A MODEL FOR ENERGY PERFORMANCE CONTRACTING (EPC) IN HONG KONG

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CERTIFICATE OF ORIGINALITY

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ABSTRACT

Buildings account for 40 percent of the world's energy use. Although a number of studies indicate that substantial energy savings can be achieved by implementing energy improvement projects in existing buildings, hesitations in project implementation are still observed around the world due to a lack of technological know-how and upfront capital. As such, Energy Performance Contracting (EPC) has been recognised as a means to tackle these problems, since Energy Service Companies (ESCOs) not only provide building owners (hosts) with the upfront capital for project implementation, but also promise a certain level of performance (savings in most cases) of energy conservation measures (ECMs) after retrofitting. Despite the fact that the EPC market is expected to grow continuously around the world, the take-up rate of EPC is still relatively low in Hong Kong. Several local studies found that (1) lack of awareness and experience; (2) legal and contractual complexities; and (3) project risks are the main reasons hindering the wider use of EPC in Hong Kong.

This research aims to develop a clear, concise and comprehensive model of EPC for Hong Kong, specifically taking into account the risk assessment and contract management issues. The main objectives of this research are to (1) investigate the concerns and understanding of local building owners and Energy Service Companies on EPC; (2) develop suitable risk assessment approaches taking into account the probabilities of saving shortfalls based on different technical solutions of common energy retrofitting; (3) develop a set of EPC contract document templates for use in Hong Kong based on a study of international best practice and the local research findings; and (4) quantify the achievable amount of energy savings by assuming different take-up rates of EPC in Hong Kong.

The above objectives have been accomplished by using qualitative and quantitative methods, including literature reviews, interviews with EPC stakeholders, and two separate questionnaire surveys targeted at both hosts and ESCOs. A risk assessment approach was developed to evaluate the probability of energy saving shortfalls, taking into account variations in the influential parameters, including weather conditions, occupancy, operating hours, etc., during the post-retrofit period. The approach entails the deployment of methods including the use of a versatile building energy simulation program (e.g. *EnergyPlus*), correlation analysis and Monte Carlo simulation. Three case studies with different retrofitting measures, including chiller replacement, change of heat rejection system and lighting retrofit, were used to demonstrate the application of three similar probabilistic models for risk assessment to suit the different technologies involved. In addition, a comparative analysis of different standard forms of EPC contract in eight jurisdictions was conducted to reflect on the various treatments of common contractual issues in EPC projects. Based on the results of this analysis, an EPC contract template and associated guidance notes were developed for use in simple retrofitting works. Finally, the above results were consolidated into a generic model which was validated by industry experts and practitioners. The potential energy savings through EPC projects were estimated under different assumed take-up rates of EPC.

The research has contributed to new knowledge of EPC project implementation in the following aspects: (1) the results of questionnaire surveys and interviews can help various stakeholders to better understand the current market development of EPC in Hong Kong, including the perceived benefits, the market barriers and the possible measures for enhancing the adoption of EPC; (2) the use of the proposed risk assessment approach would enable hosts and ESCOs to quantify the probabilities of energy saving shortfalls with different levels of guaranteed savings as promised by ESCOs; (3) the development of an EPC contract template can help contracting parties to reduce time and cost during the contract negotiation stage. The availability of such a template is pertinent when the hosts have no competent in-house engineering teams and legal representation; and (4) the consolidated generic model enables hosts and ESCOs to identify and address the key issues when implementing EPC projects, starting from the stage of pre-retrofit, through installation to post-retrofit.

Being informed by this comprehensive EPC model, it is expected that more building owners in Hong Kong will consider using EPC as a viable alternative to undertake energy retrofitting works, thereby improving overall energy performance of buildings.

LIST OF PUBLICATIONS

Refereed Journal Articles

1. **Lee, P.**, Lam, P. T. I., & Lee, W. L. An Evaluation of the Performance Risks of Lighting Retrofit in Energy Performance Contracting (EPC) Projects. Renewable & Sustainable Energy Reviews (Under Review)

2. **Lee, P.**, Lam, P. T. I., Lee, W. L., & Chan, E. H. W. A probabilistic approach for estimating energy savings in Energy Performance Contracting – A case study of replacement of air-cooled chillers with water-cooled chillers. Applied Energy (Under Review)

3. **Lee P.** and Lam, P.T.I. (2015). A Conceptual Model of Energy Performance Contracting (EPC): An alternative solution to retrofit existing buildings. International Journal of Architecture, Engineering and Construction, 4(2), 109-116. (Doi: 10.7492/IJAEC.2015.011)

4. **Lee, P.**, Lam, P. T. I., & Lee, W. L. (2015). Risks in Energy Performance Contracting (EPC) projects. Energy and Buildings, 92, 116-127. (Doi:10.1016/j.enbuild.2015.01.054)

5. Lam, P. T. I., & **Lee, P.** (2015). A comparative study of standard contract conditions for energy performance contracting in China, Japan, Singapore and Taiwan. Construction Law Journal, 31(3), 152-166.

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7. **Lee, P.**, Lam, P. T. I., & Dzeng, R. J. (2014). Current market development of energy performance contracting: A comparative study between Hong Kong and Taiwan. Journal of Property Investment & Finance, 32(4), 371 - 395. (Doi: http://dx.doi.org/10.1108/JPIF-01-2014-0003)

8. **Lee, P.**, Lam, P. T. I., Yik, F. W. H., & Chan, E. H. W. (2013). Probabilistic risk assessment of the energy saving shortfall in energy performance contracting projects- A case study. Energy and Buildings, 66, 353-363. (DOI: 10.1016/j.enbuild.2013.07.018)

Conference Presentations and Publications

1. **Lee P.** and Lam, P.T.I. (2015). A Model of Energy Performance Contracting (EPC) in Hong Kong. Proceedings of the First International Conference for Sustainable Development and Management (ICSDM 2015), Hong Kong, China, 28-30 June 2015 (CD Rom Publication. No page no)

2. **Lee P.** and Lam, P.T.I. (2015). Incentive Schemes towards the Use of Energy Performance Contracting (EPC) – A Review and Look into Possible Future

Directions. Proceedings of 2015 Seoul International Conference on Engineering and Applied Science, Seoul, South Korea, 8-10 January 2015, 313-321.

3. **Lee P.**, Lam, P.T.I., and Lee, W.L. (2014). A Probabilistic Approach to Evaluate the Performance Risks of Lighting Retrofit in Energy Performance Contracting Projects. Proceedings of 2014 Tokyo International Conference on Engineering and Applied Science, Tokyo, Japan, 17-19 December 2014, 430-439. (CD Rom Publication. No page no)

4. Lam, P.T.I., Chan, E.H.W., Yik, F.W.H. and **Lee, P.** (2012). A Contractual Framework for Energy Performance Contracting in the Quest for Energy Saving to achieve Sustainable Development. Proceedings of the 16th Pacific Association of Quantity Surveyors (PAQS) Congress, Brunei Darussalam, Brunei, 10-11 July 2012 (CD Rom Publication. No page no)

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A-D test	Anderson-Darling test
AIB	Australian Institution of Building
AHU	Air Handling Unit
ANSI	American National Standard Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BCA	Building and Construction Authority
BEEO	Building Energy Efficiency Ordinance
BMS	Building Management System
BREEF	Building Retrofit Energy Efficiency Financing
BS	Building Services
CDO	Campus Development Office
CFO	Corporate Financial Officers
CIBSE	Chartered Institution of Building Services Engineers
C&I	Commercial and Industrial
CLPE	China Light & Power Engineering
COP	Coefficient of Performance
CRW	Chiller Replacement Works
CV	Coefficient of Variation
DBT	Dry Bulb Temperature
DHR	Diffuse Horizontal Radiation
DOE	Department of Energy
DPT	Dew Point Temperature
E2PO	Energy Efficiency Programme Office
EbaR	Energy Budgets at Risk
EB	Environment Bureau
EEC	Energy Efficiency Council
EMO	Energy Management Opportunity
EMSC	Energy Management Services Contracts
EMSD	Electrical and Mechanical Services Department
EOI	Expression of Interest
EPC	Energy Performance Contracting
EPW	*EnergyPlus* Weather File
ESCO	Energy Service Company
ESPC	Energy Savings Performance Contracts
EUI	Energy Use Intensity
FBI	Federal Buildings Initiative
FEMP	Federal Energy Management Program
FMO	Facilities Management Office
GDP	Gross Domestic Product
GESP	Guaranteed Energy Savings Performance
GHR	Global Horizontal Radiation
GMIS-EB	Green Mark Incentives for Existing Buildings
GSR	Global Solar Radiation
HAESCO	Hong Kong Association of Energy Services Company
HKIVE	Hong Kong Institute of Vocation Education

HKO	Hong Kong Observatory
HVAC	Heating, Ventilation and Air Conditioning
IEA	International Energy Agent
IPMVP	International Performance Measurement & Verification Protocols
IRR	Internal Rate of Return
K-S test	Kolmogorov-Smirnov test
LBNL	Lawrence Berkeley National Laboratory
M&V	Measurement and Verification
MUSH	Municipal and State governments, Universities and Colleges, K-12 Schools, and Hospitals
NAESCO	National Association of Energy Services Companies
NEA	National Environment Agency
NGO	Non-Governmental Organisation
NPV	Net Present Value
O&M	Operation and Maintenance
OTTV	Overall Thermal Transfer Value
PB	Payback
PDF	Probability Distribution Function
SA	Serviced Apartment
SEPC	Standard Energy Performance Contract
T&C	Testing and Commissioning
TPF	Third-Party Financing
UESC	Utility Energy Savings Contracts
VAV	Variable Air Volume
WBT	Web Bulb Temperature

CHAPTER 1: INTRODUCTION

1.1	**Research Background**
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Chapter 1 – Introduction

1.1 Research Background

Buildings account for approximately 40% of the world's energy consumption (WDCSB, 2009). In Hong Kong, commercial buildings consume 66% of the total electricity consumption, and has experienced a gradual growth from 83,549 Terajoules in 2002 to 101,813 Terajoules in 2012 (equivalent to a 22 percent rise over ten years) (EMSD, 2015b). Among the energy end-uses, building services (BS) installations such as central air-conditioning (AC) and lighting systems are the two major energy end-uses which constitute 54% and 14% of total electricity consumption respectively in a typical Hong Kong office building (EMSD, 2015b). However, due to equipment oversizing, unrealistic design and use of aging equipment and technology, most existing buildings in Hong Kong are not energy efficient (Lee et al., 2001; Taylor, 2008). A study of energy performance in nineteen HKSAR Government offices has shown that only thirteen of them achieved the recommended Energy Use Index (EUI) (Li, 2008). Numerous studies indicate that a significant amount of energy can be saved in existing buildings through building retrofitting (e.g. improvement of building insulation, enhancement of building services equipment efficiency and optimisation of system operations) (Chung and Hui, 2009; Lee and Yik, 2010).

This situation is expected to change when the HKSAR Government unveiled the Energy Saving Plan for the Built Environment 2015~2025 (and beyond), which sets a new target for reducing Hong Kong's energy intensity by 40% by 2025 (HKSAR, 2015). To achieve this target, a series of measures have been introduced with regard to improving energy efficiency in existing buildings, for example, (1) relaxation of previous restrictions on the use of fresh water in evaporative cooling towers for energy-efficient air conditioning systems (EMSD, 2008); and (2) implementation of a new Building Energy Efficiency Ordinance (BEEO), requiring compliance with the Building Energy Code (BEC) for both new and existing buildings (EMSD, 2015d); However, the building owners (hosts) are still reluctant to carry out energy improvement projects until the equipment comes to the end of its life-span, simply because most of the retrofitting works involve huge upfront capital outlay and technological know-how. Therefore, the lack of upfront capital and technological know-how are often the barriers to enhancing building energy efficiency in existing buildings in Hong Kong.

As such, the concept of Energy Performance Contracting (EPC) has emerged to address this situation since Energy Service Companies (ESCOs) provides hosts with the upfront capital for project implementation. At the initial stage, ESCOs would guarantee or share the energy cost savings with hosts and pay all costs associated with design and installation. Hosts only make a series of payment to ESCOs progressively when the actual energy savings are realised. In case of saving shortfalls, ESCOs will compensate the loss incurred by hosts under the contract agreement. Apart from the traditional "fee for service" or "design-bid-build" contracts, this contractual arrangement is regarded as a viable alternative to improve building energy performance in many countries, including Australia, China, Japan, Singapore, the United Kingdom and the United States (Vine, 2005; Bloom and Wheelock, 2011; Marino et al., 2011).

A strong commitment from the government to the use of EPC has been observed in several such countries. In the U.S., extensive works and efforts, such as the development of standard contract documents, amendment of public procurement procedures, as well as the provision of project facilitators, have been made to foster the wider use of EPC in the public sector (DOE, 2014a). In Europe, an EU-Energy Performance Contracting Campaign (EPCC) was implemented by the European Commission in order to assist member states in developing a legal and financial framework for the EPC market (EC, 2015c). In Asian jurisdictions such as Taiwan and Singapore, various kinds of financial schemes have been launched to promote the use of EPC for retrofitting existing buildings (CEPD, 2005; BCA, 2014)

Although the EPC market is expected to grow continuously around the world (Bloom and Wheelock, 2011; Larsen et al., 2012), the penetration rate of EPC in Hong Kong is still low. Only few successful EPC projects have been discussed in the literature (Fong and Lee, 2003; Chow et al., 2006b). Several local studies found that the low take-up rate is mainly attributed to four major aspects: (1) lack of awareness and experience; (2) complex legal and contractual issues; (3) problems with procurement process; and (4) problems with measurement & verification (M&V) (Davies and Chan, 2001; Hui, 2002; Yik and Lee, 2004). These barriers also exist in other countries, and a number of researchers have listed out possible measures to remove these barriers, including development of standard forms of EPC contract, provision of practical guidelines to suit procurement procedures, standardisation of M&V methods, etc. Several countries have adopted these measures to promote the use of EPC in both the public and private sectors. For example, the Federal Energy Management Program (FEMP) has been launched in the U.S. to improve energy performance of federal facilities under an EPC package (DOE, 2015a). The Australian government has developed guidelines on procurement procedures for EPC projects (EEC, 2015). Both the Canadian and Singapore government have put their standard forms of EPC contract in place for public use (FBI, 2015; E2PO, 2015a). However, in Hong Kong, there is still no relevant policy or measure in relation to EPC development. Only a few research studies have been conducted to investigate the concerns and experience of local building owners and ESCOs on EPC. It is clear that the full potential of using EPC in Hong Kong has not yet been exploited.

1.2 Knowledge gaps identified

Various researchers reveal the latest market development of EPC and ESCO activities around the world. Vine (2005) conducted an international survey to measure the local ESCO activities, identify the key market barriers and provide possible measures for enhancing EPC market development in forty-one countries. Bloom and Wheelock (2011) also conducted a similar study, but with more details on the existing local policies and green financial instruments. At the regional level, Marino et al. (2011) conducted a survey of EPC market in thirty-nine European countries, focusing on the latest trends of ESCO industry and the factors which contribute to the wider adoption of EPC. Larsen et al. (2012) also carried out a local survey of the ESCO industry in the U.S., covering ESCO activity by market segment, ESCO contract types, perceived trend in project investment levels and savings. However, the above studies have little or no coverage of the latest market development in Hong Kong. Although some literature has reported the details of several successful EPC projects and presented the findings about the perception of EPC market (Davies and Chan, 2001; Hui, 2002; Fong and Lee, 2003; Yik and Lee, 2004), a knowledge gap regarding the current ESCO activities and the latest EPC market development in Hong Kong still remained open.

A number of researchers highlighted that the development of standard forms of EPC contract is a means to promote the adoption of EPC in both the public and private sectors (Vine et al., 1998; Goldman et al., 2005; Marino et al., 2011; Xu et al., 2011). To-date, several standard forms of EPC contract are available in some developed countries, including, Australia, Canada, Japan, Singapore, the UK and the U.S. The main purposes of using standard forms of contract is to reduce the transaction costs of contract negotiation and drafting in EPC projects, whilst making participants familiar with their contractual rights and obligations. In Hong

Kong, despite over a decade of market development, there is still no standard form of EPC contract published for general use, especially in the private sector.

Although the concept of EPC was first introduced in France in the 1940s (Singh et al., 2009), no comprehensive EPC risk assessment approach has yet been developed to determine the probability of energy saving shortfalls in EPC projects. Several attempts have been made to fill this knowledge gap. Mills et al. (2006) and Thumann and Woodroof (2009) have identified an array of risks associated with EPC projects. Mathew et al. (2005) has indicated the possible use of actuarial pricing approach to quantify the associated risks for project decision-making. However, this approach requires a large number of actual EPC projects, which are needed to develop a reliable actuarial database. Hence, it is not suitable for a city like Hong Kong where the number of EPC projects is still limited. Mills et al. (2006) and Jackson (2010) have suggested using the Monte Carlo technique for quantifying the risks in relation to EPC projects, but their studies only focus on the illustration of a proposed methodology and no real project data is used to demonstrate the credibility of their findings. Heo et al. (2012) proposed a probabilistic methodology based on Bayesian calibration of normative energy models to assess retrofitting performance, but the analysis ignores the uncertainties arising from system degradation and weather variations.

With the above background, therefore, the knowledge gaps are identified in this research as follows:

1. Little research findings associated with ESCO activities and the latest EPC market development in Hong Kong;

2. A risk assessment approach on EPC projects taking into account the influence of variations in the parameters affecting energy savings is not well developed;

3. A standard template of EPC contract is not available in Hong Kong; and

4. A need to estimate the achievable amount of energy savings with increased adoption of EPC in Hong Kong.

1.3 Research aims and objectives

This research aims to develop a clear, concise and comprehensive model of EPC for Hong Kong, specifically taking into account the risk assessment and contract management issues.

The main objectives of this research are as follows:

1. To investigate the concerns and understanding of local building owners and Energy Service Companies on EPC;

2. To develop suitable risk assessment approaches taking into account the probabilities of saving shortfalls based on different technical solutions of common energy retrofitting;

3. To develop a set of EPC contract document templates for use in Hong Kong based on a study of international best practice and the local research findings; and

4. To quantify the achievable amount of energy savings by assuming different take-up rates of EPC in Hong Kong.

1.4 Significance and value of the research

The research has contributed to new knowledge of EPC project implementation in the following aspects: (1) the results of questionnaire surveys and interviews can help various stakeholders to better understand the current market development of EPC in Hong Kong, including the perceived benefits, the market barriers and the possible measures for enhancing the adoption of EPC; (2) the use of suitable risk assessment approaches would enable hosts and ESCOs to quantify the probabilities of energy saving shortfalls with different levels of guaranteed savings as promised by ESCOs for different technologies; (3) the development of an EPC contract template can help contracting parties to reduce time and cost during the contract negotiation stage. The benefits are more obvious when the hosts have no competent in-house engineering teams and legal representation; and (4) the consolidated generic model enables hosts and ESCOs to identify and address the key issues when implementing EPC projects, starting from the stage of pre-retrofit, through installation to post-retrofit.

Being informed by this consolidated EPC model, it is expected that more building owners in Hong Kong will consider using EPC as a viable alternative traditional procurement for undertaking energy retrofitting works, thereby improving the overall energy performance of buildings.

1.5 An overview of the research methodology

In this research, both qualitative and quantitative methods, including literature review, semi-structured interviews with EPC stakeholders, and questionnaire surveys targeted at both hosts and ESCOs, were employed to collect the primary data and information. The relationship between the research objectives and research methods used in this study are summarised in

Figure 1.1. The details of research methods and the reasons for using particular methods are discussed in Chapter 3 (Research Methodology).

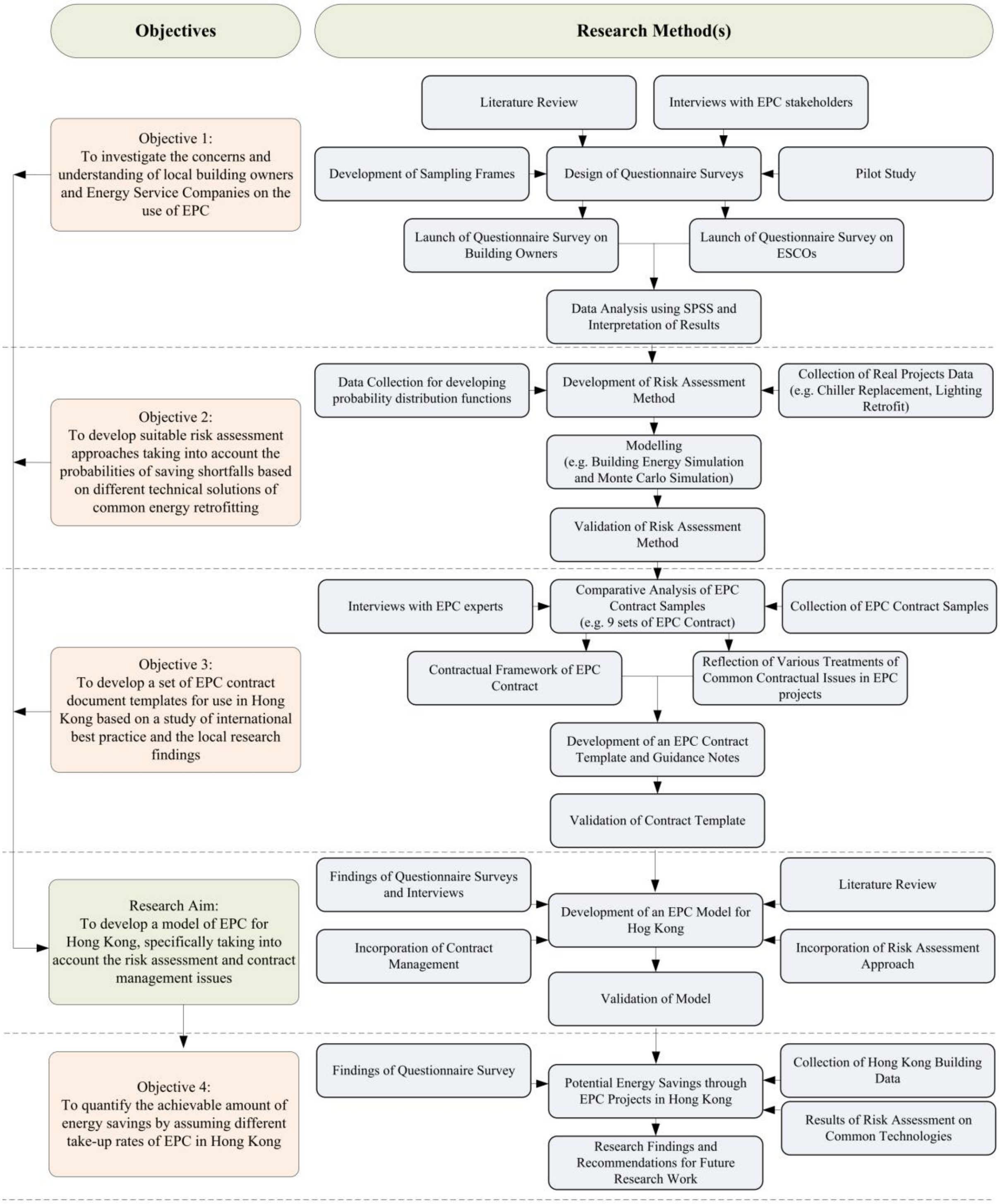

Figure 1.1: Process flow of research methodologies

A comprehensive literature review on the latest EPC development in the world was conducted. In order to investigate the concerns and understanding of hosts and ESCOs on the use of EPC in Hong Kong, two separate questionnaire surveys targeted at the local ESCOs and hosts were carried out. The statistical data from two questionnaire surveys was analysed using SPSS software. Semi-structured interviews were also conducted with key stakeholders in the EPC market, including hosts, ESCOs' key personnel, association representatives and financers in both the public and private sectors in Hong Kong.

Based on the earlier groundwork built up from the literature review, questionnaire surveys and semi-structured interviews, the types of energy retrofitting works which have the largest potential to be implemented under an EPC approach were identified. In order to quantify the probabilities of saving shortfalls, a risk assessment approach was developed, taking into account the possible variations in the influential parameters affecting energy savings. The approach entails the deployment of several methods including simulation using a versatile building energy simulation program (e.g. *EnergyPlus*), correlation analysis and Monte Carlo simulation. Three case studies with different retrofitting measures, including chiller replacement, change of heat rejection system and lighting upgrading, were used to demonstrate the application of suitable probabilistic approaches for risk assessment.

A comparative analysis of nine standard forms of EPC contract in eight jurisdictions, including Australia, Canada, China, Japan, Singapore, Taiwan, the United Kingdom and the United States, was conducted. By comparisons, the essential features of a standard form of EPC contract were identified, and the key differences between those forms were highlighted to reflect various treatments of contractual issues in EPC projects. Based on the results of this analysis, an EPC contract template and associated guidance notes were developed for use in simple retrofitting works in Hong Kong. To ensure practicality, experts and practitioners were invited to comment on the documents, which were incorporated.

To quantify the achievable amount of energy savings by assuming different take-up rates of EPC in Hong Kong, the first step is to estimate the feasibility of EPC project implementation by sectors in Hong Kong and the achievable amount of energy savings after retrofitting. The earlier groundwork can indicate which types of buildings are the most feasible for EPC project implementation. Based on the findings of the host questionnaire survey, the number of buildings where ECMs have not yet been implemented was extrapolated. In addition, the results of risk assessment based on the usual ECM technologies were adopted to estimate potential energy savings for those common ECMs under different take-up rates of EPC in Hong Kong.

In this study, the model is defined as *'a systematic description of a process which enables users to identify and address the key issues and their relationships'* (Gemino and Wand, 2004). By consolidating the above findings, a generic model of EPC projects was developed. To ensure the applicability and practicality of the model for use in Hong Kong, it was validated by a number of experts and practitioners related to the field of EPC in Hong Kong. The details of research methods and the reasons for using particular methods can be found in Chapter 3 (Research Methodology).

1.6 Structure of the thesis

The thesis comprises ten chapters, and the relationship between those ten chapters, the building blocks and model are presented in Figure 1.2. A brief summary of the contents in each chapter is described as follows:

Chapter 1 presents the aims and objectives of the research, together with the research background, identified research gaps, an overall research methodology as well as the structure of the thesis. Chapter 2 is a comprehensive literature review on the latest EPC development in the world, the EPC procurement process and the current risk assessment tools available for EPC projects. Chapter 3 describes and explains the research design and methods used to accomplish the research objectives, including semi-structured interviews, questionnaire surveys, case studies as well as risk modelling using building energy simulation and Monte Carlo simulation. Chapter 4 reports the findings of two separate questionnaire surveys targeted at two major groups of stakeholders, namely, building owners (hosts) and Energy Service Companies (ESCOs).

Chapter 5 presents a summary of twenty-six semi-structured interviews involving key stakeholders in the field of EPC market, including hosts, ESCOs' key personnel, association representatives and financers in both the public and private sectors in Hong Kong. Chapter 6 illustrates a risk assessment approach for evaluating the probabilities of energy saving shortfalls, taking into account the variations in the influential parameters affecting energy savings. Chapter 7 discusses the findings of a comparative study of nine standard forms of contracts available in eight jurisdictions, which highlight key differences for reflecting various treatments of pertinent contractual issues in EPC projects.

Chapter 8 presents a consolidated model of EPC for Hong Kong and the results of model validation by a numbers of experts and practitioners in the field of EPC. Chapter 9 presents the method for estimating potential energy savings through EPC projects for office buildings in Hong Kong. Chapter 10 is the final chapter of the thesis, which concludes the research study, summarises the main findings of the study, as well as recommends improvement measures for enhancing EPC take-up and the future research work.

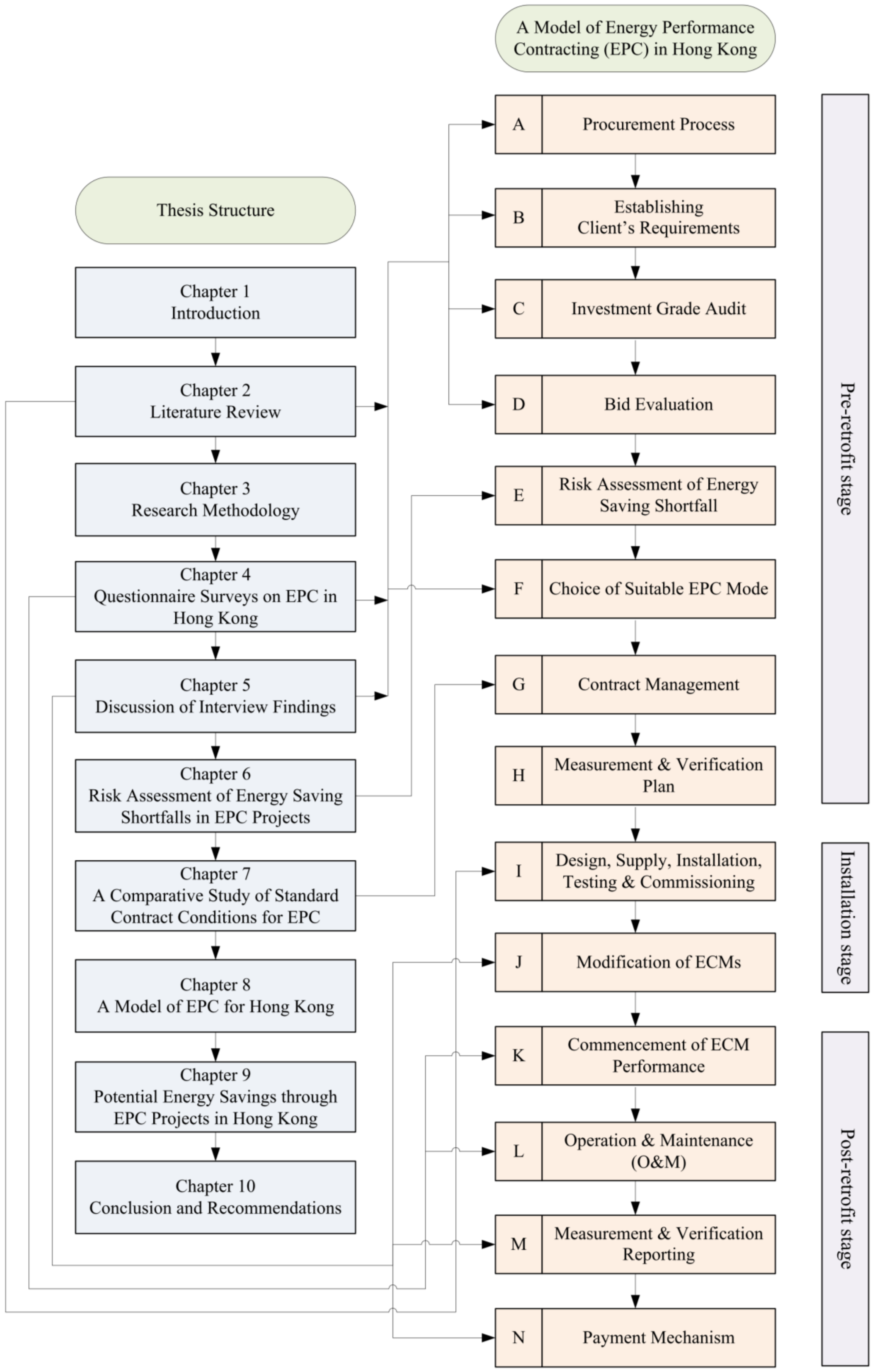

Figure 1.2: Relationship between the thesis chapters and the Building Blocks of the Model

1.7 Chapter summary

This chapter introduces the research background and identifies the research gaps. The aim and objectives of this research study are presented. The methods which fulfil the research objectives are also depicted in broad terms. The next chapter is a literature review regarding recent EPC research.

CHAPTER 2: LITERATURE REVIEW

Chapter 2 – Literature Review

2.1 Introduction

This chapter presents a comprehensive literature view on the current development of EPC worldwide. The key issues involved with the EPC procurement process, including energy audit, financing and M&V, are discussed. In addition, the perceived benefits, market barriers, as well as possible measures to enhance the use of EPC are also addressed. Finally, this chapter reviews the risks associated with energy-efficiency projects, the current practices for capital budgeting and the existing quantitative risk analysis methods.

2.2 Energy Performance Contracting (EPC)

The concept of Energy Performance Contracting (EPC) was first introduced in France in the 1940s (Singh, 2010). Due to the oil crises in the 1970s and unprecedented growth in government deficits, other EPC markets, such as Canada and the United States, also emerged. A fast growth rate of EPC was observed in North America in the 1990s. To advocate the wider use of EPC in the United States, the Lawrence Berkeley National Laboratory (LBNL) and National Association of Energy Services Companies (NAESCO) published a series of EPC guidelines and reports on the latest market development (NAESCO, 2015; LBNL, 2015). With more demonstration projects and guidelines, EPC is now widely adopted in Australia, Canada, Singapore and the United States (Bloom and Wheelock, 2011; Marino et al., 2011). In the 2000s, the World Bank launched the "Loan Guarantee Program" to further boost up the energy efficiency market in developing countries, such as China, Brazil and India (Taylor, 2008), and EPC has been described by the European Commission (EC) as an important tool for the energy efficiency upgrading of public infrastructures (EC, 2015a). In the United States, the Federal government has also committed to enter into the energy savings performance contracts (ESPCs) and utility energy savings contracts (UESCs) worth up to US$2 billion by the end of 2013 (DOE, 2015b).

2.2.1 Definition of Energy Performance Contracting

There is no standardised definition for the term "Energy Performance Contracting". Its definition varies from place to place. Regarding a legal definition, the European Parliament defines EPC in the Directive 2006/32/EC as follows (EC, 2015b):

"Energy performance contracting defines a contractual arrangement between the beneficiary and the provider (normally an ESCO) of an energy efficiency improvement measure, where investments in that measure are paid for in relation to a contractually agreed level of energy efficiency improvement."

In the U.S., it is common to use the term "Energy Savings Performance Contracts" (ESPC), instead of "Energy Performance Contracting" (EPC). According to Title 48, Federal Acquisition Regulations System, ESPC is defined as (DOE, 2015c):

"Energy-savings performance contract means a contract that requires the contractor to:

(1) Perform services for the design, acquisition, financing, installation, testing, operation, and where appropriate, maintenance and repair, of an identified energy conservation measure or a series of measures at one or more locations;

(2) Incur the costs of implementing the energy savings measures, including at least the cost (if any) in making energy audits, acquiring and installing equipment, and training personnel in exchange for a predetermined share of the value of the energy

savings directly resulting from implementation of such measures during the term of the contract; and

(3) *Guarantee future energy and cost savings to the Government."*

2.3 EPC models

In an EPC contract, the ESCO is fully responsible for design, construction, installation, commissioning and testing (T&C), but regarding project financing and agreements on energy savings, there are two alternative EPC models to constitute an energy performance contract. These models are listed as follows (Bertoldi et al., 2006; Singh, 2010):

Guaranteed Saving Model

In the guaranteed saving model, the ESCO guarantees a certain level of energy savings for energy improvement projects. The host will not take any performance risk in relation to the actual equipment/system performance. In the case of shortfall in energy savings, the ESCO is liable to compensate the host for the saving losses.

The host usually obtains financing from its own internal funds or a third party (e.g. banks or financial institutions), because the ESCO has borne the entire performance risks and no further credit risk will be taken (Xu et al., 2011). In this arrangement, the host repays the loan to the lender who bears the credit risk. This model is rather common in countries where the banking structure is well-established and the degree of familiarity with project financing is high (Dreesen, 2003).

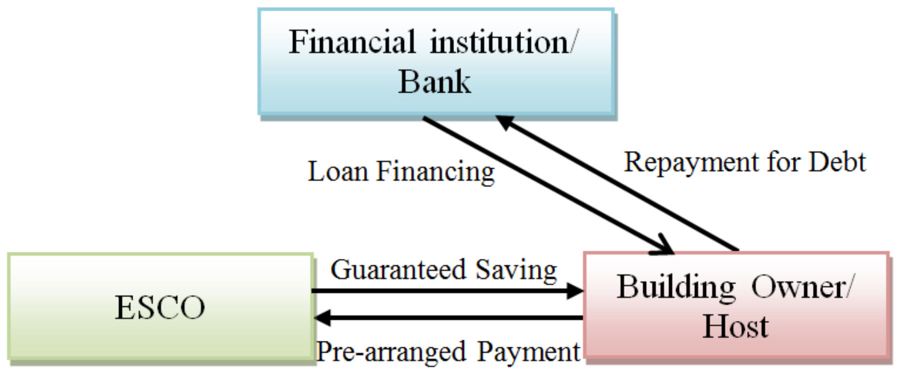

Figure 2.1: Relationships of the key stakeholders under the guaranteed saving model (Bank will not feature in case the owner uses self-funding)

Shared Saving Model

In the shared saving model, the actual energy savings are shared with the ESCO and host in accordance with an agreed percentage. In this case, both parties share the performance risks. The ESCO, instead of the host, seeks financing from his internal funds or a third party. This model is found commonly in the developing countries as the hosts have relatively low creditability, and only the overseas ESCOs with high credit standing (usually an international enterprise or equipment manufacturer) are able to offer the shared saving contract (Dreesen, 2003).

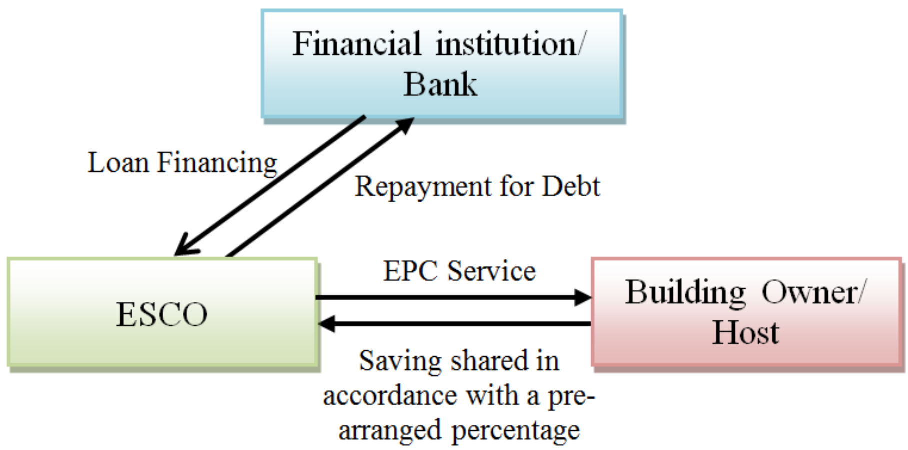

Figure 2.2: Relationship of the key stakeholders under the shared saving model (Bank will not feature in case the ESCO uses self-funding)

Other Models

Another type of EPC model is called "chauffage" (in French, means heating) or full energy services contract, which is usually found in Europe. In this model, the ESCO takes the full control over the operation of the host's utility facilities and decisions on the retrofitting approach. The host pays the ESCO with the pre-arranged contract fee regularly which is, in most cases, equal to the utility bills prior to the retrofitting works during the contract period. The concept is similar to the case that the operation of facility system/equipment is outsourced to the ESCO which has acquired the technological know-how to operate the facility. This model normally involves a large scale of facility upgrade which would incur huge implementation costs (Taylor, 2008).

2.4 Overview of EPC market

2.4.1 Worldwide

Several research studies have been conducted to investigate the size of EPC market and activities of ESCOs carrying out energy improvement projects in the world (Vine, 2005; Marino et al., 2011; Larsen et al., 2012). A research report (Bloom and Wheelock, 2011) on the outlook at the global energy efficient building market states that the EPC market is most advanced in North America, West Europe and a few leading countries in Asia Pacific, including Australia, China and Japan. The above findings are based on ESCO revenues, national energy policy, demand-side awareness of energy efficiency, public and private sector efficiency activities, as well as access to third party financing. Another study on the predicted market growth and development in the U.S. ESCO industry revealed that the ESCO industry would be expected to increase 26% per year between 2009 and 2011 and the annual revenues would reach US$ 7.1-7.3 billion in 2011 (Satchwell et al., 2010).

The European Commission DG Joint Research Centre published a status report on the ESCO market in Europe, showing that a slow market growth in most European countries has been observed due to the financial crisis and economic downturn during 2007-2010 (Marino et al., 2011). With the changes towards a more favourable legislative framework, which focuses on energy efficiency, financial incentives for retrofitting works in the public and private buildings and a stronger environmental awareness, it is expected that the market will regain the strong growth and provide more opportunities to carry out the associated energy efficiency projects in different sectors.

Other factors related to the EPC market, such as the numbers of ESCOs, existence of a relevant trade association, total project revenues, the age of ESCO market, and economic status as represented by gross domestic product (GDP), energy consumption and CO_2 emission, were studied in the previous literature. For example, Vine (2005) conducted an international survey to collect information on the date of the first ESCO being established, numbers of ESCOs and total value of ESCO projects. Based on the result of Vine's work, Okay and Akman (2010) investigated the relationship among the ESCO indicator and country indicator, which help to estimate the size and orientation of new market potential in other countries.

Market Segments

As the key feature of EPC is no upfront capital paid by the host for energy efficiency projects, the targeted customers who enter into EPC contracts are usually those who lack upfront capital, for example, the small-to-medium sized building owners, institutions, and non-profits organisations (NGO). Satchwell et al. (2010) conducted the survey of the U.S. ESCO industry revenues by market segments. This survey revealed that the markets of Municipal

Universities and State governments, Hospitals (MUSH) constituted the largest share of ESCO projects in the U.S. In the 2008 figures, the ESCO revenues in this MUSH market was worth over US$ 2.8 billion, which comprised 69 % of the total ESPC activities. As a lack of capital is a key barrier in this market, the provision of EPC services is an alternative way to undertake energy improvement projects. The details of ESCO industry revenues by market segments in the U.S are shown in Figure 2.3.

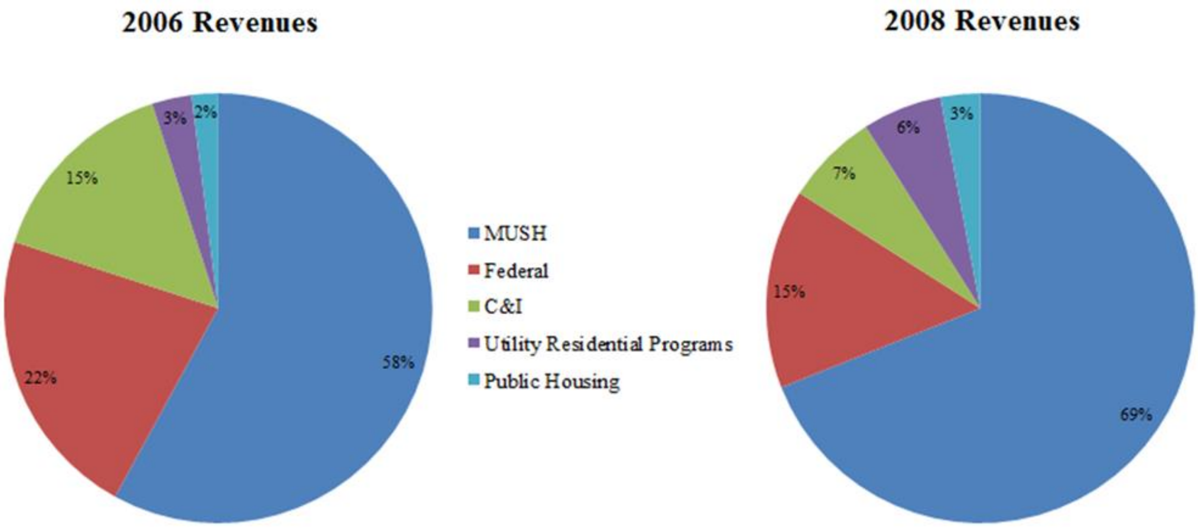

Figure 2.3: 2006 and 2008 ESCO industry revenues by market segments in the U.S (extracted from Satchwell et al. (2010))

Unlike the “MUSH” market, the commercial and industrial (C&I) sectors recorded a decrease in market share from 15% to 7%. It was attributed to the economic downturn, such that hosts from these sectors were reluctant to sign long-term performance contracts. On the other hand, the Federal market, representing the public sector, comprised a very low market share (only 15% of the total). However, the Federal government has actively promoted the use of EPC in the public sector in recent years. The government has approved the extension of the previous DOE Super-ESPC contracts, and the Energy Independence and Security Act of 2007 was enacted to eliminate the public procurement and financing barriers, by cancellation of the advance Congressional reporting requirement, as well as increase in ESCP funding flexibility

(DOE, 2015d). In the long term, it is expected that the federal market will become an important market for ESCOs.

In Hong Kong, there is no similar finding about ESCO industry revenues by market segments. Therefore, the U.S. experience of EPC market segments is important for the local reference, which gives out an insight into the potential sectors where an EPC arrangement provides sufficient incentives to undertake energy improvement projects.

2.4.2 Hong Kong

The available literature on EPC market in Hong Kong is scanty, especially in the area of total revenues of EPC projects, types of EPC contract being adopted, and nature of EPC projects. Despite the fact that the potential of ESCO market in Hong Kong is around US$100 million (Li, 2000), the HKSAR government has not yet launched relevant measures aimed at enhancing the penetration rate of EPC in both the public and private sectors. Unlike other counties such as Australia and the U.S., no EPC procurement and M&V guidelines have been developed from the relevant departments (e.g. EMSD) for activating the local market. Only several pilot EPC projects were conducted in public buildings (the details are shown in Table 2.1), and one EPC seminar, jointly organised by the Electrical and Mechanical Services Department (EMSD), Environment Bureau (EB) and Hong Kong Institute of Vocation Education (HKIVE), was held on 10 July 2008 for arousing awareness of adoption of EPC in Hong Kong (Edmonds, 2008).

Table 2.1: Details of pilot projects launched by the HKSAR government (Edmonds, 2008).

Project Name	Type	Completion Date	Contract Period	Retrofitting	Energy/Cost Saving
Police Station A	Public	April 2001	N/A	A number of innovative energy efficient installations, e.g. lighting, occupancy sensors, proper air-conditioning control etc.	Guaranteed annual energy savings: 148,400 kWh
Police Station B	Public	Nov 2003	N/A	Boilers replacement with heat pumps	Actual annual energy cost savings: HK$82,499 (179% of guaranteed savings HK$46,200)
Hospital	Public	May 2002	4 years	Installation of heat pump system for hydrotherapy pool heating	Actual energy cost savings in the 1st year: HK$150,646 against the guaranteed annual energy cost savings: HK$150,000
A Games Hall	Public	May 2003	30 months	Installation of heat pump for supplying hot water for showers	Guaranteed annual energy cost savings: HK$152,000

Regarding the EPC market in the private sector, no comprehensive data or record is available on the numbers, type and scale of EPC projects being completed in Hong Kong. Only some literature or presentations revealed several notable cases of EPC projects, mostly in institutional and commercial buildings, including:

1. The Hong Kong University of Science and Technology – 3 contracts completed, involving campus-wide lighting retrofit, library dehumidification using heat pumps and other energy saving measures to academic buildings and laboratories (Lai, 2001);.
2. The Duchess of Kent Children's Hospital – hydrotherapy pool heating;
3. Pamela Youde Nethersole Eastern Hospital – air-conditioning, lighting and building automation upgrades (Lai, 2001; Gilleard and Wan, 2008);
4. Our Lady of Maryknoll Hospital - energy conservation measures;
5. Kwong Wah Hospital – energy conservation measures (Lai, 2001; Poon, 2005);
6. Harbour City Gateway Apartments– central chiller retrofit;
7. Swire's Island Place Shopping Centre – air-con changed to water-cooling(Chow et al., 2006a);
8. Several existing hotels; and
9. A printing company's factory and a country club (Fong and Lee, 2003)

Similar to the development progress of EPC market in other countries, the Hong Kong Association of Energy Service Companies (HAESCO) was founded in 2008 to promote EPC models and solutions to the local energy efficiency market (HAESCO, 2015). However, no accreditation scheme for qualified ESCOs has yet been developed although it is regarded as a catalysis to further boost up the penetration rate of EPC in the local market (Marino et al., 2011).

2.5 Process of EPC projects

EPC Procurement Process

In the U.S., a Federal Energy Management Program (FEMP), launched by the Department of Energy (DOE), provides the recommended procedures for the EPC procurement approach under public projects (DOE, 2015f). The Australasian Energy Performance Contracting Association Inc. (AEPCA) has also developed a similar EPC practice guideline to enhance the adoption of EPC for public buildings (AEPCA, 2012). These recommended guidelines have been proven successful in many projects and meet the criteria for public service procurement in their local markets.

Singh (2010) identified six key steps that are commonly involved in a public EPC procurement process. These steps are budgeting, energy audit, request for proposal, bid evaluation, project financing, contracting, as well as measurement and verification (M&V).

Figure 2.4: Six key steps in EPC procurement process (Adapted from Singh (2010))

Budgeting is the first stage of EPC projects when the initial costs will be estimated regarding the collection of information and data for an energy audit, assigning staff to develop the bidding documents and to supervise the project. After that, an energy audit follows. The host will issue a call for "Expression of Interest" (EOI) for the EPC project. The energy audit will then be conducted by the selected ESCOs to identify energy saving potential, estimate the amount of energy savings if the proposed ECMs are conducted, and investigate data sufficiency for developing the acceptable energy use baseline.

When the energy audit is completed, there are two ways to issue the "Request for Proposals" (RFP). First, the host invites the selected ESCOs to submit their EPC proposals based on their individual energy audit findings. Second, the host issues a RFP for an open competition among the interested parties. The ESCOs who have conducted the energy audit may or may not be involved. Their proposals are solely based on the information and data disclosed by the host. The main purpose of RFP is to define the general scope of work and specify the requirements associated with system design, method of installation, financing, O&M and M&V.

The EPC proposals returned from the bidders are then evaluated based on the criteria set by the host, including the proposed solutions, energy savings, investment cost, contract period and company competence. A committee of reviewers gives a score on every submitted proposal and negotiates the contract with the bidder who has obtained the highest score. The terms of project financing are sometimes difficult to be defined clearly at the tendering stage. The host will discuss with the bidder the method of financing, either from banks, financing institutions or self-arranged sources.

2.6 EPC financing

Credit Financing and Self Financing

Bertoldi et al. (2006) classified the financing options for energy efficiency projects into three categories, namely ‘ESCO financing’, ‘host financing’ and ‘third party financing’.

ESCO financing means that ESCOs allocate their own internal funds to pay the upfront costs for energy efficiency project. The host will make scheduled payments to the ESCO if the energy saving is realised. This arrangement involves only the ESCO and the host, and no financial institution or bank will provide any financing for the project. Equipment Manufacturer-ESCOs and Utility-ESCOs, which generally have sufficient financial resources, are the most suitable parties to adopt this financing approach.

Similarly, host financing means the energy improvement project is financed by the host’s internal funds. The main role of ESCOs is to share or guarantee energy cost savings when certain retrofitting works are carried out. This arrangement is more appropriate for customers with high fiscal reserves (e.g. institutions such as universities). The self-financing approach (either by ESCOs or hosts) can further lower the transaction costs as no extra interest is paid to the third party such as financial institutions or banks.

A third-party financing (TPF) is the financial arrangement that either the ESCO or host borrows money from financial institutions or banks for meeting project implementation costs. The party (either the ESCO or host) who signs the loan contract relies on its credit standing and financial statement, the purpose of which is to obtain the lowest interest rate and provide less collateral and securities required from financial institutions. The borrower’s repayment ability mainly stems from the energy cost savings in the projects during the whole contract period, and these energy cost savings are often guaranteed by the ESCO. In case of shortfall in savings, ESCOs are liable to compensate such losses incurred by the host. As a result, it limits the risk of hosts being exposed to ESCOs' performance failure.

IEA (2015) highlighted the implications of credit financing for EPC projects on the ESCO's and host's profile in four aspects:

- Legal aspects: Transfer of ownership at the end of contract period; Flexibility and conditions for cancellation of contract.
- Collateral/Securities: Financial securities (equity capital, bonds, insurances, guarantees) required; Tangible securities/collateral (record of loan in land register, mortgage) and Personal (e.g. personal liability).
- Taxation: Increase of tax deductible expenses; Value Added Tax; Benefits from tax exemptions; Optimisation of timing of deductible expenses (e.g. upfront depreciation, interest, etc).
- Balance sheet & accounting aspects: Legal and economic property aspects; Balance sheet performance indicators (e.g. effect on debt-equity ratio, credit lines, etc).

2.7 Perceived benefits of adopting EPC

An extensive literature review on the perceived benefits of adoption of EPC was conducted, and the most important benefits can be summarised into five categories:

i) **Services –** EPC projects provide two major services: 1) turnkey services in all-in-one packages; 2) guaranteed performance (Xu et al., 2011). Apart from the traditional projects where the provisions of design, construction, installation and maintenance are included, ESCOs also provide energy audit, financing and operational services, if necessary.

Besides, ESCOs in EPC projects perform not only in accordance with the contract specifications, but also deliver the actual energy savings during the post installation stage (Yik and Lee, 2004).

ii) **Risks** – The risks inherent in EPC projects, including performance and technical risks, can be transferred or shared by the ESCOs (Hui, 2002). In the traditional projects, the contractor for replacement works does not bear responsibility on the actual equipment performance after the defects liability period. The host will suffer losses when the new equipment operates at low efficiency. Under the EPC package, the ESCO will compensate the saving losses if the promised energy savings is not achieved.

iii) **Building Energy Performance** – The primary goal of EPC projects is to reduce energy use in buildings, instead of replacing aging equipment (AEPCA, 2012). All possible energy saving solutions, including replacement of equipment, control system, operation strategy and staff training, are also considered in EPC projects, and thereby further improve building energy performance.

iv) **Financing** – In case a host lacks the upfront capital for undertaking energy improvement projects, he can request the ESCO to arrange financing either by third parties or the ESCO itself, and the ESCO also guarantees the host that the actual energy savings, being generated from energy conservation measures (ECMs), can cover all the implementation costs during the contract period (IEA, 2015).

v) **Human Resources** – The implementation of EPC project is a kind of outsourcing activity to realise energy saving potential in buildings. As such, less internal experts are required as the ESCOs offer technologies and expertise to implement energy improvement projects (Yik and Lee, 2004). In addition, staff training on system operation and control is provided by the ESCO to ensure that the newly installed equipment is operating at the optimal efficiency.

2.8 Market barriers to the adoption of EPC contracts

An extensive literature review on the market barriers to the adoption of EPC contracts was also conducted, and the most important barriers can be summarised into four categories:

(I) Policy and Institutional barriers

The inflexibility of public procurement procedures is one of the key barriers to hinder the development of EPC market (Hui, 2002; Vine, 2005; Limaye and Limaye, 2011; Marino et al., 2011). Compared to the traditional methods such as "fee for services" and "design-bid-build", the scopes of work are not clear at the beginning of the EPC project, and the purchasing officers usually have difficulties in defining a clear specification for tendering EPC projects. In addition, the existing procurement criteria usually focus on the lowest investment cost, instead of the lowest life-cycle cost, which poses a limitation on the energy solution for EPC projects.

Regarding the financing arrangement, the government procurement regulations have certain restrictions on the sources of financing in public projects. For example, in the U.S, prior to the enactment of Energy Independence and Security Act of 2007, there were several requirements to restrict the use of combination of publicly appropriated funds and private financing. It resulted in financial difficulties for ESCOs to undertake EPC projects at that time (DOE, 2015d).

(II) Contractual Issues

Apart from the traditional E&M projects where design, construction and installation are included, EPC projects also involve the post installation stage, including M&V, payment method and maintenance. These terms and clauses are unique in EPC projects, and cannot be incorporated simply by modifying the standard forms of E&M or construction contract (Hui, 2002). The high transaction costs to draft and negotiate the terms of EPC contracts are often observed in countries where no standard form of EPC contract is available, and it results in a hurdle to the use of EPC in those local markets (Marino et al., 2011).

(III) Measurement & Verification (M&V)

The primary aim of the M&V process is to ascertain the actual energy savings being achieved throughout the whole contract period, and the amount of payment can then be determined based on those actual energy savings. However, a number of literature studies reveal that it is difficult to measure building energy performance accurately and equitably (Hui, 2002; Yik and Lee, 2004; Xu et al., 2011), leading to an uncertainty in evaluating actual energy savings. Therefore, it requires expertise to carry out such works, including the identification of variables affecting energy use, establishment of energy use baseline, and adjustment mechanism. The problems associated with M&V commonly arise when no standard M&V guideline is published or authorised by the local industry. These unsolved problems usually become a barrier to the adoption of EPC.

(IV) Lacking awareness, knowledge and experience

Compared to the typical construction project, EPC projects are unique in terms of procurement, M&V, as well as payment methods. This uniqueness of EPC projects requires a learning process among all the stakeholders, including ESCOs, hosts, bankers and government officials. In some cases, the inexperience of ESCOs or hosts usually lead to mistrust and disputes in savings, because no comprehensive M&V plan is formulated prior to the installation stage (Marino et al., 2011). Therefore, a lack of awareness, knowledge and experience among the market stakeholders is one of the barriers to the use of EPC in the market.

2.9 Measures to enhance the adoption of EPC

An extensive literature review on the measures to enhance adoption of EPC contracts was also conducted, and the most effective measures can be summarised into three categories:

(I) Policy

The local government participation in promoting the use of EPC is essential to the development of EPC market in both the public and private sectors (Bertoldi et al., 2006; Xu et al., 2011). As discussed about the EPC barriers in the previous section, EPC projects are unique in terms of procurement, contract negotiation, M&V and payment method. The launch of demonstration EPC projects and M&V training programmes can enhance the stakeholders' awareness on EPC which is regarded as a way to improve building energy performance in many overseas countries. The establishment of an ESCO accreditation scheme would help to ensure the quality of EPC services and enhance industry professionalism. To reduce the transaction costs of contract negotiation, the development of standard forms of EPC contract is also important to enhance the adoption of EPC in the market. Furthermore, the government also reviews the existing procurement rules and remove the barriers to allow the use of EPC in public projects.

(II) Economic Incentives

In most cases, the financing constraints on ESCOs usually limit the EPC market expansion, and the banks are reluctant to provide financing due to no resale values of installed equipment and low income stream of EPC projects (Vine, 2005; Marino et al., 2011). As such, the government should take a lead to engage with the financial institutions for providing green financing, and setup an EPC funding scheme to encourage the use of EPC in the local market. In Singapore, the Building and Construction Authority (BCA) has cooperated with several financial institutions to launch the Building Retrofit Energy Efficiency Financing (BREEF) Scheme (BCA, 2014). Banks aim to provide loans up to S$5 million to building owners for undertaking energy improvement projects, and the risk of loan default will be shared by BCA and the financial institutions. With this economic incentive, it is expected that the penetration rate of EPC in Singapore will increase rapidly.

(III) M&V

The standardisation of M&V procedures and standards can help overcome many barriers regarding the establishment of energy use baseline and adjustment mechanism (EVO, 2012). In the U.S., the M&V guideline specifically drawn up for the Federal ESPC projects were published to enhance the stakeholders' awareness of the importance of M&V works, and allocate the risks commonly associated with EPC projects (DOE, 2015e).

2.10 Quantitative risk analysis methods

2.10.1 Risk identification

Mills et al. (2006) identified the risks associated with energy-efficiency projects and classified them into five aspects, namely economic, contextual, technology, operation, and measurement and verification (M&V) risks. Hu and Zhou (2011) proposed another classification on the risks inherent in EPC projects, namely political and legal risk, market risk, technology risk, management risk, financial risk, project quality risk as well as client risk. Based on the literature review, the risks associated with EPC projects are summarised in Table 2.2, with the additions of risk causes and consequences in the context of EPC as a particular type of EE projects.

Economic Risks

Economic risks are the possible losses which result from variations in energy costs, demand charges, material costs, equipment costs and labour costs (Binga et al., 2005; Hu and Zhou, 2011; Singhal and Swarup, 2011). In most standard forms of EPC contract, a relevant clause is stipulated that both contracting parties bear the risk of variations in energy costs and demand charges, and the baseline of those costs will be adjusted accordingly when such variations occur. However, in the guaranteed saving model, only the ESCO bears those risks. For the risk of variations in material costs, equipment costs and labour costs, it is common that the ESCO fully bears the risks associated with increases in those costs.

