CHIEF EXECUTIVE'S POLICY UNIT

PUBLIC POLICY RESEARCH FUNDING SCHEME

Energy Efficiency Retrofitting of Existing Buildings for Carbon Neutrality in Hong Kong: Policy Recommendations and Guidelines for Overcoming the Challenges

節能改造香港現有樓宇達致淨零碳排放:透過政策建議及指引克服困難

FINAL REPORT

Table of Contents

List of Tables

List of Figures

Research Team

Principal Investigator

Dr. Amos Darko (24 Jan 2023 - 19 Dec 2023)

Assistant Professor, Department of Construction Management, University of Washington

Prof. Albert P.C. Chan (19 Dec 2023- 23 Apr 2024)

Chair Professor, Department of Building and Real Estate, The Hong Kong Polytechnic University

Co-investigators

Dr. Yang YANG,

Senior Lecturer, School of the Built Environment, Oxford Brookes University

Dr. Mershack Tetteh

Lecturer, Department of Civil Engineering, College of Engineering and Physical Sciences, Aston University

Dr. Cary CHAN

Executive Director, Hong Kong Green Building Council.

Members

Dr. Linyan Chen

Postdoctoral fellow, Department of Building and Real Estate, The Hong Kong Polytechnic University

Dr. Mayowa Adegoriola

Lecturer, Department of Property, University of Auckland

Mr. Caleb Debrah

PhD candidate, Department of Building and Real Estate, The Hong Kong Polytechnic University

Executive Summary (in English)

Part A - Abstract of the Research

In response to combating climate change, the Chief Executive announced in the 2020 Policy Address that Hong Kong will strive to achieve carbon neutrality before 2050. To achieve this carbon neutrality goal, it is important to retrofit existing buildings for energy efficiency, since they account for over 90% of electricity consumption and 60% of carbon emissions in Hong Kong. Most Hong Kong buildings were built over 30 years ago and embody the lower energy efficiency standards of the times in which they were built. Without a successful urgent, large-scale retrofitting and transformation of these "substandard" buildings, it would be difficult to achieve the goal of carbon neutrality before 2050. However, large-scale retrofitting of the Hong Kong existing office buildings for energy efficiency is never an easy task. To be successful, the government and other stakeholders need to fully understand and overcome the challenges involved.

Mixed research methods were adopted, including systematic literature review, multiple case studies with a combination of semi-structured interviews, Z-numbers-based Delphi survey and focus group meetings. The policies of building energy retrofitting in Hong Kong and other countries were reviewed and compared. Meanwhile, the research team comprehensively investigated the key technical, financial, institutional, social, environmental, regulatory and other challenges facing existing office building energy efficiency retrofitting (EOBEER) in Hong Kong and assessed the criticality of these EOBEER challenges. In the end, an Innovative Energy Efficiency Retrofitting Guide and policy recommendations were proposed to overcome these challenges to support wider EOBEER in Hong Kong.

Part B – Layman summary on policy implications and recommendations

EOBEER demands a committed effort from the government, policymakers and relevant stakeholders to adopt and implement comprehensive standards, policies and strategies aimed at promoting energy efficiency in building retrofits. This collaborative approach is essential for the successful execution of these initiatives. To develop well-informed policy recommendations and strategies for EOBEER, this study utilized a mixed-methods research approach. The integration of these diverse research methods ensured a robust foundation for our findings and recommendations. Based on this comprehensive analysis, we propose three key policy recommendations for EOBEER in Hong Kong:

(1) To review and update energy auditing requirements, policies, and standards.

- **Shorten audit cycles**: It is recommended that the government reduces the ten-year energy audit cycle provided in the Building Energy Efficiency Ordinance (BEEO) to five years in the short term, aligning with upcoming government plans. Ultimately, this cycle should be shortened to three years in the long-term.
- **Enhance transparency and data disclosures:** To improve transparency in energy efficiency, it is advisable for the government to encourage facility management (FM) companies and building owners to anonymously disclose energy audits and performance data. Current efforts by Electrical and Machanical Services Department (EMSD) to list buildings with issued energy audit forms are insufficient in detail and lack categorisation of energy performance. The government should lead by example by disclosing detailed energy audits of the buildings it operates in, fostering trust and encouraging private sector participation. Additionally, the existing platform should be further developed to become more secure and user-friendly.
- **Mandatory retrofits for underperforming office buildings:** If energy audits reveal that office buildings in Hong Kong perform below the energy code, mandatory retrofitting and retro-commissioning should be required to enhance energy efficiency. This is crucial as the current ten-year requirement for building energy audits lack enforcement of stringent actions, resulting in overlooked energy savings recommendations from registered energy assessors (REAs). Implementing mandatory guidelines or practices into law will ensure adherence to EOBEER standards and policies.
- **Establish performance benchmarks:** The government must establish a benchmark to classify all existing office buildings into three categories: low, average, and high performing. This benchmark will serve as a standard process for estimating building energy performance and guide improvement efforts.
- **Proposal submission compliance post-audits:** It is recommended that FM

companies and building owners submit an improvement proposal post-audit, outlining necessary retrofit strategies and a phasing programme for implementation. The government should consider imposing penalties for non-adherence and providing rewards/incentives for achieving superior building energy performance through retrofits. A standardised assessment platform could be developed to facilitate the submission of these proposals post audits.

(2) To provide regular education and training.

- **Comprehensive awareness programmes:** The research team recommends that the government initiates programmes that raise awareness of energy-efficient practices from policymakers (mainstream) to FM companies, building owners and occupiers (downstream). These programmes are essential for fostering a comprehensive understanding and adoption of efficient energy measures.

- **Targeted training for stakeholder groups:** It is crucial to tailor government training programmes to building stakeholder groups such as FM companies, building owners (single/multi building owners), and building occupants. These programmes should highlight the specific benefits and responsibilities of each group, emphasising the importance of building retrofits. Training for FM companies and building owners, for instance, should aim at closing the knowledge gap on energy efficiency retrofitting, highlighting the financial advantages and available methods for energy savings. These sessions should include practical training on developing retrofit proposals, as discussed earlier, and applying for green incentives and green financing. In addition, the government should collaborate with relevant organisations, such as the Hong Kong Green Building Council (HKGBC), International Facility Management Association(IFMA) Hong Kong, Hong Kong Institute of Facility Management (HKIFM), Building Services Operation and Maintenance Executives Society (BSOMES), Hong Kong Association of Energy Engineers (HKAEE), the Chartered Institute of Building (CIOB) Hong Kong and the universities, to develop suitable training programmes.

- **Public education campaigns:** To complement the professional training, public education campaigns should be launched to keep building occupants informed of simple yet effective energy-saving methods such as installing automatic control systems, conscientious use of lighting, maintaining energy-efficient temperature and lighting levels to promote indoor environmental quality. This is intended to help to cultivate a culture of energy conservation and reduction to normalise energy-saving behaviours among building users and to reduce public complaints and resistance to energy regulations and standards.

(3) To provide incentives to enhance building energy retrofit adoption and implementation.

- **Financial support:** Offering financial incentives is essential to promote the adoption of building energy retrofits, particularly for small building owners who might otherwise be unable to afford such upgrades. Options could include tax rebates for building owners who may undertake energy improvements and low-interest or interest-free loans for carrying out energy improvement works. These financial measures would lower the barrier to FM companies and small buildings owners to invest in EOBEER.
- **Non-financial incentives:** In addition to financial incentives, non-financial incentives can also play a crucial role in encouraging the uptake of EOBEER. Providing free energy audit services for building owners allows them to understand the potential energy savings and areas of improvement without initial cost. Furthermore, awarding certificates to those who achieve significant energy efficiency levels based on the audit reports can serve as recognition of their efforts and commitment to sustainability, as well as serving as basis to apply for financial incentives for future retrofits and upgrades.
- **Public-private sector collaboration:** It is vital for the government to partner with the private sector to provide comprehensive support for retrofitting projects. This includes not only subsidies but also technical support to ensure the effectiveness of the upgrades. While existing schemes such as the Eco Building Fund and Smart Power Building Fund have shown success in encouraging large scale energy-saving upgrades, expanding their scope and increasing funding would significantly enhance their impact and reach.

Executive Summary (in Chinese)

第一部分 – 研究摘要

為應對氣候變化，行政長官在 2020 年施政報告中宣佈，香港將致力在 2050 年之前實現碳中和。因既有建築物消耗了香港超過 90%的電力並產生了約 60%的碳排放，在既有建築物內進行能效改造對實現碳中和尤為重要。大多數香港建築物建於三十多年前，當時的能源效率標準較低。如果不緊急對這些“低標准”建築進行大規模改造，2050 年之前難以實現碳中和目標。然而，對香港既有建築物進行大規模節能改造絕非易事。為取得成功，政府和其他利益相關者需要充分理解並克服所涉及的挑戰。

本研究採用混合研究方法，包括系統性文獻綜述、結合半結構化訪談的案例研究、基於 Z 數字的德爾菲調查法和焦點小組會議。本研究對香港及其他國家的建築節能改造政策進行了梳理和比較。同時，研究團隊全面調查了香港現有辦公建築節能改造時面臨的關鍵技術、財務、制度、社會、環境、監管等挑戰，並評估了這些挑戰的重要性。最終，本研究提出了創新的能源效率改造指南和政策建議來克服這些挑戰，以支持香港更廣泛的辦公建築節能改造。

第二部分 - 政策概述和相關政策建議

既有辦公建築節能改造需要政府和利益相關方共同努力，制定並實施旨在提高建築能源效率的標準、政策和策略。本研究採用混合研究方法，為提出政策建議奠定了堅實的研究基礎。基於綜合分析，本研究為香港的既有辦公建築節能改造提出以下三項關鍵政策建議：

(1)審查和更新能源審核要求、政策和標準。

• 縮短能源審核週期：建議政府將《建築物能源效益條例（BEEO）》中規定的十年能源審核週期短期先縮短至五年，以配合即將出台的政府計劃。從長遠來看，建議能源審核週期逐步縮短到三年。

• 提高透明度和數據披露：為了提高能源效率的透明度，政府建議設施管理公司和建築業主匿名披露能源審核和效益數據。目前，機電工程署披露的能源審核數據不夠詳

細，並缺乏能源效益分類。政府可以身作則，披露政府營運建築物的詳細能源審核結果，建立信任並鼓勵私營部門參與。另外，建議進一步改進現有平台，增加安全性和用戶友好程度。

●對表現不佳的辦公大樓進行強制改造：如果能源審核顯示辦公大樓的性能低於能源規範，應強制要求其進行改造和重新調試，以提高能源效率。這一點至關重要，因為目前十年一次的建築能源審核要求的執行力度不夠嚴格，導致註冊能源效益評核人提供的節能建議被忽視。將強制性準則或實踐要求納入法律將確保建築遵守既有辦公建築節能改造的標準和政策。

●建立能源效益基準：建議政府建立能源現效益基準，可將辦公大樓分為三類：低績效、一般績效和高績效。該基準將用於評估建築能源性能，可指導能源改造工作。

●審核後提交合規建議書：建議設施管理公司和建築業主在審核後提交一份改進建議書，概述必要的改造策略和分階段實施計劃。政府可考慮對不遵守規定的行為進行處罰，並為通過改造實現卓越能源效率的建築提供獎勵或激勵。建議政府提供標準化評估平台，便於業主在審核後提交改造提案。

(2)提供定期的教育和培訓。

●全面提高公眾意識計劃：建議政府啟動計劃，提高從政策制定者（主流）到設施管理公司、建築業主和居住者（下游）的節能實踐意識。這些計劃對於全面了解和採用高效能源措施至關重要。

●對利益相關方進行針對性培訓：對建築利益相關群體（如設施管理公司、單/多建築業主和用戶）開展政府培訓計劃至關重要。這些計劃應突顯每個群體的具體利益和責任，強調建築改造的重要性。例如，對設施管理公司和建築業主的培訓旨在縮小能源效率改造方面的知識差距，強調財務優勢並介紹可用的節能方法。這些課程應提供實際培訓，包括制定上述的改造提案、申請綠色激勵措施和綠色融資。此外，建議政府與相關組織合作，共同製定合適的培訓計劃，如香港綠色建築議會、香港國際設施管理協會、香港設施管理學會、屋宇裝備運行及維修行政人員學會、香港能源工程師學會、英國特許建造學會和大學等。

●公眾教育活動：作為專業培訓的補充，建議同時進行公眾教育活動，向用戶介紹

簡單且有效的節能方法,達到節能目的，例如安裝自動控制系統、隨手關燈、隨手調節空調溫度等提高室內環境質量。此舉旨在幫助用戶養成節能減排習慣，規範用戶行為，減少民眾對能源法規和標準的投訴和抵制。

(3)提供獎勵措施，推動建築能源改造的實施。

●財政支持：提供財政獎勵對於促進建築能源改造的實施至關重要，特別是對於難以負擔能源改造費用的小型建築業主。財政支持還可以包括為進行能源改進的建築業主提供退稅、低利率或無利息貸款。這些金融措施將減少設施管理公司和小型建築業主進行能源改造的障礙。

●非財政獎勵：除財政獎勵外，非經濟獎勵也可以鼓勵實施建築能源改造。建議為業主提供免費的能源審核服務，使他們無需初始成本即可了解建築的節能改造潛力。此外，建議根據審核報告，向那些達到顯著能源效率水平的建築業主頒發證書，認可他們的努力和可持續發展承諾，並作為未來申請能源改造財政獎勵的基礎。

●公私部門合作：政府與私營部門合作可為建築能源改造計劃提供全面支持。不僅包括補貼，還包括技術支持，確保能源改造的有效性。雖然綠適樓宇基金和智惜用電樓宇基金等現有計劃在鼓勵大規模節能改造方面取得了成功，但擴大其資助範圍和增加資助金額將顯著增強其影響力。

Chapter 1 Introduction

1.1 Background

To control the global warming trend, many countries have committed to the Paris Agreement, attempting to "limit the temperature increase to 1.5°C above pre-industrial levels (United Nations Climate Change, 2015)". Carbon neutrality means achieving net-zero carbon dioxide (CO_2) emissions in a place or by an organization, etc. over a specific period of time (Environment Bureau, 2021), which has become a crucial component of the Paris Agreement. Achieving carbon neutrality by 2050 is a common target for many countries and regions across the world. Buildings are responsible for more than 30% of global energy consumption and contribute to approximately 21% of greenhouse gas emissions worldwide (United Nations Environment Programme, 2023). After the pandemic, carbon emissions from building operations have reached an all-time high (United Nations Environment Programme, 2022).

In Hong Kong, to signify the city's commitment to the global efforts to combat climate change, the Chief Executive announced in the 2020 Policy Address that the city will strive to achieve carbon neutrality before 2050. To this end, the Government, in 2021, announced Hong Kong's Climate Action Plan 2050 (Environment Bureau, 2021), which sets out the strategies and measures to reduce carbon emissions. The plan puts forward four major decarbonization strategies, namely "net-zero electricity generation", "energy saving and green buildings", "green transport", and "waste reduction".

Buildings in Hong Kong consume about 90% of the total electricity and generate 60% of carbon emissions (Environment Bureau, 2021). The substantial energy demand not only constrains the economic development in the buildings and construction sector but also brings adverse effects on the environment. The long-term target under the energy saving and green buildings strategy in Hong Kong's Climate Action Plan 2050 is to reduce the electricity consumption of commercial buildings by 30% to 40%, and that of residential buildings by 20% to 30% by 2050.

To accomplish the above targets, the Government aims to improve the energy efficiency of buildings to reduce the energy demand, a more cost-effective way to decarbonization. As 80% of all existing buildings will be in service in 2050 (World

Economic Forum, 2022), it is not enough to make new buildings energy-efficient due to the high stock of existing buildings. Moreover, Hong Kong has over 16,000 high-rise buildings. Among them, office buildings account for a large proportion, with a significant number of skyscraper office buildings. These office buildings have energy-intensive equipment, such as heating, ventilation, air conditioning (HVAC) systems, lighting systems and elevators. A previous study demonstrated that energy use in office buildings was 10-20 times that in the residential sector (Yang et al., 2008). Achieving carbon neutrality has brought attention to energy retrofitting in existing office buildings.

Retrofitting often means making modifications or adjustments to existing buildings to improve energy efficiency or reduce energy demand (US Department of Energy, 2022). It offers a huge opportunity to improve the energy performance of buildings for their ongoing, whole life. Moreover, energy efficiency retrofitting can reduce the operating costs, particularly in older buildings, as well as aid to increase property value, attract tenants, and gain a market edge (US Department of Energy, 2022).

However, there are still a significant number of technical, financial, institutional, social, environmental, and regulatory challenges faced by building owners, tenants, facility managers, and energy managers retrofitting their existing buildings for energy efficiency (Alabid et al., 2022; Liu, Li, et al., 2020; Shaikh et al., 2017). To support a wider uptake of energy efficiency retrofitting of existing buildings to achieve the goal of carbon neutrality in Hong Kong, it is important to “fully” understand and overcome the inherent challenges.

1.2 Problem Statement

Hong Kong has over 42,000 existing buildings that take up a very large proportion of the current building stock (HKGBC, 2022). Most of them were built over 30 years ago and embody the lower energy efficiency standards of the times in which they were built, thus are currently energy inefficient or have poor energy performance. To achieve carbon neutrality before 2050, these buildings need to be retrofitted for energy efficiency on a large scale sooner than later. Moreover, most of them are tall buildings in which the daily activities of Hong Kong residents take place. The resulting use of lighting, air-conditioners, lifts, and various electric appliances consumes a large amount of energy. As a result, at present, buildings account for over 90% of electricity consumption and 60%

of carbon emissions in Hong Kong. Reducing the total electricity consumption and carbon emissions in buildings through energy efficiency and conservation is consequently critical to achieving net-zero carbon emissions in Hong Kong.

But "currently, the energy efficiency of buildings is not optimized to their full extent, and the government policy has been ineffective" (HK2050IsNow, 2020). In addition, the Government focuses more on the supply side, or the fuel mix, to reduce carbon emissions from the buildings sector, yet the demand side makes a significant contribution. To lower the cost of decarbonization and reduce the financial burden on the public, it is important to focus more on the demand side for reducing the energy demand, improving energy efficiency, and reducing carbon emissions. This can be achieved through retrofitting the existing building stock. In Hong Kong's Climate Action Plan 2050, the "top priority is to make careful planning so that Hong Kong can use zero-carbon energy for electricity generation extensively and achieve carbon neutrality before 2050." It should be noted that the cost and financial burden on the public of using zero-carbon energy for electricity generation will be extraordinarily high if the current high demand for energy is not greatly reduced first.

Despite the importance of energy efficiency retrofitting in reducing the energy demand and optimizing to create greater energy efficiency, the rate of energy efficiency retrofitting of existing buildings is still very low (Liu, Li, et al., 2020; World Economic Forum, 2022). There are a significant number of challenges that hinder the wider uptake of energy efficiency retrofitting of existing buildings. Until these challenges are better understood and overcome, retrofitting is likely to continue to be confined largely to a small cohort of existing buildings, making it difficult if not impossible to achieve carbon neutrality before 2050 and at a relatively low cost. Therefore, many studies have analyzed the challenges faced by building retrofitting (Bjørneboe et al., 2018; Davies & Osmani, 2011). Despite those efforts, the following research questions remain to be sufficiently explored:

(1) What are the key technical, financial, institutional, social, environmental, and regulatory challenges for existing office building energy efficiency retrofitting (EOBEER) in Hong Kong?

(2) What kind of policy packages and guidelines can be implemented to overcome these challenges to support wider EOBEER in Hong Kong?

1.3 Research Objectives

Four research objectives were proposed in this research and are shown as follows:

(1) To evaluate the technical, financial, institutional, social, environmental, and regulatory challenges facing existing office building energy efficiency retrofitting (EOBEER) in Hong Kong;

(2) To develop an innovative EOBEER guide for Hong Kong that addresses the challenges;

(3) To provide policy recommendations for EOBEER in Hong Kong;

(4) To disseminate the research findings and recommendations to the public.

Chapter 2 Literature Review

2.1 Review of Building Energy Retrofitting Challenges

Achieving carbon neutrality by 2050 is a global agenda. Many studies have thus examined the challenges for building retrofitting in countries around the world. In mainland China, a key challenge has to do with the impossibility to apply the same retrofitting technologies, codes and standards to all buildings due to differences in building types, heterogeneity and geographical locations (Liu, Li, et al., 2020). Large-scale retrofitting needs major financial support. For existing residential buildings in the northern heating region, the key financial challenges facing the implementation of a large-scale retrofitting program are examined. The lack of successful financing arrangements, insufficient government funding to support large-scale retrofit, and the lack of guarantee that payback will be received from retrofits have been key financial challenges (Lu et al., 2014).

Focusing on the financial challenges alone is insufficient for promoting widespread retrofit. There are several other challenges that also need to be better understood and holistically overcome. In the UK, the recent challenges for retrofit of existing homes include economic, environmental, social, and technical challenges (Alabid et al., 2022). A social challenge is that "certain retrofits increase the risk of health problems" (Ortiz et al., 2020). The study of Davies and Osmani (2011) investigated the financial and business, environmental and cultural, technical and design, and legislative challenges for low carbon housing retrofitting in the UK. The study offers valuable insights, but these are architects-only "perceived" challenges, which might not sufficiently reflect the "real" challenges on the ground for a comprehensive set of key stakeholders. In Denmark, there exist information, financial, and process challenges that make the progress of energy retrofitting of single-family houses very slow (Bjørneboe et al., 2018). A lack of political will, capability, financing, misaligned incentives, and quality assurance challenge public building retrofit in Australia (Alam et al., 2019), though these findings are perceived and from only two focus groups. Similarly, interviews were used to identify organizational, informational, financial, and regulatory challenges facing building retrofit in 10 European Union member states (Tuominen et al., 2012). In fact, jurisdictions and their building retrofitting challenges differ, making "local context" matter (Bertone et al., 2018; Liu, Li, et al., 2020). The policies and challenges in one context may not be directly applicable to another owing to distinctive local conditions, such as climatic conditions and building features, making knowledge of the challenges in a particular context conducive to the dedicated policies in that context (Liu, Li, et al., 2020). This explains why there have been a number of local context-specific studies and why such studies are necessary.

This research adopted a systematic review methodology to thoroughly examine the existing literature on the challenges of building energy retrofitting. A systematic review is an approach that seeks to comprehensively review and synthesize existing studies on a specific topic (Aromataris & Pearson, 2014). It follows structured and transparent methodologies to minimize bias and ensure a reproducible process. By conducting a systematic review, the reliability, transparency, and rigor of the literature review results are enhanced (O'Grady et al., 2021).

A comprehensive desktop search and review were conducted to identify and analyze the EOBEER challenges from the literature. The search strategies are shown in **Table 2.1**. For data retrieval, the bibliometric data source, Scopus, was utilized in this research. Compared with other databases, Scopus covers more academic literature, including a wide range of journals, conference papers, and other publications from various disciplines (Vieira & Gomes, 2009).

To ensure a comprehensive search, keyword-searching strings were employed, combining them with Boolean operators. It is important to note that the language of the literature included in this study was limited to English. The literature selection was conducted on 15 November 2022. To avoid omitting studies in the desktop search, the search in this research was not limited by publication type or year. In the end, 1506 publications were collected from the literature database.

The subsequent step involved the selection of suitable studies from the literature database. The literature selection process adhered to two specific inclusion criteria: (1) the selected studies had to be empirical, focusing on building energy retrofitting challenges, barriers, obstacles, or constraints; (2) the full text of the study was required to be available.

Table 2.1 Searching strategies for systematic literature review.

Strategy	Description
Database	Scopus
Search date	15 November 2022
Keywords	["building" OR "buildings" OR "existing building" OR "existing buildings"] **AND** ["retrofit" OR "building retrofit" OR "sustainable retrofit" OR "green retrofit" OR "sustainable building retrofit" OR "green building retrofit" OR "sustainable retrofitting" OR "green retrofitting" OR "renovation" OR "refurbishment" OR "recommissioning" OR "sustainable building upgrade" OR "green building upgrade"] **AND** ["energy" OR "energy efficiency" OR "energy retrofit" OR "energy retrofitting"] **AND** ["challenges" OR "barriers" OR "obstacles" OR "constraints"]
Limit to	Language: English
Total number of publications: 1506	

To ensure the selection of appropriate studies, a rigorous three-round literature selection process was conducted. In the first round of literature selection, a thorough review of the title and abstract of each study was conducted. While conducting the literature search on Scopus yielded a substantial number of studies, it is noted that not all of them were directly focused on the building energy retrofitting issues or qualified as empirical research. Those studies were systematically removed from the literature database. To minimize the possibility of overlooking any relevant studies, a second step was undertaken to conduct a quick review of the abstracts of the studies that were not initially included in the first round of selection. Following the two rounds of literature selection, the initial pool of studies was successfully narrowed down, from 1506 studies to 170 studies. In the third step, the full text of the selected study was thoroughly reviewed to verify that the selected literature indeed focused on building energy retrofitting challenges. In the end, 44 relevant studies were selected for review.

Although systematic reviews adopt a retrospective, observational research design, they may be subject to systematic error and publication bias. To eliminate the error and bias, the literature selection and challenge identification process was conducted by a team. The final results have been thoroughly discussed among the team.

The topic of energy efficiency retrofitting has gained significant popularity and importance, driven by the urgent global task of achieving carbon neutrality by 2050. After searching and selecting the literature in the building energy efficiency retrofitting area, 44 studies that concentrated on building energy retrofitting challenges were reviewed and investigated, including 37 academic journal articles and 7 conference papers. The basic information of these studies is shown in **Table 2.2**.

Table 2.2 Information of relevant studies.

Code	Building type	Methodology	Country	Publication type	Ref
1	Residential buildings	Questionnaire	Norway	Journal	(Jowkar et al., 2022)
2	Residential buildings	Not applicable	China	Journal	(Lv & Wu, 2009)
3	Residential buildings	Survey	Germany	Journal	(Achtnicht & Madlener, 2014)
4	Residential buildings	Survey	Not applicable	Journal	(Palmer et al., 2013)
5	Residential buildings	Interviews	UK	Journal	(Butt et al., 2021)
6	Residential buildings	Interviews	South Africa	Journal	(Amoah & Smith, 2022)
7	Residential buildings	Interviews	UK and Italy	Journal	(Rispoli & Organ, 2019)
8	Residential buildings	Not applicable	Germany	Journal	(Weiss et al., 2012)

Code	Building type	Methodology	Country	Publication type	Ref
9	Residential buildings	Questionnaire	China	Journal	(J. Ma et al., 2022)
10	Residential buildings	Workshop and interviews	Sweden	Journal	(Myhren et al., 2020)
11	Residential buildings	Interviews	Ten European Union member states	Journal	(Tuominen et al., 2012)
12	Residential buildings	Workshop, questionnaire, interview	Netherlan ds	Journal	(Tambach et al., 2010)
13	Residential buildings	Case study	Russia	Journal	(Paiho et al., 2013)
14	Residential buildings	Observation, interviews and case study	Sweden	Journal	(Palm & Reindl, 2018)
15	Residential buildings	Questionnaire s and interviews	Russia	Journal	(Paiho & Ahvenniemi, 2017)
16	Residential buildings	Modelling	European Union	Journal	(Fotiou et al., 2022)
17	Residential buildings	Interviews and case study	Denmark	Journal	(Ástmarsson et al., 2013)
18	Residential buildings	Observation, interviews, case study	Belgium	Journal	(Mlecnik, 2010)

Code	Building type	Methodology	Country	Publication type	Ref
19	Residential buildings	Survey, modelling	Norway	Journal	(Klöckner & Nayum, 2017)
20	Residential buildings	Interviews	Sweden	Journal	(Olsson et al., 2015)
21	Residential buildings	Case study, survey	Lithuania	Journal	(Streimikiene & Balezentis, 2020)
22	Residential buildings	Questionnaires	Norway	Journal	(Klöckner & Nayum, 2016)
23	Residential buildings	Observations, interviews	Belgium	Conference	(Mlecnik et al., 2011)
24	Residential buildings	Interviews	Ireland	Conference	(McDonnell & Sinnott, 2010)
25	Residential buildings	Interviews	Norway and Sweden	Conference	(Lindkvist et al., 2014)
26	Public buildings	Scenario modelling, workshops, interviews	Australia	Journal	(Bertone et al., 2018)
27	Public buildings	Survey	US	Journal	(Castleberry et al., 2016)
28	Public buildings	Focus groups, thematic analysis	Not applicable	Journal	(Alam et al., 2019)
29	Private buildings	Not applicable	Not applicable	Journal	(Martin & Gossett, 2013)

Code	Building type	Methodology	Country	Publication type	Ref
30	Office building	Semi-structured interviews	Australia	Journal	(Bruce et al., 2015)
31	Hotels	Case study, interviews	Sri Lanka	Journal	(Fasna & Gunatilake, 2020)
32	Historic buildings	Case study and interviews	New Zealand	Journal	(Paschoalin & Isaacs, 2021)
33	Historic buildings	Not applicable	New Zealand	Journal	(Besen et al., 2020)
34	Historic buildings	Questionnaires and interviews	New Zealand	Conference	(Besen & Boarin, 2020)
35	General buildings	Questionnaire, exploratory factor analysis	UK	Journal	(Dauda & Ajayi, 2022)
36	General buildings	Questionnaire, interviews	Italy	Journal	(Caputo & Pasetti, 2015)
37	General buildings	Interviews, workshop	Norway	Journal	(Xue et al., 2022)
38	General buildings	Questionnaire	Iraq	Journal	(Alfaiz et al., 2021)
39	General buildings	Not applicable	European Union	Journal	(D'Oca et al., 2018)
40	General buildings	Case study	Six European countries	Journal	(Rose et al., 2021)

Code	Building type	Methodology	Country	Publication type	Ref
41	General buildings	Questionnaire s	United States	Conference	(Medal & Kim, 2020)
42	General buildings	Questionnaire s	South Africa	Conference	(Oguntona et al., 2019)
43	Commercia l buildings	Case study	US	Journal	(Barnes & Parrish, 2016)
44	Commercia l buildings	Interviews	US	Conference	(Safari et al., 2020)

The research methods of selected studies were collected and analyzed to provide references for future research. Most studies applied the semi-structured interview, questionnaire survey and case study, while some studies applied workshops and scenario modeling. The traditional methods are effective if the research focuses on EOBEER challenges, providing references for the following research. 60% of these studies focused on residential buildings, while some focused on public buildings, historic buildings, and commercial buildings. Only one study discussed the energy efficiency retrofitting challenges in the office building, implying that the office sector still needs to be addressed for future research.

Additionally, many studies made efforts to address the challenges of building energy retrofitting in a specific country or region. Shown in **Figure 2.1**, the geographic distribution of these studies includes South Africa, the United States, Asia (e.g., China, Sri Lanka), Europe (e.g., Germany, Belgium, Sweden), and Oceania (Australia, New Zealand). Half of these studies have been conducted in the European countries. It was related to the high existing building stock and the energy crisis in Europe. Europe has a rich history and makes great efforts to preserve architectural heritages. The building materials of traditional buildings, normally brick and stone, contribute to the longevity of buildings in Europe, which is another reason for the high existing building stock. Besides, considering the structure of European energy consumption, fossil fuels account for a high proportion and depend on imports. The high energy price promotes sustainable initiatives in existing buildings to enhance energy efficiency.

Figure 2.1 Geographic distribution of selected publications.

After reviewing these studies, the economic challenges were considered critical obstacles to energy retrofitting (Jowkar et al., 2022). When homeowners make decisions on energy retrofitting, they prioritize considerations such as capital cost, an unbalanced financial plan, unclear processes, comfort concerns, and rising energy prices (J. Ma et al., 2022). Homeowners in Germany are more likely to engage in retrofitting activities when possessing financial capabilities, profitability, and favorable opportunities (Achtnicht & Madlener, 2014). The low availability of opportunities is a crucial factor in explaining the low retrofit rate in Germany. Additionally, previous studies indicated that the energy retrofitting market needs substantial financial incentives, but these incentives were lacking (Barnes & Parrish, 2016). Meanwhile, existing lease terms, mortgage covenants, and capital budget limitations hindered the extensive development of energy efficiency projects in the private sector, but the managed energy services agreement option may overcome these obstacles and foster a sustainable market (Martin & Gossett, 2013).

The lack of government's willingness to encourage retrofit programs and offer related support emerges as a significant barrier (Alfaiz et al., 2021; Bertone et al., 2018; Butt et al., 2021). The model proposed in the study of Lv and Wu (2009) sheds light on the challenges influencing energy efficiency retrofit implementation in China's northern heating region. Similar challenges are observed globally, with barriers related to regulatory aspects, including weaknesses in local policies, inconsistent national directives, outdated guidance documents, capacity issues, and limited resources. Municipalities play a crucial role in improving energy performance, but a complex and unstable regulatory framework, a fragmented built environment, and the lack of a common model for energy planning bring significant challenges in Italy (Caputo & Pasetti, 2015).

Moreover, limited information sharing, consulting, resources, and knowledge hinder building energy retrofitting, suggesting the need for collaborative public–private-people partnerships (Xue et al., 2022). The collaboration issue holds significance both within and outside the energy retrofitting project. Conversations are essential between professionals, including owners, surveyors, architects, and contractors (Rispoli & Organ, 2019). Social engagement of citizens enhances renovation motivation, influencing the decision-making process (Jowkar et al., 2022). Therefore, understanding specific situations and building energy-saving potentials is crucial for evaluating and establishing policy instruments.

After reviewing 44 studies, potential challenges for energy efficiency retrofitting of existing buildings were identified from these studies. These challenges were selected based on the frequency of the challenges in publications. If the challenge appeared in two or more publications, it would be selected. However, some challenges are critical in the energy efficiency retrofitting practice, but few previous studies discussed them. For example, most of the studies discussed the financial challenges, regulatory challenges and institutional challenges, while only some studies noticed social challenges and environmental challenges, such as the risk of disputes and social implications, lack of awareness of some human activities on the environment. These challenges were selected in the framework. Therefore, 49 building energy retrofitting challenges were identified, shown in **Table 2.3**. The frequency with which the challenges were mentioned in previous studies is provided in the table, as well as the rank based on the frequency.

Table 2.3 Challenges faced in energy efficiency retrofitting of existing buildings.

Challenge	Reference	Frequency	Rank
High investment cost in building energy retrofitting	[1,2,3,4,5,7,9,12,14,15,17,20,22,25,26,27,28,30,31,32,33,34,35]	23	1
Lack of access to financing for building energy retrofitting	[1,2,5,7,8,10,11,12,13,14,17,21,23,26,27,28,29,33,34,36,37,38]	22	2
Stakeholders' insufficient awareness and knowledge of building energy retrofitting	[2,5,6,7,10,17,21,23,26,28,29,30,31,33,36,38,40,41,43]	19	3
Building owners lack motivation to retrofit	[2,5,6,7,8,15,16,17,21,23,35,36,37,44]	14	4
Lack of government incentives	[1,4,5,6,7,13,14,15,17,25,26,40,41,44]	14	4
Lack of policies, legislation and regulations	[2,5,6,9,13,14,17,18,27,29,32,33,43,44]	14	4
Lack of skilled building professionals	[2,4,7,8,16,17,19,21,23,32,34,38,39]	13	7
Lack of knowledge about building energy retrofitting technologies	[1,3,4,9,10,11,12,13,14,15,16]	11	8
Long payback period of building energy retrofitting	[5,8,14,15,22,25,26,27,28,29]	10	9
Lack of communication and information sharing between stakeholders	[2,5,7,13,14,15,32,33,36,40]	10	9
Interruption to building operation	[4,8,16,22,23,27,30,34,40,43]	10	9
Insufficient return on investment	[1,5,7,13,15,17,25,27,36]	9	12
Uncertainties over financial gain	[5,8,21,23,27,29,32,38,39]	9	12
Lack of actual data on existing building energy performance	[5,13,14,15,18,19,20,21]	8	14

Challenge	Reference	Frequency	Rank
Split incentives	[5,7,8,15,21,22,23,24]	8	14
Lack of trust among stakeholders during building energy retrofitting implementation	[17,25,26,27,36,43]	6	16
Frequent changes in government policies and regulations	[5,7,13,22,26,34]	6	16
Deficiencies in the skills and training on building energy retrofitting	[2,3,4,5,12,13]	6	16
Lack of a straightforward guide with clear procedures	[3,18,19,21,25]	5	19
Lack of interdisciplinary expertise and collaboration	[6,13,23,41,42]	5	19
Building owners and occupants are unwilling to change	[2,4,7,13,15]	5	19
Lack of established benchmarks and criteria for building energy retrofitting	[2,5,6,16,18]	5	19
Lack of access to sustainable materials in building energy retrofitting	[1,2,3,4]	4	23
Immature building energy retrofitting technologies	[2,5,6,7]	4	23
Poor economy and market for building energy retrofitting	[4,5,27,28]	4	23
Low priority of energy efficiency	[13,15,21,44]	4	23
Lack of time	[10,15,25,42]	4	23
Lack of research and innovations implementation on building energy retrofitting technologies	[13,14,17]	3	29
Low interest to invest in building energy retrofitting	[5,33,36]	3	29
Unwillingness to increase current loans	[33,36,37]	3	29

Challenge	Reference	Frequency	Rank
Lack of leadership	[2,5,7]	3	29
Low public awareness and understanding on building energy retrofitting	[5,10,11]	3	29
Lack of citizen involvement and public support	[1,7,11]	3	29
Noise, dust, waste and carbon emissions	[6,10,30]	3	29
Lack of supervision and enforcement	[4,13,26]	3	29
Historic preservation of buildings	[26,32,35]	3	29
Lack of access to efficient building energy retrofitting technologies	[5,8]	2	38
Uncertainty about the payback period of building energy retrofitting	[5,10]	2	38
Insufficient cost and benefit-sharing mechanism among occupants	[13,34]	2	38
Lack of financial data on building energy retrofitting	[2,14]	2	38
Lack of commitment	[5,7]	2	38
Poor occupant support	[7,27]	2	38
Complexity of building energy retrofitting technologies	[5]	1	44
Lack of conviction for the host communities on the availability of adequate health and safety plan	[1]	1	44
Lack of social norms in relation to thermal and acoustic comfort, light, air quality	[5]	1	44

Challenge	Reference	Frequency	Rank
Negative perception	[21]	1	44
Risk of disputes and social implications	[40]	1	44
Lack of awareness of some human activities on the environment	[1]	1	44
Lack of integration between research, standards, and practice on building energy retrofitting	[1]	1	44
Lack of conviction for the host communities on the availability of adequate health and safety plan	[1]	1	44

Note: References are as follows:1= (Dauda & Ajayi, 2022); 2= (Alfaiz et al., 2021); 3= (Paschoalin & Isaacs, 2021); 4= (Oguntona et al., 2019); 5= (Fasna & Gunatilake, 2020); 6= (Lv & Wu, 2009); 7= (Tambach et al., 2010); 8= (Medal & Kim, 2020); 9= (Besen et al., 2020); 10= (Achtnicht & Madlener, 2014); 11= (Caputo & Pasetti, 2015); 12= (Castleberry et al., 2016); 13= (Tuominen et al., 2012); 14= (D'Oca et al., 2018); 15= (Palm & Reindl, 2018); 16= (Mlecnik et al., 2011); 17= (Butt et al., 2021); 18= (Paiho et al., 2013); 19= (Olsson et al., 2015); 20= (Palmer et al., 2013); 21= (Bertone et al., 2018); 22= (Bruce et al., 2015); 23= (Alam et al., 2019); 24= (Myhren et al., 2020); 25= (Ma et al., 2022); 26= (Paiho & Ahvenniemi, 2017); 27= (Rose et al., 2021); 28= (Fotiou et al., 2022); 29= (McDonnell & Sinnott, 2010); 30= (Jowkar et al., 2022); 31= (Amoah & Smith, 2022); 32= (Rispoli & Organ, 2019); 33= (Streimikiene & Balezentis, 2020); 34= (Safari et al., 2020); 35= (Besen & Boarin, 2020); 36= (Xue et al., 2022); 37= (Weiss et al., 2012); 38= (Klöckner & Nayum, 2017); 39= (Klöckner & Nayum, 2016); 40= (Lindkvist et al., 2014); 41= (Barnes & Parrish, 2016); 42= (Myhren et al., 2020); 43= (Mlecnik, 2010); 44= (Ástmarsson et al., 2013).

After identifying the building energy retrofitting challenges, they were classified into seven categories: technical challenges, financial challenges, institutional challenges, social challenges, environmental challenges, regulatory challenges, and other challenges, formulating a building energy retrofitting challenge framework, as **Figure 2.2** shows.

