritage value (Ginks and Painter 2017; Jimenez-Pulido et al. 2020; Zuhaib et al. 2017). A case study in Australia showed that building code development such as fire safety and disability access prevented heritage-listed buildings from being renovated for reuse because they became significantly more expensive to retrofit (Bruce et al. 2015). In another study, Ginks and Painter found a regional variation: conservation professionals in Scotland had different perceptions about energy retrofits in historic buildings than conservation professionals throughout the rest of the UK (Ginks and Painter 2017). Consequently, overcoming this gap in knowledge and beliefs should be a priority when considering potential added value for all stakeholders. For example, most companies in a US-based study believed eco-labels and energy ratings add value to their real estate assets by attracting the market and identifying improved energy performance (Christensen et al. 2018). When retrofitting historic buildings, conservation professionals and heritage agencies are encouraged not to view energy-efficiency renovations as modernizing the facilities but rather as ensuring the buildings' long-term survival (Ginks and Painter 2017).

GP—government commitment. Factors related to the GP were identified in 24 of 42 articles reviewed (57%); they included government commitment, standards and regulations, information sharing, and political influence. Government commitment is the most crucial factor, with 31 of 74 codes identified from the article (42%). Barriers to retrofits cited in the literature included lack of energy code enforcement and efficiency (Andrews et al. 2016), lack of citizen education (Valero et al. 2016), delays in getting approval from the local authority (Fasna and Gunatilake 2019), and lack of knowledge and support of high-level government officials responsible for introducing retrofit programs (Alam et al. 2019). That study (Alam et al. 2019) further expressed concerns that energy-efficiency retrofits are not a priority unless the state government mandates them. Ensuring that the mandated target is realistic and is followed by clear guidelines is necessary for a successful mandate. Further, the commitment to the energy-saving program should also start at the implementation phases (Woodroof 2011).

OI—satisfaction and wellbeing. Factors related to OI—including satisfaction and wellbeing, health and safety, educational program, and energy-efficient behavior—were mentioned in 24 of 42 articles reviewed (57%). Satisfaction and wellbeing were discussed the most, with 21 of 56 codes identified (38%). Key barriers to retrofits that were cited include interrupting productivity and complaints from tenants (Curtis et al. 2017; Strachan and Banfill 2017). One study in a hospital setting focused on understanding the impact on patients during the construction phase of retrofitting (Mohammadpour et al. 2017). Three case studies of healthcare facilities indicated various patient safety and wellbeing issues included noise, vibration, coordination, dust, and asbestos. The study suggested that considering input from the occupants as end-users during the design phase will improve current practices.

EI—eco-friendly installation. Factors included in EI, such as eco-friendly installation, carbon dioxide emissions, sustainable resources, and waste management, were observed in 17 of 42 articles reviewed (40%). The primary factor under this criterion, covering 28 of 63 codes identified (44%), is eco-friendly installation, which explores the feasibility of implementing various energy-efficiency improvement strategies with an environmental emphasis. Examples include eco-friendly refrigerants and fire suppression systems (AbdelAzim et al. 2017), use of reused building materials in the project (Nguyen et al. 2017), and use of materials with recycled content (Nguyen et al. 2017; Si and Marjanovic-Halburd 2018). An empirical study about sustainable building practices in Vietnam suggested the need to provide green building-related training to experienced practitioners to successfully implement various sustainable building applications in conventional buildings (Nguyen et al. 2017).

4.4.2.2 Key factors based on diverse regions and building types

This section discusses the 30 factors mentioned in the selected articles that apply across different regions and building types.

Factors by regions. Table 4.4 shows factors influencing retrofit decisions that emerged in different regions. Seventeen regions around the world were used as case study locations within the selected literature. Three factors discussed in most regions included life cycle cost (14 regions), system compatibility (11 regions), and coordination and collaboration (10 regions). China, the US, Australia, and the UK cover most of the 30 identified factors; 27 factors emerged in China and the US, while 23 factors emerged in studies in Australia and the UK. Denmark and Egypt explored the least number of factors—only four factors each. This observation is in line with the number of articles that explored these regions. The studies are more concentrated in the

US and China, with 14 articles undertaken in the US and six articles in China, resulting in 90% of the factors identified for each country. In contrast, Denmark and Egypt were only represented by one article each, limiting the representation of more diverse factors for these countries (13%).

Although research articles are primarily from developed countries with higher per capita income than developing countries, both types of countries see EF criteria that focuses on life cycle cost and funding mechanisms as the most dominant considerations. However, some differences in concern exist between developed and developing economies. Studies featuring developing economies raised more concerns about TPra, IC, and GP (85%, 85%, and 69% of the articles) when considering retrofit projects than did developed economies (60%, 57%, and 50% of the articles). Figure 4.5 summarizes the percentage of articles that mentioned each decision factor. In studies conducted in developing economies, TPra issues were emphasized for risk management, technology readiness, and system compatibility (54%, 38%, and 38%). In studies conducted in developed economies, the most discussed factor was system compatibility (43%), while risk management and technology readiness were only mentioned in 20% of the articles. Issues related to standards and regulation were more emphasized when considering retrofit projects in developing economies than in developed economies. This finding is consistent with Liang et al. (2015), who found that government and policy factors are significantly important in energy-efficiency retrofits in China, unlike another study in Australia that indicated the limited role of the government in green building development (Yang and Zou 2014). However, the impact of political influence in retrofit implementation was discussed in 3 of the 30 studies conducted in developed countries, yet it was not mentioned in any of the 13 studies conducted in developing countries.

Factors by building types.

Table 4.5 demonstrates how the factors influencing retrofit decisions are represented in eight building types identified in the reviewed articles. Like the representation by region, life cycle cost is the factor most discussed across diverse building types; it is mentioned for seven out of eight building types used in the literature. It is followed closely by expert skills, risk management, demand pressure, internal value, and satisfaction and wellbeing, which are equally identified in six building types. Research articles using mix commercial buildings represented the most identified factors (28 of 30 factors), followed by offices (25 factors) and education and lodging (23 factors each). Healthcare facilities covered only two of 30 factors, including satisfaction and wellbeing and health and safety. Only one article used a healthcare facility as the case study; thus, this finding does not imply that other factors were not considered by the owners and managers of healthcare buildings. Instead, additional studies that focus on this building may reveal a more comprehensive list of factors considered.

Table 4.4 Factors influencing retrofit by region.

	Factor	Australia	China	Denmark	Egypt	EU countries	Germany	Greece	Ireland	Italy	Malaysia	Nigeria	Spain	Sri Lanka	Taiwan	United Kingdom	United States	Vietnam
EF	Life cycle cost	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	Payback period	✓	✓													✓	✓	
	Funding mechanism	✓	✓			✓		✓	✓		✓					✓	✓	
	Profit distribution	✓	✓						✓								✓	
TPro	Expert skills	✓	✓			✓			✓		✓			✓		✓	✓	✓
	Management leadership	✓	✓						✓					✓			✓	
	Team training	✓	✓			✓								✓			✓	
	Coordination and collaboration	✓	✓	✓		✓		✓	✓					✓		✓	✓	✓
TPra	System compatibility	✓	✓					✓	✓	✓			✓	✓	✓	✓	✓	✓
	Project integration		✓		✓								✓		✓	✓	✓	
	Site accessibility	✓	✓											✓		✓	✓	
	Procurement process	✓												✓				
	Risk management	✓	✓						✓			✓		✓		✓	✓	
	Technology readiness		✓	✓					✓				✓	✓		✓	✓	
IC	Reputation	✓	✓					✓			✓					✓	✓	
	Demand pressure	✓	✓			✓					✓					✓	✓	
	Community engagement	✓	✓		✓			✓	✓				✓	✓		✓		✓
	Internal value	✓	✓						✓				✓		✓	✓	✓	
GP	Government commitment	✓	✓			✓			✓					✓		✓	✓	
	Standard and regulation	✓	✓						✓		✓		✓		✓	✓	✓	✓
	Information sharing	✓	✓			✓			✓					✓			✓	
	Political influence	✓				✓	✓									✓	✓	
OI	Educational program	✓	✓			✓			✓		✓					✓	✓	✓
	Energy-efficient behavior		✓						✓					✓			✓	
	Satisfaction and wellbeing	✓	✓						✓	✓				✓	✓	✓	✓	✓
	Health and safety	✓	✓						✓				✓			✓	✓	✓
EI	Sustainable resources			✓	✓			✓	✓			✓					✓	✓
	Eco-friendly installation		✓		✓			✓				✓				✓		✓
	Waste management		✓									✓				✓	✓	✓
	CO_2 emissions		✓						✓		✓		✓			✓	✓	

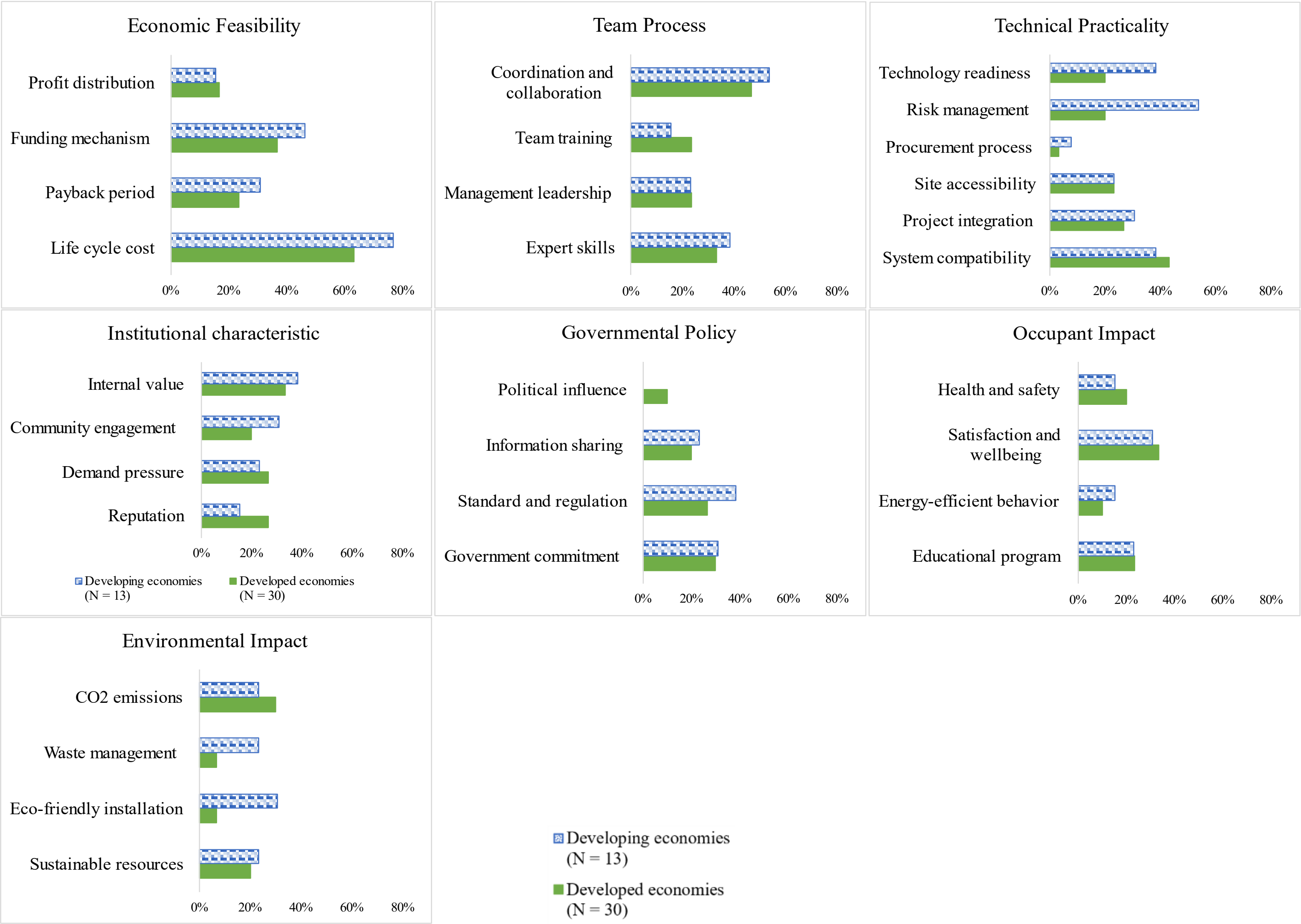

Figure 4.5 Percentage of articles with criteria influencing retrofit decisions.