Financial Risks

As discussed in Section 2.6, there are two common types of financing approach in EPC projects, namely self-financing and third-party financing (Bertoldi et al., 2006). With the former, the host pays the upfront capital for project implementation, and the ESCO bears the performance risk by a guarantee on the energy savings for the proposed ECMs. With the latter, the ESCO or the host may obtain a loan from a third party financial institution. To ensure the repayment ability, the financial institution may require the host to secure an ESCO's guarantee on the achievable energy savings (since the ESCO will compensate the loss when there is a shortfall of the guaranteed savings) or some forms of financial security from the borrower.

Project Design Risks

An accurate estimation of energy saving of proposed ECMs is critical to the success of EPC projects. Apart from a proper engineering design (Waltz, 2003), the availability of building operating data, which is used to predict energy performance for the newly installed ECMs, is important for the ESCO to evaluate the project risk of expected energy savings (Krarti, 2011). Uncertainties in estimating energy savings will become larger when the quality of system operating data is poor (EVO, 2012). In practice, before both parties commit themselves to an EPC contract, the ESCO will carry out a detailed energy audit to evaluate the room for saving and the feasibility of proposed ECMs in achieving it.

Installation Risks

EPC projects often involve the removal of existing equipment and installation of new ECMs in buildings in use. The removal and installation work are only allowed during specific hours to minimise disruption to occupants (Waltz, 2003). As such, project delay may occur, resulting in a delay in materialising the actual energy savings. In practice, the responsibility for such a saving shortfall depends on who causes the delay.

Technology Risks

Technology risks mean that the equipment performance and lifetime variations are caused by inaccurate sizing, improper system selection, as well as unexpected deterioration (Waltz, 2003; Mills et al., 2006). In general, the ESCO fully bears any technology risks during the contract period. These risks can be limited if proper system design, equipment selection and regular maintenance are performed. In some cases, the installation of additional ECMs is allowed during the post-retrofit period in case a shortfall in saving occurs. This provision enables the ESCO to improve the system energy performance and achieve the expected energy savings at its own cost.

Operational Risks

Operational risks mean variations in energy savings attributed to changes in the prescribed operation schedule and control strategy of the newly installed equipment (Hu and Zhou, 2011). For example, tenants' complaints on noise and air quality may cause a change in the prescribed schedule of system operation, leading to the extension or reduction of operating time, hence affecting the actual energy savings. These operational risks also affect the prescribed adjustment mechanism and cast doubts as to whether it fairly reflects the actual changes in energy savings. In practice, the contracting parties often negotiate on the allocation of operational risks. In most EPC contracts, the ESCO would not be liable to shortfall in savings when the host does not operate the system in accordance with the agreed control strategy and procedures.

Measurement & Verification Risks

M&V risks include modelling errors, poor data quality for M&V works, as well as measuring imprecision (Waltz, 2003; Daly et al., 2014). These risks are all intrinsic, and both parties should equally bear them. These risks can be better managed by model validation, proper metering, and implementation of recommended M&V plans.

Mills et al. (2006)) also suggested the techniques for management risks. These techniques vary from technical approaches (e.g. monitoring and diagnostics) to financial arrangement (e.g. hedging, insurance purchase) and to contractual strategies (e.g. fixed price contract, risk allocation to those who can best manage the risks).

Table 2.2: Matrix of risks associated with energy-efficiency projects (expanded from Mills et al. (2006); Hu and Zhou (2011))

Risks	Manifested as	Risk Causes	Risk Consequences	Risk Management
Economic risk	Construction cost increases	Labour/material volatility	Reduction in profits of ESCO	Price adjustment based on indices
	Interest rate increases	Interest rate volatility in loan market	Higher interest rates will increase financing cost	Interest rate swap
	Fuel cost increases	Electricity/gas price volatility	Reduction in actual cost savings	Hedging; Baseline adjustment of fuel costs
Financial risk (if third party financing is required)	Payment default	Energy saving is not achieved as expected	Inability to service loan and possible termination by banks	Guarantee on energy saving; Performance bond
Project design risk	Insufficient information on facility	Incomplete and poor quality of system operating data	Inaccurate energy baseline; Inaccurate calculation of energy saving	Due diligence; Guided site visit
	Inappropriate design	Improper design and design fault	Shortfall in energy savings	Careful design; design reviews
Installation risk	Completion delay	Adverse weather; shortage of labour; delay in project approvals	Delay in commencement of energy savings	Extension of time clauses
Technology risk	Poor system/Equipment performance	Design deficiency	Reduction in actual energy savings	Careful design; Acceptance tests
	Wrong equipment sizing	Improper equipment sizing	Equipment frequently operating at part- load condition, resulting in reduction of energy savings	Careful design; Acceptance tests
Operational risk	Degradation of equipment	Faster rate of equipment degradation due to poor maintenance	Consuming more energy to achieve the same performance, resulting in reduction of energy savings	Monitoring and diagnostics
	Faulty operation	Improper system operation (e.g. system is often operating at part load condition)	Reduction in actual energy savings	Operation staff training; Provision of system operational procedure guidelines
	Frequent breakdowns	Improper or lack of maintenance	Reduction in profits of ESCO and disturbance to host	Planned maintenance
	Unexpected consumption pattern	Changes in baseline conditions, such as weather, operating hours, load on system conditions	Change in measured energy savings	Proper contract drafting, especially in considering baseline adjustment factors; Follow established M&V guideline
Measurement & Verification risk	Poor data quality	Low resolution of operating data; missing data	Increase in uncertainty on energy saving calculation	Prior agreement on the expected quality of data; Carry out investment grade energy audit
	Modelling errors	Incorrect assumptions on technical aspects	The model might be invalid for estimating the baseline energy use after retrofitting, leading to disputes over actual energy savings	Prior agreement on the use of modelling method & assumption
	Inconsistency of data	Improper M&V design (e.g. miss out recording factors which significantly affect energy use)	Dispute over actual energy savings	Proper M&V plan design
	Imprecise/inaccurate metering	Measurement error	Increase in uncertainty in energy saving calculation	Regular calibration; Sub-metering

2.10.2 Investment analysis for energy efficiency projects

Traditional method: NPV, IRR and PB

Jackson (2010) summarised the existing practices and tools for investment decisions on energy efficiency projects, namely, Net Present Value (NPV), Internal Rate of Return (IRR) and Payback (PB) analysis. In the NPV approach, the future savings will be discounted into present values based on an assumed discounted rate. When the sum of discounted savings is greater than the total investment costs, the energy efficiency project generates net financial benefits. In an IRR analysis, the net present value is first assumed to be zero, and the IRR is then calculated. If the IRR exceeds the cost of capitals, the investment will be profitable. Payback (PB) analysis is aimed at determining the number of years required for the investment to pay for itself, simply by the total project costs divided by annual savings. Several studies reveal that NPV, IRR and PB are the most popular tools for capital budgeting in the world (Harris et al., 2000; Graham and Harvey, 2001; Ryan and Ryan, 2002).

However, the above methods have their limitations. Several assumptions regarding actual savings and equipment lifetime are made in these analyses. In order to protect against the risky investment, rules-of-thumb and conservative assumptions are usually observed, and result in most of the profitable energy-efficiency projects being screened (Ross, 1986). Besides, the probability factors, related to variations in actual savings and total investment costs, are not considered in these approaches. As such, the low-risk-long-payback investment on energy improvement projects will be rejected simply due to a long payback period. Hence, there is a need to develop a probabilistic risk analysis for fixing the problems of existing project screening tools.

Actuarial Pricing Approach

Mathew et al. (2005) have indicated the possible use of an actuarial pricing approach to quantify the associated risks for project decision-making. In this actuarial approach, a probabilistic model is developed for different energy efficiency projects. It requires to document the details of past energy efficiency projects, including type of projects, the amount of energy savings, implementation costs. With this model, the ranges of savings can be estimated under different project scenarios. However, the accuracy of these developed models will be limited when only few numbers of actual projects are available as data sources.

Value at Risk (VaR)

The concept of Value at Risk, developed by investment bank J.P. Morgan, was first introduced in risk management of the financial industry (Crouhy et al., 2006). VaR analysis estimates the greatest likely loss of a portfolio with a given probability level over a period of time. For example, a one-day 95% VaR of positive $1 million means that the portfolio has only a 5 percent chance of losing more than $1million in one day. Jackson (2010) expanded this application in analysing risk and returns of energy improvement projects, and called it Energy Budgets at Risk (EbaR). The main advantage of this method is that the uncertainties related to electricity prices, weather and operating performance are also considered and the analysis provides a probability distribution of investment outcomes. As such, more information such as the expected savings and saving variances are available for the decision maker to evaluate the energy efficiency projects.

Quantitative Risk Analysis Methods

To solve the problems involving probability, a quantitative risk analysis approach should be adopted. Several studies describe the different uncertainty analysis approaches in risk assessment, including decision trees, influence diagrams, fuzzy logic, Monte Carlo simulation and Bayesian methods (Thomas et al., 2010). These techniques have been used in difference fields, for instance, safety, finance, insurance construction projects, etc. Regarding energy efficiency projects, little literature has revealed the use of probabilistic techniques to quantify the associated project risks, and only Coefficient of Variation (CV) and Monte Carlo Simulation are adopted in recent research studies (Rickard et al., 1998; Mathew et al., 2005; Mills et al., 2006; Jackson, 2010).

Coefficient of Variation (CV)

Rickard et al. (1998) adopted the technique of coefficient of variation (CV) to compare saving uncertainties in different energy efficiency measures. With sufficient project data, each energy efficiency measure will be normalised by dividing the standard deviation of a distribution of possible outcomes by the average. Therefore, each measure with different averages and standard deviations can be meaningfully compared. The project is less risky when the value of CV is smaller. However, there are some drawbacks of this technique, for example, several simplifying assumptions have to be made for project comparison and a number of risk factors are excluded from the analysis.

Monte Carlo Simulation

Monte Carlo simulation is a method that provides a probabilistic result by iterating all possible outcomes over many times. Mills et al. (2006) and Jackson (2010) used this technique to quantity the risks associated with energy efficiency projects. Under their approaches, each influential parameter on energy use is assigned a probability distribution function. These parameters are then incorporated into a project model, and through the generation of random numbers, the probability distributions of a range of outputs can be estimated. This technique is effective in quantifying the associated risks when the model representing the actual case is well developed and the probability distribution of each influential parameter can be estimated. However, their studies mainly focused on the illustration of benefits of using this technique, and the detailed procedures are lacking. As such, there is a need to establish a probabilistic method for both hosts and ESCOs to ascertain a range of energy savings at a known confidence level.

2.11 Theoretical constructs

Constructs are the building blocks of theories, which give the explanation of how and why certain phenomena occur (Jaccard and Jacoby, 2010). In this study, the theoretical constructs are based on the predictive relationship in which one of the variables A is related to another variable B. Predictive relationship focuses more on mere association, and no presumption or implication of causation is needed in the relationship. It means that the low take-up rate of EPC in Hong Kong can be related to two factors (1) the drawbacks (including over-simplified assumptions and uncertainties arising from system degradation and climatic variations) in the existing risk assessment methods to determine the probability of energy saving shortfalls still exist; (2) there is still no standard form of EPC contract published for general use, especially in the private sector, despite over a decade of market development. Based on the predictive relationship, this research aims to develop a clear, concise and comprehensive model of EPC for Hong Kong, specifically taking into account the risk assessment and contract management issues. The literature review carried out can serve as a theoretical foundation for launching this research.

2.12 Chapter summary

This chapter provides a comprehensive literature review on the current EPC development. The perceived benefits, market barriers, as well as possible measures to enhance the use of EPC have also been fully addressed. In addition, the risks associated with energy-efficiency projects, the current practices for capital budgeting and the quantitative risk analysis method are also discussed. The literature review can serve as a theoretical foundation for launching this research and informs the formulation of interview and survey questions. The next chapter presents an overview of the research methodology

CHAPTER 3: RESEARCH METHODOLOGY

Chapter 3 – Research Methodology

3.1 Introduction

This chapter contains a discussion of the research design and methods used to accomplish the research objectives. Various statistical tests for data analysis are also introduced.

3.2 Research design

A research design is a detailed plan outlining the important steps to achieve the research objectives (Monette et al., 2002). As discussed by Chow (2005); Cheung (2009), research on the built environment is commonly conducted with four standard methods, including literature reviews, interviews, questionnaire surveys as well as case studies. Knight et al. (2008) indicated that the selection of a suitable research method mainly depends on the scope and depth of a research. With the consideration of their suitability, the following methods were employed in this study for data collection and analysis: (1) a comprehensive literature review; (2) semi-structured interviews; (3) questionnaire surveys; (4) case studies; (5) modelling (building energy simulation and Monte Carlo simulation); and (6) a comparative analysis. Based on the findings from the use of the above research methods, a consolidated model of EPC in Hong Kong was developed. To ensure the applicability and practicality of the model, the model was validated by a numbers of experts and practitioners in the field of EPC in Hong Kong.

Figure 3.1 shows the relationship between the research objectives and research methods used in this study. The first objective is to investigate the concerns and understanding of hosts and ESCOs on the use of EPC in Hong Kong. To achieve this objective, a combination of qualitative and quantitative methods, including a comprehensive literature review, questionnaire surveys and semi-structured interviews were used. Desk-top research was first carried out, and the sources of literature were mainly from peer-review journals, conference proceedings, books, trade magazines, various standard documents, as well as government reports. In order to solicit key stakeholders' views on the use of EPC in Hong Kong, two separate questionnaire surveys were conducted with building owners (or hosts) and ESCOs. Semi-structured interviews were also carried out with them and other stakeholders including relevant association representatives and financers in both the public and private sectors in Hong Kong. Prior to the launch of questionnaire surveys and interviews, ethical clearance was granted by the university.

The possibilities of using other research methods such as panel discussions, focus group meetings and workshops to understand the current market development of EPC in Hong Kong were also considered. However, these methods need more resources and time to arrange, especially when the take-up rate of EPC in Hong Kong is still relatively low. The fact that active ESCOs are usually keen competitors in a small market (but with big potential) may create an awkward situation if attempts are made to sit them together. Therefore, semi-structured interviews and questionnaire surveys are considered as more effective approaches to collect first-hand data from the expect respondents.

The second objective is to develop a risk assessment approach taking into account the probabilities of saving shortfalls based on different technical solutions of common energy retrofitting. This objective was accomplished by case studies and modelling techniques. Based on the earlier groundwork built up from the literature review, questionnaire surveys and semi-structured interviews, the energy retrofitting works which have the largest potential to be implemented under an EPC approach were identified. In order to quantify the probabilities of saving shortfalls, a risk assessment approach was developed, taking into account possible variations in the influential parameters affecting energy savings. Three case studies with different retrofitting measures, including chiller replacement, change of heat rejection system and lighting upgrading, were used to demonstrate the application of this probabilistic approach for risk assessment. The proposed approach involves the use of correlation analysis for identifying influential parameters, building energy simulation *(e.g. EnergyPlus)* for predicting building energy use, and Monte Carlo simulation for estimating the probability of post-retrofit energy savings. The details of the procedures and methods are presented in Chapter 6.

The third objective is to develop a set of EPC contract document templates for use in Hong Kong. This objective was achieved by a comparative study of different standard forms of EPC contract in overseas jurisdictions and an understanding of the stakeholders' concern as gleaned from the surveys and the interviews. First, the collection of representative standard forms of EPC contract in the overseas jurisdictions was carried out. After that, a comparison was made between nine standard forms of EPC contract in eight jurisdictions, including Australia, Canada, China, Japan, Singapore, Taiwan, the United Kingdom and the United States. By close examination and comparison, the common essential features of standard forms of EPC contract were identified, and the key differences between those contracts were highlighted to reflect various treatments of contractual issues in EPC projects. Hence, a set of EPC contract template and guidance notes was developed for common retrofitting works in Hong Kong, such as air conditioning and lighting upgrading. To ensure that the contract template and guidance notes are practical for use in Hong Kong, these documents were commented upon by related experts and practitioners.

The findings of the above three objectives were consolidated into the model, which is presented by a graphical method. The model consists of fourteen building blocks. Each block is further divided into several components for zooming into specific details. The model was validated by a numbers of experts and practitioners in the field of EPC in Hong Kong. The details are presented in Chapter 8.

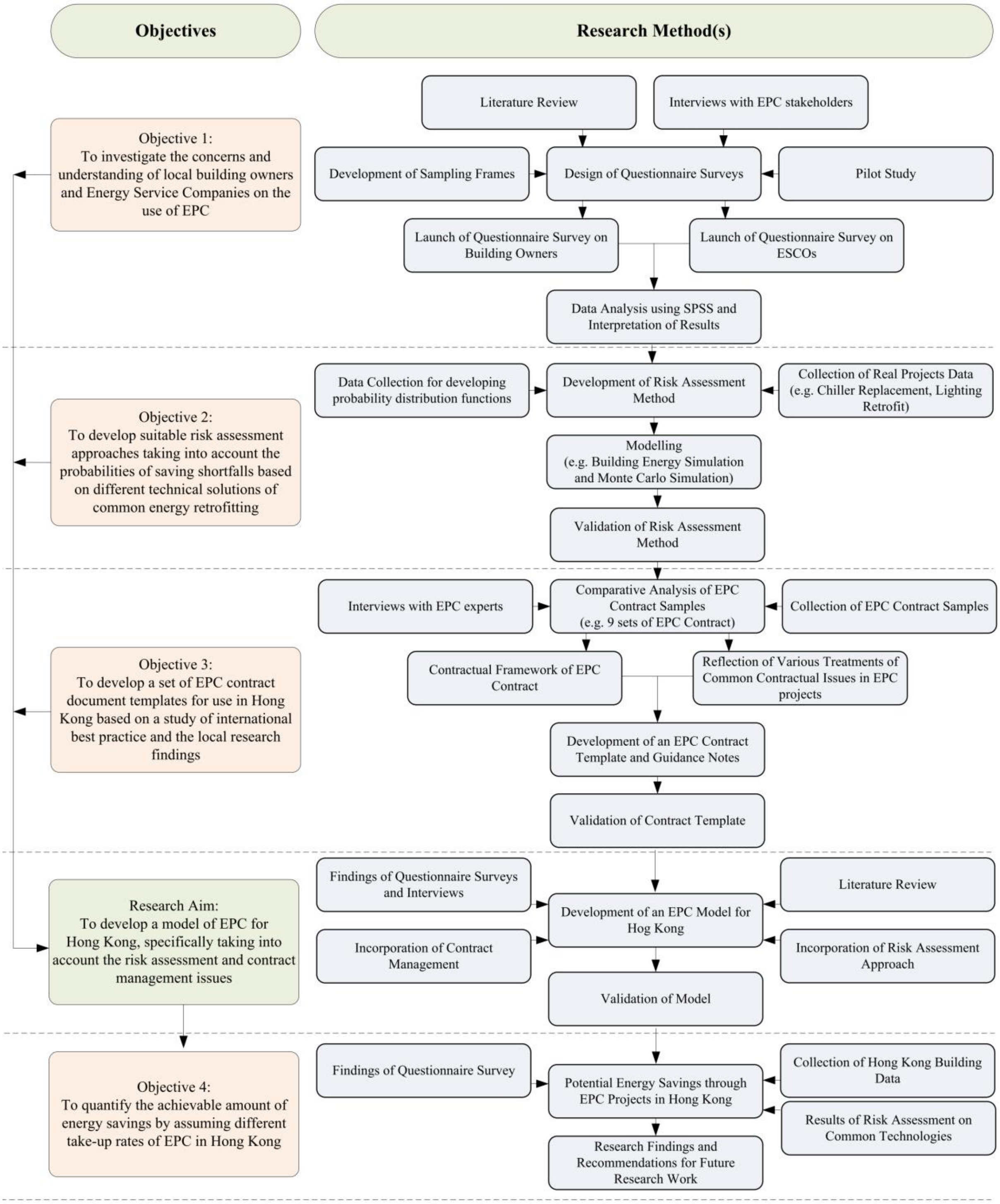

Figure 3.1: Process flow of research methodologies and objectives

The forth objective is to quantify the achievable amount of energy savings by assuming different take-up rates of EPC in Hong Kong. This objective was achieved by estimating the feasibility of EPC project implementation by pertinent sectors in Hong Kong and the achievable amount of energy savings after hypothetical retrofitting. The earlier groundwork can indicate which type of buildings are the most feasible for EPC project implementation. Based on the findings of the host questionnaire survey, the number of buildings where common ECMs have not yet been implemented was extrapolated. The results of risk assessment were also adopted to estimate potential energy savings for those common ECMs under different take-up rates of EPC in Hong Kong. More details of the research methods used in this study are discussed in the following section.

3.3 Research methods

3.3.1 Literature review

A literature review is the collection of background knowledge regarding a research study. The main purpose of conducting a literature review is to consolidate knowledge as presented in previous studies by other researchers in relation to the research topic (Chow, 2005). A literature review not only helps researchers to understand the current situation and practice of the research study, but also to identify knowledge gaps and inform future research directions. The most common sources for a literature review are from peer-review journals, conference proceedings, books, trade magazines, dissertation reports, various standard documents, as well as government reports.

In this study, a comprehensive literature review was undertaken to identify the key problems in EPC projects, including existing market barriers, possible measures to improve the take-up rate of EPC, risk perception and management.

3.3.2 Questionnaire surveys

Surveying based on questionnaires is regarded as the most common research method to collect qualitative and quantitative data in the research of social sciences. This method has been employed by a number of scholars such as Chow (2005); Yeung (2007); Cheung (2009). The merits of conducting questionnaire surveys not only include the collection of empirical data from respondents within a short period of time, but also allow respondents to complete the questionnaire at their convenience. In general, questionnaires comprise two types of questions, namely close-ended questions and open-ended questions. Closed-ended questions are used to collect the respondents' answers in a standardised format for statistical analysis, whilst the open-ended questions are employed to solicit unstructured comments based on the free will and expertise of the respondents.

A sample of the questionnaires (two host questionnaires and one ESCO questionnaire) is attached in Appendix A, B and C. It can be noted that the host questionnaire was compiled with both English and Chinese versions as some targeted respondents may not fully understand English. To ensure the readability of the questionnaires before full distribution, a pilot study was undertaken on a small sample of respondents. In this research, the Statistical Package for Social Science (SPSS) Version 19.0 was adopted as a tool for data analysis (Corp., 2010). The questionnaire design, response rates and findings are discussed in Chapter 4.

Another questionnaire was also developed to validate the model of EPC under five aspects, namely 'degree of comprehensiveness', 'degree of practicality', 'degree of adaptability for different types of building retrofit', 'degree of replicability' and 'degree of objectivity'. The selection of those aspects for model validation is based on the similar studies of Yeung

(2007); Cheung (2009) with suitable modifications. The questionnaire used for validation is attached in Appendix F.

3.3.3 Data analysis techniques

In order to analyse statistical data collected from the host and ESCO questionnaire surveys, as well as the model validation survey, various statistical tools were used, including the Mean Score (MS), the Cronbach's Alpha test, the Kendall's W-test, as well as the Mann-Whitney U Test. The rationale for employing each statistical test is depicted briefly as follows:

Mean score ranking technique

The mean score (MS) method was used to establish the relative importance of ranking questions. A five-point Likert scale was adopted to calculate the MS of each factor, and the answers were ranked in descending order. The Mean Score is computed by the following formula (Cheung, 2009):

$$Mean\ Socre = \frac{\sum(f\ x\ s)}{N}, (1 \leq MS \leq 5)$$

where s = Score given to each factor by the respondents based on the five-point Likert scale;

f = Frequency count of each rating for a particular attribute; and

N = Total number of respondents responding to that attribute.

Cronbach's alpha test

To assess the internal reliability and consistency of the questionnaires, the Cronbach's alpha test was employed. The test results show alpha values varying from 0 to 1. The higher the value is, the more reliable is the relative scale. Nunnally (1978) recommended that 0.6 is the commonly acceptable value for non-validated instrument. The Cronbach's alpha is computed as follows (Lavrakas, 2008):

$$\alpha = \frac{n}{n-1}\left(1 - \frac{\sum V_i}{V_{test}}\right)$$

Where n= number of questions;

V_i = variance of scores on each question; and

V_{test} = total variance of overall scores on the entire test.

Kendall's W-test

The Kendall's coefficient of concordance (W) was computed to evaluate the level of agreement and consistency within a particular group of sub-questions. Similar to the Cronbach's alpha test, the Kendall's W coefficient would also range from 0 (total disagreement) to 1 (complete agreement). Due to the limitation of allowable number of sub-questions for the Kendall's W test, the chi-square test was employed for acceptance or rejection of a hypothesis when the total number of sub-questions in any section was more than 7 (Siegel and Castellan, 1988). If the chi-square value is greater than the critical value at a particular level of significance (5% of significance being adopted in this study), it is concluded that the respondents' sets of ranking are consistent within the group of sub-questions. The Kendall's coefficient of concordance (W) for each attribute is calculated by the following formula (Siegel and Castellan, 1988):

$$W = \frac{\sum_{i=1}^{n}(\overline{R_i} - \overline{R})^2}{n(n^2-1)/12}$$

where n = Number of factors being ranked;

$\overline{R_i}$= Average of the ranks assigned the ith attribute; and

$\overline{R}$ = Average of the ranks assigned across attribute.

Mann-Whitney U test

The Mann-Whitney U test is a non-parametric test which is commonly employed to test whether the observations by two independent groups of respondents have the same rank distributions (Landau and Everitt, 2004). It is concluded that two groups of observations are significantly different from each other when the significance level is less than 5 % (i.e. $p<0.05$). In this study, only two questions, namely 'the potentiality of energy retrofitting work' and 'the hosts' concerns about the use of EPC' were asked of two different respondent groups (hosts and ESCOs). The formula for Mann-Whitney U is computed as follows:

$$U = N_1N_2 + \frac{N_1(N_1+1)}{2} - R_1$$

Where U = the Mann-Whitney statistic;

N_1 and N_2 = the number of cases in samples 1 and 2 respectively; and

R_1 = the sum of the ranks for the first sample.

3.3.4 Semi-structured interviews

Interviewing is one of the most popular methods of collecting data by researchers in social science research (Knight et al., 2008). Punch (2005) indicated that conducting interviews enable researchers to collect the most updated information from practitioners with hands-on experiences. Apart from that, interviewing is a powerful tool to gather greater depth of information. In general, there are three types of interviews, namely (1) structured interviews;

(2) semi-structured interviews; and (3) unstructured interviews. The structured interview is carried out with reference to a pre-designed set of questions which is not allowed to change, whilst the unstructured interview is the opposite of a structured interview. The semi-structured interview is an interview in between the structured and unstructured interviews. Naoum (2007) indicated that the semi-structured interview is widely used in qualitative research since it allows new ideas to be explored during an interview.

In this research, twenty-six semi-structured interviews were carried out with key EPC representatives from the public and private sectors in Hong Kong. The interview questions were derived from the literature review, focusing on the existing local EPC market, potentiality of energy retrofitting works, risk perception, project financing, procurement, measurement and verification (M&V), contract documents, etc. When the interviewees accepted the invitations for interview, the interview questions were sent to them in advance. During the interviews, the interviewees were asked a common set of questions pertinent to their roles. The profile of the interviewees, which comprises building owners, ESCOs' key personnel, association representatives and financers in both the public and private sectors in Hong Kong is presented in Table 5.1 of Chapter 5. The interviewees also represent 'organisational experts' or 'key informants' working at senior and responsible positions in the EPC market. To ensure the validity of the interview results, all interview transcripts were sent to the interviewees for confirmation.

3.3.5 Case studies

Case studies are widely used in building energy research, and it can facilitate in-depth investigation of particular instances within the research scope (Knight et al., 2008). In this study, three case studies were used to demonstrate the application of the proposed risk assessment approach, which enables the ESCO and host to identify the influential factors affecting energy savings, and evaluate a range of possible energy savings at a known confidence level. Three case studies involved different retrofitting measures, including chiller replacement, change of heat rejection system and lighting retrofitting, and their background information is presented in Chapter 6.

Each case study has its unique features for illustration. Case Study I involves an owner-occupied office building in which the existing air-cooled chillers were replaced with water-cooled chillers. The selection of this case study is based on the level of achievable energy savings for a single ECM work and the high upfront capital involved for implementation. Case Study II is related to a replacement project of heat rejection system in the central chiller plant in a composite building, which consists of three towers with office and serviced apartment (SA) premises. The incentives for this kind of ECM, where the existing seawater cooling is replaced with a fresh-water evaporative cooling tower system, are mainly due to the HKSAR Government’s policy on the relaxation of the use of fresh water as a cooling medium in central AC systems, as well as the poor system performance resulting from seawater corroding condenser tubes (this yielded a low coefficient of performance (COP) of chiller plants and high maintenance cost). Case Study III involves a hypothetical 40-storey office building where a bundle of lighting retrofitting measures are assumed to be implemented including replacement of existing lighting with T5 fluorescent tubes, installation of occupancy-based controls and daylight-linked lighting controls. Although it is a hypothetical case, it still serves the purpose as the assumed ECMs are very popular in lighting upgrading projects.

3.3.6 Building energy simulation

Building energy simulation is a process of studying energy performance and thermal comfort in buildings. Each building energy simulation program uses a specific simulation engine which contains mathematical and thermodynamic algorithms for calculating building energy performance (Underwood and Yik, 2004). To-date, numerous researchers have developed various building energy simulation programs, including *EnergyPlus, eQuest, ESP-r, TRNSYS,* etc. Crawley et al. (2008) conducted a comparison study between twenty major building energy simulation programs in terms of their features and capabilities, and the comparison results were presented under different themes such as 'modelling features', 'building envelope and daylighting', 'validation', etc. In this study, *EnergyPlus* was used to predict energy use of the case study buildings based on their architectural drawings, system specification and operating patterns.

The reasons for using *EnergyPlus* as a building energy simulation tool are as follows: (1) Unlike other simulation programs which are developed by commercial companies, *EnergyPlus* is developed by the Department of Energy (DOE) in the United States (DOE, 2014b); (2) *EnergyPlus* has been validated with ASHRAE Standard 140 (ASHRAE, 2007) which is a widely recognised standard for evaluating the accuracies of whole-building energy simulation programs; and (3) *EnergyPlus* is a free and open-source program which includes a number of innovative simulation capabilities such as multi-zone air flow, time-steps of less than an hour, as well as integration of plant and systems with heat balance-based zone simulation (Crawley et al., 2001). Besides, *EnergyPlus* uses text files for inputs, which allow researchers to rewrite a large number of input files automatically using *Excel VBA* (Visual Basic for Application). This feature is particularly important as this study requires more than

10,000 iterations under the different combinations of input parameters for energy use prediction.

3.3.7 Monte Carlo simulation

Monte Carlo simulation is a mathematical method where the output values are randomly generated based on assumed distributions. Such a method is widely used in various fields, including physical sciences, engineering, design, finance and business. Binder and Heermann (2010) discussed that Monte Carlo simulation mainly focuses on three distinct problems: (1) optimisation; (2) numerical integration; and (3) draw generation from a probability distribution. In this study, Monte Carlo simulation (e.g. *@Risk* by Palisade Corporation, Version 6.1) was employed to estimate the probability distribution functions (PDF) for the parameters affecting energy savings. Determination of representativeness of the PDFs for the influential parameters was based on three goodness-of-fit tests, namely the Chi-square test, the Kolmogorov-Smirnov (K-S) test, and the Anderson-Darling (A-D) test. Details of differences between the three tests are presented in Chapter 6.

In addition, Monte Carlo simulation was used to generate a sufficiently large set (an optional range from 1,000 to 10,000 depending on accuracy requirements – the higher number being more accurate) of data, each of which (an iteration) represents one possible post-retrofit condition. Based on those PDFs which are informed by the above three tests to describe the variation patterns in the influential parameters, a pre-set number of iterations is generated to simulate all possible post-retrofit conditions using Monte Carlo simulation. There are various sampling methods to create the random values in Monte Carlo simulation, and the Latin Hypercube Sampling method is widely used in the research field (Tian, 2013). The Latin Hypercube Sampling is a type of stratified sampling (Mckay et al., 1979). With the use of stratification, the cumulative curve can be divided into several equal intervals on the cumulative probability scale ranging from 0 to 1. A sample is then randomly selected from each interval such that each sample is constrained to reflect the input distribution more closely. Therefore, this ensures that the resulting sample designs are non-collapsing and generally more ‘space-filling’ than Simple Random Sampling (SRS) (the algorithm of SRS is only based on pure randomness). As a result, the Latin Hypercube Sampling is shown to be more efficient since it requires less sample sizes to reflect the actual shape of a defined distribution (Rodriguez et al., 2013). With the sufficiently large number of iterations (e.g. 10,000 iterations), a range of all possible energy savings taking into the account the variation in those influential parameters can be obtained.

3.3.8 Comparative analysis

Comparative analysis is a qualitative technique which is used to identify the similarities and differences between two or more things (Hantrais, 2009). In this study, a total of nine standard forms of EPC contract from eight jurisdictions, including Australia, Canada, China, Japan, Singapore, Taiwan, the United Kingdom and the United States (2 sets) were used for comparison. The selection of standard forms of EPC contracts was based on their representativeness, market demand for EPC projects, as well as government’s attitude towards the use of EPC. Besides, these contracts were developed either by government, relevant associations or councils, which reflects the high level of representation of its adoption in their domestic markets. By close examination and a comparative analysis, the essential features of a standard form of EPC contract were identified, and the key differences between those forms were highlighted to reflect various treatments of contractual issues in EPC projects, including performance guarantee, excess savings, saving shortfalls, equipment ownership, operation and maintenance, payment terms, change mechanism, as well as dispute resolution procedures. Details of the examined contracts are discussed in Chapter 7.

3.4 Chapter Summary

This chapter presents an overview of the research methodology. The relationship between the research objectives and research methods used in this study are summarised. Various statistical tests employed in data analysis are also introduced. The next chapter will discuss the findings of two separate questionnaire surveys targeted at the ESCO and host respondents in Hong Kong.

CHAPTER 4: QUESTIONNAIRE SURVEYS ON EPC IN HONG KONG

Chapter 4 – Questionnaire surveys on EPC in Hong Kong

4.1 Introduction

Chapter 2 summarises the previous EPC studies, including the perceived benefits, the market barriers, as well as the possible measures to enhance the use of EPC around the world. Based on the findings of the literature review, two questionnaires were developed and sent to hosts and ESCOs to investigate the latest EPC market development in Hong Kong. For the host questionnaire, it mainly focuses on the current energy saving measures in their existing buildings, their EPC experience, their ESCO selection criteria and their concerns about the use of EPC. For the ESCO questionnaire, it emphasises on the potentiality of energy retrofitting works, the arrangement of EPC projects they encountered, as well as their risk attitudes towards project implementation. The questionnaire design and survey findings are presented and discussed in this chapter.

4.2 Design of the surveys and questionnaires

Two separate questionnaire surveys were launched to solicit the views on the use of EPC in enhancing building energy efficiency from two major groups of stakeholders, namely, building owners (hosts) and energy service companies (ESCOs), in Hong Kong. The questionnaires were informed by an intensive literature review. It is acknowledged that the results of the two questionnaire surveys as reported here are adapted from two publications with the candidate as the first author, as shown in the footnotes below[1,2].

[1] Published in Lee, P., Lam, P.T.I., and Dzeng, R.J. (2014) Current market development of energy performance contracting: A comparative study between Hong Kong and Taiwan. *Journal of Property Investment & Finance*, 32(4), 371 – 395.

[2] Published in Lee, P., Lam, P.T.I., and Lee, W.L. (2015) Risks in Energy Performance Contracting (EPC) projects. *Energy and Buildings*. 92, 116-127.

4.2.1 Questionnaire survey 1 on Hosts

To ensure that the host respondents fully understand the content of each question in the context of Hong Kong, the host questionnaire was compiled with both English and Chinese versions. The questionnaire comprises three parts. In the first part, respondents were asked to provide their basic profiles (e.g. their roles and sectors of their organisations) and the corresponding buildings (e.g. the types and age of buildings that the respondents own/manage/occupy). The second part captures the information regarding the payment arrangement of utility bills in common areas, possible measures to save energy costs, payment methods for energy retrofitting, as well as the respondents' EPC experience. The third part contains the ranking questions relating to the potentiality of energy retrofitting works, the hosts' concerns about the use of EPC, and their ESCO selection criteria. Respondents were required to answer these questions in terms of relative importance or relative frequencies or likelihood (suiting the question type). A five-point Likert scale, where 1 denotes 'least important/ least likely/ least frequent' and 5 denotes 'most important/ very likely/ most frequent' was used to measure the response on those ranking questions.

4.2.2 Questionnaire survey 2 on ESCOs

The ESCO questionnaire consists of three parts. The first part relates to the organisational profiles of respondents. The second part is about their experience on EPC projects, and the respondents were asked to answer key issues in EPC projects such as allocation of equipment ownership, payment schedules, EPC contracts, as well as M&V methods for estimating energy savings. The third part focuses on the ranking questions in five aspects, covering the potentiality of retrofitting works, their perceived motivation of building owners towards the use of EPC, the hosts' concerns on the use of EPC from the encounters of ESCOs, risk perception inherent in EPC projects, and the practicality of measures to enhance the adoption of EPC. It is worth noting that the questions in Section 3 are also suitable for those respondents who have no EPC experience since these questions are related to EPC perception, instead of actual project implementation. Similarly, a five-point Likert scale, where 1 denotes "least important" and 5 denotes "most important", was employed to analyse the relative importance of the above issues.

To ensure the readability of the questionnaires before full distribution, a pilot study was conducted on a small sample of respondents. The sample of host (both English and Chinese versions) and ESCO questionnaires are attached in Appendix A, B and C respectively.

4.3 Sampling approach and response rates

The host questionnaire survey was carried out from September 2013 to November 2014. The target respondents comprise local building owners, facility managers and occupants from different sectors (e.g. public, quasi-public and private sector). Since more than 40,000 buildings are located in Hong Kong (HAD, 2015a), the surveyed buildings are only limited to commercial buildings, hotels, hospitals, and universities, where the energy use in the common areas of those building types accounts for a relatively high proportion of the total energy consumption. Due to the limited amount of achievable energy savings and the nature of multi-ownership, other types of buildings such as residential buildings are not targeted in this study.

Since there are several registration systems for all hotels, hospitals and universities through relevant licensing authorities in Hong Kong, the sampling frames of those buildings can be developed based on the corresponding registration lists, such as the list of licensed hotels, the list of higher education institutions and the list of registered hospitals (UGC, 2015; DOH, 2015; OLA, 2015). For commercial buildings, the sampling frame was developed based on the database of private buildings in Hong Kong as provided by the Home Affairs Department (HAD) (HAD, 2015a), and a screening of this database was carried out to eliminate the samples of non-commercial buildings and prevent sample duplications (e.g. the same property with different phases) and incomplete data (e.g. without information of building management companies). Hence, the total number of sampled buildings was trimmed down from over 5,000 to 1,872. To make this survey manageable, a clustered sampling technique was employed in the sampling frame of commercial buildings according to its building location (18 districts). Subsequently, a total of 885 questionnaire sets, comprising a covering letter, a blank questionnaire, and a pre-paid self-addressed return envelope, were sent to the local building owners, facility managers and occupants. A total of 168 valid questionnaires were returned, representing a response rate of 18.9%.

The ESCO questionnaire survey was carried out from September 2013 to January 2015. Since there is no ESCO accreditation scheme for the recognition of local energy retrofitting contractors in Hong Kong, the sampling frame was derived in accordance with the member lists of two relevant associations, namely, the Hong Kong Association of Energy Services Companies (HAESCO) and the Hong Kong Federation of Electrical and Mechanical Contractors Limited (HKFEMC) (HAESCO, 2015; HKFEMC, 2015). In this study, the target ESCOs are those which have capability of implementing energy efficiency projects. Due to listing duplication and the irrelevant nature of some companies (e.g. fire service installation contractors), the target ESCOs in the sampling frame were trimmed down from an original number of 178 to 137. Eventually, a total of 137 questionnaires were sent to the target respondents at managerial levels of the ESCOs, along with a covering letter and a pre-paid self-addressed return envelope. In order to increase the response rate and hence the representation of the sample, the assistance of the HAESCO in Hong Kong was sought in approaching their members. Followed up with reminders, 34 valid replies were returned, representing a response rate of 24.8%. Tables 4.1 and 4.2 summarise the profile of the host and ESCO respondents in Hong Kong respectively.

Table 4.1: Profiles of the host respondents in Hong Kong

Category	Statistic
	Percent
Your role	
Facilities Management Staff	61.9%
Tenant	10.7%
Landlord	8.9%
Member of Owner's Corporation	7.7%
Occupier (government department in public buildings)	4.8%
Unit Property Owner	3.6%
Occupier (private organisation or NGO using public building)	2.4%
	100%
Type of building	
Industrial	27.4%
Office	19.5%
Residential	15.7%
Shop	10.5%
Hotel	6.5%
Hospital	6.0%
Eating Place	4.8%
Aged People Accommodation	4.0%
Educational	3.2%
Recreational	2.4%
	100.0%
Sector	
Private	79.2%
Public	11.9%
Quasi-Public	6.5%
NGO	2.4%
	100.0%
Building age (yrs)	
Less than 5	12.6%
5-10	7.4%
11-15	10.5%
16-20	17.9%
Over20	51.6%
	100.0%

(Sample size: 168 for the host respondents)

Table 4.2: Profiles of the ESCO respondents in Hong Kong

Category	Statistic
	Percent
Work Experience	
Below 5 years	11.7%
6 – 10 years	8.8%
11 – 15 years	5.9%
16 – 20 years	11.8%
Over 20 years	61.8%
	100.0%
Years of the respondent's department	
Below 5 years	23.5%
6 – 10 years	20.6%
11 – 15 years	2.9%
16 – 20 years	11.8%
Over 20 years	41.2%
	100.0%
Staff number	
Below 25 staff	29.4%
26 – 50 staff	20.6%
51 – 100 staff	14.7%
Over 150 staff	35.3%
	100.0%
EPC Experience	
With EPC experience	35.3%
Understand it, but no real experience	50.0%
Not understand EPC and no EPC experience	14.7%
	100.0%
How many EPC project have you been involved with	
1	8.3%
2	33.3%
3	0%
4	25.1%
above 4	33.3%
	100.0%

(Sample size: 34 for the ESCO respondents)

4.4 Profile of the respondents

4.4.1 Hosts

Table 4.1shows the profile of the host respondents in Hong Kong. In this questionnaire survey, facilities management staff is the majority of respondent, accounting for 61.9% of the total number of respondents. Other respondents include tenants (10.7%), landlords (8.9%), members of owners' corporations (7.7%), public occupiers using public buildings (4.8%), unit property owners (3.6%) and private occupiers using public buildings (2.4%). Besides, 79.2% of the respondents come from the private sector, while 11.9 % of them are from the public sector. Quasi-Public and NGO consist of 6.5% and 2.4% of the total number respectively. Regarding the building types, industrial buildings, office buildings and residential buildings comprise 27.4 %, 19.5% and 15.7% respectively. Other building types are shown in Table 4.1. Furthermore, over half of their buildings are over 20 years' old.

4.4.2 ESCOs

Table 4.2 presents the profile of the ESCO respondents in Hong Kong. In this study, the respondents are mainly the practitioners of different building energy retrofitting firms, including electrical and mechanical (E&M) companies, power supply companies, equipment manufacturers, etc. In terms of the respondents' work experience, 61.8% of the respondents have been working over 20 years in the related field, 17.7 % of the respondents have work experience between 11 to 20 years, and 20.5% of the respondents have worked for less than 10 years. The numbers of staff in the respondents' companies vary considerably: 29.4% of the respondents' firms have less than 25 staff, 35.3% have between 26-100 staff, and 35.3% have over 150 staff. Hence, about 70% of the firms are medium to large in size.

As the EPC market is still at a developing stage in Hong Kong, only 35.3% of the respondents have hand-on experience in EPC projects. Fifty percent of the respondents understand the concept of EPC but without hand-on experience since some of them were involved in the stage of energy audit and project negotiation, but the projects were not implemented eventually. Among the respondents with EPC experience, 58.4% of the respondents mentioned that they implemented four or more EPC projects, and 41.6% of them were involved with one to two projects.

4.5 Data analysis

Apart from the descriptive statistics (e.g. mean scores and standard deviations), three statistical tests including Cronbach's Alpha test, Kendall's W-test, as well as Mann-Whitney U test were employed for further analysis. The detail of each test will be discussed as follows:

4.5.1 Mean score ranking technique

The 'mean score' (MS) was adopted to measure the relative importance of the ranking questions in (1) the host questionnaire (Q15 – Q17), including 'the potentiality of energy retrofitting works', 'the hosts' concerns about the use of EPC', and 'the ESCO selection criteria'; (2) the ESCO questionnaire (Q15 – Q19), including 'the potentiality of energy retrofitting works', 'the motivation of hosts towards the use of EPC', 'the hosts' concerns on the use of EPC from the encounters of ESCOs', 'risk perception inherent in EPC projects' and 'the practicality of measures to enhance the adoption of EPC'. The five-point Likert scale described previously was used to evaluate the MS of each factor, and the answers were ranked in descending order. The results of the ranking questions as reflected by the MS are shown in Tables 4.10 - 4.13 and 4.15 - 4.17.

4.5.2 Cronbach's alpha test

The Cronbach's alpha test was employed to assess the internal reliability and consistency of the questionnaires. The test results show alpha values varying from 0 to 1. The higher the value is, the more reliable the relative scale is. Nunnally (1978) recommended that 0.6 is the commonly acceptable value for non-validated instrument. As presented in Table 4.3, the Cronbach's alpha values for both the host and ESCO questionnaires are satisfactory for all sections.

4.5.3 Kendall’s W-test

The Kendall's coefficient of concordance (W) was computed to evaluate the level of agreement and consistency within a particular group of sub-questions. Similar to the Cronbach’s alpha test, the Kendall's W coefficient would also range from 0 (total disagreement) to 1 (complete agreement). Due to the limitation of allowable number of questions for the Kendall’s W test, the chi-square test is employed for acceptance or rejection of a hypothesis when the total number of sub-questions in any section is more than 7 (Siegel and Castellan, 1988). If the chi-square value is greater than the critical value at a particular level of significance (5% of significance being adopted in this study), it is concluded that the respondents' sets of ranking are consistent within the group of sub-questions. Table 4.4 shows the Kendall's W coefficients with the samples of hosts and ESCOs, indicating coherence of responses with the respective groups.

4.5.4 Mann-Whitney U test

The Mann-Whitney U test is a non-parametric test which is commonly employed to test whether two independent groups of respondents observed have the same rank distributions. It is concluded that the two groups of observations are significantly different from each other when the significance level is less than 5 % (i.e. $p<0.05$). In this study, only two questions, namely ‘the potentiality of energy retrofitting work’ and ‘the hosts' concerns about the use of EPC’ were asked of two different respondent groups (hosts and ESCOs). Therefore, the Mann-Whitney U test was only applied for those two questions and the results are shown in Table 4.5.

Table 4.3: Results of Cronbach's Alpha Test for both questionnaires

Question No.	Section in questionnaire	Cronbach's Alpha	
		Host	ESCO
Host Q15 ESCO Q15	the potentials of energy retrofitting works	0.831	0.790
Host Q16 ESCO Q17	Hosts' concern on EPC (Hosts' survey) and Reasons for hosts not considering EPC (ESCOs' survey)	0.763	0.674
Host Q17	the ESCO selection criteria	0.836	NA
ESCO Q16	Motivation of building owners towards the use of EPC	NA	0.838
ESCO Q18	Importance of risk factors relevant to EPC as perceived by ESCO	NA	0.864
ESCO Q19	Practicality of measures to enhance the adoption of EPC in Hong Kong	NA	0.802

NA denotes 'not applicable'

Table 4.4: Results of Kendall's W and Chi-Square test

Question No.	Host Q15 ESCO Q15		Host Q16 ESCO Q17		Host Q17	ESCO Q16	ESCO Q18	ESCO Q19
Role	Host	ESCO	Host	ESCO	Host	ESCO	ESCO	ESCO
N	25	24	129	32	136	29	31	32
Kendall's W	0.288	0.249	0.109	0.173	0.410	0.074	0.087	0.107
Chi-square	86.31	71.84	112.02	44.38	699.3	21.49	35.17	48.03
Degree of freedom	12	12	8	8	12	10	13	14
Chi-square critical value (at 5%)	21.03	21.03	15.51	15.51	21.03	18.31	22.36	23.69
Asymptotic significance	<0.001	<0.001	<0.001	<0.001	<0.001	0.018	<0.001	<0.001
H_0	R	R	R	R	R	R	R	R

H_0 = respondents' rankings are independent of each other within each group of sub-questions
Reject H_0 if the actual chi-square value is larger than the critical value of chi-square

Table 4.5: Results of Mann-Whitney U test

Section ID	Section in questionnaire	Respondents from hosts vs ESCOs (Bold: Asymp. Sig<0.05)
The potentials of energy retrofitting works (Host Q15 and ESCO Q15)		
3	Lighting replacement (replacing incandescent light bulbs with compact fluorescent lamps)	**0.045**
7	Replacement of air-conditioning system from air to water cooling	**<0.001**
8	Works involving heat pumps (machines capable of both heating and cooling)	**<0.001**
Hosts' concern/Likely reasons for hosts NOT considering EPC (as perceived by ESCOs) Host Q16 and ESCO Q17		
1	Lack of familiarity with EPC	**0.008**
2	Worry about its complexities (e.g. procedures, legal issues)	**0.003**
3	Not convinced that EPC can achieve higher saving than conventional approach	**0.017**
8	Worry about integrity issues of ESCOs	**0.048**

4.6 Results of host questionnaire survey

4.6.1 Electricity bill payment arrangement

Although landlords are the owners of building, they may not be directly responsible for energy bills as the landlords' buildings are divided into different areas, and the landlords often lease those areas to various tenants who are often the end-users to pay such bills. To identify potential energy savings, it is necessary to investigate the current practice of payment arrangement on energy bills in buildings.

In the host questionnaire survey, the host respondents were first asked about the electricity payment arrangement in buildings. The result (Table 4.6) shows that 32.5% of the respondents indicated that the facility management (FM) companies arrange landlords/ Owners' Corporation (OC) to pay electricity bills, while 26.4% of the respondents pay their own electricity bills as landlord/unit owners. Only few respondents claimed that the tenants share cost of electricity bills with others. Regarding the method used to apportion electricity bills, almost all respondents (97%) pay electricity bills based on meter readings. Very few respondents pay such bills based on the area used or on time of usage.

Table 4.6: Arrangement of electricity payment

Payment Arrangement of Electricity

Which arrangement(s) best describe(s) the payment of electricity in premises under your use?		Percent
Choice	a) As landlord/unit owner, you pay your own electricity bills	26.4%
	b) As unit owner/tenant, you share cost of electricity bills with someone	2.0%
	c) As tenant, your unit owner pays for electricity bills	1.5%
	d) As tenant, you pay your own electricity bills	11.2%
	e) As FM, your company arranges landlord/OC to pay electricity bills	32.5%
	f) As FM, your company collects payment from owners	12.2%
	g) As occupier, electricity bills are settled by the government	2.0%
	h) As occupier, you pay your own electricity bills	12.2%
		100.0%

Basis of electricity bill calculation

Which method is used to apportion the electricity bills?		Percent
Choice	a) Based on meter readings	97.0%
	b) Based on the area used	1.8%
	c) Based on time of usage	1.2%
		100.0%

Arrangement on the use of electricity in common areas

Which arrangement best describe(s) the use of electricity in common areas of the building?		Percent
Choice	a) Owners' Corporation pays for the electricity bills	21.6%
	b) Landlord pays for the electricity bills in common areas	22.8%
	c) You share the cost of electricity bills with someone	4.2%
	d) Electricity bills are settled by the government	7.8%
	e) FM company is responsible for paying the cost of electricity bills out of management fees collected	43.8%
		100.0%

(Sample size: 168 host respondents)

Regarding the energy bills in common areas, 43.7% of the respondents indicated that FM companies are responsible for paying such bills out of their management fees, whilst 44.4% of the respondents pay the bills directly as landlord/OC. The above results reflect that both hosts and FM companies have an incentive to save on electricity bills as the reduction in such costs would be directly beneficial to their operating expenses.

4.6.2 Measures for energy cost savings

The survey also seeks to discover which energy saving measures the hosts have considered or taken in their existing buildings. Due to the effort by various governments to promote energy savings in buildings (EMSD, 2006), more than 95% of the respondents took an initiative to save energy costs in buildings. 33.9% of the respondents adopted disciplined use in their building services (BS) systems (e.g. turning off AC or lights when not in use or set indoor air temperature to around 25ºC), whilst 31.3 % of the respondents replaced the existing appliances and luminaires with more energy efficient one. However, only few respondents (9.3%) implemented the large scale type of energy retrofitting works (e.g. chiller replacement). This implies that the hosts tend to carry out minor energy improvement works which often involve less capital and technological know-how although these measures only achieve limited energy savings.

Table 4.7. Measures for energy cost savings

Measures for energy cost savings

Which measure(s) have you considered/taken to save energy cost in your existing building		Percent
Choice	a) Do nothing for the time being	2.6%
	b) Adopt disciplined use (e.g. enforce switching off power when not in use or set air-con to around 25ºC)	33.9%
	c) Advocate energy retrofitting using more energy efficient installations in your building(s)	22.8%
	d) Replace with energy efficient appliances & luminaries (including portable time switches or sensors)	31.3%
	e) Already carried out energy retrofitting works (excluding re-wiring) to your building(s) (e.g. Replacement of air-conditioning system from air to water cooling)	9.4%
		100.0%

(Sample size: 168 host respondents)

4.6.3 Payment arrangement in retrofitting works

From the earlier results, it is observed that the hosts prefer to undertake energy saving measures with no or low cost investment (e.g. turning off light when not in use or lamp replacement). In order to investigate the payment arrangement in major retrofitting works, the respondents were asked to indicate who pays the upfront capital when energy retrofitting works are implemented. 32.6% of the respondents reveal that FM/OCs pay the upfront capital out of sinking fund, while 18.9% of the respondents pay such upfront cost as landlords. 10.3% of the respondents pay the upfront cost as part of their operating costs. Only a small portion of the respondents (9.7% and 7.4%) are willing to share the upfront cost with other owners or raise fund for paying by OC respectively. For the types of areas where the retrofit is implemented, 67.1% of the respondents indicate that the retrofitting works are related to common areas, and 24.1% of the respondents claim that the works belong to his/her owned areas. From the above results, it is observed that most retrofitting projects are implemented with the funding injection from the representatives of building owners (e.g. FM/ OC/hosts). When there are insufficient costs for project implementation, the hosts prefer to implement the projects until the amount of sinking fund is enough to cover the project cost.

When the host respondents were asked about the procurement method for the retrofitting works, 56.9% of them appointed the contractor for design and installation, whilst 43.1% of them first employed the consultant for design and then awarded the contracts for installation.

Table 4.8: Payment arrangement in retrofitting works

Payment arrangement in retrofitting works

If your building has carried out energy retrofitting works, who paid for the cost?		Percent
Choice	a) You (as tenant) shared with owner	4.0%
	b) My organisation paid upfront as part of its operating cost	10.3%
	c) FM/OC paid upfront out of sinking fund	32.6%
	d) Landlord paid	18.9%
	e) Owners' Corporation raised fund to pay	7.4%
	f) Government paid upfront	6.3%
	g) Owners shared the upfront cost	9.7%
	h) With government subsidy/loan	5.1%
	i) An energy services company (ESCO) paid first	1.7%
	j) Owner paid, since you are tenant	2.3%
	k) You paid out of a loan under guaranteed saving by an ESCO	0.6%
	l) You paid under guaranteed saving by an ESCO	1.1%
		100.0%

Area of retrofit

If your building has carried out energy retrofitting works, they were related to?		Percent
Choice	a) Owned areas	24.1%
	b) Rent areas	8.8%
	c) Common areas	67.1%
		100.0%

Type of Retrofit

If your building has carried out some energy retrofitting works, how were they organised?		Percent
Choice	a) A consultant designed and a contractor installed	43.1%
	b) A contractor designed and installed	56.9%
		100.0%

(Sample size: 168 host respondents)

4.6.4 Hosts' experience in EPC projects

Table 4.9 shows the hosts' experience in EPC projects. Only 8.5% of the respondents have been involved in EPC projects. 35.6% of the respondents understand it but have no hand-on experience, and more than half of the respondents (56%) have no concept about EPC. For those who have experience in EPC, 57.1% of the respondents used mode II where ESCOs design, supply and install equipment for hosts or third party financing together with the ESCO's guarantee on energy savings. 42.9% of the respondents adopted mode I in which ESCOs were responsible for design, financing, supply, and equipment installation for hosts in return for energy cost savings. Regarding the arrangement of operation during the post-retrofit stage, only 35.7% of the respondents prefer ESCOs to undertake the operation of the relevant facilities within the contract period. Around two-thirds of the host respondents (64.3%) prefer ESCOs not to undertake the operation since their own staff would handle this better.

Table 4.9: Experience in EPC projects in practice from the hosts' perspective.

Experience in EPC projects

Have you ever been involved with Energy Performing Contracting (EPC) to-date?		Percent
Choice	a) Yes	8.5%
	b) Know about it, but no experience	35.5%
	c) Not knowing EPC	56.0%
		100.0%

Type of EPC projects

Which of the following types of EPC projects have you been involved with?		Percent
Choice	a) (Mode I) ESCOs finance, design, supply, install equipment for host in return for energy cost saving	42.9%
	b) (Mode II) ESCOs design, supply, install equipment with host or 3rd party financing and ESCO's guarantee on energy saving	57.1%
		100.0%

Preference on operation

If EPC project is used, would you prefer ESCO to undertake operation of the relevant facilities within the contract period to ensure that the promised saving is achieved?		Percent
Choice	a) Yes	35.7%
	b) No	64.3%
		100.0%
If no, what is the reason?		Percent
Choice	a) Our own staff will handle this better	100.0%
	b) That would make EPC costly	0%
		100.0%

(Sample size: 168 host respondents)

4.6.5 Potentiality of energy retrofitting works

In order to investigate the potentiality of energy retrofitting works and the current use of EPC in the existing buildings in Hong Kong, the host respondents were asked whether they had implemented any ECMs in their buildings. Table 4.10 shows the overall results. 'Lighting replacement to more energy efficient lamps' (e.g. replace T8 with T5 or replace incandescent light bulbs with compact fluorescent lamps) was the most popular type of ECM among thirteen common ECMs since almost 60% of the respondents indicated they implemented such ECMs in their premises (Item 1 &3). This is because such retrofitting is a well-proven technology and can achieve substantial energy savings with relatively low upfront costs involved. For the types of retrofitting project, the use of EPC as a means to implement energy efficiency projects was rather uncommon in Hong Kong. Only few respondents carried out the retrofitting works under an EPC arrangement. In comparison with other ECMs, retrofitting works on central air-conditioning and lighting systems were the most common ECMs which were implemented under an EPC in Hong Kong.

For those hosts who indicated that they had not yet carried out the ECMs in the questionnaire, they were asked to rate the likelihood of future implementation of those ECMs with a Likert scale of 1-5. The same question was also asked of the ESCO respondents for direct comparison with the host respondents. The results of mean score and rankings are shown in Table 4.11. 'Lighting replacement to more efficient fluorescent lamps' was almost the top retrofitting work from the view of hosts and ESCOs (mean score = 4.05 for hosts; 4.00 for ESCOs). Although 'replacement of air-conditioning system from air to water cooling' was perceived as the second top potential ECM from the view of ESCOs, the result of Mann–Whitney U test (Table 4.5) indicated that the host respondents had significantly different view towards the potentiality of this ECM (mean score = 2.15). They thought that chiller replacement had limited potentials for implementation in future. The possible explanation for this phenomenon is that chiller replacement is a major retrofitting work which requires large upfront capital and might disrupt the normal building operation. Despite the significant amount of energy savings, it is common that hosts will consider implementing this ECM when the life-spans of existing chillers come to an end.