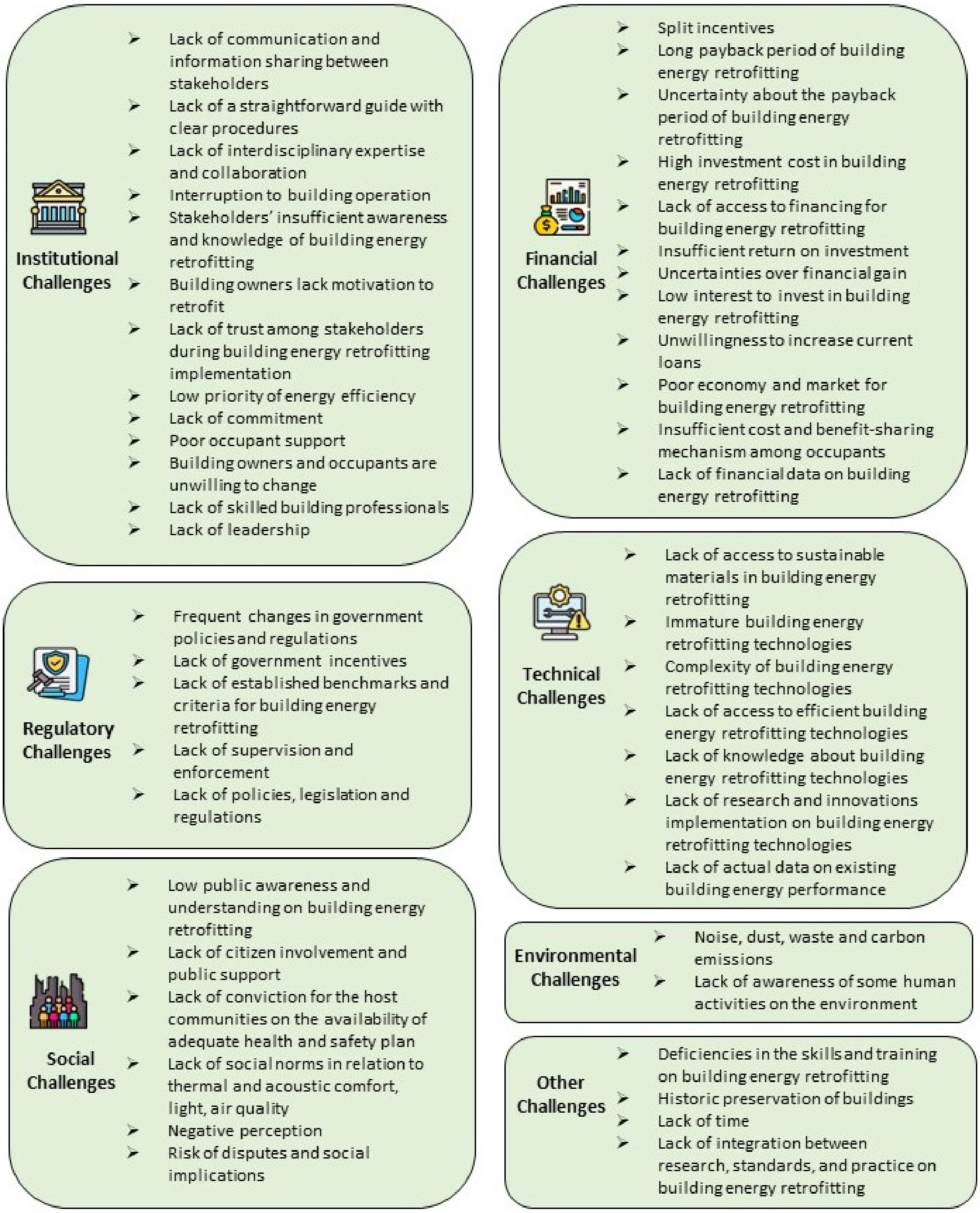


Figure 2.2 Energy retrofitting challenge framework.

From the literature review results, it is found that the top three challenges achieved consensus in previous studies are “high investment cost in building energy retrofitting (1st)”, “lack of access to financing for building energy retrofitting (2nd)” and “stakeholders’ insufficient awareness and knowledge of building energy retrofitting (3rd)”. The high cost of building energy retrofitting comes from many aspects. Building energy retrofitting initiatives include optimizing building envelopes, upgrading mechanical systems, modifying building structures, and so on. These initiatives bring high costs (Achtnicht & Madlener, 2014). Many retrofitting works need to be customized because of the unique characteristics of existing buildings. Moreover, energy retrofitting usually involves several changes in buildings, which means less work than new construction, resulting in limited economies of scale. To tackle this challenge, more government incentives, financial programs, and policy support can help mitigate the financial burden of energy retrofitting projects and encourage their implementation (Amoah & Smith, 2022). However, according to the challenge framework, “lack of government incentives (4th)” and “lack of policies, legislation and regulations (4th)” are the most critical challenges cited in previous studies, which both rank 4th in the list.

“Lack of access to financing for building energy retrofitting” ranks second on the list. Although, in theory, building energy retrofits could reduce building operating costs in the long term, retrofitting initiatives face a “long payback period of building energy retrofitting (9th)”, “insufficient return on investment (12th)” and “uncertainties over financial gain (12th)”, which make financial institutions more reluctant to provide financing (Alam et al., 2019). The technical issues of energy retrofits, such as “lack of knowledge about building energy retrofitting technologies (8th)” and “lack of actual data on existing building energy performance (14th)”, bring technical complexities and uncertainties and can be perceived as risks by financial institutions, resulting in more concerns about building energy retrofits (Alfaiz et al., 2021). Moreover, existing buildings may have complex ownership structures, e.g., residential buildings. Besides, the interest between tenants and homeowners may have conflicts, leading to “split incentives (14th)”. The involvement of various stakeholders makes it difficult to negotiate and allocate the financial burden and benefits of retrofitting, creating barriers to accessing finance (Fasna & Gunatilake, 2020).

Insufficient awareness and knowledge of energy retrofitting, which ranks third on the list, hinder the implementation of building energy retrofits. Building stakeholders may not be aware of the benefits of energy retrofitting and relevant financial support, and they have little knowledge about the new energy technologies and available incentives (Fasna & Gunatilake, 2020). For many building stakeholders, it seems that improving building energy efficiency is not an urgent task. They are "building owners lack motivation to retrofit (4th)". Some stakeholders are "building owners and occupants are unwilling to change (19th)" because of the complex process of energy retrofitting works. The discussion above reveals that the challenges have internal relationships. Improving the building energy retrofitting does not mean tackling a certain challenge. It needs critical thinking and systematic efforts to form a joint force.

2.2 Review of Policies and Guides for EOBEER in Developed Regions and Recommendations for Hong Kong

The effects of global warming and climate change are continually felt worldwide, with the built environment being a pivotal contributor to carbon emissions (Debrah et al., 2022b). Greenhouse gas (GHG) emissions and building energy consumption are responsible for approximately 40% of global emissions (Kats, 2013), hence the need to reduce the carbon footprint of buildings to combat climate change. The Paris Agreement (United Nations Climate Change, 2015) calls on the world to pursue efforts to limit global warming to 1.5°C above pre-industrial levels to mitigate the impending consequences of climate change. Hence, governments worldwide are implementing retrofitting policies to reduce the carbon footprint of buildings to achieve carbon neutrality. Achieving this target will require cutting GHG emissions by at least 40% below 1990 levels by 2030, reaching global net-zero GHG emissions by 2050 or soon after, and moving to net negative emissions thereafter (IPCC, 2021).

Consequently, various climate actions have been initiated by the government of different countries (Debrah et al., 2022a). For instance, the US has committed to an ambitious and achievable goal to reduce net GHG emissions by 50-52% below 2005 levels in 2030. In the UK, the government has launched its Clean Growth Strategy, which aims to reduce carbon emissions in buildings by 53% by 2030 (HM Government, 2017).

Similarly, the Chinese government introduced its green building policy in 2015, which aims to reduce carbon emissions by 50% by 2020 (Cao et al., 2022). In Hong Kong, the government has launched the Energy Saving Plan for Buildings, which aims to reduce carbon emissions by 20% by 2025 (Environment Bureau, 2015). Further, Hong Kong's Climate Action Plan 2050 (Environment Bureau, 2021) seeks to achieve carbon neutrality in the city before 2050. The Singapore government is committed to achieving at least 80% of buildings with green features in Singapore by 2030 (Siva et al., 2017). Singapore also implemented its Green Mark Scheme to incentivize the adoption of energy-efficient retrofits and renewable energy technologies in buildings (Building and Construction Authority, 2022).

While significant attention has been focused on ensuring that new buildings are energy efficient and achieve green building status, decarbonising the existing building stock through energy retrofit remains a global challenge. Studies show that existing buildings are responsible for over 40% of energy consumption, often associated with operational carbon emissions (Aboulnaga & Moustafa, 2016). Thus, there is an urgent need to retrofit existing stock, as 80% of all the buildings that will exist in 2050 already exist today (World Economic Forum, 2022). In this light, governments globally have taken substantial measures to enhance energy efficiency in existing buildings.

This section provides a comparative review for building energy efficiency retrofitting policies in Hong Kong compared with other countries such as Singapore, China, the US and UK. These countries/regions were selected due to their geographic distribution and their achievements in building energy retrofitting. The UK was chosen from Europe, and the US was chosen from the Americas. Singapore is a country that has many similarities with Hong Kong. The cities share similar climates and urban environments. Among Asian countries, Singapore is at the forefront of building energy efficiency. While Mainland China is close to Hong Kong, its policy system is different. The building energy retrofitting policies in these countries/regions were reviewed and compared with the policies in Hong Kong. The comparison provides valuable references for making effective policies and guidelines in Hong Kong.

2.2.1 Policies and Guides for EOBEER in Hong Kong

This part aims to review the building energy efficiency retrofitting policies in Hong Kong. The Hong Kong government formulated the Building Energy Efficiency Ordinance (BEEO) to improve the energy efficiency of buildings, regulating that buildings in Hong Kong should comply with the Building Energy Code (BEC) and Energy Audit Code (EAC). BEEO was fully implemented on 21 September 2012. According to BEEO, building energy efficiency mainly focuses on four aspects: electrical, air-conditioning, lighting, and lift/escalator installations. BEEO, including BEC and EAC, considers energy consumption in buildings.

BEC provides the technical guidelines and details of energy efficiency requirements in building service installations, which apply to all building types except private residential buildings. BEC is updated every three years. It allows the industry to take six to nine months to adapt before a new BEC is implemented. After the adaptation period, practitioners must comply with the requirements of the new BEC. The new version normally enlarges the scope of energy strategies and tightens energy requirements. Furthermore, the BEC revision considers keeping pace with the international energy code, especially the relevant energy standards in Mainland China and Singapore.

A building energy audit aims to examine the energy consumption of major building services. EAC provides technical guidelines and details of energy audit requirements for central building service installation. After the building energy audit, valuable suggestions and recommendations could be proposed based on the energy audit result. With respect to existing buildings, the existing commercial buildings and the buildings for commercial uses must be carried out an energy audit every 10 years. Because large equipment is not applicable in households and private residential buildings, it is no need to conduct energy audits in households and private residential buildings. However, the energy audit frequency is relatively low. The energy consumption status may have significant changes in 10 years. Hong Kong has set the target to achieve carbon neutrality in 2050. Only 27 years left to reach the target, which means existing commercial buildings must conduct the energy audit twice. The effect of an energy audit is not satisfied compared to the challenging task. Buildings need consistent maintenance and upgrades. Otherwise, building energy efficiency will deteriorate.

The existing buildings undergoing major retrofitting works should comply with the requirements from BEEO, which falls under the jurisdiction of the Electrical and Mechanical Services Department (EMSD), a department under the Development Bureau of the Hong Kong Government. A technical task force is responsible for updating BEC and EAC regularly to cope with technological improvement and new trends in practice. Existing buildings required to carry out alteration and addition works (A&A works) must submit the application forms and seek approval and consent from the Building Authority.

The Hong Kong government and other institutions have launched incentive policies to support building energy retrofitting:

Energy Efficiency Registration Scheme: Buildings that have better performance than the minimum requirements under BEEO and obtain green certifications could apply for the Energy Efficiency Registration Scheme. If existing buildings conduct energy efficiency retrofitting, building owners may be eligible for the tax reduction to alleviate their retrofitting cost. The Energy Efficiency Registration Scheme is linked with green building certification, e.g., BEAM, LEED, and Green Mark. It encourages better energy performance in buildings as well as promotes green retrofitting of existing buildings, including indoor environment improvement and other green features.

Green Item Subsidy: The Green Item Subsidy is a part of the Common Area Repair Works Subsidy launched by the Urban Renewal Authority. It provides subsidy and technical support to building owners when the retrofitting works include environmental-friendly works. Only private residential or composite (including residential and commercial) buildings that have been in service for over 30 years can apply.

CLP subsidies: CLP provides some funds and schemes to improve building energy efficiency. For example, the Eco Building Fund provides HK$100 million every year to subsidize energy-saving works in communal areas of residential, commercial and industrial buildings. Around 400 buildings benefit from this fund annually, estimated to save 48 gigawatt hours. Building owners may receive 10-50% of the cost of retrofitting projects.

HK Electric: HK Electric provides some funds and schemes to improve building energy efficiency. For example, the Smart Power Building Fund subsidizes building owners to enhance the energy efficiency of communal building services installations. The eligibility of the Smart Power Building Fund is similar to Eco Building Fund, but this fund serves those buildings within the supply territory of HK Electric. Unlike Eco Building Fund, the subsidy will be disbursed on a reimbursement basis.

Other incentives related to building energy efficiency include the Operation Building Bright 2.0, Second Round Lift Modernisation Subsidy Scheme, etc.

Other institutions in Hong Kong have made achievements to improve building energy efficiency. The Hong Kong Green Building Council (HKGBC) has released the HKGBC Retrofitting Guidebook to support and encourage the industry to implement retrofitting for better operation performance in energy efficiency for the existing building stocks. Showcasing successful experiences and case studies of retrofitting projects, the HKGBC Retrofitting Guidebook is an invaluable reference tool for academia and industry.

Table 2.4 provides a summary of existing policies related to building energy retrofit in Hong Kong.

2.2.2 Policies and Guides for EOBEER in Singapore

In Singapore, buildings consume about 31% of electricity (Oh et al., 2016). Furthermore, existing buildings are the overwhelming percentage of the building stock and are key to improving overall sustainability and efficiency. Hence, the Singapore government has taken tactical actions to ensure significant energy savings in the building sector, especially on the existing building stock. Thus, policies and legislation guiding existing building retrofit in Singapore includes the Building Control Act (BC Act) – Environmental Sustainability Measures for Existing Buildings, Code on Periodic Energy Audit of Building Cooling System referred to as Energy Audit Code (EAC), and Code for Environmental Sustainability of Buildings. The BC Act set out to obtain minimum environmental sustainability for existing buildings. The EAC ensures that building cooling systems are audited to meet minimum system efficiency and continue to operate in such capacity throughout their life span. Similarly, the code for environmental sustainability uses the BCA green mark criteria method in assessing the environmental performance of building development and operations.

Table 2.4 Review of Existing Building Energy Retrofit Policies in Hong Kong.

Policy document	**Buildings Energy Efficiency Ordinance (BEEO)**	**Building Energy Code (BEC) - 2021**	**Code of Practice for Building Energy Audit (EAC) 2021**	**Code of practice for overall thermal transfer value (OTTV)**
Policy objectives /goals	To ensure that building service installations meet the specified standards or compliance and ensure that installation is maintained at an acceptable standard.	1.The BEC sets out the technical guidance and details regarding the minimum energy performance requirements governing the building services installations defined in the BEEO. 2.It also provides energy efficiency requirements for major retrofitting works.	The EAC specifies the technical details and guidelines relating to the energy audit requirements governing the central building services installation under the Ordinance.	The controls on OTTV aims at reducing external heat gains through the building envelope, and hence, the electricity required for air-conditioning in commercial buildings and hotels
Target	Building owners/tenants/ occupiers	Building owners/tenants/ occupiers	Building owners/tenants/ occupiers	Design and construction professionals, e.g., structural engineers

Instrument/ process	1.Assessment of Building Service Installation (BSI) conducted by designated authorities. 2.The owners of commercial buildings should conduct an energy audit for the four key types of central BSI (air-conditioning, electrical, lift and escalator, and lighting installations) therein under the Energy Audit Code (EAC) every 10 years.	The requirements specify reducing energy consumption in the designed building through the focus on its total energy consumption and the adoption of essential energy efficiency requirements.	Collection of Building Information- of various energy-consuming equipment/systems relevant to the central building services in the last 36 months for an energy audit by a qualified person.	1.It measures the average heat gain into a building through the building envelope and consists of three major components: (a) conduction through opaque walls, (b) conduction through window glass, and (c) solar radiation through window glass. The usual practice is to have two sets of OTTV --one for the exterior walls and the other for the roof. 2.An OTTV standard limits the maximum allowable thermal transfer value, i.e., heat gain in cooling-dominant locations, for a

				building or portion of a building in W/m²
Agents/ actors	Director, Registered energy assessor (REA)	EMSD officials	Director, REA	Authorised persons, registered structural engineers, Design and building construction professional
Legal instrument /requiremen t	1.Certificate of Compliance Registration 2.Energy Audit form	N/A	Energy Audit Form/Energy Audit Report	N/A
Building service installation	Air-conditioning installation, electrical installation, lift and escalator installation, lighting installation	Same as provided in BEEO	Same as provided in BEEO	Building envelope/ facade

Table 2.5 Review of Existing Building Energy Retrofit Policies in Singapore.

Policy document	**Building Control Act (BCA) - (Environmental Sustainability Measures for Existing Buildings)**	**Code On Periodic Energy Audit of Building Cooling System referred to as Energy Audit Code (EAC)**	**Code for Environmental Sustainability of Buildings**	**Code of practice for energy efficiency standard for building services and equipment (SS530)**	**Code of Practice for air-conditioning and mechanical ventilation in buildings (SS553)**
Policy objective /goal	1.To ensure periodic energy audit is conducted for EBs as prescribed by the BC Act 2.Conduct an energy audit for cooling systems every 3 years.	To ensure that building cooling systems are audited to meet minimum system efficiency and continue to be operated efficiently throughout their life cycles.	This Code sets the minimum environmental sustainability standard for buildings and administrative requirements. It has largely adopted the BCA Green Mark's criteria as the compliance method in	This code stipulates the minimum efficiencies required for chiller plants, water heaters, motor drives, and lighting.	This code covers the operational efficiency of air-handling units in buildings.

			assessing the environmental performance of building development.		
Target	Residential, Commercial buildings, hotels, office buildings, and other mixed-used buildings as prescribed in the Act with Gross Floor Area (GFA) of ≥5,000m² and having one chiller.	EBs that have undergone Major Energy Use Change	1.Residential and Non-residential buildings. 2.Additions or extensions to EBs ≥2,000m² and major retrofitting works	Residential and Non-residential buildings	Commercial buildings, offices, and institutional buildings
Instrument/ process	1.Obtain Minimum environmental sustainability standards for EBs assessed by Engineer	The Chilled Water Plant's Operating System Efficiency (OSE) should meet the energy audit requirement	Engage a Qualified Person (QP) to ensure that the building works are designed with physical features or	Engage a Qualified Person to ensure that the building's requirements for chiller plants, water heaters,	Engage a Qualified Person to ensure that the building's requirements for air handling units are met.

	(Mechanical) before and after commencing chiller replacement works. 2.Minimum 50 green mark (GM) points.	specified in section 6 of the Energy Audit Code.	amenities specified in the Environmental Sustainability Regulations.	motor drives, and lighting are met.	
Agents/ actors	Commissioner of Building Control, Owner-appointed approved Mechanical Engineer and REA.	Building Owner, PE (Mechanical), and REA	Building Owner, Qualified Person, and Commissioner of Building Control	Building owners, Qualified Person, PE (Mechanical or Electrical)	Building Owner, Qualified Person, PE (Mechanical or Electrical)
Legal instrument /requirement e.g., energy compliance form	1.Operating System Efficiency Report 2.Energy Audit report 3.As-Built Approval	1.Energy Audit report 2.As-built schematic/layout drawings of the chiller plant room	N/A	N/A	N/A
Building service	Cooling systems - Chillers	Cooling systems - Chillers	Building Envelope – ETTV	Chiller plants	

installation e.g. Lifts	Roof – RTTV Air tightness and leakage Artificial lighting Ventilation Electrical sub-metering Luminance level	High-efficiency lighting installations Motor drive Water heaters

Further, the Building and Construction Authority (BCA) has developed Green Mark for EBs to encourage continued efficiency and savings over the life of a building. Similarly, the BCA's 2nd Green Building Masterplan (GBMP) for Singapore strongly focuses on energy efficiency in existing buildings (BCA, 2010). In addition, the 3rd GBMP provides an overarching framework for the goals and incentives of the Singapore building sector (I. Yeung, 2024). In Singapore, the specific energy efficiency requirements were contained in the BC Act and Building Control regulations. The regulations reference the ETTV (envelope thermal transfer value) guidelines and Singapore standards (SS530, CP13 & CP38) on building services installations as an acceptable solution. **Table 2.5** provides a summary of existing policies related to building energy retrofit in Singapore.

Hong Kong and Singapore are similar in several aspects. They are both high-rise and densely populated cities with sub-tropical and tropical climates, respectively. Therefore, the BCA development in Singapore is a helpful reference for Hong Kong.

Singapore's building sustainability regulations are structured differently than Hong Kong's regulations. The top-level code is based on Green Mark, the Green Building certification program of the Building and Construction Authority of Singapore (Building and Construction Authority, 2022). It covers energy efficiency, including 'water efficiency', 'environmental protection', 'indoor environmental quality (IEQ)' and 'other green features.' This high-level code called the 'Code for Environmental Sustainability of Buildings' (CESB), is similar to the minimum standards for BEAM Plus accreditation. The green mark is the key driver of Singapore's energy efficiency and operational carbon emissions. This code ensures that, outside prescribed exceptions, all buildings in Singapore meet the minimum requirements for this certification program. In addition, the energy efficiency section is covered by a set of standards called the 'Code of Practice for Energy Efficiency Standards for Building Services (CESBs).' Exceptions to the CESBs are similar to those in Hong Kong in that they exclude more minor works that are likely to consume less energy. **Table 2.6** provides the list of buildings and building conditions that are exempted from Hong Kong and Singapore's energy codes.

Table 2.6 Exemptions of Hong Kong and Singapore Energy Code.

Hong Kong	**Singapore**

Electricity supply does exceed 100A (1- or 3-phase)	New building works with GFA < 2000m²
Buildings not exceeding 3 storeys or ≤8.23 m high	Additions or extensions to existing buildings < 2000m²
Roof area ≤65 m²	Major retrofitting works to existing buildings less than < 2000m²
A declared historic monument or a proposed historic building	Type A and Type B buildings as prescribed in the BC Act e.g., Data centres and religious buildings

Singapore’s EAC targets existing buildings that have undergone significant energy change use, while the Hong Kong EAC covers a broad context of major retrofitting works. Singapore's approach is more specific as it focuses on energy change use. Its effectiveness is based on the premise that not all retrofit works may reflect major energy use change. Also, the BC Act requires that energy audits should be conducted on a three-year cycle, while the BEC stipulates energy audits on a ten-year frequency. However, there are significant issues. Firstly, the frequency of the audit – every ten years – is far too low to address the energy consumption of existing buildings effectively. Between now and 2050, buildings will undergo a maximum of three energy audits, making the 6.6% required annual reduction exceptionally difficult to achieve (I. Yeung, 2024). Furthermore, for individual buildings, a 10-year period is enough time for significant operational, maintenance, and other energy efficiency issues to manifest. Thus, without consistent upgrades and maintenance, existing building energy efficiency will be inclined to deteriorate rather than improve.

Like Hong Kong, Singapore’s compliance process requires a Qualified Person (QP) to ensure that building works comply with the Code. This includes the design as well as the methods and materials selected by the project team. The QP has overall responsibility, alongside professional mechanical and electrical engineers, to assess and score the relevant building works. A major significance of the Singapore codes is the inclusion of Green Mark schemes applicable to existing buildings. To comply with this Code, buildings must achieve a minimum score of 50 during certification. In the energy efficiency section, a minimum of 30 points is required.

This approach differs from that in Hong Kong because points must be earned beyond the minimum requirements to satisfy the higher-level code. There is also flexibility in achieving compliance. Once the baseline has been met across all categories, a designer must target different points to achieve the 30-point requirement. There are restrictions to ensure that the selected measures make a meaningful contribution to the energy efficiency of the building:

• Points for the AC system is only counted if the conditioned area is > 500m²

• Points for non-conditioned areas are only counted if the non-conditioned area is >10% of the total GFA, excluding car parks and common areas.

This Code, therefore, works in tandem with the minimum requirements listed in the 'Code of Practice for Energy Efficiency Standard for Building Services and Equipment (SS530)' by mandating energy-efficiency improvements beyond the baseline.

Similar to Hong Kong's BEC, the SS530 in Singapore provides specific technical requirements for BSIs. However, two major additional sections in SS530 cover the energy efficiency of water heaters and the provision of exterior lighting, which is not covered in the BEC.

Further, the Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings, referred to as 'SS553' in Singapore, sets out design conditions and control requirements related to AC equipment that affect energy efficiency and are applied similarly to BEC. The comparison between requirements for AC equipment in Hong Kong and Singapore's energy codes is presented in **Table 2.7**.

Table 2.7 Hong Kong and Singapore Energy Code section comparison for AC Equipment.

Regulation	**Hong Kong BEC 2021**		**Singapore SS 530: 2014 & SS 553: 2016**	
AC equipment efficiency	Air-Cooled Min. COP	Water-Cooled Min. COP	Air-Cooled Min. COP	Water-Cooled Min. COP
Unitary	≤ 7.5kW: 2.7/2.5 (split/	3.3	≤ 8.8kW: 2.9 (NEA	≤ 19kW: 3.54 ≥ 223 kW: 3.57

Regulation	Hong Kong BEC 2021		Singapore SS 530: 2014 & SS 553: 2016	
	non-split) type ≥ 200 kW: 2.65		Singapore, 2018) ≥ 223 kW: 2.84	
VRF System	≤ 20kW: 3.6 ≥ 200 kW: 3.4	4.6 (All Ratings)	≤ 17.6kW: 3.78 ≥ 70 kW: 3.28	< 19kW: 3.52 ≥ 40 kW: 2.93
Reciprocating & Scroll Chiller	≤400 kW:2.9 ≥400 kW:3.0	≤ 500kW: 4.8	≤ 528kW: 2.985 ≥ 528kW: 2.985	≤ 263kW: 4.694 ≥ 1055kW: 5.771
Screw & VSD Screw Chiller	≤500 kW: 3.1 (3.9 at 75% load) ≥ 500 kW: 4 at 75% load	≤ 500kW: 4.8 500 ≤1000 kW: 5.0 (6.8 at 75% load) > 1000kW: 7.2 at 75% load	≤ 528kW: 2.985 ≥ 528kW: 2.985	≤ 263kW: 4.694 ≥ 1055kW: 5.771
Centrifugal & VSD Centrifugal Chiller	3.2	≤ 1000kW: 5.4 > 1000 ≤3000 kW: 5.7 > 3000 kW: 5.9	≤ 528kW: 2.985 ≥ 528kW: 2.985	≤ 528kW: 5.771 ≥ 1055 kW: 6.286

Regarding lighting and installation, the list of LPD requirements for common spaces is not as extensive as that provided in BEC 2021. However, there are other options provided in SS530 for calculating LPD requirements based on room shape and illuminance requirements. Nonetheless, BEC 2021 had stricter maximum LPDs for common space requirements listed in both BEC and SS530, while some requirements are the same in both documents. **Table 2.8** shows spaces where BEC had more stringent LPD requirements than SS530.

Table 2.8 Lightening requirements differences in Hong Kong's BEC and Singapore's SS530.

Space Type LPD (W/m²)	**Hong Kong – BEC 2021 (W/m²)**	**Singapore – SS 530: 2014 (W/m²)**
Office	Area ≤ 15m²: 9.5 15m² < Area ≤ 200m²: 8.9 Area > 200 m²: 7.8	12
Plant Room	Area ≤ 15m²: 9.5 Area > 15m²: 8.8	10
Washroom	9.7	12

Lighting control is an integral part of controlling the energy efficiency of lighting installations. However, Singapore takes a different approach to interior lighting control than Hong Kong regarding automatic lighting control. For instance, SS530 requires that luminaires providing general lighting in a daylighted zone be controlled independently from luminaires in other zones. Also, in common areas receiving >150% of designed illuminance (usually on rainy/overcast days), daylight control is required via daylight sensors or timers, except if total luminaire power consumption is <120W. Meanwhile, Hong Kong BEC does not require automatic lighting control for installations <150W, and daylighting controls are necessary when automatic lighting controls are required in cases where the space is exposed to the exterior light.

Furthermore, BEC 2021 explicitly excludes all types of external lighting, apart from a single LPD requirement for car parks. It excludes building façade architectural lighting and outdoor lamps, while SS530 comprehensively addresses lighting for the building exterior and outdoor spaces. There are also provisions for timers and daylight sensors to control the lights under different conditions. These lightning requirement differences between the BEC and SS530 further buttress Singapore's strictness in achieving energy efficiency for the existing buildings.

Singapore regulates the thermal transfer into the building envelope with the Envelope Thermal Transfer Value (ETTV) that provides code on thermal envelope performance for buildings. The code covers envelope and thermal roof transfer for air-conditioned non-residential buildings and the overall transmittance for residential buildings. The code provides maximum values for ETTV, Roof Thermal Transfer Value

(RTTV), and Residential Envelope Transmittance Value (RETV). These codes correspond to the OTTV of a wall, OTTV of the roof, and RTTV in Hong Kong codes, respectively.

Thus, Singapore EBEER policies emphasise a performance-based approach, ensuring that building meets energy and other green-related requirements such as water efficiency and indoor air quality to ensure that existing buildings are energy efficient and reduce carbon emissions. Contrastingly, the performance-based approach is an alternative in Hong Kong EBEER policies because greater emphasis is placed on buildings meeting the prescriptive requirements. In the prescriptive approach of BEC 2012, a design of building services installation has to satisfy a number of requirements such as maximum allowable lighting power density, proper lighting control, maximum allowable electrical power of motor drive, minimum allowable total power factor, limit on lift decoration load, minimum allowable coefficients of performance (COP) of chillers, etc. Another approach is performance-based, which is regarded as an alternative route for meeting the prescriptive requirements of the BEC 2012. The requirements in the performance-based approach are used to reduce energy consumption in a building design by focusing on its total energy consumption and adopting basic energy efficiency requirements. It focuses on the total energy consumption of a building design, termed Design Energy (Chan & Chow, 2014).

However, this approach is inefficient in achieving energy efficiency in existing buildings because building owners are more interested in ticking the requirement boxes than ensuring that their operations will help achieve energy efficiency. Thus, for Hong Kong to record a significant difference in achieving effective energy efficiency of existing buildings, attention should be given to the operational performance of existing buildings.

2.2.3 Policies and Guides for EOBEER in mainland China

In China, existing buildings account for about 21% of the country's total energy consumption. According to the Ministry of Housing and Urban-Rural Development of the People's Republic of China (MHURD), China has about 60 billion m^2 of existing buildings. However, almost all these buildings have issues of poor functioning and energy inefficiency, leading to high energy consumption and GHG emissions (Liu, Tan, et al., 2020). The Chinese government has implemented several policies and strategies to improve energy efficiency in buildings, including existing building retrofitting policies

(Hou et al., 2016). China's actions in addressing energy efficiency challenges commenced in 2005, including developing building design standards and green building evaluation standards (J. Li & Shui, 2015). **Table 2.9** provides a summary of existing policies related to building energy retrofit in China.

In China, many energy laws and regulations are administrative legislations and guidelines issued by the state council, while some are directives given by the departments and committees under the State Council. Generally, China has developed a Building Energy Code (BEC) system to address building energy efficiency issues, including design, testing, management, and energy consumption standards (Y. Li et al., 2014). The national building codes, known as GuoBiao (G.B.) standards and the National Design Standard for Energy Efficiency of Public Buildings, GB 50189, were introduced to regulate the design of BSIs like BEC. These China codes perform a similar function to Hong Kong's BEC and EAC, acting as a baseline for provinces and cities to develop more stringent codes based on their local climate conditions.

The National Energy Conservation Law of China also addresses energy efficiency. It came into force in 1997 and had the latest amendment in 2016. The law identifies strategies to incorporate energy conservation and efficiency into broader national economic and social planning. The GB 50189-2015 aims at achieving energy efficiency improvements in new and existing buildings by providing requirements for building elements, including HVAC systems, water supply, and electrical and renewable energy installations.

Enforcement of the BEC is vested with the authorities at the district or city level. At the provincial level, some provinces and cities, like Shenzhen, Shanghai, Jiangsu, Chongqing, and Anhui, have proposed or already set up their local BEC to cater to the individual characteristics of their cities, such as the tall height in Shanghai and extremely hot and cold climates in Chongqing. For instance, a city like Shenzhen has been one of the pioneers of the development of green buildings in China. Hong Kong and Shenzhen have close climatic conditions, and Shenzhen has been one of the pioneers in developing green buildings in China (Hu & Lin, 2022). Thus, studying Shenzhen's EOBEER policies, standards, and guides would provide a valuable guideline for Hong Kong's building energy efficiency goals.

Table 2.9 Review of Existing Building Energy Retrofit Policies in mainland China.

Policy document	**The National Energy Conservation Law of China**	**GB 50189-2015 Design standard for energy efficiency of public buildings**	**SJG 44-2018 Design Code for Energy Efficiency of Public Buildings – (SJG 44-2018)-Shenzen**
Policy objective /goal	The objective of the Law is to reduce energy consumption across all end-use sectors by promoting energy efficiency with an emphasis on economic and social development as well as the economic benefits of energy efficiency.	The standard applies to efficiency improvements in new construction, expansion, and renovation of public buildings. The design standard takes into account local climate conditions and indoor environmental parameters.	To prescribe design codes and standards for achieving energy efficiency in public buildings based on Shenzen's localized climatic conditions.
Target	New and existing buildings	New construction, expansion and renovation of public buildings, energy-saving design	Newly built, renovated, and expanded public buildings (commercial and non-residential buildings) in Shenzhen.
Instrument/ process	Buildings must comply with all energy efficiency requirements as specified by relevant authorities.	Buildings must comply with all energy efficiency requirements as specified by the Ministry of Housing and Urban-Rural Development.	Buildings must comply with all energy efficiency requirements as specified by Shenzhen Housing and Construction Bureau

Agents/ actors	Building Owners/ Occupiers/tenants	Building Owners/ Occupiers/tenants	Building Owners/ Occupiers/tenants
Legal instrument /requirement e.g., energy compliance form	N/A	N/A	N/A
Building service installation	N/A	AC equipment Lighting Installations Additional section: Exterior Lighting Electric Installations Water heater	N/A

In 2018, the Shenzhen Housing and Construction Bureau (SHCB) provided the most recent version of the two codes for the energy efficiency of buildings: SJG 44-2018 – Design Code for Energy Efficiency of Public Buildings and SJG 45-2018 – Design Code for Energy Efficiency of Residential Buildings. These two codes were derived from the National Design Standard for Energy Efficiency of Public Buildings (GB 50189-2015). They were modified to suit the local climate of Shenzhen. SJG 44 applies to newly built, renovated, and expanded public buildings in Shenzhen. Renovation of existing buildings should comply with this code, except for small-scale public building projects with limited government funds and renovation of buildings with GFA less than 5,000 m^2 that does not involve renovation of the building envelope (HK2050IsNow, 2020). **Table 2.10** shows the building scope and service installation covered in Hong Kong's BEC compared to Shenzhen's (China) SJG 44-2018.

Table 2.10 Scope of Hong Kong and Shenzhen Building Energy Codes for Public Buildings.

Hong Kong – BEC 2021	**Shenzhen – SJG 44-2018**
AC Equipment	AC Equipment
Lighting Installations	Lighting Installations
	Additional section: Exterior Lighting
Electrical Installations	Electric Installations
Lifts & Escalators	
COP of OTTV	Additional: Heat Transfer in Building Envelopes
	Additional section: Water Heaters

Concerning lighting installations, SJG 44 requires the fulfillment of GB 50034 for lighting designs. GB 50034 applies to newly built, renovated, and expanded buildings. GB 50034-2013 has mandatory LPD requirements covering space types in several building types, including office buildings, shopping malls, and hotels. The LPD requirements for different spaces in China's GB 50034-2013 are more stringent than Hong Kong's BEC 2021. However, an exception is the BEC 2021 office requirements of LPD of 7.8 – 8.9 for spaces with internal floor area > 15m^2 > 200m^2. Contrastingly, GB 50034-2013 has a fixed LPD requirement of 9 for office space, irrespective of the internal floor area. However, there is a clause in GB 50034-2013 that provides that LPD requires small spaces, and the LPD limits should be increased accordingly by, at most, 20%. This is a similar provision to that in BEC, which states that LPD requirements are not required if the installation is <70W. It is also recommended that the LPD requirements be split into different building types to cater to specific applications for LPD. Setting varied limits provides opportunities to allow flexibility of LPD in meeting building-specific requirements in achieving energy efficiency. **Table 2.11** compares Hong and China LPD's requirements.

Table 2.11 Comparison of Hong Kong and China LPD requirements.

Space Type LPD (W/m^2)	**Hong Kong BEC 2021 (W/m^2)**	**China GB 50034-2013 (W/m^2)**
Office	Area ≤ $15m^2$: 9.5 $15m^2$ < Area ≤ $200m^2$: 8.9 Area > 200 m^2: 7.8	9
Restaurant	Area ≤ $15m^2$: 9.5 Area > $15m^2$: 8.8	9
Washroom	9.7	6
Plant room	Area ≤ $15m^2$: 9.5 Area > $15m^2$: 8.	4

As per external lightning similar to Singapore, China provides external lighting. The design requirements can be found in the Code for Lighting Design of Urban Nightscape, JGJ/T 163. The code applies to external lighting of buildings (new or renovated), structures, landscapes, commercial pedestrian streets, squares, and parks. Unfortunately, there are currently no mandatory requirements targeting the reduction of energy consumption for external lighting in Hong Kong. However, a voluntary charter on external lighting was launched in 2016 to reduce light pollution and energy consumption by external decorative lighting. Thus, it is essential that Hong Kong develops a code for external lighting to control the LPD and the lighting equipment to achieve a higher energy efficiency of external lighting.

Requirements for thermal transfer in building envelopes are included in Shenzhen, SJG 44, while in Hong Kong, similar requirements are found in the OTTV code. The requirements in SJG44 are split into two separate sections – thermal transfer and solar heat gains. Both factors contribute to the thermal performance of the building envelope.

2.2.4 Policies and Guides for EOBEER in the US

The United States Department of Energy (DOE) has developed several model energy codes, including International Energy Conservation Code (IECC) and ASHRAE Standard 90.1-2016, which are typically adopted or modified by state and local governments to ensure compliance with energy-efficiency regulations. The US building energy efficiency policies and codes for existing buildings are often implemented at city, national, or state levels.

Various cities and states in the US, including Austin, Chicago, Newyork, and Seattle, have their EBEER policies and strategies targeted to meet specific building energy requirements in their Jurisdictions. For Instance, Chicago takes a holistic approach to achieving energy efficiency in existing buildings by introducing the Chicago Energy Transformation Code (CETC), 2022. The CETC aims to promote energy conservation in the useful life of a building and ensure repairs and alterations to existing buildings conform with the energy conservation code. Similarly, the New York City Local Law 84 focuses on benchmarking energy and water usage in buildings, while Energy Disclosure Ordinance in Seattle and Energy Conservation Audit and Disclosure (ECAD) Ordinance in Austin, Texas, track energy performance in non-residential buildings and benchmark energy performance in commercial buildings respectively. The US energy code laws basically target building owners and tenants to ensure that existing buildings comply with the relevant EOBEER policies.

Table 2.12 provides a summary of existing policies related to building energy retrofit in the US.

Table 2.12 Review of Existing Building Energy Retrofit Policies in the US.