Table 4.5 Factors influencing retrofit by building type.

	Factor	Education	Health Care	Lodging	Mercantile	Office	Mix commercial	Historic building	Public
EF	Life cycle cost	✓		✓	✓	✓	✓	✓	✓
	Payback period	✓				✓	✓		✓
	Funding mechanism	✓		✓		✓	✓		✓
	Profit distribution			✓		✓	✓		✓
TPro	Expert skills	✓		✓		✓	✓	✓	✓
	Management leadership	✓		✓		✓	✓		✓
	Team training	✓		✓	✓	✓			✓
	Coordination and collaboration	✓		✓		✓	✓		✓
TPra	System compatibility	✓		✓		✓	✓	✓	
	Project integration	✓				✓	✓	✓	
	Site accessibility	✓		✓		✓	✓		✓
	Procurement process			✓					✓
	Risk management	✓		✓		✓	✓	✓	✓
	Technology readiness	✓		✓		✓	✓		
IC	Reputation	✓		✓		✓	✓		
	Demand pressure	✓			✓	✓	✓	✓	✓
	Community engagement			✓			✓		✓
	Internal value	✓		✓		✓	✓	✓	✓
GP	Government commitment	✓		✓			✓	✓	✓
	Standard and regulation	✓				✓	✓	✓	✓
	Information sharing			✓			✓		✓
	Political influence						✓		✓
OI	Educational program	✓			✓	✓	✓		✓
	Energy-efficient behavior	✓		✓		✓	✓		
	Satisfaction and wellbeing	✓	✓	✓		✓	✓	✓	
	Health and safety		✓	✓		✓	✓		
EI	Sustainable resources	✓		✓		✓	✓		
	Eco-friendly installation			✓		✓	✓		
	Waste management	✓				✓	✓		
	CO_2 emissions	✓		✓		✓	✓		✓

EF: Economic Feasibility; TPro: Team Process; TPra: Technical Practicality; IC: Institutional Characteristic;
GP: Governmental Policy; OI: Occupant Impact; EI: Environmental Impact.

4.5 CONCLUSIONS AND FUTURE RESEARCH

This SLR aimed to investigate what peer-reviewed articles worldwide have published on stakeholders' perceptions of energy-efficiency retrofits in buildings. This paper identified seven assessment criteria commonly used when considering a retrofit investment: economic feasibility (e.g., life cycle cost), team process (e.g., coordination and collaboration), technical practicality (e.g., system compatibility), institutional characteristic (e.g., internal value), governmental policy (e.g., government commitment), occupant impact (e.g., satisfaction and wellbeing), and environmental impact (e.g., eco-friendly installation). Though much overlap in factors influencing decisions to retrofit exists, the focus of considerations may not be uniform across different contexts, such as across regions, between developing and developed economies, and across building types. Nevertheless, substantial discussions and strong internal dependencies among many of these factors (Kim et al. 2019) suggest that comprehensive retrofitting strategies considering the seven criteria might accelerate the energy-efficiency improvements of the commercial and institutional building stock. The novelty of this research lies in it having explored comprehensive factors in commercial and institutional buildings from multi-context perspectives, unlike previous SLRs on energy-efficiency retrofit decisions.

The findings of the reviewed articles highlight common challenges and recommendations that can be summarized according to three key stakeholder groups. First, industry practitioners (e.g., facility managers, consultants, contractors) play a critical role in successful retrofit projects. Organizations should support improving the knowledge of their personnel at all levels about the evolving field of energy-efficiency improvements by exposing them to training that supplies them with credentials and know-how skills. In this way, stakeholders can address many challenges in retrofitting, such as concerns about the technical capabilities, lack of management leadership, and ineffective communication. Decision-makers should encourage collaboration with multiple disciplines. For example, inviting heritage experts when retrofitting historic buildings or healthcare specialists when retrofitting hospital buildings throughout various project phases allows the team to consider the varying priorities and added values in retrofitting.

Second, building occupants have not been very included as study participants in most reviewed articles, although they may have important insights about energy retrofitting. This finding is consistent with another literature review study that found that occupant behaviors and preferences are still not well incorporated into the research and development of retrofitting measures in housing (Ortiz et al. 2020). Building owners and managers should be inclusive and involve the occupants and the community directly affected by the projects, especially during the planning phase rather than after completing the project. Early identification of the impacts of retrofit on the occupants and their expectations may address concerns such as energy consumptive behavior due to lack of knowledge among tenants, disruption to occupants' productivity during retrofit activities, tenant retention, and health and safety impact. Building owners should provide access to energy-efficiency education by supplying a building user manual and occupant training for the new system. Moreover, the project team should continuously communicate the progress to the occupants to increase acceptance of the project and help ensure the retrofitted building achieves the intended energy-efficiency improvement.

Third, government agencies are critical players in facilitating energy-efficiency projects that provide clear regulations and set an example by retrofitting public facilities. Concerns mentioned included lack of energy code enforcement, lack of access to comprehensive and consistent information about achieving energy targets, a mismatch between retrofitting projects and the timeframe of political decisions, and a complex procurement process. Key strategies suggested throughout the reviewed articles include having a mandatory energy-efficiency retrofitting policy, flexible incentive programs, a dedicated financing mechanism, and dedicated teams to provide transparent information and facilitate organizations in preparing the business case.

The authors identified at least two needs for future studies based on this SLR's findings. First, building energy efficiency is a field of research that needs an interdisciplinary approach since it overlaps with the indoor environment and public health studies, as also suggested by Kim and Reed (2020). Motivations for sustainable upgrades have been heavily advocated based on how buildings impact the environment. Although the environmental impact is an element to consider, this review indicates that it was not the most influential criteria driving the ultimate decisions of stakeholders. It is crucial to maintain the momentum of energy efficiency by addressing the message that it is a part of more extensive efforts that require an integrated framework to protect both the environment and the health of the humans who spend most of their time in the buildings. This recommendation is consistent with a recent study on the use of public health research to regulate new facilities to improve the pressing topics of public health and climate resilience (Carmichael et al. 2020). Holistically reviewing the building regulations would realize the importance of improving energy efficiency in buildings for climate resilience and public health.

Second, this paper highlights the need for further work to better contextualize the energy-efficiency improvements through research among more diverse regions, building types, and stakeholders. This literature review is based on 42 recent articles, most of which concern the US and China and which use mixed commercial buildings as the majority of case studies. Opportunities exist for more quantitative and qualitative studies concerning other geographical locations (e.g., developing countries), building types (e.g., hospitals), and multidisciplinary stakeholders (e.g., physicians in health care projects) that have not been well represented in this review. Additional research in other less explored contexts can help clarify the findings in this literature study or supply new elements to the current extensive list of factors. In addition, this SLR was limited in scope to peer-reviewed research articles in academic journals. Future research can expand the knowledge in understanding factors associated with implementing energy-efficiency retrofits by assessing reports, books, and gray literature.

DECLARATION OF COMPETING INTEREST

None.

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Chapter 5. CONCLUSIONS

5.1 SUMMARY OF FINDINGS

This dissertation offered insights on what building industry professionals and policymakers should consider when evaluating renovations to become more energy efficient. More specifically, this dissertation addressed the following research questions (Q):

Q1: What are the factors and contexts that could influence the decision to implement energy retrofit?

Q2: How do factors that influence energy retrofit compare among different contexts?

Q3: How do stakeholders rank the importance of the factors that influence energy retrofit?

Q4: How do factors that influence energy retrofit interrelated?

The first question was investigated in Chapters 2, 3, and 4. Chapter 2 identified 15 factors influencing retrofits using pairwise comparison techniques to 236 experts in the US. Chapter 3 examined the relevancy of these factors based on six mental model interviews and sets of local reports in a specific context of a US higher education institution. Chapter 4 evaluated the factors by expanding the scope through the SLR method of relevant studies worldwide. Based on the three studies, this dissertation concluded that there are 30 key factors influencing energy-efficiency retrofits in buildings categorized into economic feasibility, team process, technical practicality, governmental policy, institutional characteristic, occupant impact, and environmental impact. Multiple contexts were examined through these chapters, but they can be categorized into three dimensions. These dimensions include physical (e.g., building scale, geographical region, building type), functional (e.g., ownership type, industry sector), and social (e.g., professional influence, personal characteristic).

The second question was addressed in Chapters 2 and 4. Chapter 2 compared how different contexts prioritize the factors. These contexts include a cross-context comparison among experts with varying building portfolios, climate zones, institution or ownership types, industry sectors, decision roles, and leadership positions. Chapter 4 identified various contexts used to study the decision-making of building energy efficiency retrofit worldwide, including geographical regions, economic classifications, and building types. Based on these two studies, some factors are perceived similarly necessary among some contexts but considerably different among others, as shown in Table 5.1. For example, multiple decision factors to retrofit perceived a similar level of importance between public and private institutions and between stakeholders of single and multiple buildings. However, a different focus of concerns was observed among geographical regions and industry sectors.

Table 5.2 Summary of factor comparison among contexts.

Context Group	Context Dimension	Comparison	Source
Physical	Building portfolio	While most factors are similarly ranked despite the portfolio size, project integration is more significant for stakeholders of multiple buildings than single building stakeholders.	Chapter 2
	Climate zone	Different climate zones mostly have a medium influence on varying important factors and a strong influence on how expert skills factor is perceived.	Chapter 2
	Geographical region	Life cycle cost, system compatibility, and coordination and collaboration were consistently observed as important retrofit factors across the regions.	Chapter 4
	Economic classification	Factors influencing retrofit decisions have similarities between developed and developing economies, especially economic feasibility, team process, institutional characteristics, and occupant impact. Some differences were more present in factors related to technical practicality, governmental policy, and environmental impact. For example, developing economies were more concerned about technology readiness, risk management, standard and regulation, and eco-friendly installation. Political influence, system compatibility, and CO2 emissions were more important for countries of a developed economy.	Chapter 4
Functional	Institution type	There is little influence on whether an institution is public or private in perceiving the importance of varying decision factors.	Chapter 2

Context Group	Context Dimension	Comparison	Source
Social	Industry sector	Different industry sectors mostly have a strong influence on varying important levels of factors, especially on prioritizing economic feasibility (e.g., life cycle cost) and institutional characteristics (e.g., reputation)	Chapter 2
	Building type	Life cycle cost, expert skills, risk management, demand pressure, internal value, and satisfaction and wellbeing were observed as important retrofit factors across most regions.	Chapter 4
	Decision role	Most factors were prioritized similarly by executives and non-executives, except that the demand pressure factor received higher importance by the non-executives.	Chapter 2
	Leadership position	While decision factors generally received a similar degree of importance, the medium influence of different leadership positions on factors prioritization was observed. System compatibility and educational program were more important for third parties, while site accessibility and occupant satisfaction were more important for building owners.	Chapter 2

This finding has a critical implication for policy makers to provide regulations and tailored incentives based on its unique contexts. For example, regulators of developing countries should investigate ways to improve the readiness of energy efficiency technology, a decision factor that was less concerning for developed countries. On the other side, political influence was observed to be considered only in developed countries. It supports previous literature showing that political orientation in the US influences the decision to purchase an energy-efficient product (Dietz et al. 2013). Further work is warranted to develop policy design principles, but this study also suggests that political support for energy efficiency should no longer be treated separately from the environmental efforts.