Table 4.10: Potentiality of energy retrofitting works and the current use of EPC in the existing buildings in Hong Kong

Host Q15: Potentiality of energy retrofitting works		Not Done	Already done	
			Using EPC	Not using EPC
1	Lighting replacement to more efficient fluorescent lamps(e.g. replace T8 with T5)	40.1%	6.1%	53.8%
2	Lighting replacement to LED lamps	55.9%	3.5%	40.6%
3	Lighting replacement (replacing incandescent light bulbs with compact fluorescent lamps)	31.1%	2%	66.9%
4	Installation of time switches and sensors	43.5%	2%	54.5%
5	Replacement of power switch gear at control room	73.2%	2.4%	24.4%
6	Improvement of existing air-conditioning system (other than cleaning)	61.4%	4.5%	34.1%
7	Replacement of air-conditioning system from air to water cooling	72.3%	4.2%	23.5%
8	Works involving heat pumps (machines capable of both heating and cooling)	78.7%	3.7%	17.6%
9	Change of energy source from gas to electric	74.5%	3.5%	22.0%
10	Change of energy source from electric to gas	90.2%	0.9%	8.9%
11	Use of renewable energy (e.g. solar and biofuel)	86.4%	2.4%	11.2%
12	Lift & escalator improvement (change of motors, excluding interior decoration)	84.7%	0.8%	14.5%
13	Building fabric improvement (e.g., insulation, double window, etc.)	85.5%	3.2%	11.3%

Sample size: 168 host respondents

Table 4.11: Mean score and rankings of the potentiality of building retrofit works

Host Q15 & ESCO Q15: Potentiality of energy retrofitting works		Host			ESCO		
		Mean	SD	Rank	Mean	SD	Rank
1	Lighting replacement to more efficient fluorescent lamps(e.g. replace T8 with T5)	***4.05***	***0.92***	***2***	***4.00***	***1.09***	***1***
2	Lighting replacement to LED lamps	***3.56***	***1.13***	***3***	3.70	0.88	4
3	Lighting replacement (replacing incandescent light bulbs with compact fluorescent lamps)	***4.12***	***1.02***	***1***	3.42	1.12	6
4	Installation of time switches and sensors	3.24	1.30	4	3.48	1.00	5
5	Replacement of power switch gear at control room	2.82	1.17	7	2.58	1.15	11
6	Improvement of existing air-conditioning system (other than cleaning)	3.10	1.16	5	***3.75***	***0.98***	***3***
7	Replacement of air-conditioning system from air to water cooling	2.15	1.20	10	***3.77***	***0.92***	***2***
8	Works involving heat pumps (machines capable of both heating and cooling)	2.03	1.19	12	3.33	0.96	7
9	Change of energy source from gas to electric	2.19	1.52	9	3.06	1.18	9
10	Change of energy source from electric to gas	1.63	0.96	13	2.34	1.08	13
11	Use of renewable energy (e.g. solar and biofuel)	2.07	1.12	11	3.03	1.28	10
12	Lift & escalator improvement (change of motors, excluding interior decoration)	2.94	1.33	6	3.07	1.10	8
13	Building fabric improvement (e.g., insulation, double window, etc.)	2.32	1.14	8	2.43	1.22	12

Numbers in bold indicate the top three rankings;
Sample size: 168 host respondents & 34 ESCO respondents

4.6.6 Hosts' concern on EPC

To identify the hosts' concern on the adoption of EPC in Hong Kong, both host and ESCO respondents were asked to rate the level of importance on the possible EPC concerns, which were based on the literature review. It is worth noting that the ESCO respondents answered the same question based on their experience with customers during the project negotiation stage. As such, a direct comparison can be made with the hosts. The results are shown in Table 4.12.

Table 4.12: Mean score and rankings of the reasons for hosts not considering EPC

Host Q16: Hosts' concern on EPC (Hosts' survey) and ESCO Q17: Reasons for hosts not considering EPC (ESCOs' survey)		Host			ESCO		
		Mean	SD	Rank	Mean	SD	Rank
1	Lack of familiarity with EPC	3.58	1.08	6	**4.12**	**0.88**	**2**
2	Worry about its complexities (e.g. procedures, legal issues)	**3.70**	**1.07**	**3**	**4.29**	**0.80**	**1**
3	Not convinced that EPC can achieve higher saving than design-bid-build	3.02	1.09	9	3.45	0.83	6
4	Worry about measurement & verification inaccuracies (assuming no fraud)	3.48	0.97	7	3.59	0.86	4
5	Not convinced that it is cost effective	3.26	1.02	8	3.41	0.99	7
6	Worry about disruption to their normal business operation or use of property	3.67	1.12	4	3.41	1.08	8
7	Worry about ESCOs' guaranteed saving not being achieved, causing problem to 3rd party financing	**3.76**	**0.99**	**2**	3.50	0.93	5
8	Worry about integrity of ESCOs	3.63	1.05	5	3.27	0.94	9
9	Long payback period	**4.04**	**0.90**	**1**	**3.82**	**1.11**	**3**

Numbers in bold indicate the top three rankings;
Sample size: 168 host respondents &34 ESCO respondents

'Long payback period' was perceived as the top three concerns among nine items from the views of hosts and ESCOs (mean score = 4.04 for hosts; 3.82 for ESCOs).This echoes with the literature findings that a short payback period is preferable as it is an effective way to mitigate project risks (Jackson, 2010; Yard, 2000). When the project payback period is shorter, the host would have more flexibility in changing their building premises and operation to suit future business needs.

‘Worry about its complexities’ was also regarded as the top three concerns by the hosts and ESCOs (mean score: 3.70 for hosts; 4.29 for ESCOs). In comparison with conventional retrofitting projects, EPC projects entail a larger work scope, including the arrangement of project financing, establishment of energy use baseline, M&V and demarcation of O&M responsibilities. Besides, the contract drafting introduces extra complexities since every EPC project is unique in terms of its patterns of building operation, scope of retrofit and methods of baseline adjustment. Considerable efforts are required from both hosts and ESCOs to negotiate the risks and responsibilities prior to project implementation.

‘Worry about ESCOs’ guaranteed saving not being achieved, causing problem to third party financing’ was ranked as the second top concern from the view of hosts (mean score: 3.76 for hosts). In a typical EPC project, the ESCO guarantees the host for a certain level of energy savings to ensure the host's repayment to the third party. However, due to various extrinsic factors such as weather conditions and changes of occupancy, the actual energy saving is uncertain. For example, due to economic downturn, the occupancy rate of a hotel drops significantly, resulting in a significant reduction in the actual energy savings, and in such a case, the ESCO is not responsible for non-performance of guaranteed savings. Therefore, the host is not risk-free despite the ESCO's guarantee on energy savings.

‘Lack of familiarity with EPC’ was considered as the second top concern in the ESCOs’ questionnaire survey (mean score = 4.12 for hosts; 3.58 for ESCOs). However, the results of Mann–Whitney U test (listed in Table 4.5) show that there is a statistically significant difference between the views of hosts and ESCOs with regard to this concern ($p<0.005$), implying the ESCO respondents thought that the ‘Lack of familiarity with EPC’ was an important concern of the hosts in considering EPC, whilst hosts were less expressive about these inadequacies. In addition, although the hosts and ESCOs held divergent views towards 'Not convinced that EPC can achieve higher saving than conventional approach' and 'Worry about integrity issues of ESCOs', their rankings were relatively low, implying that both hosts and ESCOs did not consider them as important concerns (The above two items were not within the top three concerns).

4.6.7 ESCO selection criteria

The host questionnaire survey also revealed their criteria for ESCO selection when implementing EPC projects. The results are shown in Table 4.13. 'Company reputation and track record' was the most important criterion in the process of ESCO selection (mean score = 4.48). As shown in the result of hosts' concerns on EPC projects (Table 4.12), 'worry about its complexities' was one of the top three concerns by the hosts (the reasons of project complexities have been explained in Section 4.7.5). To ensure that the EPC project is implemented successfully, it is important for the hosts to select the ESCOs with excellent track records and reputation.

'Convincing energy saving proposal' was considered as the second most important criterion (mean score = 4.39). This reflects that the hosts focus more on the amount of energy savings when the proposed ECMs are implemented, instead of the minimisation of project costs. The third ranked factor was 'ESCO capable of providing operation & maintenance during contract' (mean score = 4.35). This indicates that the hosts try to ensure that their contractors are responsible for operation and maintenance work, especially for those retrofitting solutions which are new to the local market. In addition, such an arrangement would reduce the chance of disputes on saving shortfalls due to the improper operation and maintenance by a third-party.

It is worth noting that 'ESCO provides financing' was the least important criterion among twelve items (mean score = 3.55), implying that most hosts in Hong Kong are capable of providing upfront capital for project implementation when the project is technically and economically feasible. In addition, 'lowest bid price' was not an important criterion as it ranked at ninth (mean score = 3.83). This is consistent with the finding that 'convincing energy saving proposal' is important was considered important from the view of hosts, reflecting that the hosts focus more on the actual amount of energy savings when the proposed ECMs are implemented, instead of the minimisation of project costs.

Table 4.13: Mean score and rankings of the criteria for choosing ESCO

Host Q17: Criteria for choosing ESCO		Host		
		Mean	SD	Rank
1	Company reputation and track record	***4.48***	***0.73***	***1***
2	Lowest bid price (i.e., lowest outlay for the entire contract)	3.83	0.93	9
3	Convincing energy saving proposal	***4.39***	***0.71***	***2***
4	ESCO offers guarantee on energy saving level	4.28	0.71	4
5	ESCO bears all risks (including energy price, changes in weather & use pattern)	4.12	0.82	6
6	ESCO provides financing	3.55	0.94	12
7	ESCO provides energy saving solutions in different aspects (including building fabric improvement)	3.90	0.82	8
8	ESCO has done separate energy audit before negotiating for EPC	4.06	0.76	7
9	Use of innovative technology	3.79	0.92	10
10	Long time to pay off the contract sum to the ESCO (lower instalment)	3.78	1.02	11
11	ESCO capable of providing operation & maintenance during contract	***4.35***	***0.81***	***3***
12	Short break-even period for upfront investment outlay	4.18	0.84	5

Numbers in bold indicate the top three rankings;
Sample size: 168 host respondents

4.7 Results of ESCO questionnaire survey

4.7.1 ESCOs views on EPC project in practice

Table 4.14 summarises the results on the arrangement of EPC projects in practice. Each aspect of project arrangement is discussed as follows:

Mode of EPC project

In general, guaranteed savings and shared savings are the two most common modes in EPC projects. The main difference between them lies in the risk allocation in financial and saving performance aspects. Table 4.14 reveals that 46.2% of the respondents adopt the sharing saving mode, whilst 38.5% of the respondents use the guaranteed mode. It can be seen that both models are almost equally used in EPC projects in Hong Kong.

Operation and maintenance

To ensure that the newly installed ECMs are operating at the optimal efficiency, a proper system operation and regular maintenance is vital during the post-retrofit stage of EPC projects. From Table 4.14, most respondents (76.5%) indicate that they are only responsible for maintenance work, and the system operation is managed by either the hosts or FM companies. Only 5.9% respondents expressed that the ESCOs are obligated to operate and maintain the ECMs within the contract periods. This indicates that the hosts prefer to retain the control of system operation such that a good balance of energy saving and occupant comfort can be maintained.

Ownership of equipment

In Table 4.14, 75% of the respondents indicate that the host obtains the ownership of equipment, instead of the ESCO, even when the ESCO fully pays the upfront cost for project implementation. This implies that the ownership of equipment is crucial to the host, especially for those equipment relating to the central building services (e.g. central air-conditioning) because it will affect building normal operation should disputes occur.

Energy baseline establishment

86.9% of the respondents use short/long-term measurements and use of electricity bills as the primary means to develop energy baseline in existing buildings. This reflects a lack of confidence in using the operating data provided by the host. Although direct measurements by the ESCO increase project costs and duration, it may mitigate the risk of uncertainty in baseline development, and hence minimise the chances of disputes on the M&V results.

Payment

A majority of the respondents (76.9%) tend to use scheduled payments with deduction of performance shortfalls during the contract period. Only 23.1% of the respondents make the payment based on measured cost savings. This indicates that both ESCOs and hosts prefer to have less chances of dispute when using scheduled payments since it would be easier for the ESCO to prove that the actual energy saving is more than a guaranteed level in an time frame, rather than splitting savings based on periodic measurements.

Energy saving estimation method

45.5% of the respondents mentioned that regression analysis was used for estimating expected energy savings, whilst 36.4% of the respondents adopt a simplified engineering method. However, only 18.1% of the respondents determined energy savings based on building energy simulation programmes. This implies that the industry tends to use the simplified engineering method because it provides a quick estimation with acceptable confidence, especially for non-weather dependent retrofitting such as lighting upgrading. Moreover, regression analysis is also popular as this method is recommended by several M&V guidelines for prediction and forecasting (EVO, 2012).

EPC contract documents

In practice, there are several standard forms of EPC contract available around the world (e.g. Standard Energy Performance Contract in Australia, BOMA Energy Services Performance Contract in the U.S.). However, a majority of the respondents (73.4%) still use an in-house written EPC contract, instead of a modified overseas standard form of EPC contract or a modified E&M contract. It means that different owners and ESCOs have to adapt to different forms of contract each time they enter into an EPC arrangement. This raises the issue of using standardised EPC contracts in the local market. This aspect will be further discussed in Chapter 7 & 8.

EPC financial evaluation

44% of the respondents use payback (PB) analysis as a means to evaluate the financial feasibility of EPC projects. 24% of the respondents adopt a net present value, while 20% of the respondents use an internal rate of return (IRR). It can be seen that the PB analysis is the primary tool for the ESCOs to evaluate performance risks since the ESCOs can limit those performance risks by selecting a project with a short payback period.

Table 4.14: Breakdown of responses for questions to ESCOs on the arrangement of EPC projects

Mode of EPC

Which type(s) of EPC projects have you been involved with?		Percent
Choice	a) We finance, design, supply, install equipment for host in return for a share of energy cost saving	46.2%
	b) We design, supply, install equipment with host or 3rd party financing and our guarantee on energy saving	38.5%
	c) We provide consultancy service only for clients	15.3%
		100.0%

Operation and Maintenance

Do you maintain/operate the equipment for the EPC projects within the contract periods?		Percent
Choice	a) Yes, we carry out maintenance and operation	5.9%
	b) We carry out maintenance only, with operation by host's own staff	47.1%
	c) We carry out maintenance only, with operation by property management companies	29.4%
	d) We carry out operation only, with maintenance by others	0%
	e) Host carries out their own maintenance and operation, with our advice and training	17.6%
		100%

Ownership of Equipment

How about ownership of the equipment installed under the EPC projects?		Percent
Choice	a) Ownership by host	75.0%
	b) Ownership by our organization, with leasing to host within the contract period.	25.0%
	c) Ownership by financier until loan is paid off	0%
		100.0%

Energy Baseline Establishment

Which method have you used to develop the baseline of energy consumption for EPC projects?		Percent
Choice	a) Based on electricity bills	39.1%
	b) Based on short-term measurements (e.g. logging data for less than six months)	21.7%
	c) Based on long-term measurements (e.g. logging data for six months or longer)	26.1%
	d) Based on BMS data provided by host or host's FM Company	13.1%
	e) Based on energy audit report carried out by 3rd party	0%
		100.0%

Payment

In your EPC contracts, what are the bases of the payment terms?		Percent
Choice	a) Fixed payment schedule, with deduction for performance shortfall at interim periods	61.5%
	b) Fixed payment schedule, with deduction for performance shortfall at contract end	15.4%
	c) Strictly based on measured cost saving	23.1%
		100.0%

Energy Saving Estimation Method

Which method(s) have you adopted in estimating energy saving?		Percent
Choice	a) Simplified engineering method (e.g. power rating x operating hours for lighting retrofit)	36.4%
	b) Regression analysis model	45.5%
	c) Building energy simulation program (e.g. *EnergyPlus*)	18.1%
		100.0%

EPC Contract Documents

Which basis have you encountered in preparing an EPC contract?		Percent
Choice	a) Contract written in-house and agreed with the client	73.4%
	b) Modified from a standard construction contract	0%
	c) Modified from a standard M&E contract	13.3%
	d) Direct use of an overseas standard form of EPC contract (e.g. ESPC in U.S., EPC in Canada, GESP in Singapore)	0%
	e) Modified from an overseas standard form of EPC contract (same examples as above)	13.3%
		100.0%

EPC Financial Evaluation

Which method(s) have you used for EPC project financial evaluation?		Percent
Choice	a) Net Present Worth	24.0%
	b) Internal Rate of Return (IRR)	20.0%
	c) Benefit Cost Ratio	12.0%
	d) Payback Period	44.0%
		100.0%

Sample size: 34 ESCO respondents

4.7.2 Motivation of hosts towards the use of EPC

Table 4.15 presents the ranking results on the motivation of hosts towards the use of EPC from the viewpoints of the ESCOs. 'Lack of capital to implement energy saving measures on their own' was perceived as the top motivation factor among eleven factors with the mean score of 3.85, reflecting ESCOs' belief that an EPC approach can provide a means of financing to those hosts who lack upfront capital for project implementation. However, a divergent view towards project financing was observed between the ESCOs and hosts as Table 4.13 indicates that 'ESCO provides financing' was the least important criterion for the hosts to select ESCOs. This implies that the hosts in Hong Kong emphasise more on the actual performance of ECMs, instead of the ESCOs' capability in project financing. This is also in line with the finding that 'convincing energy saving proposal' was considered as the second most important criterion for ESCO selection.

Table 4.15: ESCOs' perceived motivation of hosts towards the use of EPC, if they would consider it

ESCO: Q16. Motivation of hosts towards use of EPC, if they would consider it		ESCO		
		Mean	SD	Rank
1	Lack of capital to implement energy saving measures on their own	**3.85**	**0.89**	**1**
2	Provision of turnkey services as all-in-one package including energy audit, retrofit and financing	**3.79**	**0.86**	**2**
3	Use of energy saving for other purposes may yield better return	**3.69**	**0.90**	**3**
4	A quick way to comply with legislation requirements	3.53	0.83	6
5	Transfer the technical/performance risk from clients to ESCOs	3.31	1.00	10
6	Reliance on ESCOs' expertise	3.41	0.76	8
7	ESCOs provide staff training for better system operation and control	3.29	0.90	11
8	Budgeting of energy consumption taken care of by ESCOs	3.50	0.80	7
9	Expect higher energy efficiency than design-bid-build	3.63	0.85	4
10	More comfortable environment after installation or upgrading	3.32	0.91	9
11	EPC is a cost effective solution to achieve energy saving	3.55	0.97	5

Numbers in bold indicate the top three rankings;
Sample size: 34 ESCO respondents

'Provision of turnkey services as an all-in-one package including energy audit, retrofit and financing' was considered by ESCOs as the second top motivation factor of hosts. As highlighted by Lee et al. (2013), a lack of technological knowhow and upfront capital are the major barriers for hosts to implement energy efficiency projects in existing projects. Since an EPC approach provides the host with an all-in-one package including identification of energy saving potential, project implementation, and on-going monitoring of actual performance of ECMs, it is attractive to those hosts who lack the technological knowhow for project implementation.

'Use of energy saving for other purposes may yield better return' was ranked third. The main purpose of implementing EPC projects is not only to replace the existing energy inefficient equipment and systems, but also to achieve long-term energy savings (e.g. not only limited to the contract period). Therefore, when the EPC project is implemented successfully, the host can experience the long-term reduction in operating expenditures for electricity bills. Such cost reductions can be used for other purposes such as an expansion of core businesses.

4.7.3 Risks inherent in EPC projects

Table 4.16 shows the relative importance of risk factors inherent in EPC projects from the ESCOs' perspective. Among fourteen factors, 'Payment default of host after installation' was regarded as the most important risk factor (mean score = 3.88). In order to provide the hosts with incentives for project implementation, some ESCOs would pay the upfront capital for the hosts in EPC projects. Therefore, the regular payment to the ESCO is vital to maintain a positive cash flow. As pointed out by Yik and Lee (2004), it is often difficult to measure energy performance accurately and equitably in practice. As such, the actual energy savings may be disputable, especially in circumstances where the energy baseline and adjustment mechanism are not well established at the pre-retrofit stage. Apart from possible disputes on actual savings, host's bankruptcy and dismissal of a building management body (e.g. Owners' Corporation) are also possible reasons for non-payment.

'Not sure if baseline measurement can be correctly established' was reckoned as the second (mean score = 3.74). This echoes with previous research findings that difficulties were encountered in establishing a reliable energy use baseline in existing buildings (Hilary A. Davies, 2001; Yik and Lee, 2004). In the past decades, a weak awareness for keeping proper record of building operating data was often observed, resulting in incomplete and poor records of building operating data (e.g. low resolution, long interval and missing data) (Piette et al., 2001). In addition, the accuracy of temperature sensors and measurement devices will decrease gradually if there is no regular calibration on those sensor and devices. Therefore, most ESCOs have limited confidence on the validity of the recorded data. Being consistent with the previous finding mentioned in this Chapter, direct measurement is often conducted by the ESCO to mitigate the risk of uncertainties in establishing energy use baseline.

Table 4.16: Mean score and rankings of the relative importance of risk factors relevant to EPC as perceived by ESCOs

ESCO Q18: Please rank the relative importance of risk factors relevant to EPC as perceived by ESCO		ESCO		
		Mean	SD	Rank
1	Not sure if expected performance can be achieved (e.g. due to change in baseline condition such as weather, occupancy, room usage etc.)	3.47	0.961	5
2	Not sure if baseline measurement can be correctly established (e.g. due to incomplete and poor quality of data obtained from energy audit)	***3.74***	***0.864***	***2***
3	Not sure if energy saving determination method is accurate (e.g. system modelling error)	3.41	0.925	6
4	Not sure if measurement after installation is accurate	3.59	0.988	4
5	Not sure if host would change use pattern without informing ESCO	3.45	0.869	7
6	Not sure if host would operate plant as advised during contract period	3.39	0.899	8
7	Not sure if actual maintenance cost is smaller than the expected budget	3.33	0.924	9
8	Not sure if actual M&V cost is smaller than the expected budget	3.24	0.987	10
9	New installed equipment perform poorly due to improper design (e.g. oversizing)	3.00	0.985	13
10	New equipment deteriorate much faster than expected	3.24	1.046	11
11	Payment default of host after installation	***3.88***	***0.740***	***1***
12	Costs of installation increase (e.g. exchange rate, equipment cost, labour cost)	***3.62***	***.954***	***3***
13	Interest rate fluctuation (if the 3rd party finances the project)	3.03	1.045	12
14	Energy price fluctuation	3.00	1.206	14

Numbers in bold indicate the top three rankings;
Sample size: 34 ESCO respondents

'Costs of installation increase' was perceived as the third most important risk with a mean score of 3.62. As EPC projects are often arranged on a lump-sum basis, the ESCO has to fully bear the risks associated with increases in labour costs, equipment costs and material costs. In general, no cost adjustment mechanism is incorporated into EPC contracts for such changes. The ESCO would suffer from an increase in project implementation cost if those costs rise substantially during the installation period.

4.7.4 Practical measures to enhance the use of EPC

Table 4.17 shows the practical measures to enhance the use of EPC. 'Promote successful examples of EPC projects' was considered as the most practical measure to increase the project take-up rates (Mean Score = 4.41). This finding is consistent with other recommendations that more EPC demonstration projects should be presented to the public for validating the concept of EPC (Vine, 2005). EPC projects have several unique features as discussed in Chapter 2. At the beginning of EPC market development, hosts and industry practitioners might not be fully familiar with the whole life cycle of an EPC project, especially in the pre- and post-retrofit stages, when accurate baseline establishment and appropriate methods for baseline adjustment are crucial to the success of EPC projects. With the promotion of successful EPC projects from the government or trade associations, a clear picture of its benefits would be effectively delivered to different parties, including potential customers, ESCOs, and financial institutions, in relation to the possible application of energy efficient technologies through EPC.

'Modification of government procurement practices to facilitate the use of EPC contracts' was perceived as the second most practical measure (mean score = 4.00). Since EPC projects allow flexibilities for the interested ESCOs to propose different retrofitting solutions, it is common that the tender proposals from different ESCOs vary significantly in key evaluation aspects, such as the upfront capital costs, estimated savings, as well as payback periods. However, Marino et al. (2011) pointed out that due to the restrictions on the current public procurement process and internal accounting requirements (e.g. demarcations between capital and recurrent expenditures), the existing tender evaluation scheme in the public procurement process might not be conducive for the evaluation of different ESCOs' retrofitting proposals. To remove this barrier, a number of scholars in many countries recommend the modification of government procurement practices for EPC projects, for example, the use of life cycle cost instead of direct cost comparison for tender evaluation (Vine, 2005; Bertoldi et al., 2006). In the U.S., since EPC-related legislation was enacted, a special procurement procedure for EPC projects was developed to facilitate the use of EPC in Federal buildings. For instance, the procurement procedure for EPC projects would take priority over the current Federal Acquisition Regulation (FAR) procurement requirement if a conflict occurs (DOE, 2015c). This modification on the current procurement procedure opens up the EPC market in the public sector, and a market growth of about 7% per year between 2007 and 2010 was recorded in the U.S. ESCO industry (Larsen et al., 2012).

‘Government backing up a portion of ESCOs’ guarantee to lending banks’ was viewed as the third most practical measure (mean score = 3.97) to enhance the use of EPC. This is consistent with other research findings that the active participation of financial institutions is vital for the development of the EPC market (Vine, 2005; Marino et al., 2011). Due to the hesitation of financial institutions towards EPC project financing, especially in the immature EPC market, a high interest rate is often imposed on private borrowers to minimise the financial risk of lenders, hence discouraging the use of EPC for retrofitting projects. In order to increase the financial institutions' confidence on EPC project financing, some governments help hosts to secure loans from the lending banks. For example, the Singaporean government has worked with several financial institutions to launch the pilot ‘Building Retrofit Energy Efficiency Financing (BREEF) Scheme’, in which both the government and banks share the risk of any loan default on a 50-50 basis. The participating financial institutions provide loans up to S$5 million with low interest rate to those hosts who have insufficient upfront cost for the implementation of energy efficiency project (BCA, 2014). This measure provides an opportunity for the financers to understand the whole framework of EPC projects in practice.

Table 4.17: Mean score and rankings of the practicality of measures to enhance the adoption of EPC in Hong Kong, as perceived by ESCOs

ESCO Q19: Possible measures		ESCO		
		Mean	SD	Rank
1	Promote successful examples of EPC projects	***4.41***	***0.821***	***1***
2	Public sector takes a leading role in adopting EPC	3.70	0.918	10
3	Modification of government procurement practices to facilitate the use of EPC contracts	***4.00***	***0.739***	***2***
4	Government backs up a portion of ESCOs' guarantee to lending banks (as in Singapore)	***3.97***	***1.029***	***3***
5	Promote the value for money of EPC amongst building owners	3.91	0.793	4
6	Standard M & V procedures for major types of energy retrofitting	3.56	0.927	13
7	A suit of standard EPC contracts for use with major types of energy retrofitting	3.71	1.060	8
8	Further strengthen the requirement of Building Energy Code and efficiency standards	3.44	0.991	14
9	A joint fund by gov't, investment banks & oil companies to guarantee majority of financings obtained by ESCOs, with suppliers, equipment leasers, ESCOs and banks bearing rest of payment default risk by owners.	3.85	0.925	5
10	Establishment of awards for ESCOs based on transparent criteria	3.85	0.755	5
11	Accreditation and maintenance of a register of ESCOs (as in Singapore)	3.85	1.048	5
12	Development of new technologies and energy efficient products	3.71	0.906	8
13	Publication of clear guidelines on EPC procedures	3.64	0.822	11
14	Use of a standard consultancy agreement for energy audit	3.45	1.121	15
15	Insurance against energy efficiency shortfall (as in the US)	3.59	3.59	12

Numbers in bold indicate the top three rankings;
Sample size: 34 ESCO respondents

4.8 Chapter summary

This chapter summarises the findings of two questionnaire surveys on the potentiality of energy retrofitting works, the hosts' concerns, the motivation factors, risk perception inherent in EPC projects and the practicality of measures to enhance the use of EPC.

The survey findings indicate that most hosts have the awareness of the need to improve energy efficiency in their buildings, but they tend to carry out minor energy improvement works which often involve less capital and technological know-how. In general, the current take-up rate of EPC in Hong Kong is relatively low. Only few host respondents (less than 10%) have been involved in EPC projects. Regarding energy retrofitting works, it is found that retrofitting works on central air-conditioning and lighting systems are the most common ECMs which are implemented under EPC in Hong Kong.

In addition, it is observed that ‘long payback period’ and ‘worry about its complexities’ are the top two concerns of hosts in implementing EPC projects. The survey results also indicate that ‘payment default of host after installation’, ‘not sure if baseline measurement can be correctly established’, and ‘costs of installation increase’ are the top three key risk factors in EPC projects.

To enhance the wider adoption of EPC in Hong Kong, the respondents indicate that ‘promoting successful examples of EPC projects’, ‘modification of government procurement practices to facilitate the use of EPC contracts’, and ‘government backing up a portion of ESCOs’ guarantee to lending banks’ are the top three practical measures for better market development. The next chapter will present the findings of the semi-structured interviews, which will be triangulated with the results of the questionnaire surveys.

CHAPTER 5: DISCUSSION OF INTERVIEW FINDINGS

5.1	**Introduction**
5.2	**Selection and profile of the respondents**
5.3	**Discussion of interview findings**
5.4	**Chapter summary**

Chapter 5 – Discussion of Interview Findings

5.1 Introduction

The previous chapter depicts the results of two questionnaire surveys providing data on the key aspects of current EPC market development in Hong Kong. In order to investigate the issues arising from the analysis of the preceding questionnaire surveys, twenty-six semi-structured interviews were conducted. The interviewees comprises key stakeholders in the field of EPC market, including building owners, ESCOs' key personnel, association representatives and financers in the both public and private sectors in Hong Kong. This chapter presents the findings of those interviews, which will be triangulated with the results of the questionnaire surveys and the reported literature for informing the Model.

5.2 Selection and profile of the respondents

Twenty-six semi-structured interviews were carried out with key representatives from the public and private sectors in Hong Kong. The interview questions were derived from the literature review, focusing on the existing local EPC market, potential of energy retrofitting works, risk perception, project financing, procurement, measurement and verification (M&V), contract documents, etc. Prior to the launch of interviews, ethical clearance was granted by the university. When the interviewees accepted the invitations for interview, the interview questions were sent to them in advance. During the interviews, the interviewees were asked a common set of questions. Table 5.1 shows the profile of the interviewees, which comprises building owners, ESCOs' key personnel, association representatives and financers in both the public and private sectors in Hong Kong. The interviewees also represent 'organisational experts' or 'key informants' working at senior and responsible positions in the EPC market. All interviews were conducted between November of 2013 and March of 2015 with an average duration of 1 hour each. To ensure the validity of interview results, all interview transcripts were sent to the interviewees for confirmation. Since some interview contents may involve sensitive issues, the project details and interviewees were made anonymous in the study. The detailed questions for the interviews are presented in Appendix D.

Table 5.1: Profile of Interviewees

ID	Sector	Position of Interviewee	Nature of organization
1	Public	Manager	A building owner (University X)
2	Public	Associate Director	A building owner (University Y)
3	Public	Senior Manager	A building owner (Hospital A)
4	Public	General Manager	A building owner (Hospital B)
5	Public	Senior Engineer	Electrical and Mechanical Services Department
6	Public	Retired Chief Engineer	Electrical and Mechanical Services Department
7	Public	Senior Manager	Hospital Authority
8	Public	Senior Consultant	A trade council
9	Private	General Manager	A building owner #1
10	Private	Technical Services Manager	A building owner #2
11	Private	Group Engineering Manager	A building owner #3
12	Private	Senior Manager	A building owner #4
13	Private	Chairman of Owners' Corporation	A building owner #5
14	Private	Managing Director	A consultant
15	Private	General Manager	An ESCO #1
16	Private	Senior Manager	An ESCO #2
17	Private	Director	An ESCO #3
18	Private	Project Manager	An ESCO #4
19	Private	Manager	An ESCO #5
20	Private	Sale Directors	An ESCO #6
21	Private	Account Manager	An ESCO #7
22	Private	Director	An ESCO #8
23	Private	Manager	A bank
24	Private	Estate Manager	A Facility Management company
25	Association	Chairman	An association of energy services companies
26	NGO	Property Director	A building owner (NGO)

5.3 Discussion of interview findings

5.3.1 Current development of EPC market in Hong Kong

Most interviewees expressed that the take-up rate of EPC is still relatively low in Hong Kong despite over a decade of market development. Apart from the common barriers which have been discussed in Chapter 2: Literature Review (e.g. procurement, M&V and legal issues), another reason for the low take-up rate is the lack of a clear market direction. For the buildings under single ownership, those owners are often major developers in Hong Kong or institutional bodies which have strong financial standing and competent engineering teams. Therefore, the provision of upfront capital and technological know-how by ESCOs is not their prime consideration for project implementation. For the buildings under leases to tenants, those building owners are only responsible for utility bills in the common areas. The utility bills of leased parts of the buildings are shared by different tenants, resulting in little incentive to implement EPC projects. For the medium-sized buildings with multi-ownership, it is difficult for ESCOs to reach agreement with Owners' Corporations. For small-sized buildings with single or multi-ownership, due to the perception of a higher chance of payment default, ESCOs are hesitant to pay upfront capital for those owners.

In the public sector, several pilot EPC projects were implemented in public buildings, including hospitals, police stations and a game hall (EMSD, 2015e). However, in recent years the HKSAR Government has not actively promoted the use of EPC as a means for energy retrofitting in public buildings. Some interviewees explained the low take-up rate of EPC projects in the public sector. First, the HKSAR Government has a large fiscal surplus and reserves in recent years (FSO, 2015). When energy saving potentials are clearly identified and the proposed projects are financially justifiable in the public buildings, there is no difficulty to allocate resources to undertake such retrofitting projects. Second, accounting constraints on capital and recurrent expenditure are present. In typical EPC projects, the amount of payment is based on a sharing of actual energy savings, and this will violate established accounting rules when the operating expenditures rise above previous years' records. It was noted that the government had considered making necessary amendments on the accounting system for EPC projects in the past, but much efforts and times would be required, and the issue was not pursued by public departments which had secured sufficient budgets to carry out retrofitting using traditional capital funds.

The interviewees from non-governmental organisations (NGO) indicated that EPC is one of the alternatives to improve building energy efficiency, especially for those hosts who lack upfront capital, because some NGOs may have difficulties in allocating resources to implement such projects. Even for some NGOs who are strong in securing funding, there may be some constraints regarding the use of funding from different sources on energy improvement projects, resulting in making projects infeasible. Therefore, EPC is a way-out to solve this financial problem. However, the interviewees also mentioned that the take-up rate of EPC is rather low in NGOs due to recent launch of the Environment and Conservation Fund (ECF) by the HKSAR Government, from which subsidies are provided to NGOs for implementing energy improvement works (ECF, 2015). It is expected that NGOs will consider EPC more actively when the funding ceases.

In addition, the interviewees summarised the circumstances where EPC projects are more feasible to be implemented in Hong Kong: (1) Buildings with single or a few owners (with this condition, it is easier for the host to have consensus on the agreement of key issues, including type of retrofitting, contract sum, way of project financing and guarantee period.); (2) Hosts with strong engineering teams and legal practitioners (this would shorten project negotiation period on the critical issues, involving contract management, baseline development and adjustment mechanism); (3) Lack of upfront capital (this does not necessarily mean that the hosts have no upfront capital, since some owners prefer to borrow money from banks, especially for this low-interest rate environment, and put their investment in other aspects to yield more return); (4) Stable building operation patterns (this minimises the chances of dispute on baseline adjustment, and a single owned-office building is an example of having stable building operation patterns); (5) Higher expectation on energy savings (those hosts aim for achieving savings more than the industry norm).

Some ESCO interviewees highlighted that as the new Building Energy Efficiency Ordinance (BEEO) has been put in place (EMSD, 2015d), all commercial buildings have to conduct an energy audit according to the government schedule. It is believed that more buildings with existing equipment and system failing to meet the BEEO requirement will be identified when they complete the statutory energy audits. In light of this view, EPC projects will be considered as an effective tool to fulfil the statutory requirement in the near future.

5.3.2 Potentiality of energy retrofitting works in existing buildings

There was a general consensus among the interviewees that central air-conditioning (AC) improvement and lighting upgrading are the most common ECMs in Hong Kong. Since the central AC system accounts for almost half of the total energy consumption in office buildings in Hong Kong (EMSD, 2015b), a significant amount of energy savings can be achieved when implementing energy improvement projects on AC systems. The interviewees expressed about the common ECMs on AC systems, including chiller replacement/optimisation, installation of variable-speed drives for air-handling units and water pumps, as well as system re-commissioning. The amount of energy savings on the above retrofitting can vary from 5% to 35%, depending on the use and type of buildings, geographic locations, operational schedules, etc. In addition, due to relaxation of the use of fresh water as a cooling medium in central AC systems by the Hong Kong SAR Government since 2008, replacing air-cooled chillers with water-cooled chillers provide huge opportunities for energy savings in Hong Kong (EMSD, 2008). However, some interviewees highlighted the drawback of using water-cooled chillers since the potential spread of Legionnaires' disease can be a serious concern to certain premises such as hospitals. Special attention should be paid to the selection of locations for installation of water-cooled chillers and the control of Legionnaires' disease level in the circulation of condensing water in those premises.

In addition, a consultant interviewee indicated that using oil-free chillers is considered as one of the possible retrofitting technologies when the installation of cooling towers is unfeasible due to space constraint on the roof or prevention of Legionnaires' disease spread. However, unlike the air-cooled/water-cooled chillers, the maximum COP of oil-free chillers will be reached only at nearly 50% of full load, instead of 90% as in other types of chiller. Therefore, more oil-free chillers should be installed when the cooling demand is large. Apart from that, the implementation cost is also a concern since the cost of oil-free chillers is almost double that of water-cooled chillers.

The ESCO interviewees mentioned that another common ECM is the replacement of incandescent lamps/T8 fluorescent lamps (FL) with more energy efficient T5 FL in existing buildings in Hong Kong. This is because the project cost for such type of replacement work is relatively low compared to other ECMs, and the payback period is often short (e.g. less than two years) (Mahlia et al., 2011). This finding also echoes with the results of the questionnaire surveys that, from the perspectives of both the ESCOs and hosts, lighting replacement to more energy efficient lamps is the top ECM (1st position in ESCOs' responses and 2nd position in hosts' responses) to be implemented in Hong Kong.

An ESCO interviewee pointed out that although using LED lamps can achieve substantial energy savings due to the their high luminous efficacy, their applications are still limited to the indicating lights and exit signs in buildings nowadays. A number of studies show that the LED lamps would become more popular for application when the lamp efficacy, lifetime and colour rendering significantly improve along with cost reduction (DOE, 2012b, a; Aman et al., 2013).

The interviewees also commented on other possible energy retrofitting works, including lift upgrading, using heat pumps, as well as building fabric improvement. In general, these retrofitting works have their own limitations for project implementation under an EPC package in Hong Kong. For example, the replacement of diesel boilers with heat pumps can yield significant amounts of energy savings. However, this retrofitting is not so popular in Hong Kong, because some operators question about its reliability and durability due to the round-the-year operation in premises such as hospitals. The interviewees also highlighted the capacity constraint of electrical systems to such applications in Hong Kong. For example, the current transformers and switchboards may be unable to cater for the additional loads of newly installed heat pumps in most existing buildings. The extra cost for the expansion of existing capacity of electrical systems often causes the replacement project financially infeasible. In addition, the competitive rebate schemes offered by utility companies (e.g. Towngas) provide incentives to use the existing diesel boilers for heating. Another disadvantage of using heat pumps is that the output temperature of heat pump systems is only around 65 °C, which is much lower than that of conventional boilers (e.g. over 95°C). For laundry purpose, 65°Coutput temperature is not sufficient to kill bacteria on clothes.

For lifts, the energy use of lift systems accounts for relatively a small portion of total building energy use. The amount of energy savings may not be attractive to both hosts and ESCOs to undertake retrofitting projects. Despite the new enactment of Cap 618 Lifts and Escalators Ordinance which enhances the level of competition amongst contractors in repair and maintenance works (EMSD, 2015a), the technology of lift systems and control are still highly specialised(when it comes to the replacement of spare parts, which by law must be sold to others, but this stipulation is not effective due to the specialised knowledge involved in installation). Therefore, it is unlikely to see that lift suppliers repair lift systems of other brands. Besides, the lift operation pattern is highly variable, resulting in difficulties in the development of energy use baseline. In terms of energy saving potential and baseline development, it is unlikely to retrofit lift systems under an EPC package.

In Hong Kong, façade retrofitting such as the improvement of Overall Thermal Transfer Value (OTTV) of a building envelop, is considered as one of the possible ECMs under an EPC package. However, E&M and building works are two different types of work, and it is difficult to find a contractor/ ESCO who has the capability of doing both E&M and building works.

5.3.3 Model of EPC project

In general, guaranteed savings and shared savings are the two most common models in EPC projects. As shown in the results of the ESCO questionnaire survey (Table 4.14), both models are almost equally used in EPC projects in Hong Kong (38.5% for the guaranteed model; 46.2% for the shared model), reflecting that both models may be used. The ESCO interviewees were asked about the selection criteria of EPC models in Hong Kong. For those hosts who adopted the shared saving model, they think that they can immediately enjoy the benefit of energy cost reduction as the savings will be shared by both parties in each M&V period. However, the drawback is that since ESCOs are responsible to pay upfront capital, the retrofitting measures are often conservative, for example, lighting upgrading (replacement of T8 with T5). For the guaranteed saving model, hosts often expect higher level of guaranteed savings as the hosts absorb the financial risk. In addition, the ESCO interviewees indicated that some hosts prefer to adopt the guaranteed saving model because fewer disputes are expected during the contract period. It would be easier for ESCOs to prove that the actual savings are more than the guaranteed level in each M&V period. However, when the contract is arranged under the shared saving model, the actual savings should be determined accurately, and it is more likely for both parties to argue about the actual savings in every detail.

In Hong Kong, in order to attract more clients for project implementation, some ESCO interviewees expressed that they are willing to bear both financial and performance risks when the clients have high credibility in repayment. This type of EPC projects mostly involves a high level of upfront capital and weather-dependent retrofits such as chiller replacement. Apart from energy cost savings, the ESCO interviewees highlighted the importance of inclusion of other type of cost savings such as maintenance cost savings because retrofitting projects often lead to a reduction in such costs (after retrofitting, the ESCO is responsible to repair the equipment when a break down occurs).

For the retrofitting on central AC systems in Singapore, it is common for ESCOs to guarantee on plant efficiency instead of actual energy savings because the time and cost for M&V work can be much shorter and cheaper. When the ESCO interviewees were asked the possibility of adopting this sort of guarantee, they expressed several concerns on this arrangement. First, compared to the situation in Hong Kong, the cooling load profile in Singapore is relatively steady. The chillers can be operating at the peak load throughout a year. When this type of guarantee is applied in the Hong Kong setting, a modification, such as different guarantees on plant efficiencies in respect of different seasons, should be made. Second, difficulties in convincing the host's top management of its benefits would be expected since the guarantee on plant efficiency cannot be directly linked to the amount of cost savings to non-technical people.

5.3.4 Project financing

Most interviewees expressed that the engagement of financial institutions for project financing is very uncommon in Hong Kong's retrofitting market, although some local banks have introduced different types of green financing scheme for energy efficiency projects (HSBC, 2015; SCB, 2015). From the perspective of financers, the amount of savings guaranteed by the ESCO and the feasibility of energy saving technology are not the main considerations for financial institutions to decide the approval of project financing. Instead, banks mainly consider the lender's repayment ability, resale values of asset offered as security and interest earning potential, which should be sizeable enough compared with other lending transactions. In EPC projects, the installed equipment and systems have little resale value to the financiers. As such, the interest rates for EPC projects are generally high, discouraging both ESCOs and hosts to implement EPC projects.

Some interviewees mentioned that Owners' Corporations are the parties who often require financing for project implementation. However, Owners' Corporations have no real asset in their possession, resulting in difficulties of project financing from banks. Even though the ESCO guarantees the host for a certain level of energy savings and compensates the losses in case of saving shortfalls, the banks' attitude towards such financing will not be changed easily as the saving guarantee promised by an ESCO is not considered as collateral or security in Hong Kong. One financier was also concerned about the personal liabilities of members of the Owners' Corporation in case the procedures for awarding EPC contracts violate the Building Management Ordinance (BMO) in the situation of multiple ownerships.

The university interviewees expressed that in the semi-public sector, for example, tertiary institutions, they often have difficulties in securing sufficient funding from the government for improving building energy efficiency. Therefore, they are the parties who are interested in using EPC for project implementation. Besides, the interviewees mentioned that lower interest rates are often provided from financing institutions to this sector due to their high credibility in repayment.

5.3.5 Procurement

ESCO interviewees reckoned that in comparison to conventional or 'design-bid-build' projects, EPC projects focus more on the life-cycle cost instead of upfront investment cost. As such, the hosts may not simply evaluate tenders based on the direct capital cost comparisons in practice. This is also one reason hindering the use of EPC in the public sector in Hong Kong. Interviewees explained that the HKSAR Government adopts 'the lowest bid win' procurement method, and the life cycle cost approach is not seriously considered in the government projects. Although the government would consider the additional merits for innovative proposals, this is not yet the key criterion for tender evaluation.

In addition, unlike other conventional projects (for which the scope of work can be clearly specified at the beginning of tendering process), EPC projects emphasise more on the ESCOs' technology input. Therefore, the interested ESCOs may propose various ECMs with different guaranteed levels in the tendering stage, resulting in difficulties in assessing the best retrofit solution to the host.

Another difficulty in the procurement of EPC projects is due to an insufficient number of interested ESCOs for project bidding in Hong Kong. Some interviewees indicated that according to the 'Code of Practice on Procurement of Supplies, Goods & Services' (HAD, 2015b), five tenders are required to be invited by Owners' Corporations in the case of a contract value exceeding $20,000. Even in the private sector, a similar requirement is found. For example, in order to maintain ISO 9000 certification, the internal procurement officers are required to fulfil their in-house tendering protocol, such as a minimum number of tenders and "the lowest bid wins" criterion in their quality manuals. Hence, insufficient ESCO participation is one of the main reasons for hosts not to consider EPC as a means for building retrofitting.

It is known that EPC projects involve two stages of contract, namely energy audit contract and EPC main contract. ESCO interviewees pointed out that some hosts refuse to enter into an EPC contract after the detailed energy audit, but call for open tenders based on the retrofitting proposal by the ESCO, instead of engaging the previous ESCO to implement EPC projects. Some hosts believe that the contract price can be lower if the same design is given to other contractors to bid. However, such practices largely discourage ESCOs, especially for those with strong technical background, to provide comprehensive EPC proposals and carry out EPC projects in future. This is also one reason leading to the low take-up rate of EPC in Hong Kong.

5.3.6 Ownership of equipment

As discussed in the previous chapter, a majority of the respondents (75%) indicate that the ownership of equipment is vested in the host, instead of the ESCO, even when the upfront cost for project implementation is fully paid by the ESCO. Most interviewees pointed out that hosts are rather conservative towards the use of EPC for energy efficiency projects in the immature EPC market. In order to attract more potential customers, ESCOs with a strong financial capability would offer to the host the sole ownership of equipment. The ESCO interviewees also mentioned that even though the ESCO may retain equipment ownership, the risk of non-payment would not be considerably reduced because the resale value is rather limited when the equipment is uninstalled from the host's building, let alone the difficulty in gaining access when relationships turn sour. Instead, the ESCO would prefer to protect its own interest by inserting a contract clause to the effect that the ESCO would have to compensate for the remaining value of equipment in the event of contract termination. The selection of well-established customers, for example, those with strong cash flow, is another way to mitigate the risk of non-payment by clients.

5.3.7 Operation and maintenance

The ESCO interviewees mentioned the importance of proper system operation and maintenance (O&M) in achieving energy savings. This is because apart from the efficiency of equipment itself, the actual energy savings are highly dependent on how the O&M staff operates and maintains the system to minimise building energy use.From the ESCOs' persecptive, it will be ideal when ESCOs are fully responsible for O&M in the retrofitted buildings. However, in practice, most ESCO respondents (76.5%) are only responsible for maintenance, and the system operation is managed by either the host or FM company (refer to Chapter 4 – Table 4.14). Some interviewees explained that many hosts prefer to retain the control of system operation to ensure a good balance of occupant comfort and energy savings. They may also have their in-house staff looking after the premises' other aspects of operation, whom they have to retain anyway. In such cases when the host is reponsible for system opeartion instead of ESCOs, it is common to sitpulate the host's obligiation of system opeartion. When saving shortfalls are due to non-compliance of agreed operational procedures, the ESCO may not be liable to the host for compensation of such a shortfall.

Some owner interviewees were also concerned about the restriction on maintenance services when the energy efficiency projects are implemented under an EPC package. In practice, the maintenance obligation is often in line with the guarantee period offered by ESCOs. When the retrofit involves ECMs with a high capital cost, for example, chiller replacement, the contract period will at least last for 4 years. As such, this contractual approach limits the flexibility of using other maintenance service companies in the future.

The hospital interviewees indicated that special attention should be paid to certain premises (e.g. hospitals) regarding O&M. Compared to other types of buildings, the change of system operation and control (e.g. temperature reset, chiller optimisation, etc.) to reduce energy use is less feasible to be implemented in hospitals, because such changes may involve life and death issues, instead of only thermal comfort and indoor air quality.

5.3.8 Measurement and Verification

Although several M&V guidelines have been developed around the world (e.g. IPMVP, ASHARE Guideline 14, and M&V for Federal Energy Projects), most interviewees expressed that these guidelines only provide a conceptual approach to carry out M&V works. It may be difficult for those hosts who have no strong engineering background or support to understand the concept, e.g. on how the significance of each parameter (e.g. weather, occupancy level, etc.) influences the annual energy consumption. In addition, the interviewees mentioned that the baseline adjustment mechanism is usually proposed by the ESCOs. As such, mistrust often exists between the host and the ESCO on the M&V results.

Several scholars indicated that the development of accurate energy use baseline is important to the successful delivery of EPC projects (Marino et al., 2011). ASHRAE Guideline 14 (ASHRAE, 2002) lists the general requirements to develop suitable energy use baseline, including the duration of baseline measurement period, completeness, quality and resolution of operating data. However, the interviewees remarked that a lack or poor quality of operating data is commonly observed for baseline development for existing buildings in Hong Kong (e.g. more than 10-yearold commercial buildings). This is because the reliability of building management system (BMS) is relatively low in those buildings. This observation can be triangulated with the results of questionnaire survey in Chapter 4. Table 4.14 indicated that most respondents (86.9%) use short/long-term measurement and/or electricity bills as the primary way for baseline development. Therefore, the ESCO interviewees highlighted that more meters/ sub-meters should be installed as needed to capture sufficient operating data prior to project implementation.

In additions, some ESCO interviewees suggested to introduce remote monitoring systems to solve part of the M&V problems. These systems not only record energy savings simultaneously for ECMs, but also monitor and detect any abnormal use patterns in buildings. Moreover, the operating data recorded by a remote monitoring system will be stored in the both party’s sever. This ensures that no party can amend the operating data singly. However, the penetration rate is still low due to high costs and issues of data sensitivity.

Appointment of a M&V third party to resolve disputes between both contracting parties on the M&V results is the most common approach in a number of countries such as the U.S.. It was noted that in one EPC project in Hong Kong, the host employed a consultant as M&V verifier to check the M&V reports submitted by the ESCO. However, some interviewees commented that the ideal third party should come from the academia, instead of E&M consultants, to enhance the level of independence and fairness.

5.3.9 EPC contract documents

As discussed in Chapter 4, most respondents (73.4%) tend to use an in-house written EPC contractor a modified E&M contract, instead of adapting an overseas standard form of EPC contract, despite several standard forms of EPC contracts being available in several countries (e.g. Standard Energy Performance Contract in Australia, BOMA Energy Services Performance Contract in the U.S.). The ESCO interviewees explained that most hosts are unfamiliar with the contract terms in those overseas standard documents, hence raising a question of fairness in risk allocation in those contracts. The interviewees also mentioned that most of the in-house written EPC contracts are rather simple. Several key issues such as significant changes in building operation during the contract period and termination of contract might not be fully addressed. With previous work experience in EPC projects, the ESCO interviewees expressed that contract terms should be expressed as simple as possible such that all parties (including in-house accounting personnel of owners) understand the whole contract.

5.3.10 Evaluation method of financial feasibility in EPC projects

Regarding the evaluation method of financial feasibility in EPC projects, most interviewees mentioned that the payback analysis is the most common method due to its straightforward principle. ESCO interviewees also explained that they can limit performance risks by selecting a project with a short payback period. However, one of the disadvantages of the payback analysis is that this would eliminate certain profitable EPC projects with long payback period, for example, the replacement of oil-free chillers. This is more obvious when the hosts are very conservative in the adoption of unconventional or advance technology.

In addition, the ESCO interviewees reckoned that a dilemma is often encountered in determining the amount of guaranteed energy savings. On one hand, ESCOs try to mitigate performance risks by being conservative on the guaranteed savings, but on the other hand, they would like to increase the chances of winning bids by offering higher saving guarantees and shorter contract periods.

5.3.11 ESCO accreditation

In order to enhance the professionalism and quality of services of the ESCO industry, 'ESCO Accreditation Scheme' has been introduced in some countries such as Singapore (E2PO, 2015b). The results of the ESCO questionnaire survey (Table 4.17) indicate that 'ESCO Accreditation Scheme' was ranked at the top-fifth among twelve possible measures to enhance the wider use of EPC in Hong Kong. However, one interviewee raised the concerns about the introduction of this scheme in Hong Kong. He opined that the current EPC market in Hong Kong was not mature enough to consider an ESCO accreditation scheme due to the relatively low market volume and limited numbers of ESCOs. In addition, some interviewees remarked that government intervention may not be the best way to establish an ESCO accreditation scheme, because the government is not often in the best position to understand the market needs and wishes to establish such a scheme. It would be better if the industry practitioners can develop their own standards and practices to regulate the industry by market force, instead of government intervention.

5.4 Chapter summary

This chapter reports the findings of twenty-six semi-structured interviews. It is found that apart from those common barriers which have been discussed by the previous researchers (e.g. procurement, M&V and legal issues), the absence of a clear market direction is also a reason attributing to the low take-up rate of EPC in Hong Kong. Based on their work experience in EPC projects, it can be summarised from the interviewees that the circumstances under which EPC projects would be more feasible to be implemented in Hong Kong: (1) Buildings with single or a few owners; (2) Hosts with strong engineering teams and legal backup; (3) Hosts lacking upfront capital; (4) Stable building operation patterns; and (5) A high expectation on energy savings.

Regarding the types of retrofitting, the interviewees indicate that central air-conditioning (AC) improvement and lighting upgrading are the most common ECMs in Hong Kong. This is because the improvement on central AC systems can achieve a significant amount of energy savings, whilst lighting upgrading requires relatively low upfront capital and its payback period is short. It is observed that some ESCOs in Hong Kong are willing to bear both financial and performance risks when the host has a high credibility in repayment. In the Hong Kong market, the engagement of financial institutions for EPC project financing is very uncommon due to high interest rates being charged to both ESCOs and hosts.

It is worth noting that most EPC contracts being used in Hong Kong are the in-house written EPC contracts, instead of adapting overseas standard forms of EPC contract, as would be the case for new construction. The interviewees explain that most hosts are unfamiliar with the contract terms in those overseas standard documents, raising a question of fairness in risk allocation in those contracts. In addition, the ESCO interviewees indicate the difficulties in determining the amount of guaranteed energy savings in the tendering stage. The current method used for such determination is mainly based on payback analysis and previous work experience.

The findings of the interviews would provide insights for the stakeholders of EPC projects, including hosts, ESCOs, lawyers and financiers, to understand the current development of EPC market in Hong Kong. Moreover, the findings of the interviews and questionnaire surveys also echo with the objectives of this study to fill identified research gaps: (1) to develop suitable risk assessment approaches taking into account the probabilities of saving shortfalls based on different technical solutions of common energy retrofitting; (2) to develop a set of EPC contract document templates targeted at uncomplicated ECM work. To fill the first research gap, Chapter 6 will present a risk assessment approach for evaluating the probability of energy saving shortfalls taking into account the variations in the parameters affecting energy savings. Chapter 7 and 8 will attempt to fill the second research gap.

CHAPTER 6: RISK ASSESSMENT OF ENERGY SAVING SHORTFALLS IN EPC PROJECTS

Chapter 6 – Risk Assessment of Energy Saving Shortfalls in EPC Projects

6.1 Introduction

As discussed in the earlier chapters, there is a need for developing a risk assessment approach in EPC projects. As such, this chapter presents a specific risk assessment approach for evaluating the probability of energy saving shortfalls, taking into account variations in the influential parameters affecting energy savings. The approach involves the use of a detailed building energy simulation program (e.g. *EnergyPlus*), correlation analysis and Monte Carlo simulation techniques. Three case studies with different retrofitting measures, including chiller replacement and lighting upgrading, are used to demonstrate the application of this probabilistic approach. This proposed approach enables the ESCO and host to identify the influential factors affecting energy savings, and evaluate a range of possible energy savings at a known confidence level.

6.2 Need for a probabilistic risk assessment approach in EPC projects

As mentioned in Chapter 5, the ESCO interviewees reckoned that a dilemma is often encountered from the ESCOs' perspective in estimating the guarantee level of energy savings. On one hand, ESCOs try to mitigate performance risks by being conservative on the guaranteed level of energy saving, but on the other hand, to increase their chances of winning bids by offering higher saving guarantees and shorter contract periods within which the guarantees are to be fulfilled. Investigations on the current methods used for estimating expected energy savings in Hong Kong were conducted through the ESCO questionnaire survey (refer to Chapter 5). It was found that 45.5% of the ESCO respondents use regression analysis for estimating energy savings, whilst 36.4% of the ESCO respondents adopt the simplified engineering method (e.g. Energy consumption = Power x Operating Hours). The key weakness of both estimation methods is the lack of explanatory power when baseline conditions such as weather, economic circumstances and occupants' use behaviour change dramatically during the contract period, imposing a risk of saving shortfalls in EPC projects.

Although several attempts have been made to develop risk assessment methods which take into account the variations in the post-retrofit conditions (Chapter 2 summarised those attempts), there are still drawbacks in the existing methods such as over-simplified assumptions, insufficient real project data to develop a reliable actuarial database, as well as uncertainties arising from system degradation and climatic variations (Jackson, 2010). Therefore, there is a need for developing a simulation-based approach which takes into account the influence of yearly variations in the parameters affecting energy savings, and eventually the method enables the ESCO and host to recognise a range of possible energy savings at a known confidence level when certain ECMs are implemented.

In this chapter, three case studies with different retrofitting measures, including chiller replacement and lighting upgrading, are used to demonstrate the application of this probabilistic method. Case Study I involves an owner-occupied office building in which the existing air-cooled chillers were replaced with the water-cooled chillers. The selection of this case study is based on the amount of achievable energy savings for this single ECM work and high upfront capital involved for implementation. Case Study II is related to a replacement project of heat rejection system in the central chiller plant in a composite building, which consists of three towers with office and serviced apartment (SA) premises. The incentives for this kind of ECM, where the existing seawater cooling is replaced with a fresh-water evaporative cooling tower system, are mainly due to the HKSAR Government policy on the relaxation of the use of fresh water as a cooling medium in central AC systems, as well as the poor quality of seawater corroding condenser tubes (this resulted in a low coefficient of performance (COP) of chiller plants and high maintenance cost). The findings of the questionnaire survey and interviews (Chapter 4 & 5) indicate that lighting upgrading is one of the most common ECMs in Hong Kong due to low project cost and a short payback period. Therefore, Case Study III involves a hypothetical 40-storey office building where the common lighting retrofitting measures are assumed to be implemented including replacement of existing lighting with T5 fluorescent tubes, installation of occupancy-based controls and daylight-linked lighting controls. The details of each case study and the procedures for the proposed risk assessment approach will be presented in the following section.

6.3 Procedures and method for estimating energy savings using a probabilistic approach

Figure 6.1 shows the procedures and method used for estimating energy savings with a known confidence level. The whole procedure consists of five main steps. It is acknowledged that the details of the proposed method and results were adapted from three published/prepared papers with the candidate as the first author, as shown in the footnotes below[3,4,5].

I. Development of pre- and post-retrofit models[6]: In order to predict energy consumption of the building at different retrofit stages, two models, namely a pre- and a post-retrofit model, should be developed. The pre-retrofit model is developed

[3] Published in Lee, P., Lam, P.T.I., Yik, F.W.H., and Chan, E.H.W. (2013) Probabilistic risk assessment of the energy saving shortfall in energy performance contracting projects-A case study. *Energy and Buildings*. 66, 353-363.