Policy document	**A Guide to Energy Audits**	**Commercial Energy Policy Toolkit: Audits and Retro-Commissioning**	**ENERGY STAR Programme**	**New York City, NY: Local Law 84 (Greener, Greater Buildings Plan) – Article 309**	**Seattle, WA: Energy Disclosure Ordinance- Seattle Municipal Code 22.920**	**Austin, TX: Energy Conservation Audit & Disclosure (ECAD) Ordinance**	**2022 Chicago Energy transformation code**
Policy objective /goal	An overview of the energy audit process, including an overview of the different energy audit options available and information on how to select an energy auditor.	To maximize building energy performance with audits and retro-commissioning	1.National programme to improve energy efficiency and comfort in homes, while reducing the greenhouse gas emissions that contribute to climate change.	To benchmark energy and water use of city buildings and covered buildings in accordance	To track energy performance in non-residential and multifamily buildings and annually report to the	To benchmark energy performance in buildings For Commercial buildings 10,000 SF and greater	The Energy Transformation Code focuses on reducing greenhouse gas emissions, consistent with the City's Climate Action Plan. Its goal is to ensure addition, repairs,

			2.To deliver trusted home energy upgrades that make American homes safer, healthier, and more efficient		City of Seattle.		and alterations to existing building or structures conforms with the energy conservation code. It also aims to promote the effective use and conservation of energy over the useful life of a building.
Target	Building/Property Owners	Building/Property Owners	Building/Property Owners	Building owner and tenant	Building owners and Tenants	Building owner	Building owners/developers/occupiers
Instrument/ process	1.Preliminary review of energy-use/utility data 2.Site assessment	1.Buildings must have an energy audit and retro-commissioning	1.Homeowner interview 2.Energy bills review 3.Home evaluation	1.Buildings must benchmark energy and water performance	Building owners of non-residential buildings shall comply	The owner of a commercial facility that has a gross floor area of 10,000	Buildings must comply with all energy efficiency requirements as specified by

	3.Energy and cost analysis 4.Completion of audition report	conducted by a licensed professional once every 10 years. 2.Buildings that achieve LEED for Existing Buildings certification or the ENERGY STAR label in two of three years prior to the reporting deadline are exempted from audit and retro-	4.Safety check & testing 5.Home improvement recommendation (including replacing windows; upgrading lighting appliances, and water heating equipment; sealing air leaks and adding insulation; sealing duct; installing renewable energy systems;	annually using ENERGY STAR Portfolio Manager and report benchmarking data and ratings to New York City. 2.Benchmarking information and ratings will be publicly disclosed online beginning in 2012 for	with the benchmarking requirements by providing to the Director, using the Energy Star Portfolio Manager or a similar rating system and in such form as established by Director's rule, energy benchmarking reports and, where available, energy	square feet or greater must calculate an energy use rating for the facility using an audit or rating system approved by the director. **Disclosure required** The owner of a commercial facility must make a copy of the energy rating calculation required under this	relevant authorities.

		commissioning requirements.	improving HVAC systems	commercial buildings and 2013 for multifamily buildings. 3. City-owned buildings must annually benchmark and will be publicly disclosed each year Note - All documents and records should be kept for 36months before destroying.	performance ratings for each building according to the schedule in law. Ratings for each subsequent year shall be due each April 1st. Disclosure of energy performance should be provided mandatorily to the Director and on request to current and	article available to a purchaser or prospective purchaser of the facility before the time of sale and must provide a copy to the director not later than 30 days after the audit is complete.	

					prospective tenants negotiating a rental		
Agents/actors	US Department of Energy (DOE)/Energy Auditor	Local energy auditors/Commissioning agents/ Building operators	DOE)/ Home Performance Expert with ENERGY STAR/ EPA	Commisioner, The Director of the office of long-term planning and Sustainability, Department of environmental protection, Department of finance, Mayor and Speaker of Council	Director of the Seattle Department of Construction and Inspections or the Director's designee and The Office of Sustainability	The Director of Austin Electric Utility and Authorized energy assessor	Department of Buildings
Legal instrument /requireme				N/A	Energy benchmarking reports	Energy performance ratings	Phius standard and the gold and emerald

nt e.g., energy compliance form					energy performance ratings		certification levels under the 2020 National Green Building Standard (NGBS).
Building service installation				Building service installation e.g. Lifts	Electricity, natural gas, fuel oil and steam and water	HVAC and energy-consuming installations and appliances	HVAC installations

Table 2.13 Review of Existing Building Energy Retrofit Policies in the UK.

Policy document	**PAS 2035:2023 Retrofitting dwellings for improved energy efficiency- Specification and guidance**	**Energy Performance Certificates (EPCs)**	**The Minimum Energy Efficiency Standards (MEES)**	**Building Regulations Part L1B**	**Building Regulations Part L2B**	**Part F- Part F (Ventilation**	**Part O (Overheating)**
Policy objective /goal	To promoting and defining technically robust and responsible "whole-dwelling" domestic retrofit work	These certificates offer both a current energy efficiency rating and suggestions for improveme	MEES mandates the retrofit of properties to meet specified energy efficiency criteria	Covers the requirements for renovations and extensions to existing buildings to be energy efficient.	It aims to ensure that existing buildings meet the required energy standards.	Part F- Part F (Ventilation) To ensure that existing buildings meet the ventilation requirements during renovation	The main intention behind Building Regulations Part O is to limit excess solar gain in new and existing buildings and remove excess heat.

		nts, thus serving as both a benchmark and a guide for making buildings more energy-efficient	before it can be leased.			regarding energy efficiency	
Target	Property Owners/ Householder /Landlords/ Tenants	Property Owners/ Landlords/ Householder/ Tenants/ Buyers	Property Owners/ Landlords/ Householder/ Tenants/ Lessees	Buildings owners /renovators/ occupiers	Buildings owners /renovators/occupiers	Buildings owners /renovators/occupiers	Building professionals and renovators
Instrument/ process	1.Preliminary considerations 2.Inception (Retrofit Coordinator)	1.EPCs involve a detailed assessment of a building's	1.Buildings must have a valid EPC, which rates their energy efficiency	1.U-values need to be improved in walls, and replacement thermal	Replacement of existing building fabrics should	1.Permitted Development (PD) should be applied concerning existing building	Compliance can be achieved through one of two methods (The Simplified Method or the

	3.Assessment 4.Improvement Option Evaluation 5.Agreement of Intended Outcomes 6.Medium-Term Improvement Plan 7.Design and Specification 8.Statutory Approvals 9.Installation and Quality Control 10.Test Commission Handover 11.Evaluation	energy features, including insulation, heating and cooling systems, and lighting. 2.The building is then rated on a scale from A (most efficient) to G (least efficient)	from A (most efficient) to G (least efficient) 2.MEES require a minimum rating of 'E' for properties to be legally rented. 3.The UK government has proposed tightening these standards further, aiming for a	elements from 0.28W/m²K to 0.18W/m²K, and the minimum values for doors, windows and roof should be 1.4. 2.The U-value for doors should be 1.4, while fire doors, U-value should be 1.8. Extensions will also be required to have no more	meet the full fabric specification' for setting the level of the Fabric Energy Efficiency Standard (FEES) requirements.	improvement that requires ventilation upgrade. 2.The maximum permitted heat loss standards apply and since changes in 2010, replacement windows must now achieve the same thermal rating as new windows — a minimum performance standard based on either a 'C' Window Energy Rating (WER) or a minimum	Dynamic Thermal Modelling Method), with standards based on whether a house is cross-ventilated or not. Also, a standard is included for the maximum amount of glazing allowed in a single room. Dynamic modelling is likely to be quite an expensive process, whereas the simple method is what would be a lot more intuitive

			minimum 'B' rating by 2030 for commercial properties, signifying a progressive approach to improving building energy efficiency over time.	than 25% floor area as glazing (windows, roof windows, rooflights). Improvements are also required in lighting efficiency		whole window U value of 1.6 W/m²K (glazing and frame). 3.Additionally, safety glass is required for windows where the bottom of the glazing is within 800mm of floor level.	and easier to integrate into a standard home design," explains Siddall.
Agents/actors	Department for Energy Security & Net Zero/ British Standards Institution/ Retrofit Installer/	Energy Assessors/ Department for Business, Energy & Industrial Strategy	Energy Assessors/ BEIS	Buildings owners /renovators/ occupiers	Buildings owners /renovators/occupiers	Buildings owners/renovators/occupiers	Building professionals and renovators

	Retrofit Evaluator/ Retrofit Designer/ Retrofit Coordinator/ Retrofit Assessor						
Legal instrument /requirement, e.g., energy compliance form				1.Approved Documents L1B 2.Permitted Development (PD)	Approved Documents L2B Permitted Development (PD)	Permitted Development (PD)	Approved Documents O
Building service installation, e.g., Lifts				Walls, Roofs, Lightning Installations, Doors	New electrics HVAC systems	Windows	Wall, Roofs, Windows Heat-producing appliances Cavity wall insulation, new electrics

Thus, the US EOBEER policies and regulations are estimated to save above 14.8 exajoules of energy between 2009 and 2030, with annual savings of 1.8 exajoules in 2030 (Levine, 2013).Financially, the codes are expected to save the US more than USD 15 billion in annual savings on energy bills in 2030. Moreover, aside from its monetary benefits, it is projected to help reduce pollution and achieve carbon emissions targets (Levine, 2013). Therefore, it is worth studying the US EOBEER policies, guidelines, and initiatives to draw meaningful lessons to enhance Hong Kong EOBEER policies and reduce carbon emissions in existing buildings.

2.2.5 Policies and Guides for EOBEER in the UK

The UK has adopted different approaches to regulate energy efficiency and GHG emissions in the built environment. The UK's Ministry of Housing, Communities, and Local Government publishes a list of approved documents designed to guide compliance with building regulations. The building regulations contain functional requirements covering all aspects of the building, including fire safety, energy efficiency, and structural stability.

The Part L of approved documents covers existing non-dwellings. It guides different scenarios, including the construction of an extension, change of use or energy status, provision or extension of a water, waste, or energy-related system or piece of equipment, replacement or renovation of the wall, floor, or roof and major building renovations. Specifically, Part L1B addresses the requirements for renovations and extension of existing buildings, and Part L2B explicitly covers the retrofit of existing non-residential buildings.

Part L1B documents provide the thermal requirements for walls, roofs, doors, and lighting installations, while Part L2B specifies the requirements for new electrical appliances and HVAC systems in existing buildings.

The UK also addresses energy efficiency in buildings regarding ventilation and solar gain. Thus, Part F (Ventilation) and Part O (Overheating) of the building regulations stipulate the requirements to adhere. Part F (Ventilation) mandates that when energy efficiency works are conducted in existing buildings, ventilations must comply with existing measures for controlled services and fitting, not worse off. On the other hand, Part O (Overheating) provides the standard for removing excess heat and solar gains in buildings.

Table 2.13 provides a summary of existing policies related to building energy retrofit in the UK.

Hong Kong and the UK have varying climatic and local environmental conditions. However, the UK has been one of the major drivers of sustainability and net zero carbon emissions. Thus, studying their retrofitting policies, guidelines, and initiatives would be beneficial to Hong Kong's carbon reduction target.

The provisions of lighting installations in the Non-Domestic Building Services Compliance Guide apply to general interior lighting and display lighting of non-domestic buildings in the UK. The Lighting Energy Numeric Indicator (LENI) method guides compliance with the lighting standards. A lighting energy limit is provided for a given illuminance level and hours run instead of depending on the space type, like BEC 2021. **Table 2.14** compares Hong Kong and the UK's LPD requirements.

Table 2.14 Comparison of Hong Kong and UK LPD requirements.

Space Type	**Hong Kong BEC 2021 (W/m²)**	**UK Non-Domestic Building Services Compliance Guide**
Entrance Lobby	11.5	3.6
Office (according to Floor Area)	Area ≤ 15m²: 9.5 15m² < Area ≤ 200m²: 8.9 Area > 200 m²: 7.8	8.4
Plant Room	Area ≤ 15m²: 9.5 Area > 15m²: 8.8	3.8
Washroom	9.7	3.6

According to the above comparisons, the lighting power density limits of the UK are approximately 50% more stringent than Hong Kong. This implies that Hong Kong can also tighten the LPD requirements by around 50% to reduce energy consumption.

Unlike the OTTV code of practice provided by Hong Kong, requirements in Part L2A are broken down into thermal transfer and solar heat gain. Therefore, the limiting values provided by the two codes are different. The limiting heat transfer coefficient – U-values of each fabric element instead of OTTV of the whole building envelopes are used in the UK for heat transfer.

U-values represent the amount of thermal energy transferred across an individual fabric element per unit area, such as windows, walls, and roofs. They are affected by the thickness and material combination of the units. Unlike the UK, Hong Kong does not provide U-value limits for building fabric elements; instead, the OTTV limits for the tower and podiums are used as the average U- values for walls and roofs. The initial limits of OTTVs were 35 W/m^2 for the building tower and 75 W/m^2 for a podium. The podium's height is 20 m above the mean street level of the site. Considering the increasing cooling demand and improved thermal insulation of fenestration, tighter control was made on the two levels in two revisions: 30 and 70 W/m^2 in 2000 and 24 and 56 W/m^2 in 2011 (Yu & Ho, 2021). The current levels revised in 2019 reduced to 21 and 50 W/m^2 for the tower and podium, respectively, in response to the energy-saving plan.

Hong Kong developed its OTTV standards based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standards 90-75 and 90-80A. This practice is common in other Asian countries, including Singapore. Hong Kong's OTTV requirements are updated periodically within five to ten years, with the latest revision in 2019. Unlike Hong Kong, other Asian countries used ASHRAE as a basis for developing their OTTV limits but with some refinements to suit local climate and construction practices (Hui, 1997). Furthermore, a clear understanding of the climatic properties and local construction practices is essential for assessing the OTTV standards and their implications for building design.

2.3 Gaps in Knowledge and Policies

Hong Kong has a unique sub-tropical high-rise high-density compact context to its existing building stock. This poses unique local challenges for the energy efficiency retrofitting of the Hong Kong existing building stock, such as limited available plant space, complex densely populated high-rise buildings and very high conversion costs. There are plans to deepen energy saving in existing buildings in Hong Kong, implying an increasing demand for retrofitting. However, the challenges for such retrofitting and the pertinent polices have not been fully studied and recognized (Tan et al., 2018). Most of the existing studies focused on suggesting technologies and policies for building retrofitting (J. Li et al., 2017; Tan et al., 2018). No research has thoroughly evaluated the challenges faced by such retrofitting in the unique local context of Hong Kong. It should be highlighted that without a better understanding of the challenges faced in retrofitting and how to overcome them, even those suggested technologies by the existing studies may never achieve large-scale uptake. The impact of policies may also be better if they were suggested to link to and ease specific challenges. While some studies focused on assessing energy retrofitting technologies, it noted that there are "little discussions on the encountered technical problems" in retrofit projects in Hong Kong, not to mention how to overcome them for successful retrofitting. The study that specifically explores the challenges for EOBEER in Hong Kong and how to overcome them is of great significance for the implementation and promotion of energy efficiency retrofitting of existing buildings for carbon neutrality in Hong Kong.

From the above comparative review of building energy retrofit policies in Hong Kong and other developed regions, there is a need to improve existing EOBEER policies in Hong Kong. Studies have shown that policies for building energy conservation exist in Hong Kong. However, many of these studies (Tan et al., 2019, 2021) focused on suggesting technologies and policies for building retrofitting in Hong Kong, with less emphasis on how the content and requirements of these EOBEER policies can improve energy efficiency and encourage implementation. Also, studies have focused primarily on EOBEER policies, with less attention on the initiatives driving their implementation. The above review of other developed regions indicates gaps in Hong Kong's EOBEER policies, hindering their effective implementation. For instance, while the government has experienced some improvement in its carbon neutrality target based on EOBEER policies and initiatives implemented, some shortfalls exist. For instance, the Buildings Energy Efficiency Funding Scheme was introduced to subsidise energy improvement in existing buildings ended in 2012, and to date, there is no government-funded financial incentive scheme for EOBEER (Baker McKenzie, 2022). This huge policy pitfall should be addressed to promote building retrofitting and encourage carbon neutrality through incentive provisions for building owners (Baker McKenzie, 2016). Further, despite the Hong Kong's government's efforts to promote energy-efficient retrofits through schemes such as the BEEO, issues such as insufficient technical expertise, low awareness and participation of building owners, and regulatory barriers have impeded the widespread adoption of these measures (Cheng et al., 2021). As reviewed above, several policies exist in different countries to support energy retrofitting of existing buildings. The lessons learnt from Singapore, mainland China, US and UK could be adapted to improve EOBEER policies in Hong Kong. A summary of some gaps identified in the reviewed countries compared to Hong Kong are provided below.

Singapore's Building and Construction Authority (BCA) engages stakeholders through various channels such as workshops, training, and advisory services to promote building energy efficiency practices. Hong Kong can replicate Singapore's BCA stakeholder engagement practices by hosting regular education and training programs to engage stakeholders such as architects, developers, and building owners on the importance of building energy efficiency. Singapore's Green Mark Scheme provides financial incentives to developers, building owners, and architects who adopt building energy efficiency practices. Hong Kong can replicate the Green Mark Scheme financial incentives to incentivize developers, building owners, and architects to adopt energy-efficient practices.

China's State Council has mandated all provinces to establish a building energy efficiency information system to promote transparency and public participation in energy-saving efforts. China's Ministry of Housing and Urban-Rural Development (MOHURD) facilitates inter-departmental collaboration between various government departments and agencies to promote building energy efficiency practices. MOHURD also collaborates with research institutions and industry associations to develop technical specifications relevant to the construction sector. Hong Kong can replicate MOHURD's inter-departmental collaboration and work with research institutions, industry associations, and relevant government departments to develop and implement policies to improve building energy efficiency practices.

The UK has set up a government Green Construction Board to promote sustainable practices in the construction sector. The board comprises industry representatives and government officials, leading to effective collaboration between the public and private sectors. Hong Kong can replicate the UK Green Construction Board model to form an energy efficiency council comprising government officials, industry experts, and academics to promote sustainable building practices across sectors. The UK government has established several financial schemes such as the Energy Company Obligation and Renewable Heat Incentive to support building energy efficiency practices. Hong Kong can replicate the UK's financial schemes to incentivize developers, building owners, and architects to adopt energy-efficient practices.

The US government has created several programs and policies aimed at reducing energy consumption in public buildings. The US provides incentives such as ENERGY STAR certifications and training programs to incentivize the workforce to adopt energy-efficient practices (Energy Star, 2021). The US Environmental Protection Agency's (EPA) ENERGY STAR Buildings Program provides education and training programs to create a skilled workforce to implement energy-efficient practices in buildings. In addition, the US Federal government also offered financial assistance to support retrofitting existing buildings (DOE, 2015). Hong Kong can replicate the US EPA's training programs to empower the workforce with energy-efficient practices and financial incentives to motivate building owners, FM companies and developers to retrofit existing office buildings.

Chapter 3 Research Methodology

3.1 Research Framework

The research framework is shown in **Figure 3.1**. The research methodology includes three parts: data collection, data analysis and validation. A systematic literature review was conducted to identify energy retrofitting challenges from previous studies. These challenges are potential EOBEER challenges, which are further identified in the following research. Case studies and semi-structured interviews were combined to identify EOBEER challenges from real energy retrofitting cases in Hong Kong. Then, the Z-numbers-based Delphi survey was adopted to collect experts' opinions on the importance of EOBEER challenges, providing a quantitative method to analyse EOBEER challenges.

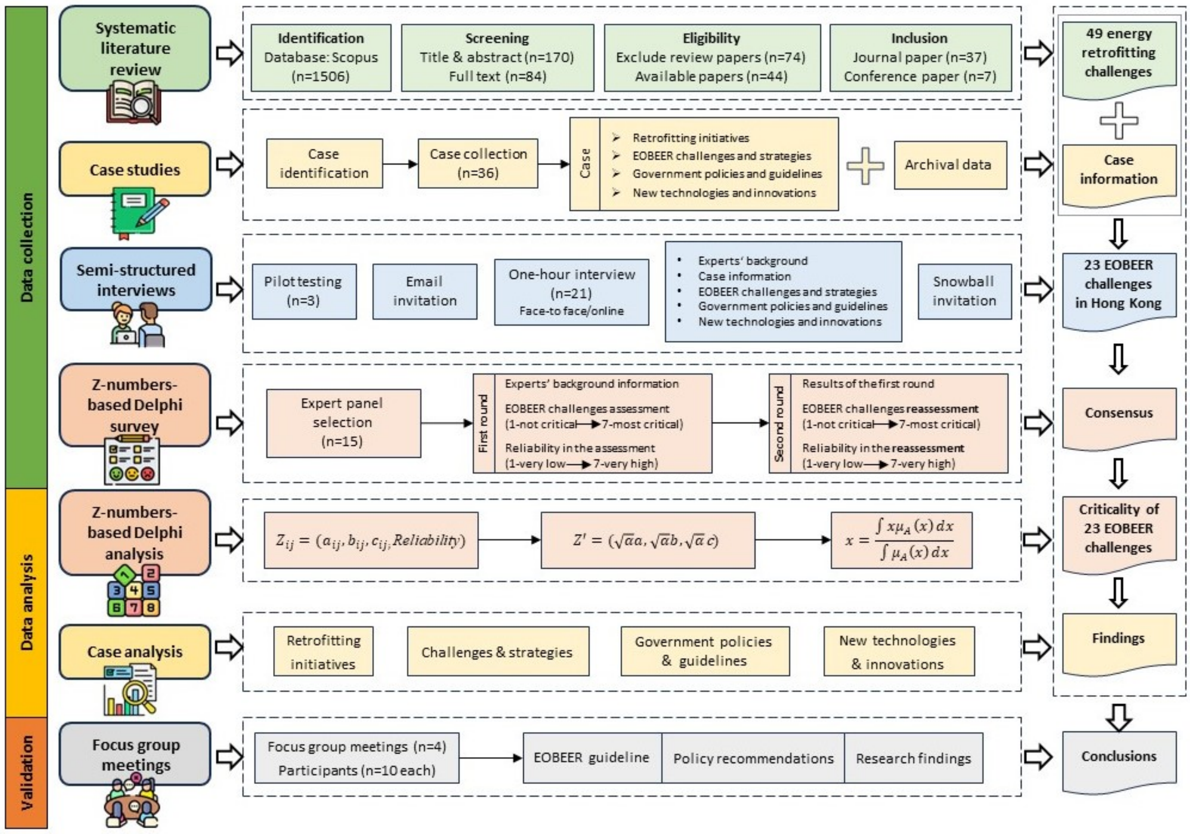


Figure 3.1 Research framework.

3.2 Semi-structured Interviews

Interviews have been widely used to gather in-depth information, conducted either in one-on-one sessions or group settings (Driscoll, 2011). Semi-structured interviews, the most common data collection method, were employed in this research (Kallio et al., 2016). Semi-structured interviews are versatile and flexible, fostering more standardized, constructive, and interactive discussions (Waara, 2008). Therefore, this research employed semi-structured interviews to collect real energy retrofitting cases and identify EOBEER challenges in each case.

Stakeholders are those who can benefit directly or indirectly from the retrofit projects (Menassa, 2011). The professionals who have rich experience in energy retrofitting and have participated in real EOBEER projects were invited to attend semi-structured interviews. Their roles include building owners, facility managers, materials and equipment suppliers, planning and design units (e.g., architects, designers, engineers, and consultants), construction and supervision units (e.g., contractors), utility companies (e.g., electric suppliers), energy service companies and subsidy suppliers.

The semi-structured interviews have combined individual and group interviews, depending on the companies and experts willing to participate in the interviews. Both face-to-face interviews and online interviews are acceptable. Most of the interviews were face-to-face interviews and conducted individually. Each interview lasted for about one hour, with the audio recorded for accuracy. The main questions in the semi-structured interview are as follows:

- Experts' background. Experts' company, position and working experience in building energy retrofitting.
- Case information. The basic information of real EOBEER project that the experts have undertaken in Hong Kong: retrofitting initiatives of each project, energy saving target (if applicable), their role/responsibilities in the project.
- Challenges and strategies. The challenges that the experts encountered in the project, addressing from technical, financial, institutional, social, environmental, and regulatory aspects. The strategies to overcome the challenges.

- Government policies and guidelines. The government policies and guidelines the experts followed in the project. Experts' suggestions on policies and guidelines for better implementation of future EOBEER projects.
- Technologies and innovations. New technologies and innovations applied in the project.
- Challenges identification. Those potential EOBEER challenges identified in the literature were presented to the experts, allowing them to select challenges that they encountered in real energy retrofitting projects.

These questions were supported by a thorough analysis of EOBEER cases in Hong Kong, contributing to a deeper understanding of the real challenges. Except for these main questions, some follow-up questions may be asked to maintain the logical flow of the interview and gain in-depth information on the research topic.

After preliminary semi-structured interview guide was developed, pilot testing could be used to improve the semi-structured interview questions and to confirm the final interview procedure (Kallio et al., 2016). A total of 24 interviews were conducted, including 3 field-testing interviews and 21 formal semi-structured interviews with 26 experts involved. The experts' roles were classified into 7 categories, as shown in **Table 3.1**. Their responsibilities in these investigated energy retrofitting projects were summarized.

Table 3.1 Experts' roles and responsibilities in building energy retrofitting works.

Role	Responsibility in building energy retrofits	Number of interviews	Number of experts
Building owner	• Ensuring projects are sustainable, energy-efficient, feasible, and meet all regulatory requirements. • Managing the entire lifecycle from identifying opportunities to ongoing maintenance for the project, including financial and project execution. • Identifying energy-saving	5 interviews	6 experts

Role	Responsibility in building energy retrofits	Number of interviews	Number of experts
	opportunities through retro-commissioning and data analysis, allocating project budget, and implementing the retrofitting projects.		
Consultant	• Building BIM models and develop platforms to collect and analyze building sensor data. • Guiding clients from energy-saving simulation and planning to implementation and ongoing monitoring. • Modifying and optimizing existing building structural frameworks.	6 interviews	6 experts
Contractor	• Identifying and selecting qualified subcontractors. • Monitoring subcontractors' work in building energy retrofitting.	1 interview	1 expert
Engineer	• Calculating the energy-saving potential and applying for funding. • Conducting energy audits before retrofits and conducting measurement and verification of building energy performance after retrofits. • Maintaining and operating all the equipment inside the building and monitoring and controlling the building's energy performance. • Ensuring retrofitting	5 interviews	5 experts

Role	Responsibility in building energy retrofits	Number of interviews	Number of experts
Supplier	implementations, verifying savings and ensuring their function as designed. • The design, supply and installation works of chiller replacement and upgrade • Lighting system design and replacement, and smart lighting control. • Replacing air filters with new air filters. • Promoting innovative glass	5 interviews	6 experts
Energy service provider	• Providing operation and maintenance services, guaranteeing energy savings and investing in retrofitting the building's equipment.	1 interview	1 expert
Utility company	• Providing funding to building energy retrofitting projects.	1 interview	1 expert

3.3 Case Study

The case study is a useful tool to explore and cultivate a profound understanding of a particular phenomenon (Yin, 2009). Case studies are often combined with other data collection techniques, such as archival data, interviews, questionnaires, and observations, to gather evidence and yield insights (Fellows & Liu, 2021). In this study, multiple cases of energy retrofit projects for existing office buildings were collected, and interviews were conducted with the key stakeholders in these cases. A multi-method approach was implemented in each case to identify the actual EOBEER challenges faced in Hong Kong from these theoretical challenges.

For the cases identification, relevant directories such as the HKGBC Retrofitting Guidebook and online electronic databases (e.g., Smart Power Building Fund, Eco Building Fund) were utilized to identify suitable retrofitting projects. Then, the snowball sampling technique, an effective approach to identifying hidden populations, was used to identify more relevant retrofitting projects. For example, in semi-structured interviews, the owners of the initial projects identified through the HKGBC Retrofitting Guidebook and online electronic databases would be asked to invite other experts with additional energy retrofitting projects. This chain-referral method continued until a representative sample was reached.

In total, 38 building energy retrofitting cases were collected. However, 36 EOBEER cases remained for further analysis, as two cases were not eligible. One case is not an office building, while another one is not located in Hong Kong. These cases showcase diverse energy retrofitting initiatives, shown as in **Table 3.2**. HVAC system upgrades were the most common, focusing on replacing or upgrading chiller plants, coolers, air handling units, and ventilation air filters. Lighting system improvements involved switching to light-emitting diode (LED) tubes. Two cases addressed building envelope improvements. One example involved transforming an industrial facility into a workspace through structural alterations, including a new light well for natural daylight and south-facing facade shading elements to minimize solar heat gain and glare. Another case involved adding an interior glass layer within the existing curtain wall to address unbalanced sunlight and heat exposure, achieving a 20-30% reduction in cooling energy.

Table 3.2 Case information and retrofitting initiatives.

Category	Number	Retrofitting initiatives
HVAC system-chiller plant	6 cases	• AI system for chiller plant optimization control; • Replacement of chiller plants; • Modification of HVAC chilled water system; • Installation of automatic tube cleaning system.

Category	Number	Retrofitting initiatives
HVAC system-air conditioning	5 cases	• Air balancing and VAV sensor calibration of the air conditioning system; • Replacement of air conditioning units.
HVAC - ventilation	10 cases	• Improvement of the fresh air supply system; • Replacement of air filters; • Replacement of air handling unit with high-efficiency EC fan.
Lighting system	6 cases	• Replaced the original lighting with LED tubes; • Installation of smart sensor control system.
ESCO	4 cases	• Use ESCO contracts to manage building energy for clients.
Facility replacement	2 cases	• Room retrofitting, gate refurbishment and toilet renovation; • Improvement of uninterruptible power supply system.
Building envelope improvement	2 cases	• Installation of an additional glass layer inside the existing curtain wall; • Installation of shading elements on the south-facing facade to reduce solar heat gain and glare and creating of openings in the floor slab to allow natural light.
BIM model	1 case	• Building BIM model based on the 2D drawing and the laser scan.

New technologies were applied to retrofit existing office buildings. In many cases, sensors were utilized to control the lighting and ventilation systems in buildings. Smart metering monitors building energy consumption, enabling benchmarking and promoting energy efficiency. For buildings with only 2D drawings, laser scanning captures detailed 3D data to generate BIM models, enhancing facility management and retrofitting design.

Additionally, 360° photos create virtual building models that integrate with BIM models and IoT devices. Some projects utilize building-integrated photovoltaics (BIPVs) on walls and facades to generate on-site renewable energy and reduce grid dependence. Walkable solar panels on the roof further improve efficiency by eliminating the need for dedicated maintenance areas. For buildings with limited structural capacity, innovative solutions like aerodynamically-based solar panels ensure safety during typhoons without requiring concrete bases.

3.4 Z-numbers-based Delphi Survey

Delphi survey is another data collection method that is commonly used in many research areas (Hasson et al., 2000). It is conducted by proceeding with multiple rounds of structured questionnaires until the consensus on experts' opinions is achieved. The experts are anonymous, allowing experts to express their opinions freely and avoid social pressure and individual factors affecting the consensus, such as experts' status, reputation, and positions. Although the Delphi method is a highly formalized method to extract the maximum amount of unbiased information from experts, it is limited by uncertainty and statistical optimism or pessimism bias (J. F. Yeung et al., 2008). The Z-Numbers-based Delphi technique was proposed, as Z-numbers consider the reliability of the information (Zadeh, 2011).

The initial stage of the Delphi survey normally contains open questions to collect the qualitative data. However, potential EOBEER challenges have been identified from the systematic literature review, and those challenges that were frequently mentioned in the semi-structured interviews were extracted for the Delphi survey. As a result, the Delphi survey in the research directly began with the EOBEER challenges evaluation. The questionnaire will comprise two sections: (1) participant background information; and (2) participants' assessment of the EOBEER challenges. Based on a scale of 1–7, participants will assess the EOBEER challenges (From 1-not critical to 7-most critical) and their confidence/reliability in the assessment (From 1-very low to 7-very high) (Tetteh et al., 2023).

The experts who participated in the semi-structured interviews were invited to attend the Delphi survey, as they have rich experience in building energy retrofitting. Building owners are regarded as "sure" participants regardless of this selection criterion, as their role in retrofit is of the utmost importance.

Consensus standards in Delphi research have never been rigorously established (von der Gracht, 2012). Various approaches, including subjective criteria, descriptive statistics, and inferential statistics, have been employed to measure consensus. The coefficient of variation is a statistical measure used to measure the relative variability or dispersion of a dataset. It is calculated as the ratio of the standard deviation to the mean, expressed as a percentage. For this research, the coefficient of variation was utilized to test the consensus in the Delphi survey. The criteria of coefficient of variation and consensus (English & Kernan, 1976) are shown in **Table 3.3**.

Table 3.3 Coefficient of variation (English & Kernan, 1976).

Coefficient of variation	Decision rule
$0 < \mathrm{V} \leq 0.5$	Good degree of consensus. No need for an additional round.
$0.5 < \mathrm{V} \leq 0.8$	Less than satisfactory degree of consensus. Possible need for an additional round
$\mathrm{V} > 0.8$	Poor degree of consensus. Definite need for an additional round.

Z-numbers-based Delphi survey is one of those fuzzy Delphi hybrid methods that enables experts to systematically identify all the critical challenges, considering experts' level of "sureness" in quantifying the challenges (Zhang & Mohandes, 2020). More importantly, it is strong at removing experts' subjectivity from the results and ensuring more objective, valid, reliable, and consistent results. The case-based interviews will aid in the selection of stakeholders for the Z-numbers-based Delphi survey.

The fuzzy set A in universe X is a set of pairs (Zadeh, 1965). The membership value $\mu_A(x)$ represents the degree of belonging of x in A.

$$A = \{(x, \mu_A(x)) : x \epsilon X\} \tag{1}$$

The triangular membership function, one of the simplest membership functions, was adopted in this research. Its formula is shown as follows:

$$f(x) = \begin{cases} 0, & x \leq a \\ \dfrac{x-a}{b-a}, & a < x \leq b \\ \dfrac{c-x}{c-b}, & b < x \leq c \\ 0, & x > c \end{cases} \tag{2}$$

Z-number is an ordered pair of fuzzy numbers (A, R), where A is a fuzzy bound of the criticality of EOBEER challenges, and R is a fuzzy bound of the reliability of EOBEER challenges. The expert's opinion collected from the Delphi survey could be presented with Z-numbers, shown as follows:

$$Z_{ij} = (a_{ij}, b_{ij}, c_{ij}; reliability) \tag{3}$$

Where $A_{ij} = (a_{ij}, b_{ij}, c_{ij})$ is the opinion of Expert i on EOBEER Challenge j.

The Z-number (Z) could be transformed into numerical numbers by following these procedures (Zhang & Mohandes, 2020):

1. Using the center of gravity method to transform the fuzzy number of reliability.

$$\alpha = \frac{\int x\mu_R(x)dx}{\int \mu_R(x)dx} \tag{4}$$

2. The fuzzy number Z' could be represented by the following formula:

$$Z' = (\sqrt{\alpha}a, \sqrt{\alpha}b, \sqrt{\alpha}c) \tag{5}$$

3. The average of the fuzzy sets Z' can be defined by the formula:

$$\overline{Z'} = (\frac{1}{n}\sum_{i=1}^{n} a_i, \frac{1}{n}\sum_{i=1}^{n} b_i, \frac{1}{n}\sum_{i=1}^{n} c_i) \tag{6}$$

4. Using the center of gravity method to transform the fuzzy number of criticality.

$$x = \frac{\int x\mu_A(x)dx}{\int \mu_A(x)dx} \tag{7}$$

The linguistic terms (LTs) assigned to each challenge were transformed to their fuzzy linguistic scale (FLS) and triangular fuzzy number (TFN) for further analysis (Kang et al., 2012), as shown in **Table 3.4** (Tetteh et al., 2023). The obtained TFNs were used to compute the criticality and the reliability of each challenge. The minimum and maximum values of the data were taken as the two terminal points of the TFNs, while the geometric mean was used as the membership degree function to avoid the effects of extreme values (Z. Ma et al., 2012).

Table 3.4 MFs Rules of linguistic terms (Tetteh et al., 2023).

Criticality			Reliability		
LTs	FLS	TFN	LTs	FLS	TFN
Not critical	1	(0,0,1)	Very low	1	(0,0,0.1)
Least critical	2	(0,1,3)	Low	2	(0,0.1,0.3)
Medium low	3	(1,3,5)	Medium low	3	(0.1,0.3,0.5)
Moderate	4	(3,5,7)	Medium	4	(0.3,0.5,0.7)
Medium high	5	(5,7,9)	Medium high	5	(0.5,0.7,0.9)
Very critical	6	(7,9,10)	High	6	(0.7,0.9,1.0)
Most critical	7	(9,10,10)	Very high	7	(0.9,1.0,1.0)

In total, 15 experts attended the Z-numbers-based Delphi survey. All these experts have participated in face-to-face/online semi-structured interviews before attending the Delphi survey, so they are familiar with the research objectives. Those experts include 4 building owners, 4 engineers, 3 suppliers, 2 consultants, 1 contractors, 1 energy service provider.

3.5 Focus Group Meetings

Focus group meeting involves pre-planned and controlled discussions that are held within a target group until a defined consensus criterion is reached (Wimpenny & Gass, 2000). It is valuable as it supports collaborative and open discussion among participants to arrive at meaningful results (Krueger, 2014).

Focus group meetings are organized to solicit participants' views on the proposed EOBEER guide and policy recommendation packages and validate the research findings. To allow for diversity of participants in each focus group meeting, a within-group design was used (Krueger, 2014). Key stakeholders involving building owners, tenants, facility managers, energy managers, developers, investors, financial and insurance companies, materials and equipment suppliers and manufacturers, energy auditors, utility companies, government departments and authorities, energy saving service departments, commissioning providers, planning and design units, including architects, designers, engineers, and consultants, and construction and supervision units, including contractors, industry-led bodies promoting awareness and solutions, such as HKGBC and HK Electric, were invited to participate in the focus group meetings. Stakeholders who did not participate in the interviews/surveys also were invited, to minimize bias and obtain a more detailed understanding of the subject.

Krueger (2014) indicated that a maximum of four focus groups is sufficient to generate adequate results. In this study, four focus group meetings were organized. Except our research team, 16 experts attended the focus group meetings. Their profiles are shown in **Table 3.5**. We also invited those experts who cannot attend focus group meetings to review research findings (i.e., Innovative Energy Efficiency Retrofitting Guide and policy recommendations) and to provide comments or suggestions through Emails. Three experts from three companies (i.e., consultant company, construction company and facility management company) provided their valuable comments which were included in the research findings.

Table 3.5 Profiles of focus group meeting participants.

Code	Affiliation	Position
Expert 1	Engineering company	Energy service manager
Expert 2	Engineering company	Director
Expert 3	Non-profit organization	Executive director
Expert 4	Consultant company	Director
Expert 5	Consultant company	Managing director
Expert 6	Building owner-facility management	Assistant director
Expert 7	Building owner-facility management	Vice President
Expert 8	Utility company	Department head
Expert 9	Engineering company	Senior director
Expert 10	Building owner-facility management	Senior building services manager
Expert 11	Consultant company	Associate director
Expert 12	Building owner-facility management	Senior building services engineer
Expert 13	Building owner-facility management	Associate Director

Code	Affiliation	Position
Expert 14	Lighting company	Business Development Specialist
Expert 15	Energy service company	Energy Business Line Director
Expert 16	Consultant company	Director

Each meeting lasted for about one hour and was recorded for further analysis. The participants were informed of the research findings and the proposed guide and policy recommendations during the meeting. Here is an agenda of the focus group meetings:

1. A brief introduction to this research, including research background, research framework, Innovative Energy Efficiency Retrofitting Guide and policy recommendations.
2. A discussion session to collect participants' comments and suggestions. Relevant questions include: (1) Do you think the proposed Innovative Energy Efficiency Retrofitting Guide are technically feasible and appropriate in the context of Hong Kong? Why or why not? (2) Do you think the proposed policy recommendation packages are technically feasible and appropriate in the context of Hong Kong? Why and why not?

After focus group meetings, the proposed Innovative Energy Efficiency Retrofitting Guide and policy recommendation packages were modified according to criticisms, comments, and suggestions of the focus groups.

Chapter 4 Research Results

4.1. EOBEER Challenges in Hong Kong

After conducting semi-structured interviews and analysing cases collected from the real world, 23 EOBEER challenges that practitioners most encountered in Hong Kong were identified. These challenges were classified into seven categories: financial challenges, technical challenges, regulatory challenges, institutional challenges, social challenges, environmental challenges and other challenges.

4.1.1. Financial Challenges

Financial challenges refer to the difficulties or obstacles that individuals or organizations face in managing their finances when conducting energy retrofitting. Financial challenges are the primary concern before building owners make retrofitting decisions. Retrofitting existing office buildings can be expensive, and the initial costs can cause challenges when the cost savings are realized over an extended period. The upgrade costs can vary depending on the upgrade type, the building size, and the complexity of retrofitting. Organizations, especially small and medium-scale enterprises, are often financially constrained to take up retrofit initiatives. Further, government incentives for existing office building retrofit in Hong Kong are absent, discouraging retrofitting projects on finance. The financial challenges and their description are shown in **Table 4.1**.

Table 4.1 Financial EOBEER challenges.