The third question was addressed in Chapter 2. This chapter concluded that at the criteria level, economic feasibility is the most important (37%), followed by technical practicality (20%), occupant impact (17%), institutional characteristic (14%), and environmental impact (12%). At the factor level, the three most important factors across all US respondents were payback period, life-cycle cost, and funding mechanism. This study also identified the most important factor under each criterion, which include payback period (economic feasibility), system compatibility (technical practicality), occupant satisfaction (occupant impact), expert skills (institutional characteristic), and sustainable resources (environmental impact).

The fourth question was addressed in Chapter 3. This study identified 45 reinforcing loops and 13 balancing loops from 36 codes interconnected with energy efficiency activities. The CLDs presented have visualized the complex web of factors that influence energy retrofit decisions in a higher education institution. It can help explain the underlying energy efficiency retrofit dynamics, how an organization requires complex processes and multidisciplinary interactions among stakeholders during energy efficiency decisions. Moreover, the results highlighted a picture of the facilitating and inhibiting factors dan can be targeted to improve policy and practice of energy efficiency retrofit.

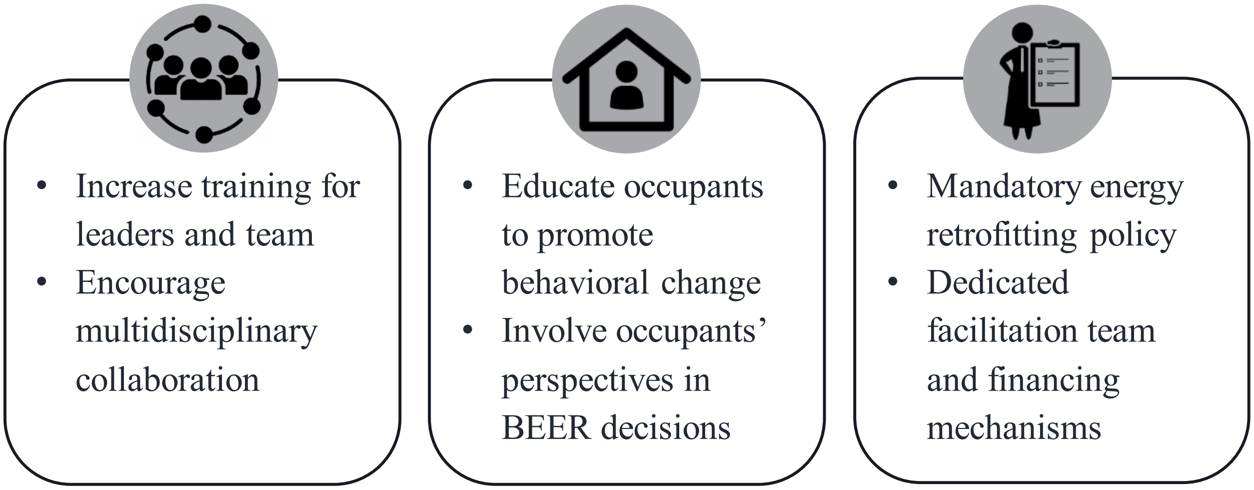
5.2 CONTRIBUTION TO KNOWLEDGE

The three studies presented in this dissertation contribute to knowledge by comprehensively and systematically examining factors and contexts in the decision-making of energy efficiency retrofit. Researchers and practitioners can utilize the identified criteria and factors to develop a full scale of multi-criteria decision-making model to recognize the importance of context in energy efficiency. This study also extends the context theory that was dominantly used in the organizational behavior field to create a framework of the impact of contexts in energy efficiency decision-making. More specifically, the findings of Chapter 2 provide theoretical contribution by examining the prioritization of factors to retrofit. These findings also contribute to practice by providing building professionals with the empirical data needed and demonstrating how the AHP technique can be practical to help them prioritize what can be an exhaustive list of factors in energy retrofit decisions. Chapter 3 contributes to theory by providing significant insights from understanding interrelationships of a comprehensive list of decision factors by multiple stakeholders. This study contributes to practice by presenting empirical data and lessons learned from the UW case study to help organizations with similar structures in their retrofit decision process. The study in Chapter 4 stands as both theoretical and practical contributions. This SLR fills the existing literature gap by creating evidence to support energy efficiency decisions in research and practice. The synthesis of the empirical studies provides a common language for broadening the perspectives of energy efficiency retrofit from different contexts.

5.3 THE PATH FORWARD

The findings of this dissertation are limited to its case studies. Thus, assumptions beyond these case studies require additional research to confirm applicability. Future work should seek to expand the number of participants of multiple context dimensions, especially for specific contexts that had a small sample size for this study, such as geographical regions, building types, and stakeholder characteristics. This work is expected to spark greater interest in the decision-making of energy efficiency retrofit and give perspectives for new research opportunities in investigating the factor interrelationships in different contexts and examine their impact on better policy and practice. Strategies can be further developed based on testing the outcomes of different scenarios from these varying factor interrelationships.

This dissertation proposes additional research and improvement of practice in (1) team training, (2) occupant education, and (3) policy support.



- **Strengthen the project team through training and multidisciplinary collaboration.** The role of facility management is increasingly essential and complex, from focusing on repairing broken equipment to identifying energy conservation opportunities and meeting other aggressive sustainability goals. More institutions such as in the US have recently established energy efficiency-related training and credentials, and this study recommends that such an approach be made more in other countries.
- **Educate and involve the occupants in promoting behavioral change.** There have been repetitive concerns on the need to increase occupants' knowledge about why retrofit is needed. Awareness is critical for the occupants to tolerate uncomfortable disruptions during the renovation project and enable energy-efficient behavior. Improving understanding could be achieved by providing an engagement program that lets the occupants know about their impact of behavior on energy consumption and the active role they can play, including how to operate the newly installed technology efficiently.

- **Increase government commitment through context-based approach policies and dedicated team.** Setting mandatory efficiency policies for government buildings is critical to set good examples. Additionally, a team and financing mechanisms dedicated to facilitating the business case of energy efficiency projects should exist in any organization to allow for the successful implementation of energy efficiency.

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APPENDIX 1. DECISION FACTORS AND DEFINITIONS

Factor	Description
Occupant impact	The impact of retrofit on the relationship between occupants and the building
Educational programs	Availability of occupant engagement and training necessary to make sure the retrofit installed in the building is operating properly and acceptable for the occupant
Occupant satisfaction	Occupant's comfort, wellbeing, and productivity
Energy-efficient behavior	The impact of occupant's behavior change to the building upgrade performance
Environmental impact	The impact of retrofit to the environment as well as climate change mitigation at the construction and operation phase
CO_2 emissions	The impact of retrofit on the amount of carbon footprint reduced
Sustainable resources	Sustainable way of using raw materials and other resources to retrofit, including renewable options
Waste management	Availability of building waste management from the retrofit project
Institutional characteristics	The impact of retrofit on the organization's competencies and business goals
Expert skills	Workforce knowledge and capabilities to evaluate, install and operate a retrofit project
Reputation	Branding, including pursuance of sustainable certification
Demand pressure	Alignment with an institutional goal, government policy, and market demand
Economic feasibility	The assessment of the financial aspects of retrofit decisions
Life cycle cost	Total expense over the life of retrofit technology, including initial investment, electric utility rates, and maintenance and operation costs
Funding mechanism	Financing options to help fund the project, including incentives such as grants, tax credits, and rebates
Payback period	Amount of time needed to recover the assumed higher investment cost of retrofit technology
Technical practicality	The technical complexity of retrofit implementation
Project integration	The scale of the retrofit project and synergy with other renovation projects, such as overlapping O&M project with resource conservation measures
Site accessibility	The availability of building or space for renovation, such as due to building ownership type (single or multi-tenant), disturbance to the surrounding environment during retrofit and proximity from production to the project site
System compatibility	Manufacturability and compatibility of the equipment or system with the existing building structural typology

APPENDIX 2. AHP QUESTIONNAIRE

- How would you characterize your organization?

  ○ Private

  ○ Public

- You have selected a private organization. In which sector is your organization?

  ○ Finance

  ○ Information Technology

  ○ Mining

  ○ Transportation

  ○ Higher Education

  ○ Early Education (K-12)

  ○ Telecommunication

  ○ Construction

  ○ Pharmaceuticals

  ○ Real Estate

  ○ Wholesale and retail trade

  ○ Other, please specify: ____

- You have selected a public organization. In which sector is your organization?

  ○ Police

  ○ Army

  ○ Mining

  ○ Health

  ○ Manufacturing

  ○ Electricity

  ○ Higher Education

  ○ Early Education (K-12)

  ○ Transportation

  ○ Telecommunication

  ○ Agriculture

  ○ Banking

  ○ Insurance

  ○ Other, please specify: ____

- Select the size of your organization (globally) in terms of the workforce:

  ○ Large (more than 250 employees)

  ○ Medium (50 to 249 employees)

  ○ Small (10 to 49 employees)

  ○ Micro (less than 10 employees)

- Select the number of buildings your organization (globally) manage and operate:

  ○ 100 buildings or more

  ○ 50 to 99 buildings

  ○ 2 to 49 buildings

  ○ 1 building

- Where is your work location?

  ○ City ____

  ○ State/ Country ____

- How would you characterize your job role in relation to building retrofit investment decisions?

  ○ I manage the building operations and maintenance, and directly/ indirectly help make building investment decisions for the organization I work for (e.g. building owner, in-house engineering team in real estate developer)

  ○ I work for an organization that provide service to help other organizations make building investment decisions (e.g. external consultant)

  ○ Other, please specify: ____

- Select the job title that best represents your role within the organization?

  ○ Designer/ Architect

  ○ Project developer

  ○ Research scientist

  ○ Data analyst

  ○ Consultant

  ○ Other, please specify: ____

  ○ Auditor

  ○ Project coordinator

  ○ Manager/ supervisor

  ○ Executive

  ○ Engineer

- When making retrofit decisions, how many buildings do you typically consider simultaneously?

  ○ Only 1 building at a time

  ○ More than 1 building at a time

- You have selected more than 1 building to consider simultaneously when making retrofit decisions. Please specify:

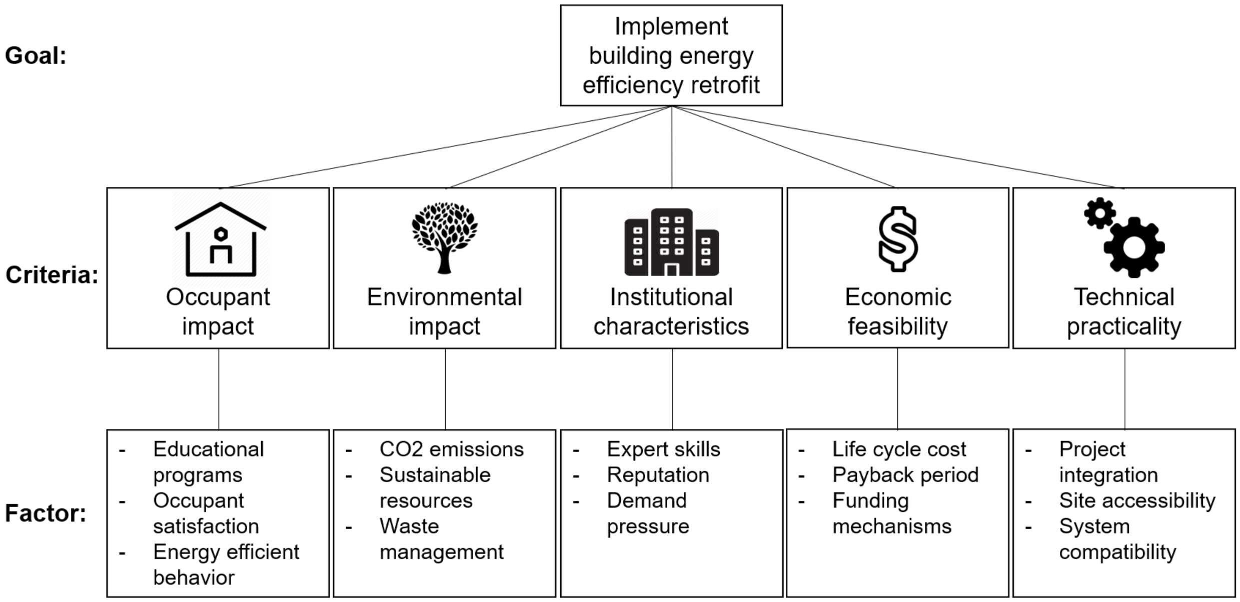
  ○ 2 to 25 buildings

  ○ 26 to 50 buildings

  ○ 51 to 100 buildings

  ○ More than 100 buildings

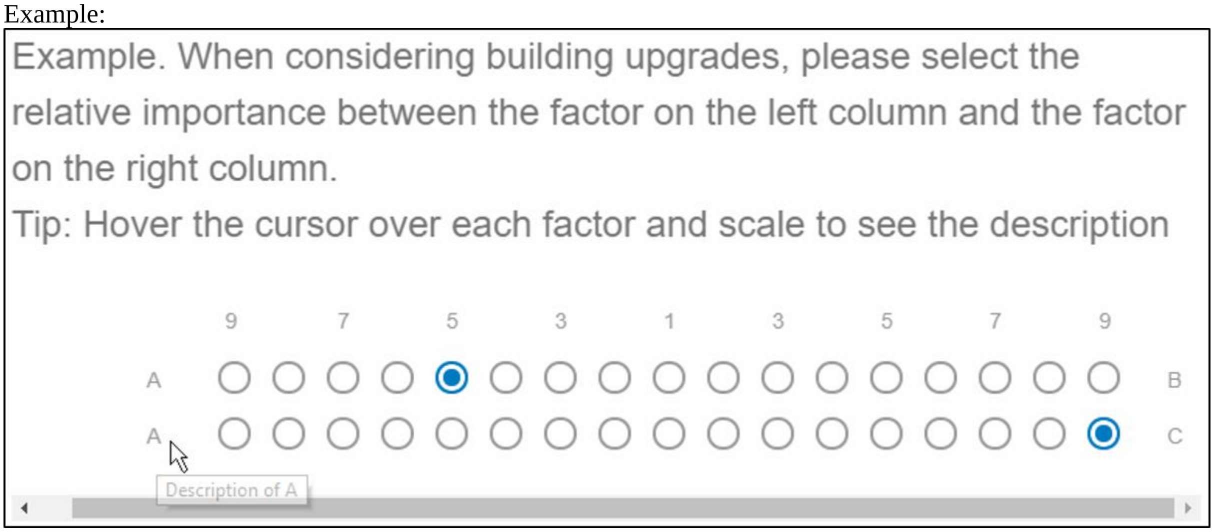
This is the guideline for answering the following questions. The figure below shows a hierarchical structure of factors affecting the selection and implementation of energy efficiency retrofits. The term category implies the division of factors that have shared commonalities.



We will ask you to scale the relative importance of categories and factors that affect your decision in implementing energy efficiency retrofits in buildings, from scale 1 to 9. If you have the preference for the factor on the left, select the value on the left of scale 1. If you have the preference for the factor on the right, select the value on the right of the scale 1.

Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor
A	A has **extreme** importance than B	intermediate value	A has **very strong** importance than B	intermediate value	A has **strong** importance than B	intermediate value	A has **moderate** importance than B	intermediate value	A and B have **equal** importance	intermediate value	B has **moderate** importance than A	intermediate value	B has **strong** importance than A	intermediate value	B has **very strong** importance than A	intermediate value	B has **extreme** importance than A	**B**

Example:



Example. When considering building upgrades, please select the relative importance between the factor on the left column and the factor on the right column.

Tip: Hover the cursor over each factor and scale to see the description

	9		7		5		3		1		3		5		7		9	
A	○	○	○	○	●	○	○	○	○	○	○	○	○	○	○	○	○	B
A	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●	C

Interpretation: If scale 5 on the left is selected when comparing A and B, it implies that **A is strongly more important than B**. If scale 9 on the right is selected when comparing A and C, it implies that **C is extremely more important than A.**

- **Category comparison (1 of 2)**
  When considering building upgrades, please select the relative importance between the category on the left column and the category on the right column.
  Tip: Hover the cursor over each category and scale to see the description

	9		7		5		3		1		3		5		7		9	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Occupant impact																		Environmental impact
Occupant impact																		Institutional characteristics
Occupant impact																		Economic feasibility
Occupant impact																		Technical practicality
Environmental impact																		Institutional characteristics
Environmental impact																		Economic feasibility
Environmental impact																		Technical practicality

- **Category comparison (2 of 2)**

  When considering building upgrades, please select the relative importance between the category on the left column and the category on the right column.
  Tip: Hover the cursor over each category and scale to see the description

	9		7		5		3		1		3		5		7		9	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Institutional characteristics																		Economic feasibility
Institutional characteristics																		Technical practicality
Economic feasibility																		Technical practicality

- Please type in the box below if you wish to elaborate on the answers given in category comparisons:

- **Factor comparison: Occupant impact**
  When considering building upgrades, please select the relative importance between the factor on the left column and the factor on the right column.
  Tip: Hover the cursor over each factor and scale to see the description

	9		7		5		3		1		3		5		7		9	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Educational programs																		Occupant satisfaction
Educational programs																		Energy-efficient behavior
Occupant satisfaction																		Energy-efficient behavior

- **Factor comparison: Environmental impact**
  When considering building upgrades, please select the relative importance between the factor on the left column and the factor on the right column.
  Tip: Hover the cursor over each factor and scale to see the description

	9		7		5		3		1		3		5		7		9	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
CO2 emissions																		Sustainable resources
CO2 emissions																		Waste management
Sustainable resources																		Waste management

- **Factor comparison: Institutional characteristics**
  When considering building upgrades, please select the relative importance between the factor on the left column and the factor on the right column.
  Tip: Hover the cursor over each factor and scale to see the description

	9		7		5		3		1		3		5		7		9	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Expert skills																		Reputation
Expert skills																		Demand pressure
Reputation																		Demand pressure

Questionnaire S1. (Continued)

- **Factor comparison: Economic feasibility**
  When considering building upgrades, please select the relative importance between the factor on the left column and the factor on the right column.
  Tip: Hover the cursor over each factor and scale to see the description

	9		7		5		3		1		3		5		7		9	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Life cycle cost																		Payback period
Life cycle cost																		Funding mechanism
Payback period																		Funding mechanism

- **Factor comparison: Technical practicality**
  When considering building upgrades, please select the relative importance between the factor on the left column and the factor on the right column.
  Tip: Hover the cursor over each factor and scale to see the description

	9		7		5		3		1		3		5		7		9	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Project integration																		Site accessibility
Project integration																		System compatibility
Site accessibility																		System compatibility

- Please type in the box below if you wish to elaborate on the answers given in factor comparisons:
- Thank you for participating in the survey. If you have any additional comments, please fill in the text box below.

APPENDIX 3. LOCAL WEIGHTS OF CRITERIA AND FACTORS

APPENDIX 3.1 LOCAL WEIGHTS OF CRITERIA AND FACTORS BY PHYSICAL CONTEXT (%)

Criteria and Factor	Portfolio Size		Climate Zone				
	Single	Multiple	Cold/ very cold	Hot-dry/ mixed-dry	Hot-humid	Marine	Mixed-humid
Economic feasibility	36.1	37.3	36.4	32.9	39.9	37.5	37.8
Payback period	38.0	38.1	41.8	38.3	39.3	29.6	41.0
Lifecycle cost	36.0	38.6	34.9	40.1	38.6	36.0	39.2
Funding mechanism	26.0	23.3	23.4	21.3	22.1	34.1	19.6
Technical practicality	19.4	21.2	19.9	17.9	24.6	19.2	19.7
System compatibility	48.5	42.5	48.7	46.9	51.2	41.1	42.1
Project integration	30.4	38.7	32.2	33.0	33.3	33.3	37.1
Site accessibility	21.1	18.9	19.1	20.1	15.4	26.0	20.3
Occupant impact	19.5	15.2	18.0	17.0	12.0	16.2	20.0
Occupant satisfaction	47.7	40.1	46.1	34.1	41.7	42.6	46.0
Energy-efficient behavior	33.3	38.8	36.1	41.8	39.2	35.8	33.5
Educational program	19.5	21.1	17.8	23.5	20.0	21.6	20.5
Institutional characteristics	13.6	13.5	13.4	15.5	14.2	14.0	12.9
Expert skills	41.2	48.1	41.8	56.8	45.8	43.6	44.2
Reputation	30.9	26.7	28.4	23.9	33.8	27.1	31.0
Demand pressure	27.9	25.2	29.9	19.4	20.4	29.3	24.8
Environmental impact	11.4	12.8	12.3	16.7	9.2	13.1	9.6
Sustainable resources	40.4	36.7	35.8	33.5	45.7	42.0	37.5
Waste management	35.1	33.6	34.1	36.5	35.9	34.4	34.4
CO_2 emission	24.6	29.7	30.1	30.5	19.6	23.7	29.2

Appendix 3.2 Local weights of criteria and factors by functional context (%)

Criteria and Factor	Institution Type		Industry Sector						
	Public	Private	Consumer discretionary	Energy	Financial	Healthcare	Producer durables	Technology	Utilities
Economic feasibility	37.2	37.1	40.1	38.2	33.7	34.6	36.1	30.0	39.2
Payback period	38.4	36.9	31.4	60.7	48.7	36.4	36.8	51.7	43.1
Lifecycle cost	36.8	37.7	38.9	17.8	32.6	34.7	39.3	34.7	38.8
Funding mechanism	24.7	25.3	29.4	21.2	18.7	28.9	24.1	13.7	18.1
Technical practicality	19.4	21.3	19.3	24.3	13.6	22.8	22.5	18.7	25.2
System compatibility	45.4	46.5	40.9	56.0	55.9	47.8	44.4	44.4	56.0
Project integration	34.5	32.4	37.3	21.4	25.7	33.3	34.2	37.4	31.7
Site accessibility	20.1	21.6	22.3	22.6	18.4	18.9	21.3	18.2	12.3
Occupant impact	18.8	14.4	15.6	14.6	23.2	18.9	16.6	20.5	13.1
Occupant satisfaction	45.2	41.7	42.3	42.5	45.3	47.6	45.8	47.8	29.0
Energy-efficient behavior	35.1	38.2	35.9	34.2	31.9	31.2	38.0	36.1	48.9
Educational program	20.2	20.1	21.8	22.6	22.8	21.2	16.3	16.1	22.1
Institutional characteristics	13.2	14.7	13.9	14.8	14.8	13.5	13.0	14.0	11.7
Expert skills	43.9	44.9	46.0	39.2	40.5	54.1	43.8	27.1	42.7
Reputation	28.8	28.6	26.6	28.4	36.5	20.0	30.8	52.1	17.9
Demand pressure	26.5	27.2	27.3	32.4	23.0	25.9	25.4	20.7	39.3
Environmental impact	11.4	12.4	11.2	8.1	14.6	10.3	11.8	16.8	10.8
Sustainable resources	38.6	38.7	37.5	34.6	39.0	36.9	39.8	45.8	38.9
Waste management	33.3	37.1	35.7	34.6	33.6	35.9	33.9	30.4	35.2
CO_2 emission	28.1	24.2	26.8	29.6	27.4	26.2	26.3	23.8	25.9

APPENDIX 3.3 LOCAL WEIGHTS OF CRITERIA AND FACTORS BY SOCIAL CONTEXT (%)

Criteria and Factor	Decision Role		Leadership Position	
	Owner	Third-Party	Executive	Non-Executive
Economic feasibility	36.9	40.2	38.7	37.3
Payback period	38.2	36.8	41.3	37.5
Lifecycle cost	37.1	37.3	33.6	37.5
Funding mechanism	24.7	25.6	25.1	24.9
Technical practicality	20.0	20.6	20.6	20.0
System compatibility	44.5	54.4	45.1	45.5
Project integration	34.5	29.6	37.4	33.5
Site accessibility	21.5	16.0	17.5	21.0
Occupant impact	17.8	12.5	17.1	17.0
Occupant satisfaction	44.9	36.8	42.1	44.1
Energy-efficient behavior	36.0	36.8	39.8	35.9
Educational program	19.1	26.4	18.1	20.0
Institutional characteristics	13.4	15.6	11.7	14.0
Expert skills	44.0	46.2	47.9	43.6
Reputation	29.9	25.0	30.8	28.6
Demand pressure	26.1	28.8	21.4	27.1
Environmental impact	11.8	11.1	11.9	11.8
Sustainable resources	39.0	36.9	36.1	39.0
Waste management	34.7	36.9	37.0	33.9
CO_2 emission	27.1	26.1	26.9	27.1