[4] Lee, P., Lam, P.T.I., and Lee, W.L. (2015) An Evaluation of the Performance Risks of Lighting Retrofit in Energy Performance Contracting (EPC) Projects. *Energy and Buildings,* Under Review

[5] Lee, P., Lam, P.T.I., Lee, W.L. and Chan, E.H.W. (2015) A probabilistic approach for estimating energy savings in Energy Performance Contracting Projects – A case study of air-cooled chiller replacement with water-cooled chillers. (Preparation for submission)

[6] 'Predicted energy use' is used to describe energy use which is simulated by the detailed building energy simulation (e.g. *EnergyPlus*), whilst 'actual energy use' is used to describe the level of energy use which is collected from actual energy data, for example, electricity bills.

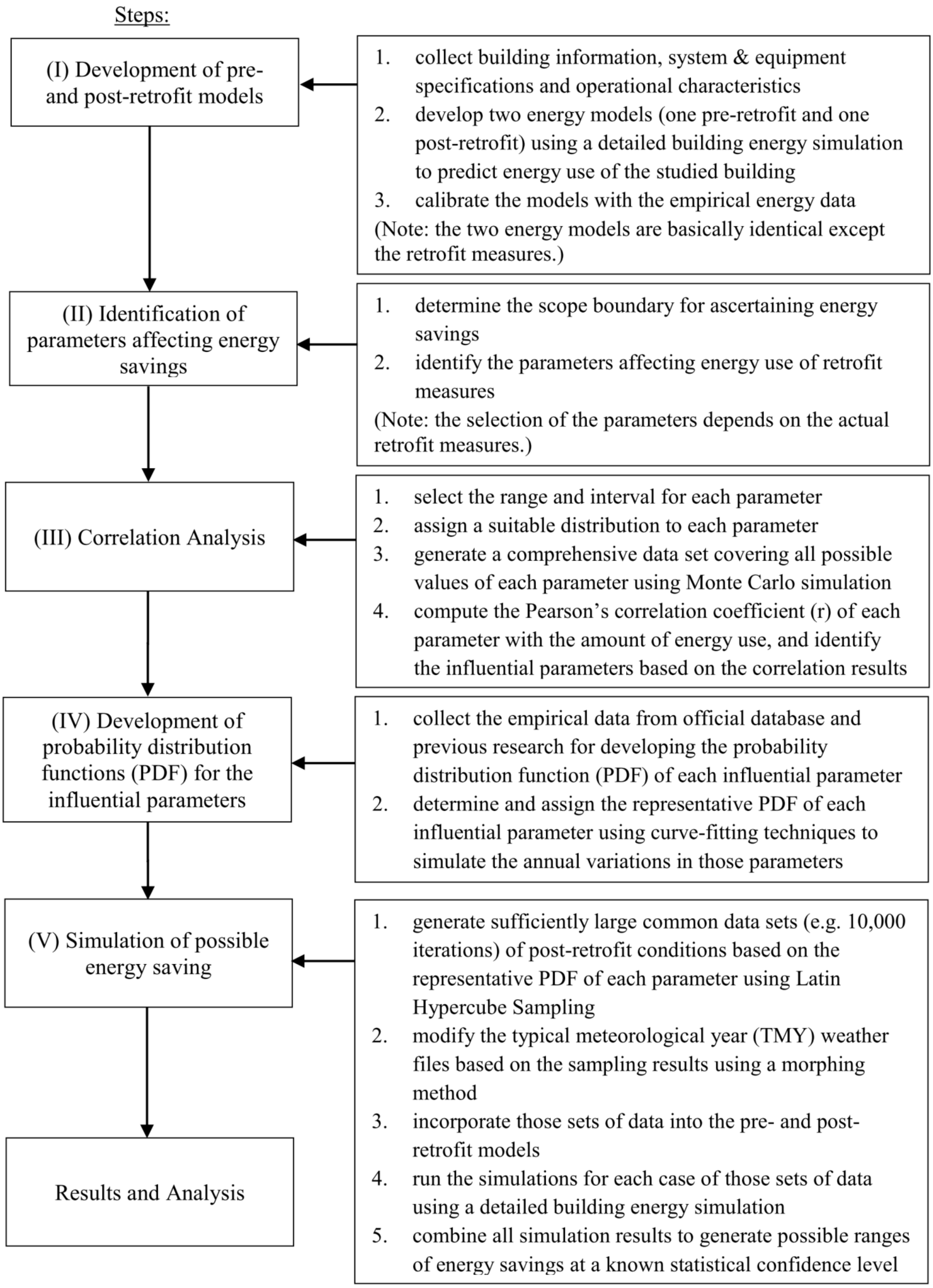

Figure 6.1: Procedures and method for estimating energy savings using a probabilistic approach

using a detailed building energy simulation program (e.g. *EnergyPlus*) which allows the user to input all essential information and data, including building information, system and equipment specifications, operational characteristics as well as the measured energy use data. These information and data can be obtained from a detailed energy audit. Based on the pre-retrofit model, the post-retrofit model is also developed similarly but except the retrofitted systems and the conditions with significant changes from the baseline (e.g. change of system operation). The information of the proposed retrofitted systems (e.g. new water-cooled chillers) can be obtained from the manufacturer. To ensure that the models truly predict the actual energy consumption of the building, the models should be calibrated with the measured energy use data. The calibration results should fulfil the requirements of ASHRAE Guideline 14 such as the coefficient of variation of the root mean squared error 'CV(RMSE)' and normalised mean bias error (NMBE) (ASHRAE, 2002). The calibration procedures may refer to other publications and guidelines (Manfren et al., 2013). By inputting the same set of data of the post-retrofit conditions into the two models, the actual energy savings taking into account the variations from the baseline conditions can be ascertained.

II. **Identification of parameters affecting energy savings:** Various parameters would change accordingly during the contract period, and these variations often lead to uncertainties in the achievable energy savings. Therefore, it is important to identify those parameters affecting energy savings for the respective ECM. The identification of those parameters can be based on the literature and previous project experience. For example, for chiller replacement projects, the parameters affecting energy savings can be categorised into three aspects, namely 'building load', 'system control and operation', as well as 'chiller plant' (Lam and Hui, 1996; Lam et al., 2008). It is worth noting that some parameters may be excluded for analysis after consideration of the nature of EPC projects. For example, building height, directional orientation and materials used in building façades are very unlikely to change during the post-retrofit period.

III. **Correlation analysis:** In order to eliminate the parameters which are less influential to energy savings, correlation analysis is carried out to evaluate the degree of standardised covariance between energy use and those parameters identified in Step II. Prior to the correlation analysis, a sufficiently large dataset which covers all possible values of those parameters with predicted energy use should be assembled. First, each parameter is assigned a suitable uniform distribution with a possible range of its values which can reflect designs similar to the studied building. Second, Monte Carlo simulation is adopted to generate such a dataset. Monte Carlo simulation is a mathematical method where sample values are randomly generated based on the assumed distributions. With the sufficiently large number of iterations (e.g. 10,000 iterations), all possible values for each identified parameter will be generated. Third, the dataset is incorporated into a detailed building energy simulation program (e.g. *EnergyPlus*) for estimating the energy consumption of the building. When the identified parameters involve climatic variables such as dry bulb temperature and solar radiation, the new typical meteorological year (TMY) weather files taking into account the possible variations in climatic conditions should be generated. The algorithm of weather adjustment for the existing weather file can be achieved using a "morphing method", which has been widely used by other researchers for constructing future weather conditions (Chan, 2011a; Jentsch et al., 2013). Details of the morphing method and simulation procedures are shown in the case study section of this chapter. With the results of predicted energy use and the input parameters, a correlation analysis can be conducted to evaluate the Pearson's correlation coefficient (r) for each parameter which indicates the strength of linear dependence between the energy use and the studied parameter. The value of r ranges from 0 to ±1 at a certain level of p-value (usually the criterion is set below 0.01 or 0.05, with the former being more stringent). The higher the absolute value is, the more influential the parameter affects energy consumption.

IV. Development of probability distribution functions for the influential parameters[7]:

Based on the results of the correlation analysis, the influential parameters affecting energy use are identified. To simulate the variations in those influential parameters during the post-retrofit period, each influential parameter is assigned a suitable probability distribution function (PDF) which describes the relative likelihood for a random variable to be within a given range of probabilities. The determination of a suitable PDF for each influential parameter is based on three goodness-of-fit tests, namely the Chi-square test, the Kolmogorov-Smirnov (K-S) test, and the Anderson-Darling (A-D) test (Ang and Tang, 2007). To ensure the representativeness of the PDF, the empirical data should be used to fit into those tests. Those empirical data can be obtained from actual measurement, official database and previous research. There are two criteria to determine the most suitable PDF for each influential parameter: (1)

[7] In reality, the method for the imputation of Probability Distribution Functions (PDF) for the significant parameters will not be disclosed to building owners since this is related to the level of risks which the ESCO are willing to bear in EPC projects, and hence is a commercially sensitive issue. However, if the building owner can understand the principle of imputation of PDFs for those influential parameters, the building owner may have more confidence in project implementation.

For some influential parameters, both parties may have the same opinions about the PDFs since official data (e.g. weather data from the Hong Kong Observatory) is used for determination. However, several influential parameters are more related to future economic conditions, for example, occupancy rates in hotels. For such cases, both parties may have different views towards the imputation of PDFs.

the value of goodness-of-fit is the lowest compared with other previous assumed distributions; (2) such a value is below the critical value. Although those three tests give the same indication of goodness-of-fit, they have different constraints in use. For example, K-S test is more suitable when the sample size is less than 30. The A-D test provides more statistically significant results when the tails of a distribution reflect an essential distribution characteristic such as spread.

V. **Simulation of possible energy savings:** Based on those PDFs which are the most suitable to describe the variations in the influential parameters, a sufficiently large set of data is generated to simulate all possible post-retrofit conditions using Monte Carlo simulation. There are various sampling methods to create the random values in Monte Carlo simulation, and the Latin Hypercube Sampling method is recommended to be used since it requires less sample sizes to reflect the actual shape of a defined distribution (for details, please refer to Section 3.3.7). Finally, the datasets, each of which represents one possible post-retrofit condition, will be incorporated into the pre- and post-retrofit models for estimating possible energy savings. With the sufficiently large iterations (e.g. 10,000 iterations), a range of all possible energy savings taking into the account the variations in those influential parameters can be obtained.

The above procedures and method for estimating energy savings with a known confidence level are demonstrated through three case studies.

6.4 Case Study I – Replacement of air-cooled chillers with water-cooled chillers in an office building

6.4.1 Description of the office building

The first case study involves an owner-occupied office building which is 17 storeys high with a total gross floor area (GFA)[8] of around 24,000 m^2. The glass curtain wall and windows are installed at three orientations. In order to maximum nature light, an open plan office is designed. Table 6.1 shows the design parameters of the building in Case Study I.

Two separate chiller plant systems were used to provide cooling to this building prior to the retrofitting. The first system, which consisted of 3 units of 300-ton air-cooled chiller, mainly served the office premises with operating hours from 08:15 to 19:00, whilst another system, which consisted of 2 units of 180-ton air-cooled chiller, solely served the 24-hour operation areas including data centre premises, a security room, and a BMS control room. A primary pumping system was employed for both systems to deliver chilled water to air-side equipment throughout the whole building.

Table 6.1: The design parameters of the building in Case Study I

	Unit	Building 'A'
Location	-	City district in Hong Kong
Total gross floor area (GFA)[1]	m^2	24000
Total air-conditioned area	m^2	16500
Number of stories	-	17
Aspect ratio	Length/depth	1.35
Orientation	Degrees	0 (Main entrance facing north)
Window U-value (N,E,S,W elevation)	W/m^2K	2.67 for all sides
Window SHGC[2] (N,E,S,W elevation)	-	0.635 for all sides
Wall U-value (N,E,S,W elevation)	W/ m^2K	3.3 for all sides
Window-to-wall ratio (N,E,S,W elevation)	-	0.72 (N),0.16 (E),0.71 (S),0.59 (W)

Note: 1: Gross floor area is a statutory building parameter measured to the external faces of a building without deductions for lift, stair voids and other openings.
2. SHGC = Solar Heat Gain Coefficient

[8]The gross floor area of a building means the area contained within the external walls of the building measured at each floor level (including any floor below the level of the ground), including the thickness of the external walls of the building. The Building Authority may disregard essential building services areas from gross floor area calculation. (Cap 123 – Building Planning Regulations for Hong Kong SAR)

6.4.2 Replacement of air-cooled chillers with water-cooled chillers

After almost 15 years' operation of the building, an ESCO was invited to conduct an energy audit to identify energy saving potential. It was found that when the existing air-cooled chillers were replaced with water-cooled chillers, a substantial amount of energy savings would be achieved together with reductions in maintenance costs due to aging of the existing chiller plants. Finally, the host agreed with the ESCO’s proposal where the existing air-cooled chiller plants were replaced with 3 units of 400-ton water-cooled chillers. To achieve higher energy saving, variable speed chilled water pumps were also used together with condensing water pumps and cooling towers. An automatic control system was employed for chiller plant optimisation.

Table 6.2: The components of chiller plant equipment for calculation of energy savings in case study I

	Pre-Retrofit Stage	Post-Retrofit Stage
Chiller Plant	Annual chiller energy use	Annual chiller energy use
	Annual chilled water pump energy use	Annual chilled water pump energy use
Heat Rejection	Air-cooled system	Annual condensing water pump energy use + Annual cooling tower fan energy use
Annual energy use	A = sum of the above	B = sum of the above
Actual energy saving	Energy Savings = A – B (calculated based on the same post-retrofit conditions)	

In this project, an EPC guaranteed saving package was employed and the actual energy saving was ascertained based on the post-retrofit conditions per annum. According to the guideline of International Performance Measurement and Verification Protocol (IPMVP) (EVO, 2012), an isolation approach was employed in which individual electricity meters were installed to measure the annual energy consumption of the whole chiller plant, including chillers, chilled water pumps, condensing water pumps and cooling towers. For illustration purpose, savings other than the direct energy consumption (e.g. reduction in maximum demand load and maintenance costs) are not considered in this study. Table 6.2 shows the components of chiller plant equipment for energy saving calculation in this case study.

6.4.3 Development of building energy models

In this study, two building energy models were developed using *EnergyPlus* (Version 8.1) to represent the actual energy use of central chiller plants at the pre- and post-retrofit stages. Being developed by the Department of Energy (DOE) in the United States, *EnergyPlus* is a detailed building energy simulation program which allows building professionals to model energy use in various systems, including heating, cooling and lighting systems. This program has been validated with ASHRAE standard 140 (ASHRAE, 2007) which sets out the standard method of test for the evaluation of building energy analysis computer programs. With the proven accuracy for simulating energy use in the actual buildings, *EnergyPlus* is considered as one of the most popular simulation programs in the field of building energy use (Chan, 2011a; Boyano et al., 2013).

Pre-retrofit model

This building consists of a ground floor with an entrance lobby and plant rooms, 14 floors of office premises and 2 floors of data centre premises. Each floor of office premises is basically of the same configuration except the AC operating schedule, which can be summarised into two types of schedules (Schedule 1: Weekdays (08:15-19:00); No AC in weekend/holidays; Schedule 2: Weekdays (08:15-19:00); Saturday (08:15-13:30); No AC on Sunday/holidays). For simplicity, only three typical floors were evaluated to represent the whole building. The first typical floor model, denoted as TY1, represents the office premises with the AC operating schedule 1. Similarly, the second typical floor model, denoted as TY2, represents the office premises with the AC operating schedule 2. The third typical floor model, denoted as TY3, represents the data centre premises. Since the top floor of this building are used to house the portable water and fire services water tanks and the building is atop a basement floor which is used as a car park, it would be reasonable to assume that heat transfer to the air-conditioned areas caused by direct solar heat gain and ground temperature variations would be rather limited. Therefore, no roof and ground floors are modelled in this study.

Table 6.3: Description of *EnergyPlus* inputs.

		Unit	Office Premises	Data Centre
Internal loads	Occupant	-	10 m^2/person	15 m^2/person
	Lighting	W/m^2	15	16
	Electric Equipment	W/m^2	25	500
	Operating Schedule	-	Based on the local BEC[1]	Based on the local BEC[1]
Shading		-	Assumed no shading device	Assumed no shading device
Thermostat set point	Cooling	℃	24	20
	Heating	℃	22	16
HVAC system	Air Side	-	CAV[2]	CRAC[3]
	Water Side (before retrofit)	-	3 units of 300-ton air-cooled chiller & 2 units of 180-ton air-cooled chiller; COP: ranging from 2.62-2.83; Part-load performance: default curves from *EnergyPlus;* Constant speed chilled water pumps: Pump efficiency: ranging from 72% - 80%; Measured power: 4 pumps (office): ranging from 17.4kW - 17.8kW 2 pumps(data-centre): 8.5kW & 8.8kW	
	Water Side (after retrofit)	-	3 units of 400-ton water-cooled chillers; COP:6.05; 3+1 variable speed chilled water pumps: 30kW; 1 variable speed + 3 constant speed condensing water pumps: 30kW; 3 cooling towers: 15kW	
	AC schedule	-	Schedule 1: Weekdays (08:15-19:00); No AC in Weekend/holidays Schedule 2: Weekdays (08:15-19:00); Saturday (08:15-13:30); No AC on Sunday/holidays	24 hrs/7 days non-stop AC service
Supply air temperature		℃	Summer: 14 Winter: 18	Summer: 14 Winter: 18
Infiltration		ACH	0.1	0.1
Ventilation		-	0.01 m^3/s/person	0.01 m^3/s/person
Exterior wall		-	Concrete wall with gypsum plaster	
Interior Wall		-	Concrete wall with gypsum plaster	
Fenestration		-	Glass curtain wall and windows	
Thermal zoning		-	Core and perimeter zoning	

Notes: 1: BEC = Building Energy Code (Hong Kong SAR Government)
2: CAV = Constant air volume
3: CRAC = Computer room air conditioner unit

The pre-retrofit model was developed based on the actual architectural drawings, construction materials, equipment nameplate data, operating schedules, as well as occupancy patterns. In addition, the ESCO conducted a spot measurement to determine the actual COP of individual chillers under different loading conditions (e.g. 50%, 70% and full loading). The measurement found that the COP of chillers varied from 2.62 to 2.83. For those missing data (after due enquiries to the data provider) which are required as inputs to *EnergyPlus*, estimations are made based on common practices and local regulatory requirements, such as the Building Energy Code (EMSD, 2012). To ensure the representativeness of the model, the predicted energy use of two separate chiller plants by *EnergyPlus* were compared to the complete year of electricity bill data. Figures 6.2 and 6.3 show the comparison results. To determine compliance of the predicted values with the measured values, two statistical indices, namely the Coefficient of Variation of the Root Mean Squared Errors (CVRMSE) and the Normalised Mean Bias Error (NMBE), were applied. According to ASHRAE Guideline 14, the model is declared to be calibrated when CVRMSE and NMEB are less than 15% and 5% with monthly data respectively (ASHRAE, 2002). The pre-retrofit model in this study fulfils the calibration requirements. Table 6.4 presents the results of CVRMSE and NMBE for the models.

Table 6.4: Calibration errors for the pre- and post-retrofit models and ASHRAE requirements.

	ASHRAE Guideline 14 requirement (permissible)	Pre-retrofit energy model (Office Chiller Plant)	Pre-retrofit energy model (Data Centre Chiller Plant)	Post-retrofit energy model (Whole Chiller Plant)
Minimum period spanned by baseline data	12 months	12 months	12 months	12 months
CV(RMSE)[1]	15%	8.88%	7.23%	10.91%
NMBE[2]	5%	4.09%	-0.42%	2.03%

Notes: 1: CV(RMSE) = the coefficient of variation of the root mean squared errors
2: NMBE= normalised mean bias error

Prior to the project implementation, the total energy use for two central chiller plants was 3,058,634 kWh per annum. The chiller plant for the office premise consumed 57.7% of the total energy use for air-conditioning systems (1,765,542 kWh per annum), whilst the chiller plant for the data centre premises accounted for 42.3% of the total (1,293,092 kWh per annum).

Post-retrofit model

Development of the post-retrofit model was based on the pre-retrofit model except for the chiller plant system. The chiller manufacturer's data and relevant specifications of new pump performance were adopted for energy use prediction. Similarly, one complete year of post-retrofit data was collected for model calibration. The details of a new chiller plant are listed in Table 6.3. In addition, the input data for the post-retrofit model was revised accordingly when deviations were found between the pre- and post-retrofit conditions regarding occupancy rate and operating schedules. Figure 6.4 shows the comparison result for the post-retrofit model, and the model also fulfils the calibration requirements of ASHRAE Guideline 14.

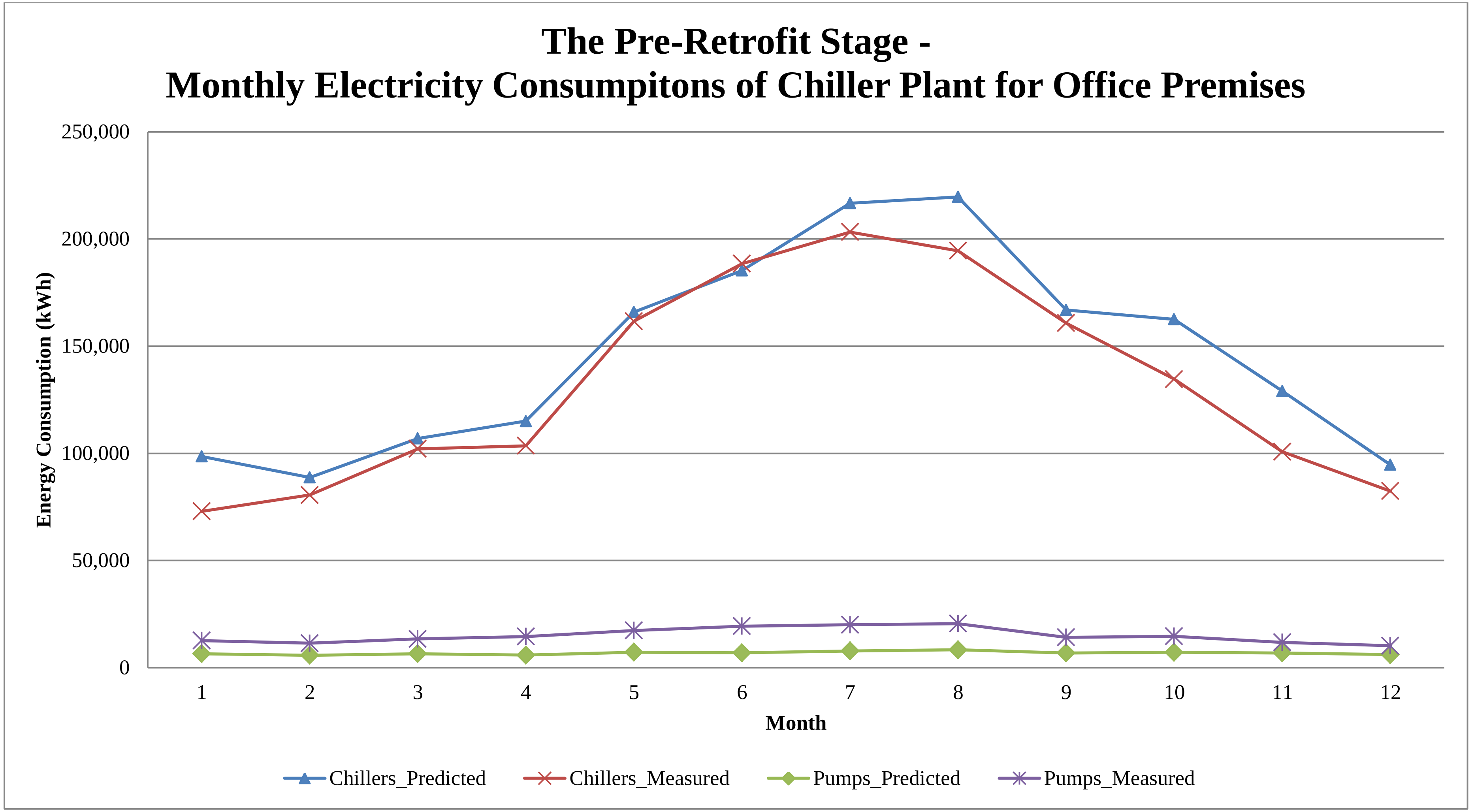

Figure 6.2: Comparison between the measured data and the predicted results on the electricity use of air-cooled chiller plant (office premises) at the pre-retrofit stage (Case Study I)

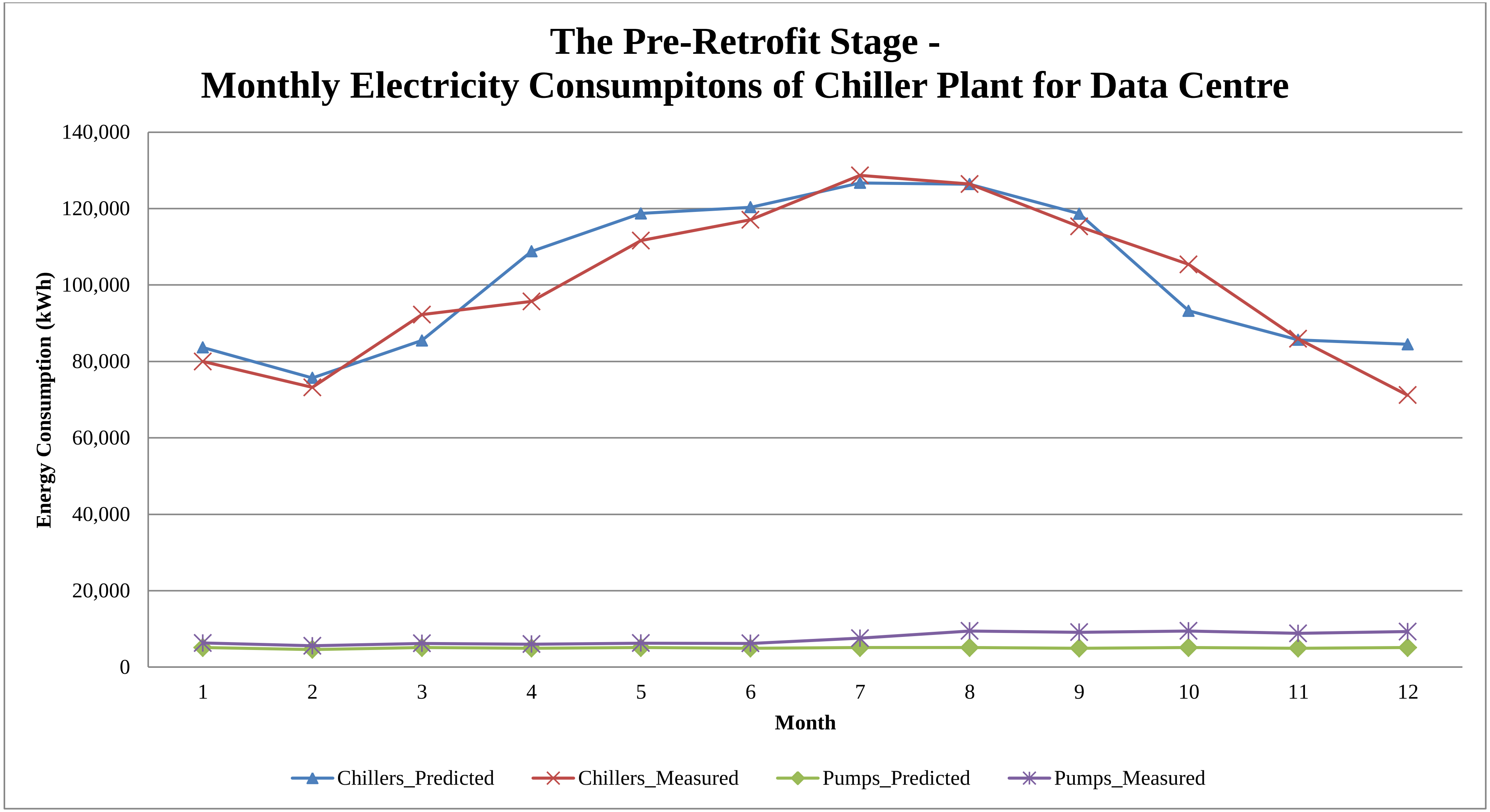

Figure 6.3: Comparison between the measured data and the predicted results on the electricity use of air-cooled chiller plant (data centre) at the pre-retrofit stage (Case Study I)

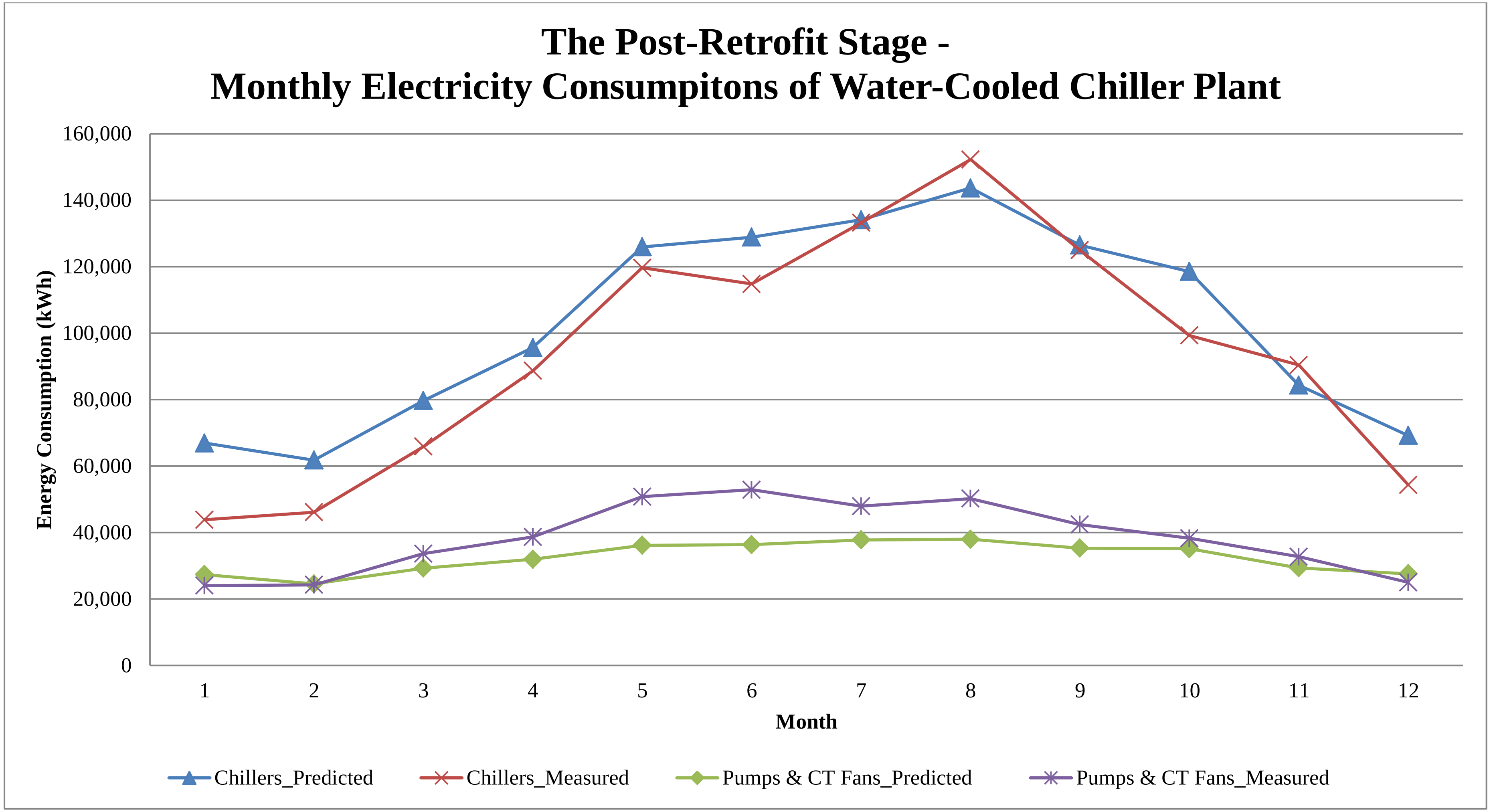

Figure 6.4: Comparison between the measured data and the predicted results on the electricity use of water-cooled chiller plant at the post-retrofit stage (offices and data centre combined) (Case Study I); Note: CT = Cooling Tower

6.4.4 Correlation analysis

Twelve types of parameters affecting energy use in the pre-retrofit model were identified based on the literature review (Lam and Hui, 1996; Lam et al., 2008). Since two separate chiller plant systems were used to provide cooling to the office and data centre premises, a total of twenty-four parameters were considered in the correlation analysis. The range of each parameter selected was based on the empirical data and previous studies relating to parametric analysis (Lam and Hui, 1996; Lam et al., 2008). For instance, the range of annual mean dry bulb temperature was selected in accordance with the highest and lowest values throughout the last 20 years of the Hong Kong Observatory (HKO) weather data (HKO, 2015). Tables 6.5 and 6.6 presents the ranges selected for the identified parameters. To ensure that the full range of possible values for those parameters would be covered in the data set, each parameter was assigned with a suitable uniform distribution. Monte Carlo simulation was employed to generate 10,000 sets of data which contain different combinations of possible values of those parameters. Generally, 10,000 iterations are considered as sufficiently large to simulate all possible conditions during the contract period (Yi and Chan, 2013). Since some of the identified parameters involve climatic variables such as dry bulb temperature, a 'morphing" method' was employed to modify the existing Hong Kong typical meteorological year (TMY) weather files (Belcher et al., 2005). In *EnergyPlus*, the Hong Kong TMY weather file comprises 8,760 hourly climatic variable data, including dry bulb temperature, solar radiation, wind speed, etc (DOE, 2014b). This weather file is often used to represent the typical weather condition over a year. Based on the algorithm of the 'morphing' method and Monte Carlo simulation results, the new Hong Kong TMY weather files taking into account annual variations in the weather conditions can be adopted.

The morphing method involves three operations, namely (1) a shift, (2) a linear stretch; and (3) a shift and a stretch, as listed in equations (6.1) – (6.3) below.

$$x = x_o + \Delta x_m \qquad \text{Eq.(6.1)}$$

$$x = \alpha_m x_o \qquad \text{Eq.(6.2)}$$

$$x = x_o + \Delta x_m + \alpha_m \times (x_o - \langle x_o \rangle_m) \qquad \text{Eq.(6.3)}$$

where x_o = existing hourly climatic variable; Δx_m = absolute change in monthly mean climatic variable for month 'm'; α_m = fractional change in monthly mean climatic variable for month 'm'; $<x_o>_m$ = climatic variable x_o average over month 'm'.

This method is not only effective to develop possible weather conditions, but also preserve the characteristics of real weather pattern after modification. Numerous researchers employed this method to create future climate conditions for analysis of changes in building energy use (Chan, 2011b, a; Jentsch et al., 2013). It is noted that this morphing method has its advantages and drawbacks. For example, one drawback is the ignorance of possible extreme weather conditions. However, since there is no standardised methodology for constructing future weather in the building simulation field to-date, the morphing method is still considered acceptable due to the fact that the generated weather data is meteorologically consistent (Chen et al., 2012).

In this study, the hourly dry bulb temperature (DBT) of the existing Hong Kong TMY weather file was morphed by a combination of a shift and a stretch to create a new set of Hong Kong TMY weather file. The equation for morphing is shown as follows Eq. (6.4) and (6.5):

$$\alpha dbt_y = \frac{\Delta TMAX_y - \Delta TMIN_y}{\langle dbt_{o\,max} \rangle_y - \langle dbt_{o\,min} \rangle_y} \qquad \text{Eq.(6.4)}$$

$$dbt = dbt_o + \Delta TEMP_y + \alpha dbt_y \times (dbt_o - \langle dbt_o \rangle_y) \qquad \text{Eq.(6.5)}$$

where $<dt_{0\ max}>_y$, $<dt_0>_y$ and $<dt_{0\ min}>_y$ = yearly mean daily maximum, average and minimum temperature of *EnergyPlus* weather file data respectively; $\Delta TMAX_y$, $\Delta TEMP_y$ and $\Delta TMIN_y$= absolute change in yearly mean daily maximum, average and minimum temperature of Hong Kong weather data respectively; dt_0= existing hourly temperature of *EnergyPlus* weather file.

For the dew point temperature (DPT) variable, a stretch method was used based on published literature (Belcher et al., 2005). To ensure that the other affected climatic variables such as relative humidity (RH) were consistent with the adjustment, the RH variable was also adjusted in accordance with the new DBT and DPT values by using ASHRAE psychometric formulae (ASHRAE, 2009). All the morphing processes involved above were automatically carried out using an Excel VBA program. As such, 10,000 new TMY weather files, taking into account the annual variations in weather conditions, were developed for *EnergyPlus* simulation.

These 10,000 sets of data, including two types of file: (1) weather files and (2) input data files, were incorporated into *EnergyPlus* for energy use prediction. The whole process was automatically performed using *jEPlus*, which is an open-source parametric analysis tool for *EnergyPlus* simulations (Zhang and Korolija, 2010). It enables users to run all simulations automatically with a CSV-style text file, which comprises weather files and input files with the respectively calibrated energy models. With the use of *jEPlus*, a maximum of eight simulations in each run were performed simultaneously, and all the simulation results were automatically grouped together for further analysis. The total 10,000 simulations for each energy model were conducted with 8 desk-top computers with two quad-core processors, using 9 hours to complete all simulations.

Table 6.5: Results of correlation analysis – Office Premises

Parameter(s)	Unit	Minimum	Base Case	Maximum	Pearson Correlation	Sig. (2-tailed)
Building Load						
Annual mean dry bulb temperature[1] (Office)	℃	22.5	23.24	24.0	0.007	0.495
Annual mean dew point temperature[1] (Office)	℃	18.1	19.01	20.0	-0.008	0.447
Annual mean global solar radiation[1] (Office)	MJ/m^2	11.82	12.97	14.55	0.009	0.352
Occupant density (Office)	m^2/person	1	10	30	-0.422	<0.01
Lighting load (Office)	W/m^2	10	15	30	0.242	<0.01
Equipment load (Office)	W/m^2	10	25	40	0.343	<0.01
AC operating hours (Office)[2]	hours	17:00	19:00	22:00	0.226	<0.01
Annual mean occupancy rate (Office)[3]	% (floor)	100% (14)	100% (14)	100% (14)	-	-
Ventilation rate (Office)	m^3/s/person	0.005	0.01	0.02	0.095	<0.01
Infiltration rate (Office)	ACH	0.05	0.1	0.25	0.011	0.278
System control and operation						<0.01
Thermostat set point (Office)	℃	20	24	28	-0.155	<0.01
HVAC plant						
Overall COP of chiller plant (Office)	-	2	2.7	4	-0.596	<0.01

Notes:

1: The annual mean temperature was taken as the average value of the daily mean dry bulb temperature throughout a year. Dew point temperature and global solar radiation are defined in the same way as dry bulb temperature.

2: AC operating hours (Office Premises) involving two parameters, the AC start-up time and operating duration, would be adjusted. In this study, the AC start-up time, which is 8:15 am, remained unchanged and only the operating duration was changed.

3: Occupancy rate was assumed to be unchanged as this building is a single owner building and all floors have been fully occupied over a decade.

Table 6.6: Results of correlation analysis – Data Centre

Parameters(s)	Unit	Minimum	Base Case	Maximum	Pearson Correlation	Sig. (2-tailed)
Building Load						
Annual mean dry bulb temperature[1] (Data Centre)	℃	22.5	23.24	24.0	0.002	0.833
Annual mean dew point temperature[1] (Data Centre)	℃	18.1	19.01	20.0	-0.007	0.467
Annual mean global solar radiation[1] (Data Centre)	MJ/m^2	11.82	12.97	14.55	0.003	0.793
Occupant density (Data Centre)[3]	m^2/person	-	-	-	-	-
Lighting load (Data Centre)	W/m^2	5	16	30	0.034	<0.01
Equipment load (Data Centre)	W/m^2	200	500	1000	0.739	<0.01
AC operating hours (Data Centre) [2]	hours	24	24	24	-	-
Annual mean occupancy rate (Data Centre)[3]	% (floor)	100% (2)	100% (2)	100% (2)	-	-
Ventilation rate (Data Centre)	m^3/s/person	0.005	0.01	0.02	0.042	<0.01
Infiltration rate (Data Centre)	ACH	0.05	0.1	0.25	-0.008	0.413
System control and operation						
Thermostat set point (Data Centre)	℃	18	20	28	-0.045	<0.01
HVAC plant						
Overall COP of chiller plant (Data Centre)	-	2	2.85	4	-0.605	<0.01

Notes:
1: The same treatment is made as shown in Table 6.5.
2: AC operating hours (Data Centre) was assumed to be unchanged as it is very unlikely for the data centre to reduce the operating hours given the steady business mode of the owner.
3: Due to the nature of data centre, occupancy rate and occupancy density was assumed to be unchanged.

Based on the results of predicted energy consumption and the input parameters, the Pearson correlation coefficient (r) of each parameter can be determined using SPSS software (IBM Corp., 2010). Table 6.5 and 6.6 show the results of Pearson correlation coefficient for the case study building. It was found that the energy use of chiller plant is significantly correlated with: (1) equipment load (offices: $r = 0.343$, $p<0.01$; data centre: $r = 0.739$, $p<0.01$); (2) overall COP of chiller plant (offices: $r = -0.596$, $p<0.01$; data centre: $r = -0.605$, $p<0.01$); (3) occupant density (offices: $r = -0.422$, $r<0.01$); (4) lighting load (offices: $r = 0.242$, $p<0.01$); (5) AC operating hours (offices: $r = 0.226$, $r<0.01$); (6) thermostat set point (offices: $r = -0.155$; $p<0.01$). Among those influential parameters, the equipment load (data centre) has the largest correlation with the energy use of chiller plant. The parameters with negative correlation coefficient mean that the energy use of chiller plant increases with a decrease in each of those parameters' value. For those parameters where the value of Pearson correlation coefficient is less than 0.1, they are considered as non-influential parameters, implying variations in those parameters have only limited impact on actual energy savings. The results of the influential parameters identified in this correlation analysis are consistent with other previous studies in that commercial buildings where COP, equipment load, lighting load, as well as cooling set point are the parameters sensitive to energy use in the sub-tropical climate (Lam and Hui, 1996; Lam et al., 2008).

6.4.5 Probability distribution of the influential parameters

Based on the results of the above correlation analysis, seven influential parameters were finally identified. To simulate the annual variations in those parameters and thereby quantify the uncertainties in energy savings, a probability distribution function (PDF) would be developed for each influential parameter using three curve-fitting techniques, namely, the Chi-square test, the Kolmogorov-Smirnov (K-S) test, and the Anderson-Darling (A-D) test

(Ang and Tang, 2007). The features of these tests were described in Section 6.3. In this study, these tests were performed using the built-in functions of *@Risk* , which is a widely applied Monte Carlo simulation tool for risk analysis (Palisade Corporation, 2015). The empirical data, official database and previous research will be used to develop the suitable PDF for the influential parameters, and the step-by-step approach will be described in the next section. Table 6.7 indicates the factors contributing to annual variations of the influential parameters and the methods used in simulating the variations in those parameters. The results of the curve-fitting tests are summarised in Table 6.8.

(i) Thermostat set point (office)

Several studies indicated that the indoor air temperature setting can significantly affect the energy consumption of chiller plants (Lee et al., 2007; Lee and Yik, 2010). In practice, the setting of indoor air temperature varies substantially as different occupants could have different thermal sensation to the indoor environment. In order to reduce building energy use, the HKSAR Government recommends occupants to set the indoor temperature at 25.5°C (EMSD, 2006). However, the indoor air temperature set-point is not often set as recommended. From the field survey of Mui and Wong (2007), during which 422 samples were collected in 61 offices, it was found that the recorded air temperatures in typical office buildings varied from 19°C to 25.4 °C with an average of 23±1.5 °C. In order to develop the PDF of thermostat set-point, the study result of Mui and Wong (2007) was used to describe the variations in indoor air temperature setting. Although their study was not aimed at investigating the possible variation of indoor air temperatures in a single building, it was still considered applicable as the choice of indoor air temperature setting depends on occupants' behaviours, rather than building characteristics and location. Based on the findings of Mui and

Wong (2007), a normal distribution was used for the indoor air temperature set-point parameter.

(ii) AC operating hours (office)

Although the AC operating hours are generally in line with the working hours (e.g. 08:30 to 18:00 in Hong Kong), the actual operating hours for office premises still change from building and building due to overtime working. To suit their business needs, some tenants may request for extensions of AC operating hours, leading to uncertainties in energy savings. Therefore, it is important to consider the impact on the possible extension or reduction of operating hours on energy savings.

However, there is no empirical data to describe the variation in long-term AC operating hours in a single building. An alternative way to develop such a PDF is employed by using published data from a property consultant on AC operating hours in different office buildings in Hong Kong. It is assumed that the AC operating hours is dependent on tenants' preference and relative negotiation power, instead of building characteristics and location. As such, the data from *Primeoffice* was adopted to determine a suitable PDF of AC operating hours. *Primeoffice* is a property search engine, and its database contains information from over 1,800 office buildings in Hong Kong (Primeoffice, 2015). It provides basic building information such as typical floor areas, AC system types (e.g. central AC, window-type) and AC operating hours. Based on the data retrieved from *Primeoffice* (suitable sample sizes: 521), a logistic continuous distribution was determined as the PDF of AC operating hours.

Table 6.7: Factors contributing to the annual variations of influential parameters and simulation methods used for generating the data sets of post-retrofit conditions

Influential parameters	Factors contributing to annual variations	Simulation Methods
Occupant density (Office)	Due to change of tenants, floor layouts are redesigned to suit the latest business and occupation needs	Change of 'Zone Floor Area per Person of People' in *Energyplus*
Lighting load (Office)	Lamp deterioration, manufacturing process deviation and replacement of existing lamps with new lamps	Change of 'Watts per Zone Floor Area of Lights' in *Energyplus*
Equipment load (Office)	Due to the provision of more workstations in the office or replacement of the existing equipment with more energy efficient one	Change of 'Watts per Zone Floor Area of Electric Equipment' for office premises in *Energyplus*
Equipment load (Data Centre)	Due to the installation of more servers in the data centre or replacement of the existing equipment with more energy efficient one	Change of 'Watts per Zone Floor Area of Electric Equipment' for data centre premises in *Energyplus*
AC operating hours (Office)	Change of office hours due to change of tenants	Change of AC operating schedule for the office premise in *Energyplus*
Thermostat set point (Office)	A change of tenants may lead to a change of indoor air temperature setting as it depends on occupants' behaviours	Change of thermostat set point for the office premise in *Energyplus*
Overall COP of chiller plant after retrofit	Chiller deterioration: (1) scaling of evaporator coil and chilled water tubes, affecting heat exchange between refrigerants and chilled water; (2) normal wear and tear, leading to an increase in compressor power consumption	Change of COP of each chiller in *Energyplus*

Table 6.8: Results of Chi-Square, K-S and A-D tests and the assumed distributions for the influential parameters

							Curve-fitting parameters			
Parameter(s)	Unit	Distribution	5% level	Mean	95% level	Standard deviation	Chi-Square test	K-S test	A-D test	Sample Sizes
Building Load										
Occupant density (Office)	m^2/person	Triangular continuous	8.7	10	12.2	1.123	0.091	0.162	0.261	11
Lighting load (Office)	W/m^2	Triangular continuous	13.7	15	15.4	0.525	-	-	-	-
Equipment load (Office)	W/m^2	Triangular continuous	7.4	17.1	30.	7.23	2	0.096	0.28	30
Equipment load (Data Centre)	W/m^2	Triangular continuous	432	500	568	40.82	-	-	-	-
AC operating hours (Office)[1]	hour	Logistic continuous	17.30	18.75	20.19	0.89	2392.2	0.19	22.2	521
System control and operation										
Thermostat set point (Office) [2]	℃	Normal continuous	20.53	23	25.47	1.50	2.59	0.054	0.15	422
HVAC Plant										
Overall COP of chiller plant after retrofit	-	Triangular continuous	5.97	6.05	6.06	0.028	-	-	-	-

Notes:

1: The unit of AC operating hours is represented in terms of hours, for example, 19:30 = 19.5

2: Due to the house rule setting the lowest limit in thermostat set-points, 21.5℃ will be used for simulation when the sampling data is lower than 21.5℃. All the parameters above are represented in terms of annual mean values.

(iii) Overall COP of chiller plant

The Coefficient of Performance (COP) is a primary indicator to assess actual chiller plant performance. It is a dimensionless value defined as the cooling energy produced by a chiller plant divided by the energy consumed by the chiller plant. The higher the COP is, the higher energy efficiency the chiller plant has (ASHRAE, 2009). Generally, chiller plant performance will gradually deteriorate over time due to two main reasons: (1) scaling of evaporator coil and chilled water tubes, affecting heat exchange between refrigerants and chilled water; (2) normal wear and tear, leading to an increase in compressor power consumption. In order to consider the impact on energy savings due to chiller deterioration, it is important to develop the PDF of the overall COP of a chiller plant to describe such changes in its value over time. However, in practice, it is difficult to determine the PDF of COP as such variations depend on a number of factors, including frequency and quality of maintenance work, operating hours, as well as operating conditions. When considering the nature of EPC projects, the chiller plant performance will not be far below the expected COP as the ESCO will carry out active maintenance (e.g. tube chemical cleaning) to avoid potential shortfall in energy savings. Therefore, the extreme case of a large degree of deterioration is unlikely to happen. In this study, the PDF of chiller plant COP is based on the study of Masaaki et al. (2008), in which the degree of deterioration of chiller performance was investigated. It was found that the COP will deteriorate at an annual average rate of 2.53%. Therefore, due to the inherent motivation of the ESCO to carry out proper maintenance, it is reasonable to assume that the worst scenario for annual COP deterioration rate would not be more than 2.53%, and the best scenario would be no COP deterioration. Hence, in the case study, a triangular distribution was assumed for the PDF of COP deterioration.

(iv) Equipment load (office and data centre)

Equipment load for AC system is defined as the internal heat gain contributed by electric equipment (ASHRAE, 2009). In general, the common equipment loads in office premises include desktop computers, laptop computers, laser printers, photocopiers, fax machines and desk fans, whilst in data centre premises, the common equipment loads are severs, computing devices, uninterruptable power supply (UPS) devices, etc. Due to the optimisation of floor space usage, the power density (W/m^2) of a data centre is much higher than that of office premises. Dunn and Knight (2005) carried out a survey on the equipment load in 30 air-conditioned offices, and found that the average equipment loads range from $6W/m^2$ to $34W/m^2$. As office automation needs to keep pace with technological advancement and business requirements, it is reasonably foreseen that there will be a change in equipment loads after several years. Therefore, the impact of the possible increase (e.g. due to the provision of more workstations in the office / installation of more servers in the data centre) or reduction in equipment loads (e.g. replacement of the existing equipment with more energy efficient one) have to be addressed.

Similar to other parameters, there is hardly any reliable data or research finding which describes the long term variation in equipment loads in a single building. Hence, an approximation needs to be made to consider such variations. It is assumed that a change of floor layout would be the main cause leading to a change of equipment load. The study of Dunn and Knight (2005) was employed to determine the suitable PDF of equipment loads in office premises since it recorded the possible typical equipment loads in 30 air-conditioned offices. Based on the curve-fitting result, a triangular continuous distribution was the best fitting distribution to describe the possible variations in equipment loads. For the data centre in the present case study, a triangular continuous distribution was assumed and the most likely value in this PDF was set to be the existing value of equipment load with a possible variation of 13% from its mean value, which is based on the information regarding the power trend chart of data centre equipment in ASHRAE guidelines (ASHRAE, 2012).

(v) Lighting Load (office)

Lighting load is defined as the total wattage of lighting equipment per lit area, and the change of its value can be summarised into three factors: (1) lamp deterioration; (2) manufacturing process deviation; (3) replacement of existing lamps with new lamps. In practice, due to lamp deterioration and manufacturing process deviation, the actual lamp power of fluorescent lamps (FLs) may deviate from the rated value resulting in more heat being dissipated. In addition, there may be a possibility that the existing T8 FLs are replaced with T5 FLs, leading to reduction in lighting load. Therefore, there is a chance of increasing or decreasing lighting load during the EPC contract period. The PDF of lighting load can be derived from the study of Guan et al. (2015) and the current situation of lamps being used in the case study building. Guan et al. (2015) conducted a comparison study of actual performance of compact fluorescent lamps (CFLs) with the rated specifications provided by the manufacturer after a lamp ageing process. The results show that the actual lamp power can vary from 1.36% to 4.58% of the rated value. Although Guan et al. used the CFLs as a case study lamp, the use of their finding is considered acceptable since the maintenance practice and life span of CFLs are similar as FLs. At the time of conducting energy audit, the portion of T8 FLs and T5 FLs used was 2:1 in this case study building. It is reasonable to foresee that T8 FLs will be gradually replaced by T5 FLs, resulting in less heat dissipation to the indoor environment. In this study, a triangular distribution was assumed for PDF of lighting load. The most likely value was set to be the existing value of lighting load, and 4.58% of its original value was assumed to be the worst case for the increase in lighting load, while 12% less of its original value is assumed to be the best case for lamp replacement in that building (assuming the remaining T8 FLs are replaced with T5 FLs).

(vi) Occupant density (office)

Occupant density is one of the factors contributing to the internal heat gains for AC systems since the heat from the body surface will be dissipated to indoor environment, resulting in an increase in cooling load and thereby consuming more energy to maintain indoor air temperature. Generally, occupant density does not vary significantly in an existing office building unless the floor layout is redesigned to suit the latest business and occupation needs. From the ESCO's perspective, it is difficult to predict the future change in occupant density. To develop a suitable PDF, an approximation is made based on the number of occupants in each floor of the studied building. According to the energy audit report, the occupant density on each floor ranges from 8 m^2/person to 30 m^2/person[9] (The floor with the largest occupant density (m^2/person) is to accommodate the top management rooms and conference rooms). Based on the curve-fitting result, a triangular continuous distribution was the best fitting distribution to describe the possible variations in occupant density.

6.4.6 Simulation of energy savings

Figure 6.5 shows the procedures of estimating energy savings which takes into account the impact of yearly variations on the influential parameters. Based on the determined PDFs of the influential parameters, 10,000 sets of data were generated to simulate all possible post-retrofit conditions using Monte Carlo simulation. In this study, the commonly used Latin Hypercube Sampling method was adopted to generate the random numbers because it requires less sample sizes to reflect the actual profile of a defined distribution (For details,

[9] The definition of occupant density is consistent with the local Building Energy Code (BEC) published by EMSD.

please refer to Section 3.3.7). These 10,000 sets of data were then incorporated into *EnergyPlus* for energy use prediction. To ensure that energy saving is calculated under the same post-retrofit environmental conditions, the same sets of data were used for both the pre- and post-retrofit models. Similar to the correlation analysis, the whole process was automatically performed using *jEPlus*. The total 30,000 simulations (20,000 simulations for the pre-retrofit models and 10,000 simulations for the post energy model) were undertaken with 8 computers with two quad-core processors. Eventually, 15 hours were used to complete all simulations. The calculation time would be shortened when higher performance computers were employed to run parts of the simulations simultaneously (For example, each computer handles 3,000 iterations in a setup of ten computers). In this study, 4 time-step per hour was adopted and the conduction transfer was used as a heat balance algorithm in *EnergyPlus*, as commonly practised in this type of simulation.

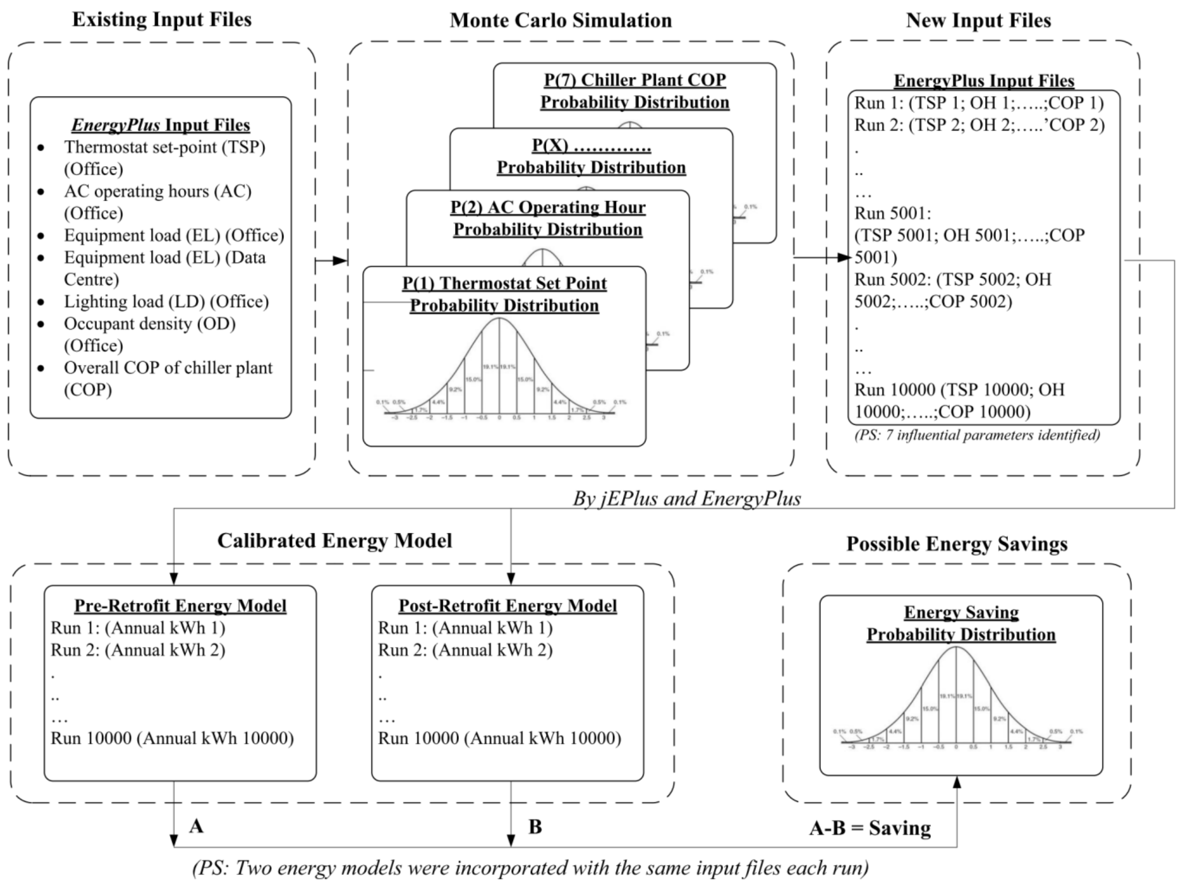

Figure 6.5: Procedures for estimating a range of energy savings using Monte Carlo and *EnergyPlus* simulation

6.4.7 Results and discussion – Probability of energy savings

Figures 6.6 and 6.7 show a range of possible energy savings for chiller replacement taking into account the possible annual variations in the influential parameters. The results indicate that the possible annual energy savings during the post-retrofit period would vary from 1,149,000 kWh (37.6% of baseline consumption) to 1,504,000 kWh (49.2% of ditto) at 90% confidence. Based on the curve-fitting results, the probability of energy savings in the case study project can be best described by a 'Weibull' distribution with a mean saving of 1,318,000 kWh (43.1% of baseline consumption) and a standard deviation of 108,136 kWh. The results imply that the variations of annual energy savings in chiller replacement projects can be estimated with a defined degree of certainty in the sub-tropical climate.