Code	Financial challenges
F1	***Long payback period of building energy retrofitting*** This challenge refers to the long duration required for energy savings to offset the initial investment in energy retrofitting.
F2	***Uncertainty about the payback period of building energy retrofitting*** This challenge means the duration required for energy savings to offset the initial investment is surrounded by uncertainty.
F3	***High investment cost in building energy retrofitting***

	This challenge refers to the significant upfront expenses required to implement energy efficiency improvements.
F4	***Lack of access to financing for building energy retrofitting*** This challenge refers to the difficulty in obtaining the necessary financial resources to undertake energy efficiency improvements.
F5	***Poor economy and market for building energy retrofitting*** This challenge refers to adverse economic circumstances and a lack of demand or opportunities in the market for energy efficiency improvements in existing buildings.

4.1.2. Technical Challenges

Technical challenges refer to the difficulties or obstacles that arise due to the complex nature of technology, systems, or processes in energy-efficiency upgrades of existing office buildings. The building systems of pre-1980s buildings are often outdated and have limited capacity for energy-efficient upgrades. Retrofitting complicated building systems can cause additional technical challenges, such as the potential of compromising fire safety and HVAC systems. Also, new technologies and innovations bring new trends to retrofit existing office buildings, requiring specialized skills and expertise. The technical challenges and their description are shown in **Table 4.2**.

Table 4.2 Technical EOBEER challenges.

Code	Technical challenges
T1	***Lack of access to sustainable materials in building energy retrofitting*** This challenge refers to the difficulty in obtaining environmentally friendly and resource-efficient materials for use in energy retrofit projects, such as energy-efficient insulation, low-emissivity windows, and renewable energy systems.
T2	***Complexity of building energy retrofitting technologies*** This challenge refers to the complicated nature of technologies involved in implementing energy efficiency improvements
T3	***Lack of knowledge about building energy retrofitting technologies***

	This challenge refers to a limited understanding or awareness of the available technologies for improving energy efficiency in existing office buildings.
T4	***Lack of research and innovation implementation on building energy retrofitting technologies*** This challenge refers to insufficient efforts and limited application of cutting-edge research and innovative solutions in energy efficiency retrofit projects.
T5	***Lack of actual data on existing building energy performance*** This challenge refers to the absence of accurate and comprehensive information regarding the energy consumption of existing office buildings.

4.1.3. Regulatory Challenges

Regulatory challenges refer to the difficulties or obstacles that arise from the regulatory environment surrounding energy retrofitting improvements. Regulatory challenges come from the need to comply with various building codes and standards, which can vary across jurisdictions. Regulatory challenges are encountered when existing building codes and standards do not align with retrofitting objectives, rendering them non-compliant with the standards. Retrofitting can also require permits that add difficulties regarding time and finances. The regulatory challenges and their description are shown in **Table 4.3**.

Table 4.3 Regulatory EOBEER challenges.

Code	Regulatory challenges
R1	***Lack of government incentives*** This challenge refers to the absence of incentives provided by the government, such as financial incentives, tax credits, grants, or subsidies to encourage energy retrofitting in existing office buildings.
R2	***Lack of established benchmarks and criteria for building energy retrofitting*** This challenge refers to the absence of standardized guidelines, benchmarks and criteria that practitioners can rely on when undertaking energy retrofitting projects.

R3	***Lack of policies, legislation and regulations*** This challenge refers to the absence of specific policies, legislation, and regulations on energy retrofitting in existing office buildings.

4.1.4. Institutional Challenges

Institutional challenges refer to obstacles or difficulties that arise from the structure practices within organizations, institutions, and stakeholders. These issues are related to ownership, management, and legal agreements that may affect the retrofitting process. The conflicts between multiple building owners, tenants, designers, consultants, and contracts can inhibit the decision-making process of energy retrofitting. The institutional challenges and their description are shown in **Table 4.4**.

Table 4.4 Institutional EOBEER challenges.

Code	Institutional challenges
I1	***Interruption to building operation*** This challenge refers to energy retrofitting activities that disrupt the normal operation of the existing office buildings. This can include temporary shutdowns of some areas, relocation of occupants, or limitations on access to certain areas of the building.
I2	***Stakeholders' insufficient awareness and knowledge of building energy retrofitting*** This challenge refers to the lack of understanding and familiarity among various individuals and organizations involved in the retrofitting process. This includes building owners, occupants, contractors, policymakers, and other relevant stakeholders.
I3	***Building owners lack motivation to retrofit*** This challenge refers to building owners not willing to invest in energy retrofitting projects for their existing buildings.
I4	***Lack of trust among stakeholders during building energy retrofitting implementation***

	Trust is crucial for successful collaboration and effective implementation of retrofitting projects. This challenge refers to the absence or breakdown of trust between various individuals and organizations involved in the retrofitting process.
I5	***Building owners and occupants are unwilling to change*** This challenge refers to the resistance or reluctance among these individuals to adopt new practices or behaviours related to building energy efficiency.

4.1.5 Social Challenges

Social challenges refer to the potential disruption to the public during the energy retrofitting process, which can lead to dissatisfaction. Energy retrofitting initiatives have interactions with others in society. For example, if the public may have little knowledge of energy retrofitting works, they may hold a conservative opinion on energy retrofitting and think it is not necessary. The social challenges and their description are shown in **Table 4.5**.

Table 4.5 Social EOBEER challenges.

Code	Social challenges
S1	***Low public awareness and understanding on building energy retrofitting*** This challenge refers to the lack of knowledge and familiarity among the general public regarding the concept, benefits, and importance of retrofitting existing buildings for improved energy efficiency.
S2	***Lack of citizen involvement and public support*** This challenge refers to the limited engagement and participation of citizens in energy retrofitting initiatives, as well as a lack of overall public support for these efforts.

4.1.6 Environmental Challenges

Environmental challenges refer to the impact of energy retrofitting on the environment, such as natural resource consumption, waste generation, and carbon emissions. The primary challenge encountered in retrofitting existing office buildings includes the environmental impacts in terms of noise, dust, waste and carbon emissions during the retrofitting. If environmental challenges associated with existing office building retrofitting are not adequately tackled, it could undermine the initial aim of reducing carbon emissions. The environmental challenges and their description are shown in **Table 4.6**.

Table 4.6 Environmental EOBEER challenges.

Code	Environmental challenges
E1	***Noise, dust, waste and carbon emissions*** This challenge refers to the negative environmental and health impacts that can arise during the process of retrofitting buildings for improved energy efficiency.

4.1.7. Other Challenges

Other challenges refer to the other obstacles or difficulties of energy retrofitting projects that are not mentioned above. The other challenges and their description are shown in **Table 4.7**.

Table 4.7 Other EOBEER challenges.

Code	Other challenges
O1	***Deficiencies in the skills and training on building energy retrofitting*** The challenge refers to the lack of knowledge, expertise, and specialized training among professionals and workers involved in retrofitting projects.
O2	***Lack of integration between research, standards, and practice on building energy retrofitting*** The challenge refers to the disconnect and limited coordination between these three key components (i.e., research, standards and practice) in the field of retrofitting existing buildings for improved energy efficiency

4.2. EOBEER Challenges Assessment

These challenges were quantified through the Z-numbers-based Delphi survey. This Delphi survey was conducted in two rounds. After two rounds, the coefficient of variation of all responses is less than 0.5. According to **Table 3.1**, a good degree of consensus on the criticality of EOBEER challenges was achieved among experts (von der Gracht, 2012). In the end, the final results are shown in **Table 4.8**.

Table 4.8 Criticality of EOBEER challenges.

Rank	Code	Category	Challenges	Criticality
1	R1	Regulatory challenges	Lack of government incentives	7.58
2	T3	Technical challenges	Lack of knowledge about building energy retrofitting technologies	6.94
3	R3	Regulatory challenges	Lack of policies, legislation and regulations	6.90
4	I3	Institutional challenges	Building owners lack motivation to retrofit	6.87
5	F1	Financial challenges	Long payback period of building energy retrofitting	6.82
6	T5	Technical challenges	Lack of actual data on existing building energy performance	6.82
7	R2	Regulatory challenges	Lack of established benchmarks and criteria for building energy retrofitting	6.79
8	F3	Financial challenges	High investment cost in building energy retrofitting	6.59
9	I2	Institutional challenges	Stakeholders' insufficient awareness and knowledge of building energy retrofitting	6.34
10	O1	Other challenges	Deficiencies in the skills and training on building energy retrofitting	6.16
11	I4	Institutional challenges	Lack of trust among stakeholders during building energy retrofitting implementation	6.06

Rank	Code	Category	Challenges	Criticality
12	I5	Institutional challenges	Building owners and occupants are unwilling to change	5.88
13	T4	Technical challenges	Lack of research and innovation implementation on building energy retrofitting technologies	5.82
14	F5	Financial challenges	Poor economy and market for building energy retrofitting	5.78
15	F4	Financial challenges	Lack of access to financing for building energy retrofitting	5.78
16	T2	Technical challenges	Complexity of building energy retrofitting technologies	5.62
17	O2	Other challenges	Lack of integration between research, standards, and practice on building energy retrofitting	5.53
18	F2	Financial challenges	Uncertainty about the payback period of building energy retrofitting	5.48
19	E1	Environmental challenges	Noise, dust, waste and carbon emissions	5.40
20	S1	Social challenges	Low public awareness and understanding on building energy retrofitting	5.30
21	S2	Social challenges	Lack of citizen involvement and public support	4.78
22	I1	Institutional challenge	Interruption to building operation	4.77
23	T1	Technical challenge	Lack of access to sustainable materials in building energy retrofitting	4.07

The top 5 EOBEER challenges are "lack of government incentives," "lack of knowledge about building energy retrofitting technologies," "lack of policies, legislation, and regulations," "building owners lack motivation to retrofit," and "long payback period of building energy retrofitting." In the top 5 EOBEER challenges, two come from the regulatory challenges. The others are from the categories of technical challenges, regulatory challenges, and institutional challenges, respectively.

Regulatory challenges, including "lack of government incentives," "lack of policies, legislation and regulations" and "lack of established benchmarks and criteria for building energy retrofitting," are considered the primary barriers to promoting building energy retrofitting. As the top EOBEER challenge, the "lack of government incentives" is the only one whose criticality is more than 7 in Table 11. From semi-structured interviews, many practitioners mentioned that there are few government incentives in Hong Kong, especially financial incentives.

China Light and Power (CLP) and Hong Kong Electric (HK Electric) are two electric providers in Hong Kong. These two utility companies have launched the Eco Building Fund and Smart Power Building Fund, providing subsidies for energy-saving improvement works in existing buildings. However, the application procedures are strict, and the subsidies are limited. The building owners need to invest in the retrofit projects by their own money first. After completing the retrofitting works, building owners need to prove that the retrofitting initiatives can save electricity significantly before they get subsidies from utility companies. Moreover, the subsidies are more likely to provide the retrofitting and retro-commissioning works of the lighting, air-conditioning, lifts and escalators, and electrical installations in office buildings. The scope covers retrofits that are directly related to electricity saving. Other types of energy retrofitting works, such as façade improvement, are not included.

It lacks specific policies, legislation and regulations on energy retrofitting in Hong Kong. Most retrofitting projects should follow the mandatory building code in Hong Kong, including the Buildings Energy Efficiency Ordinance (BEEO), Building Energy Code (BEC) and Energy Audit Code (EAC). However, no specific policies, legislation and regulations are launched for energy retrofitting works. Furthermore, it lacks benchmarks and criteria for building energy retrofitting, which bothers practitioners during the implementation of energy retrofitting. Due to the lack of local guidelines, international industrial guidelines were applied in the industry, such as the International Performance

Measurement and Verification Protocol (IPMVP), international lighting standard (IEC 60598), EPA building commissioning guidelines.

Considering financial challenges, the “long payback period of building energy retrofitting” and “high investment cost in building energy retrofitting” are the most important. The payback period is a crucial financial element when building owners and managers consider energy retrofitting initiatives. The long payback period diminishes the opportunities for building owners and managers to benefit from energy-saving renovations. The high cost of energy retrofitting not only comes from the technologies and equipment but also the installation fee and labour costs. In some cases, almost half of the cost is for labour installation and the accessory for the wireless. Another reason is that the cost of energy (e.g., electricity) is relatively low compared to the rent. The building owners and managers are likely to pay for the energy, not the energy renovation. These financial burdens make it difficult to justify that the investment in energy retrofit is reasonable, particularly for medium-sized companies.

As for the technical challenges, “lack of knowledge about building energy retrofitting technologies” and “lack of actual data on existing building energy performance” are the main obstacles in energy retrofitting projects. Stakeholders, such as building owners and managers, may not understand the technical requirements and principal theory for energy-saving technologies. The rapid evolution of these technologies poses more difficulties for stakeholders, fostering a conservative attitude toward embracing energy retrofitting technologies. Some office buildings may lack adequate records on the structural materials or drawings, posing challenges in verifying the structure and materials before the retrofitting works. In some cases, destructive testing may be necessary to test the strength and suitability of the existing materials for the new requirements.

Notable institutional challenges include “building owners lack motivation to retrofit” and “stakeholders’ insufficient awareness and knowledge of building energy retrofitting.” Social aspects, especially the role of the public, have received insufficient attention in energy retrofitting cases and interviews. Many practitioners prioritize their responsibility to their clients. It lacks channels to collect public opinions and communication mechanisms between the project and the public. Furthermore, practitioners emphasized that the energy retrofitting projects they have been involved in had no impacts or minimal impacts on the environment. However, when it comes to handling the waste generated from the projects, there is a notable absence of recycling processing methods or mechanisms. Landfill appears to be the only available option.

4.3 Strategies to Overcome EOBEER Challenges

Energy efficiency retrofitting in existing office buildings saves energy and building operation costs, contributes to achieving carbon neutrality and benefits the environment. To facilitate the implementation of energy efficiency retrofitting and provide practical solutions to the challenges for practitioners, strategies to overcome EOBEER challenges are proposed by the research team. These strategies are proposed based on the results of semi-structured interviews and the comments and suggestions in focus group meetings.

The strategies to overcome each financial EOBEER challenge are shown in **Table 4.9**. These strategies include implementing funding programs, green financing, energy performance contracting (ESCOs), Cost-benefit analysis and modeling, case studies and benchmarking and improving financial data transparency. The funding programs (e.g., grants, subsidies, and tax credits) from governments and institutions can lessen the upfront financial burden. Innovative financial tools like green loans and bonds specifically target sustainable projects. Partnering with ESCOs allows building owners to avoid upfront costs. ESCOs finance, implement, and guarantee energy savings, collecting their fee from the achieved savings. Providing clear data on payback periods, benefits, and annual savings can help building owners make informed decisions. Thorough analysis and modeling tools can accurately predict the financial viability of a retrofit project. Meanwhile, studying successful retrofit projects and comparing energy use against similar buildings helps establish realistic expectations for payback periods.

Table 4.9 Strategies to overcome financial EOBEER challenges.

Code	Challenges	Strategies
F1	Long payback period of building energy retrofitting	• Encourage clients to apply for retrofitting funding. Encourage eligible clients to apply for funding applicable to energy efficiency retrofit works such as CLP ECO Building Funds and Smart Power Building Funds from

Code	Challenges	Strategies
		HK Electric. • Promote energy performance contracting. Energy performance contracting involves partnering with energy service companies that finance, implement, and guarantee energy savings from retrofitting projects. The energy service companies are paid from the energy savings achieved, allowing building owners to avoid upfront costs and benefit from immediate energy cost reductions. • Develop innovative financing mechanisms. Green finance is a new trend to address financing obstacles faced by sustainable projects and initiatives. It includes various financial instruments, such as green bonds, green loans, green insurance and green investment funds.
F2	Uncertainty about the payback period of building energy retrofitting	• Disclose more financial information on building energy retrofitting, showing the benefits of the retrofitting investment, the payback period, and the annual savings. • Perform a thorough cost-benefit analysis to determine the financial viability of building energy retrofitting projects. • Utilize energy modeling and simulation tools to estimate the potential energy savings and payback period of retrofitting measures. • Use case studies and benchmarking. Study and analyze case studies of similar retrofitting projects to understand their payback periods. Benchmarking against similar buildings or projects can provide references to estimate the payback period.

Code	Challenges	Strategies
F3	High investment cost in building energy retrofitting	• Provide financial incentives by the government and institutions, such as grants, subsidies, or tax credits to offset the upfront costs of energy retrofitting. • Promote energy performance contracting. Energy performance contracting involves partnering with energy service companies that finance, implement, and guarantee energy savings from retrofitting projects. The energy service companies are paid from the energy savings achieved, allowing building owners to avoid upfront costs and benefit from immediate energy cost reductions. • Develop innovative financing mechanisms. Green finance is a new trend to address financing obstacles faced by sustainable projects and initiatives. It includes various financial instruments, such as green bonds, green loans, green insurance and green investment funds.
F4	Lack of access to financing for building energy retrofitting	• Increase government funding. Increase government funding for building energy retrofitting projects and initiatives, including grants, subsidies, and low-interest loans. Consider relaunching the defunct Buildings Energy Efficiency Funding Scheme. • Develop innovative financing mechanisms. Green finance is a new trend to address financing obstacles faced by sustainable projects and initiatives. It includes various financial instruments, such as green bonds, green loans, green insurance and green investment funds. • Promote energy performance contracting. Energy performance contracting involves partnering with

Code	Challenges	Strategies
		energy service companies that finance, implement, and guarantee energy savings from retrofitting projects. The energy service companies are paid from the energy savings achieved, allowing building owners to avoid upfront costs and benefit from immediate energy cost reductions.
F5	Poor economy and market for building energy retrofitting	• The government needs to motivate the market by encouraging various energy-efficient initiatives and products. Offer financial incentives to building owners and occupants to encourage them to invest in building energy retrofitting.

The strategies to overcome each technical EOBEER challenge are shown in **Table 4.10**. The main strategies include improving access to sustainable materials, standardizing retrofitting technologies and providing training programs to promote technology adoption, bridging the knowledge gap through educational campaigns and demonstration projects, driving innovation and implementation, and facilitating building energy performance data collection and sharing.

Table 4.10 Strategies to overcome technical EOBEER challenges.

Code	Challenges	Strategies
T1	Lack of access to sustainable materials in building energy retrofitting	• Reputable organizations like HKGBC can play a crucial role in promoting sustainable materials and facilitating communication with manufacturers. • Collaborate with research institutions and universities to explore innovative and sustainable materials for building energy retrofitting. Support research projects that focus on developing new materials or improving the sustainability of existing materials. • Collaborate with other retrofitting projects,

Code	Challenges	Strategies
		organizations, or municipalities to procure sustainable materials.
T2	Complexity of building energy retrofitting technologies	• Standardize building energy retrofitting technologies and processes. Develop clear guidelines and standardized protocols for retrofitting projects, making it easier for building owners and professionals to understand and implement retrofitting measures. • Provide education and training programs to building owners, professionals, and contractors on building energy retrofitting technologies. Offer workshops, webinars, and certification programs to enhance their knowledge and skills in retrofitting. • Offer technical assistance and support to building owners and professionals throughout the retrofitting process. Establish a network of experts and consultants who can provide specialized advice and assistance to overcome technical challenges. • Invest in research to advance building energy retrofitting technologies and make them more user-friendly and accessible. Support research institutions and industry collaborations to develop innovative solutions that simplify retrofitting processes and reduce complexity.
T3	Lack of knowledge about building energy retrofitting technologies	• Launch awareness campaigns. Launch comprehensive awareness campaigns to educate industry practitioners about building energy retrofitting technologies. These campaigns can include informative materials, workshops, webinars, and public events that explain the concept, benefits, and available technologies for retrofitting buildings. • Implement demonstration projects. Implement

Code	Challenges	Strategies
		demonstration projects that showcase successful examples of building energy retrofitting. These projects can be open to the industry, allowing practitioners to see firsthand the technologies used in retrofitting and understand their effectiveness. • Integrate technologies into educational institutions. Integrate building energy retrofitting technologies into educational curricula at schools, colleges, and vocational training centers. This will help future professionals, such as architects, engineers, and construction workers, gain knowledge and skills in retrofitting technologies.
T4	Lack of research and innovation implementation on building energy retrofitting technologies	• Increase funding for research and development in building energy retrofitting technologies. Governments, industry associations, and research institutions can allocate more resources for research projects focused on innovative retrofitting technologies. • Foster collaboration between research institutions, industry stakeholders, and government agencies to promote the implementation of research findings and innovative technologies. Encourage knowledge sharing, joint research projects, and technology transfer between academia and industry.
T5	Lack of actual data on existing building energy performance	• Collect energy performance data in existing office buildings. Establish programs or initiatives to collect data on building energy performance. It involves conducting energy audits, implementing monitoring systems, or collaborating with building owners and managers to gather energy consumption data. Benchmarking tools can be used to compare building performance against similar structures and identify

Code	Challenges	Strategies
		areas for improvement. • Implement policies that require building owners to disclose energy performance data. The approaches include energy efficiency ratings, energy consumption data, or other relevant metrics. A standardized framework for collecting and sharing building energy performance information is needed for the mandatory disclosure. • Establish energy data sharing platforms. Create online platforms or databases where building owners can voluntarily share their energy performance data, fostering transparency and enabling benchmarking and best practice sharing.

The strategies to overcome each regulatory EOBEER challenge are shown in **Table 4.11**. The main strategies include implementing a combination of financial and regulatory incentives, establishing clear benchmarks and collaborating with existing certification programs, and creating a comprehensive policy framework with stakeholder involvement and ongoing monitoring. By implementing these strategies, building energy retrofits can become more feasible and contribute to a more sustainable building stock.

Table 4.11 Strategies to overcome regulatory EOBEER challenges.

Code	Challenges	Strategies
R1	Lack of government incentives	• Introduce financial incentives. Financial incentives could be utilized to offset the costs associated with energy retrofitting, such as grants, subsidies, or tax credits. The financial incentives can include direct funding for projects and financial support for energy audits. • Implement regulatory incentives. The Government

Code	Challenges	Strategies
		implements regulatory incentives to reduce bureaucratic hurdles and administrative burdens, such as expedited permitting processes or streamlined regulations for retrofitting projects.
R2	Lack of established benchmarks and criteria for building energy retrofitting	• Establish standardized guidelines and provide benchmarking and performance-based rating tools for building energy retrofitting, similar to those used in other countries to incentivize energy efficiency. • Collaborate with existing certification programs. Work together with BEAM Plus to align retrofitting benchmarks and criteria with their established frameworks.
R3	Lack of policies, legislation and regulations	• Establish new policies, legislation and regulations. Establish new policies, legislation and regulations to provide adequate support for the implementation of energy efficiency retrofitting in existing office buildings. Engage relevant stakeholders, including industry associations, non-profit organizations, and community groups, in developing new policies, legislation, and regulations. • Establish mechanisms to monitor and evaluate the effectiveness of the implemented policies, legislation, and regulations. Regularly assess their impact, identify areas for improvement, and make necessary adjustments to ensure their continued relevance and effectiveness. • Digitalize the application and approval process by the Building Department and other related government departments to shorten the processing time for retrofit approval.

The strategies to overcome each institutional EOBEER challenge are shown in **Table 4.12**. In order to minimize the interruption to building operation, flexible scheduling, occupant relocation, and controlling noise and dust generated in retrofitting processes are the optimal strategies. Educational programs and knowledge-sharing platforms could contribute to raising stakeholders' awareness. Financial incentives, energy labelling, and energy audits could be utilized to motivate building owners. Fostering open communication, defining roles, and collaboration among stakeholders could help build trust among stakeholders. Moreover, financial transparency, occupant involvement, and pilot projects could address concerns of building owners and occupants.

Table 4.12 Strategies to overcome institutional EOBEER challenges.

Code	Challenges	Strategies
I1	Interruption to building operation	• Rescheduling of retrofit operations to outside working hours or weekends. • Consider temporarily relocating occupants or providing alternate spaces during the retrofitting process. • Implement effective noise and dust control measures to minimize their impact, including using barriers, sealing off work areas, and implementing proper ventilation systems to control dust and maintain indoor air quality.
I2	Stakeholders' insufficient awareness and knowledge of building energy retrofitting	• Develop and implement educational programs and awareness campaigns. These initiatives include workshops, seminars, webinars, and informational materials such as brochures and videos. By these approaches, the stakeholders are informed about the benefits and importance of building energy retrofitting. • Establish knowledge-sharing platforms. Case studies and success stories of building energy retrofitting projects are shared, and the positive outcomes and benefits are demonstrated. Highlight the energy savings,

Code	Challenges	Strategies
		improved comfort, and reduced environmental impact achieved through retrofitting.
I3	Building owners lack the motivation to retrofit	• Provide financial incentives. Providing financial incentives, such as grants, tax credits, or low-interest loans, can help overcome the financial barriers that deter building owners from retrofitting. • Implement energy performance label systems. Implementing energy performance labelling systems can create transparency and awareness about the energy efficiency of buildings. Making this information available to potential buyers or tenants will attract more occupants. • Conduct energy audits. Conducting energy audits and benchmarking the energy performance of buildings can provide building owners with a clear understanding of their energy consumption and potential savings through retrofitting.
I4	Lack of trust among stakeholders during building energy retrofitting implementation	• Foster a transparent communication environment among stakeholders. Clearly communicate project goals, timelines, and expected outcomes. Address any concerns or doubts raised by stakeholders promptly and provide regular updates on the progress of the retrofitting project. • Clearly define the roles and responsibilities of each stakeholder involved in the retrofitting project. This will enable stakeholders to effectively communicate expectations and understand their specific obligations, ensuring that they can fulfil their commitments. • Foster collaboration and partnerships among stakeholders, such as building owners, contractors,

Code	Challenges	Strategies
		energy service companies, and government agencies. Encourage stakeholders to work together towards a common goal and share risks and rewards.
I5	Building owners and occupants are unwilling to change.	• Disclose more financial information on building energy retrofitting, showing the benefits of the retrofitting investment, the payback period, and the annual savings. • Involve building owners and occupants in the decision-making process. Understand their concerns and priorities and tailor retrofitting solutions to meet their specific needs. • Implement pilot retrofitting projects in buildings to showcase the benefits and outcomes to building owners and occupants. Use these projects as examples to encourage wider adoption of retrofitting practices.

The strategies to overcome each social EOBEER challenge are shown in **Table 4.13**. The strategies focus on public education through workshops, informational materials, and demonstration projects showcasing successful retrofits. Collaboration with media outlets further spreads awareness. To encourage citizen involvement, the strategies suggest incorporating public opinion through consultations and partnering with local organizations to reach specific communities.

Table 4.13 Strategies to overcome social EOBEER challenges.

Code	Challenges	Strategies
S1	Low public awareness and understanding of building energy retrofitting	• Develop and implement educational programs and awareness campaigns. These initiatives include workshops, seminars, webinars, and informational materials. By these approaches, the stakeholders are informed about the benefits and importance of building energy retrofitting.

Code	Challenges	Strategies
		• Implement demonstration projects. Implement demonstration projects that showcase successful examples of building energy retrofitting. These projects can be open to the industry, allowing practitioners to see firsthand the technologies used in retrofitting and understand their effectiveness. • Collaborate with local media outlets to raise awareness about building energy retrofitting. Provide them with informative and engaging content, such as press releases, articles, and interviews, to educate the public about the benefits and importance of retrofitting.
S2	Lack of citizen involvement and public support	• Involve citizens and local communities in the decision-making process for building energy retrofitting projects. Seek their input, opinions, and ideas through public consultations, focus groups, or surveys. • Collaborate with local community organizations, non-profit groups, or environmental associations to promote building energy retrofitting. Partner with these organizations to organize events, workshops, or information sessions that target specific communities or interest groups.

The strategies to overcome the environmental EOBEER challenge are shown in **Table 4.14**. The strategies focus on waste reduction through government-enforced recycling programs and creating a supportive environment for such practices. Additionally, strategies emphasize pre-construction planning to minimize environmental impacts, using construction techniques that generate less noise, dust, and waste, and implementing environmental management plans to outline specific reduction measures.

Table 4.14 Strategies to overcome environmental EOBEER challenge.

Code	Challenges	Strategies
E1	Noise, dust, waste, and carbon emissions	• Enforce waste recycling. The government should enforce waste recycling, and an enabling environment should be given to facilitate practical implementation. • Develop a comprehensive pre-construction plan that includes strategies to minimize noise, dust, waste, and carbon emissions. • Employ construction techniques that minimize noise, dust, waste, and carbon emissions. • Develop and implement environmental management plans that outline specific measures to minimize noise, dust, waste, and carbon emissions.

The strategies to overcome other EOBEER challenges are shown in **Table 4.15**. For the skills gap, solutions involve developing a workforce through government collaboration with professional bodies, offering on-the-job training and mentorship, and establishing educational programs and certifications. To bridge the research-practice gap, the strategies focus on creating collaborative platforms for knowledge sharing, fostering partnerships between researchers and practitioners, developing user-friendly resources from research findings, and integrating research into building energy policies.

Table 4.15 Strategies to overcome other EOBEER challenges.

Code	Challenges	Strategies
O1	Deficiencies in the skills and training on building energy retrofitting	• Develop the workforce for building energy retrofitting. The government closely collaborates with professional bodies and provides on-the-job training opportunities for practitioners interested in building energy retrofitting. Pair them with experienced professionals who can serve as mentors and guide them through real-world projects. • Educate professionals in educational institutions, such

Code	Challenges	Strategies
		as universities and technical colleges, to develop specialized courses or degree programs focused on building energy retrofitting. • Establish professional certification and accreditation programs. These certifications can serve as a benchmark for competency and ensure that professionals have the necessary skills and knowledge to carry out retrofitting projects effectively. Continuous professional development should be encouraged by the renewal of certificates.
O2	Lack of integration between research, standards, and practice on building energy retrofitting	• Create collaborative platforms that bring together researchers, industry professionals, policymakers, and standards organizations to facilitate knowledge exchange and collaboration. These platforms can include conferences, workshops, and working groups where stakeholders can share research findings, discuss challenges, and develop practical solutions for building energy retrofitting. • Foster partnerships between research institutions and industry practitioners to bridge the gap between research and practice. Encourage joint research projects, knowledge transfer programs, and collaborative initiatives that allow researchers to work closely with practitioners to understand their needs and develop practical solutions. • Develop effective strategies for transferring research findings into practical guidance and disseminating it to industry professionals and policymakers. The outputs include the creation of user-friendly guides, manuals, and online resources that summarize research findings

Code	Challenges	Strategies
		and provide actionable recommendations. • Ensure that research findings and standards are integrated into building energy retrofitting policies and regulations. Collaborate with policymakers to incorporate the latest research findings into policy frameworks, codes, and guidelines.

Chapter 5 Policy Implications and Recommendations

5.1 Focus Group Meetings

Utilising a mixed methods research approach – including literature reviews, interviews, case study analysis, and Delphi surveys – we have developed the following policies to promote EOBEER projects in Hong Kong. These polices are designed to address the specific needs and challenges of office building energy efficiency in Hong Kong identified through the comprehensive research process. Hence, the following policy recommendation were presented to experts in four focus group meetings:

(1) To provide incentives to improve building energy retrofit adoption and implementation.

- Financial support can be provided to building owners who conduct retrofitting to achieve a certain energy savings level. Also, tax rebates may be provided to building owners undertaking energy improvement actions and low-interest or interest-free loans for energy improvement works.
- Non-financial incentives to encourage EOBEER uptake may include providing free energy audit services for building owners and awarding certificates to building owners who have achieved a certain level of energy efficiency based on the audit reports.
- The government should collaborate with the private sector to provide subsidies and technical support for retrofitting projects, calling for more funding schemes. Eco Building Fund and Smart Power Building Fund effectively encourage energy-saving upgrades, but expanding their scope and increasing funding could enhance their impact.

(2) To review and update energy auditing requirements, policies, and standards.

- It is recommended that the government reviews and updates the ten-year energy audit cycle provided in the Building Energy Efficiency Ordinance (BEEO) to a three-year cycle. Having a shorter time frame for an energy audit will enable building owners to monitor the energy consumption pattern of their building service installations and identify measures to improve energy efficiency.

- Building owners often overlook the energy savings recommendations made by the registered energy assessor (REA) during energy audits. Therefore, to ensure the goal of an energy audit is realized, the government should mandate building owners take action to improve the energy performance of their installations before the next audit cycle.
- To promote transparency and energy efficiency, the government should encourage building owners to disclose energy audits and energy performance data. The government can lead by disclosing the energy audits of the buildings operated by the government. This will build trust and encourage private participation. Moreover, the government should consider a secure and user-friendly public platform for disclosing energy audits and performance data from both public and private sectors. Providing energy audit information to relevant stakeholders should be encouraged to track energy consumption in buildings for benchmarking purposes. This action will help drive change in energy utilization and create awareness among building owners.
- If energy audits of office buildings in Hong Kong reveal the energy performance below the energy code, mandatory energy retrofitting and retro-commissioning should be implemented to enhance building energy efficiency. This is because while the government requires building energy audits every ten years, there are no actions after that. So, the government could consider putting some guidelines or practice into law to ensure developers adhere to acceptable EOBEER standards and policies.

(3) To provide regular education and training.

- The research team recommends that the government develops programmes to create awareness from the mainstream (policymakers) to the downstream (building owners and occupiers) of efficient energy practices that are vital to promoting effective EOBEER.
- There should be increased public education on the benefits and methods of energy saving in buildings from the occupant side, such as installing simple automatic control systems, turning off the lights when not in use, and adjusting

the temperature and lighting levels to a comfortable and energy-efficient range. This is intended to help to create a social norm and culture of energy saving and reduce the complaints and resistance from the building users.

(4) To streamline permitting and tendering processes in EOBEER.

- It is recommended that the permitting process for EOBEER should be streamlined to hasten the process and to reduce delays.
- The researchers encourage amendments in the public sector tendering process. It is recommended that the government mandates contractors to provide a turnkey solution, from the assessment to the implementation of the retrofit project, and to commit to energy savings. This would avoid the situation where the project stops after the assessment phase because the client prefers not to progress with recommendations.

(5) Encourage the employment of digital technology and intelligent data management systems for EOBEER.

- Improving data collection and availability to support a data-driven decision-support system for building stocks energy retrofit policy. The government should therefore provide more details and guidelines on how to record and use the energy data of the buildings, such as the timing, frequency, and key performance indicators. This would help the building owners and operators to monitor and analyze their energy performance and identify potential areas for improvement.
- The government should also provide more skills and training to the building professionals and technicians on new technologies and innovations for energy saving, such as AI control optimization and data analytics. This would help to improve the quality and capacity of the retrofitting industry and increase the trust and acceptance of the new technologies among the stakeholders.
- The government departments in charge of building energy retrofitting, such as the Electrical and Mechanical Services Department, Building Department and Fire Services Department, should consider incorporating the latest technology, such as the Internet of Things (IoTs) and cloud computing, into their policies and guidelines. Moreover, innovative products and materials can also play a

crucial role in improving building energy efficiency. For example, new types of insulation can help to reduce heat loss, while high-efficiency windows can let in light without letting in heat. The government should work with the private sector to identify and promote these innovative products and materials.

- The government should consider reviewing and revising building energy standards and codes, incorporating insights from the private sector. Specifically, the calculation method for lighting power density (LPD) should be revised to account for dimmable fixtures and smart lighting systems. By gathering data on energy consumption and power usage over time, the LPD can be accurately determined and adjusted. This would encourage the use of energy-efficient and smart lighting solutions, ultimately promoting better retrofitting practices in Hong Kong.
- Standardize the measurement and verification protocol: The researchers recommend using a common framework, such as the international IPMVP protocol, to measure and verify the energy savings from the retrofit project. This would increase trust and transparency.

(6) To consider the environmental dimension of EOBEER.

- To minimize environmental impact and promote resource recovery, the government should develop regulations for handling waste generated during building energy retrofitting processes. These regulations could include specific disposal or recycling guidelines for different waste types, such as construction debris, hazardous materials, and old insulation. Additionally, mandatory waste minimization strategies during retrofitting projects, supported by dedicated collection and handling systems, could significantly reduce waste generation and ensure safe and responsible disposal.

The six major policy recommendations were presented to experts during the four focus group meetings. Experts commented on various aspects of the suggested recommendations based on their experiences in EOBEER. At the end of the focus group meeting, we reached a consensus on the following key policy recommendations on EOBEER. While all the experts agreed that the proposed policies were critical to EOBEER in Hong Kong, the following key policies were developed based to refine the initial outcomes of the study, as discussed below:

5.2 Policy Recommendations

Through extensive consultations with practitioners involved in EOBEER projects and through thorough policy reviews in Hong Kong and internationally, this research has formulated several key policy recommendations for the government. The policies outlined below represent the top three policy recommendations, which have been refined through a series of focus group meetings that built upon insights from the initial interviews, case study analysis and Delphi surveys:

(1) To review and update energy auditing requirements, policies, and standards.

- **Shorten audit cycles**: It is recommended that the government reduces the ten-year energy audit cycle provided in the Building Energy Efficiency Ordinance (BEEO) to five years in the short term, aligning with upcoming government plans. Ultimately, this cycle should be shortened to three years in the long-term. Shorter audit cycles or intervals will enable facility management (FM) companies and building owners to regularly monitor and improve the energy consumption patterns in building service installations.
- **Enhance transparency and data disclosures:** To improve transparency in energy efficiency, it is advisable for the government to encourage FM companies and building owners to anonymously disclose energy audits and performance data. Current efforts by EMSD to list buildings with issued energy audit forms are insufficient in detail and lack categorisation of energy performance. The government should lead by example by disclosing detailed energy audits of the buildings it operates in, fostering trust and encouraging private sector participation. Additionally, the existing platform should be further developed to become more secure and user-friendly. This would enhance the disclosure of energy audits and performance data across both public and private sectors. This would be key to benchmarking and drive improvements in energy utilisation in office buildings, and other built assets in general.

- **Mandatory retrofits for underperforming office buildings:** If energy audits reveal that office buildings in Hong Kong perform below the energy code, mandatory retrofitting and retro-commissioning should be required to enhance energy efficiency. This is crucial as the current every ten-year requirement for building energy audits lack enforcement of stringent actions, resulting in overlooked energy savings recommendations from registered energy assessors (REAs). Implementing mandatory guidelines or practices into law will ensure adherence to EOBEER standards and policies.
- **Establish performance benchmarks:** The government must establish a benchmark to classify all existing office buildings into three categories: low, average, and high performing. This benchmark will serve as a standard process for estimating building energy performance and guide improvement efforts.
- **Proposal submission compliance post-audits:** It is recommended that FM companies and building owners submit an improvement proposal post-audit, outlining necessary retrofit strategies and a phasing programme for implementation. The government should consider imposing penalties for non-adherence and providing rewards/incentives for achieving superior building energy performance through retrofits. For better results, government agencies, such as the EMSD should assess the technical proposals submitted by building owners and FM companies, assisting them in applying for government subsidies and incentives. A standardised assessment platform could be developed to facilitate the submission of these proposals post audits.

(2) To provide regular education and training.

- **Comprehensive awareness programmes:** The research team recommends that the government initiates programmes that raise awareness of energy-efficient practices from policymakers (mainstream) to FM companies, building owners and occupiers (downstream). These programmes are essential for fostering a comprehensive understanding and adoption of efficient energy measures.
- **Targeted training for stakeholder groups:** It is crucial to tailor government training programmes to building stakeholder groups such as FM

companies, building owners (single/multi building owners), and building occupants. These programmes should highlight the specific benefits and responsibilities of each group, emphasising the importance of building retrofits. Training for FM companies and building owners, for instance, should aim at closing the knowledge gap on energy efficiency retrofitting, highlighting the financial advantages and available methods for energy savings. These sessions should include practical training on developing retrofit proposals, as discussed earlier, and applying for green incentives and green financing. In addition, the government should collaborate with relevant organisations, such as the Hong Kong Green Building Council (HKGBC), International Facility Management Association (IFMA) Hong Kong, Hong Kong Institute of Facility Management (HKIFM), Building Services Operation and Maintenance Executives Society (BSOMES), Hong Kong Association of Energy Engineers (HKAEE), the Chartered Institute of Building (CIOB) Hong Kong and the universities, to develop suitable training programmes. This collaboration ensures that the programmes are comprehensive and cater to the specific industry's needs.

- **Public education campaigns:** To complement the professional training, public education campaigns should be launched to inform building occupant about simple yet effective energy-saving methods such as installing automatic control systems, conscientious use of lighting, maintaining energy-efficient temperature and lighting levels to promote indoor environmental quality. This is intended to help to cultivate a culture of energy conservation and reduction to normalise energy-saving behaviours among building users and to reduce public complaints and resistance to energy regulations and standards.

(3) To provide incentives to enhance building energy retrofit adoption and implementation.

- **Financial support:** Offering financial incentives is essential to promote the adoption of building energy retrofits, particularly for small building owners who might otherwise be unable to afford such upgrades. Options could include tax rebates for building owners who may undertake energy improvements and low-interest or interest-free loans for carrying out energy improvement works. These financial measures would lower the barrier to FM companies and small buildings owners to invest in EOBEER.