APPENDIX 4. WEIGHT DIFFERENCES AMONG CONTEXTS

Appendix 4.1 Weight differences according to physical context (%)

Criteria and Factor	S vs. M	CVC vs. HDMD	CVC vs. HH	CVC vs. Mr.	CVC vs. MH	HDMD vs. HH	HDMD vs. Mr.	HDMD vs. MH	HH vs. Mr.	HH vs. MH	Mr. vs. MH
Economic feasibility	1	4	4	1	1	7*	5	5	2	2	0
Payback period	0	3	2	12**	1	1	9*	3	10*	2	11**
Lifecycle cost	3	5*	4	1	4	2	4	1	3	1	3
Funding mechanism	3	2	1	11**	4	1	13**	2	12**	2	15**
Technical practicality	2	2	5	1	0	7*	1	2	5*	5	1
System compatibility	6*	2	2	8*	7*	4	6*	5	10**	9*	1
Project integration	8*	1	1	1	5	0	0	4	0	4	4
Site accessibility	2	1	4	7*	1	5	6*	0	11**	5	6*
Occupant impact	4	1	6*	2	2	5*	1	3	4	8*	4
Occupant satisfaction	8*	12**	4	4	0	8*	8*	12**	1	4	3
Energy-efficient behavior	5*	6*	3	0	3	3	6*	8	3	6*	2
Educational program	2	6*	2	4	3	4	2	3	2	0	1
Institutional characteristics	0	2	1	1	1	1	2	3	0	1	1
Expert skills	7*	15**	4	2	2	11**	13**	13**	2	2	1
Reputation	4	4	5*	1	3	10*	3	7*	7*	3	4
Demand pressure	3	10**	9*	1	5*	1	10*	5*	9*	4	4
Environmental impact	1	4	3	1	3	8*	4	7*	4	0	4
Sustainable resources	4	2	10*	6*	2	12**	8*	4	4	8*	4
Waste management	1	2	2	0	0	1	2	2	2	1	0
CO_2 emission	5*	0	11**	6*	1	11**	7*	1	4	10*	6*

Note: S = single; M = multiple; CVC = cold/ very cold; MH = mixed-humid; HH = hot-humid; HDMD = hot-dry/ mixed-dry; Mr. = marine.

*Medium weight difference (5% < variation ≤ 10%).

**Large weight difference (variation > 10%).

APPENDIX 4.2 WEIGHT DIFFERENCES ACCORDING TO FUNCTIONAL CONTEXT (%)

Criteria and Factor	P vs. Pr.	CD vs. E	CD vs. F	CD vs. H	CD vs. PD	CD vs. T	CD vs. U	E vs. F	E vs. H	E vs. PD	E vs. T
Economic feasibility	0	2	6^{*}	6^{*}	4	10^{**}	1	5	4	2	8^{*}
Payback period	2	29^{**}	17^{**}	5	5^{*}	20^{**}	12^{**}	12^{**}	24^{**}	24^{**}	9^{*}
Lifecycle cost	1	21^{**}	6^{*}	4	0	4	0	15^{**}	17^{**}	22^{**}	17^{**}
Funding mechanism	1	8^{*}	11^{**}	1	5^{*}	16^{**}	11^{**}	3	8^{*}	3	8^{*}
Technical practicality	2	5^{*}	6^{*}	4	3	1	6^{*}	11^{**}	2	2	6^{*}
System compatibility	1	15^{**}	15^{**}	7^{*}	4	3	15^{**}	0	8^{*}	12^{**}	12^{**}
Project integration	2	16^{**}	12^{**}	4	3	0	6^{*}	4	12^{**}	13^{**}	16^{**}
Site accessibility	1	0	4	3	1	4	10^{*}	4	4	1	4
Occupant impact	4	1	8^{*}	3	1	5	3	9^{*}	4	2	6^{*}
Occupant satisfaction	4	0	3	5^{*}	3	5^{*}	13^{**}	3	5^{*}	3	5^{*}
Energy-efficient behavior	3	2	4	5	2	0	13^{**}	2	3	4	2
Educational program	0	1	1	1	6^{*}	6^{*}	0	0	1	6^{*}	7^{*}
Institutional characteristics	2	1	1	0	1	0	2	0	1	2	1
Expert skills	1	7^{*}	6^{*}	8^{*}	2	19^{**}	3	1	15^{**}	5	12^{**}
Reputation	0	2	10^{*}	7^{*}	4	26^{**}	9^{*}	8^{*}	8^{*}	2	24^{**}
Demand pressure	1	5^{*}	4	1	2	7^{*}	12^{**}	9^{*}	7^{*}	7^{*}	12^{**}
Environmental impact	1	3	3	1	1	6^{*}	0	7^{*}	2	4	9^{*}
Sustainable resources	0	3	2	1	2	8^{*}	1	4	2	5^{*}	11^{**}
Waste management	4	1	2	0	2	5^{*}	1	1	1	1	4
CO_2 emission	4	3	1	1	1	3	1	2	3	3	6^{*}

Note: P = public; Pr. = private; CD = consumer discretionary; E = energy; F = financial; H = healthcare; PD = producer durables; T = technology; U = utilities.
*Medium weight difference (5% < variation ≤ 10%).
**Large weight difference (variation > 10%).

Criteria and Factor	E vs. U	F vs. H	F vs. PD	F vs. T	F vs. U	H vs. PD	H vs. T	H vs. U	PD vs. T	PD vs. U	T vs. U
Economic feasibility	1	1	2	4	6*	2	5	5	6*	3	9*
Payback period	18**	12**	12**	3	6*	0	15**	7*	15**	6*	9*
Lifecycle cost	21**	2	7*	2	6*	5	0	4	5	1	4
Funding mechanism	3	10**	5*	5*	1	5	15**	11**	10**	6*	4
Technical practicality	1	9*	9*	5*	12**	0	4	2	4	3	7*
System compatibility	0	8*	11**	11**	0	3	3	8*	0	12**	12**
Project integration	10**	8*	8*	12**	6*	1	4	2	3	2	6*
Site accessibility	10**	0	3	0	6*	2	1	7*	3	9*	6*
Occupant impact	2	4	7*	3	10**	2	2	6*	4	4	7*
Occupant satisfaction	13**	2	1	3	16**	2	0	19**	2	17**	19**
Energy-efficient behavior	15**	1	6*	4	17**	7*	5	18**	2	11**	13**
Educational program	0	2	7*	7*	1	5	5*	1	0	6*	6*
Institutional characteristics	3	1	2	1	3	1	1	2	1	1	2
Expert skills	4	14**	3	13**	2	10**	27**	11**	17**	1	16**
Reputation	10**	16**	6*	16**	19**	11**	32**	2	21**	13**	34**
Demand pressure	7*	3	2	2	16**	1	5*	13**	5	14**	19**
Environmental impact	3	4	3	2	4	2	7*	1	5*	1	6*
Sustainable resources	4	2	1	7*	0	3	9*	2	6*	1	7*
Waste management	1	2	0	3	2	2	6*	1	4	1	5
CO$_2$ emission	4	1	1	4	1	0	2	0	2	0	2

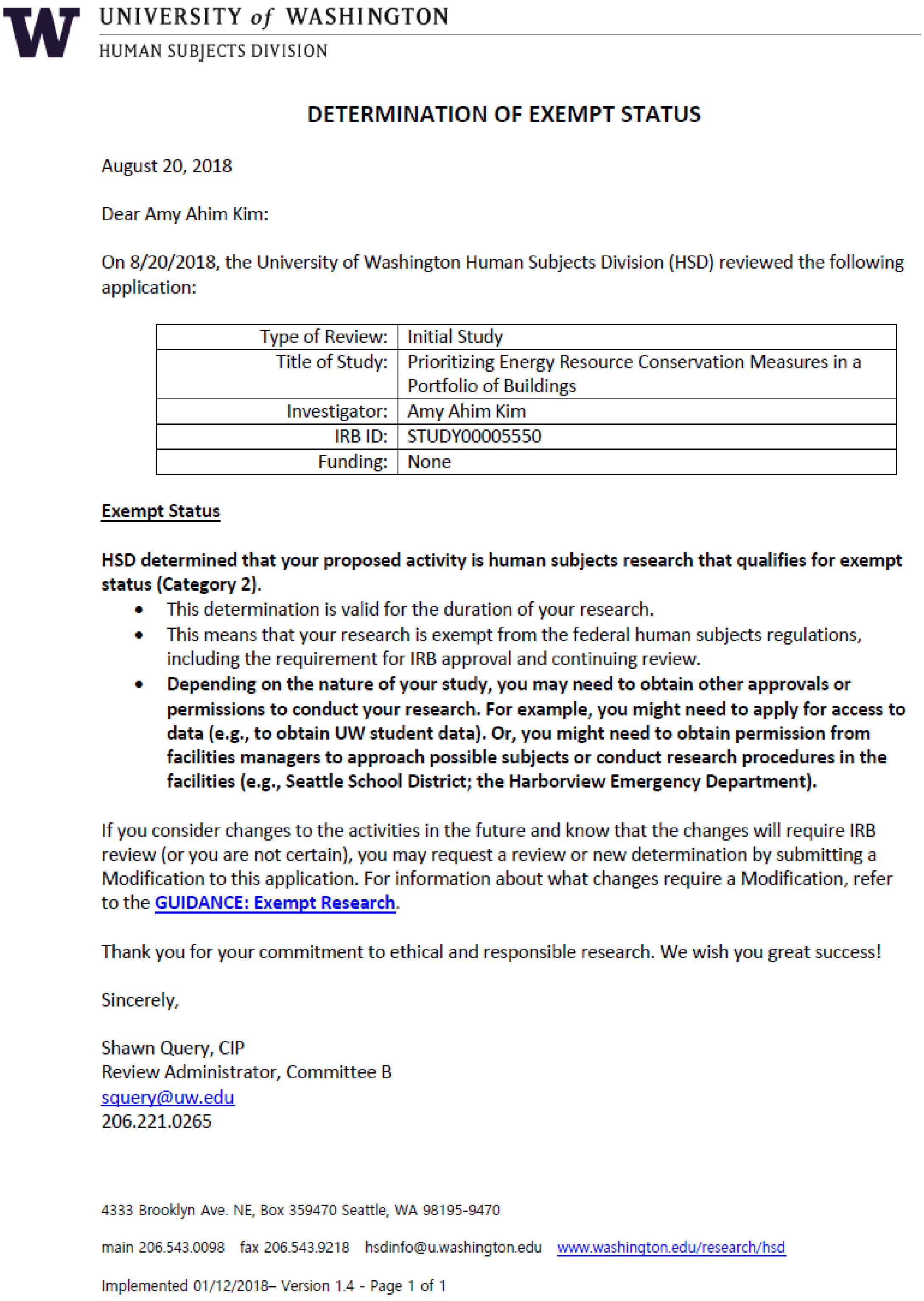
Note: E = energy; F = financial; H = healthcare; PD = producer durables; T = technology; U = utilities.
*Medium weight difference (5% < variation ≤ 10%).
**Large weight difference (variation > 10%).