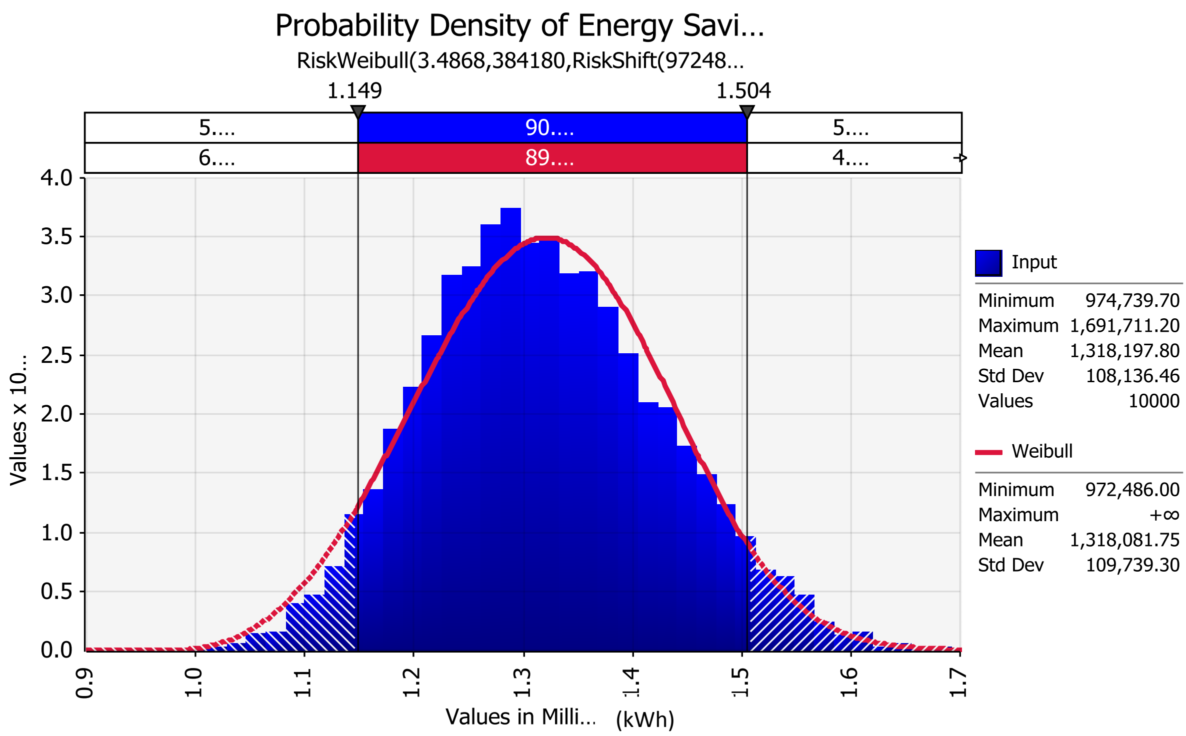

Figure 6.6: Probability density function of energy savings in the Case Study I project
(based on @Risk – the Monte Carlo Simulation Program developed by Palisade Corp.)

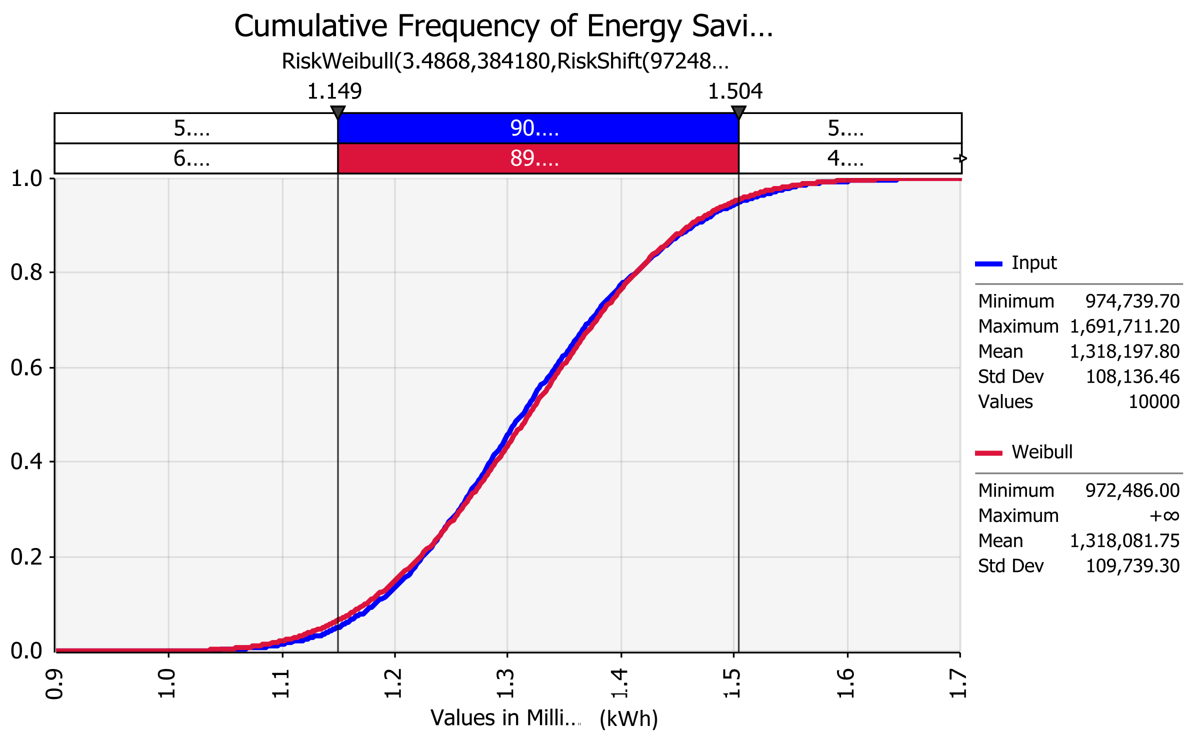

Figure 6.7: Cumulative frequency of energy savings in the Case Study I project
(based on @Risk – the Monte Carlo Simulation Program developed by Palisade Corp.)

6.4.8 Validation of the proposed method

To ensure that the result of the proposed method is within the confidence level of energy savings, the above estimation is compared with the M&V results of the case study building in the first 4 years of the 8-year EPC contract (only the first 4-year data is available at the time of writing). The results of the Actual Energy Saving are as follows: 1st year (1,266,938kWh – a minor shortfall); 2nd year (1,476,390 kWh – a surplus); 3rd year (1,273,766kWh – a minor shortfall) and 4th year (1,261,053 kWh – a minor shortfall). The above results are well within the confidence level, showing that the proposed method is reliable as a pre-installation estimating tool. It is noted that the actual annual cost savings in the project not only reckon the energy savings, but also the changes in additional maintenance cost, water charge and maximum demand (kVA charges levied by the utility company) cost savings. Therefore, the actual annual cost savings in those four years exceed the guaranteed amount despite the minor shortfalls in energy savings in three of the recorded years.

6.5 Case Study II – Retrofitting on heat rejection system in composite buildings

Similar to Case Study I, the retrofitting work of Case Study II is also related to the central chiller plant. However, Case Study II is a replacement project of heat rejection system, instead of chiller replacement, and the potentiality of this retrofitting is mainly attributed to the HKSAR Government policy on relaxing the use of fresh water as a cooling medium in central AC systems, as well as the poor quality of the seawater, corroding condenser tubes (this results in a low COP and high maintenance cost). This case study is used to illustrate the application of this risk assessment method for other retrofitting works.

6.5.1 Description of the composite buildings

There are three commercial towers in this development with a total GFA of around 240,000m^2. The first two towers, denoted as A and B, are symmetrical in building shape, and each consists of 16 office storeys and 14 serviced apartment (SA) storeys. The remaining tower, denoted as C, is solely for 30 storeys of office premises. A double-glazed curtain wall system is used for building facades and the window-to-wall ratio (WWR) is around 0.79 for four orientations. Table 6.9 shows the design parameters of these towers.

Table 6.9:Design parameters of the building towers in Case Study II

	Unit	Tower A	Tower B	Tower C
Location	-	City district in Hong Kong		
Total gross floor area (GFA)[1]	m^2	77000	77000	84000
Total air-conditioned area	m^2	50000	50000	54500
Number of stories	-	30 (SA:14; Office:16)	30 (SA:14; Office:16)	30 (All office premises)
Aspect ratio	Length/depth	1.91	1.91	1.91
Orientation	Degrees	335	335	335
Window U-value (N,S,E,W)	W/m^{2}K	2.67	2.67	2.67
Window SHGC[2] (N,S,E,W)	-	0.635	0.635	0.635
Wall U-value (N,S,E,W)	W/ m^{2}K	3.3	3.3	3.3
Window-to-wall ratio (N,S,E,W)	-	0.79	0.79	0.79

Note:

1:Gross floor area is a statutory building parameter measured to the outside faces of external walls of building without deductions for lifts, stair voids and other openings.

2. SHGC = Solar Heat Gain Coefficient

A central chiller plant system, which comprises 3 units of the day-mode 1800-ton chiller and 2 units of the night-mode 450-ton chiller, is adopted to provide cooling to those three towers (this is different from Case Study I where two separate chiller plants were used to provide cooling to the office and data centre premises respectively). A primary-secondary pumping system is used and the seawater cooling system was adopted for heat rejection prior to the retrofitting. The 3 day-mode chillers operating from 08:00 to 19:00 are capable of providing air conditioning for both the office and SA premises. For the remaining hours, the AC operation is switched from the day-mode to the night mode, and only the SA premises are provided with air conditioning service.

6.5.2 Retrofitting on heat rejection system

After 5-year operation of the building, an ESCO conducted an energy audit, and it was found that the seawater cooling system was supplied with seawater, which was discharged from an adjacent central chiller plant for chiller condenser cooling. Since the ‘indirect’ seawater supply was at much higher temperatures than the original design level, the chiller plant had been running at rather low COP. The poor quality of the seawater also exacerbated corrosion of condenser tubes, causing further lowering of the COP. Eventually, the host accepted the ESCO’s proposal under which the existing seawater cooling system should be replaced with a fresh-water evaporative cooling tower system, and the project was implemented under an EPC guaranteed saving package.

Similar to Case Study I, the actual energy saving was calculated based on the post-retrofit period conditions per annum. The isolation approach was adopted to measure the annual energy consumption of the whole chiller plant, including chillers, chilled water pumps and seawater pumps. Other energy and avoided-cost savings (e.g. reduction in maximum demand use and maintenance costs) were not considered in this study. Table 6.10 shows the component of chiller plant equipment for energy saving calculation in this project.

Table 6.10: The component of chiller plant equipment for energy saving calculation in Case Study II

	Pre-Retrofit Stage	Post-Retrofit Stage
Chiller Plant	Annual chiller energy use	Annual chiller energy use
	Annual chilled water pump energy use	Annual chilled water pump energy use
Heat Rejection	Annual sea water pump energy use	-
	-	Annual condensing water pump energy use
Annual energy use	A = sum of the above	B = sum of the above
Actual energy saving	Energy Savings = A – B (calculated based on the post-retrofit conditions)	

6.5.3 Development of building energy models

Similarly, two building energy models, representing the energy consumption at the pre- and post-retrofit stages, were developed using *EnergyPlus* (DOE, 2014b).

Pre-retrofit model

The composite buildings consist of two types of premises: offices and serviced apartments (SA), housed in a total of 90 usable floors. For simplicity, a model with only three typical floors was developed to represent the whole composite buildings. As tower A and tower B are symmetrical to each other in shape, the first typical floor model, denoted as TY1, represents the SA premises of towers A and B. Similarly, the second typical floor model, denoted as TY2, represents the office premises of towers A and B. The third typical floor model, denoted as TY3, represents the office premises of the whole tower C. With the same reasons as stated in Case Study I, no roof and ground floors were modelled.

Table 6.11 shows the *EnerygPlus* input details. The pre-retrofit model was developed with reference to equipment nameplate data, operating schedules, occupancy patterns, etc. A spot measurement was also conducted by the ESCO to evaluate the overall COP of the chiller plant. The other baseline conditions, including the occupancy rate of the office and SA premises, were obtained from relevant documentary records. To ensure that the operating conditions of the chiller plant in the pre-retrofit period could be realistically modelled, a complete year of monthly energy use data of the chiller plant was collected and used as the basis for comparison.

Table 6.11: Description of *EnergyPlus* inputs

		Unit	Office	Serviced Apartment
Internal loads	Occupant	-	8 m^2/person	42 person/floor
	Lighting	W/m^2	15	15
	Electric Equipment	W/m^2	25	12
	Operating Schedule	-	Based on the local BEC[1]	Based on the local BEC[1]
Shading		-	No shading device	No shading device
Thermostat set point	Cooling	℃	24.5	24.5
	Heating	℃	22	22
HVAC system	Air Side	-	VAV	VAV
	Water Side	-	Direct seawater cooled chiller; COP: 4.135; Part-load performance: default curves from EnergyPlus[2]	
Supply air temperature		℃	Summer: 14 Winter: 18	Summer: 14 Winter: 18
Infiltration		ACH	0.1	0.1
Ventilation		-	0.01 m^3/s/person	0.63 m^3/s/floor
Exterior wall		-	Concrete wall with gypsum	Concrete wall with gypsum
Interior Wall		-	Concrete wall with gypsum	Concrete wall with gypsum
Fenestration		-	Curtain wall with double glazing	Curtain wall with double glazing
Thermal zoning		-	Core and perimeter zoning	Core and perimeter zoning

Notes:
1:BEC = Building Energy Code (EMSD) [30]
2:Seawater-cooled chiller system is not directly supported in *EnergyPlus*. A “District Cooling” object with the specified leaving temperature on condenser loop is used to simulate the effect of using seawater as a heat rejection method in this study.

Post-retrofit model

The post-retrofit model was developed based on the pre-retrofit model except the retrofitted part. Similarly, one complete year of post-retrofit data was collected for calibration of the post-retrofit model. Other data and information, including new occupancy rate, operating schedules, as well as plant performance after retrofit, were also recorded.

Better chiller performance was observed after the retrofitting. This was mainly attributed to the lower incoming condenser water temperature for chiller heat rejection (approximately 5℃ reduction). Apart from the chiller plant, there was no significant change from the baseline conditions, except the occupancy rate, which was 31% higher than the pre-retrofit conditions.

The predictions of the two building energy models and the actual consumption figures are shown for comparison in Figure 6.8 and 6.9. Both models in this study comply with the calibration requirements of CVRMSE and NMBE as listed in Table 6.12. It is noted that the measured values of total chiller plant energy use in April and September in the post-retrofit case were discarded, as these data were found erroneous. Much effort had been made to account for the large deviation between the measured and predicted values of these two months, for example, checking on (1) maintenance records; (2) occupancy rate; (3) monthly outdoor temperature; (4) monthly relative humidity; (5) numbers of holiday happening on weekdays; (6) monthly billing period. The investigation concluded that the large deviation was most likely due to missing sub-meter readings but records of those readings could not be retrieved.

Table 6.12: Calibration errors for the pre- and post-retrofit models and its requirement

	ASHRAE Guideline 14 requirement (permissible)	Pre-retrofit energy model	Post-retrofit energy model
Minimum period spanned by baseline data	12 months	12 months	10 months
CV(RMSE)[1]	15%	7.98%	8.50%
NMBE[2]	5%	4.55%	1.23%

Notes: 1: CV(RMSE) = the coefficient of variation of the root mean squared errors
2: NMBE= normalised mean bias error

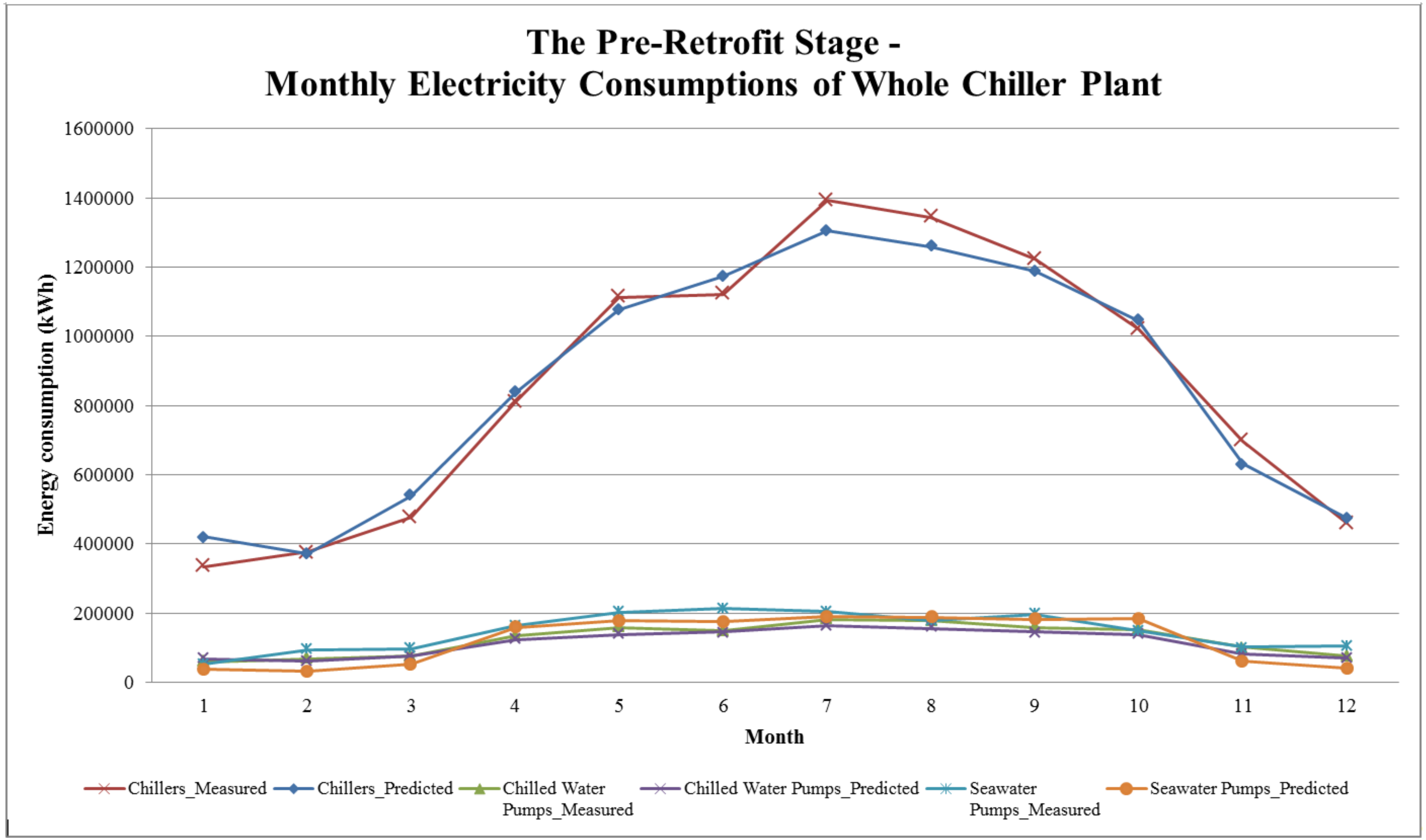

Figure 6.8: Comparison of the measured data with the predicted results on the chiller plant electricity consumption at the pre-retrofit stage (Case Study II)

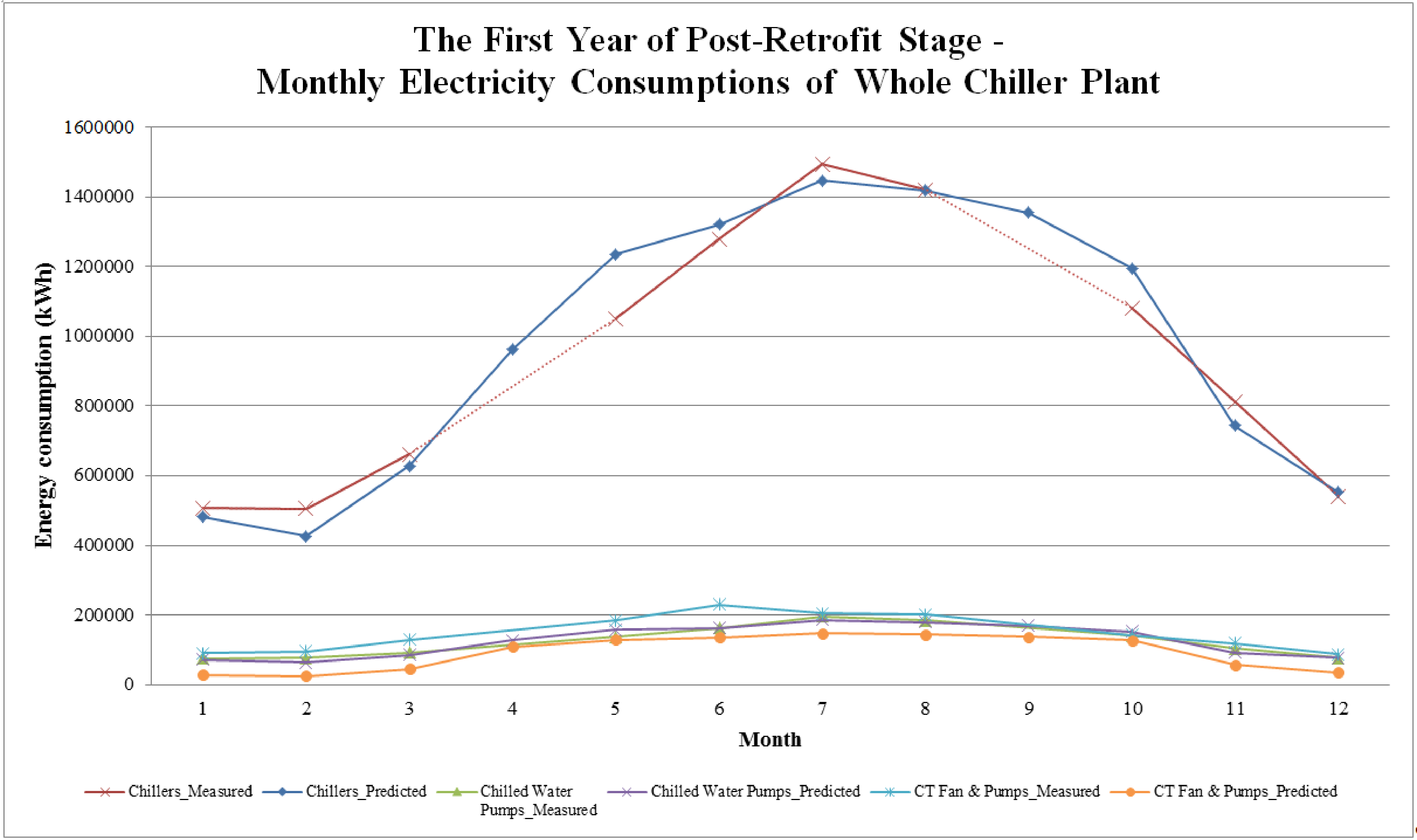

Figure 6.9: Comparison of the measured data with the predicted results on the chiller plant electricity consumption after the first year of post-retrofit stage (Case Study II)

6.5.4 Correlation analysis

Similar to Case Study I, twelve types of parameters affecting energy consumption were identified based on literature reviews. As the chiller plant provides cooling to both the office and SA premises, the total number of parameters for correlation analysis is twenty. Table 6.13 lists all parameters and its value being considered in correlation analysis. Each parameter was first assigned with a suitable uniform distribution, and Monte Carlo simulation was then employed to generate 10,000 sets of data which contain different combinations of possible value of those parameters. As climate variables were also involved in this type of retrofitting, a 'morphing method' was adopted (for details of morphing method, please refer to 6.4.4). With the generation of 10,000 sets of data, these data were incorporated into *EnergyPlus* for energy use prediction. The 10,000 simulations for the pre-retrofit model were carried out with 10 computers with two quad-core processors. Nine hours were needed to complete all simulations.

With the result of predicted energy use and those input parameters, the Pearson correlation coefficient (r) of each parameter were evaluated using SPSS software (IBM Corp., 2010). Table 6.13 shows the results of Pearson correlation coefficient for the case study building. It was found that the energy use of chiller plant is significantly correlated with (1) overall COP of chiller plant ($r = -0.649$, $p < 0.001$); (2) annual mean occupancy rate (office: $r = 0.421$, $p < 0.001$; SA: $r = 0.248$, $p < 0.001$); (3) equipment load (office: $r = 0.176$, $p < 0.001$); (4) lighting load (office: $r = 0.131$, $p < 0.001$); and (5) AC operating hours (office: $r = 0.124$, $p < 0.001$). Those parameters where the value of Pearson correlation coefficient is less than 0.1 are considered as the non-influential parameters, meaning changes in those parameters have little impact on actual energy savings. Compared to the correlation results in Case Study I, the influential parameters being identified in Case Study II are consistent with that in Case Study I.

6.5.5 Probability distribution of the influential parameters

With the result of the above correlation analysis, six influential parameters were identified. In order to describe the annual variations in those parameters and thereby quantify the uncertainties in energy savings, a PDF will be developed for each influential parameter using those three curve-fitting techniques mentioned previously. Similar to Case Study I, the empirical data, official database and previous research will be used to develop the most suitable PDF for the influential parameters, and the step-by-step approach will be described in the next section. Table 6.14 indicates the factors contributing to annual variations of the influential parameters and the methods used in simulating these variations in those parameters. The results of the curve-fitting tests are summarised in Table 6.15.

Table 6.13: Results of Correlation Analysis – Case Study II

Building Load	Unit	Minimum	Base Case	Maximum	Pearson Correlation	Sig. (2-tailed)
Annual mean dry bulb temperature[1]	℃	22.5	23.24	24.0	0.012	0.219
Annual mean dew point temperature[1]	℃	18.1	19.01	20.0	0.003	0.773
Annual mean global solar radiation[1]	MJ/m^2	11.82	12.97	14.55	0.004	<0.001
Occupant density (Office)	m^2/person	1	8	30	-0.095	<0.001
Occupant density (SA)	person/floor	35	42	45	0.064	<0.001
Lighting load (Office)	W/m^2	10	20	30	0.131	<0.001
Lighting load (SA)	W/m^2	10	20	30	0.061	<0.001
Equipment load (Office)	W/m^2	10	25	40	0.176	<0.001
Equipment load (SA)	W/m^2	10	12	40	0.066	<0.001
AC operating hours (Office)[2]	hours	17:00	19:00	22:00	0.124	<0.001
AC operating hours (SA)[3]	hours	24	24	24	-	-
Annual mean occupancy rate (Office)[4]	%(floor)	50% (31)	73.4% (47)	100% (62)	0.421	<0.001
Annual mean occupancy rate (SA)[4]	%(floor)	50% (14)	73.4% (21)	100% (28)	0.248	<0.001
Ventilation rate (Office)	m^3/s/person	0.005	0.01	0.02	0.025	<0.005
Ventilation rate (SA)	m^3/s/person	0.005	0.01	0.02	0.012	0.230
Infiltration rate (Office)	ACH	0.05	0.1	0.25	-0.002	0.856
Infiltration rate (SA)	ACH	0.05	0.1	0.25	-0.003	0.746
System control and operation						
Thermostat set point (Office)	℃	20	24	28	-0.07	<0.001
Thermostat set point (SA)	℃	20	24	28	-0.016	<0.001
HVAC Plant						
Overall COP of chiller plant	-	3	4.1365	5	-0.649	<0.001

Notes:

1:The annual mean temperature was taken as the average value of the daily mean dry bulb temperature throughout a year. Dew point temperature and global solar radiation are defined in the same way as dry bulb temperature.

2: AC operating hours (Office Premises) involves two parameters, the AC start-up time and operating duration, would be adjusted. In this study, the AC start-up time, which is 8:00 am, remains unchanged and only the operating duration was changed.

3: AC operating hours (SA Premises) are assumed to be unchanged as it is very unlikely for SA operators to reduce the operating hours.
4: The data on occupancy rate is in terms of the annual mean percentage. The occupancy rate was converted into the number of floors being fully occupied. Besides, it is assumed that a tenant rents the office floor in terms of a whole floor, instead of half-floor. Similarly, the SA operator will try to occupy the whole floor for minimising the operation costs.

Table 6.14: Factors contributing to the annual variations of influential parameters and simulation methods used for generating the data sets of post-retrofit conditions

Influential parameters	Factors contributing to annual variations	Simulation Methods
Lighting load (Office)	Lamp deterioration, manufacturing process deviation and replacement of existing lamps with new lamps	Change of 'Watts per Zone Floor Area of Lights' in *Energyplus*
Equipment load (Office)	Due to the provision of more workstations in the office or replacement of the existing equipment with more energy efficient one	Change of 'Watts per Zone Floor Area of Electric Equipment' for office premises in *Energyplus*
AC operating hours (Office)	Change of office hours due to change of tenants	Change of AC operating schedule for the office premise in *Energyplus*
Occupancy rate (Office)	Uncertain economic conditions (e.g. some tenants may move out due to economic downturn or rental increases)	Change of number of floor for the office premise in *Energyplus*
Occupancy rate (SA)	Uncertain economic conditions (e.g. some tenants may move out due to economic downturn or rental increases)	Change of number of floor for the SA premise in *Energyplus*
Overall COP of chiller plant after retrofit	Chiller deterioration: (1) scaling of evaporator coil and chilled water tubes, affecting heat exchange between refrigerants and chilled water; (2) normal wear and tear, leading to an increase in compressor power consumption	Change of COP of each chiller in *Energyplus*

Table 6.15: Results of Chi-Square, K-S and A-D tests and the assumed distribution for the selected parameters

Parameter(s)	Unit	Distribution	5% level	Mean	95% level	Standard deviation	Curve-fitting parameters: Chi-Square test	K-S test	A-D test	Sample Sizes
Building Load										
Lighting load (Office)	W/m^2	Triangular continuous	13.7	15	15.4	0.525	-	-	-	-
Equipment load (Office)	W/m^2	Triangular continuous	7.4	17.1	30.	7.23	2	0.096	0.28	30
AC operating hours (Office)[1]	Hour(s)	Logistic continuous	17.30	18.75	20.19	0.89	2392.2	0.19	22.2	521
Occupancy rate (Office)[2]	%(Floor)	Triangular continuous	81.1%(50)	90.2%(56)	97.3%(61)	4.9	0.15	0.17	0.34	13
Occupancy rate (SA)[2]	%(Floor)	Normal continuous	69.9% (20)	81.3%(23)	92.6% (26)	7.06	1.08	0.16	0.45	13
HVAC Plant										
Overall COP of chiller plant after retrofit	-	Triangular continuous	4.031	4.137	4.45	0.089	-	-	-	-

Notes:
1:The unit of AC operating hours is in terms of hours, for example, 19:30 = 19.5
2:As there is no occupancy rate of individual tower available for office and SA premises in the annual report, the mean value of the whole composite buildings was used.

s

(i) Occupancy Rate for Offices and SA Premises

Due to the economic growth or downturn, occupancy rates in offices and SA premises vary from time to time. For example, in 2003, the average occupancy rate dropped dramatically from 90.5% to 81.3% for the office premises and from 80.2% to 69.6% for the SA premises due to the economic impact of the Severe Acute Respiratory Syndrome (SARS) outbreak in that year. After that, the occupancy rates increased gradually to nearly the highest (Offices: 94% and SA: 88%) in 2011. In order to truly predict the variation of occupancy rates in the studied buildings, the PDFs of occupancy rate for the offices and SA premises were derived from 11 years' data (2001-2011) of the developer's annual reports. Based on those empirical data, the most suitable distributions to describe the sample variations of occupancy rates for the offices and SA premises are the triangular and normal continuous distribution respectively (the K-S test value for the office premise is 0.17, which is below the critical value of $D_{n=13}^{\alpha=0.05}$= 0.35 at 5% significance level, while the K-S test value for the SA premise is 0.16 which is also below the critical value of $D_{n=13}^{\alpha=0.05}$= 0.35 at 5% significance level).

(ii) Overall COP of chiller plant

The approach to develop the PDF of COP in Case Study II is the same as that in Case Study I. However, the main difference between two case studies on PDF determination is the best scenario of chiller plant performance after the active maintenance (e.g. tube chemical cleaning). In Case Study I, the existing air-cooled chillers were replaced with the new water-cooled chillers. Therefore, the best scenario would be no COP deterioration due to the use of new chillers. In Case Study II, since the existing chillers have been operating more than 5 years and no chiller is replaced during the retrofitting, the current chiller performance may be improved after active maintenance. Based on the study of Masaaki et al. (2008) in which the degree of improvement of chiller plant was investigated after tube chemical cleaning, 7.6%

improvement of chiller performance were assumed for the best case in this case study (assuming high quality of maintenance work during the contract period). For the deterioration rate, both case studies adopted the same approach for the determination.

(iii) Lighting load, equipment load, and operating hours

Other influential parameters such as lighting load (office premises), equipment load (office premises), and operating hours of AC system (office premises) in Case Study II are the same as that in Case Study I. The method and procedures for determining the suitable PDFs for those parameters can be referred to Section 6.4.5.

6.5.6 Simulation of energy savings

In order to simulate all possible post-retrofit conditions, 10,000 sets of data were generated based on the determined PDFs of the influential parameters using Monte Carlo simulation. These 10,000 sets of data were incorporated into *EnergyPlus* for energy use prediction. The total 20,000 simulations (10,000 simulations for the pre-retrofit models and 10,000 simulations for the post energy model) were conducted with 8 computers with two quad-core processors, using 15 hours to complete all simulations.

6.5.7 Results and discussion – Probability of energy savings

Figures 6.10 and 6.11 show the actual energy savings for all possible combinations of the influential parameters and the fitted distributions of energy savings in the case study buildings. The possible energy savings after 1-year retrofit period would range from 380,000 kWh (2.77% of baseline conditions) to 1,054,000 kWh (7.67% ditto) with 90% confidence, which is best fitted by a ‘Weibull’ distribution with a mean of 684,000 kWh (4.98%) and a standard deviation of 207,160 kWh. With a comparison between two case studies, the replacement project of heat rejection system in Case Study II has a narrower range of possible energy savings (from 2.77% to 7.67% with 90% confidence) than the chiller replacement project in Case Study I (from 37.6% to 49.2% with 90% statistical significance).

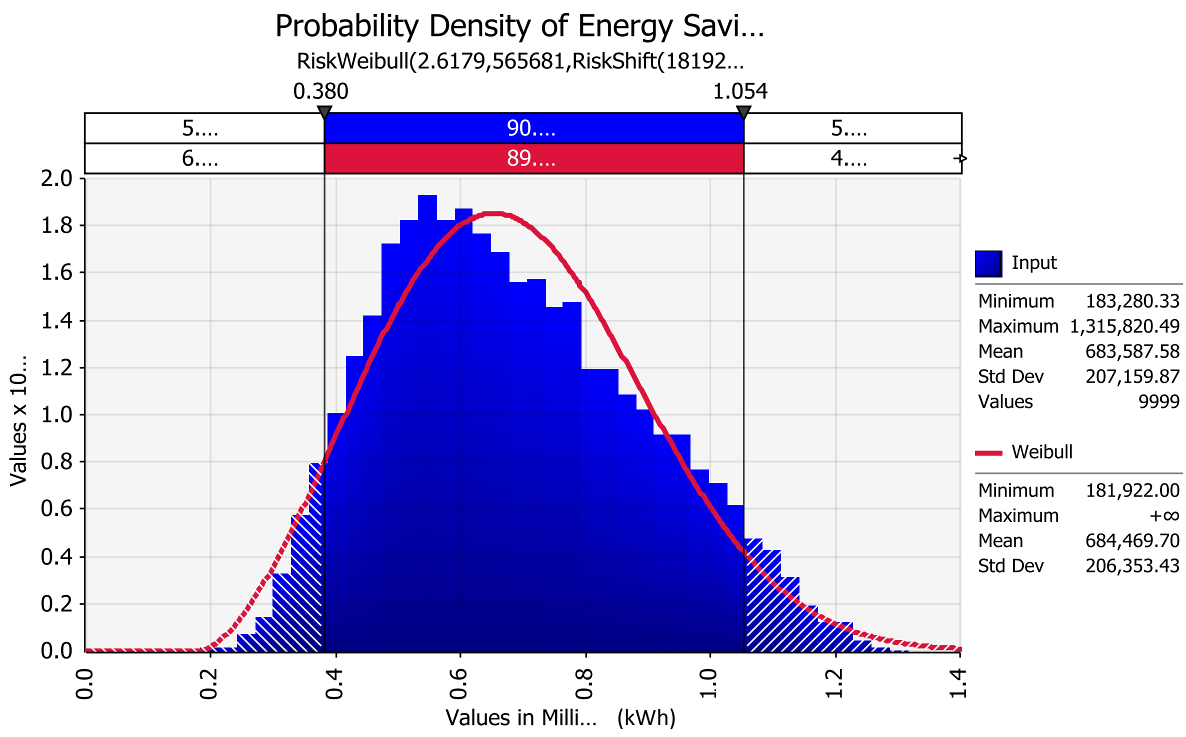

Figure 6.10: Probability density function of energy savings in Case Study II project
(based on @Risk – the Monte Carlo Simulation Program developed by Palisade Corp.)

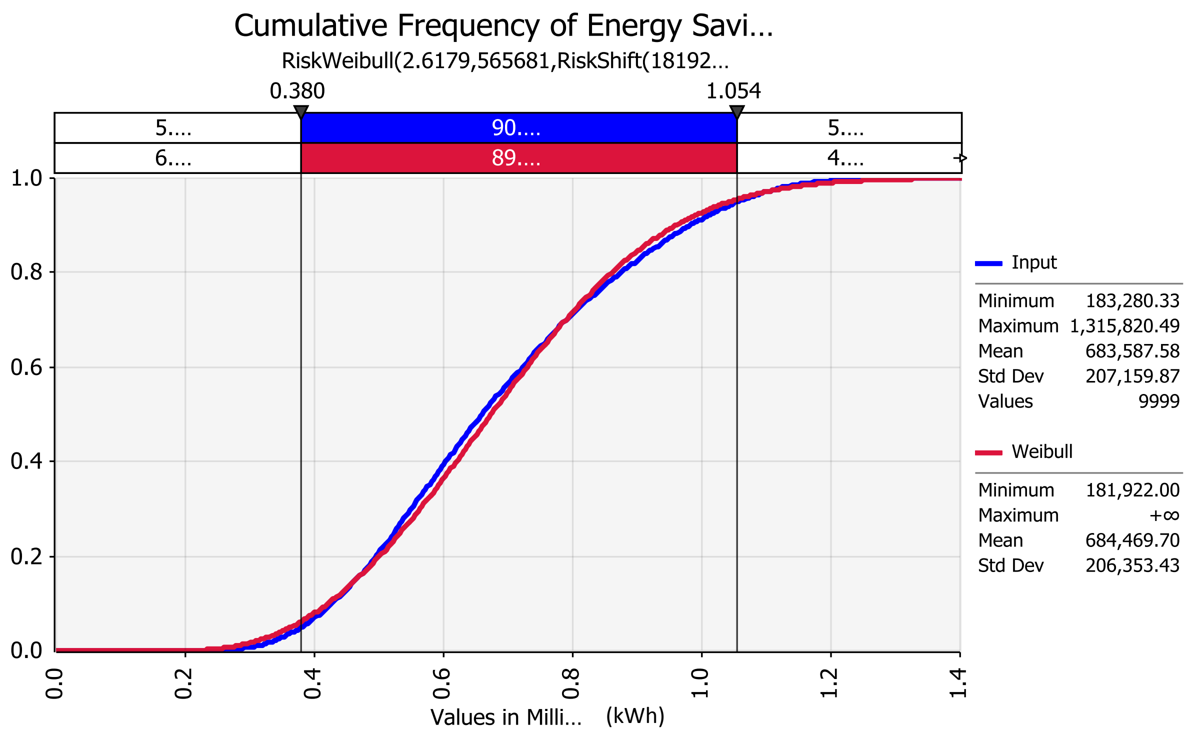

Figure 6.11: Cumulative frequency of energy savings in Case Study II project
(based on @Risk – the Monte Carlo Simulation Program developed by Palisade Corp.)

6.5.8 Validation of the proposed method

Due to the sensitive issues related to M&V data, the M&V results over the entire contract period would not be disclosed in this thesis. However, the confidence of the estimated results can rely on how the two building energy models represent the actual energy consumption of the building at the pre- and post-retrofit stages. In this study, the two models fulfilled the calibration requirements of ASHRAE Guideline 14, implying that the two models are representative enough of the actual performance of chiller plant at the pre- and post-retrofit stages. In addition, *EnergyPlus* has been validated with the ASHRAE standard 140 and its accuracy in energy prediction has been illustrated in published research for actual buildings (Witte et al., 2001; Carroll and Hitchcock, 2005). Since the same set of data describing the post-retrofit conditions were incorporated into both models for energy use prediction, the results obtained by *EnergyPlus* can reflect a range of possible energy savings at a known confidence level.

6.6 Case Study III – Lighting retrofitting in an office building

Unlike the previous two case studies, Case Study III is related to the lighting upgrading, which is one of the most common retrofitting works in Hong Kong. In this section, a hypothetical square-shaped (36m×36m) 40-stoery office building is used to represent a typical office building in Hong Kong, which serves as a pre-retrofit model for an evaluation of performance risks in a lighting retrofitting project. This hypothetical building is developed based on survey findings of 64 commercial buildings in Hong Kong, which summarised the representative design characteristics of existing commercial buildings (Chan and Chow, 1998).

6.6.1 Description of the hypothetical office building

Table 6.16 presents the building characteristics and lighting system of this pre-retrofit building model. The window heights and floor-to-floor height are 1.6m and 3.2m respectively, and a window-to-wall ratio (WWR) of 0.5 is reckoned. The windows consist of double-glazing of 6mm reflective glass each, and the centre-of-glass window transmittance is 0.75. Figure 6.12 shows the typical floor of the building. This office building is an open plan design and divided into three zones, namely, ‘perimeter zone’, ‘interior zone’ and ‘lift core’. Similar to other existing buildings in the 1990s, ceiling-mounted recessed T8 fluorescent lamps with magnetic ballasts are assumed to be used in this this pre-retrofit model, and the lighting power density is 25W/m^2 (Lee and Yik, 2010), which also represents the lighting design and lamp performance at that time. A manual on-off control is employed to switch electrical lighting in the pre-retrofit design. Regarding the occupancy pattern, the data is based on the suggestions in Hong Kong’s Building Energy Code for simulation purpose (EMSD, 2012). In actual practice, all the above information can be obtained through an energy audit.

Table 6.16: Descriptions of a model building

	Unit	Office Building ‘C’
General		
Number of storeys	-	40 storeys above ground
Floor dimension	m	36 x 36 (L x W)
Floor-to-floor height (m)	m	3.2
Orientation	-	N/E/S/W
Window-to-wall ratio	-	0.5
Window transmittance	-	0.75
Design criteria		
Occupancy density	m^2/person	9
Lighting load density	W/m^2	25
Lighting system	-	ceiling-mounted recessed T8 fluorescent lamps with magnetic ballasts

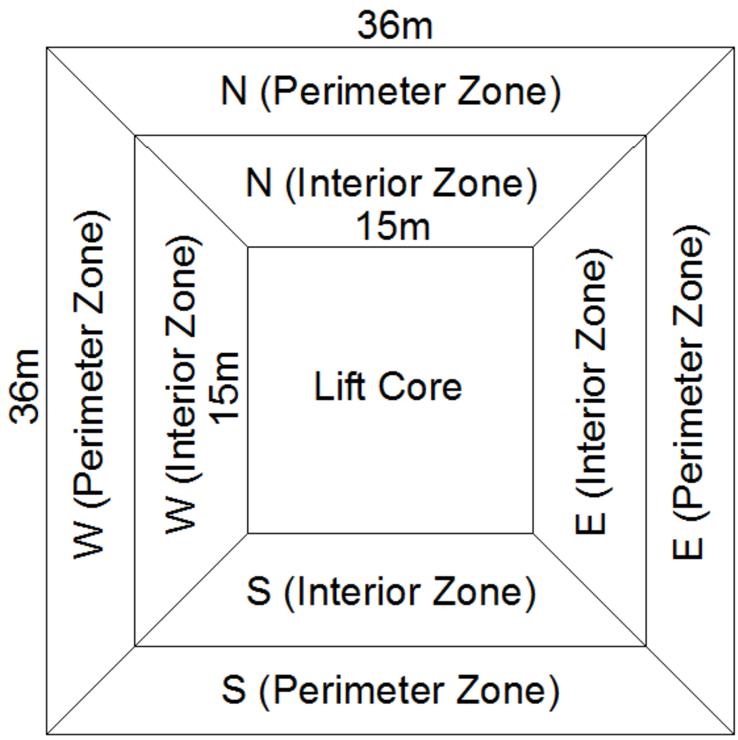

Figure 6.12: Typical floor zones of an open-plan office model building

6.6.2 Lighting retrofitting

Regarding lighting retrofitting, a replacement of existing lighting with T5 tubes, installation of daylight-linked lighting controls and occupancy-based controls are the most common measures to improve energy performance in an existing lighting system. The New York Times Headquarters Building is a famous example for those applications in which T5 dimmable tubes with daylighting and occupancy controls are adopted to reduce energy consumption in the lighting system (Fernandes et al., 2014). In this study, the above lighting improvement measures are assumed to be implemented in the hypothetical building for an illustration of this probabilistic approach.

T5 fluorescent tubes

In the current fluorescent lamp technology, T5 FTs are the latest and most energy efficient lighting lamps, and it has been widely used in different lighting retrofitting projects, such as

Langham Place Hotel in Hong Kong (Cheung and Fan, 2013). T5 FTs can reach a luminous efficacy of more than 100 lm/W, which consume 12% and 45% less energy than its predecessors T8 and T12 respectively (Mahlia et al., 2011).

Daylight-linked lighting controls

Based on the level of available daylight, the artificial lighting intensity can be reduced accordingly using dimmable electronic ballasts to maintain the pre-set level of illuminance in the zone. Several studies indicated that the use of daylight not only reduces energy use, but also enhances working performance and visual comfort (Heschong et al., 2002; Kruger and Fonseca, 2011). Haq et al. (2014) summarised various daylighting studies relating to the determination of energy saving from daylighting controls. It was found that the amount of energy savings can range from 11% to 65.5% depending on different control methods, obstructions and window properties.

Occupancy-based controls

With the use of occupancy sensors, the lamps are switched on automatically when the sensors detect any occupant in a given zone, and switched off when there is no occupant. This lighting control is particularly useful in open plan offices as a zone occupancy lighting control scheme is used. Roisin et al. (2008) found that 8.7% - 11% energy saving can be achieved when an occupancy-based control scheme is adopted in the lighting system.

6.6.3 Development of building energy models

Similar to other two case studies, *EnergyPlus* is used to simulate the energy consumption of lighting system in this pre-retrofit model. In *EnergyPlus*, there are two daylighting algorithms, which are the split-flux and radiosity methods, for simulation. The split-flux method calculates the daylight factor at a point, through totalling the direct and reflected daylight, whilst the radiosity method determines the radiation transfer among surfaces based on the results of form factor. Its accuracy in predicting the performance of daylighting and light control systems has been illustrated in actual buildings (Witte et al., 2001; Carroll and Hitchcock, 2005). Although there are several other lighting simulation programs such as *Radiance* and *Daysim*, which use more advanced daylighting algorithms (e.g. the ray-tracing method) in calculating daylight illuminance in space, these programs are only limited to modelling lighting systems. When the retrofitting involves a combination of lighting upgrading and air-conditioning improvement, which are commonly implemented in existing buildings, *Energyplus* is capable of modelling those systems and estimating energy savings due to the combined retrofitting.

Pre-retrofit model

In this study, only one typical floor, which represents the average conditions in the entire 40 storeys, was constructed using *EnergyPlus*. Based on the said building configurations and a typical office operating pattern described in local building energy codes, the lighting energy use for this pre-retrofit model is 2,953,000 kWh per annum.

Post-retrofit model

Similarly, the post-retrofit model was developed based on the characteristics of the pre-retrofit model except the retrofitting measures. Table 6.17 shows the scope of lighting retrofitting works and the simulation methods used in this study. The details of each lighting retrofitting measure are described as follows:

Table 6.17: Pre-and post-retrofit models and the simulation methods for the proposed lighting retrofitting measures

	Pre-retrofit model	Post-retrofit model	Simulation methods
Lighting system	Ceiling-mount recessed T8 fluorescent lamps	Ceiling-mount recessed T5 fluorescent lamps	Input of lighting power density (LPD) to represent the arrangement of fluorescent lamps.
		Daylight-linked lighting controls (with installation of automatic roller shades to control direct sunlight and window glare)	Installation of two photo-sensors to monitor the current horizontal illuminance in each perimeter zones. Determination of fractional outputs of electric lighting so as to maintain a 500lux set-point level at a working plane.
		Occupancy-based controls	Input of lighting schedule with 15-minute intervals between 6:00am to 8:00am and between 8:00pm to 1:00am. Development of eight sub-divided zones (based on 4 orientations in each of the two non-core zones) with individual lighting use patterns. (based on the assumption that occupancy is directly linked to lighting use)

6.6.4 Simulation method of lighting retrofitting measures

The use of T5 tubes in the post-retrofit model can be simulated through reductions in lighting power density (LPD). LPD is defined as the electrical power consumed by lighting installations per unit floor area (EMSD, 2012). As discussed above, T5 FTs have a higher luminous efficacy than T8 FTs, enabling each luminaire to be arranged with wider distances and less power consumption without compromising the illuminance of the office environment. Wu (2015) carried out a technical study in Hong Kong on the actual performance of T5 FTs, showing the use of T5 FTs can reduce the LPD to a value of 18 W/m^2 in an office building.

For daylighting simulation, dimmable daylighting controls were assumed to be implemented in all open-plan perimeter zones. Two photo-sensors were installed at a working plane 0.75m above the floor-level and at a horizontal depth of 2.5m from the window to monitor the current horizontal illuminance in each perimeter zone. The outputs of all fluorescent lamps in four perimeter zones were adjusted accordingly in response to the photo-sensor signal to maintain a 500lux set-point level. Roller shades were also installed in the perimeter zones to control direct sunlight and window glare. When the total solar-irradiance incident exceeds 200 W/m^2, which is the preferred comfort level (Li and Wong, 2007), the roller shades will operate automatically.

Occupancy-based controls were implemented in all the zones of the post-retrofit model (four perimeter zones and four interior zones). By using the occupancy-based control, the lamps in the particular zone will be switched off automatically when there is no occupant in that zone. As *EnergyPlus* cannot directly support the occupancy-based controls for lighting energy use simulation, an alternative is used to achieve such a simulation. Based on the assumption that occupancy is directly linked to lighting use, the lighting schedule in each zone was developed separately with consideration of the effect of occupancy. In typical office buildings, the occupancy-based controls are particularly effective when occupants arrive early or leave late in the day sporadically, which can be detected by motion sensors (Fernandes et al., 2014). Therefore, the low occupancy hours between 6:00am to 8:00am and between 8:00pm to 1:00am are the most effective hours to achieve energy savings using occupancy-based controls. In addition, with the consideration of effect of time delay where the occupancy control system waits for a pre-fixed intervals before it switches off the lamps, the intervals of lighting schedule was refined from an hour to 15 minutes. The details of simulation of the effect of occupancy-based controls are presented in Section 6.5.1.

6.6.5 Probability distribution of the influential parameters

Literature shows that the performance of the above lighting retrofitting measures will be affected by a number of factors, including sky conditions, occupancy patterns and lamp deterioration (Haq et al., 2014). In order to evaluate a range of possible energy savings at a known confidence level, each influential parameter should be assigned a PDF. In this study, four influential parameters affecting energy savings in relation to this lighting retrofitting were identified. They were daylighting availability, occupancy rates, lamp condition and lighting use patterns. In this study, correlation analysis (CA) is not conducted since the purpose of CA is to eliminate the parameters which are less sensitive to energy use. As only four parameters were identified, the number of parameters is considered as manageable to develop their respective PDFs. Similar to the previous case studies, the determination of corresponding PDF for those parameters is based on the empirical data from official database and previous research. Table 6.18 shows the test results and the assigned probability distribution functions of those influential parameters. Table 6.19 indicates the factors contributing to annual variations of the influential parameters and the methods used in simulating these variations, including a morphing approach for adapting a weather file to incorporate daylight availability. Each influential parameter will be discussed as follows:

Table 6.18: Factors contributing to the annual variations of influential parameters and simulation methods used for generating common data sets of post-retrofit conditions

Influential parameters	Factors contributing to annual variations	Simulation Methods
Daylight availability	Positon of the sun, cloudiness, concentration of suspended particulates in the air, etc.	Stretch of global solar radiation (GSR) and diffuse solar radiation (DSR) in a TMY weather file with monthly scaling factor derived from the 17 years' Hong Kong Observatory measured data.
Occupancy rates (in term of number of floors)	Uncertain economic conditions (e.g. some tenants may move out due to economic downturn or rent increase)	Change of number of floor.
Lamp power	manufacturing process deviation, lamp deterioration, etc.	Change of lighting power density (LPD).
Lighting use pattern	Change of office hours due to change of tenants	Change of hourly lighting schedules Note: eight sub-divided zones (based on four orientations in each of the two non-core zones) were developed with individual lighting use patterns.

Table 6.19: The assigned probability distribution functions of influential parameters

Parameter(s)	Unit	Distribution	5% level	Mean	95% level	Standard deviation	Curve-fitting parameters: Chi-Square test	K-S test	A-D test	Sample Size
Climatic Parameters										
Monthly Mean Global Solar Radiation (January)	MJ/m^2	ExtValue continuous	8.16	10.35	13.47	1.68	0.12	0.13	0.24	17
Monthly Mean Global Solar Radiation (February)	MJ/m^2	ExtValueMin continuous	6.28	10.28	13.08	2.14	1.53	0.16	0.42	17
Monthly Mean Global Solar Radiation (March)	MJ/m^2	Pareto continuous	9.31	11.17	15.54	2.41	0.88	0.16	-	17
Monthly Mean Global Solar Radiation (April)	MJ/m^2	Logistic continuous	8.92	12.14	15.35	1.98	0.47	0.09	0.15	17
Monthly Mean Global Solar Radiation (May)	MJ/m^2	ExtValueMin continuous	11.22	14.41	16.64	1.71	0.12	0.11	0.23	17
Monthly Mean Global Solar Radiation (June)	MJ/m^2	Uniform continuous	10.56	13.96	17.36	2.18	0.82	0.11	0.22	17
Monthly Mean Global Solar Radiation (July)	MJ/m^2	Uniform continuous	12.25	17.05	21.84	3.08	2.94	0.13	0.33	17
Monthly Mean Global Solar Radiation (August)	MJ/m^2	ExtValue continuous	12.92	15.75	19.81	2.17	0.82	0.10	0.16	17
Monthly Mean Global Solar Radiation (September)	MJ/m^2	Uniform continuous	12.22	14.79	17.35	1.65	1.53	0.14	0.48	17
Monthly Mean Global Solar Radiation (October)	MJ/m^2	Laplace continuous	12.30	14.51	16.72	1.36	2.24	0.21	0.81	17
Monthly Mean Global Solar Radiation (November)	MJ/m^2	Normal continuous	9.64	12.10	14.55	1.49	0.82	0.10	0.15	17
Monthly Mean Global Solar Radiation (December)	MJ/m^2	Uniform continuous	8.61	10.96	13.30	1.50	1.53	0.14	0.34	17
Climatic Parameters										
Occupancy rates	% (Floor)	Triangular continuous	81.1% (32)	90% (36)	97.3% (39)	4.9	0.15	0.17	0.34	13
Lamp Power (in terms of Lighting Power Density)	W/m^2	Normal continuous	16.65	18[a]	19.36	0.824[1]	-	-	-	-
Lighting use patterns[2]	hour	Discrete	Refer to the study of Yun et al. (2012)				-	-	-	-

[1] the mean value of PDF is 18 W/m^2 which is adopted from Wu's study which evaluates the actual performance of T5 FL, whilst the standard deviation is assumed to be 0.824 W/m^2 (based on the maximum lamp degradation percentage for a conservative evaluation).
[2] the lighting use patterns are defined based on hourly lighting use conditions where 'all the lighting was off", 'half of the lighting was on', and 'all the lighting was on' are used in this study. As for simulating the effect of occupancy-based controls, the intervals of lighting use condition are refined from an hour to 15 minutes during low-occupancy hours (between 6:00am to 8:00am and between 8:00pm to 1:00am).

Daylight availability

Daylight availability is one of the most critical factors affecting energy savings in daylighting control system, and its availability depends on the position of the sun, cloudiness, as well as concentration of suspended particulates in the air. In fact, the amount of daylight varies from year to year. This can be reflected by the measured data of global solar radiation retrieved from the Hong Kong Observatory (HKO), as the level of daylight is closely related to the level of solar radiation. From the latest 17 years' measured data (1997-2013) of monthly mean daily global solar radiation (GSR), the overall range (maximum to minimum) is 49.3 percent of the annual mean. February and April are the two months with the greatest variation within a year, having a range of 71 percent and 67 percent of the monthly mean respectively. This uncertainty in year-round daylight availability can significantly affect the actual energy savings for daylighting control systems.

To predict the variations in daylight availability over a year, twelve PDFs of individual months of Global Solar Radiation (GSR) were derived based on the latest 17 years' measured data (1997-2013) retrieved from HKO. The selection of the most suitable PDF for an individual month was performed using @Risk, which calculates and ranks the values of those three test results (Chi-square test, K-S test, and A-D test) with all possible PDFs. As the sample size is less than 30 for the GSR parameter, the K-S test is more suitable to be used when compared with others (Ang and Tang, 2007). For instance, in the determination of the most suitable PDF of GSR in the month of January, the observed data of this parameter (sample sizes = 17) was fitted to all possible distributions using *@Risk*. After that, *@Risk* automatically ranked the values of K-S test with those distributions. Based on the test result, 'an extreme value (Extvalue) distribution' achieves the lowest value (0.13), implying that the extreme value (Extvalue) distribution best describes the pattern of the sampled data. Apart from the selection of the lowest value, the value also needs to be below the critical value, which is $D_{n=17}^{\alpha=0.05}$= 0.32 at 5% significance level in this case. The assigned distribution can be regarded as an acceptable representation of the observed data when those two criteria are fulfilled. Similarly, the same technique was employed to determine the suitable PDFs for the remaining months and the test results are listed in Table 6.19.

With the determined PDF of GSR for individual months, all the possible Hong Kong weather data files taking into account the monthly variations in GSR can be constructed. *EnergyPlus* requires hourly meteorological input data for building energy use simulation. It uses Typical Meteorological Year (TMY) as a weather file to represent the long-term typical weather conditions over a year. To predict the possible daylight conditions over a year, the TMY weather file for Hong Kong's global location was modified by a morphing method (for the details of morphing method, please refer to Section 6.4.4). As a result, 10,000 new TMY weather files were generated based on the results of Monte Carlo simulation.

In this study, the GSR and diffuse solar radiation (DSR) as contained in Hong Kong TMY weather files were morphed by a stretch algorithm to generate other possible sets of Hong Kong TMY weather file for simulation in *EnergyPlus*. A scaling factor (αgsr_m) was calculated based on Eq.(6.6):

$$\alpha gsr_m = 1 + \frac{\Delta DSWF_m}{\langle gsr_o \rangle_m} \qquad \text{Eq.(6.6)}$$

where αgsr_m is the scalar factor of global solar radiation for each month; $<gsr_o>_m$ is the monthly mean daily global solar radiation of *EnergyPlus* weather file data; $\Delta DSWF_m$ is the predicted absolute change in monthly mean daily global solar radiation of Hong Kong Observatory weather data.

It is worth noting that each month of GSR and DSR was stretched with different scaling factors because the variation in its value is different from month to month in Hong Kong. The scaling factor calculated for each month was then applied to the current hourly GSR and DSR of typical Hong Kong TMY weather file. Same as the treatment of Belcher et al. (2005) on the scaling factor of DSR, it was assumed that DSR changes in proportion to GSR.

$$gsr = \alpha gsr_m \, x \, gsr_o \qquad \text{Eq.(6.7)}$$

$$dsr = \alpha gsr_m \, x \, dsr_o \qquad \text{Eq.(6.8)}$$

where gsr_o is the current hourly global solar radiation of *EnergyPlus* weather file data; dsr_o is the current hourly diffuse solar radiation of *EnergyPlus* weather file data;

All the morphing processes involved above were automatically performed using *Excel VBA*. As such, 10,000 weather files taking into account the annual variations in GSR and DSR were constructed.

Lighting use patterns

Lighting use pattern is one of the influential factors affecting actual energy savings in lighting retrofitting. Lighting use patterns may change from time to time, especially when there are changes of tenants. This is because new tenants may request for extension of lighting operating hours in order to suit their business needs. Therefore, an accurate determination of variations in lighting use patterns is critical to the success of achieving expected energy savings in EPC projects. Yun et al. (2012) carried out a field measurement on the actual office setting to investigate a daily variation in lighting use patterns. The measurement period lasted six months in four offices and three lighting use conditions, namely ‘all the lighting was off’, ‘half of the lighting was on’, and ‘all the lighting was on’, were simulated to determine the probability of hourly lighting use conditions for weekdays in office premises.

For example, the probability under the 'all the lighting was on' condition in an office was over 95 percent at 11:00am, whilst the probability under this condition at 9:00pm was less than 20 percent. In this study, the PDF of hourly lighting use condition was derived based on the Yun et al. (2012) study, in which a discrete distribution is used with the probability of three lighting use conditions (i.e., all the lighting was off/ half of the lighting was on/ all the lighting was on).