- **Non-financial incentives:** In addition to financial incentives, non-financial incentives can also play a crucial role in encouraging the uptake of EOBEER. Providing free energy audit services for building owners allows them to understand the potential energy savings and areas of improvement without initial cost. Furthermore, awarding certificates to those who achieve significant energy efficiency levels based on the audit reports can serve as recognition of their efforts and commitment to sustainability, as well as serving as basis to apply for financial incentives for future retrofits and upgrades.
- **Public-private sector collaboration:** It is vital for the government to partner with the private sector to provide comprehensive support for retrofitting projects. This includes not only subsidies but also technical support to ensure the effectiveness of the upgrades. While existing schemes such as the Eco Building Fund and Smart Power Building Fund have shown success in encouraging large scale energy-saving upgrades, expanding their scope and increasing funding would significantly enhance their impact and reach.

Chapter 6 Public Dissemination

6.1 Publications

6.1.1 Conference papers

For this project, two review papers have been accepted by the 46th Australasian Universities Building Education Association (AUBEA) Conference. The details of the publications are shown in the following:

Chen L., Darko A., Adegoriola M., Chan A.P.C., Yang Y., Tetteh M.O. (2023) Review of Challenges to Energy Efficiency Retrofitting of Existing Building Stock. In *Proceedings of the 46th Australasian Universities Building Education Association (AUBEA) Conference*, Auckland, New Zealand.

Adegoriola M., Darko A., Chen L., Chan A.P.C., Yang Y., Tetteh M.O. (2023) Existing building energy efficiency retrofit policies: Review and recommendations for Hong Kong. In *Proceedings of the 46th Australasian Universities Building Education Association (AUBEA) Conference*, Auckland, New Zealand.

6.1.2 Journal papers

For this project, a full-length research paper has been submitted to a top-tier international academic journal, *Energy and Buildings*, which has been accepted.

Chen L., Darko A., Adegoriola M., Chan A.P.C., Yang Y., Tetteh M.O. (2024) Challenges to Energy Retrofitting of Existing Office Buildings in High-rise High-density Cities: The Case of Hong Kong. *Energy and Buildings*. (Accepted)

6.2 Research Dissemination

(a) Australasian Universities Building Education Association (AUBEA) 2023 Conference

The project team members attended the 46th Australasian Universities Building Education Association (AUBEA) Conference, organized by Massey University, Auckland, New Zealand. The project team members delivered two academic presentations entitled

Review of Challenges to Energy Efficiency Retrofitting of Existing Building Stock and *Existing building energy efficiency retrofit policies: Review and recommendations for Hong Kong*.

(b) 2023 Built Environment Research Workshop

A project team member attended 2023 Built Environment Research Workshop, organized by CIB Future Leaders Network. This event has been held at Massey University, Auckland, New Zealand. A poster entitled *Critical Challenges to Energy Efficiency Retrofitting of Existing Office Buildings: The Case of Hong Kong* was presented in this research workshop to disseminate research findings with young researchers from other universities around the world.

(c) Public lecture in BRE Research Seminar

The research team organized a public lecture to disseminate their research findings in the BRE Research Seminar. The Buildings Department, Electrical and Mechanical Services Department (EMSD), West Kowloon Cultural District Authority, utility companies, experts who have participated in our research, practitioners in the industry, PolyU staff and students, and the public were invited to attend this lecture.

This lecture is hybrid, available both online and in person. All the PolyU staff and students joined in person. Government officials, utility companies, experts, and the public can choose to join the lecture online or in person, based on their availability.

This public lecture has 49 participants, including 31 participants in ZS710, PolyU campus and 18 online participants. For the government side, two representatives from Buildings Department, one representative from EMSD, and one representative from West Kowloon Cultural District Authority joined the seminar online. For utility companies, one representative from HK Electric joined the seminar. Other representatives were from Swire Properties, Plus 8 Consulting Limited, Mtech Engineering Co., LTD, CxAsia Limited, and other companies.

Figure 6.1 shows the flyer of this seminar, and details of the seminar are as follows:

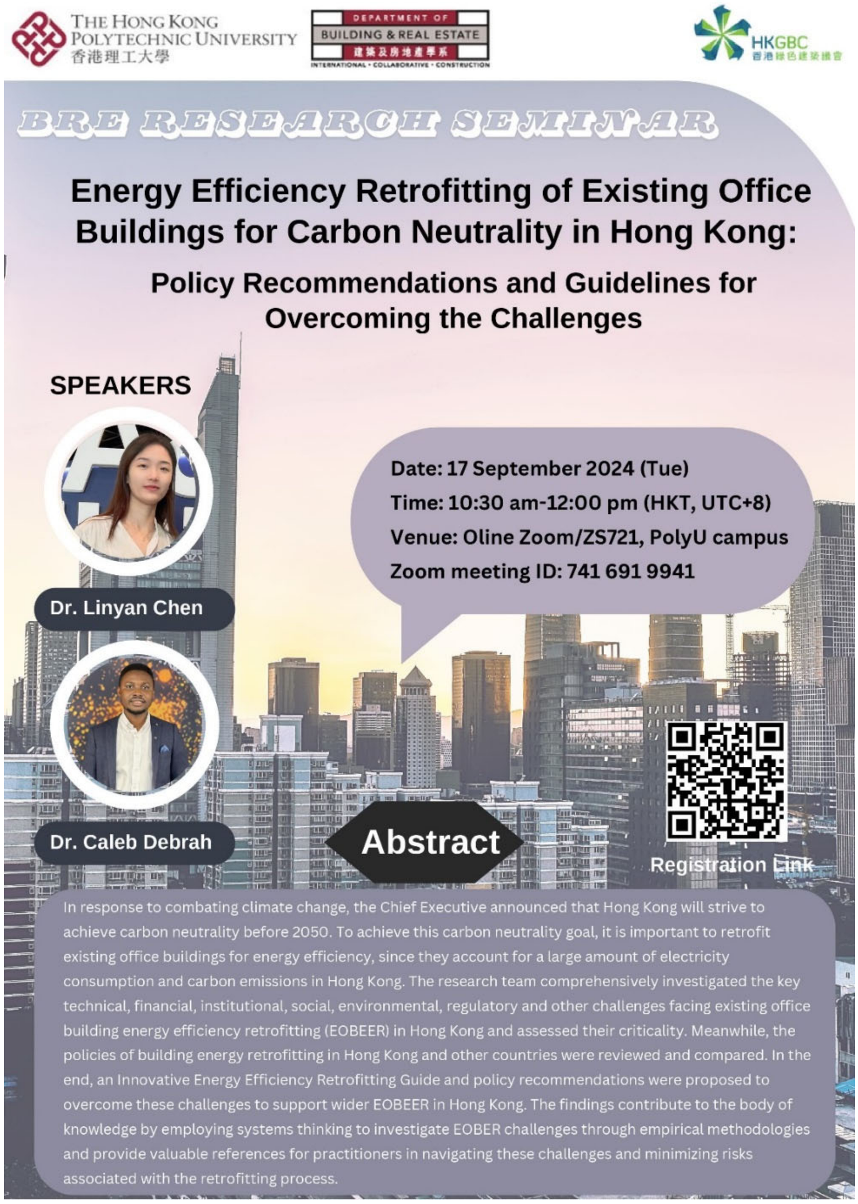


Figure 6.1 Flyer of the public lecture.

Date: Tuesday, 17 September 2024

Time: 10:30 am - 12:00 pm

Venue: ZS701, PolyU campus/Online via Zoom

Presentation title: Energy Efficiency Retrofitting of Existing Office Buildings for Carbon Neutrality in Hong Kong: Policy Recommendations and Guidelines for Overcoming the Challenges

Presenters: Dr. Linyan Chen and Dr. Caleb Debrah

Lecture abstract: In response to combating climate change, the Chief Executive announced that Hong Kong will strive to achieve carbon neutrality before 2050. To achieve this carbon neutrality goal, it is important to retrofit existing office buildings for energy efficiency, since they account for a large amount of electricity consumption and carbon emissions in Hong Kong. The research team comprehensively investigated the key technical, financial, institutional, social, environmental, regulatory and other challenges facing existing office building energy efficiency retrofitting (EOBEER) in Hong Kong and assessed their criticality. Meanwhile, the policies of building energy retrofitting in Hong Kong and other countries were reviewed and compared. In the end, an Innovative Energy Efficiency Retrofitting Guide and policy recommendations were proposed to overcome these challenges to support wider EOBEER in Hong Kong. The findings contribute to the body of knowledge by employing systems thinking to investigate EOBER challenges through empirical methodologies and provide valuable references for practitioners in navigating these challenges and minimizing risks associated with the retrofitting process.

6.3 Focus Group Meetings

Four focus group meetings were held to solicit the opinions of different stakeholders concerning the energy efficiency retrofitting of existing office buildings, as detailed in Section 3.5. The relevant slides are shown in Appendix C.

Chapter 7 Conclusions

This study aims to identify challenges faced by energy efficiency retrofitting in existing office buildings and overcome these challenges by proposing strategies and creating an enabling regulatory environment. The research objectives include: (1) To evaluate the technical, financial, institutional, social, environmental, and regulatory challenges facing existing office building energy efficiency retrofitting (EOBEER) in Hong Kong; (2) to develop an innovative EOBEER guide for Hong Kong that addresses the challenges; (3) to provide policy recommendations for EOBEER in Hong Kong; and (4) to disseminate the research findings and recommendations to the public. This study adopted mixed research methods, including systematic literature review; multiple case studies with a combination of semi-structured interviews, Z-numbers-based Delphi survey and focus group meetings.

For Objective 1, this study first conducted a systematic literature review to identify 49 technical, financial, institutional, social, environmental, regulatory and other challenges faced by building energy retrofitting from previous research. Then, this study employed 24 semi-structured interviews with professionals in Hong Kong who have rich experience in energy retrofitting and have participated in EOBEER projects. 36 real EOBEER cases were collected from semi-structured interviews. Afterward, 23 critical EOBEER challenges in Hong Kong were identified from semi-structured interviews and case studies. These challenges were further evaluated through a Z-numbers-based Delphi survey with 15 experts involved. Results show that *lack of government incentives (R1), lack of knowledge about building energy retrofitting technologies (T3), lack of policies, legislation and regulations (R3), building owners lack motivation to retrofit (I3),* and *long payback period of building energy retrofitting (F1)* are the most significant EOBEER challenges in Hong Kong.

For Objective 2, an innovative EOBEER guide for Hong Kong was developed by the research team, shown in Appendix D. This guide summarizes the main content of this study. It sheds light on EOBEER challenges faced in energy retrofitting projects in Hong Kong and proposes effective strategies to overcome each EOBEER challenge, which could be a useful guideline for practitioners in the industry. This guide was verified and revised based on the comments and suggestions from experts in focus group meetings.

For objective 3, this study first reviewed the status quo of EOBEER policies in the United States, United Kingdom, Singapore, mainland China and Hong Kong. Policy comparison and analysis were conducted to lay the foundation for policy recommendations. Then, a clear overview of EOBEER policies in Hong Kong was obtained through semi-structured interviews and case analysis from practitioners' perspectives. The policies and guidelines that real projects followed were investigated, and participants were invited to put forward suggestions on policies for better implementation of future EOBEER projects. In the end, policy recommendations were formulated by the research team and verified by focus group meetings. Three key policy recommendations were proposed as: to review and update energy auditing requirements, policies, and standards; to provide regular education and training; and to provide incentives to enhance building energy retrofit adoption and implementation.

For objective 4, the research findings were disseminated at the 46th Australasian Universities Building Education Association (AUBEA) Conference with two academic presentations. Furthermore, a poster was presented and illustrated at 2023 Built Environment Research Workshop, organized by CIB Future Leaders Network.

The research findings will help the Government formulate and revise relevant policies, guidelines, standards and codes of practice, contributing to a wider EOBEER implementation and reaching Hong Kong's net-zero target by 2050.

References

Aboulnaga, M., & Moustafa, M. (2016). Sustainability of higher educational buildings-Retrofitting approach to improve energy performance and mitigate CO2 emissions in hot climates. *Renewable Energy and Environmental Sustainability*, *1*, 28.

Achtnicht, M., & Madlener, R. (2014). Factors influencing German house owners' preferences on energy retrofits. *Energy Policy*, *68*, 254–263.

Alabid, J., Bennadji, A., & Seddiki, M. (2022). A review on the energy retrofit policies and improvements of the UK existing buildings, challenges and benefits. *Renewable and Sustainable Energy Reviews*, *159*, 112161.

Alam, M., Zou, P. X., Stewart, R. A., Bertone, E., Sahin, O., Buntine, C., & Marshall, C. (2019). Government championed strategies to overcome the barriers to public building energy efficiency retrofit projects. *Sustainable Cities and Society*, *44*, 56–69.

Alfaiz, S. K., Abd Karim, S. B., & Alashwal, A. M. (2021). Critical success factors of green building retrofitting ventures in Iraq. *International Journal of Sustainable Construction Engineering and Technology*, *12*(1), 12–17.

Amoah, C., & Smith, J. (2022). Barriers to the green retrofitting of existing residential buildings. *Journal of Facilities Management*. https://www.emerald.com/insight/content/doi/10.1108/JFM-12-2021-0155/full/html

Aromataris, E., & Pearson, A. (2014). The systematic review: An overview. *AJN The American Journal of Nursing*, *114*(3), 53–58.

Ástmarsson, B., Jensen, P. A., & Maslesa, E. (2013). Sustainable renovation of residential buildings and the landlord/tenant dilemma. *Energy Policy*, *63*, 355–362. https://doi.org/10.1016/j.enpol.2013.08.046

Baker McKenzie. (2016). *Global Sustainable Buildings Index*. https://resourcehub.bakermckenzie.com/en/resources/global-sustainable-buildings-index

Baker McKenzie. (2022). *Global Sustainable Buildings Index*. https://resourcehub.bakermckenzie.com/en/resources/global-sustainable-buildings-index/asia-pacific/hong-kong

Barnes, E., & Parrish, K. (2016). Small buildings, big impacts: The role of small commercial building energy efficiency case studies in 2030 Districts. *Sustainable Cities and Society*, *27*, 210–221.

BCA. (2010). *Existing Building Retrofit*. https://www1.bca.gov.sg/docs/default-source/docs-corp-news-and-publications/publications/for-industry/existingbldgretrofit.pdf

Bertone, E., Stewart, R. A., Sahin, O., Alam, M., Zou, P. X. W., Buntine, C., & Marshall, C. (2018). Guidelines, barriers and strategies for energy and water retrofits of public buildings. *Journal of Cleaner Production*, *174*, 1064–1078. https://doi.org/10.1016/j.jclepro.2017.11.065

Besen, P., & Boarin, P. (2020). Energy retrofit of historic buildings in Aotearoa New Zealand: Current practice, challenges and opportunities. *Imaginable Futures: Design Thinking, and the Scientific Method, 54th International Conference of the Architectural Science Association*, 471–480.

Besen, P., Boarin, P., & Haarhoff, E. (2020). Energy and seismic retrofit of historic buildings in new zealand: Reflections on current policies and practice. *The Historic Environment: Policy & Practice*, *11*(1), 91–117.

Bjørneboe, M. G., Svendsen, S., & Heller, A. (2018). Initiatives for the energy renovation of single-family houses in Denmark evaluated on the basis of barriers and motivators. *Energy and Buildings*, *167*, 347–358.

Bruce, T., Zuo, J., Rameezdeen, R., & Pullen, S. (2015). Factors influencing the retrofitting of existing office buildings using Adelaide, South Australia as a case study. *Structural Survey*, *33*(2), 150–166.

Building and Construction Authority. (2022). *Building Retrofit Energy Efficiency Financing Scheme*. https://www1.bca.gov.sg/buildsg/sustainability/green-mark-incentive-schemes/building-retrofit-energy-efficiency-financing-breef-scheme

Butt, B., Jones, R. V., & Fuertes, A. (2021). Opportunities and barriers to business engagement in the UK domestic retrofit sector: An industry perspective. *Building*

Services Engineering Research and Technology, *42*(3), 293–305. https://doi.org/10.1177/0143624420975640

Cao, Y., Xu, C., Kamaruzzaman, S. N., & Aziz, N. M. (2022). A systematic review of green building development in China: Advantages, challenges and future directions. *Sustainability*, *14*(19), 12293.

Caputo, P., & Pasetti, G. (2015). Overcoming the inertia of building energy retrofit at municipal level: The Italian challenge. *Sustainable Cities and Society*, *15*, 120–134.

Castleberry, B., Gliedt, T., & Greene, J. S. (2016). Assessing drivers and barriers of energy-saving measures in Oklahoma's public schools. *Energy Policy*, *88*, 216–228.

Chan, A., & Chow, T. (2014). Calculation of overall thermal transfer value (OTTV) for commercial buildings constructed with naturally ventilated double skin façade in subtropical Hong Kong. *Energy and Buildings*, *69*, 14–21.

Cheng, J., Wong, N., Ho, T., Kwong, H. F., Ng, R. T., & Cheung, H. (2021). A case study of lighting retrofit to improve building energy efficiency and lighting quality by using luminaires with nano optical coating. *Transactions Hong Kong Institution of Engineers*, *27*(4), 156–165.

Dauda, J. A., & Ajayi, S. O. (2022). Understanding the impediments to sustainable structural retrofit of existing buildings in the UK. *Journal of Building Engineering*, *60*, 105168.

Davies, P., & Osmani, M. (2011). Low carbon housing refurbishment challenges and incentives: Architects' perspectives. *Building and Environment*, *46*(8), 1691–1698.

Debrah, C., Chan, A. P. C., & Darko, A. (2022a). Green finance gap in green buildings: A scoping review and future research needs. *Building and Environment*, *207*, 108443.

Debrah, C., Chan, A. P., & Darko, A. (2022b). Artificial intelligence in green building. *Automation in Construction*, *137*, 104192.

D'Oca, S., Ferrante, A., Ferrer, C., Pernetti, R., Gralka, A., Sebastian, R., & op 't Veld, P. (2018). Technical, financial, and social barriers and challenges in deep building renovation: Integration of lessons learned from the H2020 cluster projects. *Buildings*, *8*(12), 174.

DOE. (2015). *DOE to Fund up to $454Million for Retrofit Ramp-Ups in Energy Efficiency*. https://www.energy.gov/articles/doe-fund-454-million-retrofit-ramp-ups-energy-efficiency

Driscoll, D. L. (2011). Introduction to primary research: Observations, surveys, and interviews. *Writing Spaces: Readings on Writing*, *2*(2011), 153–174.

Energy Star. (2021). *Learn about ENERGY STAR labels*. https://www.energystar.gov/products/energy_star_labels

English, J. M., & Kernan, G. L. (1976). The prediction of air travel and aircraft technology to the year 2000 using the Delphi method. *Transportation Research*, *10*(1), 1–8.

Environment Bureau. (2015). *Energy Saving Plan for Hong Kong's Built Environment 2015-2025+*.
https://www.eeb.gov.hk/sites/default/files/pdf/EnergySavingPlanEn.pdf

Environment Bureau. (2021). *Hong Kong's Climate Action Plan 2050*. https://www.info.gov.hk/gia/general/202110/08/P2021100800588.htm

Fasna, M. F. F., & Gunatilake, S. (2020). Overcoming barriers for building energy efficiency retrofits: Insights from hotel retrofits in Sri Lanka. *Built Environment Project and Asset Management*, *10*(2), 277–295.

Fellows, R. F., & Liu, A. M. (2021). *Research methods for construction*. John Wiley & Sons.

Fotiou, T., Capros, P., & Fragkos, P. (2022). Policy modelling for ambitious energy efficiency investment in the EU residential buildings. *Energies*, *15*(6), 2233.

Hasson, F., Keeney, S., & McKenna, H. (2000). Research guidelines for the Delphi survey technique. *Journal of Advanced Nursing*, *32*(4), 1008–1015. https://doi.org/10.1046/j.1365-2648.2000.t01-1-01567.x

HK2050IsNow. (2020). *Decarbonising Hong Kong Buildings Policy Recommendations and Next Steps*. https://www.hkgreenfinance.org/research-report/decarbonising-hong-kong-buildings-policy-recommendations-and-next-steps/

HKGBC. (2022). *Hong Kong: Green Building in Action*. https://www.hkgbc.org.hk/eng/resources/publications/HKGBC-

Publication/Reports/green-building-in-action/images/Green_Building_in_Action_2022ENG.pdf

HM Government. (2017). *The Clean Growth Strategy*. https://assets.publishing.service.gov.uk/media/5ad5f11ded915d32a3a70c03/clean-growth-strategy-correction-april-2018.pdf

Hou, J., Liu, Y., Wu, Y., Zhou, N., & Feng, W. (2016). Comparative study of commercial building energy-efficiency retrofit policies in four pilot cities in China. *Energy Policy*, *88*, 204–215.

Hu, Y., & Lin, Y. (2022). Comparison of green building policies and regulations between central and local governments of China: Analysis based on text similarity. *Frontiers in Environmental Science*, *10*, 1064852.

Hui, S. C. (1997). Overall thermal transfer value (OTTV): How to improve its control in Hong Kong. *Proc. of the One-Day Symposium on Building, Energy and Environment*, *16*, 12–1.

IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. https://www.ipcc.ch/report/ar6/wg1/

Jowkar, M., Temeljotov-Salaj, A., Lindkvist, C. M., & Støre-Valen, M. (2022). Sustainable building renovation in residential buildings: Barriers and potential motivations in Norwegian culture. *Construction Management and Economics*, *40*(3), 161–172. https://doi.org/10.1080/01446193.2022.2027485

Kallio, H., Pietilä, A.-M., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: Developing a framework for a qualitative semi-structured interview guide. *Journal of Advanced Nursing*, *72*(12), 2954–2965. https://doi.org/10.1111/jan.13031

Kang, B., Wei, D., Li, Y., & Deng, Y. (2012). Decision making using Z-numbers under uncertain environment. *Journal of Computational Information Systems*, *8*, 2807–2814.

Kats, G. (2013). *Greening our built world: Costs, benefits, and strategies*. Island Press.

Klöckner, C. A., & Nayum, A. (2016). Specific barriers and drivers in different stages of decision-making about energy efficiency upgrades in private homes. *Frontiers in Psychology*, *7*, 1362.

Klöckner, C. A., & Nayum, A. (2017). Psychological and structural facilitators and barriers to energy upgrades of the privately owned building stock. *Energy*, *140*, 1005–1017.

Krueger, R. A. (2014). *Focus groups: A practical guide for applied research*. Sage publications.

Levine, M. (2013). *Building Energy-Efficiency Best Practice Policies and Policy Packages*.

Li, J., Ng, S. T., & Skitmore, M. (2017). Review of low-carbon refurbishment solutions for residential buildings with particular reference to multi-story buildings in Hong Kong. *Renewable and Sustainable Energy Reviews*, *73*, 393–407.

Li, J., & Shui, B. (2015). A comprehensive analysis of building energy efficiency policies in China: Status quo and development perspective. *Journal of Cleaner Production*, *90*, 326–344.

Li, Y., Yang, L., He, B., & Zhao, D. (2014). Green building in China: Needs great promotion. *Sustainable Cities and Society*, *11*, 1–6.

Lindkvist, C., Karlsson, A., Sørnes, K., & Wyckmans, A. (2014). Barriers and challenges in nZEB projects in Sweden and Norway. *Energy Procedia*, *58*, 199–206.

Liu, G., Li, X., Tan, Y., & Zhang, G. (2020). Building green retrofit in China: Policies, barriers and recommendations. *Energy Policy*, *139*, 111356.

Liu, G., Tan, Y., & Li, X. (2020). China's policies of building green retrofit: A state-of-the-art overview. *Building and Environment*, *169*, 106554.

Lu, S., Feng, W., Kong, X., & Wu, Y. (2014). Analysis and case studies of residential heat metering and energy-efficiency retrofits in China′ s northern heating region. *Renewable and Sustainable Energy Reviews*, *38*, 765–774.

Lv, S., & Wu, Y. (2009). Target-oriented obstacle analysis by PESTEL modeling of energy efficiency retrofit for existing residential buildings in China's northern heating region. *Energy Policy*, *37*(6), 2098–2101.

Ma, J., Qian, Q. K., Visscher, H., & Song, K. (2022). Barriers for Homeowners in Decisions to Undertake Government-Led Energy Efficiency Renovation Projects in Northern China. *Sustainability*, *14*(12), Article 12. https://doi.org/10.3390/su14127298

Ma, Z., Cooper, P., Daly, D., & Ledo, L. (2012). Existing building retrofits: Methodology and state-of-the-art. *Energy and Buildings*, *55*, 889–902. https://doi.org/10.1016/j.enbuild.2012.08.018

Martin, A., & Gossett, S. (2013). Breaking Down Financial Barriers Towards a More Sustainable Commercial Real Estate Market. *Strategic Planning for Energy and the Environment*, *32*(3), 56–65. https://doi.org/10.1080/10485236.2013.10596287

McDonnell, A., & Sinnott, D. (2010). Barriers and enablers to energy efficient retrofitting of dwellings in Ireland. *26th Annual ARCOM Conference, Association of Researchers in Construction Management, Leeds*, 1437–1446. https://www.arcom.ac.uk/-docs/proceedings/ar2010-1437-1446_McDonnell_and_Sinnott.pdf

Medal, L., & Kim, A. (2020). Context-Driven Factors for Implementing Energy Efficiency Retrofit in a Portfolio of Buildings. *Construction Research Congress 2020*, 491–500. https://doi.org/10.1061/9780784482858.054

Menassa, C. C. (2011). Evaluating sustainable retrofits in existing buildings under uncertainty. *Energy and Buildings*, *43*(12), 3576–3583.

Mlecnik, E. (2010). Adoption of highly energy-efficient renovation concepts. *Open House International*, *35*(2), 39–48.

Mlecnik, E., Cre, J., Kondratenko, I., & Hilderson, W. (2011). Innovations in very low energy retrofit projects. *Proceedings of the PLEA 27th Conference on Passive and Low Energy Architecture, Louvain-La-Neuve, Belgium*, 13–15. https://www.researchgate.net/profile/Erwin-Mlecnik/publication/339500546_Innovations_in_Very_Low_Energy_Retrofit_Projects_Experience_of_Belgian_exemplary_projects/links/5e5656b4a6fdccbeba033257/Innovations-in-Very-Low-Energy-Retrofit-Projects-Experience-of-Belgian-exemplary-projects.pdf

Myhren, J. A., Heier, J., Hugosson, M., & Zhang, X. (2020). The perception of Swedish housing owner's on the strategies to increase the rate of energy efficient refurbishment of multi-family buildings. *Intelligent Buildings International*, *12*(3), 153–168. https://doi.org/10.1080/17508975.2018.1539390

O'Grady, T., Chong, H.-Y., & Morrison, G. M. (2021). A systematic review and meta-analysis of building automation systems. *Building and Environment*, *195*, 107770.

Oguntona, O. A., Maseko, B. M., Aigbavboa, C. O., & Thwala, W. D. (2019). Barriers to retrofitting buildings for energy efficiency in South Africa. *IOP Conference Series: Materials Science and Engineering*, *640*(1), 012015. https://iopscience.iop.org/article/10.1088/1757-899X/640/1/012015/meta

Oh, S. J., Ng, K. C., Thu, K., Chun, W., & Chua, K. J. E. (2016). Forecasting long-term electricity demand for cooling of Singapore's buildings incorporating an innovative air-conditioning technology. *Energy and Buildings*, *127*, 183–193.

Olsson, S., Malmqvist, T., & Glaumann, M. (2015). Managing sustainability aspects in renovation processes: Interview study and outline of a process model. *Sustainability*, *7*(6), 6336–6352.

Ortiz, M., Itard, L., & Bluyssen, P. M. (2020). Indoor environmental quality related risk factors with energy-efficient retrofitting of housing: A literature review. *Energy and Buildings*, *221*, 110102.

Paiho, S., & Ahvenniemi, H. (2017). Non-technical barriers to energy efficient renovation of residential buildings and potential policy instruments to overcome them—Evidence from young Russian adults. *Buildings*, *7*(4), 101.

Paiho, S., Hedman, Å., Abdurafikov, R., Hoang, H., Sepponen, M., Kouhia, I., & Meinander, M. (2013). Energy saving potentials of Moscow apartment buildings in residential districts. *Energy and Buildings*, *66*, 706–713.

Palm, J., & Reindl, K. (2018). Understanding barriers to energy-efficiency renovations of multifamily dwellings. *Energy Efficiency*, *11*(1), 53–65. https://doi.org/10.1007/s12053-017-9549-9

Palmer, K., Walls, M., Gordon, H., & Gerarden, T. (2013). Assessing the energy-efficiency information gap: Results from a survey of home energy auditors. *Energy Efficiency*, *6*(2), 271–292. https://doi.org/10.1007/s12053-012-9178-2

Paschoalin, R., & Isaacs, N. (2021). Applying international guidelines on historic building's retrofit in new zealand: A critical context view. *Heritage*, *4*(4), 3697–3711.

Rispoli, M., & Organ, S. (2019). The drivers and challenges of improving the energy efficiency performance of listed pre-1919 housing. *International Journal of Building Pathology and Adaptation*, *37*(3), 288–305.

Rose, J., Thomsen, K. E., Domingo-Irigoyen, S., Bolliger, R., Venus, D., Konstantinou, T., Mlecnik, E., Almeida, M., Barbosa, R., & Terés-Zubiaga, J. (2021). Building renovation at district level–Lessons learned from international case studies. *Sustainable Cities and Society*, *72*, 103037.

Safari, M., Asadi, S., & Freihaut, J. (2020). Business Development in Small Commercial Building Energy Retrofit Projects—A Review on Current Industry Practices. *Construction Research Congress 2020*, 1366–1374. https://doi.org/10.1061/9780784482889.146

Shaikh, P., Shaikh, F., Sahito, A., Uqaili, M., & Umrani, Z. (2017). An overview of the challenges for cost-effective and energy-efficient retrofits of the existing building stock. *Cost-Effective Energy Efficient Building Retrofitting*, 257–278.

Siva, V., Hoppe, T., & Jain, M. (2017). Green buildings in Singapore; analyzing a frontrunner's sectoral innovation system. *Sustainability*, *9*(6), 919.

Streimikiene, D., & Balezentis, T. (2020). Willingness to pay for renovation of multi-flat buildings and to share the costs of renovation. *Energies*, *13*(11), 2721.

Tambach, M., Hasselaar, E., & Itard, L. (2010). Assessment of current Dutch energy transition policy instruments for the existing housing stock. *Energy Policy*, *38*(2), 981–996.

Tan, Y., Liu, G., Zhang, Y., Shuai, C., & Shen, G. Q. (2018). Green retrofit of aged residential buildings in Hong Kong: A preliminary study. *Building and Environment*, *143*, 89–98.

Tan, Y., Luo, T., Xue, X., Shen, G. Q., Zhang, G., & Hou, L. (2021). An empirical study of green retrofit technologies and policies for aged residential buildings in Hong Kong. *Journal of Building Engineering*, *39*, 102271.

Tan, Y., Luo, T., Xue, X., Shen, G., Wong, J., & others. (2019). *Green retrofitting aged residential buildings: An empirical study in Hong Kong*.

Tetteh, M. O., Chan, A. P., Mohandes, S. R., & Agyemang, D. Y. (2023). Diagnosing critical barriers to international construction joint ventures success in the developing country of Ghana. *Construction Innovation*, *23*(5), 1151–1185.

Tuominen, P., Klobut, K., Tolman, A., Adjei, A., & de Best-Waldhober, M. (2012). Energy savings potential in buildings and overcoming market barriers in member states of the European Union. *Energy and Buildings*, *51*, 48–55. https://doi.org/10.1016/j.enbuild.2012.04.015

United Nations Climate Change. (2015). *The Paris agreement*. https://unfccc.int/process-and-meetings/the-paris-agreement

United Nations Environment Programme. (2022). *2022 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector*.

United Nations Environment Programme. (2023). *The Buildings Breakthrough: Global push for near-zero emission and resilient buildings by 2030 unveiled at COP28*. https://www.unep.org/news-and-stories/press-release/buildings-breakthrough-global-push-near-zero-emission-and-resilient

US Department of Energy. (2022). *Retrofit Existing Buildings*. https://www.energy.gov/eere/buildings/retrofit-existing-buildings

Vieira, E., & Gomes, J. (2009). A comparison of Scopus and Web of Science for a typical university. *Scientometrics*, *81*(2), 587–600.

von der Gracht, H. A. (2012). Consensus measurement in Delphi studies: Review and implications for future quality assurance. *Technological Forecasting and Social Change*, *79*(8), 1525–1536. https://doi.org/10.1016/j.techfore.2012.04.013

Waara, F. (2008). Mitigating contractual hazards in public procurement: A study of Swedish local authorities. *Construction Management and Economics*, *26*(2), 137–145.

Weiss, J., Dunkelberg, E., & Vogelpohl, T. (2012). Improving policy instruments to better tap into homeowner refurbishment potential: Lessons learned from a case study in Germany. *Energy Policy*, *44*, 406–415.

Wimpenny, P., & Gass, J. (2000). Interviewing in phenomenology and grounded theory: Is there a difference? *Journal of Advanced Nursing*, *31*(6), 1485–1492.

World Economic Forum. (2022). *Accelerating the Decarbonization of Buildings: The Net-Zero Carbon Cities Building Value Framework*.

Xue, Y., Temeljotov-Salaj, A., & Lindkvist, C. M. (2022). Renovating the retrofit process: People-centered business models and co-created partnerships for low-energy buildings in Norway. *Energy Research & Social Science*, *85*, 102406.

Yang, L., Lam, J. C., & Tsang, C. L. (2008). Energy performance of building envelopes in different climate zones in China. *Applied Energy*, *85*(9), 800–817.

Yeung, I. (2024). *Unlocking the potential of nature in climate action – A report on Hong Kong's nature-based solutions*. https://www.hk2050isnow.org/resource/unlocking-the-potential-of-nature-in-climate-action-a-report-on-hong-kongs-nature-based-solutions/

Yeung, J. F., Chan, A. P., & Chan, D. W. (2008). Establishing quantitative indicators for measuring the partnering performance of construction projects in Hong Kong. *Construction Management and Economics*, *26*(3), 277–301.

Yin, R. K. (2009). *Case study research: Design and methods* (Vol. 5). sage.

Yu, F., & Ho, W. (2021). Tactics for carbon neutral office buildings in Hong Kong. *Journal of Cleaner Production*, *326*, 129369.

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, *8*(3), 338–353.

Zadeh, L. A. (2011). The concept of a Z-number-A new direction in uncertain computation. *2011 IEEE International Conference on Information Reuse & Integration*, xxii–xxiii.

Zhang, X., & Mohandes, S. R. (2020). Occupational Health and Safety in green building construction projects: A holistic Z-numbers-based risk management framework. *Journal of Cleaner Production*, *275*, 122788. https://doi.org/10.1016/j.jclepro.2020.122788

Appendices

Appendix A – Semi-structured Interview Guides

Semi-structured Interview Questions

The **existing office building energy efficiency retrofitting** in this research involves replacements, modifications, and refurbishments of existing office buildings to enhance the energy efficiency, conservation, and savings, including improving the fresh air supply system, lighting system, air conditioning system, uninterruptible power supply system, distributed generation system, lifts and escalators, pump motors, building envelopes, etc.

Please note that the research scope is the **existing office building or existing building with office space**. Additionally, this research is based on real building energy efficiency retrofitting cases **in Hong Kong**.

Your identity and participation will be kept strictly confidential. The data will be confidentially secured and analyzed in aggregate, and the findings will be utilized for academic and research purposes only. We are grateful for your participation.

Your background information

Company name: ______________________________

Position: ______________________________

Years of work experience in building energy retrofitting: ______________

Please provide 1-3 or more cases that you have been involved in.

Case 1:

Project name: ______________________________

Building owner: ______________________________

Case 2:

Project name: ______________________________

Building owner: ______________________________

Case 3:

Project name: ______________________________

Building owner: ______________________________

Part 1: Basic Questions

Answer the questions based on the specific energy efficiency retrofitting case.

1. Retrofitting initiatives (e.g., improving lighting system, air conditioning system, uninterruptible power supply system, lifts and escalators, pump motors, building envelope):

2. Energy saving target (if applicable):

3. What were your role/responsibilities in this building energy retrofitting project?

4. What technical, financial, institutional, social, environmental, and regulatory challenges were encountered in the project?

Technical challenges: Financial challenges: Institutional challenges: Social challenges: Environmental challenges: Regulatory challenges:

5. What strategies were adopted to overcome the challenges for successful retrofitting?

6. What strategies do you suggest for overcoming challenges for better retrofitting?

7. Which government policies and guidelines were followed in the implementation of the existing office building energy efficiency retrofitting?

8. What are your suggestions on policies and guidelines for better implementation of the existing office building energy efficiency retrofitting in Hong Kong?

9. What new technologies and innovations were applied in this building energy retrofitting project?

Part 2: Challenge identification

A list of challenges that may be encountered in energy efficiency retrofitting of existing office buildings was prepared. Please choose the challenges that you encountered in this building energy retrofitting case by highlighting the text or ticking them. Also, please clarify your strategies that you adopted/suggest to overcome the challenges for successful retrofitting.

Technical challenges (T)		
T1	Lack of access to sustainable materials in building energy retrofitting	☐
T2	Immature building energy retrofitting technologies	☐
T3	Complexity of building energy retrofitting technologies	☐
T4	Lack of access to efficient building energy retrofitting technologies	☐
T5	Lack of knowledge about building energy retrofitting technologies	☐
T6	Lack of research and innovations implementation on building energy retrofitting technologies	☐
T7	Lack of actual data on existing building energy performance	☐
Financial challenges (F)		
F1	Split incentives	☐
F2	Long payback period of building energy retrofitting	☐
F3	Uncertainty about the payback period of building energy retrofitting	☐
F4	High investment cost in building energy retrofitting	☐
F5	Lack of access to sustainable materials in building energy retrofitting	☐
F6	Insufficient return on investment	☐
F7	Uncertainties over financial gain	☐
F8	Low interest to invest in building energy retrofitting	☐
F9	Unwillingness to increase current loans	☐
F10	Poor economy and market for building energy retrofitting	☐
F11	Insufficient cost and benefit-sharing mechanism among occupants	☐
F12	Lack of financial data on building energy retrofitting	☐
Institutional challenges (I)		

I1	Lack of communication and information sharing between stakeholders	☐
I2	Lack of a straightforward guide with clear procedures	☐
I3	Lack of interdisciplinary expertise and collaboration	☐
I4	Interruption to building operation	☐
I5	Stakeholders' insufficient awareness and knowledge of energy retrofitting	☐
I6	Building owners lack motivation to retrofit	☐
I7	Lack of trust among stakeholders during building energy retrofitting implementation	☐
I8	Low priority for energy efficiency	☐
I9	Lack of commitment	☐
I10	Poor occupant support	☐
I11	Building owners and occupants are unwilling to change	☐
I12	Lack of skilled building professionals	☐
I13	Lack of leadership	☐
Social challenges (S)		
S1	Low public awareness and understanding on building energy retrofitting	☐
S2	Lack of citizen involvement and public support	☐
S3	Lack of conviction for the host communities on the availability of adequate health and safety plan	☐
S4	Lack of social norms in relation to thermal and acoustic comfort, light, air quality	☐
S5	Negative perception	☐
S6	Risk of disputes and social implications	☐
Environmental challenges (E)		
E1	Noise, dust, waste and carbon emissions	☐
E2	Lack of awareness of some human activities on the environment	☐
Regulatory challenges (R)		

R1	Frequent changes in government policies and regulations	☐
R2	Lack of government incentives	☐
R3	Lack of established benchmarks and criteria for building energy retrofitting	☐
R4	Lack of supervision and enforcement	☐
R5	Lack of policies, legislation and regulations	☐
Other challenges (O)		
O1	Deficiencies in the skills and training on building energy retrofitting	☐
O2	Historic preservation of buildings	☐
O3	Lack of time	☐
O4	Lack of integration between research, standards, and practice	☐

Part 3: Contact information of other project participants/stakeholders

Grateful if you could provide contact information of other relevant participants/stakeholders who were involved in this project but with different roles from yours, e.g., the client, investors, manufacturers/suppliers.

Appendix B – Z-numbers-based Delphi Survey

Appendix B.1 – Questionnaires for Z-numbers-based Delphi Survey (Round 1)

Title of Project: Energy Efficiency Retrofitting of Existing Office Buildings for Carbon Neutrality in Hong Kong: Policy Recommendations and Guidelines for Overcoming the Challenges

節能改造香港現有辦公樓宇達致淨零碳排放：透過政策建議及指引克服困難

Delphi Survey Questionnaire

The information is collected by the Building and Real Estate Department of The Hong Kong Polytechnic University and the Hong Kong Green Building Council for the project "Energy Efficiency Retrofitting of Existing Office Buildings for Carbon Neutrality in Hong Kong: Policy Recommendations and Guidelines for Overcoming the Challenges" that is funded by the Public Policy Research Funding Scheme (Project Code: 2022.A6.207.22C). The research team will not disclose the collected information (including personal information, audio records, texts, and data) that will only be used for the research reports and be destroyed after the project is completed. If you have any questions, please contact Dr. Amos Darko (Email: amos1.darko@polyu.edu.hk; Tel: +852 5111 0009).