APPENDIX 4.3 WEIGHT DIFFERENCES ACCORDING TO SOCIAL CONTEXT (%)

Criteria and Factor	BO vs. TP	Ex. vs. NE
Economic feasibility	3	1
Payback period	1	4
Lifecycle cost	0	4
Funding mechanism	1	0
Technical practicality	1	1
System compatibility	10*	0
Project integration	5	4
Site accessibility	5*	4
Occupant impact	5*	0
Occupant satisfaction	8*	2
Energy-efficient behavior	1	4
Educational program	7*	2
Institutional characteristics	2	2
Expert skills	2	4
Reputation	5	2
Demand pressure	3	6*
Environmental impact	1	0
Sustainable resources	2	3
Waste management	2	3
CO_2 emission	1	0

Note: BO = building owner; TP = third-party; Ex. = executive; NE = non-executive.
*Medium weight difference (5% < variation ≤ 10%).

APPENDIX 5. IRB APPROVAL



UNIVERSITY *of* WASHINGTON
HUMAN SUBJECTS DIVISION

DETERMINATION OF EXEMPT STATUS

August 20, 2018

Dear Amy Ahim Kim:

On 8/20/2018, the University of Washington Human Subjects Division (HSD) reviewed the following application:

Type of Review:	Initial Study
Title of Study:	Prioritizing Energy Resource Conservation Measures in a Portfolio of Buildings
Investigator:	Amy Ahim Kim
IRB ID:	STUDY00005550
Funding:	None

Exempt Status

HSD determined that your proposed activity is human subjects research that qualifies for exempt status (Category 2).

- This determination is valid for the duration of your research.
- This means that your research is exempt from the federal human subjects regulations, including the requirement for IRB approval and continuing review.
- **Depending on the nature of your study, you may need to obtain other approvals or permissions to conduct your research. For example, you might need to apply for access to data (e.g., to obtain UW student data). Or, you might need to obtain permission from facilities managers to approach possible subjects or conduct research procedures in the facilities (e.g., Seattle School District; the Harborview Emergency Department).**

If you consider changes to the activities in the future and know that the changes will require IRB review (or you are not certain), you may request a review or new determination by submitting a Modification to this application. For information about what changes require a Modification, refer to the **GUIDANCE: Exempt Research**.

Thank you for your commitment to ethical and responsible research. We wish you great success!

Sincerely,

Shawn Query, CIP
Review Administrator, Committee B
squery@uw.edu
206.221.0265

4333 Brooklyn Ave. NE, Box 359470 Seattle, WA 98195-9470

main 206.543.0098 fax 206.543.9218 hsdinfo@u.washington.edu www.washington.edu/research/hsd

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APPENDIX 6. QUOTES FROM INTERVIEWS

APPENDIX 6.1 ECONOMIC FEASIBILITY

Complexity of Funding Mechanism (EF1)

As one survey respondent (FM2) said, “And on our buildings, we get no money from the state or anyone else; we’re self-funded, so we can only base what we build on what we can borrow.”

A respondent (FM3) said, “Our budget has been pretty good, so we’ve used some of that money to do projects. We don’t have it set up right now that there’s X amount budgeted for those. But we’re getting those capital projects approved by administration.”

“In a major capital improvement, the UW Medical Center management prepares a priority list and then determine the amount of funding for EE projects against the amount that goes to medical equipment or other things” said another respondent (FM3).

Cost Saving (EF2)

According a survey respondent (FM3), “We pay about half a million dollars a month on energy bills... Annually, we also look at how energy prices are changing.”

A respondent (FM5/FM6) said, “They came out, they set up meters and monitors to monitor how long duration of a run, stuff like that, and that information came through. Then they also look at what are we spending, what the consumption of the bulbs are that we have in it now versus if we go to LED or technology.”

Funding (EF3), External Funding Source (EF4), and Internal Funding Source (EF5)

Funding is a very important factor in building EE activities.
“So, a lot of what we're doing is brought up there because it always involves funding it, always involves budget impacts” (FM5/FM6).
“… money can be a risk constraint, not everyone sees the importance of energy efficient buildings. They would rather spend the money someplace else. So, it’s always the question of who you’re talking to and when you sell it, you have to sell it in a way that it’s important to them” (FM2).

There are two types of building: the state-funded buildings managed by UW Facilities Services and other non-state buildings managed by UW Housing and Food Services, Intercollegiate Athletics, and the UW Medical Center. External sources of funding are mainly from the state. The proportion varies for the UW main facilities, which have support from the state particularly for capital projects, and other services like the UW Medical Center and UW Housing and Food Services, which are mostly self-funded with sometimes minor support from the state or Seattle City Light.

“And on our buildings we get no money from the state or anyone else, we’re self-funded so we can only base what we build and what we can borrow “ (FM2).
“….and as part of our annual budget, a little bit of that money comes from the state, I think it’s like a tenth of one percent, if I would recall it right, and I don’t get involved too much in those finances. But most of our is just generated of the services we provide” (FM3).

UW facilities like the power plant are mainly funded by the Board of Regents through capital funding groups and the university.
“So I may not say entirely correctly but they'll go to the Board of Regents and because any project over a certain dollar value has to be approved by them and of course the university has to have money either appropriated from the state as part of the capital improvements of the campus …. or the Regents will fund it through a capital planning group” (FM4).
“Well, budget is a big inherent problem, I think. In the plant it costs a lot there. You know we can't switch to biomass we're not set up for, we don't have to room for it and it would be tens if not hundreds of millions of dollars to switch to that sort of fuel” (FM4).

UW Tower is funded by the university while trying to make the building pay for itself, working together with the Real Estate Office.
“Now that we're working with real estate, we're trying to set up some reserves and get the building so that it pays for itself” (FM5/FM6).

When a project gets external funding such as from Seattle City Light, it usually has a good chance of being co-funded internally by the university.
“If it’s funded by City Light, then can we get the rest funded internally from UW. So if you can be funded by City Light, then try and get it funded by the university” (FM5/FM6).

Length of Funding Cycle (EF6)

The funding cycle differs among different units.
“UW Facilities Services usually has a biennium funding cycle, which appears in July and lasts for two years” (FM1).
“We are out like eight years so opportunities over the next eight years. So we’ll look at what money we have available and say okay we want to do this chunk in the next two years” (FM3).

Life Cycle (EF7)

A respondent (FM1) said, “I think that’s the best way to think about it is the cycle of life of capital assets. You start planning and execute stuff, and then they have a living, operational life.” Another respondent (FM3) said, “If it costs more but is more energy efficient, what’s the cost over the life of the product.”

Payback/Return on Investment (EF8)

A respondent (FM2) said, “If I can find the very quick payback, I can almost always implement it because we’ll find the money for something that pays back in a short time.” Another respondent (FM3) said, “...we identify projects based on return on investment.”

A respondent (FM3) said, “So, individual components can look right. But to get that project done, with the aging infrastructure and the domino effect of, if we do this, then we have to this, this, and this—your return on investment can drop significantly.”

Rebate (Incentive) (EF9)

A respondent (FM2) said, “We get rebates for almost all of our buildings based on how it goes beyond code.” Another respondent (FM3) said, “What potential energy savings in grants, and things like that we can get rebates… The current project we have right now is about 1.5 million, and we’re getting close to half a million in grants and rebates.”

APPENDIX 6.2 ENVIRONMENTAL IMPACT

Carbon Dioxide Emissions (EI1)

A respondent (FM1) said, “…our executive director of campus operation says steam is killing us on carbon emissions. We have to get carbon emissions down. Let’s fund a bunch of those steam projects. Great! That’s exactly what I wanted to do. Those are great ROIs. They’re great carbon reduction opportunities.” Another respondent (FM2) said, “…reduce my carbon footprint.”

Energy Conservation (EI2)

A respondent (FM2) said, “First of all, I look at energy as part of the sustainability overall.” Another respondent (FM5/FM6) said, “When you’re thinking reduction and you know energy conservation, that’s probably the green side of it.”
“We have some HVAC improvements that we’re doing some efficiency improvements where we look at set points and the programming and controls of how our managing the HVAC, and then we’ll find some efficiencies there, and I’ll make those adjustments in the programming in a building automation system. So that would solely be done for energy efficiency” (FM3).
“We don't start up great projects based solely on energy conservation and efficiency. It's more about reliability of providing the service but inherently built into the process of ensuring reliability right behind it comes energy conservation” (FM4).

Sustainable Resources (EI3)

“So we come up with different methodologies to basically find free energy in different places.... That’s how we came up with this energy scavenging system ... We created a 125,000 gallon rainwater system in one building” (FM2).
“You know we can't switch to biomass we're not set up for, we don't have to room for it and it would be tens if not hundreds of millions of dollars to switch to that sort of fuel.” (FM4).

Waste Management (EI4)

[Note: There is no interview quote. Secondary data are used].

APPENDIX 6.3 INSTITUTIONAL CHARACTERISTICS

Coordination/Collaboration (IC1)

“...usually we start talking to either real-estate, we work with them or campus engineering operations to say if this is something we're looking at, we have an opportunity here and so” (FM5/FM6).
“We are like a satellite on our own. We don't do a lot of coordination with them [Campus Engineering]” (FM5/FM6).

Demand Pressure (IC2)

“And it certainly the way market is going the buildings get smarter and smarter and more and more data is coming out of the buildings, so that is where technology I think really has a great potential” (FM1).
“We committed to the idea that we’re going to, that this audits are going to be living documents and that were least committed to as we complete RCMs in the buildings” (FM1).
“…we can only do that based on what we want the students and what other things are so we’re like a market yet, like a not for profit housing group if you will” (FM2).
“…the need to replace the boiler to meet a newer maybe a greater capacity to fit the size constraints of the building the air pollution requirements” (FM4).

External Expert Skills (IC3) and Internal Expert Skills (IC4)

“The process in which we use is I hired two energy engineers or specialist in analyzing existing buildings systems and identifying energy waste in those system, through an audit process that that they conducted” (FM1).
“And many of the subject matter experts like our building emission control contractors who actually do understand the issues” (FM1).
A respondent (FM2) said, “I don’t use software, but my consultant uses a lot of different software. We do major energy analysis. eQuest, I think, is one of the ones they use.”
“We work with external consultants to develop the plan and generally they execute it. We don’t do much within house staff. It’s almost all contracted out” (FM3).
“There’s also the university looking at lean principles. So, they’re looking at lean principles more and more in terms of this and this just kind of one of those things, and we rely I think a lot more on contractors for, information and help” (FM2).

The university also has internal experts who have the capability to work on EE projects. However, the number is limited, and the university often requires the services of external experts in any case.
“We have an architect, two electrical engineers, and five mechanical engineers who maintain a database of building conditions” (FM1).
“We have a team of seven engineers, building engineers... We try to keep the labor inside of our area instead of farming it out to somebody else, because that saves money. We do it ourselves” (FM5/FM6).

"We also happen to have highly motivated and skilled and experts and all range of urban development and urban sciences that can lend valuable insight and skill and vision, to that process of um developing our campuses more effectively and then we might be able to share that broadly with the larger community and make changes of the city levels." (FM1).

"Because I've been involved in building here for 17 years, I know a lot of the people to talk to in facilities, engineering, custodial, or other places on campus who have interest in sustainability, so I'm able to put people together, oftentimes with the right people" (FM2).

Organization Commitment (IC5)

[Note: There is no interview quote. Secondary data are used].

Reputation (IC6)

More than 58% of the 2014 respondents of Sustainability Survey found the "Cool School" ranking somewhat to very important. The percentage of respondents who found the Green Honor Roll award somewhat important to very important increased from 32% doubled to 64%. (UW 2014)

"I really like the fact that the UW is paying attention to the Smart Grid and LEED initiatives," said a respondent of the survey (UW 2014)

"All of our buildings are LEED projects, so and they've all been LEED Gold except the, one for the first one which was silver, so there's a whole energy analysis required by LEED, there's an energy analysis required by the city of Seattle" (FM2).

APPENDIX 6.4 OCCUPANT IMPACT

Educational Program (OC1)

"So, the dashboard is one of the method we've used for energy conservation, trying to reduce plug loads, trying to get people turn their lights off, trying to do all these kinds of things" (FM2).

"So, we try in how you get incoming freshmen being excited about reducing energy or becoming more sustainable. How we create eco citizens. So, the dashboard is a one way we try to use other methodologies" (FM2).