It should be noted that eight sub-divided zones (based on 4 orientations in each of the 2 non-core zones) were developed with individual lighting use patterns in a typical office floor of this building model. The main advantage of this zoning is to more accurately simulate the effect of occupancy-based controls which is often installed separately in each zone of a typical floor. This is because the lighting in one particular zone is switched off due to no occupant being present, and vice versa. In addition, the intervals of lighting schedule is refined from an hour to 15 minutes between 6:00am to 8:00am and between 8:00pm to 1:00am in each simulation run so as to consider the effect of time delay where the occupancy-based control is programed with a pre-fixed interval to avoid frequent on-off operations of lighting. With the consideration of the above configurations, a total of 241 discrete distributions for the lighting use patterns were developed (17 time-slots at 1-hour interval (17 discrete distributions); 7 timeslots at 15-min interval (7x4x8=224 discrete distributions)).

Occupancy rates and lamp conditions

The approach to determine the suitable PDF for the parameters of 'occupancy rates' and 'lamp conditions' is the same as that in Case Study I and II. The details can be referred to in Section 6.4.5. and 6.5.5. It is noted that for the 'lamp conditions' in this case study, T5 FLs were assumed to be used for energy savings. Therefore, the values of 5% level and 95% level were revised accordingly. In this study, a normal distribution was assumed for the PDF of LPD, and the mean value of PDF was 18 W/m^2 which was adopted from Wu's study which evaluates the actual performance of T5 FL (Wu, 2015). The standard deviation was assumed to be 0.824 W/m^2 (based on the maximum lamp degradation percentage as a conservative evaluation).

6.6.6 Simulation of energy saving

The whole procedure can be divided into two main steps. First, Monte Carlo simulation was used to generate 10,000 common sets of data based on the assigned PDF to simulate the possible annual conditions during the post-retrofit period. By doing so, two individual groups of files were created. One file group contains 10,000 common sets of data describing the possible lighting schedules, values of occupancy rate and lighting power density. Another file group is 10,000 sets of weather file which takes into account the annual variations in daylight availability. Second, *jEPlus* was utilised to automatically substitute the base case value of both the pre- and post-retrofit models with the common data sets of the post-retrofit conditions and run the simulation through *EnergyPlus*. The result of each *EnergyPlus* simulation run represents one of the operating conditions during the post-retrofit period. With 10,000 simulation runs, a range of possible energy savings taking into account the annual variations in those influential parameters can be obtained. It is noted that 20,000 iterations were performed (10,000 iterations for each model) in this study with a multi-core processor computer. The whole simulation took 10 hours to complete.

6.6.7 Results and discussion - Probability of energy savings

Figures 6.13 and 6.14 show the probability of energy savings in this lighting retrofitting project. The result shows that the variations in actual energy savings can be substantial. The possible annual energy saving can range from 1,267,000 kWh (43% of pre-retrofit consumption) to 1,927,000 kWh (65% ditto) with 90% confidence. The maximum energy saving can be 2 times higher than the minimum one. The mean value of energy savings is 1,564,000 kWh (53%) with a standard deviation of 201,391 kWh. The distribution of possible energy savings can be best described by a Gamma distribution.

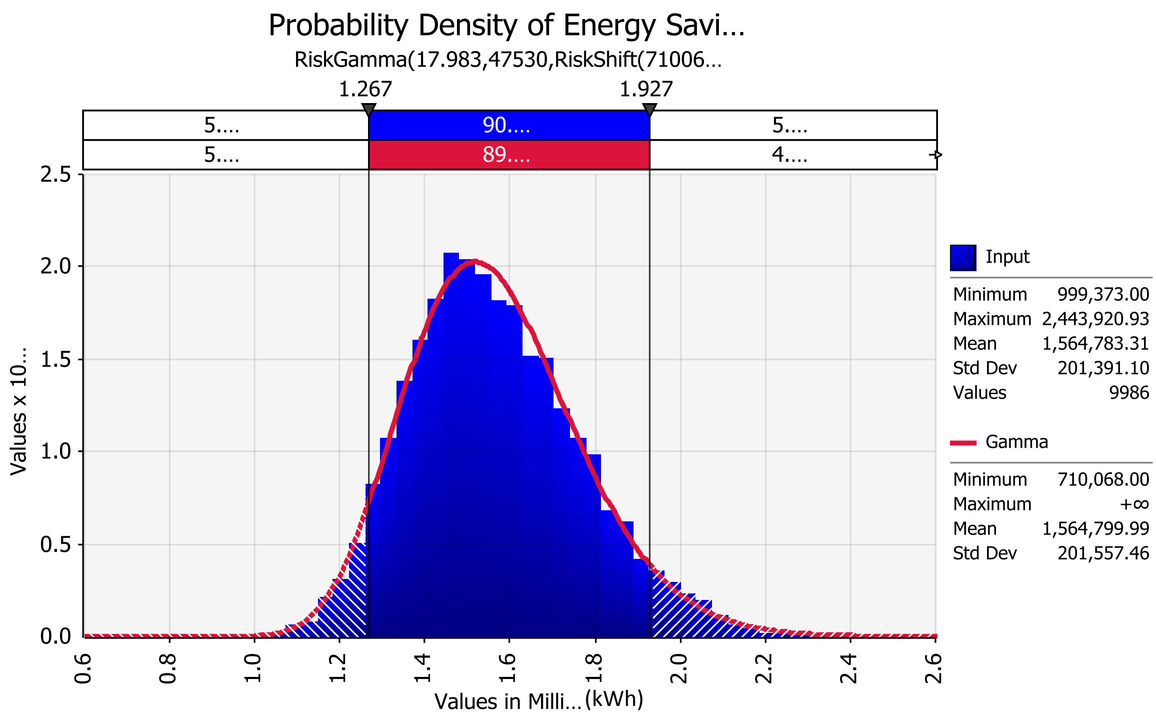

Figure 6.13: Probability Density Function of energy savings in the lighting retrofitting Case Study III project
(based on *@Risk* – the Monte Carlo Simulation Program developed by Palisade Corp.)

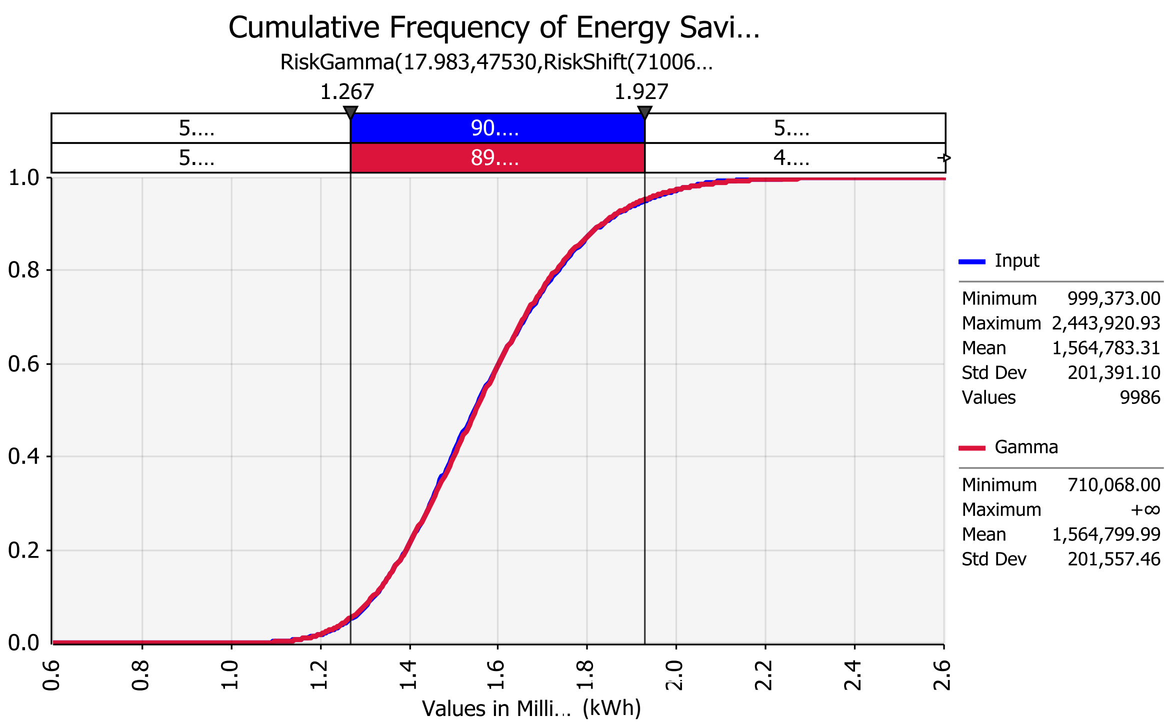

Figure 6.14: Cumulative frequency of energy savings in the lighting retrofitting Case Study III project
(based on *@Risk* – the Monte Carlo Simulation Program developed by Palisade Corp.)

6.6.8 Validation of the proposed method

Unlike Case Study I and II, there is no empirical data (e.g. electricity bills) to calibrate the pre- and post- retrofit models to ensure that the models are representative of the actual buildings. Therefore, a comparison of estimated energy savings between the simplified engineering approach and the probabilistic approach was made, as well as seeking validation of the method from experts. The simplified engineering approach is commonly used in practice and involves fundamental equations with reasonable assumptions (Krarti, 2011). Table 6.20 shows the comparison result of these two methods. In the simplified engineering approach, the estimation of energy savings for the proposed lighting retrofitting measures can be divided into three parts: (1) energy savings from replacement of T8 with T5, which can be predicted based on the reduction in Lighting Power Density (LPD) (in this study, the reduction in LPD is from 25W/m^2 to 18W/m^2, contributing to 28% of energy savings); (2) energy savings from installation of occupancy-based controls, which can be evaluated based on a related study by the Electric Power Research Institute (EPRI) (EPRI., 1999) (e.g. 20% to 25% of energy savings for open space office); and (3) energy savings from installation of daylighting controls, which can be calculated by the following equation (Krarti et al., 2005):

$$f_d = b[1 - \exp(-a\tau_w A_w/A_p)]\frac{A_p}{A_f} \qquad \text{Eq.(6.9)}$$

where f_d is the annual percent saving in the use of artificial lighting with daylighting controls in office buildings; A_w/A_p is window-to-perimeter floor area; A_p/A_f is perimeter-to-total floor area; a and b are coefficients which depend on the building location; τ_w is the visible transmittance of the glazing. Since the coefficients of a and b are not available for Hong Kong, published data for several locations near to Hong Kong such as Shanghai, Kuala Lumpur and Singapore are used for estimation (see Table 6.21). By a pro-rata estimate based on the latitudes for these locations, it was calculated that the installation of daylighting controls can achieve 32.8% energy savings in Hong Kong. With the summation of the above estimated energy savings, the total maximum energy saving by these retrofit measures is 2,362,400kWh (80%), which is below the range of energy savings at 90% confidence. It is noted that *EnergyPlus* is employed to predict the energy savings after the lighting retrofitting in this study. Its accuracy in predicting the energy use of daylighting and light control systems has been demonstrated in actual buildings. Although there is no empirical data to support the simulation results in this study, it is still believed that the results will be valuable to both ESCOs and hosts in estimating energy savings due to the confidence on *EnergyPlus*.

Table 6.20: Comparison between the simplified engineering approach and the probabilistic approach

	Simplified Engineering Approach	Probabilistic Approach
Energy savings from replacement of T8 with T5 (kWh)[a]	826,840 (28%)	Mean value: 1,564,000 (53%) Range: From 1,267,000 (43%) to 1,927,000 (65%) with 90% confidence Savings profile resembles Gamma distribution
Energy savings from installation of occupancy-based controls (kWh)[b]	From 590,600 to 738250 (20%-25%)	
Energy savings from installation of daylighting controls (kWh)[c]	944,960 (32.8%)	
Total energy savings (kWh)	Maximum savings 2,362,400 (80%)	

[a] The percentage of energy savings from the replacement of T8 with T5 is calculated based on the reduction in Light Power Density (LPD) from $25W/m^2$ to $18W/m^2$.
[b] The percentage of energy savings from the installation of occupancy-based controls is determined based on the study by the Electric Power Research Institute (EPRI).
[c] The percentage of energy savings from the installation of daylighting controls is calculated based on a formula suggested by the study of Krarti et al. (2005)

Table 6.21: Coefficient *a* and *b* of Eq. 7 for various locations (see the study of Krarti et al. (2005) for a full list of published locations)

Location[a] (Coordinates)	*a*	*b*	Estimated Energy Savings (%)
Shanghai (31.2° N, 121.5° E)	19.4	67.29	32%
Hong Kong (22.3° N, 114.2° E)	N/A	N/A	32.8% (pro-rata estimate)
Kuala Lumpur (3.1° N, 101.7° E)	20.15	72.37	34.5%
Singapore (1.3° N, 103.8° E)	23.27	73.68	35.2%

Note: N/A means not available

In addition, the proposed method has been commented by a Chartered Engineer who is specialised in lighting technologies. He commented that the proposed approach to evaluate the probability of energy savings for lighting retrofitting is reasonable and that the most influential parameters affecting energy savings for the ECMs have been considered. From his previous work experience, the replacement of T8 FTs with T5 FTs can often contribute to around 30% of energy savings in most office buildings. With the additional savings from daylighting and occupancy-based controls, the predicted result of energy savings from the proposed method are reasonable (ranging from 43% to 65% of pre-retrofit consumption with 90% confidence). However, it was noted that the proposed method did not consider the impact on savings due to different site conditions. For example, in practice, it is common that not all FTs in the respective zone are connected together, especially when the buildings are more than 10 years old. Some of the FLs may be connected to other zones. Therefore, the daylighting and occupancy-based controls may not achieve energy savings as expected. The proposed method will be more applicable when there is no constraint on wiring issues in buildings. It would be difficult to build algorithm to take into consideration the actual site conditions. Hence, this is accepted as a limitation of the method.

6.7 Lessons learnt from the above three case studies

Case Study I and II are related to retrofitting works on the central chiller plant. As identified by correlation analysis, the key factors leading to saving uncertainties include (1) overall COP of chiller plant; (2) equipment load; (3) occupant density; (4) occupancy rate; (5) lighting load; (6) thermostat set point; and (7) AC operating hours. In order to mitigate the performance risks on the chiller plant retrofitting, three approaches are suggested as follows: (1) frequent maintenance; (2) clear contractual stipulations; and (3) increase in risk premium. For instance, to ensure that the chiller plant is operating at the optimal conditions, the ESCO should review the operating data of a chiller plant from time to time. Once the operating performance of the chiller plant is not as expected, possible rectifications such as tube chemical cleaning and parts replacement should be carried out. Besides, a contractual approach may be used to limit the range of possible settings in thermostat set-points. When the host wishes to adjust the setting beyond the agreed limit, prior consent should be obtained from the ESCO for baseline adjustment. For the parameters of AC operating hours, lighting load, equipment load and occupancy rate, a baseline adjustment mechanism should be well developed prior to project implementation. For example, the energy baseline should be adjusted accordingly based on an agreed formula when the changes in these parameters are more than 5% of the original situation. For the parameter of occupant density, it may be very difficult to evaluate the occupant density, which changes from time to time. Therefore, one possible way of mitigating this type of risk would be to increase the risk premium at the bidding stage and/or provide a lower level of guarantee on energy savings (having known the possible range at a certain confidence level). These are possible ways to manage the risks of energy saving shortfalls for chiller plant retrofitting under an EPC project setting.

For lighting retrofitting, the key factors leading to saving uncertainties often involve four aspects: (1) daylight availability; (2) occupancy rates (3) lighting use pattern; and (4) lamp conditions. Since the variability in the parameter of daylight availability is an intrinsic risk, it is difficult for the ESCO to truly predict the actual variations in climatic conditions from year to year (e.g. cloudiness). Therefore, it is suggested that the ESCO should increase the risk premium at the bidding stage and/or provide a lower level of guarantee on energy savings (also based on a known range at a known confidence level). For the parameter of lamp conditions, the ESCO should obtain the information regarding lamp deterioration rate from the manufacturers or suppliers such that the estimated energy savings would not be too aggressive. For the parameters of occupancy rate and lighting use patterns, the baseline adjustment mechanism should be well established and agreed upon prior to project implementation.

In comparison with the other estimation approaches, the proposed probabilistic approach not only considers the annual variations in the influential parameters during the post-retrofit period, but also provides a range of possible energy savings at a given confidence level. With the additional information on the probability of energy savings, the ESCO can more accurately estimate the amount of possible energy savings, as well as the probability of energy saving shortfall when a certain amount of energy savings is anticipated. For example, in Case Study III, it can be found from Figure 6.13 that there will be a 95% chance to achieve the guaranteed level when the ESCO guarantees the host 1,267,000 kWh (43%) energy savings per year in that lighting retrofitting project.

6.8 Chapter summary

This chapter presents a risk assessment approach for evaluating the probability of energy saving shortfalls, taking into account the variations in the influential parameters affecting energy savings. The approach involves the use of a detailed building energy simulation program (e.g. *EnergyPlus*), correlation analysis and Monte Carlo simulation technique. Three case studies with different retrofitting measures, including chiller replacement, change of heat rejection system and lighting upgrading, were used to demonstrate the application of this probabilistic approach.

Based on those three case studies, it is found that for the chiller plant retrofitting, the key factors leading to saving uncertainties include (1) overall COP of chiller plant; (2) equipment load; (3) occupant density; (4) occupancy rate; (5) lighting load; (6) thermostat set point; and (7) AC operating hours, whilst for the lighting retrofitting, the key factors leading to saving uncertainties often involve four aspects (1) daylight availability; (2) occupancy rates (3) lighting use patterns; and (4) lamp conditions. It is suggested that the ESCO can better manage those risks by an increase in risk premium, proper maintenance work and clear contractual stipulations to ensure that the actual energy savings are achieved as expected.

With the use of the proposed approach, the ESCO and host would be able to identify the influential factors affecting energy savings, and evaluate a range of possible energy savings at a given confidence level. This would help both parties to evaluate the level of expected energy savings prior to project implementation.

The next chapter will discuss the comparison results between different standard forms of EPC contract in overseas countries. The findings will provide a solid foundation for developing the local EPC contract template, which will be used in building up the model of EPC for Hong Kong in Chapter 8.

CHAPTER 7: A COMPARATIVE STUDY OF STANDARD CONTRACT CONDITIONS FOR EPC

Chapter 7 – A Comparative Study of Standard Contract Conditions for Energy Performance Contracting

7.1 Introduction

The findings of Chapter 4 and 5 suggest a need for developing a set of EPC contract templates for use in Hong Kong. In order to develop such templates, this chapter first highlights the difference between EPC contracts and construction contracts. Second, the backgrounds and purposes of standard forms of EPC contract available in eight jurisdictions, including Australia, Canada, China, Japan, Singapore, Taiwan, the United Kingdom and the United States, are discussed. Third, a comparative study of those contracts is conducted to highlight key differences for reflecting various treatments of common contractual issues in EPC projects, including performance guarantee, excess savings, saving shortfalls, equipment ownership, operation and maintenance, payment terms, change mechanism, as well as dispute resolution procedures. The findings of this comparative analysis provide a solid foundation for developing a local EPC contract template, which will be discussed in Chapter 8 (A Model of EPC for Hong Kong).

7.2 Need for EPC contract templates in Hong Kong

A standard form of contract is intended as a legally binding agreement between two contracting parties in which the provisions and terms are standardised. The primary advantage of using standard form of contracts is to reduce transaction costs including time and resources as both contracting parties may negotiate the contract based on the framework of the standardised contract template (Patterson, 2010). In the construction industry in Hong Kong, the use of standard forms of contract is very common in both public and private building projects. For example, the HKSAR Government has developed a set of standard contract forms, including *the General Conditions of Contract for Building Works, the*

General Conditions of Contact for E&M Engineering Works, Design & Build Contracts as well as a Sub-contract for Building Works(HKSAR, 1999a, b, c, 2000), whilst the private sector has also developed several standard forms of contract for building works such as *the Agreement and Schedule of Conditions of Building Contract and Nominated Sub-Contract for Use in HKSAR: Private Edition* (HKIA, 2005b, a).

As discussed in Chapter 2, a number of standard forms of EPC contract have been developed in several foreign countries, including Australia, Singapore, the United States, etc. However, with over a decade of market development, no standard form of EPC contract has yet been developed in Hong Kong. A number of researchers highlighted that the lack of standardisation of EPC contracts is one of the key barriers to further development of the EPC markets for both the public and private sectors (Davies and Chan, 2001; Hui, 2002). A questionnaire survey was conducted to investigate the current use of EPC contracts in Hong Kong (refer to Chapter 4). The result shows that a majority of ESCO respondents (73.4%) still use an in-house written EPC contractor a modified E&M contract, instead of adapting an overseas standard form of EPC contract. This raises the question of suitability in adopting these foreign EPC contracts in the local market. Targeted at this conundrum, there is a need to develop a set of EPC contract templates, which are particularly suitable for use in the market of Hong Kong.

7.3 Differences between EPC contracts and construction contracts

An EPC contract is not only a contract for the design and installation of ECMs to be implemented in accordance with host's requirements, but also a service contract where the ESCO provides the host with a number of services, including the ongoing performance monitoring of ECMs, project financing, operation (if required by the host), maintenance and staff training (Bertoldi et al., 2006). Although the clauses in relation to design and installation are similar to construction contracts, there are several features of EPC contracts which make them distinctively different.

First, an EPC contract is often a two-stage contract for works on existing buildings. The ESCO and host will first enter into the first stage service contract where the ESCO performs a detailed energy audit on the host's building and drafts the project proposal. This stage allows the ESCO to understand the current building energy use, identify the scope of work, determine the level of performance guarantee of proposed ECMs, estimate the likely cost and contract period and devise the payment schedule. After the detailed study, an option is given to the host as to whether the second stage contract will be carried on or not. If the host decides not to enter into the second stage contract, the host is obliged to pay for the consultancy fee for the first stage work.

Second, baseline establishment and energy saving determination of proposed ECMs are the unique provisions for EPC contracts. The general principle of EPC projects is that retrofitting works are paid entirely through savings. To ensure that the newly installed ECMs will generate energy savings as expected, a savings guarantee is often made an obligation of the ESCOs in EPC contracts. An ESCO is liable for compensation to the host when the actual saving is less than the guaranteed level. In comparison with construction contracts, the ESCO is not only responsible for the testing and commissioning (T&C) after installation, but also guarantees the system performance and energy use without compromising occupants' comfort and business efficacy.

Third, project financing is another feature in EPC projects. Unlike the construction project where the host normally provides upfront capital for implementation, EPC projects may be financed either by the ESCO or financial institutions. When the upfront capital is obtained by the host from a financial institution, a separate loan agreement is formed between them. As such, the issues of collateral warranty and ownership of equipment become key aspects of negotiation during the pre-contract period.

Forth, a deferred payment schedule is another main difference between EPC contracts and construction contracts. Since the payment to the ESCO is tied to actual savings being achieved during the post-retrofit stage, interim payments are not commonly made by the host for the work done by the ESCO during the construction stage. In the guaranteed model, it is only when actual savings are more than the guaranteed level that payment will be made by the host. For the shared saving model, the amount of saving will be shared between both parties at an agreed percentage when actual savings are materialised in each M&V period. Therefore, the amount of each payment highly depends on the actual performance of newly installed ECMs.

Fifth, changes in an EPC contract are sometimes entailed due to irregularities in weather conditions. This is different from a construction contract where post-contract changes are mostly initiated due to human factors. A change of ownership of the subject premises may also pose problems affecting the continuation of an EPC contract. Assignment of payment rights (to financiers for repayment of loans) and obligations (to new owners for payment to hosts) is more complicated than construction contracts.

Sixth, an EPC contract often entails regular maintenance and long term monitoring of the energy (and/or water) performance of the ECMs. The payback periods for both the host and the ESCO often range from several to ten years (Larsen et al., 2012). Hence, the relationship between the host and the ESCO after installation lasts longer than a conventional construction contract.

7.4 Standard forms of EPC contract

As discussed in Chapter 2 regarding the current use of EPC contracts in overseas countries, a total of nine standard forms of EPC contract in eight jurisdictions, including Australia, Canada, China, Japan, Singapore, Taiwan, the United Kingdom and the United States (2 sets), are used for comparison (Table 7.1). The selection of studied EPC contracts are based on their representativeness, market demand for EPC projects, as well as government's attitude towards the use of EPC. These contracts were developed by either government, relevant associations or councils to facilitate the use of EPC in their domestic markets.

Table 7.1: A list of nine standard forms of EPC contract in eight jurisdictions for comparison

	Jurisdiction	Name of contract	Developed by
1	Australia	Standard Energy Performance Contract (SEPC),	The Energy Efficiency Council (EEC), Australia
2	Canada	Model Energy Management Service Contract (EMSC) (First-out style contract)	Natural Resources Canada (NRC) (The Federal Building Initiative)
3	China	Chinese National Standard of Energy Performance Contract (CEPC)	The Standardisation Administration of the People's Republic of China
4	Japan	Japanese Energy Service Agreement (JESA)	The Japan Association of Energy Service Companies (JAESCO)
5	Singapore	The Guaranteed Energy Savings Performance (GESP) Contracting Services tender document	The Energy Efficiency Programme Office (E2PO), Singapore Government
6	Taiwan	Taiwanese Energy Performance Contract (TEPC)	The Public Construction Commission under the "Executive Yuan", Taiwan
7	The United Kingdom (U.K.)	Energy Performance Contracting (UKEPC)	The Department of Energy and Climate Change, UK Government
8	The United States (U.S.)	Energy Services Performance Contract (ESPC-BOMA)	The Building Owners and Managers Association (BOMA), US
9	The United States (U.S.)	Energy Savings Performance Contracts (DOE-ESPC)	Department of Energy (DOE) (Federal Energy Management Program), US

All these studied contracts are classified as the guaranteed saving contract except the Chinese contract (shared saving model). The Chinese EPC contract is still considered for comparison in this study due to its market potential in EPC projects and its nature of a national standard. The original languages of the Taiwanese and Japanese contracts are Chinese and Japanese respectively and they have been expressed below in English. The backgrounds and purposes of these standard forms are discussed as follows:

7.4.1 Australia – Standard Energy Performance Contract (SEPC) (EEC, 2015)

A set of standard EPC documents, namely *Standard Detailed Facility Study Agreement and Standard Energy Performance Contract*, were developed by the Energy Efficiency Council which is a non-governmental organisation to promote the use of energy efficiency technologies in buildings. These documents were reviewed and endorsed by market stakeholders, including the ESCO representatives, relevant Commonwealth government departments and state government departments, as well as public and private sector facility owners and operators. A Best Practice Guide was also published to highlight the key issues when using this national standard EPC contract. The guide is freely downloadable and the contract is available for purchase.

7.4.2 Canada – Federal Buildings Initiative: Energy Management Services Contracts (EMSC) (FBI, 2015)

The Natural Resources Canada's Office of Energy Efficiency initiated the Federal Building Initiative (FBI) which promotes federal agencies to improve building energy efficiency in federal buildings with a set of services and products. These include opportunity assessments, a list of pre-qualified ESCOs and consultation. A model of performance contracting documents was developed in 1995 to facilitate the use of EPC. As at 2013, more than 80 retrofitting projects were undertaken under the EPC package and these projects are estimated to contribute 15-20% energy savings in the retrofitted buildings, resulting in over C$43 million in annual energy cost savings (NRC, 2015).

The model form of contract is available from FBI's website. Some sections are outdated, for instance, the M&V methods, but a recent Guide to Federal Buildings (*Her Majesty the Queen in Right of Canada*) has been published (GCP, 2013), although it is not intended as a companion volume of the standard form.

7.4.3 China – Chinese Energy Performance Contract (CEPC) (SAPRC, 2015)

In order to promote the wider use of EPC in China, the Standardisation Administration of the People's Republic of China promulgated the Chinese Energy Performance Contract, which forms part of the national standard documents in the *General Technical Rules for Energy Performance Contracting* in 2010. This contract has been drafted and reviewed by market stakeholders, including the ESCO industry, relevant government departments, as well as law firms. Unlike other EPC contracts, this EPC contract was developed based on the shared saving model, rather than the typical guaranteed saving model. Comparatively, this contract is rather simple and only sets out the essential clauses and terms regarding the contractual obligations of both parties.

7.4.4 Japan – Japanese Energy Service Agreement (JEPA) (JAESCO, 2015)

The Japanese government started to develop the EPC market in 1996 and launched various programmes to enhance the use of EPC, including the implementation of a feasibility study and development of M&V guidelines (Vine et al., 1998). To further promote the use of ECMs in the public sector, the Japan Association of Energy Service Companies (JAESCO) proposed the EPC business model to the Japanese government for adoption in 2007. In this connection, the JAESCO developed the *Energy Service Agreement* for the private sector to use in retrofitting projects.

7.4.5 Singapore – The Guaranteed Energy Savings Performance (GESP) Contracting Services tender document (E2PO, 2015a)

To improve building energy efficiency in the public sector, the Singapore government encourages public sector agencies to implement energy improvement projects through an EPC approach, where an ESCO guarantees the long-term energy savings. To assist public sector agencies in implementing building retrofit projects, the Energy Efficiency Programme Office (E2PO), which is a multi-agency committee in Singapore aiming to promote the use of energy efficiently, developed a set of Guaranteed Energy Savings Performance (GESP) Contract documents. These documents include the *Note to Building Owners*, *Consultancy Agreement*, *Scope of Work*, *Conditions of Contract*, *Schedule P – Specifications of Measurement and Verification for Chilled Water Plant*.

7.4.6 Taiwan – Taiwanese Energy Performance Contract (TEPC) (PCC, 2015)

The Taiwan Government launched a ‘Subsidy Scheme for Promotion on the Use of Energy Performance Contracting to facilitate the wider use of EPC for improving building energy efficiency in Taiwan. The subsidy scheme enables the eligible parties managing central and local government buildings, public hospitals and tertiary institutions to receive a subsidy for implementing EPC projects (CEPD, 2005). As such, the Guaranteed Energy Performance Contract was developed by the Public Construction Commission as a standard contract for adoption in public projects. From 2006 to 2012, 91 EPC projects were implemented with the use of this standard form and the total project costs exceeded New Taiwan Dollar 1.186 billion (US$396 million) (TGPF, 2015).

7.4.7 The United Kingdom – Energy Performance Contract (UKEPC) (DOECC, 2015)

In order to meet the London's CO_2 emission reduction target, 'RE:FIT', one of the retrofitting schemes in London, has been launched to reduce energy use in public buildings there. With the assistance of RE:FIT Programme Delivery Unit (PDU), the interested London public organisations can implement ECMs in their buildings under an EPC package. To-date, almost 200 public organisations in London have participated in RE:FIT, and more than 440 of public buildings have been retrofitted, resulting in 30,000 tonnes of CO_2 reduction per annum (REFIT, 2015). Those retrofitted buildings under this programme include central government buildings, museums and educational buildings. In order to facilitate the process of project implementation, a set of *Contract Guidance Note and Model Contract for EPC* was developed by the Department of Energy and Climate Change. With the further use of EPC, it is expected that more than 600 buildings will be retrofitted, generating 45,000 tonnes of CO_2 saving by 2015.

7.4.8 The United States – Energy Services Performance Contract (BOMA-ESPC) (BOMA, 2015b)

With the collaboration of major real estate companies and ESCOs in the US, the Building Owners and Managers Association (BOMA), an over 100-year-old real estate association, has developed a set of EPC contract templates for standardising the contractual terms and conditions for the private sector. In order to avoid bias, a partnership with the Clinton Climate Initiative (CCI) serving as a liaison body between building owners, ESCOs, operators and financial partners is established in the process of developing this standard form(BOMA, 2015a). This set of EPC documents, named as a ‘Tool Kit’, includes all the necessary documents, such as RFQ and RFP templates, an Investment Grade Audit contract template, and the BOMA EPC contract, as well as an overview of the process, aiming to facilitate the process of project development and contract negotiation. This Tool Kit is intended for private sector use, especially for those building owners or real estate professionals who have little understanding of EPC projects.

7.4.9 The United States – Federal Energy Management Program: Energy Savings Performance Contract (DOE-ESPC) (DOE, 2015e)

In 1998, the Department of Energy (DOE) developed the Energy Savings Performance Contract which allows the Federal government to implement energy improvement projects without the need for upfront capital and special Congressional appropriations. To-date, the contract has gone through several modifications to the latest November 2012 version. The contract has been authorised by statute, the Energy Independence and Security Act of 2007, as a standard form of EPC contract for Federal agencies to upgrade their facilities (DOE, 2015a). The law also eliminates the public procurement and financing barriers, by cancelling advance Congressional reporting requirements and increasing ESCP funding flexibility. A particular feature of this standard form is that it is meant to be used as a term contract without definite quantity, since individual Task Orders are issued for ESCO selection to suit individual projects under an umbrella arrangement lasting for five years (but contract obligations can last for a maximum of 25 years).

7.5 A Comparative Study of Standard Contract Conditions for EPC in Australia, Canada, China, Japan, Singapore, Taiwan, the U.K. and the U.S.

Tables 7.2 & 7.3 summarise the results of comparison between nine standard forms of EPC contract (all are based on the guaranteed saving model, except the Chinese contract). The reasons for the differences among those standard forms are mainly due to (1) different publishers of EPC contracts and (2) different jurisdictions. Among those standard forms, six of them are public EPC contracts, while the remaining three contracts are private contracts which are often developed by the relevant industrial associations (e.g. the Building Owners and Managers Association (BOMA) and the Energy Efficiency Council (ECC)). Therefore, the contract terms in the public sector are more conservative as compared with those in the private sector. For example, the sharing of excess savings may not be considered in the public sector. However, in the private sector, the excess savings clause will be included to encourage the ESCO to achieve energy savings more than the guaranteed level. Another difference in terms of the contract conditions lies in the ‘Assignment’ clause, since public sector contracts do not contain provisions regarding the possible assignment of the contracts to other parties.

In addition, four of them (e.g. SPEC, EMSC, GESP & UKEPC) are the contracts under Common Law Jurisdictions, while the remaining five contracts (e.g. CEPC, JESA, TEPC, BOMA-ESPC & DOE-ESPC) are under Civil Law Jurisdictions. Since the principles of ‘reasonable skill and care’ and ‘fitness for purpose’ have been well established under common law, the treatment of ‘Design Liability’ in those common law contracts will be based on those unwritten principles. However, the contracts under Civil Law Jurisdictions often include codified laws to stipulate the design liability. Therefore, different jurisdictions lead to the differences among the studied EPC contracts.

The different treatments of key contractual issues are discussed below:

Savings guarantee/ shared savings

As discussed in Chapter 2, guaranteed and shared saving models are two common EPC models for energy retrofitting. The main difference between these two models lies in the allocation of performance and financial risks. Among all studied EPC standard contracts, most of them only account for cost savings in energy and water consumption. Other possible cost savings such as operational cost savings are not mentioned in those contracts. It is only in the CEPC and TEPC contracts that other types of cost savings are mentioned for both contracting parties to negotiate. In addition, most contracts stipulate that the guarantee provided by an ESCO is based on the quantity of energy cost saving from the baseline energy use, but in the TEPC contract the ESCO only guarantees the host a percentage of energy saving.

As it is known that the determination of actual energy savings is rather difficult for central AC systems, a special arrangement is made in the GESP contract, which only allows ESCOs to guarantee on chilled water plant efficiency (Coefficient of Performance), instead of actual energy savings, to avoid disputes on the actual quantities of savings.

Excess savings and saving shortfalls

When the actual energy saving is below the guaranteed level, the ESCO is obligated to compensate losses to the host. The most common treatment for compensation is to adjust the amounts in payment schedules based on the actual saving shortfalls. However, in some contracts (e.g. TEPC contract), no payment is made to the ESCO when a shortfall occurs in any M&V period. This seems to be quite strict. On the other hand, the provision of excess savings is given in several studied contracts, providing ESCOs with an incentive to achieve savings more than the guaranteed level. However, different treatment of excess savings were found and can be classified into three categories: (1) the excess savings will be used to offset the ESCO's liability for future shortfalls (e.g. BOMA contract); (2) the excess savings will be shared by both parties (e.g. JESA, SEPC and UKEPC contracts); (3) The guarantee period can be shortened when the total project cost is fully recovered by actual savings (e.g. EMSC contract). In order to reduce the chances of dispute, some studied contracts explicitly stipulate that excess savings are not considered. For the shared saving contract, there is no concept of excess saving or saving shortfall as all the savings are shared by both contracting parties based on pre-agreed percentages.

Performance Commencement Date

In EPC projects, the date of performance commencement is defined as a date on which ECMs are put into operation and from then on the calculation of energy savings starts. Generally, this date begins when the host issues a certificate of acceptance of the ECMs. However, in practice the newly installed ECMs may not be operating at the expected efficiency immediately after the date of acceptance certificate. In order to mitigate the risks of improper system operation due to the transition period right after installation, the ESCO may request for the revision of commencement date for further system optimisation. As such, the SEPC and EMSC contracts allow for the change of commencement date with the host's consent. Another justification for such changes is due to accounting purposes. For example, the date of performance commencement is intended to be consistent with the issue date of utility bills. However, in the BOMA and ESPC contracts, the provision for change of performance commencement date is not given, implying that the ESCO bears the risk of saving shortfalls if the newly installed system is not ready for operation. In addition, the delay within construction and installation phases may not necessarily be a justification for the postponement of the performance commencement date.

Contract Period and M&V Period

Unlike a conventional retrofit project for which a warranty and a defects liability period are the only contractual redress against imperfections after the issue of an acceptance certificate, the contract period in an EPC project not only covers the design and installation stages, but also the post-retrofit stage during actual ECM performance. This contract period is usually fixed as agreed, but it may be revised in some conditions, for example, when significant deviations from baseline building operations occur. To encourage early contract completion, the EMSC contract stipulates that the contract may be completed earlier than the original expiry data of performance guarantee when the total project costs are fully covered by the actual energy savings. Regarding the M&V period, it often follows a complete year cycle, starting from the performance commencement date. This is because this arrangement can consider the monthly variations in energy savings due to seasonal climate changes, especially for weather-dependent ECMs such as replacement of air-conditioning chillers. In several standard contracts, the M&V period can be arranged on a monthly or quarterly basis, depending on the number of M&V periods required during the contract period.

Additional Energy Conservation Measures (ECMs)

When saving shortfalls occur during the contract period, the host is entitled to receive compensation from the ESCO. However, this is not the main purpose of implementing EPC projects as the host aims at achieving the promised savings, instead of getting compensation. Therefore, the provision of additional energy conservation measures (ECM) is given for ESCOs to improve the original design in the event of consecutive shortfalls. The improvement of original design includes replacement, removal, alteration, installation of additional equipment and revision of current operation procedures, but such improvement is subject to the prior written approval of the host and the ESCO has to pay those additional costs in full. To avoid the host rejecting any change even when the ESCO bears the costs of changes (say, due to worry about disruption to business or operation), the protection is given to the ESCO in the SECP contract that additional works are allowed to be implemented when such works are reasonable to be installed for achieving more energy savings. However, in the JESA and GESP contracts, no such provision is stipulated, implying that the design of ECMs is final once both parties have agreed.

Payment

In general, the payment terms and schedules are negotiated by both contracting parties as provided in standard forms of EPC contracts. Through the comparison of standard forms, the main difference lies in the conditions upon which payment is made. In the BOMA and SEPC contracts, construction progress payments are made to the ESCO periodically based on the percentage completion of ECMs, while in the ESPC and EMSC contracts, no payment is required to begin until all ECMs are installed and operating as stated in the contract. These different arrangements may induce different cash flow patterns. For example, in the GESP contract, payments are made when all equipment installations are completed based on an agreed schedule, and in the event of shortfalls in energy saving, an ESCO has to compensate the host on an annual basis. In particular for chillers, the ESCO has to pay for shortfalls beyond the EPC contract period in the remaining life of the equipment. In the JESA contract, payment will be adjusted when saving shortfalls occur. Comparatively, the TEPC contract focuses more on whether the ESCO achieves savings more than the guaranteed level, as the contract stipulates that no payment is made when the actual savings are below the guaranteed level. By contrast, the shared saving contract CEPC stipulates that payment is made during each M&V period, and the amount depends on the agreed sharing percentages of materialised savings.

Financing

As mentioned in Chapter 2, self-financing and third party financing are two common types of financing approach in EPC projects. When the project is implemented through third party financing, a separate contract apart from the EPC contract is often made between the borrower (either the host or ESCO) and the financial institution. The guarantee from the ESCO can be instrumental to the financing contract since it gives confidence to the lender that the loan will be repaid out of the saving made. Besides, the issues of collateral warranty and ownership of equipment become key aspects of contract negotiations in this financing arrangement.

In the guaranteed saving contract, several standard contracts stipulate that the ESCO is responsible to pay the upfront capital in full for project implementation (e.g. DOE-ESPC contract). In a shared saving contract such as the CEPC contract, a provision is given for both contracting parties to decide the percentages of the total upfront capital costs each party pays for project implementation. To encourage hosts on the wider use of energy efficient systems and equipment, some financial incentive schemes are available in the federal or local government of the U.S. For example, in the EPSC contract, a provision is stated that the ESCO is responsible for utilising any applicable funding and tax incentives for the implementation of ESPC projects.

Design liability

Under common law, the principles of ‘reasonable skill and care’ and ‘fitness for purpose’ have been established clearly via precedent cases. Therefore, it has been reported that “fitness for purpose” is a more stringent requirement than “reasonable skill and care’ (Murdoch and Hughes, 2008). This distinction has found its way into contracts under common law jurisdictions. The SEPC contract stipulates that ESCO shall conduct ECMs with due care and skill, whilst giving a warranty that the equipment shall be ‘fit for its intended purpose’. In the GESP contract, the ESCO is responsible to ‘design, execute, complete and perform the works and services with due care and diligence’, and a requirement for fitness for purpose is also stated to ensure host’s satisfaction with the installed ECMs.

Based on the civil law of Japan, the JEPA standard form only stipulates the exercise of care by an ESCO throughout the project. A client may, however, refuse final payment if defects are found to his dissatisfaction under the Civil Code. In the case of China, the CEPC standard form just mentions an ESCO’s responsibility to complete design, installation, operation and maintenance on time in accordance with specified standards. However, it states that such works may be executed by a client’s approved third party. Other regulations regarding design are also contained in the Construction Law and Contract Law of the People’s Republic of China. For the TEPC standard form, the ESCO should verify designed materials to ensure appropriateness, taking care of interface issues. The public sector form requires authentication of drawings, etc. by a licensed professional technologist. The installation team should also participate in such verification task to guard against possible on-site problems brought about by problematic designs. Records of such verification need to be kept. During the design stage, the operator may comment on means to meet targeted performance.

Ownership of equipment

The general principle regarding the issues of ownership of equipment depends on who pays the upfront capital of equipment for project implementation. Since the ESCO often pays the upfront capital, it is typical for the ESCO to own the equipment in the first place and its title will be transferred to the host upon payment in full. However, in practice, both the GESP and TEPC contracts state that the ownership of equipment will be transferred to the host upon the issue of acceptance certificate, regardless of the amount of payment made by the host. This is because such arrangement can avoid the dispute of equipment ownership when the contract is terminated and ensure that the equipment can be put in operation as planned.

Performance and payment bonds

Similar to construction projects, the provision of payment bond is to ensure timely payment for labour and materials, whilst the provision of performance bond is to ensure that the host receives a compensation due to a default in ESCO's performance. In the DOE-ESPC and BOMA-ESPC contracts, the amount of performance bond is equal to a certain percentage of the total amount of the contract sum. In the GESP contract, the host is entitled to call a certain amount of performance bond in case of a shortfall in savings. In some EPC contracts such as the CEPC and JESA contracts, no performance or guarantee bond is required. However, in public EPC contracts such as the GESP and TEPC contracts, a bank guarantee or security deposit is necessary.

Operation and maintenance (O&M)

Proper operation and maintenance are critical in achieving the optimal energy efficiency of equipment, thereby maximising the long-term energy savings. Since the ESCO promises to achieve the expected energy savings, the ESCO is often responsible for all maintenance works of newly installed ECMs at its own cost, including periodic inspections, preventive maintenance as well as corrective maintenance. The host will take up the duties of maintenance when the EPC contract ends.

In most situations, the host itself will manage the property with in-house staff or engage a third party such as a facility management company for system operation. The purpose is to ensure the absolute control of building operation. As such, in order to ensure that the newly installed ECM are operating at design conditions, most standard contracts stipulate that the host has to comply with operational procedures laid down by the ESCO. For any failure or non-compliance with the agreed procedures resulting in consequential financial losses, the ESCO may reduce his liability for shortfalls of guaranteed savings. However, a special arrangement is made in the JESA contract that the ESCO is responsible for the operational work and should comply with operational procedures set out by the host.

Risk of changes

Due to changes in building operation, weather conditions and level of occupancy, the baseline conditions may vary from time to time. These variations may result in reductions in actual energy saving being achieved by the ESCO. Therefore, a mechanism for baseline adjustment is incorporated in most standard forms. In general, the conditions under which a baseline adjustment is allowed and the method for adjustment are negotiated by both contracting parties before the signing of contract. However, it may be difficult to reach a mutual agreement as it involves numerous technical issues. As such, in some contracts such as the GESP contract, it stipulates that a baseline adjustment will be made when the energy consumption increases or decreases by a certain percentage (e.g. at least 5%). When the ESCO guarantees the host a certain energy cost saving (in dollar amount) instead of a quantity of energy savings (in kWh), adjustments for the unit prices of electricity, fuels and water are permissible when substantial deviations occur from the baseline conditions.

Assignment of the contract

In general, an assignment is allowed when prior written consent is given by the affected contracting party. However, in practice, certain restrictions are given in EPC contracts, especially for a public contract where a public procurement process has been undertaken. For example, in the GESP contract, an assignment by the ESCO may lead to a termination of the contract, whilst in the TEPC contract, assignment by the ESCO is explicitly prohibited, except when company restructuring takes place with an approval of the host. In the SEPC contract, a provision is clearly stated that such consent shall not be unreasonably withheld if the transferee is going to enter into an agreement in substantially identical terms to the original agreement and the ESCO determines that the transferee is of at least equal financial standing as the original host. In some standard forms such as the CEPC contract, the whole section of assignment is blank such that both contracting parties are able to negotiate the conditions upon which an assignment is envisaged.

Termination

In EPC projects, non-payment and assignment of interest without prior approval are common events of default leading to a contract termination. Significant differences exist regarding the termination clauses in the standard forms under comparison. For example, standard forms such as the CEPC and GESP contracts allow the ESCO to terminate the contract when no payment is made by the host, whilst in the TEPC contract, non-payment by the host is not a reason for contract termination unless a 3-month period (or an inserted period during tender) has expired. Late payments would accrue interest at a stated rate. It is worth noting that in the

UKEPC contract, the host is entitled to terminate the contract when the ESCO fails to rectify the situation where the installed ECMs achieve less than 70% of the guaranteed savings within 3 months. This is the only studied contract in which non-performance of the guarantee may lead to a contract termination.

In addition, the provision of termination for convenience is introduced in some standard forms, and this allows the host to terminate any portion or the whole EPC contract at any time, presumably due to more advanced energy saving measures being available in the market. For example, the host may terminate the contract without default during the post-retrofit period. The host may compensate the ESCO for the early termination value if the upfront capital has not been fully paid by the host. Further payments to the ESCO (including M & V fees) would then stop.

Dispute resolution

In EPC projects, payments to the ESCO are often linked to the actual energy savings being achieved by the ESCO. Therefore, it is not surprising that the contracting parties may have disputes on baseline adjustment, the quality of M&V works, etc. In most standard forms, a mechanism for dispute resolution is an essential element, and mediation and arbitration are the most common ways to resolve disputes in EPC contracts. Apart from mediation and arbitration, technical expert determination is another approach to resolve disputes in relation to technical or engineering issues, and this is introduced in the GESP contract as the first approach to settle disputes. Usually, after these alternative dispute resolution means are exhausted, the parties may resort to formal legal proceedings.

To save on the length of this thesis, a number of tables follow to show the detail comparisons of the standard forms of contract, the pertinent aspects of which have been highlighted in the above paragraphs. Since different legal jurisdictions are involved, the tables (Tables 7.2 and 7.3) are classified by Common Law jurisdictions (e.g., Australia, Canada, Singapore and the U.K.) and non-Common Law jurisdictions (e.g. those places based on civil or continental law, including China, Japan, Taiwan, the U.S.) respectively. It is acknowledged that these details were adapted from two publications co-authored by the candidate, as shown in the footnote below[10,11].

[10]Published in Lam, P.T.I., and Lee, P. (2014) A comparative study of standard contract conditions for Energy Performance Contracting in Australia, Canada and the United States. *Construction Law Journal*, 30(7), 357-376.

[11]Published in Lam, P.T.I., and Lee, P. (2015) A comparative study of standard contract conditions for Energy Performance Contracting in China, Japan, Singapore and Taiwan. *Construction Law Journal*, 31(3), 152-166.

Table 7.2: A comparison between nine standard forms of EPC contract in eight jurisdictions (All standard forms in Table 7.2 belong to Common Law Jurisdictions) *(Table 7.3 is an extension of Table 7.2)*

	Australian Standard Energy Performance Contract (SEPC)	Canada's Federal Buildings Initiative: Energy Management Service Contracts (EMSC)	Singapore's Guarantee Energy Savings Performance Contract (GESP)	UK' Energy Performance Contract (UKEPC)
Scope of contract application	Private buildings in Australia	Federal buildings in Canada	Public buildings in Singapore (private sector may adapt it for use)	Public buildings in London
Contract sum designation	Lump sum contract	Lump sum contract in a first-out style (i.e., the contract will expire when the project cost is expended or the 'payback period" is reached, whichever is earlier)	Lump sum contract	Lump sum contract
Contract type	Guaranteed saving model	Guaranteed saving model	Guaranteed saving model	Guaranteed saving model
Scope of cost savings	It includes • Cost savings in energy consumption • any agreed operational costs savings (Clause 7.4)	It includes • Cost savings in energy consumption • any agreed operational costs savings (Clause 1.12, Appendix A)	It includes cost savings in energy and water consumption (if applicable), but it excludes operational cost savings. (Clause 4.12)	It includes • Cost savings in energy and water consumption (if applicable) (Schedule 2A, Clause 1.2)
Saving shortfalls	If the guaranteed cost savings are not achieved ***in any guarantee year***, the ESCO shall pay the host the amount of the shortfall. (Clause 7.5)	If the guaranteed cost savings are not achieved in ***any month***, the ESCO shall pay the host the amount of the shortfall. (Clause 23.4, 23.6)	If ***the guaranteed energy savings*** are not achieved ***in any guarantee year***, the ESCO shall pay the host the amount of the shortfall. For the chiller plant retrofit, a specific calculation method of saving shortfall is used. (Clause 33.2).	If ***the guaranteed energy savings*** are not achieved ***in any guarantee year***, the ESCO shall pay the host the amount of the shortfall. (Schedule 2A, Clause 9.4.2)
Excess savings	When the actual savings in energy use and operational costs exceed the guaranteed cost savings ***in any guarantee year***, the host shall reimburse the ESCO for the payment up to the amount of the excess. (Clause 7.6)	If the actual savings exceed the guaranteed savings ***in any month***, the host shall reimburse the ESCO for the payment up to the amount of the excess. (Clause 23.4, 23.7)	No relevant provision.	When the actual savings in energy use and operational costs exceed the guaranteed savings ***in any guarantee year***, the excess amount may be used to offset the ESCO's liability for any future shortfall. (Schedule 2A, Clause 9.4.1)
Performance guarantee commencement date (PGCD)	The issue date of the acceptance certificate shall be the date of performance guarantee commencement date. The change of commencement date is not allowed unless the host agrees in writing with signed returns, or the nomination of a revised date by the ESCO prior to commencement of installation of the ECMs. (Clause 4.3)	The performance guarantee commencement date is the date on which the host's representative delivers written notice of no objection to the entire project. The commencement date may be extended with the approval of the host's representative. (Clause 14)	The performance commencement date shall be ***the first day of the month*** after the month in which all certificates of acceptance are in final form and accepted by the host. (Clause 17.4).	The performance commencement date shall be the date after the issue date of the acceptance certificate. (Schedule 2A, Clause 9.1)
Performance Guarantee Year & Guarantee period	The performance guarantee year is a complete year, starting from the PGCD. The guarantee period is fixed as agreed.	The performance guarantee year is a complete year, starting from the PGCD. The "payback period" can be shortened when the total project costs have been fully paid or extended	A performance guarantee year is a complete year, starting from the PCD. The total guarantee period is negotiable but not more than 7 years.	A performance guarantee year is a complete year, starting from the PCD. The guarantee period, which means the payback period in the contract, is defined

	(Clause 7.1; Schedule 1, item 5)	when the ESCO experiences additional costs, loss of utility incentive or loss of other cost savings but no more than 8 years. (Clause 23.3, 29, 36.2)	(Clause 17.5)	based on "Payment Model". The guidelines provided by the client set out the method for payback calculations. (Schedule 2A Clause 1.2)
Installation period savings	No installation saving is included in the overall energy savings.	No installation saving is included in the overall energy savings.	No saving during installation period is included in the overall energy savings. (Clause 17.5)	No provision is given that savings during installation period are included in the overall energy savings.
Additional ECMs	Similar to the BOMA contract in the US. However, the host may also allow and pay for changes which are reasonable as compared with the energy savings achievable by the change. (Clause 3.1, 3.2)	No relevant provision.	No relevant provision.	If the installed ECMs achieve less than 70% of the guaranteed savings, the host may instruct the ESCO to replace with the equivalent ECMs at the ESCO's own cost. (Clause 8.2)
Payment	Progress claims are payable by the host based on the ESCO's invoice for achievement of benchmarks (i.e., milestones) listed in the timetable of the specifications. (Clause 2.7)	The host shall pay each month to the ESCO a sum equal to one twelfth of the estimated annual energy savings upon completion of installation until the total project cost has been fully paid or until the payback period ends, whichever occurs first. (Clause 23.3)	The host shall make payments as set out in Schedule C (Contract Price). (Clause 33.2)	The number of instalments during the contract period is negotiable. (Schedule 2A Clause 4.2.9)
Financing	No relevant provision, although the accompanying Guide mentions about several approaches of financing EPC contracts.	The ESCO is responsible to finance the total project cost either directly, or by arranging with a third party financial institution. (Clause 22)	ESCO is responsible to pay the upfront costs during installation.	ESCO may be responsible to pay the upfront cost during installation. Third-party financing is allowed. (Schedule 2E)
Design liability/ responsibility	ESCO conducts ECM installation with due care and skill. Equipment shall be fit for its intended purpose. (Clause 2.4, 10.2)	ESCO to design, engineer, acquire, install & commission all equipment & systems with complete responsibility as would be assumed by a general contractor. (Clause 7.0)	ESCO shall, with due care and diligence, design, execute, complete and perform the works and services in accordance with the contract and to the satisfaction of the host. In addition, a 'fitness for purpose' requirement also applies. (Clause 4.1)	ESCO shall, with due care and diligence, design, execute, complete and perform the works and services in accordance with the contract and to the satisfaction of the host. (Clause 5.3)
Ownership of equipment	The title of equipment shall transfer to the host when the full payment of equipment is made. (PS: the transfer of equipment titles is not necessarily at the end of contract period) (Clause 4.4)	The ESCO or a financial institution that has provided financing for the ECMs may not retain title to any equipment purchased and installed as part of the ECM as security for the financing. (Clause 30)	Except for metering equipment, the title of all plant, equipment and other items installed shall transfer to the host from the performance commencement date. (Clause 24.9)	The title of equipment shall transfer to the host upon the installation of equipment. If third-party financing is used in the project, the third party may retain the ownership of equipment. (Clause 16.2.2; Schedule 2E)
Performance and guarantee bonds	No relevant provision.	Performance bond and a labour and materials payment bond, each in the amount of at least 50 percent of the total project cost during the Installation	The ESCO shall deposit with the host 5-10% of the contract price, which may be utilised to defray any shortfall in savings or loss or damage sustained as	Performance bond and guarantee bond are optional.