Existing office building energy efficiency retrofitting (EOBEER) in this research involves replacements, modifications, and refurbishments of existing office buildings to enhance energy efficiency, conservation, and savings, including improving the fresh air supply system, lighting system, air conditioning system, uninterruptible power supply system, distributed generation system, lifts and escalators, pump motors, building envelope, etc.

Thank you for your participation. Please answer these questions based on your experience in the existing office building energy efficiency retrofitting project you have been involved in.

Part 1: Personal information.

Company name: ______________________________

Position: ______________________________

Work experience in building energy retrofitting: ______________

Part 2: Assessment of EOBEER challenges.

Before you assess EOREER challenges, please find the example below and read the illustration of the assessment.

Please assess the significance of this challenge "Lack of access to recycled and sustainable materials (T1)"

1 — 7

Not Critical — Most Critical

Technical challenges (T)		Rating							
T1	Lack of access to recycled and sustainable materials	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☑5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Medium low	☐4 Medium	☐5 Medium high	☑6 High	☐7 Very high

Please confirm your confidence in the assessment of the challenge significance.

1 — 7

Very Low — Very High

Technical challenges (T)		Rating							
T1	Lack of access to sustainable materials in building energy retrofitting	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high
T2	Complexity of building energy retrofitting technologies	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high
T3	Lack of knowledge about building energy retrofitting technologies	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high
T4	Lack of research and innovation implementation on building energy retrofitting technologies	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high
T5	Lack of actual data on existing building energy performance	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high

Financial challenges (F)		Rating							
F1	Long payback period of building energy retrofitting	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high
F2	Uncertainty about the payback period of building energy retrofitting	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high
F3	High investment cost in building energy retrofitting	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high
F4	Lack of access to finance building energy retrofitting	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high
F5	Poor economy and market for building energy retrofitting	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high

Institutional challenges (I)		Rating								
I1	Interruption to building operation	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high
I2	Stakeholders' insufficient awareness and knowledge of building energy retrofitting	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high
I3	Building owners lack motivation to retrofit	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high
I4	Lack of trust among stakeholders during building energy retrofitting implementation	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high
I5	Building owners and occupants are unwilling to change	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high

Regulatory challenges (R)		Rating								
R1	Lack of government incentives	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high
R2	Lack of established benchmarks and criteria for building energy retrofitting	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high

Social challenges (S)		Rating								
S1	Low public awareness and understanding on building energy retrofitting	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high
S2	Lack of citizen involvement and public support	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high

Environmental challenges (E)		**Rating**							
E1	Noise, dust, waste and carbon emissions	Significance	☐1 Not critical	☐2 Least critical	☐3 Fairly critical	☐4 Moderate	☐5 Critical	☐6 Very critical	☐7 Most critical
		Confidence	☐1 Very low	☐2 Low	☐3 Mediu m low	☐4 Medium	☐5 Medium high	☐6 High	☐7 Very high

Appendix B.2 – Questionnaires for Z-numbers-based Delphi Survey (Round 2)

Title of Project: Energy Efficiency Retrofitting of Existing Office Buildings for Carbon Neutrality in Hong Kong: Policy Recommendations and Guidelines for Overcoming the Challenges

節能改造香港現有辦公樓宇達致淨零碳排放：透過政策建議及指引克服困難

Delphi Survey Questionnaire (Second round)

Thank you for participating in the first round of Delphi survey conducted by The Hong Kong Polytechnic University and Hong Kong Green Building Council, led by Dr Amos Darko. The Delphi survey aims to quantify the significance of the challenges faced in the existing office building energy efficiency retrofitting (EOBEER) in Hong Kong.

Your answers and other panelists' answers from the first round have been summarized. You will be able to see a summary of all experts' responses, and you will then be asked if you would like to adjust your answer from the first round or not.

- If your answer is "No", please tick the box (☐ ⟶ ☒)
- If your answer is "Yes", please reassess the challenges and your confidence in the challenge assessment.

<table>
<tr><th rowspan="2">Rank</th><th rowspan="2">Challenge</th><th rowspan="2">Mean</th><th rowspan="2">SD</th><th rowspan="2">Result
(1st round)</th><th rowspan="2">Your answer
(1st round)</th><th colspan="3">Would you like to change your assessment?</th></tr>
<tr></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Lack of government incentives</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td colspan="2">Yes</td><td rowspan="2">☐ No</td></tr>
<tr><td>How would you reassess the importance of this challenge?
☐ 1-Not critical
☐ 2-Least critical
☐ 3-Fairly critical
☐ 4-Moderate
☐ 5-Critical
☐ 6-Very critical
☐ 7-Most critical</td><td>How confident are you in reassessing this challenge?
☐ 1-Very low
☐ 2-Low
☐ 3-Medium low
☐ 4-Medium
☐ 5-Medium high
☐ 6-High
☐ 7-Very high</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Lack of actual data on existing building energy performance</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td colspan="2">Yes</td><td rowspan="2">☐ No</td></tr>
<tr><td>How would you reassess the importance of this challenge?
☐ 1-Not critical
☐ 2-Least critical
☐ 3-Fairly critical
☐ 4-Moderate
☐ 5-Critical
☐ 6-Very critical
☐ 7-Most critical</td><td>How confident are you in reassessing this challenge?
☐ 1-Very low
☐ 2-Low
☐ 3-Medium low
☐ 4-Medium
☐ 5-Medium high
☐ 6-High
☐ 7-Very high</td></tr>
</table>

<table>
<tr><th>Rank</th><th>Challenge</th><th>Mean</th><th>SD</th><th>Result
(1st round)</th><th>Your answer
(1st round)</th><th colspan="3">Would you like to change your assessment?</th></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Long payback period of building energy retrofitting</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td colspan="2">Yes</td><td rowspan="2">☐ No</td></tr>
<tr><td>How would you reassess the importance of this challenge?
☐ 1-Not critical
☐ 2-Least critical
☐ 3-Fairly critical
☐ 4-Moderate
☐ 5-Critical
☐ 6-Very critical
☐ 7-Most critical</td><td>How confident are you in reassessing this challenge?
☐ 1-Very low
☐ 2-Low
☐ 3-Medium low
☐ 4-Medium
☐ 5-Medium high
☐ 6-High
☐ 7-Very high</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">Lack of knowledge about building energy retrofitting technologies</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td colspan="2">Yes</td><td rowspan="2">☐ No</td></tr>
<tr><td>How would you reassess the importance of this challenge?
☐ 1-Not critical
☐ 2-Least critical
☐ 3-Fairly critical
☐ 4-Moderate
☐ 5-Critical
☐ 6-Very critical
☐ 7-Most critical</td><td>How confident are you in reassessing this challenge?
☐ 1-Very low
☐ 2-Low
☐ 3-Medium low
☐ 4-Medium
☐ 5-Medium high
☐ 6-High
☐ 7-Very high</td></tr>
</table>

<table>
<tr><th rowspan="2">Rank</th><th rowspan="2">Challenge</th><th rowspan="2">Mean</th><th rowspan="2">SD</th><th rowspan="2">Result
(1st round)</th><th rowspan="2">Your answer
(1st round)</th><th colspan="3">Would you like to change your assessment?</th></tr>
<tr></tr>
<tr><td rowspan="2">5</td><td rowspan="2">Lack of policies, legislation and regulations</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td colspan="2">Yes</td><td rowspan="2">☐
No</td></tr>
<tr><td>How would you reassess the importance of this challenge?
☐ 1-Not critical
☐ 2-Least critical
☐ 3-Fairly critical
☐ 4-Moderate
☐ 5-Critical
☐ 6-Very critical
☐ 7-Most critical</td><td>How confident are you in reassessing this challenge?

☐ 1-Very low
☐ 2-Low
☐ 3-Medium low
☐ 4-Medium
☐ 5-Medium high
☐ 6-High
☐ 7-Very high</td></tr>
<tr><td rowspan="2">6</td><td rowspan="2">Building owners lack motivation to retrofit</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td colspan="2">Yes</td><td rowspan="2">☐
No</td></tr>
<tr><td>How would you reassess the importance of this challenge?
☐ 1-Not critical
☐ 2-Least critical
☐ 3-Fairly critical
☐ 4-Moderate
☐ 5-Critical
☐ 6-Very critical
☐ 7-Most critical</td><td>How confident are you in reassessing this challenge?

☐ 1-Very low
☐ 2-Low
☐ 3-Medium low
☐ 4-Medium
☐ 5-Medium high
☐ 6-High
☐ 7-Very high</td></tr>
</table>

Rank	Challenge	Mean	SD	Result (1st round)	Your answer (1st round)	Would you like to change your assessment?		
						Yes		
7	Lack of established benchmarks and criteria for building energy retrofitting					How would you reassess the importance of this challenge? ☐ **1-Not critical** ☐ **2-Least critical** ☐ **3-Fairly critical** ☐ **4-Moderate** ☐ **5-Critical** ☐ **6-Very critical** ☐ **7-Most critical**	How confident are you in reassessing this challenge? ☐ **1-Very low** ☐ **2-Low** ☐ **3-Medium low** ☐ **4-Medium** ☐ **5-Medium high** ☐ **6-High** ☐ **7-Very high**	☐ **No**
						Yes		
8	Stakeholders' insufficient awareness and knowledge of building energy retrofitting					How would you reassess the importance of this challenge? ☐ **1-Not critical** ☐ **2-Least critical** ☐ **3-Fairly critical** ☐ **4-Moderate** ☐ **5-Critical** ☐ **6-Very critical** ☐ **7-Most critical**	How confident are you in reassessing this challenge? ☐ **1-Very low** ☐ **2-Low** ☐ **3-Medium low** ☐ **4-Medium** ☐ **5-Medium high** ☐ **6-High** ☐ **7-Very high**	☐ **No**

<table>
<tr><th rowspan="2">Rank</th><th rowspan="2">Challenge</th><th rowspan="2">Mean</th><th rowspan="2">SD</th><th rowspan="2">Result
(1st round)</th><th rowspan="2">Your answer
(1st round)</th><th colspan="3">Would you like to change your assessment?</th></tr>
<tr></tr>
<tr><td rowspan="2">9</td><td rowspan="2">High investment cost in building energy retrofitting</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td colspan="2">Yes</td><td rowspan="2">☐ No</td></tr>
<tr><td>How would you reassess the importance of this challenge?
☐ 1-Not critical
☐ 2-Least critical
☐ 3-Fairly critical
☐ 4-Moderate
☐ 5-Critical
☐ 6-Very critical
☐ 7-Most critical</td><td>How confident are you in reassessing this challenge?
☐ 1-Very low
☐ 2-Low
☐ 3-Medium low
☐ 4-Medium
☐ 5-Medium high
☐ 6-High
☐ 7-Very high</td></tr>
<tr><td rowspan="2">10</td><td rowspan="2">Lack of access to financing for building energy retrofitting</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td colspan="2">Yes</td><td rowspan="2">☐ No</td></tr>
<tr><td>How would you reassess the importance of this challenge?
☐ 1-Not critical
☐ 2-Least critical
☐ 3-Fairly critical
☐ 4-Moderate
☐ 5-Critical
☐ 6-Very critical
☐ 7-Most critical</td><td>How confident are you in reassessing this challenge?
☐ 1-Very low
☐ 2-Low
☐ 3-Medium low
☐ 4-Medium
☐ 5-Medium high
☐ 6-High
☐ 7-Very high</td></tr>
</table>

Rank	Challenge	Mean	SD	Result (1st round)	Your answer (1st round)	Would you like to change your assessment?		
						Yes		
11	Lack of research and innovation implementation on building energy retrofitting technologies					How would you reassess the importance of this challenge? ☐ **1-Not critical** ☐ **2-Least critical** ☐ **3-Fairly critical** ☐ **4-Moderate** ☐ **5-Critical** ☐ **6-Very critical** ☐ **7-Most critical**	How confident are you in reassessing this challenge? ☐ **1-Very low** ☐ **2-Low** ☐ **3-Medium low** ☐ **4-Medium** ☐ **5-Medium high** ☐ **6-High** ☐ **7-Very high**	☐ **No**
						Yes		
12	Uncertainty about the payback period of building energy retrofitting					How would you reassess the importance of this challenge? ☐ **1-Not critical** ☐ **2-Least critical** ☐ **3-Fairly critical** ☐ **4-Moderate** ☐ **5-Critical** ☐ **6-Very critical** ☐ **7-Most critical**	How confident are you in reassessing this challenge? ☐ **1-Very low** ☐ **2-Low** ☐ **3-Medium low** ☐ **4-Medium** ☐ **5-Medium high** ☐ **6-High** ☐ **7-Very high**	☐ **No**

<table>
<tr><th rowspan="2">Rank</th><th rowspan="2">Challenge</th><th rowspan="2">Mean</th><th rowspan="2">SD</th><th rowspan="2">Result
(1st round)</th><th rowspan="2">Your answer
(1st round)</th><th colspan="3">Would you like to change your assessment?</th></tr>
<tr></tr>
<tr><td rowspan="2">13</td><td rowspan="2">Building owners and occupants are unwilling to change</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td colspan="2">Yes</td><td rowspan="2">☐ No</td></tr>
<tr><td>How would you reassess the importance of this challenge?
☐ 1-Not critical
☐ 2-Least critical
☐ 3-Fairly critical
☐ 4-Moderate
☐ 5-Critical
☐ 6-Very critical
☐ 7-Most critical</td><td>How confident are you in reassessing this challenge?
☐ 1-Very low
☐ 2-Low
☐ 3-Medium low
☐ 4-Medium
☐ 5-Medium high
☐ 6-High
☐ 7-Very high</td></tr>
<tr><td rowspan="2">14</td><td rowspan="2">Noise, dust, waste and carbon emissions</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td colspan="2">Yes</td><td rowspan="2">☐ No</td></tr>
<tr><td>How would you reassess the importance of this challenge?
☐ 1-Not critical
☐ 2-Least critical
☐ 3-Fairly critical
☐ 4-Moderate
☐ 5-Critical
☐ 6-Very critical
☐ 7-Most critical</td><td>How confident are you in reassessing this challenge?
☐ 1-Very low
☐ 2-Low
☐ 3-Medium low
☐ 4-Medium
☐ 5-Medium high
☐ 6-High
☐ 7-Very high</td></tr>
</table>

<table>
<tr><th rowspan="1">Rank</th><th>Challenge</th><th>Mean</th><th>SD</th><th>Result (1st round)</th><th>Your answer (1st round)</th><th colspan="3">Would you like to change your assessment?</th></tr>
<tr><td rowspan="2">15</td><td rowspan="2">Deficiencies in the skills and training on building energy retrofitting</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td colspan="2">Yes</td><td rowspan="2">☐ No</td></tr>
<tr><td>How would you reassess the importance of this challenge?
☐ 1-Not critical
☐ 2-Least critical
☐ 3-Fairly critical
☐ 4-Moderate
☐ 5-Critical
☐ 6-Very critical
☐ 7-Most critical</td><td>How confident are you in reassessing this challenge?
☐ 1-Very low
☐ 2-Low
☐ 3-Medium low
☐ 4-Medium
☐ 5-Medium high
☐ 6-High
☐ 7-Very high</td></tr>
<tr><td rowspan="2">16</td><td rowspan="2">Poor economy and market for building energy retrofitting</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td colspan="2">Yes</td><td rowspan="2">☐ No</td></tr>
<tr><td>How would you reassess the importance of this challenge?
☐ 1-Not critical
☐ 2-Least critical
☐ 3-Fairly critical
☐ 4-Moderate
☐ 5-Critical
☐ 6-Very critical
☐ 7-Most critical</td><td>How confident are you in reassessing this challenge?
☐ 1-Very low
☐ 2-Low
☐ 3-Medium low
☐ 4-Medium
☐ 5-Medium high
☐ 6-High
☐ 7-Very high</td></tr>
</table>

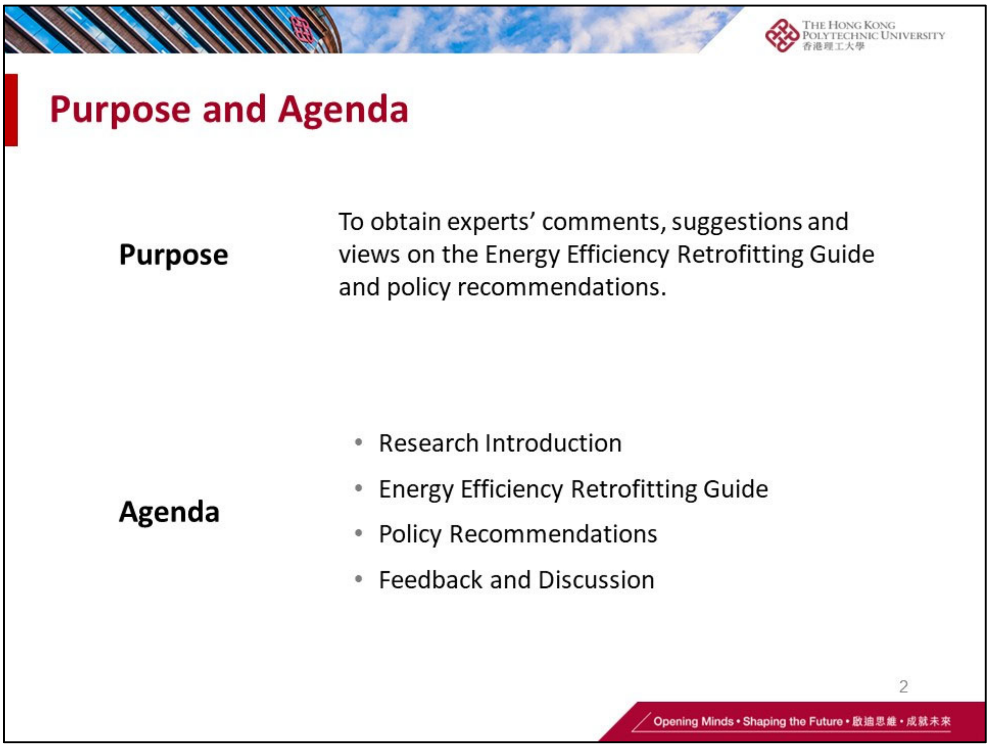
Rank	Challenge	Mean	SD	Result (1st round)	Your answer (1st round)	Would you like to change your assessment?		
						Yes		
17	Lack of trust among stakeholders during building energy retrofitting implementation					How would you reassess the importance of this challenge? ☐ **1-Not critical** ☐ **2-Least critical** ☐ **3-Fairly critical** ☐ **4-Moderate** ☐ **5-Critical** ☐ **6-Very critical** ☐ **7-Most critical**	How confident are you in reassessing this challenge? ☐ **1-Very low** ☐ **2-Low** ☐ **3-Medium low** ☐ **4-Medium** ☐ **5-Medium high** ☐ **6-High** ☐ **7-Very high**	☐ **No**
						Yes		
18	Lack of integration between research, standards, and practice on building energy retrofitting					How would you reassess the importance of this challenge? ☐ **1-Not critical** ☐ **2-Least critical** ☐ **3-Fairly critical** ☐ **4-Moderate** ☐ **5-Critical** ☐ **6-Very critical** ☐ **7-Most critical**	How confident are you in reassessing this challenge? ☐ **1-Very low** ☐ **2-Low** ☐ **3-Medium low** ☐ **4-Medium** ☐ **5-Medium high** ☐ **6-High** ☐ **7-Very high**	☐ **No**

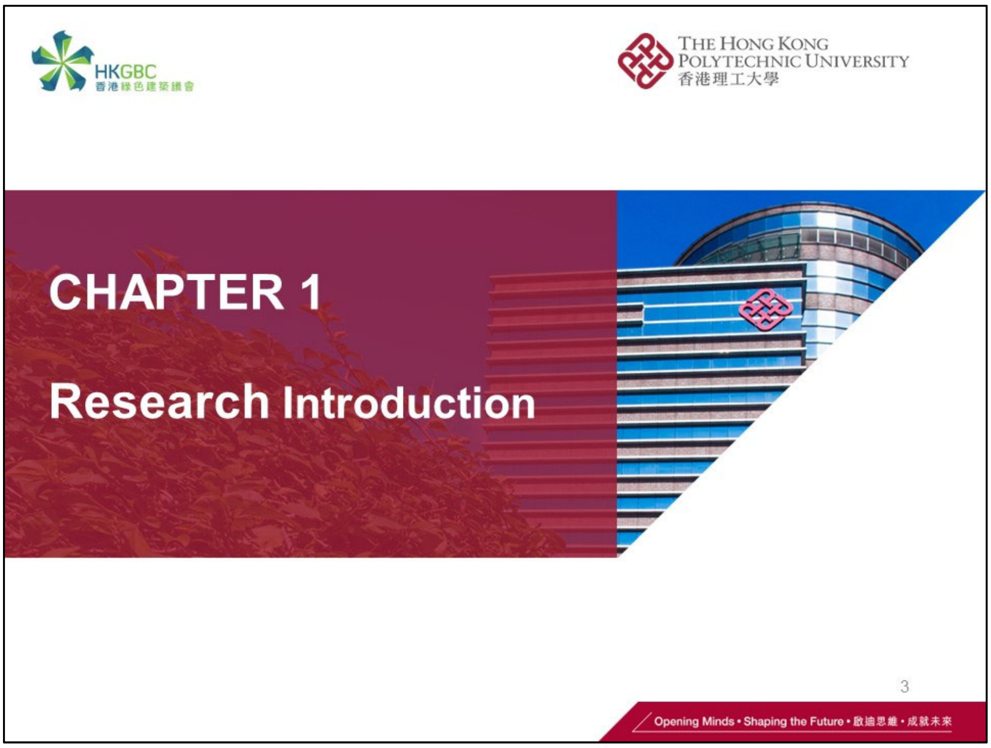
Rank	Challenge	Mean	SD	Result (1st round)	Your answer (1st round)	Would you like to change your assessment?		
						Yes		
19	Lack of citizen involvement and public support					How would you reassess the importance of this challenge? ☐ **1-Not critical** ☐ **2-Least critical** ☐ **3-Fairly critical** ☐ **4-Moderate** ☐ **5-Critical** ☐ **6-Very critical** ☐ **7-Most critical**	How confident are you in reassessing this challenge? ☐ **1-Very low** ☐ **2-Low** ☐ **3-Medium low** ☐ **4-Medium** ☐ **5-Medium high** ☐ **6-High** ☐ **7-Very high**	☐ **No**
						Yes		
20	Complexity of building energy retrofitting technologies					How would you reassess the importance of this challenge? ☐ **1-Not critical** ☐ **2-Least critical** ☐ **3-Fairly critical** ☐ **4-Moderate** ☐ **5-Critical** ☐ **6-Very critical** ☐ **7-Most critical**	How confident are you in reassessing this challenge? ☐ **1-Very low** ☐ **2-Low** ☐ **3-Medium low** ☐ **4-Medium** ☐ **5-Medium high** ☐ **6-High** ☐ **7-Very high**	☐ **No**

<table>
<tr><th>Rank</th><th>Challenge</th><th>Mean</th><th>SD</th><th>Result
(1st round)</th><th>Your answer
(1st round)</th><th colspan="3">Would you like to change your assessment?</th></tr>
<tr><td rowspan="2">21</td><td rowspan="2">Low public awareness and understandin g on building energy retrofitting</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td colspan="2">Yes</td><td rowspan="2">☐
No</td></tr>
<tr><td>How would you reassess the importance of this challenge?
☐ 1-Not critical
☐ 2-Least critical
☐ 3-Fairly critical
☐ 4-Moderate
☐ 5-Critical
☐ 6-Very critical
☐ 7-Most critical</td><td>How confident are you in reassessing this challenge?
☐ 1-Very low
☐ 2-Low
☐ 3-Medium low
☐ 4-Medium
☐ 5-Medium high
☐ 6-High
☐ 7-Very high</td></tr>
<tr><td rowspan="2">22</td><td rowspan="2">Interruption to building operation</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td colspan="2">Yes</td><td rowspan="2">☐
No</td></tr>
<tr><td>How would you reassess the importance of this challenge?
☐ 1-Not critical
☐ 2-Least critical
☐ 3-Fairly critical
☐ 4-Moderate
☐ 5-Critical
☐ 6-Very critical
☐ 7-Most critical</td><td>How confident are you in reassessing this challenge?
☐ 1-Very low
☐ 2-Low
☐ 3-Medium low
☐ 4-Medium
☐ 5-Medium high
☐ 6-High
☐ 7-Very high</td></tr>
</table>

Rank	Challenge	Mean	SD	Result (1st round)	Your answer (1st round)	Would you like to change your assessment?		
						Yes		No
						How would you reassess the importance of this challenge?	How confident are you in reassessing this challenge?	
23	Lack of access to sustainable materials in building energy retrofitting					☐ **1-Not critical** ☐ **2-Least critical** ☐ **3-Fairly critical** ☐ **4-Moderate** ☐ **5-Critical** ☐ **6-Very critical** ☐ **7-Most critical**	☐ **1-Very low** ☐ **2-Low** ☐ **3-Medium low** ☐ **4-Medium** ☐ **5-Medium high** ☐ **6-High** ☐ **7-Very high**	☐ **No**

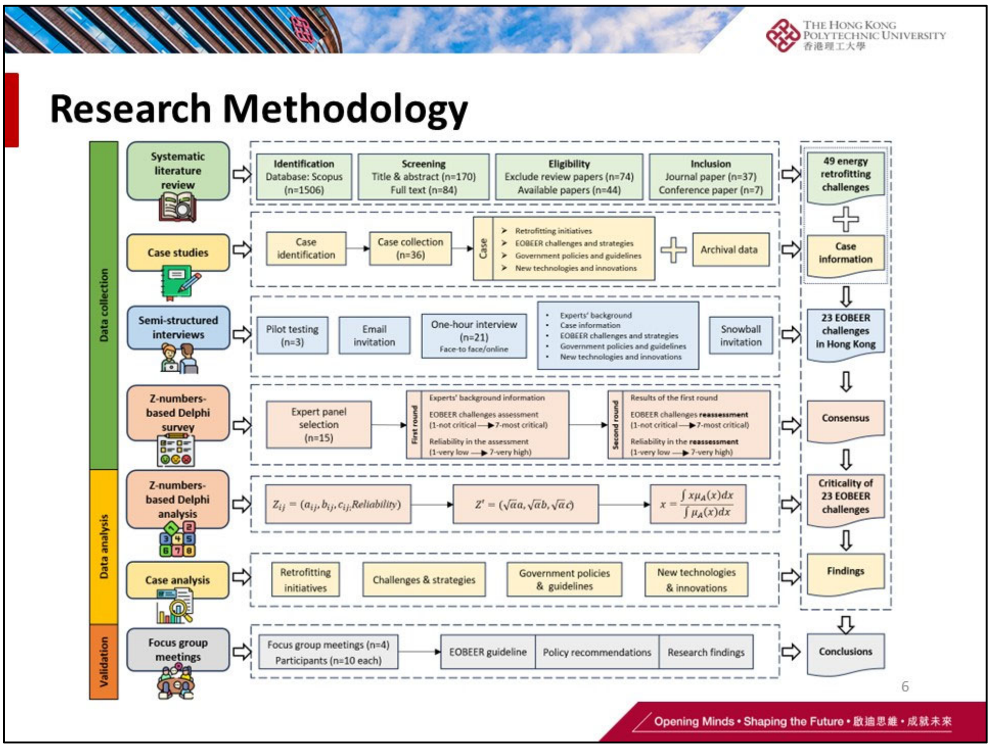
Appendix C – Slides for Focus Group Meetings

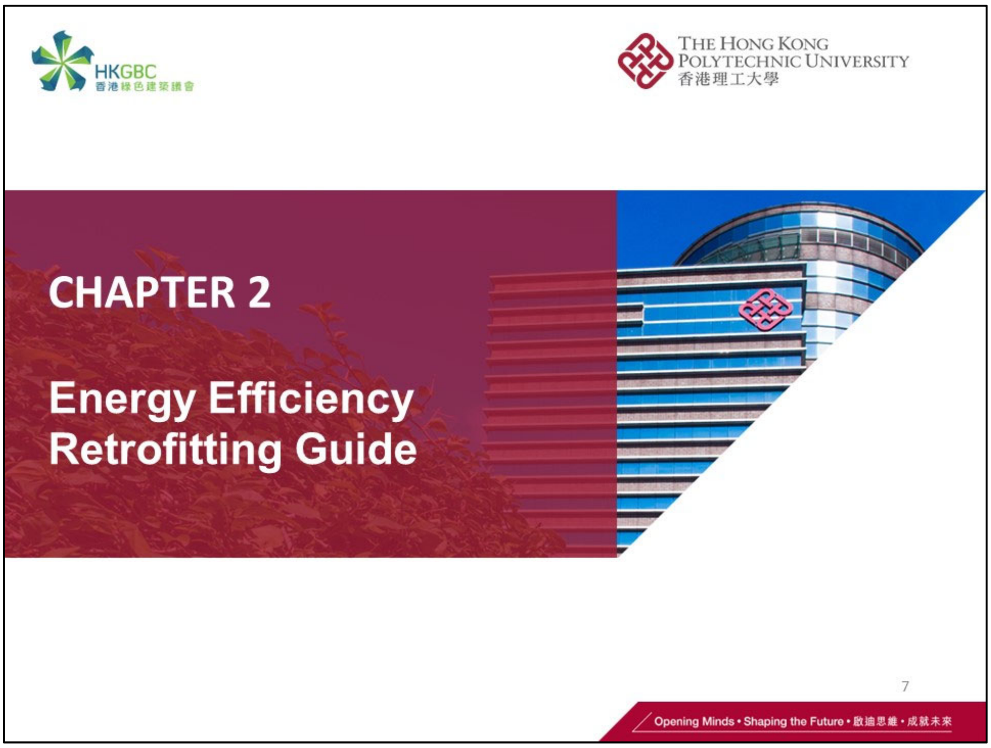


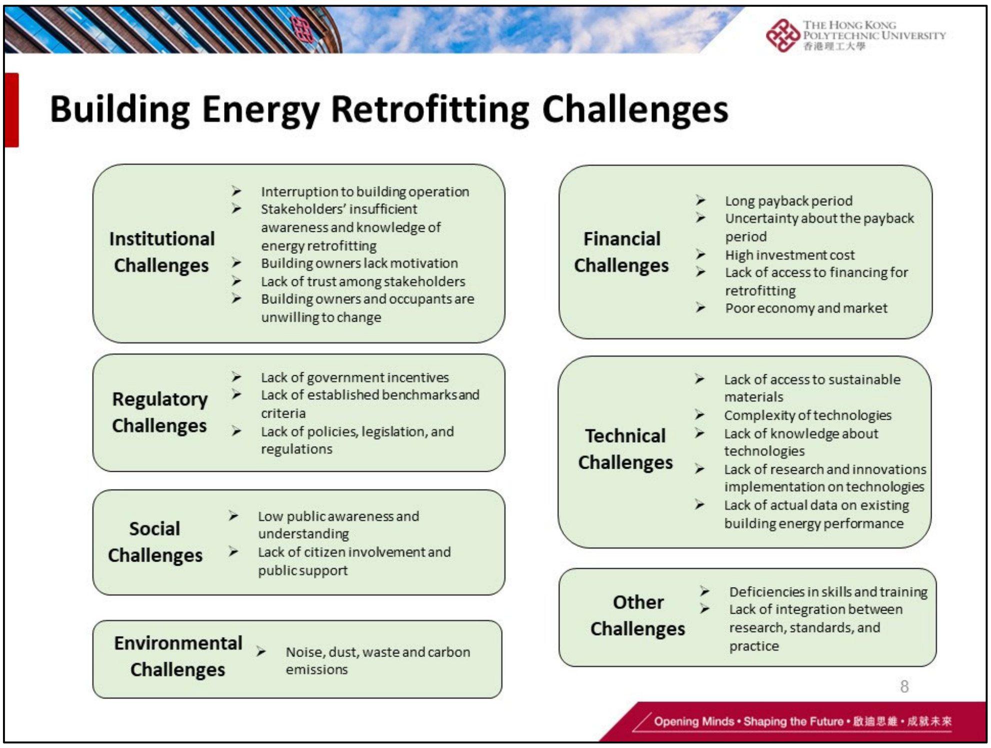

HKGBC
香港綠色建築議會
The Hong Kong Polytechnic University
香港理工大學
CHAPTER 1
Research Introduction
3
Opening Minds • Shaping the Future • 啟迪思維 • 成就未來


The Hong Kong Polytechnic University
香港理工大學
Background
Hong Kong's
October 2021
CLIMATE
ACTION
PLAN
2050
~90%
Buildings
66%
Electricity
Generation
18%
Transport
Waste
and
Others
4
Opening Minds • Shaping the Future • 啟迪思維 • 成就未來


THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學
Research Objectives
To evaluate the technical, financial, institutional, social, environmental, and regulatory challenges faced by building energy retrofitting in Hong Kong;
To develop an innovative building energy retrofitting guide for Hong Kong that addresses the challenges;
To provide policy recommendations for building energy retrofitting in Hong Kong;
To disseminate the research findings and recommendations to the public.
5
Opening Minds • Shaping the Future • 啟迪思維 • 成就未來


THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學
Research Methodology
Data collection
Data analysis
Validation
Systematic literature review
Identification
Database: Scopus
(n=1506)
Screening
Title & abstract (n=170)
Full text (n=84)
Eligibility
Exclude review papers (n=74)
Available papers (n=44)
Inclusion
Journal paper (n=37)
Conference paper (n=7)
49 energy retrofitting challenges
Case studies
Case identification
Case collection (n=36)
Case
Retrofitting initiatives
EOBEER challenges and strategies
Government policies and guidelines
New technologies and innovations
Archival data
Case information
Semi-structured interviews
Pilot testing (n=3)
Email invitation
One-hour interview (n=21)
Face-to face/online
Experts' background
Case information
EOBEER challenges and strategies
Government policies and guidelines
New technologies and innovations
Snowball invitation
23 EOBEER challenges in Hong Kong
Z-numbers-based Delphi survey
Expert panel selection (n=15)
First round
Experts' background information
EOBEER challenges assessment
(1-not critical → 7-most critical)
Reliability in the assessment
(1-very low → 7-very high)
Second round
Results of the first round
EOBEER challenges reassessment
(1-not critical → 7-most critical)
Reliability in the reassessment
(1-very low → 7-very high)
Consensus
Z-numbers-based Delphi analysis
$Z_{ij} = (a_{ij}, b_{ij}, c_{ij}; Reliability)$
$Z' = (\sqrt{\alpha}a, \sqrt{\alpha}b, \sqrt{\alpha}c)$
$x = \frac{\int x\mu_A(x)dx}{\int \mu_A(x)dx}$
Criticality of 23 EOBEER challenges
Case analysis
Retrofitting initiatives
Challenges & strategies
Government policies & guidelines
New technologies & innovations
Findings
Focus group meetings
Focus group meetings (n=4)
Participants (n=10 each)
EOBEER guideline
Policy recommendations
Research findings
Conclusions
6
Opening Minds • Shaping the Future • 啟迪思維 • 成就未來


HKGBC
The Hong Kong Polytechnic University
香港理工大學
CHAPTER 2
Energy Efficiency Retrofitting Guide
7
Opening Minds • Shaping the Future • 啟迪思維 • 成就未來


The Hong Kong Polytechnic University
香港理工大學
Building Energy Retrofitting Challenges
Institutional Challenges
➢ Interruption to building operation
➢ Stakeholders' insufficient awareness and knowledge of energy retrofitting
➢ Building owners lack motivation
➢ Lack of trust among stakeholders
➢ Building owners and occupants are unwilling to change
Financial Challenges
➢ Long payback period
➢ Uncertainty about the payback period
➢ High investment cost
➢ Lack of access to financing for retrofitting
➢ Poor economy and market
Regulatory Challenges
➢ Lack of government incentives
➢ Lack of established benchmarks and criteria
➢ Lack of policies, legislation, and regulations
Technical Challenges
➢ Lack of access to sustainable materials
➢ Complexity of technologies
➢ Lack of knowledge about technologies
➢ Lack of research and innovations implementation on technologies
➢ Lack of actual data on existing building energy performance
Social Challenges
➢ Low public awareness and understanding
➢ Lack of citizen involvement and public support
Other Challenges
➢ Deficiencies in skills and training
➢ Lack of integration between research, standards, and practice
Environmental Challenges
➢ Noise, dust, waste and carbon emissions
8
Opening Minds • Shaping the Future • 啟迪思維 • 成就未來

THE HONG KONG POLYTECHNIC UNIVERSITY 香港理工大學

Rank of Building Energy Retrofitting Challenges

Rank	Category	Challenges
1	Regulatory	Lack of government incentives
2	Technical	Lack of knowledge about building energy retrofitting technologies
3	Regulatory	Lack of policies, legislation and regulations
4	Institutional	Building owners lack the motivation to retrofit
5	Financial	Long payback period of building energy retrofitting
6	Technical	Lack of actual data on existing building energy performance
7	Regulatory	Lack of established benchmarks and criteria for building energy retrofitting
8	Financial	High investment cost in building energy retrofitting
9	Institutional	Stakeholders' insufficient awareness and knowledge of building energy retrofitting
10	Other	Deficiencies in the skills and training on building energy retrofitting
11	Institutional	Lack of trust among stakeholders during building energy retrofitting implementation
12	Institutional	Building owners and occupants are unwilling to change.
13	Technical	Lack of research and innovation implementation on building energy retrofitting technologies
14	Financial	Poor economy and market for building energy retrofitting
15	Financial	Lack of access to financing for building energy retrofitting
16	Technical	Complexity of building energy retrofitting technologies
17	Other	Lack of integration between research, standards, and practice on building energy retrofitting
18	Financial	Uncertainty about the payback period of building energy retrofitting
19	Environmental	Noise, dust, waste, and carbon emissions
20	Social	Low public awareness and understanding of building energy retrofitting
21	Social	Lack of citizen involvement and public support
22	Institutional	Interruption to building operation
23	Technical	Lack of access to sustainable materials in building energy retrofitting

9

Opening Minds • Shaping the Future • 啟迪思維 • 成就未來

THE HONG KONG POLYTECHNIC UNIVERSITY 香港理工大學

Strategies to Overcome Challenges (Top 10)

Top 1
Lack of government incentives

- Provide financial incentives by the government, e.g., grants and subsidies.
- Implement regulatory incentives to reduce bureaucratic hurdles and administrative burdens, such as expedited permitting processes or streamlined regulations.

Top 2
Lack of knowledge about technologies

- Launch awareness campaigns to educate practitioners, e.g., seminars, workshops, webinars, and public events.
- Implement demonstration projects that showcase successful examples.
- Integrate technologies into educational institutions, e.g., schools, colleges, and vocational training centers.

Top 3
Lack of policies, legislation and regulations

- Establish new policies, legislation and regulations.
- Establish mechanisms to monitor and evaluate the effectiveness of the implemented policies, legislation, and regulations.
- Digitalize the application and approval process by related government.

Top 4
Building owners lack the motivation to retrofit

- Provide financial incentives, e.g., grants, subsidies, or low-interest loans.
- Implement energy performance labeling systems.
- Conduct energy audits and benchmark the energy performance of buildings.

10

Opening Minds • Shaping the Future • 啟迪思維 • 成就未來

Strategies to Overcome Challenges (Top 10)

Challenge	Strategies
Top 5 Long payback period of building energy retrofitting	• Encourage eligible buildings to apply for ECO Building Funds (CLP) or Smart Power Building Funds (HKE). • Promote energy performance contracting. • Develop innovative financing mechanisms, e.g., green finance: green loans and green investment funds.
Top 6 Lack of actual data on existing building energy performance	• Collect energy performance data in existing office buildings, including energy audits and building energy monitoring systems. • Implement policies that encourage building owners to disclose energy performance data. • Establish online energy data platforms or databases, allowing building owners to voluntarily share their energy performance data.
Top 7 Lack of established benchmarks and criteria	• Establish standardized guidelines and provide benchmarking and performance-based rating tools. • Collaborate with BEAM Plus to align retrofitting benchmarks and criteria with their established frameworks.