"The sustainability group has been working quietly and diligently trying to change the attitude of the people who come to work here and go to school here" (FM4).

"There's a group called UW solar which is student organization. [They] came back to me and said if we want to do some more projects and we have grants. They had three different grants, so we were doing three projects on three buildings here" (FM2).

Energy-Efficient Behavior (OI2)

"[The] biggest users of energy on the campus are the people, right? You can make buildings more and more efficient, but you will waste that efficiency if the people who inhabit those buildings aren't changing their habits, don't change of leaving doors open, leaving windows open… Energy efficiency has to be like a pool of everyone's contribution." (FM4).

“We do have energy dashboards in all of our new buildings we have a lucid dashboard which to actually identifies electrical water and gas usage in the buildings. We also use it as a potential behavior change scenario, so you can go in and compare at least electrically we have electric meters on our floors, such that I can identify, all the different floors in a particular building, what their energy usage, and then we can look at them simultaneously and see, who is better and who is worse” (FM2).

“You want people have a personal commitment, you want to use peer to peer pressure on people getting to change stuff and then we try to provide the right infrastructure, to make it easy, easy for them to make those changes” (FM2).

Expectation (OI3)

The expectation from the occupants on UW EE efforts is quite high. The sustainability survey indicated that they are conscious of not just their needs being satisfied but also the campus effort to achieve a reputation in sustainability.

“Why aren't we going for platinum LEED? Why don't we have a living building planned? Why aren't our older buildings being retrofitted for efficiency and energy production?”, said a respondent of the survey (UW 2014).

“It is not enough to maintain current levels of energy- we need to use much less energy if we even hope to slow climate change. Turn off lights in all UW buildings at night, fix heating/cooling so that they work [in appropriate setting]. I have used fans in the winter and heaters in the summer”, said another respondent of the survey (UW 2014).

“It is surprising to me that so many lights are left on 24 hours/day all over campus, even in empty classrooms and offices. It seems like such an easy and obvious way to cut energy consumption. I would like to see campus-wide policy in place to turn out not-vital lights at night”, said another one.

Satisfaction (OI4)

“One of the purposes of the improvements is to improve the productivity of occupants through environmental control in the building” (FM1).

“We get a lot of trouble calls because the lighting’s always going out in the gyms of the IMA that’s really a pain. We got to build scaffolding and…. Replacing [them] with LED that last as twice as long, [it is a] good opportunity let’s do it” (FM2).

“We look at comfort, we look at personal control” (FM2).

“An application of human-centric lighting, which is more like natural lighting—covering the whole spectrum of the sun from 2,500 K at sunset or sunrise to 6,500 K at full brightness—improves the quality of life of the occupants” (FM5/FM6).

“They start talking about how lighting impacts your day or your feeling. Human centric lighting's more like natural lighting and it covers the whole spectrum of the Sun from 2500 K when it's a sunset, sunrise, to the brightness of a day is 6500 K” (FM5/FM6).

“Sometimes we will even bring it up with our customers and let them look at it or talk to them about it if it looks like something that would be a good thing for the building at that point… ultimately it's all about customers and students” (FM5/FM6).

APPENDIX 6.5 TECHNICAL PRACTICALITY

Completion Time (TP1)

For UW Facilities Services, projects generally take 12 months to two years although some lighting upgrades can take three to four months to complete.

“These projects, some are only 12 months long, but some are 18 months long so if you need to do it in 2 years you don’t have a lot of load... Then you have lighting upgrades that can take three to four months” (FM1).

At the UW Medical Center, the projects managed by or purchased through the Department of Enterprise Services are usually two years in length.

“The ones managed by or purchased through department of enterprise services, those have a contract length that we have to finish it. That’s usually two years” (FM3).

While large projects at the UW Power Plant may take different length of time.

“... a year the year and a half of planning and budgeting and designing before construction starts. Obviously the smaller projects you go a little quicker the larger projects take a look take more time... The shortest would probably be nine months from start to construction and that would be a fairly small project but typically I'd say a year and a half is the quickest” (FM3).

An interesting finding is that, in general, it takes longer to do the paperwork and get all the approvals than it does to do the work, due to impediments such as the speed of the process, change of technology, and other barriers.

“Generally it takes longer to do the paperwork and get all the approvals than it does to do the work” (FM5/FM6).

Functionality/Reliability (TP2)

“While there are maybe some energy savings, that’s not the primary motivation to do the work, it’s the improvement for functionality” (FM3).

“For a power plant, the reliability of the equipment is paramount because it needs to work continuously and tirelessly” (FM4).

“We don’t start up great projects based solely on energy conservation and efficiency. It’s more about the reliability of providing the service but inherently built into the process of ensuring reliability. Right behind it comes energy conservation” (FM4).

“When 30- to 40-year-old equipment is upgraded or replaced, built-in energy conservation and enhancement go along with it, just from the new technology that replaces the old technology” (FM4).

Monitoring (TP3)

“A contracted project usually comes with guaranteed performance of energy savings, so the contractor must measure and monitor the performance of the installed system and improve and make some adjustments if it has not achieved what is promised” (FM3).

“Fortunately for us the project delivery methods that we’re using are through the department of enterprise services come with guaranteed electrical or energy savings. So, the contractor has to measure those to improve that they delivered on what they’ve said, or they have to go back and make some adjustments” (FM3).

In the long term, facilities managers need to have their own monitoring sensors and meters to evaluate performance on a regular basis.
“Well, basically you're talking about the sensors, they'll come back out. They'll set up their sensors again, basically [to know] how long are the lights on, how many people are” (FM5/FM6).

Project Integration (TP4)

Integrating a project into the activities of the university is also a key for success.
“But, there are other systems, like lighting systems in buildings, plumbing fixtures, irrigation systems and the landscape, building envelope opportunities, you know replacing windows, weather stripping that’s kind of things, replacing components of the buildings like roofs can we increase the amount of insulation for instance all those, all, are also possible resource conservation opportunities and we made the decision to, identify those, a peer review process of another program we operate within facilities services called the minor capital program.”(FM1)
“The third way is through regular maintenance activities just absorb maintenance. We have electricians in buildings all the time replacing light bulbs, right? …We found that through our straight standard maintenance, programs and so we’re working with that shops who do that kind of work to develop strategies to be able to capture resource conservation opportunities in those areas as well. That’s been kind of the most evolutionary component of the program is how do we, um capture those opportunities and raise the level of awareness and competency of our building maintainers…” (FM1)
“It’s not just a series of small things that you do at the ground level of maintaining and upgrading facilities, those certainly is that. But, it’s also about how you coordinate all these activities broadly” (FM1).

EE projects are often challenging to coordinate, in terms of the project types, their delivery methods and processes, and their commonalities. Work management is an issue due to lack of coordination (FM1).
“So, work management is a huge issue. There’s a tremendous amount of human resource waste in our systems, because we don’t have really good awareness about where the coordination points and what are all the various things going on campus.... We don’t know where people work in any given day, week or month, and we got many different people, managing those activities” (FM1).
“New process starting up now on campus for new buildings that's called design-build or progressive design-build where instead of a much more regimented step-by-step approach” (FM4).
“In design-build, you’re hiring a team. Once the team is hired and you give them guidance on what you’re hoping to see, they are free to buy whatever they want because they’re not the state. They have a lot more leeway and get the equipment that we want because then the contractor team can go in and research and find the best pricing” (FM4).

Regulation and Bureaucracy (TP5)

“So, there's one external influence on upgrades to the plant, the Seattle energy code. What we perform upgrade work it has to conform the Seattle energy code so that ups the efficiency

requirements or the amount of insulation or whatever the part of the code we're touching. That part of the energy code will dictate what the minimum is" (FM4).
"The applicable regulatory agencies balancing all the needs that we want to meet and then and stay within budget how long does it take usually for the whole process until you implement" (FM4).
"We also look at any regulatory issues that might be solved" (FM3).

The bureaucracy in designing and executing retrofit projects takes a great deal of time. It often it takes longer to do the paperwork than to do the actual construction.
"So a lot of what we're doing is brought up there because it always involves funding it, always involves budget impacts or it could be a long-term capital project if any things that deal with the elevator. So yeah there are a lot of what used to the university, there's a lot of meetings that go on, a lot of committees. I figure they have maybe the longer it takes to get something done I would fall under impediments" (FM5/FM6).
"I have to sell to him, and he may have to sell to the director. So, there's at least two steps and then, the other thing is we still have to be able to afford it" (FM2).
"I think there's a big difference between working for the state and working for the corporate site. We both worked in this building on both sides of it. In a corporation you could get something you run, you didn't have all the regulatory and all the sign-off and stuff like, so the impediments would be I guess just processes" (FM5/FM6).

Site Accessibility (TP6)

"You don't do steam work on the steam system on the winter time, because operation that you have to do that in the summer" (FM1).
"Accessibility can also be based on the space since lack of space may create an implementation problem (FM4).
"You know there's the difference between occupied and unoccupied. Unoccupied, you got all the freedom of not impacting anybody. Occupied building you need to unoccupy it. How fast can you make that transition?" (FM5/FM6).

Speed and Ease of Implementation (TP7)

Running a project with a small team (with a balanced scope) affects the speed of the process due to a faster decision-making process.
"Keep it a small, keep it contained and you know I mean there's times when you really need to go big, like the hole out the ground out there for light rail [project]" (FM5/FM6).
Speed is also affected by the bureaucratic process.
"So it always [about] getting the information moving it quickly, time can be a constraint, money can be a risk constraint, not everyone sees the importance of energy efficient buildings. They would rather spend the money someplace else. So, it's always the question of who you're talking to and when you sell it, you have to sell it in a way that it's important to them. (FM2)
"I guess possibly the impediment be the speed the things to move on and a lot of times it's what it takes to get through all the signatures to get where you're going" (FM5/FM6).
"When we do the solar projects. We don't do them as construction projects. I do it as a purchase order. Because then, I don't need to write every [details], I don't have to have a consultant draw

everything up and do all these things, and then spend a lot more money on the management of it" (FM2).

System Compatibility (TP8)

System compatibility looks at how the project is compatible with existing systems and facilities. "The first step was to do a desk evaluation of the facilities by looking at historical records, engineering drawings, studies, reports, commissioning manuals all the written documentation that describes the existing condition of the building and its systems" (FM1).

It is also important that newly installed retrofits produce similar or better performance than the replaced equipment and do not create unnecessary complexity.
"We have to decide like for like replacement like capacity meet the same capacity or larger capacity…. [we don't want to] end up with a power plant with five different kinds of chilling machines. So it is difficult in the current way of doing things where you can end up with machines or equipment you didn't want because the specifications you wrote were too broad, because in the end when a project is awarded to somebody to build, it's on lowest bidder" (FM4).

Use of Technology (TP9)

As targeted in the UW CAP (UW 2009), technology is deployed to reduce energy consumption. "It's certainly important, and we, facility managers in general need to really focus on elevating their competencies in the use and the management of technology. But you can only do that if you have the resources and the awareness the institutional maturity to be able to appreciate what the technology is doing to your buildings and then we can do development management system around that to keep the technology healthy and performing the function that is intended" (FM1). Newer technology is also expected to require less maintenance and to automate some processes. "Newer technology generally requires less maintenance. So, we use all of those factors and apply them maybe a little bit differently depending on the type of equipment" (FM3).

Technology such as an energy management system or energy use dashboard is deemed important in an EE project.
"I think you can build some really cool like say technology tools that's the management dashboard, energy management system.... They build this model of our campus they're able to move these labors in different project types we have" (FM1).
"We've also recently started using BIM, very much exclusively, and so now we have much greater coordination reducing cost that way" (FM2).

APPENDIX 6.6 ADDITIONAL FACTORS

Government Commitment (G1)

[Note: There is no interview quote. Secondary data are used].

Government Energy-Efficiency Requirement (G2)

[Note: There is no interview quote. Secondary data are used].

Government Support (G3)

[Note: There is no interview quote. Secondary data are used].