		Period. (Clause 53.1)	a result of any breach of contract (Security deposit). No payment bond is required. (Clause 4.5)	(Schedule 8)
Operational Responsibility	The host shall comply with the operational procedures laid down by the ESCO for any ECMs The ESCO will not be liable to the host for a shortfall of energy saving when such shortfall is due to operational deficiency arranged by the host . (Clause 8.4;8.5)	The host shall operate the improvements during the post-installation period in accordance with the ESCO's prescriptions and promptly provide the ESCO with the information it requires relevant to the operation of the improvements, including: 1. Results of preventive maintenance, 2. irregularities in energy consumption, and 3. results of inspections or tests (Clause 17)	The host shall follow and implement the ECM procedures and methods of operation set forth in Schedule J. For the purpose of determining the host and ESCO's compliance, a checklist as set forth in Schedule K (Facility Maintenance Checklist) shall be used to measure and record the host and ESCO's compliance. Upon the date of acceptance, the ESCO shall submit for acceptance of the operation and maintenance manuals. (Clause 6.3; 19)	The host shall operate the equipment in accordance with the technical specification. (Clause 4.2c)
Maintenance	The maintenance work may be arranged by the ESCO or a third-party, or the host itself. (Clause 5)	The ESCO shall provide to the host the instruction and training that is necessary to ensure the proper operation and maintenance of the ECMs. The host is required to perform the regular maintenance work. (Clause 16, 17)	The ESCO is responsible for maintenance work during the contract period. (Clause 4.10)	Maintenance services by the ESCO are optional in the contract. If the host is responsible for maintenance works, the host has to follow the maintenance regime listed in the O&M manual provided by the ESCO. (Clause 9.1, Schedule 2D)
Dealing with risk of changes (M&V)	The host should inform the ESCO details on any significant change in any of the stated factors, resulting in a change in energy use. Upon the host's approval, the ESCO may adjust the energy baseline or the amount of guaranteed energy savings. If both parties disagree on the changes, a dispute resolution process will be invoked. (Clause 8)	The baseline energy consumption and demand shall remain constant except the following circumstances: • a change in the use of the facilities • a change in the occupancy rate of facilities • a modification to or enlargement of the facilities • implementation of new standards • an increase in the interest rate used in calculating any financing charges (Clause 28)	A baseline adjustment shall be made when the energy consumption increases or decreases ***by at least 5%,*** due to any changes in structural, operational or otherwise in nature which reasonably could be expected, as judged by the host. The adjustment shall be in accordance with the provisions and procedures set forth in Schedule D & E. (Clause 21.1)	Risk of changes is negotiated by both contracting parties. The parties may make a reference to the international M&V guidelines, such as IPMVP. (Schedule 2A Clause 4.2.16)
Assignment	Without the prior written consent of another party, no contracting party may assign or transfer its right to others. Reasonable consent should be given when: 1. The ESCO assigns its rights to its wholly	No provision on assignment by the host (presumably due to the public sector nature of host). Except for purposes of financing the improvement works, the ESCO may not assign the contract, either fully or in part, without the written consent of the	The contract may be terminated when the ESCO has either assigned his interests, rights or benefits or transferred his liability to any other person without the prior written consent of the host, which consent shall not be unreasonably withheld.	The ESCO is forbidden to assign all or any part of the Services without the prior written consent of the host. (Clause 11.1).

	owned subsidiary or that of the ESCO's parent company, or wishes to assign its rights to receive payment to his lender. 2. The transferee enters into an agreement in substantially identical terms to the contract and such transferee is of at least equal financial standing as the host. (Clause 18)	host, such consent should not be unreasonably withheld. (Clause 47)	(Clause 32.1).	
Termination upon default	Either party may terminate the contract in the event of default by any contracting party, e.g., due to non-payment, etc. <u>Termination by ESCO</u> If the host sells, transfers or assigns her interest, the ESCO will use its best endeavours to enable this contract to be novated to the purchaser or assignee of that interest. However, it is not necessary for the ESCO to enter into a novation of the contract, and the ESCO may exercise the right of contract termination upon notice of an assignment. (Clause 16.1, 16.2)	<u>Termination by Host</u> No provision is given for the host to terminate the contract. When the ESCO is in default under the contract, the host is entitled to reduce the payment by an amount equal to all costs as a result of ESCO's default. <u>Termination by ESCO</u> No provision is made for the ESCO to terminate the contract. In the event of host's default, such as non-compliance with conditions of the contract, only the compensation of the outstanding costs would be made to the ESCO. (Clause 33 and 35)	*Termination by Host:* If in the opinion of the host, the ESCO has failed to comply with a provision of the Contract, including engagement of any unapproved subcontractor, assignment, etc, the host may terminate the contract. *Termination by ESCO:* The ESCO may terminate the contract or exercise all remedies available at law when the host fails to make payments to the ESCO. (Clause 31.1, 32.1)	*Termination by Host:* The host may terminate the contract in whole or in part when the ESCO fails to perform a provision as stipulated in the contract. If the ESCO fails to rectify the situation where the installed ECMs achieve less than 70% of the guaranteed savings within 3 months, the host may terminate the contract. No relevant clause is provided for the termination of contract by the ESCO. The unaffected party may terminate the contract if a Force Majeure Event has occurred for more than 6 months. (Clause 8.5,28)
Termination without default (Termination for Convenience)	No relevant provision.	The host may terminate the contract by acquiring all the ECMs for the termination value set forth in Appendix E, at any time after the first anniversary of the Commencement Date and prior to the expiry of the Contract. (Clause 15)	The host may terminate the contract at any time before the performance commencement date. The host shall pay the ESCO for all works executed prior to the date of termination. (Clause 4.12, 32.4)	The host may terminate the contract in whole or in part, at any time. The amount of termination charges are listed in Attachment 1-10. (Clause 28.4, Attachment 1-10)
Dispute Resolution before litigation	Unsettled dispute may be referred to Expert Determination. (Clause 17)	Disputes shall be settled by arbitration. (Clause 38)	Disputes shall be settled by reference to the Technical Expert or arbitration. (Clause 34)	Disputes shall be settled by mediation. (Clause 27)

Table 7.3: A comparison between nine standard forms of EPC contracts in eight jurisdictions (All standard forms in Table 7.2 belong to Civil Law Jurisdictions)

	Chinese National Standard of Energy Performance Contract (CEPC)	Japanese Energy Service Agreement (JESA)	Taiwanese Energy Performance Contract (TEPC)	US' BOMA Energy Services Performance Contract (BOMA-ESPC)	US' Federal Energy Management Program: Energy Savings Performance Contracts (DOE-ESPC)
Scope of contract application	Public and private buildings in China	Private buildings in Japan	Public buildings in Taiwan	Private buildings in the United States	Federal buildings in the United States
Contract sum designation	Lump sum contract	Lump sum contract	Lump sum contract	Lump sum contract	Indefinite delivery/indefinite quantity (IDIQ), similar to a term contract
Contract type	Shared saving model	Guaranteed saving model	Guaranteed model on saving percentage	Guaranteed saving model	Guaranteed saving model
Scope of cost savings	No specified clause is relevant to the scope of cost savings, but the work undertaken shall be related to an energy management project.	It includes cost savings in energy and water consumption (if applicable), but it excludes operational cost savings. (Clause 1)	No relevant clause is specified in the scope of cost savings, but the work undertaken shall be related to an energy management project. (Clause 2.2).	It includes • Cost savings in energy and water consumption and associated utility costs (if applicable) • non-measured savings (not related to energy) (Schedule C, Section I - D)	It includes • Cost savings in energy and water consumption and associated utility costs (if applicable) • Cost savings in energy and water-related operations (if applicable) and maintenance costs (Section C.1)
Saving shortfalls	N/A (No section on saving shortfalls and excess saving in the contract, and all the materialised savings are shared by the contracting parties with the agreed percentages. (Clause 4.1 & 4.2)	If ***the guaranteed energy savings*** are not achieved ***in any guarantee year***, the host shall adjust the payment in accordance with the formula set out in Clause 16. No payment is made when the shortfall in savings is more than the fixed annual payment (Clause 16.2).	If ***the declared percentage of savings*** is not achieved ***in any M&V period***, no payment is made to the ESCO by the host. (Clause 5.1)	Same as SEPC in Australia. (Schedule B, Section II)	If the guaranteed cost savings are not achieved in ***the guarantee period***, the host shall adjust the payment in subsequent periods to reflect the lower performance level in the current year. When the ECM performance level is restored, the host will adjust the payment schedule accordingly. (Clause G.5)
Excess savings		No excess saving is included for the annual payment, only the fixed amount of payment is made to the ESCO as listed in Clause 2.3. However, the final excess savings will be shared by both parties as an incentive to achieve higher savings. (Clause 2.3, 16.1 & 16.3)	No relevant provision.	When the actual savings in energy use and operational costs exceed the guaranteed savings ***in any guarantee year***, the excess amount may be used to offset the ESCO's liability for any future shortfall. (Schedule B, Section VI)	No relevant provision.
Performance guarantee commencement date (PGCD)	The commencement date of shared saving is negotiable. (Clause 2.3)	The performance commencement date is stated in Clause 7.	The performance commencement date shall be the date after the issue date of the acceptance certificate. (Clause 15.3)	The performance guarantee commencement date is the first day of the first utility billing period following the earlier to occur of: (1) the month in which Final Acceptance of the entire project; or	The performance guarantee commencement date is stated in the attachment document. No relevant clause is mentioned about the change of PGCD.

				(2) the Final Acceptance Date set forth in Section 1.4 of the Contract (Schedule B; Section 1; Clause 1.4)	(Attachment J-9)
Performance Guarantee Year & Guarantee period	The total shared saving period and M&V period are negotiable. (Clause 2.3)	A performance guarantee year is a complete year, starting from the PCD. The contract period is specified in Clause 2.4.	The performance guarantee period and total guarantee period are as stated in the tender document. (Clause 7.3, 7.4& 15)	The performance guarantee year is a complete year, starting from the PGCD. An alternative is given that for budgeting purposes, the host can seek to align the performance guarantee year with the calendar year. The guarantee period is fixed as agreed. (Schedule B, Section I; Section III)	The performance guarantee year and guarantee period are fixed as agreed. The contract period may be for a term up to twenty-five (25) years. (Section F3)
Installation period savings	No saving during installation period is included in the overall energy savings.	No saving during installation period is included in the overall energy savings.	No saving during installation period is included in the overall energy savings.	An option is available for including installation period savings, and such savings can either belong exclusively to the ESCO or be shared in accordance with the agreement. (Clause 2.2)	No installation saving is included in the overall energy savings.
Additional ECMs	Subject to the host's approval, an ESCO shall have the right to modify or replace any of the ECMs or install additional ECMs in the event of unforeseeable situations, and the ESCO is responsible for all costs in relation to such works, unless the host is in default. (Clause 7.3)	No relevant provision.	No specific provision in relation to additional ECMs is given. However, the ESCO may modify the design at his own cost with the approval of host, if necessary. (Clause 21.1)	Subject to the host's written approval, the ESCO shall have right to modify or replace any of the ECMs or install additional ECMs, provided that any costs incurred due to such modifications or additions shall be the sole responsibility of the ESCO. The host shall not unreasonably withhold or delay such actions. (Schedule VII)	Similar to the BOMA contract, but the period of implementation may count afresh from the modified ECM installation. (attachment G-2 and J-2)
Payment	Payment to the ESCO is made when savings are achieved during ***each M&V period***. The amount of payment depends on the agreed percentages of shared savings. (Clause 4.4)	Payment is made on an ***annual basis***. In the first year, payment to the ESCO is calculated based on the actual savings. For subsequent years, payments to the ESCO are made in accordance with "Saving shortfalls" & "Excess savings" terms.	The number of instalments during the contract period is negotiable. Payment to an ESCO is made when the level of energy saving exceeds the agreed percentage. (Clause 5.1)	During the installation period, payments to the ESCO for the work performed should be made, and the total shall constitute the contract sum. 4 options of payment method are available, including i & ii: construction progress payments(based on a Schedule of	The frequency of payments, including any partial payments, from the host to the ESCO will be negotiable. (Clause G.4)

		(Clause 16)		Values, either submitted shortly after works commencement or attached to the contract);iii: share of installation period savings; or iv: through an escrow agent due to a financing arrangement. During the guarantee period, “performance tracking service” payments are also paid to the ESCO based on a schedule. (Clause 10.1; Schedule E, Section I; Section II)	
Financing	Either host or ESCO is responsible to pay the upfront costs during installation. (Clause 18.3)	ESCO is responsible to pay the upfront costs during installation.	ESCO is responsible to pay the upfront costs during installation.	The ESCO is responsible to pay the upfront costs for project implementation. (Schedule E, section I)	The host is not liable to provide any financing for the project, and the ESCO may solicit and select financing offers through a competitive selection process. The host will consider the assignment of payments due for the works to protect a financier upon the ESCO’s request. (Section H7, H9)
Design liability/ responsibility	ESCO responsible for design, installation, etc. in accordance with specified standards (approved 3rd party may be allowed) (Clause 6.1) Construction Law and Contract Law also apply.	ESCO shall carry out the entire ECM contract with due care. (Clause 6) Civil Code also applies.	Licensed Technologist’s authentication is required. ESCO to verify design and its interface. Installation team to comment on design for mitigating on-site problems. Operator may also comment. (Clause 9)	Customer relies heavily upon ESCO’s skill, knowledge, professional training & experience in preparing any plan, drawing, specification or other document. The skill, knowledge, etc., should be reasonably required for similar projects. (Clause 4.2, 4.3)	All the installed ECMs shall comply with the provision of services required for facilities as specified in each Task Order. (Section C3 and Clause 5.2))
Ownership of equipment	The title of equipment shall transfer to the host when full payment of equipment is made. (Clause 8)	The title of equipment shall transfer to the host after the contract period. (Clause 10)	The title of equipment shall transfer to the host after acceptance and payment by host. (Clause 9.11)	When the host has discharged payment of the works to the ESCO, the latter cannot voluntarily file liens against the host. (Clause 10.7)	Title to all equipment installed by the ESCO can be vested either in the host or ESCO or a third party, subject to the host’s approval. The benefit of government financial incentives (e.g., tax credits) is part of the consideration for allocation of ownership of the works to ESCO or a third party.

					(Clause H2)
Performance and guarantee bonds	No relevant provision.	No performance or guarantee bond is required. (Clause 2.5)	Defect liability bonds may be required and their amounts are listed in the tender document (Clause 14).	Performance and payment bond shall be in an amount equal to the Contract Sum during the Installation Period. (Clause 4.12)	Performance bond shall be in an amount equal to 100 percent of the total bonded amount for all ECMs. Payment bond shall comply with Schedule TO-2 Bonded Amount. (Clause H8.2)
Operational Responsibility	The host shall comply with operational procedures laid down by the ESCO for any ECMs. The ESCO provides training to the host's staff in accordance with the Schedule 6. (Clause 5.7 & 6.3)	ESCO is responsible for the operational work, and comply with the operational indicators agreed with the host to achieve energy efficiency. (Clause 8)	The host is responsible for the operational work. The ESCO shall provide training to the host's staff, and the staff training plan shall comply with the relevant requirements as stipulated in Clause 16.4. (Clause 16)	The host is required to provide electronic means of access to allow the ESCO continuous remote access to performance tracking monitoring systems for performing and completing the Contract Services. (Clause 3.4)	The host shall comply with the operational procedures laid down by the ESCO for any ECMs The ESCO shall conduct periodic inspections to determine host's compliance with operational procedures. (Clause C6.1)
Maintenance	The ESCO is responsible for maintenance work during the contract period. (Clause 6.1)	The ESCO is responsible for maintenance work during the contract period. (Clause 9)	The ESCO is responsible for maintenance work during the contract period. (Clause 2.5)	Similar to the EMSC contract in Canada. The host is required to perform the regular maintenance work in accordance with Schedule G. (Clause 4.13, Schedule F)	The ESCO shall be responsible for the repair of all installed ECMs and conduct preventive maintenance of all installed ECMs. (Clause C8.1)
Dealing with risk of changes (M&V)	Risk of changes is negotiated by both contracting parties, and any agreed adjustment method shall be set forth in the Schedule 2. (Clause 4.1)	Either host or ESCO can propose baseline adjustment when the following circumstances occur: • Significant changes in system operation such as operating conditions, weather, etc. • Changes in an unit price of electricity, fuels and water The details of baseline adjustment are set forth in Clause 2.6. (Clause 2.6, 15)	Risk of changes is negotiated by both contracting parties. The parties may make reference to the local M&V guidelines, as developed by the Taiwan Green Productivity Foundation (TGPF). (Clause 15.3)	The causes for adjustment to the energy savings calculation is set forth in the Schedule C. The schedule lays down the responsibility and action to be taken when certain circumstances happen, for example, change in occupancy and occupancy hour, abandonment of an existing site. (Schedule B &C)	Risk of changes is negotiated by both contracting parties. The performance risk and responsibility matrix lists out the ESCO's approach to deal with possible changes (e.g. change of operating hours, load, weather, etc.) at the time of awarding a specific Task Order. (Attachment J-7)
Assignment	An assignment may be allowed, and the conditions upon which either party has the right for assignment are negotiable. (Clause 12)	Without the prior consent of the host, ESCO may not assign or transfer its right to others. (Clause 3)	The ESCO is forbidden to assign part or full interests, rights and benefits to any other person unless the ESCO undergoes a restructuring. Any assignment initiated by the ESCO has to obtain a written consent of the host.	Without the prior written consent of the host, the ESCO shall not assign the contract. The host may assign this contract to his affiliate or a lender for collateral purposes.	No provision on assignment by the host. (presumably due to the public sector nature of host)

			(Clause 21.13).	This contract shall be binding upon, and the benefits belong to, the successors and permitted assigns of the parties. (Clause 14)	
Termination upon default	Either party may terminate the contract in the event of major default by another party. *Termination by Host:* The host may terminate the contract when a project delay caused by the ESCO is more than the agreed period. *Termination by ESCO:* The ESCO may terminate the contract when the host fails to make the agreed payment within the agreed period. (Clause 11.3, 11.4 & 11.5)	*Termination by Host:* The host may terminate the contract when the ESCO fails to perform a provision set out in Clause 20. *Termination by ESCO:* The ESCO may terminate the contract when there is a significant modification work of the host's facility, leading to the ESCO's damage, or the ESCO is no longer able to provide the contract services due to the host's fault. (Clause 21 & 22)	*Termination by Host:* The host may terminate the contract when the ESCO fails to perform the provision as stipulated in Clause 22.1 *Termination by ESCO:* In the event of non-payment by the host beyond a stated period, the ESCO may terminate. Otherwise, only interest may be added to the payment due to the ESCO. (Clause 22, 22.10)	<u>Termination by Host</u> The host may terminate the contract when the ESCO fails to perform a provision as stipulated in the contract. <u>Termination by ESCO</u> The ESCO may terminate the contract when the host fails to make payments to the ESCO after a stated period. (Clause 13.1,13.4)	The host may terminate the contract in accordance with the relevant incorporation of Federal Acquisition Regulations in respect of Contract Termination – Debarment. (Part II Contract Clause deems incorporation of 48 CFR 52.222-12 Contract Termination – Debarment) No relevant clause is provided for the termination of contract by the ESCO.
Termination without default (Termination for Convenience)	No relevant provision.	No relevant provision.	In the event of policy change when the existing contract is no longer beneficial to general public, the host may terminate the contract in whole or in part. Compensation shall be made to the ESCO, but not including loss of potential profit in the contract (Clause 22.5).	The host may terminate the contract in whole or in part, at any time. The host shall pay the ESCO a portion of the Contract Sum for Performance Tracking Services. (Clause 13.3)	The host may terminate the contract in whole or in part, if the contracting officer determines that a termination is in the host's interest. (Part II Contract Clause deems incorporation of 48 CFR 52.249-2 Termination for the Convenience of the Government (Fixed – Price))
Dispute Resolution before litigation	Disputes shall be settled by mediation or arbitration. (Clause 15)	Disputes shall be settled by mediation or arbitration. (Clause 29)	Disputes shall be settled by mediation, arbitration or other agreed dispute resolution means (Clause 23).	Unsettled disputes shall be referred to arbitration. (Clause 7)	Dispute resolution will be settled in accordance with an agreed plan in the M & V attachment. (Attachment J-8)

7.6 Chapter summary

This chapter presents a comparative study of nine standard forms of EPC contract in eight jurisdictions. The special features of standard form of EPC contract are identified, and the key differences between those contracts are highlighted to reflect various treatments of common contractual issues in EPC projects. The findings of this comparative study show that the guaranteed saving model is the more common model adopted in those standard forms. For the sake of simplicity, most contracts only consider cost savings in energy and water consumption. Other types of cost savings such as operational cost savings are often not dealt with.

It is observed that several standard forms provide the ESCO with an incentive to achieve energy savings higher than the guaranteed level. For example, the amount of excess savings can be used (1) to offset the ESCO's liability for future shortfalls; (2) as a 'gain' which is shared by the contracting parties; and (3) to shorten the guarantee period. Regarding the payment arrangement, the host often starts to make payments when actual savings are materialised during the post-retrofit period, and most standard forms stipulate that actual payment will be adjusted based on the amount of excess savings and saving shortfalls in each M&V period. Although the ESCO often pays the upfront capital for project implementation, the ownership of equipment is usually transferred to the host upon the issue of acceptance certificate, instead of upon full payment made by the host. In addition, it is common that the ESCO is responsible for maintenance work during the contract period, whilst the host is responsible for system operation. However, in order to protect the interest of the ESCO, the host has to comply with the operational procedures laid down by the ESCO to ensure that the system is operating at the expected efficiency.

Due to the concern of fairness in the tendering stage, modifications of installed ECMs may not be allowed in some standard forms when actual energy savings are less than the guaranteed level during the post-retrofit period. This is more common in the public EPC contracts. Regarding the clauses dealing with risk of changes, it is observed that a baseline adjustment mechanism is often negotiated by both contracting parties before the signing of contract, and *the International Performance Measurement and Verification Protocol* (IPMVP) is the most popular guideline for reference. However, several jurisdictions (e.g. Singapore, Taiwan and the U.S.) use their own M&V guidelines. In addition, restrictions on assignment are often given in EPC contracts, especially for the public contracts where a public procurement process has been undertaken. The provision of termination for convenience is introduced in some standard forms, and this allows the host to terminate the contract without default during the post-retrofit period. As EPC projects involve the calculation of energy savings and baseline adjustment which are the common grounds for disputes, most standard forms stipulate alternative means of dispute resolution (e.g. mediation and arbitration) and its procedures when disputes occur, before litigation takes place.

The findings of this contract comparison would enable the stakeholders of EPC projects, including hosts, ESCOs, lawyers and financiers, to better understand the terms of EPC contracts and the various issues of concern in different jurisdictions. Besides, the findings highlight the common treatment of key contractual issues in EPC projects, which provide a solid foundation for developing a local EPC contract template. The details of an EPC contract template for use in Hong Kong will be discussed in Chapter 8 (A Model of EPC for Hong Kong).

CHAPTER 8: A MODEL OF EPC FOR HONG KONG

Chapter 8 – A Model of EPC for Hong Kong

8.1 Introduction

This chapter presents a model of energy performance contracting (EPC) for Hong Kong. This model is developed based on an extensive literature review, the findings from the questionnaire surveys, as well as the semi-structured interviews with key stakeholders from the public and private sectors in Hong Kong, as described in the earlier chapters. The risk assessment approach and the essence of a comparative study of different standard contract forms is also incorporated into the model. To ensure the applicability and practicality of the model for use in Hong Kong, it was validated by a number of experts and practitioners related to the field of EPC, or representatives of potential clients of EPC in Hong Kong.

8.2 A Model of EPC for Hong Kong

The development of this model is intended to help hosts and ESCOs to identify and address the key issues and their relationships when implementing EPC projects, starting from the stage of pre-retrofit, through installation, to post-retrofit. In this study, the model is defined as *‘a systematic description of a process which enables users to identify and address the key issues and their relationships’* (Gemino and Wand, 2004). The findings of earlier chapters have been consolidated into the model, which is presented by a graphical method to aid understanding. The model consists of fourteen building blocks as summarised in Figure 8.1. Each block is further divided into several components for zooming into specific details.

The pre-retrofit stage comprises fourteen building blocks, namely, ‘Procurement’, ‘Establishing Client’s Requirement’, ‘Investment Grade Audit’, ‘Bid Evaluation’, ‘Risk Assessment of Energy Saving Shortfalls’, ‘Choice of Suitable EPC Mode’, ‘Contract Management’ and ‘Measurement & Verification Plan’. The installation stage consists of two building blocks: 'Design, Supply, Installation, Testing & Commissioning', and 'Modification of ECMs'. The post-retrofit stage involves four building blocks, including 'Commencement of ECM Performance', 'Operation & Maintenance', 'Measurement & Verification Reporting' and 'Payment Mechanism'. Each building block is discussed in detail in the following sections.

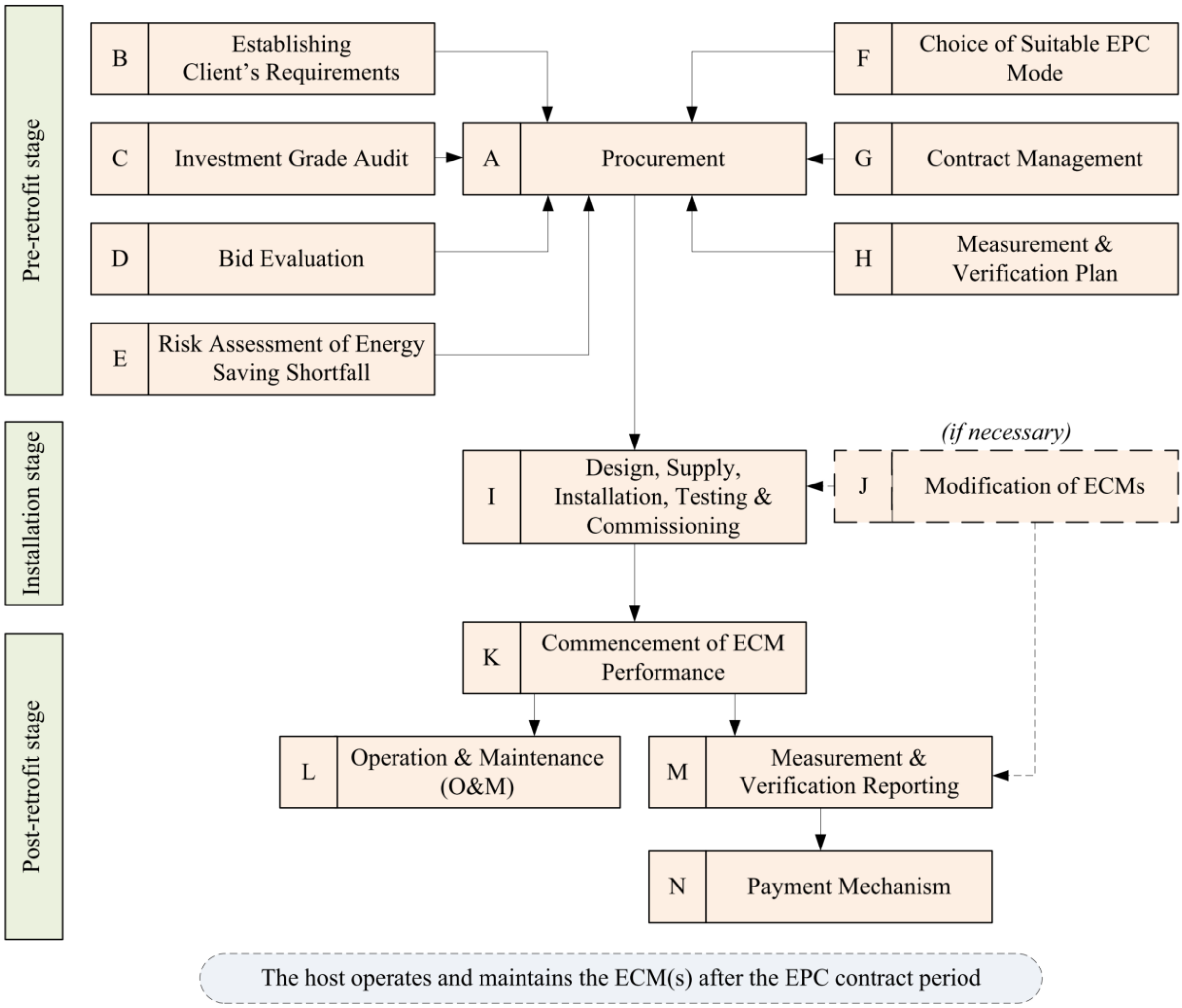

Figure 8.1: A Model of Energy Performance Contracting for Hong Kong

A: Procurement Process

As presented in Figure 8.2 ('Building Block A'), there are two approaches to procure EPC projects: (1) solicited by hosts; (2) initiated by the ESCO. For the former, the host may issue a call for Expression of Interest (EOI). The notice of EOI mainly sets out the host's requirements for project development as shown in Figure 8.3. The interested ESCOs may respond to the call and demonstrate their capabilities to undertake investment grade audits (IGA) and EPC projects. The host may consider engaging independent consultants to review the preliminary proposals if the host has no competent engineering team. After reviewing the responses from the interested ESCOs, the host may invite the shortlisted ESCO(s) to conduct an investment grade audit (IGA), which would form the first-stage of EPC contract. It should be noted that there may be more than one ESCO to be awarded the IGA contract.

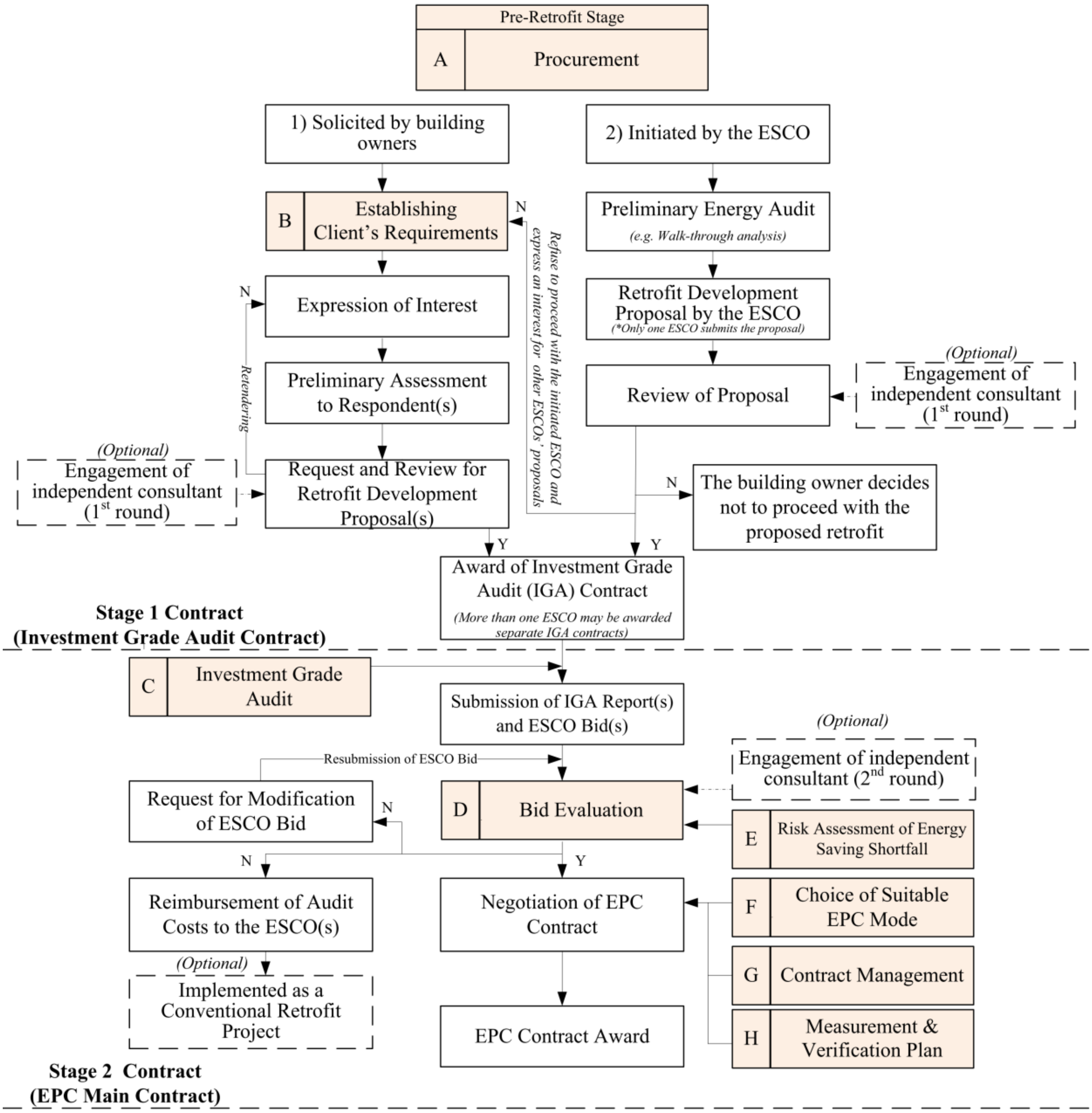

Figure 8.2: Building Block A - Procurement

For the latter, the ESCO would take an initiative to propose the ECMs to the host. Those ESCOs are often the equipment manufacturers who periodically conduct maintenance work in the host's premises. When the host is interested in the ESCO's preliminary proposal, the host would sign the first-stage of EPC contract with the ESCO, who would later conduct IGA.

With the result of IGA, the ESCO(s) will propose suitable ECMs and estimate the corresponding energy savings, together with the means of project financing to the host for consideration. The key criteria for bid evaluation are shown in Building Block D (Figure 8.5). As highlighted by the interviewees, the host may consider engaging independent consultants for the review of project proposals at this stage because some ESCOs may have a strong bias towards their energy efficient products, instead of providing the best retrofitting solution to the host. If the host agrees the proposal in principle, both the host and a selected ESCO would negotiate the EPC contract and implement the project. If the host decides not to proceed with EPC, the host may reimburse the cost of IGA.

In order to facilitate the process of project negotiation, four building blocks, which deal with the key issues in implementing EPC projects (e.g. project risks, M&V and contractual issues), are incorporated into the model, namely 'risk assessment of energy saving shortfalls', 'choice of suitable EPC mode', 'measurement & verification plan' and 'contract management'. These building blocks enable the practitioners to better evaluate the risk of saving shortfalls for any proposed ECM, strike an appropriate balance between the level of certainty in savings and the M&V costs, as well as tackle the problem of ambiguity in common contractual issues in EPC projects. These building blocks would be discussed in detail in the next section.

B: Client's Requirements

Figure 8.3 ('Building Block B') shows the essential elements of client's requirements for project implementation. In general, the purpose of implementing EPC projects from the client's perspective is not only to replace ageing equipment and systems in their existing buildings, but also to improve building energy efficiency. Therefore, apart from the basic requirements in conventional projects such as definitions of the work scope, constraints and limitations (e.g. working hours) as well as functional needs (e.g. thermal comfort), the client's requirements in EPC projects include his expectations on targeted energy savings, risk allocation, competence of ESCOs, means of financing, as well as operation and maintenance. In order to implement EPC projects with the expected outcomes, it is important for both ESCOs and hosts to understand those requirements, especially for the allocation of financial and performance risks.

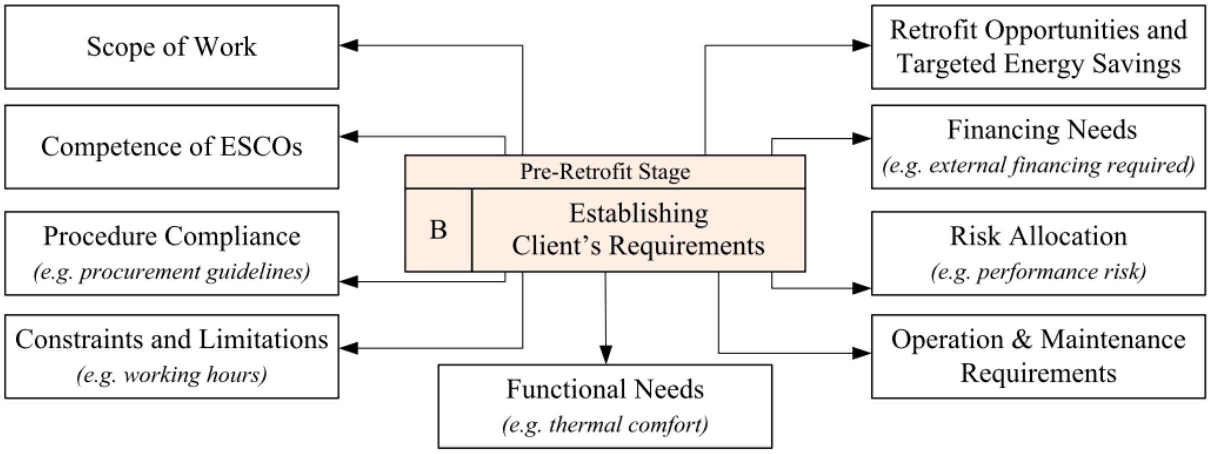

Figure 8.3: Building Block B – Establishing Client's Requirements

C: Investment Grade Audit

In comparison with conventional energy audits, investment grade audits (IGA) not only focus on the review of building energy performance, identification of possible ECMs as well as implementation of a cost-benefit analysis of proposed ECMs, but also emphasise on the expected level of energy savings if the proposed ECMs are implemented. Hence, the IGA report would be more comprehensive and detail the method and procedures for the development of an energy use baseline, as well as lay out the measurement & verification (M&V) plan, which enables the host to understand the ascertainment method of energy savings. In addition, the ESCO would propose the means of project financing. It should be noted that the IGA report is an important document in EPC projects since it often forms part of an EPC contract when both parties agree with its content. Therefore, attention should be paid on the key issues such as the baseline adjustment mechanism and M&V method to avoid ambiguity arising from those issues. Figure 8.4 ('Building Block C') outlines the key elements of conducting investment grade audits.

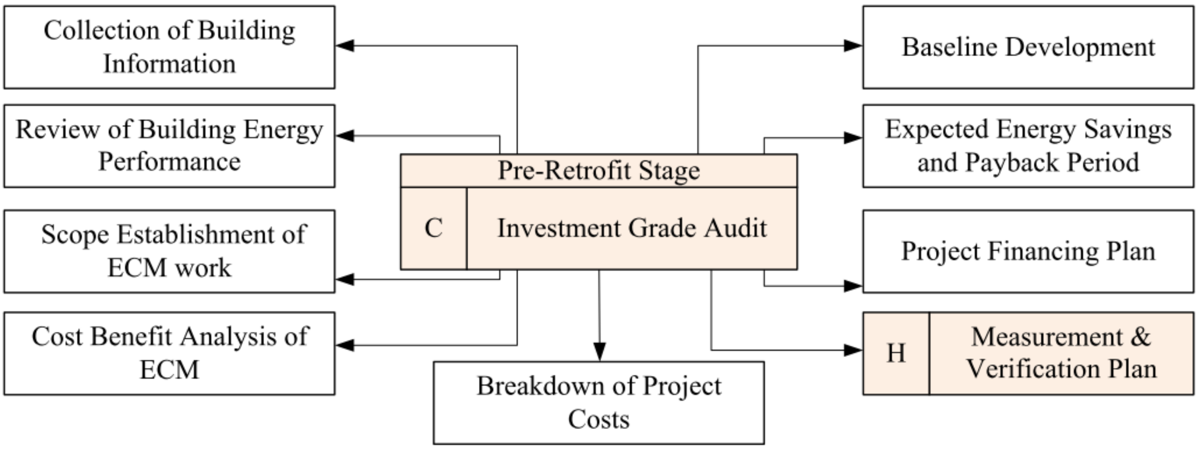

Figure 8.4: Building Block C – Investment Grade Audit

D: Bid Evaluation

The criteria of bid evaluation for EPC projects is rather different from the that of conventional projects since EPC projects are developed with the collaboration of ESCO in technological inputs, instead of clear specifications provided by the host. Therefore, different ESCOs may propose various building retrofitting solutions under the same building and system conditions. Apart from the previous project track records of ESCOs and contract prices, the host may evaluate their bids based on the amount of expected savings, mode of EPC being used (e.g. guaranteed/ shared savings), method of project financing (e.g. self-financing or third party financing), etc., as shown in 'Building Block D'. As such, a set of prioritised requirements established by the host is particularly important in the process of bid evaluation. The approach as represented by 'Building Block E' enables the host to evaluate the probability of saving shortfalls at a known confidence level, and this can enhance the host's confidence in whether the ESCO can feasibly deliver the promised savings in each M&V period. In addition, the ESCO may propose different payment methods for EPC projects, and this would be discussed in detail in 'Building Block N'. Figure 8.5 outlines the important elements when the host evaluates EPC project bids submitted by the ESCOs.

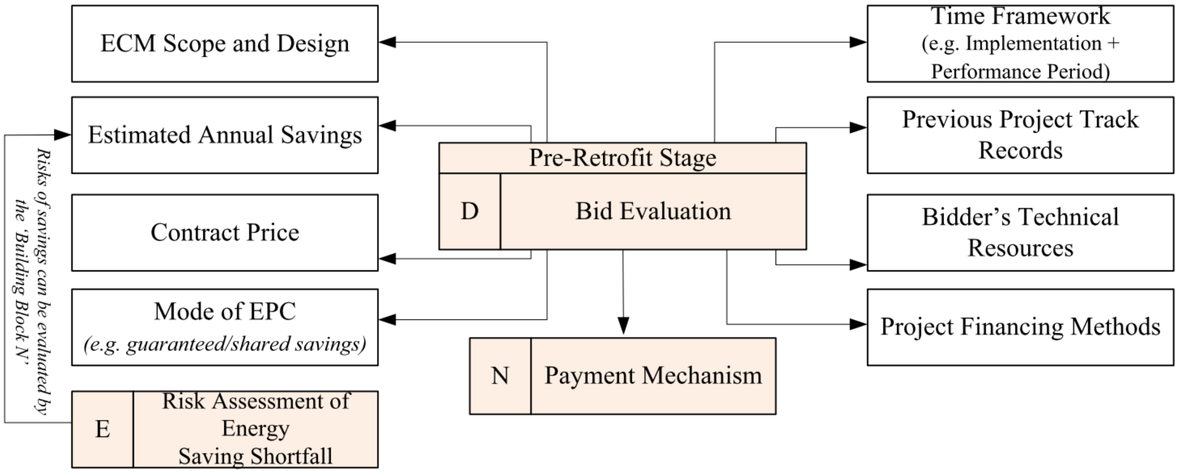

Figure 8.5: Building Block D – Bid Evaluation

E: Risk Assessment of Energy Saving Shortfall

A proper assessment method on the performance risk is critical to the successful delivery of EPC projects. Figure 8.6 details the procedures and methods used for quantifying the probability of possible energy savings at a defined level of confidence, based on the proposed ECMs by the ESCO. As shown in 'Building Block E', the entire procedures comprise six steps, namely 'development of pre-and post-retrofit models', 'identification of parameters affecting energy savings', 'correlation analysis', 'development of probability functions for the influential parameters', 'simulation of possible energy savings' and 'estimation of the

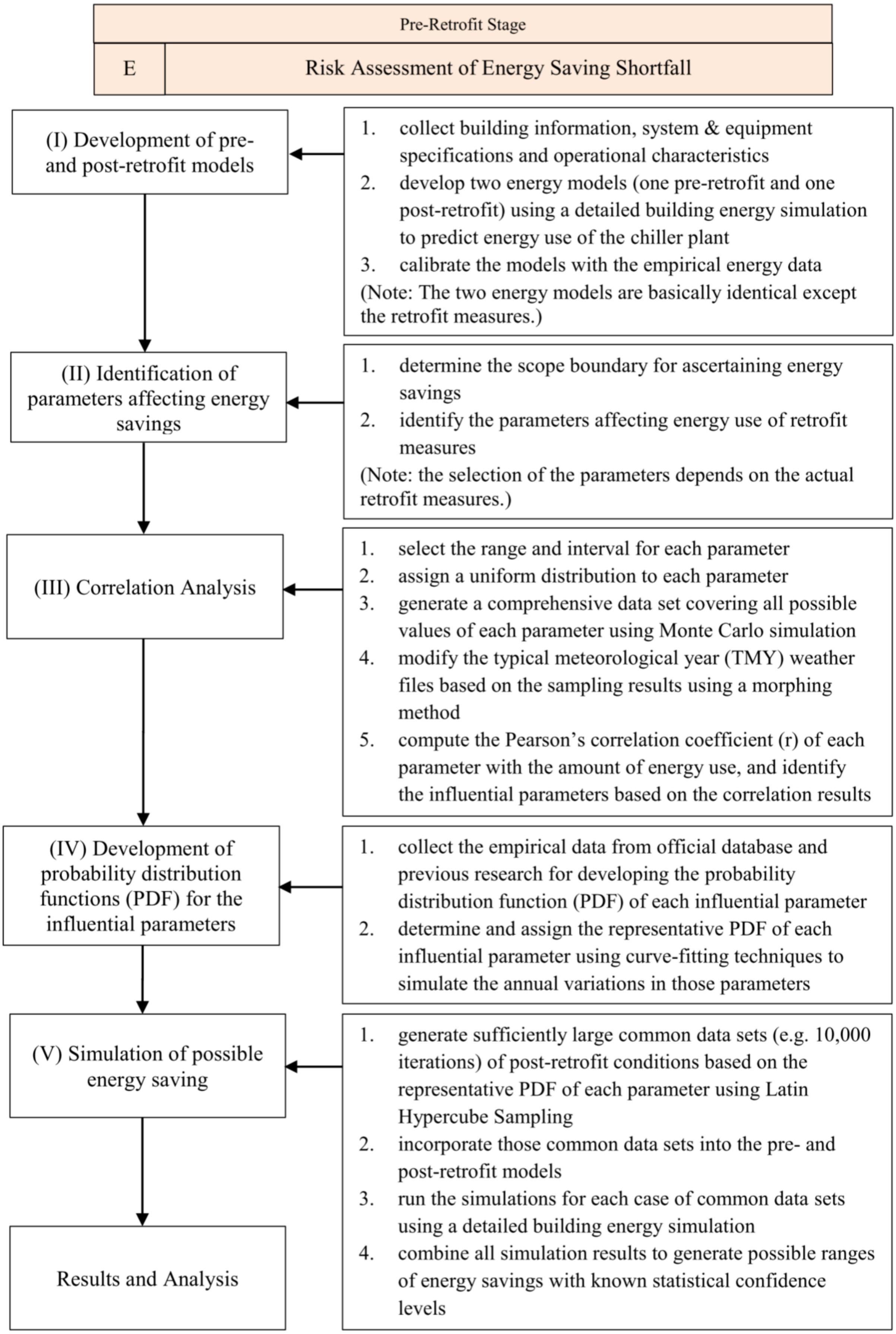

Figure 8.6: Building Block E - Risk Assessment of Energy Saving Shortfall

probabilities of energy saving shortfalls'. The detailed discussion of this risk assessment method is presented in Chapter 6. In addition, three case studies (e.g. replacement of air-cooled chillers with water-cooled chillers, replacement of heat rejection system for a central chiller plant, as well as replacement of existing lighting with T5 fluorescent tubes plus installation of daylight-linked lighting controls and occupancy-based controls) were used to demonstrate the application of this assessment method. With the use of this assessment method, it is anticipated that both the host and ESCO would better understand and manage the performance risk of energy retrofitting projects.

F: Choice of Suitable EPC Mode

With a clear understanding of client's requirements and energy saving potential, it is important to select a suitable EPC mode for project implementation. Guaranteed savings and shared savings are the two common modes in EPC projects and their features have been fully discussed in Chapter 2. Figure 8.7 ('Building Block F') outlines the approach and key issues when the host decides the EPC mode. In general, the main consideration lies on the allocation of financial and performance risks.

As discussed in Chapter 5, it is common to see that the host with a strong financial background is willing to pay the upfront capital for project implementation, and the ESCO only provides the guarantee on energy savings. In this arrangement, the host often expects the ESCO to achieve energy savings more than the industry norm. However, despite their strong financial standing, some hosts may still prefer to borrow money from financial institutions, especially for the prevailing low-interest rate environment, because their investment in other aspects may yield more returns. Besides, due to the high credibility in repayment, the relatively low interest rate is often offered to the semi-public sector from financial institutions.

In some cases (e.g. multiple ownerships), the ESCO may be hesitant to bear the financial risk despite the strong confidence in its energy efficient technologies, because the ESCO is afraid of payment default from those hosts. Therefore, the selection of financing method depends on a number of factors, including interest rates, credibility of lenders, etc.

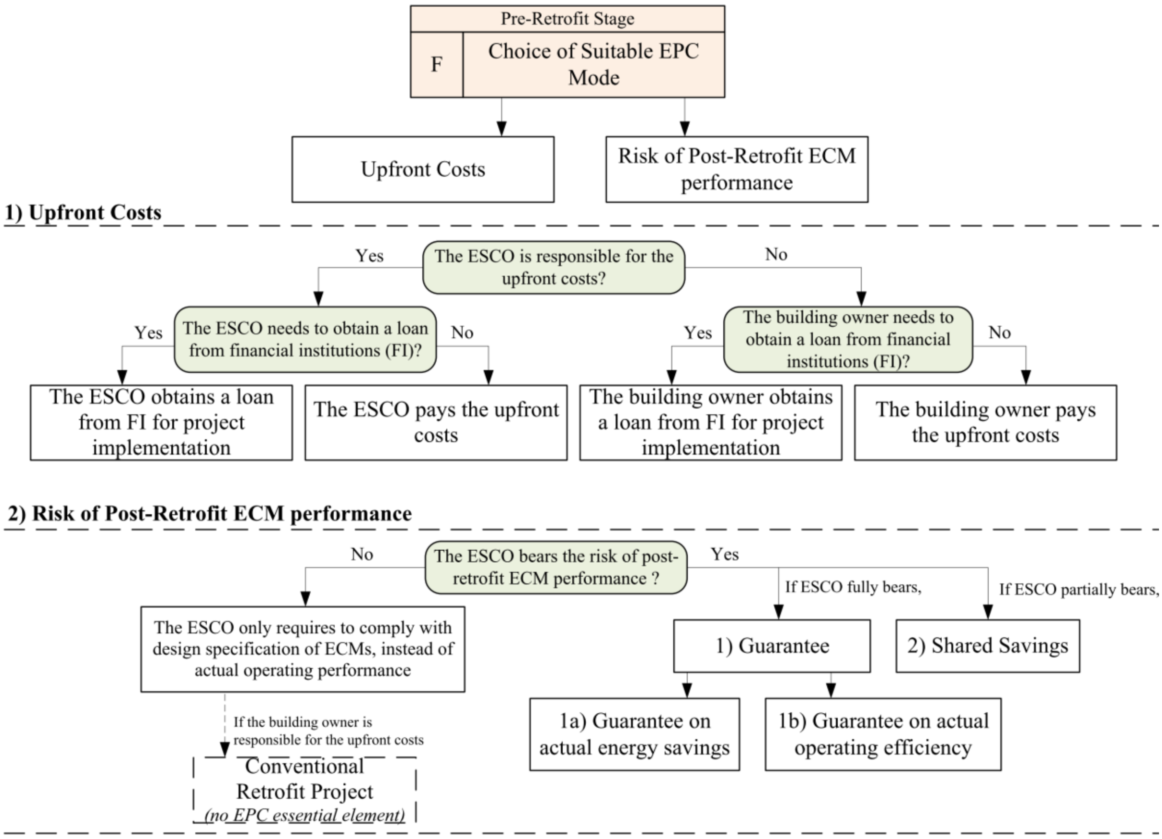

Figure 8.7: Building Block F – Choice of Suitable EPC Model

As for the allocation of performance risk, on one hand, the host prefers the ESCO to fully bear the performance risk by providing a guarantee on actual savings due to their competence on energy efficient technologies. On the other hand, some hosts may consider the use of the shared saving mode because they can immediately enjoy the benefit of energy cost reduction as the savings will be shared by both parties in each M&V period. However, since ESCOs are responsible to pay the upfront capital in this arrangement, the retrofitting measures are often conservative, for example, lighting upgrading (replacement of T8 with T5) only. It should be noted that if the host is willing to pay the upfront cost and bear the performance risk, then the host may consider implementing the project through the conventional method, instead of EPC.

G: Contract Management

As discussed in Chapter 7, a comparison between nine standard forms of EPC contract from eight jurisdictions were made, highlighting various treatments of particular contractual issues in EPC projects. Based on the findings of contract comparison and interviews, an EPC contract template (Appendix G) and guidance notes (Appendix H) were developed for the single retrofitting work such as chiller replacement or lighting upgrading. As mentioned in Chapter 5, the guaranteed saving model is more preferable in Hong Kong in term of M&V arrangement and risk allocation, and therefore this contract template is based on the guaranteed saving model. Unlike other standard forms of EPC contract in overseas countries, this contract template is targeted at hosts who have no strong in-house engineering team and legal representatives. Therefore, the template is made simple to the extent that it covers the essential elements in EPC projects, and enables a lay person to understand the contractual obligations when the contracting parties agree to implement a EPC project based on the guaranteed saving model. A set of guidance notes was also developed to aid the use of the template (Appendix H).

Figures 8.8 and 8.9 ('Building Block G') contain all the essential provisions in this EPC contract template, sub-divided due to space limitation. They include the mode of EPC, scope of savings, treatment of excess savings and saving shortfall, performance commencement date, guarantee period, payment, design liability, ownership of equipment, performance and guarantee bonds, operation and maintenance, dealing with risk of changes, liquidated damages, extension of time, assignment, termination upon default, as well as dispute resolution. Possible alternatives of those provisions are also provided, and thus the template enables both hosts and ESCOs to understand the pertinent contractual issues and risks during the stage of contract negotiation.

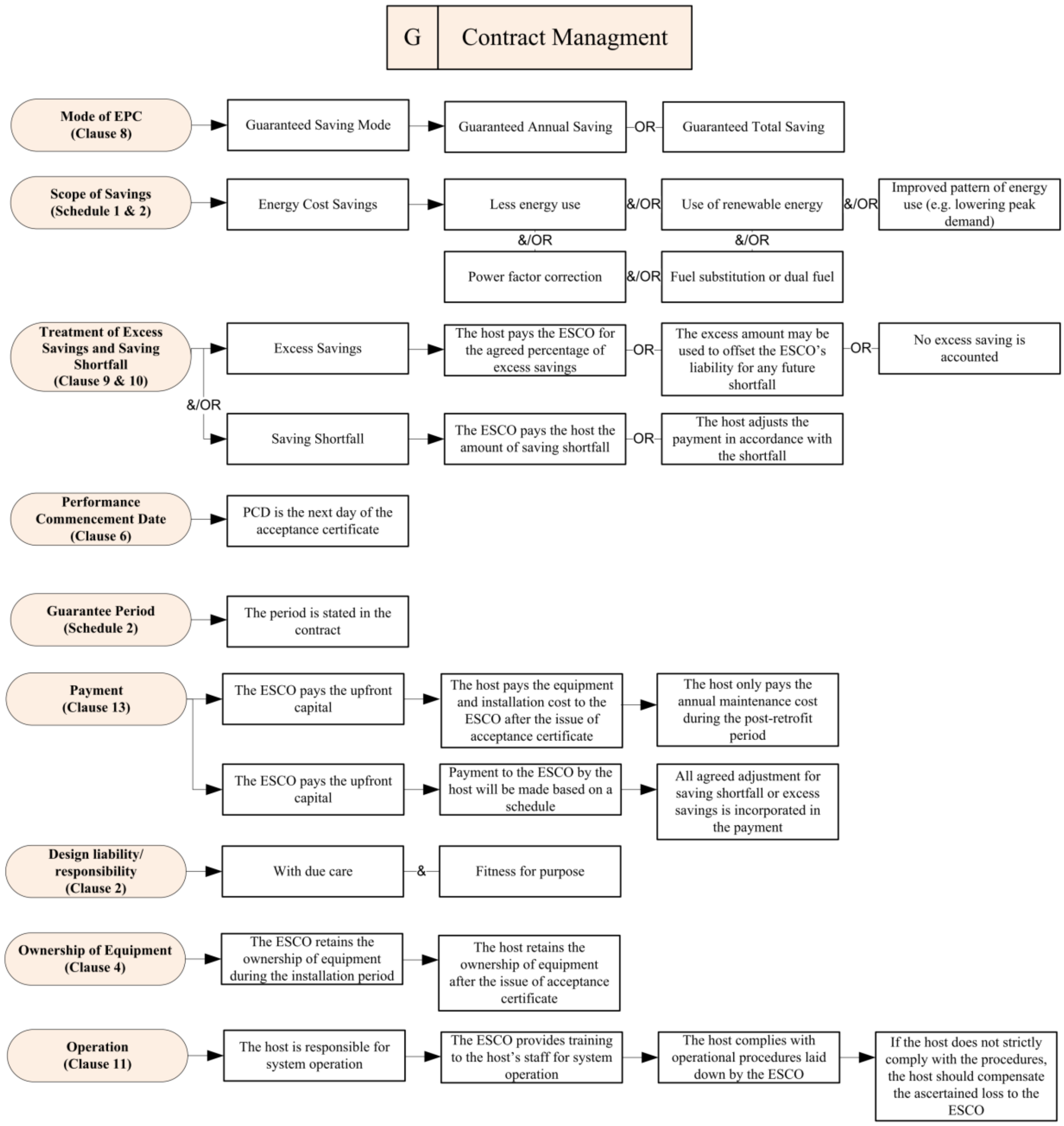

Figure 8.8: Building Block G - Contract Management of essential provisions (a)[12]

For example, the ESCO can guarantee energy savings either (a) in each guarantee year of not less than the Guaranteed Annual Savings, or (b) at the end of the total guarantee period of not less than the Guaranteed Total Saving, thus providing flexibility for the contracting parties to reduce their burden of M&V works. Similarly, for the treatment of excess savings, four options are given: (1) no excess savings is accounted for in payment; (2) the host should pay

[12] Note: Regarding the shaded boxes in Figure 8.8 and 8.9, please refer the clause numbers to the proposed contract template (Appendix G) and guidance notes (Appendix H) for details.

the ESCO for the agreed percentage of the excess in each guarantee year; (3) the excess savings are used to offset the ESCO's liability for any future shortfall; or (4) the host should pay the ESCO for the agreed percentage of the excess at the end of the guarantee period. These options provide different incentives for the ESCO to maximise the achievable energy savings.

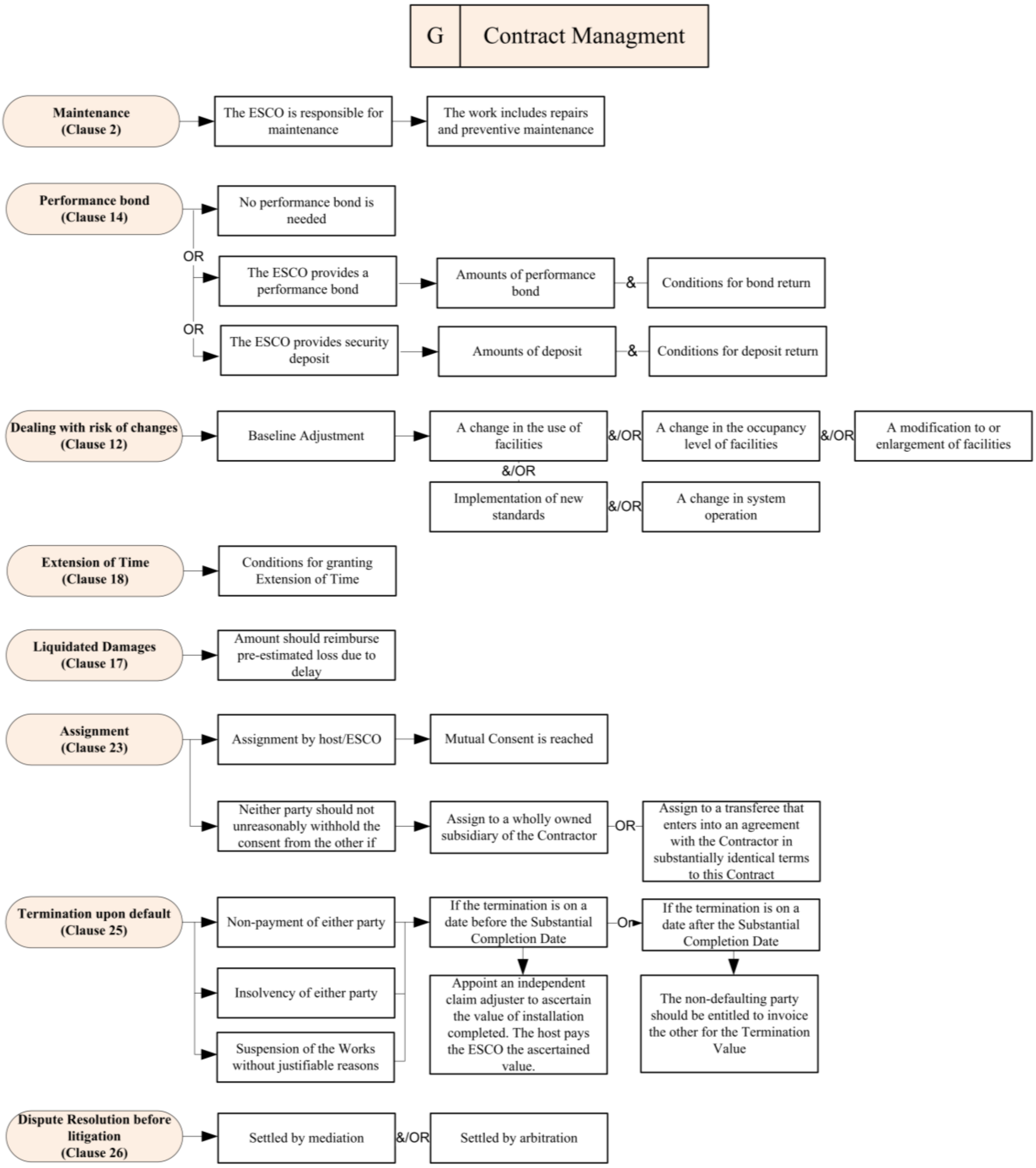

Figure 8.9: Building Block G - Contract Management of essential provisions (b)[12]

As the interviewees indicated that the guaranteed model where the ESCO bears both financial and performance risks is also common in Hong Kong, this contract template incorporates the revised model by providing an alternative for payment arrangement, by which the host starts making the scheduled payment to the ESCO after the issue of acceptance certificate. The actual amount of disbursement in each payment will be adjusted in accordance with the agreed treatment of excess savings and saving shortfalls.

In addition, the draft contract template and guidance notes were commented by three experts in the field of EPC. To ensure that the experts fully understand the contract template prior to the discussion, the template with guidance notes were sent to the experts in advance. On average, the duration of discussion on the model was around 1.5 hour. The comments from the above experts are summarised in Appendix E and those comments have been incorporated into the contract template as presented in the Response Column.

H: Measurement and Verification (M&V) Plan

In practice, a dilemma is often felt in conducting M&V works. On one hand, the level of certainty in determining energy savings should be as high as possible, but on the other hand, the costs of M&V should be minimised. In order to strike an appropriate balance between the level of certainty in savings and M&V costs, each M&V activity should be carried out with the consideration of the elements as shown in Figure 8.10 ('Building Block H'). Apart from the development of energy use baseline, its adjustment is particularly important to the successful delivery of EPC projects since ambiguity is often encountered in this aspect when baseline conditions change dramatically. It is advised that both the host and ESCO should clearly determine the causation factor and the degree of variations in those factor(s) to trigger baseline adjustment (e.g. baseline energy use will be adjusted when five percent of variation in occupancy level is exceeded). In addition, both parties should agree on the appointment of a M&V third party in case of disputes on the M&V results. The interviewees pointed out that the ideal third party should come from the academia, instead of E&M consultants, to enhance the level of independence and fairness.