11

Opening Minds • Shaping the Future • 啟迪思維 • 成就未來

Strategies to Overcome Challenges (Top 10)

Challenge	Strategies
Top 8 High investment cost in building energy retrofitting	• Provide financial incentives, e.g., grants, subsidies, or low-interest loans. • Implement energy performance labeling systems. • Develop innovative financing mechanisms, e.g., green finance: green loans and green investment funds.
Top 9 Stakeholders' insufficient awareness and knowledge	• Launch awareness campaigns to educate practitioners about technologies, e.g., seminars, workshops, webinars, and public events. • Establish knowledge-sharing platforms. Case studies and success are shared, showing positive outcomes and benefits.
Top 10 Deficiencies in the skills and training	• Develop the workforce. Provide on-the-job training opportunities for practitioners. • Educate professionals in educational institutions, e.g., schools, colleges, and vocational training centers. Develop specialized courses or programs. • Establish professional certifications, ensuring that professionals have the necessary skills and knowledge.

12

Opening Minds • Shaping the Future • 啟迪思維 • 成就未來

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

CHAPTER 3

Policy Recommendations

13

Opening Minds • Shaping the Future • 啟迪思維 • 成就未來

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

1 Government Incentives

- Financial incentives
  - Funding schemes
  - Innovative financing mechanism (e.g., Property Assessed Clean Energy Programs in the US)
- Non-financial incentives
  - Award certificates, like Energy Star in the US
- Funding schemes
  - Relaunch Buildings Energy Efficiency Funding Schemes (2009-2012, $450 million)
  - Eco Building Fund and Smart Power Building Fund: expand scope and increase funding

14

Opening Minds • Shaping the Future • 啟迪思維 • 成就未來

THE HONG KONG POLYTECHNIC UNIVERSITY 香港理工大學

2 Energy Audits

❖ Energy audit cycle

- Shorten energy audit cycle
  E.g., From 10 years to 3/5 years

❖ Actions after energy audit

- Mandatory actions for buildings with poor energy performance

❖ Disclose energy audit reports

- Building energy platform
- Public sectors: disclose
- Private sectors: disclose anonymously

15

Opening Minds • Shaping the Future • 啟迪思維 • 成就未來

THE HONG KONG POLYTECHNIC UNIVERSITY 香港理工大學

3 Permitting and tendering processes

❖ Streamline permitting processes

- Hasten permitting times and processes to avoid/reduce delays

❖ Amendments in the public tendering process

- Mandatory actions for turnkey solutions
  E.g., Mandates for contractors to proceed with implementation after assessment.

16

Opening Minds • Shaping the Future • 啟迪思維 • 成就未來

4 Digital technologies and intelligent data management

❖ Data-driven decision support system

- Guidelines on how to record and use energy data of buildings
  E.g., Timing, frequency, and key performance indicators
- Government support, guidelines and policies on incorporating latest technologies and innovative products in energy retrofits
  E.g., Internet of Things (IoTs), Cloud Computing, etc.

❖ Skills training on new technologies and innovations for energy savings

- Training of professionals and technicians on AI control optimization and data analytics.

❖ Standardized measurement and verification protocol

- Common framework for measurement and verification
  E.g., IPMVP Protocol
- Review and revise building energy standards and codes
  E.g., Updating calculation method for lighting power density (LPD).

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

5 Education, Training and Public Awareness

❖ Public awareness

- Develop programmes to improve awareness on energy-efficient practices

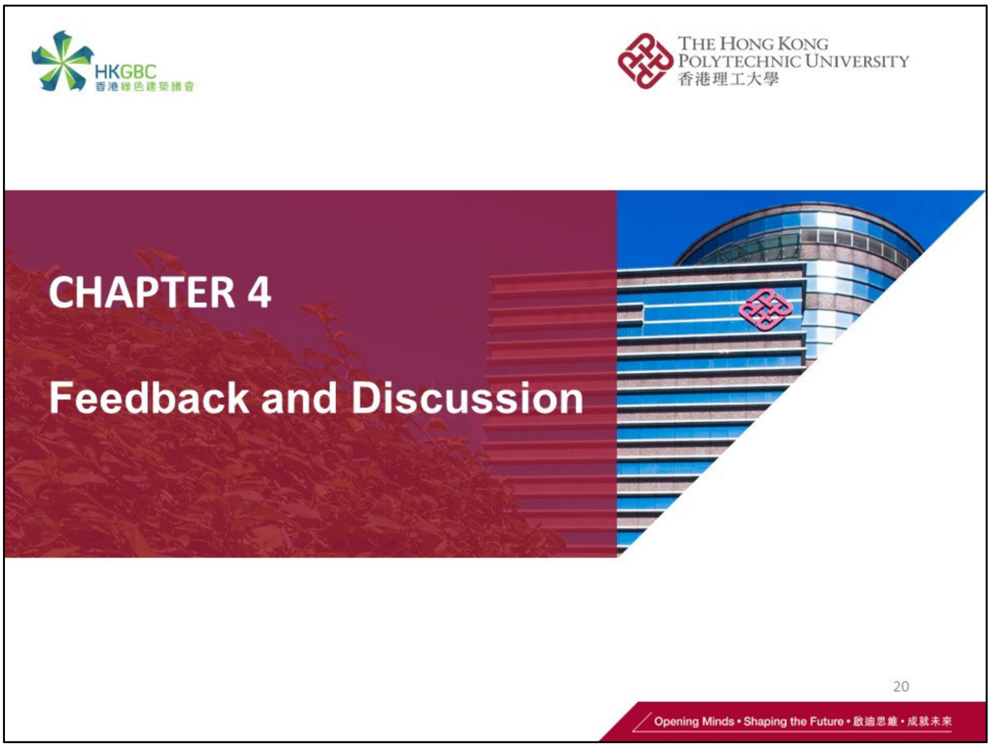
❖ Public education and training

- Increase public education and training on the benefits and methods of energy savings in buildings
  E.g., Installation of simple automatic control systems, turning off lights when not in use.

6 Environmental considerations in retrofits

❖ Waste issues

- Regulations for reducing and recycling waste


HKGBC
香港綠色建築議會
THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學
CHAPTER 4
Feedback and Discussion
20
Opening Minds • Shaping the Future • 啟迪思維 • 成就未來


Thank you
THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學
Opening Minds • Shaping the Future
啟迪思維 • 成就未來

Appendix D – *Innovative Energy Efficiency Retrofitting Guide*

Innovative Energy Efficiency Retrofitting Guide

Practical Ways to Overcome Challenges

Office Buildings

1. Introduction

Retrofitting any office building to improve its energy efficiency is challenging work. To be successful, the retrofitting project stakeholders must have the ability to identify and overcome the challenges that come with this type of work. This *Innovative Energy Efficiency Retrofitting Guide* has been developed by researchers from The Hong Kong Polytechnic University (PolyU) and the Hong Kong Green Building Council (HKGBC) to help office building owners, tenants, facility managers, and energy managers identify and overcome challenges during retrofitting. Emphasis is placed on current technical, financial, institutional, social, environmental, and regulatory challenges that impact retrofitting and the strategies that have been pursued to overcome them in diverse real-world project case studies.

Buildings consume roughly 40% of the world's energy, with office buildings accounting for a significant proportion. In Hong Kong, buildings in the commercial sector consume more energy than those in other sectors. Office buildings consume most of the energy, accounting for 13% of total energy consumption (Figure 1). Most of the existing office buildings were built over 30 years ago and embody the low energy efficiency standards of the times in which they were built. It is high time to retrofit these buildings to upgrade their aging systems, equipment, operation, and assemblies, and improve energy efficiency and performance.

Such energy efficiency retrofitting in existing office buildings offers several benefits. It provides a cost-effective means to improve energy efficiency and decrease the energy demand and consumption, as well as carbon emissions of a jurisdiction. It can reduce operating costs, especially in older buildings, as well as assist to increase property value, attract tenants, and gain a market edge. Building owners can meet regulatory requirements regarding high energy efficiency while improving the indoor environmental (e.g., air) quality of their buildings, positively impacting the health, wellbeing, comfort, happiness, productivity, and quality of life of occupants.

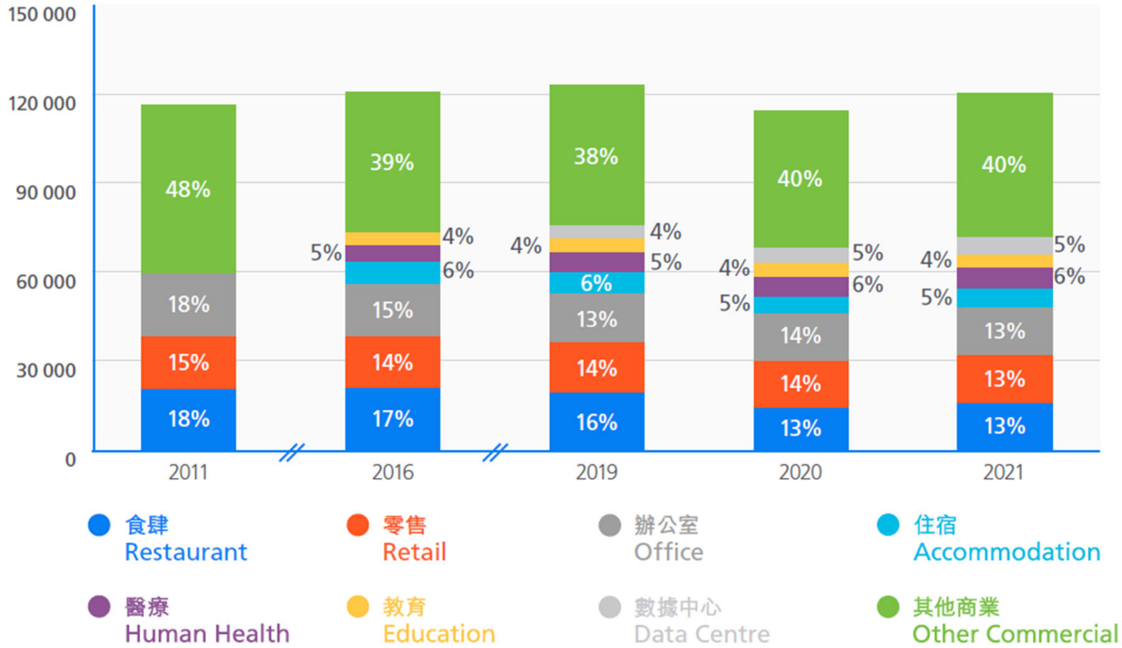


Figure 1. Total energy consumption in the commercial sector by segment.

Existing retrofitting guides have placed too much emphasis on the measures to retrofit buildings. There is currently very little guidance and resources on how to deal with specific challenges during retrofitting. But without a better understanding of the challenges faced in retrofitting and how to overcome them, those suggested measures by the existing guides may never see or achieve successful, large-scale uptake and implementation. A guide that addresses this gap is urgently needed and is of significant importance. This is where the innovation and innovativeness of this guide lies.

This guide offers diverse real-world case studies and critical examinations of the most pressing technical, financial, institutional, social, environmental, and regulatory challenges faced in existing office building energy efficiency retrofitting. Combining insights from diverse case studies and leading industry experts, building owners and operators, energy and carbon managers, and sustainability and other consultants, with the results of an expert Delphi survey, this guide offers practical solutions to these challenges. This guide offers specific and practical guidance, strategies, and best practices for overcoming the challenges faced in building energy retrofitting tailored to office buildings. The information in this guide can be used by building owners, tenants, facility managers, and energy managers to overcome challenges and successfully execute retrofitting projects to improve the energy efficiency and performance of office buildings.

1.1 Purpose and benefits of the guide

Energy efficiency retrofitting of existing office buildings has several benefits. But many research studies have proved that there are still a significant number of technical, financial, institutional, social, environmental, and regulatory challenges faced by building owners, tenants, facility managers, and energy managers (who are interested in) retrofitting their existing office buildings for energy efficiency. This guide addresses these challenges by offering insightful information on practical strategies for overcoming them. Case studies are included, to show how those strategies have been successfully applied in real office building energy efficiency retrofitting projects.

Building owners, tenants, facility managers, and energy managers who wish to improve the energy efficiency of their office buildings by the appropriate retrofitting will benefit from this guide. They will identify proven strategies to tackle specific challenges that come with executing existing office building energy efficiency retrofitting projects. When faced with new challenges, they can draw lessons from the case studies included in this guide. Recommendations for successful retrofitting are included to help building owners, tenants, and managers plan and manage the process effectively.

In addition to challenges and solutions, this guide also includes a plethora of energy efficiency retrofit initiatives, measures, and technologies for office buildings. Furthermore, a list of policies and guidelines applicable to various projects is outlined. This information will guide practitioners and building owners on the necessary regulations to adhere to and permissions to seek an intended improvement project. The Government considering regulations or incentives for energy efficiency improvements in existing office buildings will also benefit from this guide. It is clear that some identified challenges lack solutions at the project level and require government interventions.

For tenants, this guide will help them better understand the importance of retrofitting and the role they can play in supporting the process. This guide provides them with information on how they can improve their energy use and reduce their energy costs and the environmental footprint of their operations. This guide offers a useful tool for building owners, tenants, and managers to successfully implement energy efficiency improvement projects in their existing office buildings.

1.2 Approach to developing the guide

The approach to developing this guide consists of a series of research activities (Figure 2). A literature review was conducted to identify potential challenges and hindering factors that might be encountered by building owners, tenants, facility managers, and energy managers during building energy efficiency retrofitting. A literature review is an effective way of obtaining a comprehensive understanding of the subject. This review was conducted mainly based on data gathered through Scopus, a reliable academic literature database. A dataset of 40+ relevant studies was identified and systematically reviewed. After the initial step of identifying a total of 49 challenges, a categorization framework was developed (Figure 3), covering technical, financial, institutional, social, environmental, regulatory, and other challenges hindering the energy efficiency retrofitting of existing buildings.

A total of 36 individual real-world case studies in Hong Kong were then conducted to verify the theoretical challenges to identify the real challenges facing existing office building energy efficiency retrofitting. Case study is a useful tool for exploring and generating deep understanding of a particular phenomenon. Each of the 36 case studies is an energy efficiency improvement project conducted in an existing office building, facility, or space.

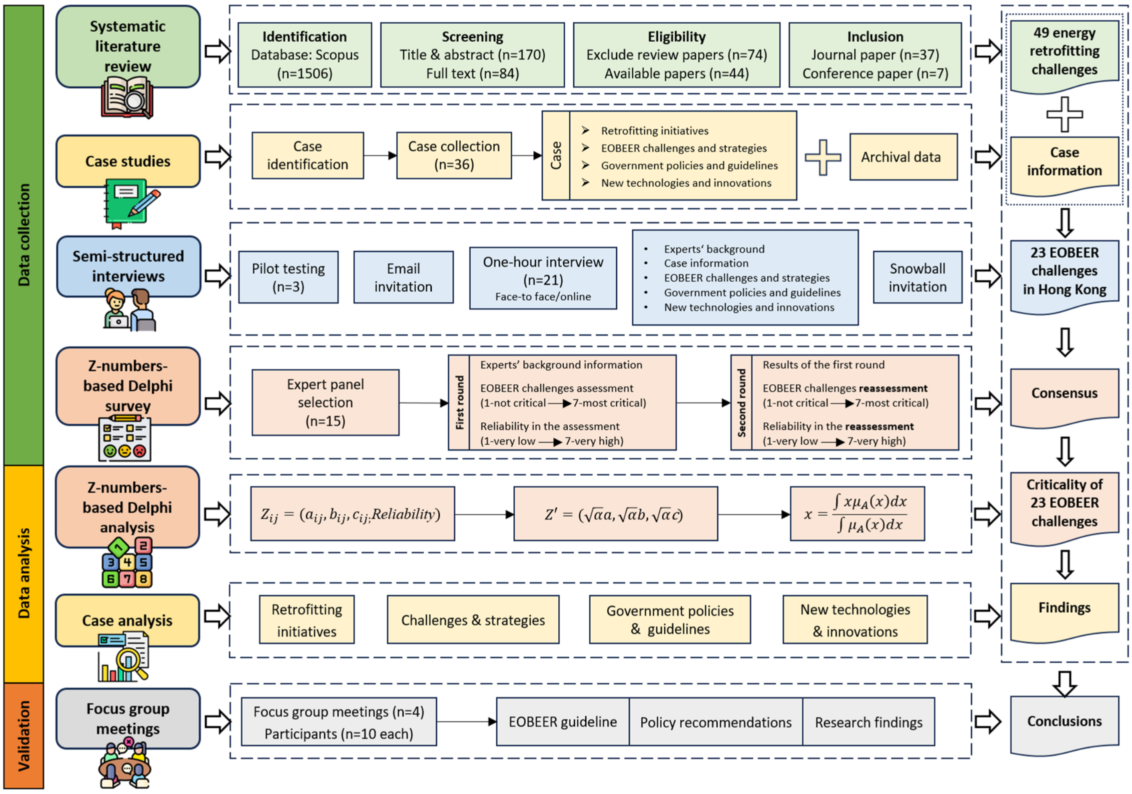


Figure 2. Approach to developing the guide.

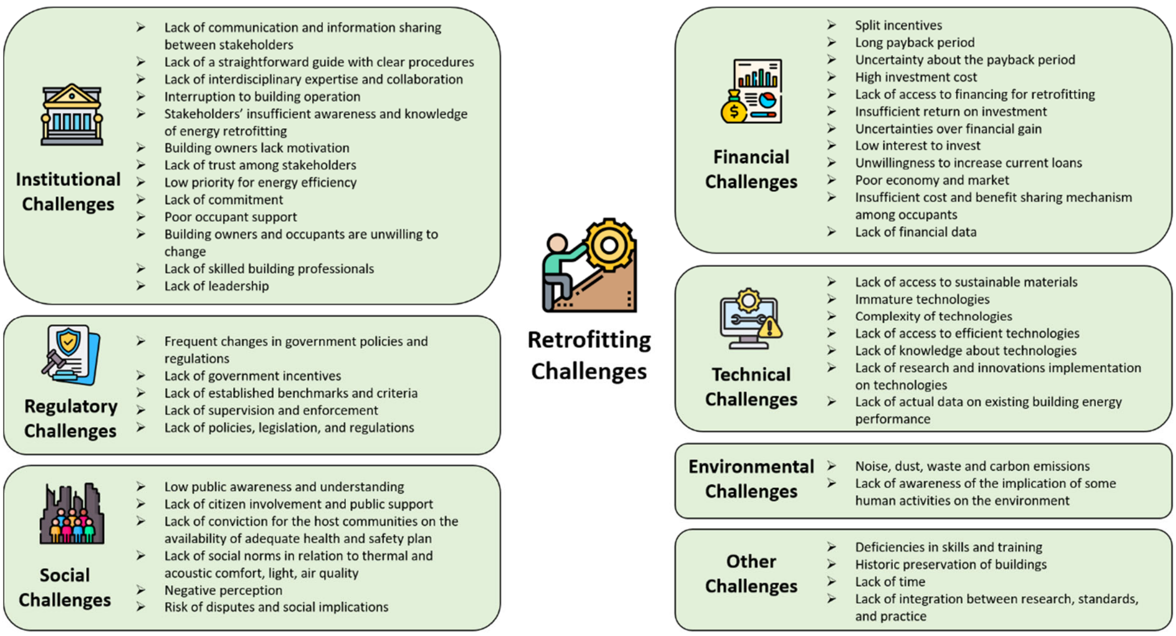


Figure 3. Theoretical framework for building energy efficiency retrofitting challenges.

In each case, semi-structured interviews, guided by a written questionnaire, findings from the literature review, and open discussions, were conducted with key project stakeholders, such as the building owner, facility manager, sustainability consultant, material supplier, energy and building information modelling service provider, designer, and main contractor. Semi-structured interviews were chosen over structured and unstructured interviews because they allow for more standardized, constructive, and interactive discussions. These interviews provide rich information about the various challenges and hindering factors encountered during the retrofitting project implementation from a general perspective rather than from the perspective of a single stakeholder. This makes this guide broadly useful to a wide range of stakeholder groups, building owners, tenants, facility managers, energy managers, government, etc. The interviews also shed light on various strategies used to overcome the challenges to successfully retrofit the buildings. It is expected that stakeholders who need to undertake retrofitting projects in the future may learn from these successful experiences.

The interviews were conducted either face-to-face or online at the convenience of the participants. They lasted on average 60 minutes and in many cases involved one, two, or more stakeholders of the project. In some cases, the stakeholders have been involved in more than one retrofitting project with different or similar challenges and solution strategies. These stakeholders were allowed to share their experience in the many different retrofitting projects. The interviews were tape-recorded, then later transcribed into written scripts and analyzed manually. The interview questionnaire and research project information were sent to participants days prior to the interview. This helped them prepare ahead of the interview and in some cases, written responses to the interview questions were also received from project stakeholders. Where such written responses were received prior to the interview, the interview provided an opportunity for both the researchers and participants to elaborate in more detail on the written responses, providing deeper insight into the points raised about the retrofitting project. These case-based interviews enabled the gathering of sufficient real case information about each of the 36 retrofitting projects and their key stakeholders:

- Background information of the stakeholder being interviewed;

- Background information of the project in terms of, for example, the retrofitting initiatives/measures implemented;
- Energy saving target of the project;
- The stakeholder's roles and responsibilities in the project;
- Challenges encountered and strategies implemented during the retrofitting project implementation;
- Existing government policies and guidelines followed in the project;
- Recommended policies and guidelines;
- New technologies and innovations applied in the project.

Some cases had hard archival data in the form of project documentation, which were also collected and analyzed along with the interview data. The analysis of the interview and archival data identified and consolidated the real challenges and the strategies used to respond to them in the case studies.

The consolidated list of real challenges was then used to conduct a 15-expert Z-numbers-based Delphi method survey and analysis to objectively quantify the criticality of the challenges and identify the most critical or top challenges. Prioritizing their challenges and identifying the top ones is very important for stakeholders to know quickly where best to focus their attention in an energy efficiency retrofitting project. Z-numbers-based Delphi method was chosen for this exercise because as a fuzzy Delphi hybrid method, it is powerful at removing subjectivity and bias from the information collected from the survey, ensuring more objective, valid, reliable, and consistent information. At least 10 experts are sufficient to produce valid and reliable information from a Z-numbers-based Delphi method survey and analysis. The 15 experts were selected from the project stakeholders who participated in the case-based interviews earlier on, focusing on those with the most and rich experience in retrofitting and willing to participate in this follow-up Z-numbers-based Delphi method survey. More than 86% of them had at least five years' experience in retrofitting, with over 50% of them having more than 20 years' experience in retrofitting. The information from the survey therefore provides penetrating and important insights from years of experience into the top challenges confronting the energy efficiency retrofitting of existing office buildings. This guide offers information on these top challenges as well, plus recommended strategies to overcome them.

As a final step, focus group meetings were organized with key stakeholders to validate the information collected from the case studies, semi-structured interviews, archival data, and Delphi survey, as well as the content of this guide. Focus group meetings allow collaborative and open discussion among participants to arrive at meaningful information. To minimize bias and obtain more detailed information, stakeholders who did not participate in the earlier interviews and Delphi survey were also involved in the focus group meetings. This step was used to obtain helpful criticisms, comments, suggestions, and corrections made to this guide.

2. Defining Retrofitting

Retrofitting is a term used to describe the process by which existing buildings are upgraded to be more energy-efficient and sustainable. It encompasses a wide range of activities aimed at reducing the amount of energy consumed by buildings, thereby minimizing the environmental impact of human development. The process of retrofitting buildings has evolved over time, and there are various perspectives about what retrofitting entails and how it is conducted.

There are several schools of thought on what retrofitting means, but they all share a common goal of improving energy efficiency in buildings. According to the UK Government's Department for Business, Energy & Industrial Strategy, retrofitting refers to "the process of improving the energy and environmental performance of existing buildings through the implementation of a range of measures." This definition highlights the importance of implementing a wide range of energy-saving measures, such as insulation, installation of more efficient heating systems, and use of renewable energy sources.

The U.S. Department of Energy defines retrofitting as "the addition of new technology and features to older systems and buildings." This definition emphasizes the importance of upgrading older buildings with newer energy-saving technologies. Retrofitting involves adding new systems, such as smart lighting and ventilation systems, as well as upgrading the insulation and windows to improve the energy efficiency of these buildings.

Based on the above definitions, this guide defines retrofitting as the process of upgrading existing buildings with new technologies, systems, equipment, operational behaviours, or materials to improve their energy efficiency, functionality, safety, or overall sustainability, all done in a way that is profitable or viable to the building owner or tenant. Retrofitting techniques involve improving the building envelope, HVAC systems, lighting, insulation, and water systems. Energy efficiency retrofitting measures can include installing energy-efficient equipment, lighting, renewable energy systems, building automation and control systems, insulation, ventilation, operational and behavioural changes, and others. A more comprehensive retrofit can involve a complete overhaul of HVAC, electrical, and plumbing systems. Building envelope retrofitting is necessary to reduce energy loss through fixtures, such as windows, doors, and roofs.

Retrofit can also be classified based on their energy savings realization, whether standard or deep retrofit. The term **"standard retrofit"** describes the modernization of pre-existing structures using well-established technology and methods to increase energy efficiency. The restoration strategy concentrates on the most straightforward energy-saving techniques, which typically provide a rapid return on investment. A typical retrofit can involve replacing outdated windows with double or triple-glazed ones to stop heat loss and replacing inefficient lighting fixtures with more energy-efficient ones.

Deep retrofit, on the other hand, refers to the modernization of the building envelope, primary building systems, and interior components in order to significantly increase energy efficiency. The energy savings goal of the retrofit strategy is at least 50%, and it also seeks to increase occupant comfort. A deep retrofit attempts to improve a building's performance, for example, by integrating new technology and altering the building's architecture to use less energy.

Deep retrofitting is appropriate for larger commercial structures where energy performance can benefit from significant improvements, whereas standard retrofits are appropriate for structures where simple changes can considerably reduce energy usage. Prior to selecting the most appropriate retrofit strategy, building owners and facilities managers should weigh the economic, social, and environmental costs associated with each retrofit.

3. Challenges to Existing Office Building Energy Retrofitting

The current energy crisis and increasing environmental concerns have increased the demand for energy-efficient buildings. Retrofitting of existing buildings is a primary strategy to reduce the energy consumption of office buildings. Energy retrofitting is a complicated process that involves innovative building systems and advanced technologies. The retrofitting of existing office buildings presents several challenges that must be addressed to achieve significant energy savings. The challenges encountered in energy efficiency retrofitting of existing office buildings in Hong Kong are classified into seven categories: financial, technical, social, institutional, environmental, and regulatory challenges.

3.1 Financial Challenges

Financial challenges refer to the difficulties or obstacles that individuals or organizations face in managing their finances when conducting energy retrofit works. Financial challenges are the primary concern before building owners make retrofitting decisions. Retrofitting existing office buildings can be expensive, and the initial costs can cause challenges when the cost savings are realized over an extended period. The upgrade costs vary depending on the upgrade type, the building size, and the complexity of retrofitting. Organizations, especially small and medium-scale enterprises, are often financially constrained to take up retrofit initiatives. Further, government incentives for existing office building retrofit are absent in Hong Kong, discouraging retrofitting projects. The financial challenges and their description are shown in Table 1.

Table 1. Financial challenges and description.

Code	Financial challenges and description
F1	**Long payback period of building energy retrofitting** This challenge refers to the long duration required for energy savings to offset the initial investment in energy efficiency retrofitting.
F2	**Uncertainty about the payback period of building energy retrofitting**

Code	Financial challenges and description
	This challenge means the duration required for energy savings to offset the initial investment is surrounded by uncertainty.
F3	**High investment cost in building energy retrofitting** This challenge refers to the significant upfront expenses required to implement energy efficiency improvements.
F4	**Lack of access to financing for building energy retrofitting** This challenge refers to the difficulty in obtaining the necessary financial resources to undertake energy efficiency improvements.
F5	**Poor economy and market for building energy retrofitting** This challenge refers to adverse economic circumstances and a lack of demand or opportunities in the market for energy efficiency improvements in existing buildings.

3.2 Technical Challenges

Technical challenges refer to the difficulties or obstacles that arise due to the complex nature of technology, systems, or processes in energy-efficiency upgrades of existing office buildings. The building systems of pre-1980s buildings are often outdated and have limited capacity for energy-efficient upgrades. Retrofitting complicated building systems could cause additional technical challenges, such as the potential of compromising fire safety and HVAC systems. Also, new technologies and innovations bring new trends to retrofit existing office buildings, requiring specialized skills and expertise. The technical challenges and their description are shown in Table 2.

Table 2. Technical challenges and description.

Code	Technical challenges and description
T1	**Lack of access to sustainable materials in building energy retrofitting** This challenge refers to the difficulty in obtaining environmentally friendly and resource-efficient materials for use in energy retrofit projects, such as energy-efficient insulation, low-emissivity windows, and renewable energy systems.
T2	**Complexity of building energy retrofitting technologies** This challenge refers to the complicated nature of technologies involved in implementing energy efficiency improvements.

Code	Technical challenges and description
T3	**Lack of knowledge about building energy retrofitting technologies** This challenge refers to a limited understanding or awareness of the available technologies for improving energy efficiency in existing office buildings.
T4	**Lack of research and innovation implementation on building energy retrofitting technologies** This challenge refers to insufficient efforts and limited application of cutting-edge research and innovative solutions in energy efficiency retrofit projects.
T5	**Lack of actual data on existing building energy performance** This challenge refers to the absence of accurate and comprehensive information regarding the energy consumption of existing office buildings.

3.3 Regulatory Challenges

Regulatory challenges refer to the difficulties or obstacles that arise from the regulatory environment surrounding energy efficiency retrofitting improvements. Regulatory challenges come from the need to comply with various building codes and standards, which can vary across jurisdictions. Regulatory challenges are encountered when existing building codes and standards do not align with retrofitting objectives, rendering them non-compliant with the standards. Retrofitting can also require permits that add difficulties regarding time and finances. The regulatory challenges and their description are shown in Table 3.

Table 3. Regulatory challenges and description.

Code	Regulatory challenges and description
R1	**Lack of government incentives** This challenge refers to the absence of incentives provided by the government, such as financial incentives, tax credits, grants, or subsidies to encourage energy retrofitting in existing office buildings.
R2	**Lack of established benchmarks and criteria for building energy retrofitting** This challenge refers to the absence of standardized guidelines, benchmarks and criteria that practitioners can rely on when undertaking energy retrofitting projects.
R3	**Lack of policies, legislation and regulations**

Code	Regulatory challenges and description
	This challenge refers to the absence of specific policies, legislation, and regulations on energy retrofitting in existing office buildings.

3.4 Institutional Challenges

Institutional challenges refer to obstacles or difficulties that arise from the structure practices within organizations, institutions, and stakeholders. These issues are related to ownership, management, and legal agreements that may affect the retrofitting process. The conflicts between multiple building owners, tenants, designers, consultants, and contracts can inhibit the decision-making process of energy retrofitting. The institutional challenges and their description are shown in Table 4.

Table 4. Institutional challenges and description.

Code	Institutional challenges and description
I1	**Interruption to building operation** This challenge refers to energy retrofitting activities that disrupt the normal operation of the existing office buildings. This can include temporary shutdowns of some areas, relocation of occupants, or limitations on access to certain areas of the building.
I2	**Stakeholders' insufficient awareness and knowledge of building energy retrofitting** This challenge refers to the lack of understanding and familiarity among various individuals and organizations involved in the retrofitting process. This includes building owners, occupants, contractors, policymakers, and other relevant stakeholders.
I3	**Building owners lack motivation to retrofit** This challenge refers to building owners not willing to invest in energy retrofitting projects for their existing office buildings.
I4	**Lack of trust among stakeholders during building energy retrofitting implementation** Trust is crucial for successful collaboration and effective implementation of retrofitting projects. This challenge refers to the absence or breakdown of trust between various individuals and organizations involved in the retrofitting process.

Code	Institutional challenges and description
I5	**Building owners and occupants are unwilling to change** This challenge refers to the resistance or reluctance among these individuals to adopt new practices or behaviours related to building energy efficiency.

3.5 Social Challenges

Social challenges refer to the potential disruption to the public during the energy retrofitting process, which can lead to dissatisfaction. Energy retrofitting initiatives have interactions with others in society. For example, if the public may have little knowledge of energy retrofitting works, they may hold a conservative opinion on energy retrofitting and think it is not necessary. The social challenges and their description are shown in Table 5.

Table 5. Social challenges and description.

Code	Social challenges and description
S1	**Low public awareness and understanding on building energy retrofitting** This challenge refers to the lack of knowledge and familiarity among the general public regarding the concept, benefits, and importance of retrofitting existing office buildings for improved energy efficiency.
S2	**Lack of citizen involvement and public support** This challenge refers to the limited engagement and participation of citizens in energy retrofitting initiatives, as well as a lack of overall public support for these efforts.

3.6 Environmental Challenges

Environmental challenges refer to the impact of energy retrofitting on the environment, such as natural resource consumption, waste generation, and carbon emissions. The primary challenge encountered in retrofitting existing office buildings includes the environmental impacts in terms of noise, dust, waste and carbon emissions during the retrofitting. If environmental challenges associated with existing office building retrofits are not adequately tackled, it may negate the initial retrofit to reduce carbon emissions. The environmental challenges and their description are shown in Table 6.

Table 6. Environmental challenges and description.

Code	Environmental challenges and description
E1	**Noise, dust, waste and carbon emissions** This challenge refers to the negative environmental and health impacts that can arise during the process of retrofitting buildings for improved energy efficiency.

3.7 Other Challenges

Other challenges refer to other obstacles or difficulties of energy retrofitting projects that are not mentioned above. The other challenges and their description are shown in Table 7.

Table 7. Other challenges and description.

Code	Other challenges and description
O1	**Deficiencies in the skills and training on building energy retrofitting** The challenge refers to the lack of knowledge, expertise, and specialized training among professionals and workers involved in retrofitting projects.
O2	**Lack of integration between research, standards, and practice on building energy retrofitting** The challenge refers to the disconnect and limited coordination between these three key components (i.e., research, standards and practice) in the field of retrofitting existing office buildings for improved energy efficiency.

3.8 The Rank of Retrofitting Challenges

Experts assessed the challenges of energy efficiency retrofitting in offices to ascertain their criticality. Table 8 shows the results with the rank of each challenge. Prioritizing these challenges and identifying the most significant ones is critical for practitioners in prioritizing their difficulties, devising solutions to overcome them, and developing ambitious but feasible targets and objectives.

Table 8. Rank of energy efficiency retrofitting challenges.

Rank	Code	Challenges
1	R1	Lack of government incentives
2	T3	Lack of knowledge about building energy retrofitting technologies
3	R3	Lack of policies, legislation and regulations
4	I3	Building owners lack the motivation to retrofit
5	F1	Long payback period of building energy retrofitting
6	T5	Lack of actual data on existing building energy performance
7	R2	Lack of established benchmarks and criteria for building energy retrofitting
8	F3	High investment cost in building energy retrofitting
9	I2	Stakeholders' insufficient awareness and knowledge of building energy retrofitting
10	O1	Deficiencies in the skills and training on building energy retrofitting
11	I4	Lack of trust among stakeholders during building energy retrofitting implementation
12	I5	Building owners and occupants are unwilling to change.
13	T4	Lack of research and innovation implementation on building energy retrofitting technologies
14	F5	Poor economy and market for building energy retrofitting
15	F4	Lack of access to financing for building energy retrofitting
16	T2	Complexity of building energy retrofitting technologies
17	O2	Lack of integration between research, standards, and practice on building energy retrofitting
18	F2	Uncertainty about the payback period of building energy retrofitting
19	E1	Noise, dust, waste, and carbon emissions
20	S1	Low public awareness and understanding of building energy retrofitting
21	S2	Lack of citizen involvement and public support
22	I1	Interruption to building operation
23	T1	Lack of access to sustainable materials in building energy retrofitting

4. Strategies to Overcome Energy Efficiency Retrofitting Challenges

Energy efficiency retrofitting in existing office buildings saves energy and building operation costs, contributes to achieving carbon neutrality and benefits the environment. To facilitate the implementation of energy efficiency retrofitting and provide practical solutions to the challenges for practitioners, the guide proposes the corresponding strategies that may help overcome these challenges above, as shown in Table 9.

Table 9. Strategies to overcome energy efficiency retrofitting challenges.

Code	Challenges	Strategies
R1	Lack of government incentives	• Introduce financial incentives. Financial incentives could be utilized to offset the costs associated with energy retrofitting, such as grants, subsidies, or tax credits. The financial incentives can include direct funding for projects and financial support for energy audits. • Implement regulatory incentives. The Government implements regulatory incentives to reduce bureaucratic hurdles and administrative burdens, such as expedited permitting processes or streamlined regulations for retrofitting projects.
T3	Lack of knowledge about building energy retrofitting technologies	• Launch awareness campaigns. Launch comprehensive awareness campaigns to educate industry practitioners about building energy retrofitting technologies. These campaigns can include informative materials, workshops, webinars, and public events that explain the concept, benefits, and available technologies for retrofitting buildings. • Implement demonstration projects. Implement demonstration projects that showcase successful examples of building energy retrofitting. These projects can be open to the industry, allowing practitioners to see firsthand the technologies used in retrofitting and understand their effectiveness. • Integrate technologies into educational institutions. Integrate building energy retrofitting technologies into educational curricula at schools, colleges, and vocational training centers. This will help future professionals, such as architects, engineers, and construction workers, gain knowledge and skills in retrofitting technologies.

Code	Challenges	Strategies
R3	Lack of policies, legislation and regulations	• Establish new policies legislation and regulations. Establish new policies legislation and regulations to provide adequate support for the implementation of energy efficiency retrofitting in existing office buildings. Engage relevant stakeholders, including industry associations, non-profit organizations, and community groups, in developing new policies, legislation, and regulations. • Establish mechanisms to monitor and evaluate the effectiveness of the implemented policies, legislation, and regulations. Regularly assess their impact, identify areas for improvement, and make necessary adjustments to ensure their continued relevance and effectiveness. • Digitalize the application and approval process by the Building Department and other related government departments to shorten the processing time for retrofit approval.
I3	Building owners lack the motivation to retrofit	• Provide financial incentives. Providing financial incentives, such as grants, tax credits, or low-interest loans, can help overcome the financial barriers that deter building owners from retrofitting. • Implement energy performance label systems. Implementing energy performance labelling systems can create transparency and awareness about the energy efficiency of buildings. Making this information available to potential buyers or tenants will attract more occupants. • Conduct energy audits. Conducting energy audits and benchmarking the energy performance of buildings can provide building owners with a clear understanding of their energy consumption and potential savings through retrofitting.
F1	Long payback period of building energy retrofitting	• Encourage clients to apply for retrofitting funding. Encourage eligible clients to apply for funding applicable to energy efficiency retrofit works such as CLP ECO Building Funds and Smart Power Building Funds from HK Electric. • Promote energy performance contracting. Energy performance contracting involves partnering with energy service

Code	Challenges	Strategies
		companies that finance, implement, and guarantee energy savings from retrofitting projects. The energy service companies are paid from the energy savings achieved, allowing building owners to avoid upfront costs and benefit from immediate energy cost reductions. • Develop innovative financing mechanisms. Green finance is a new trend to address financing obstacles faced by sustainable projects and initiatives. It includes various financial instruments, such as green bonds, green loans, green insurance, and green investment funds.
T5	Lack of actual data on existing building energy performance	• Collect energy performance data in existing office buildings. Establish programs or initiatives to collect data on building energy performance. It involves conducting energy audits, implementing monitoring systems, or collaborating with building owners and managers to gather energy consumption data. Benchmarking tools can be used to compare building performance against similar structures and identify areas for improvement. • Implement policies that require building owners to disclose energy performance data. The approaches include energy efficiency ratings, energy consumption data, or other relevant metrics. A standardized framework for collecting and sharing building energy performance information is needed for the mandatory disclosure. • Establish energy data sharing platforms. Create online platforms or databases where building owners can voluntarily share their energy performance data, fostering transparency and enabling benchmarking and best practice sharing.
R2	Lack of established benchmarks and criteria for building energy retrofitting	• Establish standardized guidelines and provide benchmarking and performance-based rating tools for building energy retrofitting, similar to those used in other countries to incentivize energy efficiency. • Collaborate with existing certification programs. Work together with BEAM Plus to align retrofitting benchmarks and criteria with their established frameworks.