UW Energy Efficiency Activities (UW1)

In total there are 30 quotes from interviews which discuss or mention about various types of EE activities, which include all types of EE retrofits on building systems related to utility (e.g., steam, electricity, natural gas, compressed air, and water); plumbing; lighting; heating, ventilation, and air conditioning; building envelope; metering; and all other process optimizations or improvements related to energy conservation.

APPENDIX 7. LIST OF LOOPS

Loop Name	Description
R1	the more UW1 , the more IC6 , the more IC5 , the more UW1
R2	the more UW1 , the more IC6 , the more G3 , the more EF9 , the more UW1
R3	the more UW1 , the more IC6 , the more G3 , the more IC5 , the more UW1
R4	the more UW1 , the more EI2 , the more IC6 , the more IC5 , the more UW1
B1	the more UW1 , the more EI2 , the less EI1 , the less IC2 , the less UW1
R5	the more UW1 , the more EI2 , the more G3 , the more IC5 , the more UW1
R6	the more UW1 , the more EI2 , the more G3 , the more EF9 , the more UW1
R7	the more UW1 , the more TP3 , the more EI2 , the more IC6 , the more IC5 , the more UW1
B2	the more UW1 , the more TP3 , the more EI2 , the less EI1 , the less IC2 , the less UW1
R8	the more UW1 , the more TP3 , the more EI2 , the more G3 , the more IC5 , the more UW1
R9	the more UW1 , the more EI2 , the more IC6 , the more G3 , the more EF9 , the more UW1
R10	the more UW1 , the more EI2 , the more IC6 , the more G3 , the more IC5 , the more UW1
R11	the more UW1 , the more EI2 , the more G3 , the more EF4 , the more EF3 , the more UW1
R12	the more UW1 , the more EI2 , the more EF2 , the more EF5 , the more EF3 , the more UW1
B3	the more UW1 , the more TP2 , the more OI4 , the less OI3 , the less IC2 , the less UW1
R13	the more UW1 , the more IC6 , the more G3 , the more EF4 , the more EF3 , the more UW1
R14	the more UW1 , the more TP3 , the more EI2 , the more G3 , the more EF9 , the more UW1
B4	the more UW1 , the more IC6 , the more OI4 , the less OI3 , the less IC2 , the less UW1
R15	the more UW1 , the more IC3 , the more TP9 , the more TP7 , the less TP1 , the more UW1
R16	the more UW1 , the more TP3 , the more EI2 , the more IC6 , the more G3 , the more IC5 , the more UW1
R17	the more UW1 , the more TP3 , the more EI2 , the more IC6 , the more G3 , the more EF9 , the more UW1
R18	the more UW1 , the more IC4 , the more IC1 , the more TP4 , the more TP7 , the less TP1 , the more UW1
R19	the more UW1 , the more TP3 , the more EI2 , the more EF2 , the more EF5 , the more EF3 , the more UW1
B5	the more UW1 , the more EI2 , the more IC6 , the more OI4 , the less OI3 , the less IC2 , the less UW1
R20	the more UW1 , the more TP3 , the more EI2 , the more G3 , the more EF4 , the more EF3 , the more UW1
R21	the more UW1 , the more EI2 , the more IC6 , the more G3 , the more EF4 , the more EF3 , the more UW1
B6	the more UW1 , the more TP3 , the more EI2 , the more IC6 , the more OI4 , the less OI3 , the less IC2 , the less UW1
R22	the more UW1 , the more IC3 , the more TP9 , the more TP3 , the more EI2 , the more G3 , the more EF9 , the more UW1
R23	the more UW1 , the more IC3 , the more TP9 , the more TP3 , the more EI2 , the more G3 , the more IC5 , the more UW1
B7	the more UW1 , the more IC3 , the more TP9 , the more TP2 , the more OI4 , the less OI3 , the less IC2 , the less UW1
B8	the more UW1 , the more IC3 , the more TP9 , the more TP3 , the more EI2 , the less EI1 , the less IC2 , the less UW1
B9	the more UW1 , the more IC4 , the more IC1 , the more TP3 , the more EI2 , the less EI1 , the less IC2 , the less UW1
R24	the more UW1 , the more IC4 , the more IC1 , the more TP3 , the more EI2 , the more IC6 , the more IC5 , the more UW1
R25	the more UW1 , the more IC3 , the more TP9 , the more TP3 , the more EI2 , the more IC6 , the more IC5 , the more UW1
R26	the more UW1 , the more TP3 , the more EI2 , the more IC6 , the more G3 , the more EF4 , the more EF3 , the more UW1
R27	the more UW1 , the more IC4 , the more IC1 , the more TP3 , the more EI2 , the more G3 , the more EF9 , the more UW1
R28	the more UW1 , the more IC4 , the more IC1 , the more TP3 , the more EI2 , the more G3 , the more IC5 , the more UW1
B10	the more UW1 , the more IC6 , the more IC5 , the more OI1 , the more OI2 , the more EI2 , the less EI1 , the less IC2 , the less UW1
R29	the more UW1 , the more IC4 , the more IC1 , the more TP3 , the more EI2 , the more EF2 , the more EF5 , the more EF3 , the more UW1
R30	the more UW1 , the more IC6 , the more IC5 , the more OI1 , the more OI2 , the more EI2 , the more G3 , the more EF9 , the more UW1

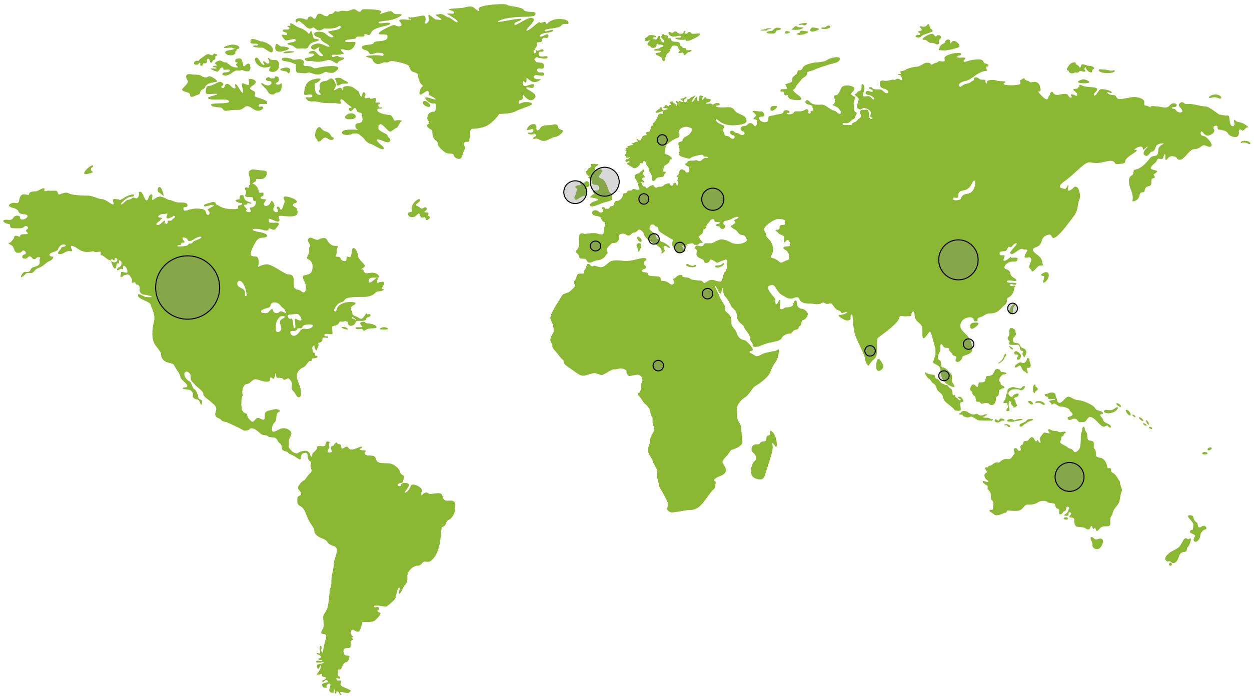
R31	the more UW1	, the more IC3	, the more TP9	, the more TP3	, the more EI2	, the more IC6	, the more G3	, the more EF9	, the more UW1		
R32	the more UW1	, the more IC3	, the more TP9	, the more TP3	, the more EI2	, the more G3	, the more EF4	, the more EF3	, the more UW1		
R33	the more UW1	, the more IC4	, the more IC1	, the more TP3	, the more EI2	, the more G3	, the more EF4	, the more EF3	, the more UW1		
R34	the more UW1	, the more IC3	, the more TP9	, the more TP3	, the more EI2	, the more EF2	, the more EF5	, the more EF3	, the more UW1		
R35	the more UW1	, the more IC4	, the more IC1	, the more TP3	, the more EI2	, the more IC6	, the more G3	, the more EF9	, the more UW1		
R36	the more UW1	, the more IC3	, the more TP9	, the more TP3	, the more EI2	, the more IC6	, the more G3	, the more IC5	, the more UW1		
R37	the more UW1	, the more IC4	, the more IC1	, the more TP3	, the more EI2	, the more IC6	, the more G3	, the more IC5	, the more UW1		
B11	the more UW1	, the more IC6	, the more G3	, the more IC5	, the more OI1	, the more OI2	, the more EI2	, the less EI1	, the less IC2	, the less UW1	
R38	the more UW1	, the more IC3	, the more TP9	, the more TP3	, the more EI2	, the more IC6	, the more G3	, the more EF4	, the more EF3	, the more UW1	
B12	the more UW1	, the more IC3	, the more TP9	, the more TP3	, the more EI2	, the more IC6	, the more OI4	, the less OI3	, the less IC2	, the less UW1	
R39	the more UW1	, the more IC6	, the more IC5	, the more OI1	, the more OI2	, the more EI2	, the more EF2	, the more EF5	, the more EF3	, the more UW1	
B13	the more UW1	, the more IC4	, the more IC1	, the more TP3	, the more EI2	, the more IC6	, the more OI4	, the less OI3	, the less IC2	, the less UW1	
R40	the more UW1	, the more IC4	, the more IC1	, the more TP3	, the more EI2	, the more IC6	, the more G3	, the more EF4	, the more EF3	, the more UW1	
R41	the more UW1	, the more IC6	, the more IC5	, the more OI1	, the more OI2	, the more EI2	, the more G3	, the more EF4	, the more EF3	, the more UW1	
R42	the more UW1	, the more IC6	, the more G3	, the more IC5	, the more OI1	, the more OI2	, the more EI2	, the more EF2	, the more EF5	, the more EF3	, the more UW1
R43	the more IC5	, the more OI1	, the more OI2	, the more EI2	, the more IC6	, the more IC5					
R44	the more IC5	, the more OI1	, the more OI2	, the more EI2	, the more IC6	, the more G3	the more IC5				
R45	the more IC5	, the more OI1	, the more OI2	, the more EI2	, the more G3	, the more IC5					

Note:

EF1	Complexity of funding mechanism	OI1	Educational program
EF2	Cost saving	OI2	Energy efficient behavior
EF3	Funding	OI3	Expectation
EF4	External funding source	OI4	Satisfaction
EF5	Internal funding source	TP1	Completion time
EF6	Length of funding cycle	TP2	Functionality/ reliability
EF7	Life cycle	TP3	Monitoring
EF8	Payback/ ROI	TP4	Project integration
EF9	Rebate (incentive)	TP5	Regulation & bureaucracy
EI1	CO2 emissions	TP6	Site accessibility
EI2	Energy conservation	TP7	Speed and ease of implementation
EI3	Sustainable resources	TP8	System compatibility
EI4	Waste management	TP9	Use of technology
IC1	Coordination/ collaboration	G1	Government commitment
IC2	Demand pressure	G2	Government EE requirement
IC3	External expert skills	G3	Government support
IC4	Internal expert skills		
IC5	Organization commitment		
IC6	Reputation		

APPENDIX 8. THE DISTRIBUTION MAP OF STUDY POPULATION

The distribution of study population in Chapter 2.



The distribution of study population in Chapter 4.