Code	Challenges	Strategies
F3	High investment cost in building energy retrofitting	• Provide financial incentives by the government and institutions, such as grants, subsidies, or tax credits to offset the upfront costs of energy retrofitting. • Promote energy performance contracting. Energy performance contracting involves partnering with energy service companies that finance, implement, and guarantee energy savings from retrofitting projects. The energy service companies are paid from the energy savings achieved, allowing building owners to avoid upfront costs and benefit from immediate energy cost reductions. • Develop innovative financing mechanisms. Green finance is a new trend to address financing obstacles faced by sustainable projects and initiatives. It includes various financial instruments, such as green bonds, green loans, green insurance, and green investment funds.
I2	Stakeholders' insufficient awareness and knowledge of building energy retrofitting	• Develop and implement educational programs and awareness campaigns. These initiatives include workshops, seminars, webinars, and informational materials such as brochures and videos. By these approaches, the stakeholders are informed about the benefits and importance of building energy retrofitting. • Establish knowledge-sharing platforms. Case studies and success stories of building energy retrofitting projects are shared, and the positive outcomes and benefits are demonstrated. Highlight the energy savings, improved comfort, and reduced environmental impact achieved through retrofitting.
O1	Deficiencies in the skills and training on building energy retrofitting	• Develop the workforce for building energy retrofitting. The government closely collaborates with professional bodies and provides on-the-job training opportunities for practitioners interested in building energy retrofitting. Pair them with experienced professionals who can serve as mentors and guide them through real-world projects.

Code	Challenges	Strategies
		• Educate professionals in educational institutions, such as universities and technical colleges, to develop specialized courses or degree programs focused on building energy retrofitting. • Establish professional certification and accreditation programs. These certifications can serve as a benchmark for competency and ensure that professionals have the necessary skills and knowledge to carry out retrofitting projects effectively. Continuous professional development should be encouraged by the renewal of certificates.
I4	Lack of trust among stakeholders during building energy retrofitting implementation	• Foster a transparent communication environment among stakeholders. Clearly communicate project goals, timelines, and expected outcomes. Address any concerns or doubts raised by stakeholders promptly and provide regular updates on the progress of the retrofitting project. • Clearly define the roles and responsibilities of each stakeholder involved in the retrofitting project. This will enable stakeholders to effectively communicate expectations and understand their specific obligations, ensuring that they can fulfil their commitments. • Foster collaboration and partnerships among stakeholders, such as building owners, contractors, energy service companies, and government agencies. Encourage stakeholders to work together towards a common goal and share risks and rewards.
I5	Building owners and occupants are unwilling to change.	• Disclose more financial information on building energy retrofitting, showing the benefits of the retrofitting investment, the payback period, and the annual savings. • Involve building owners and occupants in the decision-making process. Understand their concerns and priorities and tailor retrofitting solutions to meet their specific needs. • Implement pilot retrofitting projects in buildings to showcase the benefits and outcomes to building owners and

Code	Challenges	Strategies
		occupants. Use these projects as examples to encourage wider adoption of retrofitting practices.
T4	Lack of research and innovation implementation on building energy retrofitting technologies	• Increase funding for research and development in building energy retrofitting technologies. Governments, industry associations, and research institutions can allocate more resources for research projects focused on innovative retrofitting technologies. • Foster collaboration between research institutions, industry stakeholders, and government agencies to promote the implementation of research findings and innovative technologies. Encourage knowledge sharing, joint research projects, and technology transfer between academia and industry.
F5	Poor economy and market for building energy retrofitting	• The government needs to motivate the market by encouraging various energy-efficient initiatives and products. Offer financial incentives to building owners and occupants to encourage them to invest in building energy retrofitting.
F4	Lack of access to financing for building energy retrofitting	• Increase government funding. Increase government funding for building energy retrofitting projects and initiatives, including grants, subsidies, and low-interest loans. Consider relaunching the defunct Buildings Energy Efficiency Funding Scheme. • Develop innovative financing mechanisms. Green finance is a new trend to address financing obstacles faced by sustainable projects and initiatives. It includes various financial instruments, such as green bonds, green loans, green insurance and green investment funds. • Promote energy performance contracting. Energy performance contracting involves partnering with energy service companies that finance, implement, and guarantee energy savings from retrofitting projects. The energy service companies are paid from the energy savings achieved, allowing building owners to avoid upfront costs and benefit from immediate energy cost reductions.

Code	Challenges	Strategies
T2	Complexity of building energy retrofitting technologies	• Standardize building energy retrofitting technologies and processes. Develop clear guidelines and standardized protocols for retrofitting projects, making it easier for building owners and professionals to understand and implement retrofitting measures. • Provide education and training programs to building owners, professionals, and contractors on building energy retrofitting technologies. Offer workshops, webinars, and certification programs to enhance their knowledge and skills in retrofitting. • Offer technical assistance and support to building owners and professionals throughout the retrofitting process. Establish a network of experts and consultants who can provide specialized advice and assistance to overcome technical challenges. • Invest in research to advance building energy retrofitting technologies and make them more user-friendly and accessible. Support research institutions and industry collaborations to develop innovative solutions that simplify retrofitting processes and reduce complexity.
O2	Lack of integration between research, standards, and practice on building energy retrofitting	• Create collaborative platforms that bring together researchers, industry professionals, policymakers, and standards organizations to facilitate knowledge exchange and collaboration. These platforms can include conferences, workshops, and working groups where stakeholders can share research findings, discuss challenges, and develop practical solutions for building energy retrofitting. • Foster partnerships between research institutions and industry practitioners to bridge the gap between research and practice. Encourage joint research projects, knowledge transfer programs, and collaborative initiatives that allow researchers to work closely with practitioners to understand their needs and develop practical solutions.

Code	Challenges	Strategies
		• Develop effective strategies for transferring research findings into practical guidance and disseminating it to industry professionals and policymakers. The outputs include the creation of user-friendly guides, manuals, and online resources that summarize research findings and provide actionable recommendations. • Ensure that research findings and standards are integrated into building energy retrofitting policies and regulations. Collaborate with policymakers to incorporate the latest research findings into policy frameworks, codes, and guidelines.
F2	Uncertainty about the payback period of building energy retrofitting	• Disclose more financial information on building energy retrofitting, showing the benefits of the retrofitting investment, the payback period, and the annual savings. • Perform a thorough cost-benefit analysis to determine the financial viability of building energy retrofitting projects. • Utilize energy modeling and simulation tools to estimate the potential energy savings and payback period of retrofitting measures. • Use case studies and benchmarking. Study and analyze case studies of similar retrofitting projects to understand their payback periods. Benchmarking against similar buildings or projects can provide references to estimate the payback period.
E1	Noise, dust, waste, and carbon emissions	• Enforce waste recycling. The government should enforce waste recycling, and an enabling environment should be given to facilitate practical implementation. • Develop a comprehensive pre-construction plan that includes strategies to minimize noise, dust, waste, and carbon emissions. • Employ construction techniques that minimize noise, dust, waste, and carbon emissions. • Develop and implement environmental management plans that outline specific measures to minimize noise, dust, waste, and carbon emissions.

Code	Challenges	Strategies
S1	Low public awareness and understanding of building energy retrofitting	• Develop and implement educational programs and awareness campaigns. These initiatives include workshops, seminars, webinars, and informational materials. By these approaches, the stakeholders are informed about the benefits and importance of building energy retrofitting. • Implement demonstration projects. Implement demonstration projects that showcase successful examples of building energy retrofitting. These projects can be open to the industry, allowing practitioners to see firsthand the technologies used in retrofitting and understand their effectiveness. • Collaborate with local media outlets to raise awareness about building energy retrofitting. Provide them with informative and engaging content, such as press releases, articles, and interviews, to educate the public about the benefits and importance of retrofitting.
S2	Lack of citizen involvement and public support	• Involve citizens and local communities in the decision-making process for building energy retrofitting projects. Seek their input, opinions, and ideas through public consultations, focus groups, or surveys. • Collaborate with local community organizations, non-profit groups, or environmental associations to promote building energy retrofitting. Partner with these organizations to organize events, workshops, or information sessions that target specific communities or interest groups.
I1	Interruption to building operation	• Rescheduling of retrofit operations to outside working hours or weekends. • Consider temporarily relocating occupants or providing alternate spaces during the retrofitting process. • Implement effective noise and dust control measures to minimize their impact, including using barriers, sealing off work areas, and implementing proper ventilation systems to control dust and maintain indoor air quality.

Code	Challenges	Strategies
T1	Lack of access to sustainable materials in building energy retrofitting	• Reputable organizations like HKGBC can play a crucial role in promoting sustainable materials and facilitating communication with manufacturers. • Collaborate with research institutions and universities to explore innovative and sustainable materials for building energy retrofitting. Support research projects that focus on developing new materials or improving the sustainability of existing materials. • Collaborate with other retrofitting projects, organizations, or municipalities to procure sustainable materials.

5. Real World Case Studies

Case 1

Building A

Retrofit initiatives: The retrofit initiatives focused on achieving energy efficiency of chiller plants through the following:

- Centralized chilled water plant improvement: Two existing 3,000-tonne seawater-cooled chillers were replaced with two new 1000-tonne and one 2000-tonne direct seawater-cooled chillers. For the new chillers, new primary pumps were also installed. Two new primary pumps for chilled water and two new heating water pumps for the heating water system were installed in one chiller. Two new primary pumps were installed for another chiller. A constant flow control valve was built on the discharge side of each chiller for automatic flow rate control of chilled water going through each chiller. The central chiller plant was outfitted with a chilled water decoupling system. It consists of a secondary water distribution system with variable flow and continuous water flow through each chiller evaporator.

- Chilled water plant control: A DDC control system is provided for fully automatic control, energy optimization control, monitoring, supervision, and data logging for chilled water plant operation. The DDC control system predicts the building load need based on the loading profile from previous years. The expected building load is analysed to establish the most suitable chiller plant layout.
- Implementation of digital insight: This further enables system fault detection, chiller optimization and real-time energy dashboards.

Challenges encountered on this project and solutions are provided in Table 10.

Table 10. Challenges and Solutions for Case 1

Category	Challenges and solutions
Technical challenges	**Transportation of big-size equipment:** The equipment is quite heavy. The limited size and access to the building plant room made it difficult to carry out the retrofitting works efficiently. **Solutions:** • Worked closely with the FM company to ensure proper transportation routing for the delivery of large components to the chiller plant. • Prior to delivery, mock-ups are created to simulate the size and dimensions of the equipment. This ensures that there's adequate space and clearance for the large components through narrow entrances and corridors. Mock-ups can be made from paper or wood to mimic the size and shape of the actual equipment. • From the factory to the site, chillers are split into multiple pieces for transportation. Prior to

Category	Challenges and solutions
	transportation, all refrigerant and oil are removed. • Careful attention is paid to the physical conditions of the environment, such as the condition of the floor and walls, to prevent damage during equipment movement. Protective measures like steel platforms may be used to safeguard the floor from heavy loads. After the delivery, efforts are made to restore the environment to its original condition. This includes ensuring that the space looks the same as before the equipment was moved in, and any temporary protective measures are removed. • After delivery, the vacuum inside the equipment is checked, and the oil and refrigerant are recharged. • After reassembly, the equipment undergoes thorough testing and commissioning to ensure that it performs as expected. This process requires expertise from chiller manufacturers to guarantee optimal performance.
Institutional challenges	**Lack of communication:** It needs clear and effective communication among the project participants. **Solutions:** • They had close communication every week and held regular project meetings with the client to ensure that key parameters and milestones are achieved. This could involve aligning expectations, ensuring timely progress updates, and adhering to the required procedures and method statements.
	Timing management and coordination: The project has a short timeframe for each step of work, and any delays or issues can disrupt the entire process.

Category	Challenges and solutions
	Solutions: • Provided timely progress updates, and adhered to the required procedures and method statements.
	Disruptions to tenants: The retrofitting works needed to be carried out without causing any inconvenience or disruption to the building's tenants. The retrofitting works could generate noise, smoke, and other factors that could affect both the comfort of the building occupants and external surroundings. **Solutions:** • Scheduled work during non-business hours, such as nights or weekends, to minimize disturbance. • Replace one chiller, and then start to replace another chiller, minimizing disruption to tenants.
	Delivery disruptions: The delivery of equipment and components can be at risk, especially during the COVID-19 pandemic. Delays and disruptions in delivery can affect the progress of the project. **Solutions:** No solution was provided at the project level.
Environmental Challenges	**Handling and disposing of refrigerants:** In Hong Kong, the Environmental Protection Department (EPD) requires the destruction of refrigerants because they contribute to global warming when released into the air. **Solutions:** Collected refrigerants are handled in any of the two ways. • Recycle the refrigerants, utilizing their own recycling capabilities. They would then sell the recycled

Category	Challenges and solutions
	refrigerants and use them in other chiller plants. This approach saved costs as they could use the old refrigerants instead of buying new ones. • Ensured proper disposal of the refrigerants, as they contained potentially harmful substances.

Case 2

Building owner: The Hong Kong Polytechnic University

Building name: One block in the Hong Kong Polytechnic University

Retrofit initiative: The retrofit initiatives focused on achieving energy efficiency of lighting through the following:

- LED replacement. Replace the fluorescent tubes with LED tubes to increase the lighting efficiency.
- Smart lighting control. Use the LED tubes with wireless smart control built in. The smart control can be realized with a mobile app and with a wireless switch. Besides, smart control could include motion sensors, occupancy sensors, etc.

Challenges encountered on this project and solutions are provided in Table 11.

Table 11. Challenges and Solutions for Case 2

Category	Challenges and solutions
Technical challenges	**Difficult to replace fluorescent tubes with LED lighting:** It is not that easy to replace the fluorescent tube with LED. There are many types of fluorescent tubes, and three technologies exist with fluorescent tubes. Each of these technologies requires different LED replacement products. **Solutions:** • LED suppliers usually provide compatibility lists to ensure proper matching. If the LED tube is compatible, a

Category	Challenges and solutions
	direct replacement can be done by simply replacing the lamp. • If the LED tube is incompatible, there are two options. Option one involves rewiring the circuitry to fit the new LED tube by removing the electronic ballast. Option two requires replacing the entire fitting with a new one with LED chips installed.
	A hesitant attitude of clients towards new technologies: Clients are hesitant to accept and use these technologies in Hong Kong. While the necessary technologies for retrofitting lighting with smart systems are readily available, the main challenge lies in getting people to accept and use these technologies in Hong Kong. Project owners in Hong Kong are often hesitant to adopt new products or technologies without local references and examples of successful implementation. This creates a chicken and egg issue, as the lack of local users makes it difficult to convince others to adopt the technology. **Solutions:** No solution was provided at the project level.
Financial challenges	**High labour cost of LED replacement:** High cost to replace the fluorescent tube to LED if it needs rewiring the circuitry to fit the new LED tube by removing the electronic ballast or replace the entire fitting with a new fitting that already has LED chips installed. **Solutions:** • To overcome this challenge, some utility companies, like CLP and HK Electric, provide funding reimbursements for projects that can demonstrate energy savings.

Category	Challenges and solutions
	High cost of LED replacement: Replacing the fluorescent tube with LED is at a high expense if the circuitry must be rewired to accommodate the new LED tube by removing the electronic ballast, or the complete fitting must be replaced with a new fitting that already has LED chips installed. **Solutions:** • To overcome this challenge, some utility companies, like CLP and HK Electric, provide funding reimbursements for projects that can demonstrate energy savings.
	No green financing: No green financing is provided in Hong Kong for the retrofitting projects. Although green financing is popular in Europe and the US, it is not yet widely adopted in Hong Kong. The drawback of CLP and HK Electric funding is that the end users only receive the money after completing the project. This poses a challenge for those who do not have the necessary funds to invest upfront. **Solutions:** No solution was provided at the project level.

Case 3

Building B

Retrofit initiative: Retrofit an existing industrial facility to a workspace. The structural alteration was needed to modify and optimize the existing framework to a more commercial co-workspace.

- Light wells: Openings in the floor slab were created to allow natural light to penetrate into the building, which would improve the well-being and attractiveness of the office space.

- Shading devices: Shading elements on the south-facing façade were designed to reduce solar heat gain and glare, which would impact the energy consumption for cooling and lighting.
- Sensory devices: Sensor-based lighting and building management systems were utilized to optimize the energy efficiency and the comfort level of the occupants.

Challenges encountered on this project and solutions are provided in Table 12.

Table 12. Challenges and Solutions for Case 3

Category	Challenges and solutions
Technical challenges	**Constraints on floor-to-floor heights and structural alteration**: The existing industrial buildings have low ceiling heights and column layouts that limit the flexibility and reuse of the space. Structural alteration is costly and requires building department approval. **Solutions:** No solution was provided at the project level.
	Optimizing natural light and ventilation: The existing industrial buildings have deep floor plans and only two sides with openings, which reduce the natural light and ventilation in the interior. **Solutions:** • Light wells and shading devices were introduced to improve the indoor environment, but these also have cost and design implications.
Financial challenges	**The financial information and data are not easy to access due to their sensitive nature.** **Solutions:**

Category	Challenges and solutions
	No solution was provided at the project level.
	High cost of innovation and technology: Innovation and technology are key to improving energy efficiency and reducing carbon footprint, but they also come at a high cost, for example, sensory devices, BIPV, ether cable lighting, and recycled materials. These products are either too expensive, too new, or not available in Hong Kong. **Solutions:** No solution was provided at the project level.
	Lack of consultation and participation: There is no consultation or participation from the public or the neighboring community for retrofitting projects, unlike in the UK where there is a notification and objection period. **Solutions:** No solution was provided at the project level.
Institutional challenges	**Disruption to the occupants and the neighborhood:** Retrofitting projects can cause inconvenience and disturbance to the occupants and the neighborhood, such as noise, dust, debris, and traffic. **Solutions:** • The contractors communicated with the occupants and the neighborhood in advance and provided them with alternative arrangements and compensations.
	Lack of awareness and education: There is a lack of awareness and education among the public and the stakeholders about the benefits and the importance of energy retrofitting, and this leads to skepticism and resistance.

Category	Challenges and solutions
	Solutions: No solution was provided at the project level.
Regulatory challenges	**Lack of government incentives:** There is no financial support or subsidy from the government for retrofitting projects in Hong Kong, unlike in other countries such as Singapore, UK, or US. This makes it hard for the private sector to invest in greener strategies and technologies that could reduce energy consumption and carbon footprint. **Solutions:** No solution was provided at the project level.
	Slow approval process: The approval process from the building department delays the implementation of retrofitting works and affects the commercial return of the investors. The process could be improved by using digital applications and intelligent assessments. **Solutions:** No solution was provided at the project level.
	No environmental policy or regulation: There is no environmental policy or regulation in Hong Kong that requires or encourages retrofitting projects to meet certain standards or criteria for energy efficiency or carbon neutrality. **Solutions:** No solution was provided at the project level.
Environmental challenges	**Overshadowing neighboring buildings and streets:** Adding more floors or changing the facade of the building create shading

Category	Challenges and solutions
	effects on the surrounding environment, affecting the natural light and ventilation of other buildings and public spaces. **Solutions:** • The impact was considered in the retrofitting design.
	Waste generation from retrofitting works: There was no process to recycle materials in Hong Kong, and that all the waste from retrofitting works went to the landfill. **Solutions:** No solution was provided at the project level.

Case 4

Building C

Retrofit initiative: Replace air filters, which can achieve the same or higher filtration efficiency with the original grading and enhance IAQ. Energy saving can also be attained through a reduction in pressure drop, hence on the fan power.

Challenges encountered on this project and solutions are provided in Table 13.

Table 13. Challenges and Solutions for Case 4

Category	Challenges and solutions
Financial challenges	**High Costs of installation, labor and material:** The installation fee, including accessories like electrical wires and metal conduits, can be quite significant, sometimes accounting for nearly half of the total project cost. Labor costs for installing or integrating electrical components into the control panel were noted as a substantial part of the initial investment for clients. Material Costs: While the system itself has low material costs, the upfront

Category	Challenges and solutions
	installation costs can take up a significant portion of the total project cost. **Solutions:** • Apply funding. If the installation can reduce the carbon emission or carbon footage, clients can apply funding.
Institutional challenges	**Occupant Disturbance:** The installation will disturb the occupants and operation of the buildings. **Solutions:** • The need to schedule installation work during off-hours to avoid disturbing building tenants. Work outside working hours, working day 7 pm-12 am, Saturday and Sunday. • Ensuring that retrofitting work causes minimal disruption to building occupants.
Environmental challenges	**Noise Containment:** Installation work generates noise, but it is well-contained within the plant room, avoiding disturbance to tenants and the public. **Solutions:** No solution was provided at the project level.
Regulatory challenges	**Product Standards:** There is a challenge in labeling filters according to their grade. The replacement filters enhanced by technology need to be tested and labeled correctly to match or exceed the performance of traditional filters. **Solutions:** • Do some tests by the third party.

Case 5

Building D

Retrofit initiative: The initiatives include photovoltaic (PV) panel installation and chiller plant replacement. The project involved retrofitting existing rooftops with PV panels to generate electricity. Another initiative was the replacement of chiller plants to improve energy efficiency.

Challenges encountered on this project and solutions are provided in Table 14.

Table 14. Challenges and Solutions for Case 5

Category	Challenges and solutions
Technical challenges	**Sourcing PV Panels:** Difficulty in finding suitable photovoltaic (PV) panels in the market due to a variety of options and the lack of mature products. The space on the rooftop is limited, but there are so many utilities on the rooftop, and they need for maintenance access. It's very difficult to find the location to place the PV panel on the rooftop. Moreover, the safety concerns should be addressed before the installation. The structural loading capacity of buildings for installing PV panels and the typhoon in Hong Kong should be considered. **Solutions:** • Sourcing innovative PV panel solutions that do not require concrete bases, making them walkable and reducing the need for reserved maintenance space. • Carefully evaluate the structural limitations and implementing appropriate solutions.
	Fast technologies update: For the long time waiting for registration, the PV panel project may have already been updated. **Solutions:** No solution was provided at the project level.

Category	Challenges and solutions
Financial challenges	**Long payback period:** The payback period of this retrofitting project is long. It is difficult to justify retrofitting projects with a long payback period to senior management and convince them to invest in, especially if the payback period exceeds 10 years. **Solutions:** • Apply incentives for this project to shorten the payback period.
Social challenges	**Reflection and Glare:** Concerns about the angle of installed PV panels potentially causing glare to neighbors, which requires careful consideration and planning to avoid negative impacts. **Solutions:** • Consultation and Modelling. Hiring consultants to model the impact of PV panel reflections on neighbors and ensure no negative effects.
Regulatory challenges	**Submission Procedures:** The tedious and time-consuming process of submitting retrofitting projects for approval can delay project implementation. **Solutions:** No solution was provided at the project level.

Case 6

Building E

Retrofit initiative: The project involved replacing air conditioning units with more advanced products that convert power supply from AC to DC, resulting in about 10% energy savings.

Challenges encountered on this project and solutions are provided in Table 15.

Table 15. Challenges and Solutions for Case 6

Category	Challenges and solutions
Financial challenges	**Budget Pressure:** The building owner faced budget constraints, especially during periods like the COVID-19 pandemic, which impacted financial resources globally. **Solutions:** • Prioritize projects before submitting proposals for consideration due to limited funds.
Social challenges	**Occupant Disruption:** Retrofitting activities such as replacing air conditioning units require occupants to vacate the area, causing inconvenience. The limited availability of spare space to relocate occupants during retrofitting poses a significant challenge. **Solutions:** • Proactively identified empty or spare spaces to temporarily relocate occupants during retrofitting.
Environmental challenges	**End-of-Life Assessment:** Assessing the condition and performance of systems to determine if they are at the end of their life is crucial to prevent premature replacement and additional waste. **Solutions:** • Making a justification for the retrofitting project, assessing the condition of units, and focusing on areas with increasing energy consumption.

Case 7

Building F

Retrofit initiative: A system that adds an additional glass layer inside the existing curtain wall to improve energy efficiency and occupant comfort, saving 20% to 30% of cooling energy and reducing the unbalanced exposure to sunlight and heat.

Challenges encountered on this project and solutions are provided in Table 16.

Table 16. Challenges and Solutions for Case 7

Category	Challenges and solutions
Financial challenges	**Lack of funding:** The project required significant financial investment, but there was a lack of funding available. Finding clients who were willing to pay for the installation is a challenge because the installation is innovative in Hong Kong. **Solutions:** • Finding a forward-thinking customer or building owner who is willing to try new things and work with them to substantiate claims. • Collaborating with universities to conduct studies and analysis to gain reputable validation for the innovative solution. • Collaborating with organizations like HKGBC and other NGOs to make it easier to promote the innovative solution and gain support.
	High expenses for project submissions: Project submissions for innovative solutions can be costly, particularly for medium-sized companies. The financial burden of these expenses makes it difficult to justify the investment in helping the industry. **Solutions:** No solution was provided at the project level.

Category	Challenges and solutions
Institutional challenges	**Limited support and collaboration from project owners:** Finding project owners who are supportive and willing to work with innovative companies can be challenging. **Solutions:** • Finding a forward-thinking clients or building owner who is willing to try new things and work with them to substantiate claims.
Environmental challenges	**Lack of a recycling system to deal with solid wastes:** Currently, there is no recycling system in place for glass in the industry. When glass is torn down or reaches its end of life, it is typically sent to the landfill instead of being recycled. This issue is not unique to glass but applies to all building materials. To recycle glass from construction sites, specific infrastructure is required. This includes crushers to break the glass into smaller sizes and packaging facilities to transport it to recycling plants. These facilities are not readily available, making it difficult to implement a recycling process. **Solutions:** No solution was provided at the project level.
Regulatory challenges	**Lack of a clear procedure or framework for innovation**: There is no specific category for this project, making it difficult to determine which submission process to follow. Neither new building nor alteration and addition (A&A) nor minor works category adequately fits this type of innovations, which is a barrier to implementing them. **Solutions:** No solution was provided at the project level.

Category	Challenges and solutions
	Limited communication and collaboration between industry and government departments: There is a need for better communication and collaboration between government departments and the industry. This would allow for discussions and finding solutions for innovations that do not fit into current regulations. **Solutions:** No solution was provided at the project level.
	Limited incentives: Without any incentives or regulations mandating glass recycling, there is little motivation for industry players to invest in the required infrastructure and processes. The current practice is to simply pay a landfill fee and dispose of the glass, which is a more cost-effective solution. **Solutions:** No solution was provided at the project level.

Case 8

Building G

Retrofit initiative: The retrofit initiatives to improve energy efficiency are shown as follows:

- AI system for chiller plant optimization control: this project uses AI method to balance the energy consumption of different components of the air conditioning system, such as chillers, pumps, and cooling towers. It can adjust the operation according to the dynamic factors such as weather, occupancy, and cooling demand. This can improve the energy efficiency and reduce the cooling load of the system.
- Replacement of air handling unit with high efficiency EC fan: this project

replaces the conventional fan in the air handling unit with fans, which can modulate the speed and airflow according to the demand. This can reduce the fan power and noise, and improve the indoor air quality and comfort.

Challenges encountered on this project and solutions are provided in Table 17.

Table 17. Challenges and Solutions for Case 8

Category	Challenges and solutions
Technical challenges	**Lack of knowledge about building energy retrofitting technologies:** Building owners or building management team may not understand the technical requirement and principle theory for energy saving products. **Solutions:** • Explanation more on technical side and provide successful case information to make confidence to stakeholders
	Lack of actual data on existing building energy performance: This makes it difficult to establish a baseline energy performance and to verify the energy savings after the retrofit. **Solutions:** No solution was provided at the project level.
	Lack of skilled building professionals: This affects the quality and effectiveness of the retrofit projects, as well as the operation and maintenance of the energy-efficient systems and equipment. **Solutions:** No solution was provided at the project level.
Financial challenges	**Lack of financial data:** This makes it hard to justify the investment and to calculate the return on investment of the retrofit projects.

Category	Challenges and solutions
	Solutions: No solution was provided at the project level.
	High upfront costs: Energy retrofits require high upfront costs, which can be a barrier for small and medium-sized enterprises or non-profit organizations. Energy retrofits are often seen as a luxury or a low priority, rather than a necessity or a long-term investment. **Solutions:** No solution was provided at the project level.
Institutional challenges	**Lack of communication and information sharing between stakeholders:** This leads to conflicts, misunderstandings, and delays in the retrofit projects, especially between the operation and maintenance team and the project team. **Solutions:** • Enhance the communication and information sharing between stakeholders.
	Lack of trust and willingness to change: This hinders the adoption of new technologies and innovations for energy efficiency, especially among the non-technical or financial decision-makers and the building operation and maintenance staff. **Solutions:** No solution was provided at the project level.
Social challenges	**Lack of public awareness and education:** There is a low level of public awareness and education on energy saving and environmental issues. Many people do not know the basic standards or best practices for indoor comfort, lighting, air quality, or energy use. They may also not be aware of the simple and effective ways to

Category	Challenges and solutions
	save energy in their daily lives, such as using automatic control systems or turning off the lights when not in use. This can reduce the motivation and participation of the public in the retrofitting projects. **Solutions:** No solution was provided at the project level.
Regulatory challenges	**Innovations may not comply with existing regulations:** Some innovative products from other countries may not comply with the local fire regulation requirements in Hong Kong. This limits the adoption of new technologies that can improve indoor air quality and reduce cooling demand. **Solutions:** No solution was provided at the project level.
	Lack of incentives and support: Some building owners or managers may not have enough financial incentives or support from the government or the public to undertake the retrofitting projects, and may face some regulatory or policy barriers. **Solutions:** No solution was provided at the project level.

Case 9

Building H

Retrofit initiative: The retrofit initiatives to improve energy efficiency are shown as follows:

- Modification of HVAC Chilled Water System: Modified chilled water system from existing constant primary and variable secondary to variable primary system. The use of existing primary chilled water pump sets was suspended and a new bypassing primary loop system was completed. The related performances are continuously monitored by a smart energy management platform.

- Smart energy management platform: A centralized cloud platform to collect, analyze, and visualize real-time energy and operation data. It enables real-time data collection, big data analytics based on the artificial intelligence rule-based expert system and machine learning to identify and alert on energy saving opportunities and predictive maintenance.

Challenges encountered on this project and solutions are provided in Table 18.

Table 18. Challenges and Solutions for Case 9

Category	Challenges and solutions
Technical challenges	**Detecting the inefficiency of the chiller and finding the reason:** It would not be easy to detect the inefficiency of the chiller and find the reason without retro-commissioning and data analysis. **Solutions:** • The team discovered the chiller had a lower speed than the design after conducting retro-commissioning, which involved collecting and analyzing data from the building management system and the chiller system. • Check the refreshing temperature and consult with the chiller supplier to identify the cause of the inefficiency, which was the impurity of the seawater cooling tower that affected the chiller operation.
Financial challenges	**Calculating the payback period:** It was not easy to calculate the payback period of the automatic tube cleaning system, because it involved some assumptions and uncertainties about the energy savings and the chiller performance. **Solutions:**

Category	Challenges and solutions
	• Collect and analyze data from the building management system and other sources, such as the chiller manufacture
	Getting funding for high-cost projects: If the retrofitting project required a high cost, it would be hard to get funding from the company or other sources. And the government did not provide any incentives or subsidies for this kind of project. **Solutions:** No solution was provided at the project level.
Institutional challenges	**Disruption to operation:** Installing new equipment or systems may cause some interruption to the normal operation of the building or the occupants, especially during work hours. **Solutions:** • Careful planning and scheduling to minimize the impact.
	Engagement with tenants: Retrofitting project may affect the tenants' comfort, satisfaction, or behavior, which requires effective communication and collaboration with them. This may also involve some benefits for the tenants to participate in the retrofitting process. **Solutions:** No solution was provided at the project level.
	Lack of specific energy saving target: There is no specific energy saving target or requirement for individual retrofitting projects, only for the whole company or portfolio, which may reduce the accountability and transparency of the energy performance improvement. **Solutions:** No solution was provided at the project level.

Category	Challenges and solutions
Regulatory challenges	**Lack of government incentives:** There was no government support or subsidy for their retrofitting project, which may limit the financial feasibility or attractiveness of some energy efficiency measures. **Solutions:** No solution was provided at the project level.
	Existing building energy code: The existing building energy code is not very stringent or comprehensive, and only applies to certain types of retrofitting projects that need to be submitted to the EMSD. This may limit the scope and impact of the energy efficiency retrofitting measures. **Solutions:** No solution was provided at the project level.

Case 10 and Case 11

Building I

Retrofit initiative:

- Case 11 involved replacing old LED lights with more efficient and modernized LED lights, saving 10% of energy and reducing maintenance costs.
- Case 12 project involved replacing fluorescent tubes with LED lights and installing sensor control in the stair area, saving 60% of energy and reducing energy waste in low occupancy areas.

Challenges encountered on these projects and solutions are provided in Table 19.

Table 19. Challenges and Solutions for Case 10 and Case 11

Category	Challenges and solutions
Technical challenges	**Matching the design specification and the actual product:** The service provider had to check the model and wattage of the LED lights to make sure they were the same or similar to the ones specified in the tender. However, there were often discrepancies or updates in the products, which required clarification and verification. **Solutions:** No solution was provided at the project level.
	Measuring the energy saving and consumption: The service provider had to calculate the energy saving and consumption before and after the retrofitting, as well as test some models in the real case. This was challenging because some products did not have much information about their energy performance or power consumption. **Solutions:** • Use international standards for measurement and verification: The IPMVP protocol or ISO 50015 standards are recommended to compare the energy saving of the traditional and new facilities. The Hong Kong guidelines are not suitable for retrofitting projects.
Financial challenges	**Limited fund support:** Quality Service Provider cost has the ceiling amount during the fund support. **Solutions:** • Overcome the challenge by tapping into funding support provided by CLP and HK Electric. However, there is a ceiling on the amount of funding provided.

Category	Challenges and solutions
	The client must ensure that the energy-saving cost, including the product or solution cost and the QSP cost.
	High cost: Employ cost of Registered Energy Assessors (REA) professional is higher. This requirement is mandated by Hong Kong guidelines and contributes to the overall project cost. **Solutions:** • Applying funding support provided by CLP and HK Electric.
Environmental challenges	**Waste generation:** Replacing the existing LED lights with more efficient and modernized ones could generate waste and require proper disposal of the old lights. **Solutions:** No solution was provided at the project level.

Case 12

Building J

Retrofit initiative: Replacement of conventional filters with new filters. The high-efficiency and low-pressure drop air filters can improve indoor air quality and save energy.

Challenges encountered on this project and solutions are provided in Table 20.

Table 20. Challenges and Solutions for Case 12

Category	Challenges and solutions
Technical challenges	**Lack of awareness and knowledge of alternative air filters:** Most facility managers or building service practitioners do not think there is any problem with the existing filters and do not know there are other choices that can improve indoor air quality and energy efficiency. Air filters are a small component in the HVAC system and

Category	Challenges and solutions
	are often overlooked by the facility managers or building energy managers. They do not think that replacing the air filters can save energy and they focus on other options such as chillers. **Solutions:** No solution was provided at the project level.
Financial challenges	**Higher initial cost:** New filters are more expensive than conventional filters, sometimes four times higher. This requires the clients to spend more money upfront to replace the existing filters. **Solutions:** • Applying funding provided by CLP Eco Building Fund.
	Limited funding options: The Eco Building Fund from CLP is one of the few funding options available for the clients to apply for subsidies for the filters. However, this fund is not widely known or used, and the application process may take a long time. The HK Electric does not have a similar fund or include air filters as an option for energy saving. **Solutions:** No solution was provided at the project level.
Regulatory challenges	**Fire service department approval:** They need to get the fire service department approval for new filters and it takes a long time, sometimes a few months, to process the application. **Solutions:** No solution was provided at the project level.
	IAQ guideline update: The IAQ guideline of Hong Kong government used PM 10 instead of PM 2.5 for a long time, which was

Category	Challenges and solutions
	not consistent with other countries and did not reflect the actual impact of air quality on human health. **Solutions:** • The manufacturer had to educate the clients and the public about the importance of PM 2.5 and how the filter could improve it.

Case 13

Building K

Retrofit initiative: Air balancing and variable air volume (VAV) sensor calibration of the air conditioning system. Those existing VAV boxes are already not very well calibrated, so the office space is not cool enough, and more fun power is needed. Therefore, the sensors are calibrated to ensure accuracy, which could reduce 10% fun power and 10% operation cost on the air side.

Challenges encountered on this project and solutions are provided in Table 21.

Table 21. Challenges and Solutions for Case 13

Category	Challenges and solutions
Technical challenges	**Lack of information and drawing.** The building has been operated for more than 30 years. The old drawing is not sufficient. Furthermore, the building has been renovated for many times, so it takes time to search the building information. **Solutions:** • With limited information available on-site, the team diligently gathered all they could. Their focus was on understanding the overall airflow, supply air path, and identifying the box model (if possible) to determine its

Category	Challenges and solutions
	function. This information would allow them to create a basic reference diagram. While the diagram might not be perfect, it would provide a shared understanding of the system for tasks like air balancing or locating sensors.
Financial challenges	**Lack of money for the new technologies to develop a new drawing and BIM model:** The client can only afford to do some consultancy work, and some demonstration work for how to reduce the energy use based on some simple action. For example, calibration or some air balancing. But they don't have the budget or resources to investigate other updated equipment or technology into the system at that stage. **Solutions:** No solution was provided at the project level.
Institutional challenges	**Lack of awareness on how to achieve carbon neutrality:** People may not be aware of this topic. The client or the contractor, even the building consultant, may not have much information on how to achieve this zero carbon. What they did may be using some low carbon footprint material for the construction and doing some planting or buying the reliable energy, green power certificate to offset their carbon footprint. **Solutions:** No solution was provided at the project level.
Regulatory challenges	**No regulations or guidelines to follow.** **Solutions:** No solution was provided at the project level.

Case 14

Building L

Retrofit initiative: This project is a chiller plant upgrade to improve energy efficiency in 20-year-old buildings. They replace inefficient chillers gradually with similar or higher capacity models that use next-generation refrigerant, aiming for significant energy savings without disrupting business operations. An energy audit is being conducted to determine the exact energy savings of chillers to replace.

Challenges encountered on the project and solutions are provided in Table 22.

Table 22. Challenges and Solutions for Case 14

Category	Challenges and solutions
Technical challenges	**Lack of knowledge on technical aspects:** The building owner or operators were not familiar with the latest environmental refrigerant and had some hesitations in embracing new refrigerants and technology including the safety measures to be taken for utilizing new HFO refrigerant. **Solutions:** • Stakeholder engagement is required to solve the uncertainty and concerns from building owners or operators regarding the new refrigerant technology.
	Lack of building energy performance data: Evaluating energy performance and baseline data collection are prominent tasks before proposing any retrofit works on existing buildings in Hong Kong. The absence of records for building energy use and chiller plant maintenance, and the need to collect annual data. Since, it was impossible to review hourly records in past years and had to complete missing data and remedy any human errors/equipment faults. **Solutions:**

Category	Challenges and solutions
	• More comprehensive energy audit is recommended and should be carried out before the retrofitting works. It will ensure the most up to date and accurate building information can be obtained. • Energy audit, past operating data collection and analysis have been completed to evaluate the potential energy-saving opportunities.
Financial challenges	**Split incentive:** Replacing the entire chiller plant offers the greatest energy savings, benefiting tenants with lower energy bills. However, for the building owner who shoulders the upfront cost, a full retrofit might not be financially attractive due to a slow return on investment. **Solutions:** No solution was provided at the project level.
Institutional challenges	**Disruption to building operation.** **Solutions:** • To avoid significant system disruption and ensure sufficient cooling load back up, the retrofitting work has been divided into two phases and planned to carry out in an off-peak load season (i.e in Winter). Time to achieve the overall energy saving depends mainly on the replacement program and actual site progress.
Social challenges	**Public lacks of knowledge:** General public does not aware the necessity and benefits of adopting the new HFO refrigerant. Some of them may have misunderstanding and incorrect information and are reluctant to adopt new technologies due to uncertainty in assessing the overall advantage.

Category	Challenges and solutions
	Solutions: No solution was provided at the project level.
Environmental challenges	**Waste generation:** Retrofitting old chiller usually represents a large amount of retired refrigerant disposal. Handling this retired chemical waste is cost and time-consuming. **Solutions:** No solution was provided at the project level.
Regulatory challenges	**Lack of policies and regulations for retrofitting projects:** At beginning of this project, there was no regulation or government policy to enhance building owner to use HFO refrigerant. In addition, there is no incentive scheme to lead the trades for energy-saving improvement works in Hong Kong whether significant energy saving and boost reduction of carbon dioxide emission could be achieved for this type of retrofitting project. **Solutions:** No solution was provided at the project level.

6. Conclusions

The demand for energy-efficient buildings has been increasing due to the advancement in building technology and awareness of climate change and its impacts. Retrofits for existing office buildings are vital to improve energy efficiency, reduce operational costs, and conserve limited natural resources. Retrofitting existing office buildings requires multiple processes, techniques, and interventions that can be challenging to execute. This guidebook, based on real cases in Hong Kong, reviews possible challenges encountered in energy retrofitting projects and provides possible solutions to these challenges, enabling the realization of the potential benefits of retrofitting existing office buildings.

The benefits of the guidebook extend beyond building owners, managers, and tenants to the office buildings sector and governments in achieving carbon neutrality targets. As such, the guidebook provides an essential resource for promoting sustainable energy use in the existing office building sector.