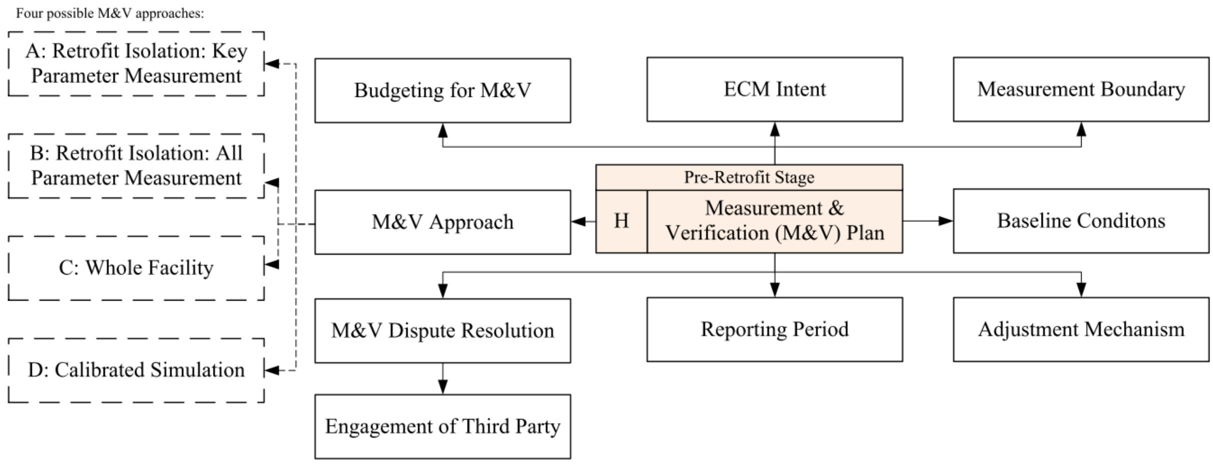

Figure 8.10: Building Block H - Measurement & Verification Plan

Regarding the M&V approach, the International Performance Measurement and Verification Protocol (IPMVP) provides four M&V options as listed in Figure 8.10 (EVO, 2012), and twelve examples of common retrofitting such as pump efficiency improvement, boiler efficiency improvement in the IPMVP are listed to illustrate its application in the IPMVP.

I: Design, Supply, Installation, Testing & Commissioning

Once an ESCO is appointed, the installation stage follows. This stage is similar to conventional projects, which involve design, supply, installation, as well testing & commissioning (T&C). During this stage, the ESCO shall submit design drawings, installation plans, work schedules and material samples for the host’s review and approval. When the ECM work is not completed on the scheduled date, the host may claim the ESCO for liquidated damages or the ESCO requests for an extension of time due to the event(s) as set forth in the contract. Once the ECMs are completed with satisfactory performance, the host would issue a Certificate of Substantial Completion, and the post-retrofit stage commences. Figure 8.11 (‘Building Block I’) depicts the essential elements to cater for the installation stage.

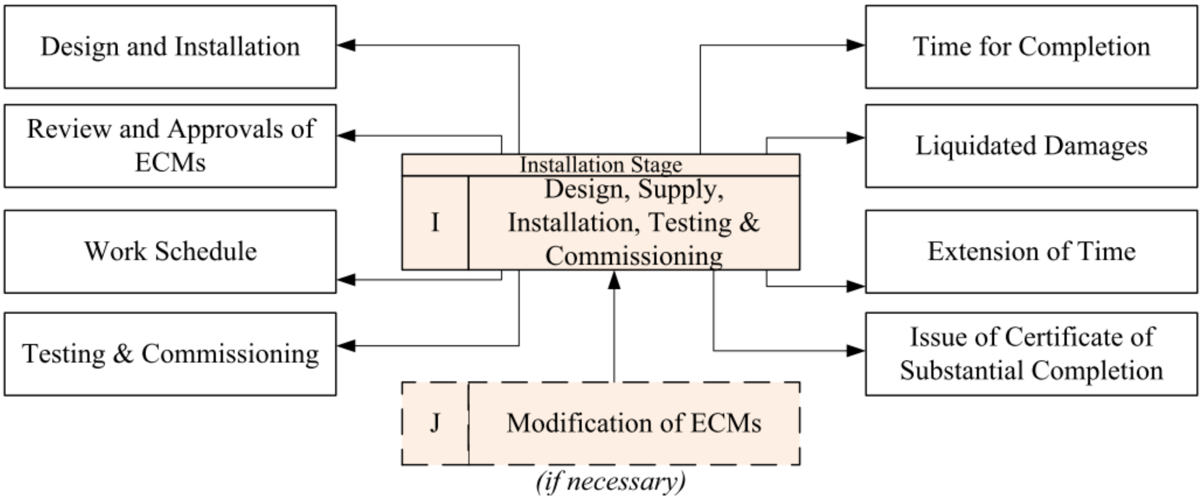

Figure 8.11: Building Block I - Design, Supply, Installation, Testing & Commissioning

J: Modification of ECMs

Although the ESCO fully complies with the contract specifications to undertake installation works, the expected energy savings may not be achieved due to problems in system design and operation. Since the intended propose of EPC contract is to achieve the expected energy savings, instead of seeking compensation from the ESCO due to saving shortfalls, an alternative is often given to the ESCO for modification of ECMs. Figure 8.12 (‘Building Block J’) outlines the situations where the ESCO may exercise the modification option. The ESCO may modify the installed ECMs or install additional equipment at the ESCO’s own cost at the stage of Testing & Commissioning. The ESCO may also exercise the modification option when the ESCO records consecutive saving shortfalls during the post-retrofit period. It should be noted that such improvement is subject to the prior written approval of the host. To avoid the host rejecting any change even when the ESCO bears the costs of changes, a provision may be made in the contract that additional works are allowed to be implemented by the ESCO when such works are reasonable to be installed for achieving the promised energy savings.

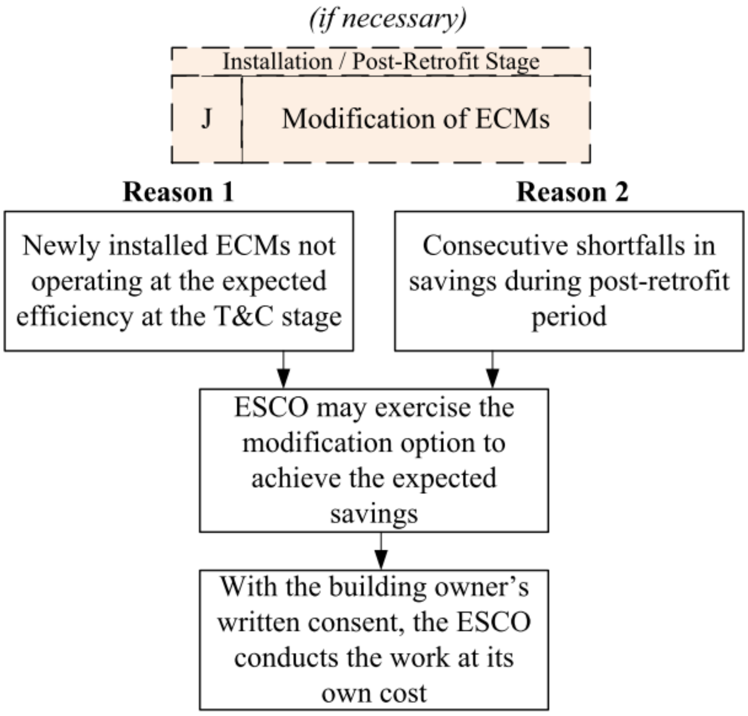

Figure 8.12: Building Block J - Modification of ECMs

K: Commencement of ECM performance

The commencement performance date is an important milestone for the entire EPC project as it kicks start the monitoring and recording of the ongoing performance of ECMs, maintenance and repair of the ECMs (resulting from normal wear and tear). The ESCO also checks the compliance of said the agreed operation procedures, as well as calculate the accumulated savings. In general, the commencement performance date is the day after substantial completion. Figure 8.13 ('Building Block K') shows the important elements during the post-retrofit stage, which include, operation and maintenance, measurement and verification reporting, and payment mechanism. Each detail component of the building block would be discussed in the next section.

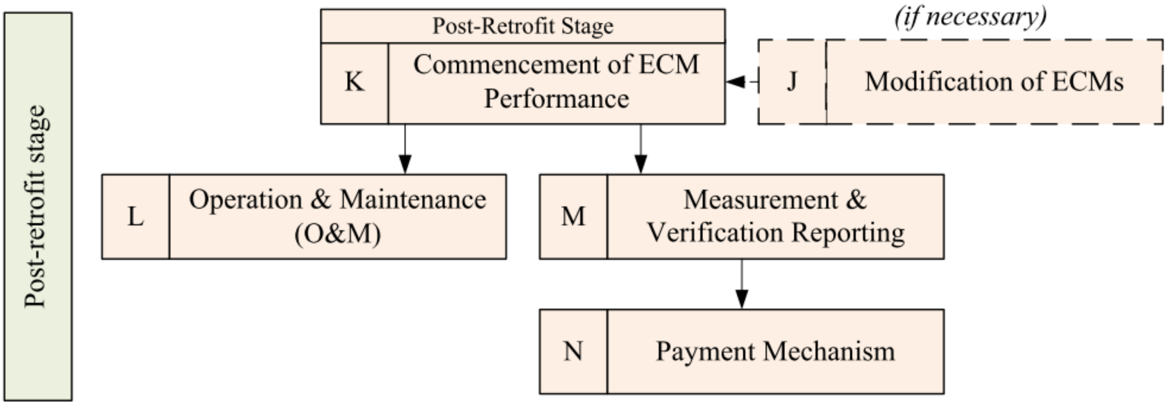

Figure 8.13: Building Block K - Commencement of ECM performance

L: Operation & Maintenance (O&M)

Proper operation and maintenance for ECMs are essential to improve system efficiency and thereby maximise energy savings. Figure 8.14 ('Building Block L') shows the key elements to ensure that the system is operating at optimal efficiency from the O&M perspective. They comprise O&M manual, regular maintenance and repair, staff training for O&M, as well as compliance checking of operation procedures.

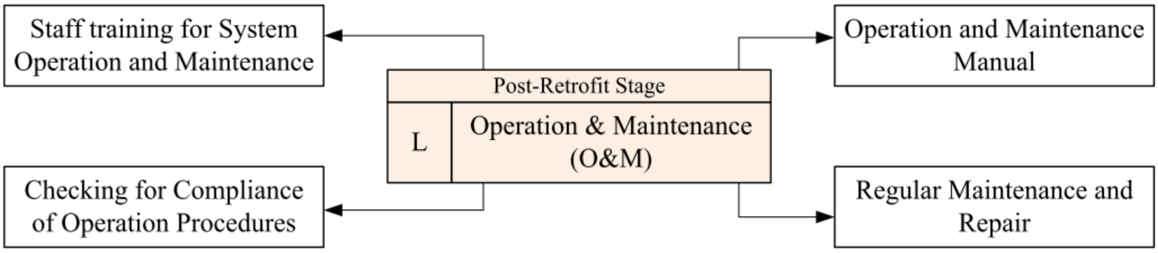

Figure 8.14: Building Block L - Operation and Maintenance

After the substantial completion of ECMs, the ESCO should provide the host with operation and maintenance manuals and train their staff for proper O&M procedures, which are important to achieve the expected energy savings. To ensure that the owner's staff complies with the said operation procedures, the host should grant the ESCO access to the premises for regular inspection. The ESCO should also provide regular maintenance on the ECMs. In the event of a failure in ECMs or metering devices, the host should promptly notify the ESCO of such a failure and request the ESCO to carry out necessary repair works. It is worth noting that when the host does not strictly follow the required operation procedures, resulting in less energy savings being achieved, the host should compensate the ascertained loss by the host to the ESCO.

M: Measurement & Verification Reporting

M&V reporting is particularly important since this report will be an official document to determine whether the ESCO actually achieves energy savings more than the guaranteed level. Figure 8.15 ('Building Block M') depicts the procedures and actions during the M&V reporting. It involves data collection on building use pattern and system operating data, baseline adjustment (if necessary), report on actual energy savings.

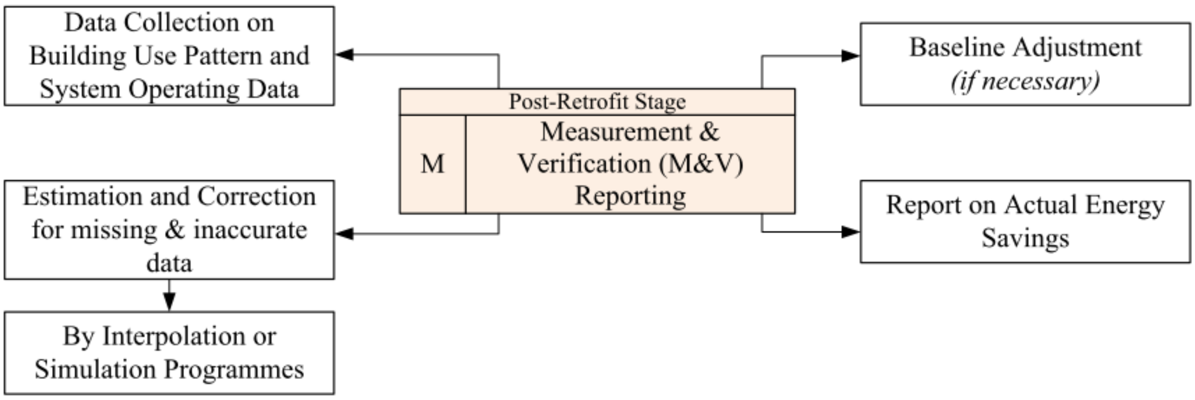

Figure 8.15: Building Block M - Measurement & Verification Reporting

As discussed in Chapter 5 regarding the issues of M&V, it is advised that remote monitoring systems should be installed since this system not only records energy savings simultaneously for ECMs, but also monitors and detects the abnormal use patterns in buildings. Moreover, the operating data recorded by the remote monitoring system will be stored in a third-party's server (e.g. cloud server). This ensures that no party can amend the operating data and identical sets of data are sent to both parties. In addition, it is common to see that missing or inaccurate data is often found when retrieving the system operating data. This may result in difficulties in determining actual energy savings. Interpolation or simulation programmes may be used to estimate those missing data.

N: Payment Mechanism

Figure 8.16 ('Building Block N') depicts two payment approaches which can be adopted in EPC projects. The first one is 'scheduled payment'. Such payment arrangement is similar to conventional construction projects where both contracting parties would follow the payment schedule as set forth in a contract. Before the signing of contract, the key payment arrangement such as the number of payment, timing and amount of each term have been determined and agreed by both parties. In order to incorporate the concept of saving guarantee into the payment arrangement, the scheduled payment would be adjusted based on the agreed treatment of saving shortfalls& excess savings. For example, the next payment would be deducted with a certain percentage if saving shortfalls occur, or an additional payment would be made if the ESCO achieves actual savings more than the guaranteed level. The main advantage of this payment arrangement is that both parties can understand the cash flow in advance for the entire period of an EPC project. In addition, this payment arrangement may allow the ESCO to receive the payment during the installation period, for example, agreed payment at 25% of works completed. This arrangement would be more beneficial to small-medium ESCOs who have limited cash flow in business.

The second payment approach is the payment linked to actual savings. In such a payment arrangement, the amount of payment is calculated based on the actual cost savings being achieved by the ESCO, and the timing of payment is in line with the period of M&V. Although this arrangement is fair to the extent that the host only pays for the achieved savings, it has one major drawback in that the actual amount of energy savings is sometimes difficult to ascertain, and may eventually lead to a dispute. However, this payment arrangement allows both parties to determine the payment criterion, for example, payment would only be made when actual savings exceed the guaranteed level. Besides, unlike the scheduled payment, no payment would be made to the ESCO before substantial completion, and this arraignment may limit to the scale of ECMs, especially for the small to medium-sized ESCOs.

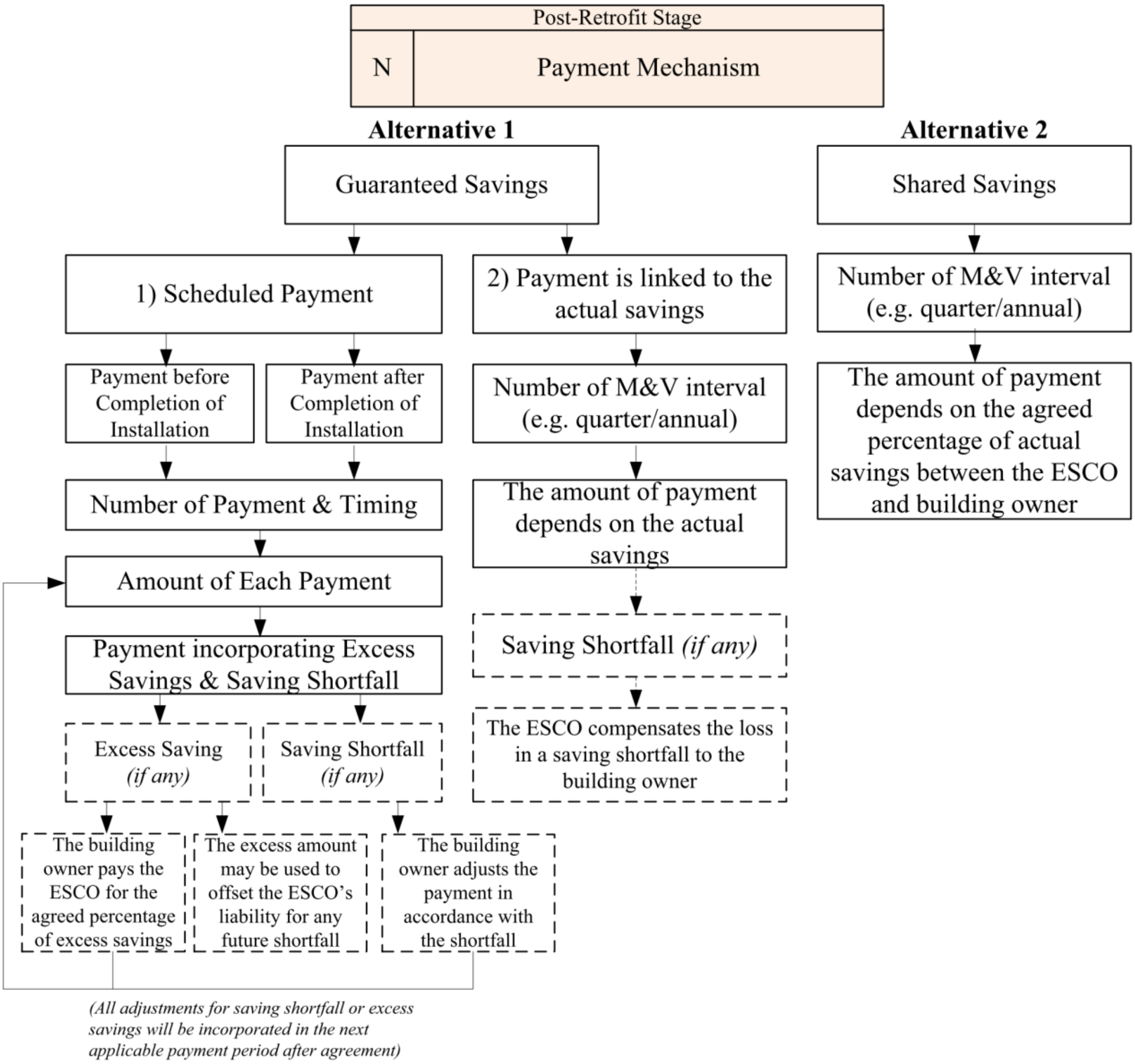

Figure 8.16: Building Block N - Payment Mechanism

For the shared saving model, the payment is made based on a pre-agreed percentage of actual savings between the ESCO and host. The key issues to be decided for this payment arrangement is the number of M&V intervals (e.g. quarterly/ annually).

8.3 Validation of the Model

To ensure that the model is practicable for use in Hong Kong, the model was validated by two groups of people: (1) experts who have intimate knowledge of EPC; (2) industry practitioners who have no experience in EPC, but are potential users (in order to make sure that the model is understandable to them).

8.3.1 Design of the questionnaire for model validation

A questionnaire was developed to validate the model of EPC under five aspects, namely 'degree of comprehensiveness', 'degree of practicality', 'degree of adaptability for different types of building retrofit', 'degree of replicability' and 'degree of objectivity'. The selection of those aspects for model validation is based on the similar study of Yeung (2007); Cheung (2009) with suitable modifications. The detailed explanation of each aspect is given in the questionnaire. A five-point Likert scale, where 1 denotes "poor" and 5 denotes "excellent", was used to analyse their degree of satisfaction of the above items. Prior to the launch of this questionnaire survey, a pilot study was carried out with a few researchers to ensure the readability of the questionnaire before full distribution. The questionnaire used for validation is attached in Appendix F.

8.3.2 Profile of the respondents

For the first stage of model validation, face-to-face discussions were conducted with eight experts in the field of EPC to solicit their views on the model presentation and contents. Eight experts are considered as sufficient for model validation since the previous researchers[13] also validated their models with a similar number of experts in their PhD theses approved by two universities. To avoid the bias caused by differences in the stakeholders' perspectives, the validation experts were selected almost equally from both hosts and ESCOs who have sound knowledge of EPC. Most of them have been working in their relevant fields more than 20 years. Table 8.1 shows the profile of eight experts.

Table 8.1: Validation Respondents' Profiles (based on expert interviews)

I.D.	Designation	Role	Years of experience
1	Managing Director	Practitioner (ESCO)	≥ 35 years
2	Director	Practitioner (host – University FM Dept.)	≥ 20 years
3	Senior Manager	Practitioner (host)	≥ 20 years
4	University Lecturer	Academic	≥ 20 years
5	Manager	Practitioner (ESCO)	≥ 15 years
6	Manger	Practitioner (ESCO)	≥ 15 years
7	Director	Practitioner (ESCO)	≥ 20 years
8	Director	Practitioner (host - NGO)	≥ 20 years

To ensure that the experts fully understand the model prior to the discussion, the model with self-explanatory notes were sent to the experts in advance. On average, the duration of discussion on the model was around 1 hour. The comments from the above experts are summarised in Table 8.2 and those comments have been incorporated into the model as presented in the response column.

Table 8.2Experts' comments on the model and the responses from them

Extracts of Comments by Experts	Response in Thesis
Expert No. 1 Comments: The model is comprehensive. However, in practice, payback period is important to hosts as it is commonly regarded as a primary tool to determine the financial feasibility of retrofitting projects. It is suggested that 'payback period' is added in the Building Block C (Investment Grade Audit).	The suggestion was noted and incorporated into the model. As revised, the expected energy savings and payback are highlighted in the Building Block C such that the IGA report should contain such details.
Expert No. 2 Comments: Disputes in energy savings often occur in EPC projects.	M&V dispute resolutions were added in Building Block H (M&V Plan). Dispute

[13] Yeung (2007) and Cheung (2009) validated their models with 7 and 9 experts respectively.

It is better to emphasise and introduce M&V dispute mechanism in the model. For example, a third party is introduced when disputes in savings occur during the post-retrofit stage. The scope of the model should be clearly defined. Users may misinterpret the purpose of this model. They may think that the model is used to decide whether the energy improvement project is undertaken in a conventional way or under an EPC package.	resolution alternative are provided in the contract template. Besides, more information was given that the ideal third party for verifying M&V results should come from academia, instead of E&M consultants, to enhance the level of independence and fairness. The presentation method for the model was revised such that the user can understand the model which is used to identify and address the key issues when implementing EPC projects, instead of deciding the best procurement method for energy retrofitting.
Expert No. 3 Comments: Since some hosts may not have strong in-house engineering teams to evaluate the ESCO's proposal, a measure should be introduced to protect the interest of hosts for choosing the best retrofitting solutions, for example, engagement of third party consultant. In the model, there are two ways for project procurement: 1) solicited by hosts; 2) initiated by ESCOs. Since the host may refuse to proceed with the initial ESCO and express an interest for other ESCOs' proposals, it is suggested that a loop is added to link up two paths. In practice, the payment is made after the agreement on the measurement & verification (M&V) report. Thus, it is suggested that the model should present this relationship between payment and M&V reporting.	In the Building Block A (Procurement), it is highlighted that the host may engage an independent consultant when the host has not got a strong engineering team to evaluate the ESCO's proposal. A relationship between the two procurement methods has been given in the model (Figure 8.2). When the host decides not to proceed with the ESCO's retrofitting proposal in Path 2, the host may call for expression of interest for an Investment Grade Audit Contract such that the project may be carried out continuously One more building block (Measurement & Verification (M&V) reporting, Figure 8.10) was added to emphasise the relationship between M&V results and payment. Besides, the method to solve the missing data problem during M&V reporting was described.
Expert No. 4 Comments: Now the scope of retrofitting is limited to energy conservation measures (ECMs) in the model. Other types of retrofitting which is not related to energy may be considered, for example, water savings & carbon reduction in the model.	It is noted that there are some types of retrofitting which are not related to energy savings. Some of them may be related to water savings. However, this model only presents about energy savings because the amount of water savings is very limited in buildings and the cost of water is relatively low in Hong Kong. Therefore, the incentive for water saving is not very big compared to energy savings. In addition, carbon trading is not mature in Hong Kong. In the market, very few contractors promote the use of energy

Most building owners find difficulties in tender evaluation because different ESCOs may propose various retrofitting solutions. It is recommended that the model outlines the important elements for the tender evaluation process for EPC projects.	efficient equipment based on the concept of carbon reduction. As revised, Building Block D (Bid Evaluation, Figure 8.5) details the essential elements for tender evaluation, including contract price, previous project track records, estimated annual savings, etc.
Expert No. 5 Comments: The model mainly covers all essential elements for implementing EPC projects. However, it would be better if the following issues are also addressed in the model. Insurances against saving shortfall are available in the U.S. market, and one of the merits in the model is to assess the risk of saving shortfalls when the ESCO guarantees a certain level of savings. It will be better if the model can include the possibility of the host purchasing insurances against saving shortfalls based on the risk assessment result. Besides, the model outlines the different scenarios for project financing in the 'Building Block F'. It is expected that more information should be given on the selection of different method for project financing, for example, interest rate, impact on balance sheet, etc. Regarding the 'Modification of ECMs', some practical experience show that the host may not allow the ESCO to modify the ECMs at its own costs when the consecutive shortfalls in savings occur. It would be better if the condition where the host is not allowed to unreasonably withhold the ESCO's request for modification of ECMs is included in the model. Post-installation savings are important in some EPC projects, especially for the bundle type of retrofitting projects. For	Unlike the EPC market in the U.S., there is no insurance company which offers relevant insurances against the risks of saving shortfalls in Hong Kong. Therefore, no further point is made about the possibility of taking out this type of insurance. More information is given to describe the selection of financing method for project implementation. In practice, for those hosts who have no upfront funding to retrofit their buildings (say in the case of an Owners' Incorporated), the common way for project financing is from the ESCOs. If an ESCO is not willing to pay the upfront cost, it is very unlikely that this kind of host can borrow money from the bank at an acceptable interest rate in Hong Kong. As discussed in Chapter 5, the engagement of financial institutions for EPC project financing is rather limited in Hong Kong. The successful cases where the banks provide financing are related to projects in the semi-public sector (e.g. university), because their credibility in repayment is much higher compared to other hosts. As revised, Building Block J (Modification of ECMs) was provided with more information on different treatments of this provision. For example, the ESCO may consider incorporating the relevant protection in the contract, for example, additional works should be allowed for implementation at the ESCO's own cost when such works are reasonable to be installed for achieving more energy savings. In this model, post installation savings(before full completion) are not considered because this may impose complexities in project

example, the retrofitting project involves lighting and chiller replacement. As such, the completion date for these two retrofitting works may be significantly different. It may not be fair to the ESCO when the calculation of savings start on the date of completion of both works.	implementation. For the situation where the host undertakes more than one retrofitting work, it is advised that two separate EPC contracts are executed such that the completion date in each work can be clearly defined.
Expert No. 6 Comments: The model is comprehensive, covering all essential elements in the whole cycle of EPC projects. The Building Block H – 'Measurement & Verification Plan', which is shown in the pre-retrofit stage, enables the users to understand the importance of detailed M&V plan in EPC projects. However, it is better to have a further elaboration on the item 'baseline adjustment', for example, to list out the common approaches for baseline adjustment in practice.	Building Block H (Measurement & Verification Plan) provides information on the possible guidelines for developing M&V plans (e.g. IPMVP guideline). Based on the interview findings, it is advised that both the host and ESCO should agree on which factor and the degree of variations in those factor(s) to trigger baseline adjustment (e.g. baseline energy use will be adjusted when more than five percent of variations in occupancy level is observed). This will reduce the M&V costs.
Expert No. 7 Comments: The risk assessment method in the model seems to be too complicated as it requires a number of simulations. In practice, the building energy simulation method is not an ideal way of predicting energy savings because it requires empirical data for model development, and those data are not easy to obtain in practice. It is expected that a more simplified way of risk assessment is available.	It is noted that this proposed method requires empirical data. However, for other methods such as regression analysis, empirical data is also needed. In addition, the use of building energy simulation method not only provides more accurate results, but also explains the impact on energy savings when certain parameters change during the post-retrofit period. Other methods cannot quantify the amounts of saving shortfall when certain parameters change significantly. Therefore, the building energy simulation method provides the highest explanation power compared to other methods.
Expert No. 8 Comments: In practice, it is often the case that the retrofit project turns out to be a conventional retrofit project after the negotiation of an EPC contract.	In Building Block F (Choice of Suitable EPC Mode), an alternative is listed for the host to consider implementing conventional projects when the host has sufficient upfront capital and does not require the ESCO to bear the performance risk.

For the second stage of validation, with the assistance of the Hong Kong Institute of Surveyors (HKIS) and the Hong Kong Polytechnic Alumni Association (HKPAA), two seminars were held to present the concept of EPC and the model to their members who may have no experience in EPC but knowledgeable with retrofitting projects. The audience of the first seminar mainly comprised building surveyors, whilst those of the second seminar were from the background of facility management. The duration of each seminar was around one hour with a 15-minute 'question and answer' session. At the end of the seminar, the audiences were invited to complete the questionnaire for model validation and solicit their feedback. Table 8.3 shows the profiles of the audiences in the two seminars.

Table 8.3: Validation Respondents' Profile (through seminars)

I.D.	Organiser	Targeted audiences	Number of respondents	Years of experience
Seminar 1	Hong Kong Institute of Surveyors (HKIS)	building surveyors	69	From 1 year to more than 20 years
Seminar 2	Hong Kong Polytechnic Alumni Association (HKPAA)	facility managers	30	From 1 year to more than 20 years

8.3.3 Validation results

Table 8.4, 8.5 and 8.6 show the overall results of validation questionnaire returned from the experts, i.e., HKIS audiences and HKPAA audiences respectively. It is noted that the 'degree of comprehensiveness' was scored the highest among the five validation aspects for all respondents. For the experts' questionnaire, more than 85% of respondents marked a score of either 4 or 5 in the 'degree of comprehensiveness', implying that this model covers all essential elements and well describes the key relationships between different building blocks. For the 'degree of objectivity' (Mean Score: 3.88), most expert respondents indicated that the model is objective and there is no biased or misleading element in favour of a particular choice for project implementation. Overall, the mean values of those five aspects are all above 3, implying the overall model is comprehensive, practical, reliable and adaptable for different types of building energy retrofitting.

Relatively, 'the degree of practicality' scored the lowest in the expert questionnaire. This means some building blocks (e.g. risk assessment method) in the model may not be fully practical for application due to the concerns on data availability. However, this model at least provides a scientific solution to evaluate the risks of saving shortfalls and three case studies with different retrofitting measures, including chiller replacement and lighting retrofit, were used to demonstrate the reliable application of this probabilistic method.

Overall, the experts gave higher average scores than the non-experts (e.g. HKIS and HKPAA audiences) among the five validation aspects, and it is anticipated that their evaluation would be more reliable since they should have a better understanding of the features of EPC projects.

Table 8.4: Results of the validation questionnaire for the experts

Validation Criteria	**Poor ←**				**→Excellent**	**Mean**
	1	**2**	**3**	**4**	**5**	
1. Degree of Comprehensiveness	0.0% (0)	0.0% (0)	12.5% (1)	62.5% (5)	25.0% (2)	4.13
2. Degree of Practicality	0.0% (0)	0.0% (0)	50.0% (4)	50% (4)	0.0% (0)	3.50
3. Degree of Adaptability for different types of building retrofits	0.0% (0)	0.0% (0)	37.5% (2)	62.5% (5)	0.0% (0)	3.63
4. Degree of Replicability	0.0% (0)	0.0% (0)	25.0% (2)	75.0% (6)	0.0% (0)	3.75
5. Degree of Objectivity	0.0% (0)	0.0% (0)	25.0% (2)	62.5% (5)	12.5% (1)	3.88

Table 8.5: Results of the validation questionnaire for HKIS audiences

Validation Criteria	**Poor ←**				**→Excellent**	**Mean**
	1	**2**	**3**	**4**	**5**	
1. Degree of Comprehensiveness	0.0% (0)	2.9% (2)	40.6% (28)	55.1% (38)	1.4% (1)	3.55
2. Degree of Practicality	1.4% (1)	14.5% (10)	40.6% (35)	43.5% (17)	0.0% (0)	3.26
3. Degree of Adaptability for different types of building retrofits	0.0% (0)	24.6% (17)	50.7% (35)	24.6% (17)	0.0% (0)	3.00
4. Degree of Replicability	0.0% (0)	11.6% (8)	47.8% (33)	39.1% (27)	1.4% (1)	3.30
5. Degree of Objectivity	1.4% (1)	4.3% (3)	43.5% (30)	47.8% (33)	2.9% (2)	3.46

Table 8.6: Results of the validation questionnaire for HKPAA audiences

Validation Criteria	**Poor ←**				**→Excellent**	**Mean**
	1	**2**	**3**	**4**	**5**	
1. Degree of Comprehensiveness	0.0% (0)	3.3% (1)	30.0% (9)	50% (15)	13.3% (4)	3.76
2. Degree of Practicality	0.0% (0)	13.3% (4)	16.7% (5)	56.7% (17)	10% (3)	3.66
3. Degree of Adaptability for different types of building retrofits	0.0% (0)	6.7% (2)	36.7% (1)	40.0% (12)	13.3% (4)	3.62
4. Degree of Replicability	0.0% (0)	3.3% (1)	26.7% (8)	56.7% (17)	10.0% (3)	3.76
5. Degree of Objectivity	0.0% (0)	3.3% (1)	36.7% (11)	43.3% (13)	13.3% (4)	3.69

8.4 Chapter summary

This chapter is a discussion on a generic model of EPC for Hong Kong, which is developed based on an extensive literature review, findings from the questionnaire surveys, as well as semi-structured interviews with key stakeholders from the public and private sectors in Hong Kong. The model was validated by eight experts in the field of EPC and audiences from two seminars in that they are comprehensible and objective (e.g. not biased or misleading element in favour of a particular choice for project implementation). It is expected that the model enables the practitioners (both hosts and ESCOs)to identify and address the key issues and their relationships when implementing EPC projects, starting from the stage of pre-retrofit, through installation, to post-retrofit. As the previous eight chapters discussed the benefits of using EPC as a means to improve energy efficiency in existing buildings, the next chapter attempts to predict the achievable amount of energy savings under different take-up rates of EPC in Hong Kong.

CHAPTER 9: POTENTIAL ENERGY SAVINGS THROUGH EPC PROJECTS IN HONG KONG

Chapter 9 – Potential Energy Savings through EPC Projects in Hong Kong

9.1 Introduction

This chapter presents the estimating rationale and results of energy saving potential through the hypothetical implementation of EPC projects in Hong Kong. Since the current profiles of electricity consumption differ by sectors in Hong Kong, the estimation needs to be done by considering the feasibility of EPC project implementation by sector. To illustrate the principles, in this thesis the scope of estimation is only limited to private office buildings, which account for 8.2% of the total electricity consumption amongst different building types in Hong Kong. The findings of the host questionnaire survey in Chapter 4 are used to predict the number of the private office buildings where chiller replacement and lighting upgrading have not yet been implemented. The estimation of potential energy saving also adopts the results of risk assessment in Chapter 6. Based on the above findings, different take-up rates of EPC are assumed to predict potential energy savings through EPC projects in the private office buildings in Hong Kong.

9.2 Potential energy savings through EPC projects in Hong Kong

In 2015, the HKSAR Government unveiled the Energy Saving Plan for the Built Environment 2015~2025 (and beyond), which sets a new target for reducing Hong Kong's energy intensity by 40% by 2025 (HKSAR, 2015). In order to achieve this new target, the HKSAR Government will take the lead to reduce energy consumption in both existing and new government buildings. For example, for the existing government buildings, more green managers will be appointed in bureaus and departments, and energy-related systems will be retrofitted actively to reduce energy consumption. For the new public-owned buildings, the government will periodically review, expand and tighten the relevant ordinances and regulations such as the Building Energy Efficiency Ordinance (BEEO) to further improve building energy efficiency. To ensure the solid contribution of energy savings from the public sector, the government has committed to achieving 5% electricity reduction by 2020 (2014 as base) in the public-owned buildings.

For the private sector, there is no numerical target for electricity reduction. The pace of building retrofitting in the private sector mainly depends on the attitudes of individual building owners towards building energy efficiency. As discussed in the earlier chapters, the lack of upfront capital and technological know-how are the main reasons for the hosts not to implement energy efficiency projects in their existing buildings. As found in the questionnaire survey in Chapter 4, most host respondents (more than 85%) have only adopted disciplined use (e.g. set indoor temperature to around 25ºC) and undertaken minor retrofitting works (e.g. replace existing lighting with energy efficient luminaires) to reduce energy consumption in their buildings. Only 10% of host respondents carried out major energy retrofitting works in their buildings, reflecting that most hosts have the awareness of reducing energy use in buildings, but they intend to improve the central building services (BS) systems until those systems and equipment come to the end of their life-spans. Therefore, EPC may be considered as a catalyst to speed up the building retrofitting process, especially for the BS systems and equipment operating at low efficiency. In comparison with other countries and cities such as Singapore and the U.S., the current take-up rate of EPC in Hong Kong is relatively low, showing that the potential of EPC has not been fully explored. With the implementation of the suggested measures in this research to enhance the wider use of EPC, it is expected that more retrofitting projects will be carried out under an EPC approach in the future.

In this study, the estimation of potential energy savings through EPC projects in Hong Kong was made with the consideration of two key aspects: (1) a profile of electricity consumption by different sectors in Hong Kong; (2) the feasibility of EPC project implementation. In Hong Kong, 155,079 TJ (equivalent to 43,078 million kWh) of electricity was consumed in 2012, and the commercial sector accounted for 66% of the total electricity consumption. Other three sectors, namely residential, industrial and transport sectors, accounted for 26%, 6% and 2% of the total electricity consumption respectively (this study uses 2012 end-use energy data since such a database is the most comprehensive one publicly accessible). Table 9.1 shows the Hong Kong's electricity consumption by sectors in 2012. It can be seen that the potential energy saving in industrial buildings is rather limited as it only constitutes 6% of the total electricity consumption in Hong Kong. For the residential buildings, the electricity consumption in the common areas (e.g. lift lobbies and corridors) is also relatively small, and due to the nature of multiple ownerships it is unlikely for those residential owners to implement energy efficiency projects through EPC. Therefore, the commercial sector is the only sector being considered for estimating potential energy saving through EPC projects in this study.

Table 9.1: Hong Kong's electricity consumption by sectors in 2012

Sector	Electricity consumption	
	(TJ)	(%)
Commercial	101,813	(66%)
Residential	41,189	(26%)
Industrial	9,356	(6%)
Transport	2,722	(2%)
Total	155,079	(100%)

TJ denotes Terajoules.

According to the EMSD classification system, the commercial sector consists of restaurant, retail, office, accommodation, human health, education, as well as other commercial segments (seven segments in total). Table 9.2 shows Hong Kong's electricity consumption by commercial segments in 2012. It can be seen that the restaurant, retail and office segments are the top three segments consuming significant amounts of electricity in Hong Kong (restaurant segment: 12%; retail segment: 17%; office segment: 12%). As discussed in Chapter 5, the circumstances under which EPC projects are considered feasible to be implemented by the host in Hong Kong are summarised into five aspects: (1) Buildings with single or a few owners; (2) Hosts with strong engineering teams and legal backup; (3) Hosts lacking upfront capital; (4) Stable building operation patterns; and (5) A high expectation on energy savings. For the retail and restaurant segments, the building operation patterns often change dramatically to suit the latest business needs. Apart from that, the retail and restaurant tenants may move out from time to time due to economic downturn or rental increase. Therefore, most ESCOs are reluctant to implement EPC projects in shopping malls as it is difficult to reach agreement from both parties on baseline adjustment mechanism. As such, only office buildings are considered for estimating the energy saving potential through EPC projects in this study.

Table 9.2: Hong Kong's electricity consumption by commercial segments in 2012

Sector	Electricity consumption	
	(TJ)	(%)
Restaurant	12265	(12.0%)
Retail	17238	(16.9%)
Office	12663	(12.4%)
Accommodation	10211	(10.0%)
Human health	3321	(3.3%)
Education	3164	(3.1%)
Other commercial	42951	(42.2%)
Total	101,813	(100%)

9.3 Private office buildings in Hong Kong

According to the Hong Kong end-use data, the office segment accounted for 12,663 TJ of electricity consumption (8.2% of the total electricity consumption; 12.4% of the electricity consumption in the commercial sector) in 2012 (EMSD, 2015b). The statistics compiled by the Rating and Valuation Department (RVD) indicated that the total stock of private offices amounted to 10,897,100 m^2 at the end of 2012 (RVD, 2015). However, there is no official data reporting the number of office buildings in Hong Kong and their ages in publicly accessible databases. Hence, an alternative way is used to estimate those data. *Primeoffice* is a property search engine, and its database collects information from over 1,800 office buildings in Hong Kong (Primeoffice, 2015). It provides basic building information such as the ages of buildings, typical floor areas, types of AC systems (e.g. central AC, window-type) and AC operating hours. By retrieving the data from *Primeoffice*, the total number of office buildings and year built can be obtained. Table 9.3 shows the age bands of office buildings and their AC systems used in Hong Kong. It is found that the total number of office buildings in Hong Kong is 1,875, and the majority of office buildings (77%) use the central AC system to provide cooling. In addition, it is observed that the older the office building is, the more frequently non-central AC system (e.g. split type AC) is being used.

Table 9.3: The age bands of office buildings and their AC systems in Hong Kong

Age	No. of office buildings	No. of office buildings with central AC systems (percent)		No. of office buildings with non-central AC systems (e.g. split type AC) (percent)	
Less than 10	180	173	(95%)	7	(4%)
10-19	587	501	(85%)	86	(15%)
20-29	521	369	(71%)	152	(29%)
30-39	421	304	(72%)	117	(28%)
40-49	143	88	(62%)	55	(38%)
>50	23	15	(64%)	8	(36%)
Total	1875	1450	(77%)	425	(23%)

To ensure consistency of those data, an Energy Use Intensity (EUI) is calculated for the office building. EUI is defined as the total annual energy consumption in a building per unit gross floor area. EUI enables the building operators to understand the current building energy performance by making comparison with other similar types of buildings. Based on the above data, the calculated EUI for office buildings is 1,162 MJ/m^2/annum[14] which is comparable to

[14] The EUI for office buildings is calculated as follows: [12,663 TJ (annual electricity consumption in the office segment)/10,897,100 m^2(total private office areas) = 1,162 MJ/m^2/annum].

other official EUI data released by the EMSD (Private office building (single tenant): 1,271MJ/m^2/annum; Private office building (multiple tenants): 944MJ/m^2/annum) (EMSD, 2015c). Table 9.4 outlines the details of single office building on average in Hong Kong.

Table 9.4: Electricity consumption in Hong Kong office buildings

	All office buildings in Hong Kong	Single office building (on average)
Electricity consumption (TJ)	12,663	2.18 (EUI: 1162 MJ/m^2/annum)
Area (m^2)	10,897,100	5,811
No. of buildings	1,875	NA

9.4 Potential energy saving in private office buildings

For the office buildings in Hong Kong, air-conditioning accounts for 54% of the total electricity consumption, while lighting and office equipment constitute 14% and 13% of the total respectively. For the remaining 19% (others), the energy data cannot be further broken down into other end-uses. Table 9.5 shows the end-uses of electricity consumed in office buildings in Hong Kong. It can be seen that the air-conditioning and lighting are the top two electricity end-uses which have the largest potential for energy savings when retrofitting works are implemented on these two aspects in the office buildings.

Table 9.5: End-uses of electricity consumed in office buildings in Hong Kong in 2012

End-uses of electricity	Electricity consumption	
	(TJ)	(%)
Space conditioning	6,809	(54%)
Lighting	1,809	(14%)
Office equipment	1,599	(13%)
Others	2,446	(19%)

As discussed in the earlier chapter, air-cooled chillers were commonly used in existing commercial buildings in the past decade since the HKSAR Government restricted the use of fresh water for cooling to ensure the sufficiency of fresh water for domestic use (e.g. drinking). With a view to reducing energy use in existing buildings, coupled with the agreement of mainland China in providing a stable water supply, the government has been encouraging the use of water-cooled chillers together with cooling towers since 2008 (EMSD, 2008), which are significantly more energy efficient than the conventional air-cooled chillers (Yik et al., 2001). This relaxation on the use of fresh water provides an incentive for building hosts to replace the existing air-cooled chillers with water-cooled chillers. Another common ECM in the existing office buildings is the replacement of incandescent lamps/T8 fluorescent lamps (FL) with more energy efficient T5 lamps. This is because the project cost for such type of retrofitting is relatively low compared to other ECMs, and the payback period is often short (e.g. less than two years) (Mahlia et al., 2011). Since the chiller replacement and lighting upgrading are the most common retrofitting works in the office buildings, the potential energy saving through EPC projects is estimated based on these two types of retrofitting works.

In order to estimate the number of the office buildings where the chiller replacement and lighting upgrading have not yet been implemented, the findings of the host questionnaire survey are used. As discussed in Chapter 4, a questionnaire survey targeted at the host respondents was launched to investigate the current development of EPC market in Hong Kong. The target respondents include local building owners, facility managers and occupants. The questionnaire captured the basic profile of respondents and the corresponding buildings, as well as the potentiality of energy retrofitting works. A total of 885 survey questionnaires were sent to the target respondents, and 168 valid questionnaires were returned, representing a response rate of 18.9%.

Table 9.6 depicts the potentiality of energy retrofitting works and the current use of EPC in the existing office buildings in Hong Kong. A majority of host respondents (64.9%) indicated that chiller replacement has not yet been implemented in their office buildings. For those who implemented such a replacement work, only 5.4% of the respondents mentioned that the work was undertaken under an EPC package. It can be seen that the potentiality of energy savings in chiller replacement has not been fully explored.

Table 9.6: Potentiality of energy retrofitting works and the current use of EPC in the existing office buildings in Hong Kong

Host Q15: Potential energy retrofitting works	Not Done	Already done	
		Using EPC	Not using EPC
Lighting replacement to more efficient fluorescent lamps (e.g. replace T8 with T5)	31.1%	6.7%	62.2%
Installation of time switches and sensors	45.2%	2.4%	52.4%
Replacement of air-conditioning system from air to water cooling	64.9%	5.4%	29.7%

For the energy improvement work on lighting systems, more than half of the host respondents replaced the existing lamps with more energy efficient lamps (e.g. T5 fluorescent lamps) and/or installed time switches and sensors for better lighting control. Similar to the chiller replacement work, most host respondents implemented the lighting upgrading projects through the conventional approach, instead of EPC. With the implementation of the suggested measures to enhance the wider use of EPC in this research, it is expected that the take-up rate of EPC will increase in the future. In order to predict the possible energy savings through EPC Projects in Hong Kong, different take-up rates of EPC are assumed for both the chiller replacement and lighting upgrading works (e.g. 10%, 15% and 20%) as possible scenarios.

9.4.1 Potential energy saving for chiller replacement

The equations for calculating potential energy saving for chiller replacement are shown as follows:

$$\text{Number of office buildings feasible for chiller replacement} = (A - B) \times C \qquad \text{(Eq. 9.1)}$$

where A = The total number of office buildings with central AC systems in HK;

B = The number of office buildings with central AC systems but built less than 10 years ago;

C = Percentage of office buildings not having implemented chiller replacement (%)

$$\text{Energy consumpiton for AC systems in those office buildings} = D \times E \times F \times G \qquad \text{(Eq. 9.2)}$$

where D = The total number of office buildings feasible for chiller replacement;

E = Average area of a single office building (m^2/building);

F = Average EUI for a single office building (MJ/m^2/annum);

G = Percentage of AC consumption of electricity to total building consumption(%)

$$\text{Potential energy saving for chiller replacement} = H \times I \times J \qquad \text{(Eq. 9.3)}$$

where H = the total energy consumption for AC systems in those potential office buildings (MJ);

I = Take-up rate of EPC (%);

J = Energy savings from chiller replacement (%)

As discussed in Section 9.3, the total number of office buildings in Hong Kong was approximately 1,875 at the end of 2012 (Please refer to Table 9.4). Amongst those office buildings, around 1,450 of them (77%) use central AC systems (Table 9.3). With the consideration of existing chiller conditions, it is unlikely for those hosts of buildings less than 10 year old to implement chiller replacement projects since the life-spans of their chillers would range from 10-15 years. Therefore, only 829 office buildings[15] will be reckoned as

[15]The estimation of number of office buildings which is feasible to implement chiller replacement works (based on Eq. 9.1): [(1450 (the total number of office buildings with the central AC systems in HK; Table 9.3) – 173 (the office buildings built less than 10 years ago; Table 9.3)) x 64.9% (not yet implement chiller replacement; Table 9.6) = 829 buildings].

being feasible to implement chiller replacement works. For those 829 office buildings, the total electricity consumption for the central AC system is estimated to be 3,022.8 TJ[16] (by Eq. 9.2). As demonstrated in Chapter 6, the annual energy saving is estimated to be 43.1% of baseline consumption when the air-cooled chillers are replaced with water-cooled chillers in a commercial building. Although the actual percentage of energy savings for chiller replacement for an office building depends on a number of factors including the geographic location, operational schedule and air-conditioned areas of the building, the percentage is still considered as acceptable for estimation. Table 9.7 shows the energy savings for chiller replacement in the office buildings at different take-up rates of EPC (by Eq. 9.3). At the current take-up rate of EPC (5%), it only contributes to the energy savings of 99.9 TJ for chiller replacement in office buildings. If the take-up rate of EPC increases 4 times from the current level, it will be estimated that 256 more office building (13.7 % of the total number of office buildings in Hong Kong) will implement chiller replacement works, contributing to 399.6 TJ of energy savings (equivalent to 3.16% of the total electricity consumption in office buildings).

Table 9.7: Estimated energy savings for chiller replacement in office buildings at different take-up rates of EPC

EPC take-up rate	No. of office buildings for chiller replacement	Total floor areas (m2)	Total electricity consumption (TJ)	Total electricity consumption (AC portion) (TJ)	Mean energy savings 43.1% (TJ)
5%	64	371,000	431.2	231.8	99.9
10%	128	742,000	862.4	463.7	199.8
15%	192	1,113,000	1393.6	695.6	299.7
20%	256	1,484,000	1724.8	927.4	399.6

[16] The estimation of energy consumption for AC systems in those office buildings (based on Eq. 9.2): [(829 (the no. of office buildings considered feasible to implement chiller replacement) x 5811 m^2/building (average floor areas in typical single office building; Table 9.4) x 1162 MJ/m^2/annum (average EUI for office buildings; Table 9.4) x 54% (percentage of AC end-use of electricity; Table 9.5) = 3022.8 TJ)].

9.4.2 Potential energy saving for lighting upgrading

The equations for calculating potential energy saving for lighting upgrading are shown as follows:

$$\text{Number of office buildings feasible for lighting upgrading} : \text{K x L} \qquad \text{(Eq. 9.4)}$$

where K = The total number of office buildings in HK;

L = Percentage of office building not yet being implemented lighting upgrading (%)

$$\text{Energy consumpiton for lighting systems in those office buildings} = \text{M x N x O x Q} \qquad \text{(Eq. 9.5)}$$

where M = The total number of office buildings feasible for lighting upgrading;

N = Average area of a single office building (m^2/building);

O = Average EUI for a single office building (MJ/m^2/annum);

Q = Percentage of lighting consumption of electricity to whole building consumption (%)

$$\text{Potential energy saving for lighitng upgrading} = \text{R x S x T} \qquad \text{(Eq. 9.6)}$$

where R = The total energy consumption for lighting systems in those potential office buildings (MJ);

S = Take-up rate of EPC (%);

T = Energy savings from lighting upgrading (%)

Regarding the lighting upgrading, the total number of office buildings where the lighting upgrading has not yet been implemented is 583[17]. For those 583 office buildings, the total electricity consumption for the lighting system is estimated to be 551.1 TJ[18] (by Eq. 9.5). As illustrated in Chapter 6, the annual energy savings are estimated to be 53% of baseline

[17] The estimation of number of office buildings which is feasible to implement lighting upgrading works (based on Eq. 9.4): [1875 (the total number of office buildings; Table 9.3) x 31.1% (not yet implement lighting upgrading works; Table 9.6) = 583 buildings].

[18] The estimation of energy consumption for lighting systems in those office buildings (based on Eq. 9.5): [583 (the no. of office buildings) x 5811 m^2/building (average floor area in typical single office building; Table 9.4) x 1162 MJ/m^2/annum (average EUI for office buildings; Table 9.4) x 14% (percent of lighting end-use of electricity; Table 9.5) = 551.1 TJ].

consumption when the replacement of existing lighting with T5 tubes, installation of daylight-linked lighting controls and occupancy-based controls are implemented in a 40-storey office building (with typical design features such as regularly shaped open plan in Hong Kong). The detailed description of this office building can be referred to Section 6.5.1.

Table 9.8: Estimated energy savings for lighting upgrading in office buildings at different take-up rates of EPC

EPC take-up rate	No. of office buildings for lighting replacement	Total floor areas (m^2)	Total electricity consumption (TJ)	Total electricity consumption (lighting portion) (TJ)	Mean savings 53%% (TJ)
6.7%	126	716,00	848.42	121.20	64.24
10%	188	1,069,000	1,266.30	180.90	95.88
15%	281	1,603,000	1,899.45	271.35	143.82
20%	375	2,138,000	2,532.60	361.80	191.75

Table 9.8 shows the energy savings for lighting upgrading in the office building at different take-up rates of EPC (by Eq. 9.6). At the current take-up of EPC (5%), it only contributes to the energy savings of 62.2 TJ for lighting upgrading in office buildings. If the take-up rate of EPC increases 4 times from the current level, it will be estimated that 375 more office buildings (20% of the total number of office buildings in Hong Kong) will implement lighting upgrading works, contributing to 191.8 TJ of energy savings (equivalent to 1.51% of the total electricity consumption in office buildings).

9.5 Chapter summary

This chapter presents the method for estimating energy saving potential through EPC projects in the office buildings in Hong Kong based on the findings in this research. It is found that among 1875 office buildings in Hong Kong, around 829 of them would be considered feasible to implement chiller replacement works. For the lighting upgrading, the total number of office buildings where the lighting upgrading has not yet been implemented is 583. If the take-up rate of EPC in Hong Kong increases from the current level (5%) to 20% for both types of retrofitting works, this will contribute to energy savings of 399.6 TJ for chiller replacement (equivalent to 3.16% of the total electricity consumption in office buildings) and 191.8 TJ for lighting upgrading (equivalent to 1.51% of the total electricity consumption in office buildings). The next chapter is the final chapter of the thesis, which concludes the research study, summarises the main findings of the study, as well as recommends improvement measures for enhancing EPC take-up and the future research work.

CHAPTER 10: CONCLUSION AND RECOMMENDATIONS

Chapter 10 – Conclusion and Recommendations

10.1 Introduction

This chapter concludes the research study. The research aims and objectives are reviewed and the results which demonstrate fulfilment of the research objectives are depicted. The main findings of the study are summarised, followed by the significance and value of the research. In addition, limitations of the study are highlighted together with recommendations for future research work.

10.2 Review of the Research Objectives

This research aims to develop a clear, concise and comprehensive model of EPC in order to enhance energy efficiency upgrading in Hong Kong, specifically taking into account the risk assessment and contract management issues. In order to fulfil the research aim, the main objectives are identified as follows:

1. To investigate the concerns and understanding of local building owners and energy service companies on EPC;
2. To develop risk assessment approaches taking into account the probabilities of saving shortfalls based on different technical solutions of common energy retrofitting;
3. To develop a set of EPC contract document templates for use in Hong Kong based on a study of international best practice and the research findings; and
4. To quantify the achievable amount of energy savings by assuming different take-up rates of EPC in Hong Kong.

The details of research methods which were employed to achieve the above research objectives have been explained in Chapter 3.

10.3 Fulfilment of the Research Objectives

Table 10.1 presents the relationship between the research objectives and research methods used in this study. The first objective is to investigate the concerns and understanding of hosts and ESCOs on the use of EPC in Hong Kong. To achieve this objective, a combination of qualitative and quantitative methods, including a comprehensive literature review, questionnaire surveys and semi-structured interviews, were used. The desk-top research was undertaken to understand the latest development of EPC in the world (Chapter 2). In order to solicit the views on the current use of EPC in Hong Kong, two separate questionnaire surveys were conducted with the two key stakeholders of EPC, namely the hosts and ESCOs (Chapter 4). Semi-structured interviews were also carried out with key stakeholders in the EPC market, including hosts, ESCOs' key personnel, association representatives and financers in both the public and private sectors in Hong Kong (Chapter 5).

The second objective is to develop suitable risk assessment approaches taking into account the probabilities of saving shortfalls based on different technical solutions of common energy retrofitting. This objective was accomplished by case studies and modelling techniques (Chapter 6). Based on the earlier groundwork built up from the literature review, questionnaire surveys and semi-structured interviews, the energy retrofitting works which have the largest potential to be implemented under an EPC approach were identified. In order to quantify the probabilities of saving shortfalls, a risk assessment approach was developed, taking into account the possible variations in the influential parameters affecting energy savings. Three case studies with different retrofitting measures, including chiller replacement, change of heat rejection system and lighting upgrading, were used to demonstrate the application of this probabilistic method for risk assessment.

The third objective is to develop a set of EPC contract document templates for use in Hong Kong. This objective was achieved by a comparative study of different standard forms of EPC contract in the overseas jurisdictions (Chapter 7) and an understanding of the stakeholders' concern as gleaned from the surveys and the interviews. First, the collection of representative standard forms of EPC contract in the overseas jurisdictions was carried out. After that, a comparison was made between nine standard forms of EPC contract in eight jurisdictions, including Australia, Canada, China, Japan, Singapore, Taiwan, the United Kingdom and the United States. By comparisons, the common essential features of standard form of EPC contract were identified, and the key differences between those contracts were highlighted to reflect various treatments of contractual issues in EPC projects. Hence, a set of EPC contract template and guidance notes was developed for common retrofitting works in Hong Kong, such as air conditioning and lighting upgrading (Chapter 8). To ensure that the contract template and guidance notes are practical for use in Hong Kong, these documents were commented upon by related experts and practitioners.

Finally, the findings of the above objectives were consolidated into the model, which is presented by a graphical method (Chapter 8). The model consists of fourteen building blocks. Each block is further divided into several components for zooming into specific details. The model was validated by a numbers of experts and practitioners in the field of EPC in Hong Kong. The details of the model and validation are presented in Chapter 8.

The forth objective is to quantify the achievable amount of energy savings by simulating different take-up rates of EPC in Hong Kong. This objective was achieved by estimating the feasibility of EPC project implementation by sectors in Hong Kong and the achievable amount of energy savings after retrofitting. The earlier groundwork shows that private office buildings are the most feasible type of buildings for EPC project implementation. Based on the findings of the host questionnaire survey in Chapter 4, the number of the private office buildings where chiller replacement and lighting upgrading have not yet been implemented was extrapolated. In addition, the results of risk assessment in Chapter 6 were adopted to estimate potential energy savings for chiller replacement and lighting upgrading under different take-up rates of EPC in Hong Kong.

Table 10.1: Relationship between the research objectives and research methods used in this study

No.	Research Objective	Research Method
1	To investigate the concerns and understanding of local building owners (including commercial and institutional facilities) and Energy Service Companies on EPC.	• Literature review (Chapter 2) • Questionnaire surveys (Chapter 4) • Semi-structured interviews (Chapter 5)
2	To develop suitable risk assessment approaches taking into account the probabilities of saving shortfalls based on different technical solutions of common energy retrofitting.	• Literature review (Chapter 2) • Questionnaire surveys (Chapter 4) • Semi-structured interviews(Chapter 5) • Building energy simulation and Monte Carlo simulation (Chapter 6) • Case Studies (Chapter 6)
3	To develop a set of EPC contract document templates for use in Hong Kong, based on a study of international best practice and the local research findings;	• Literature review (Chapter 2) • Semi-structured interviews (Chapter 4) • Comparative analysis of different standard forms of EPC contracts (Chapter 7) • Experts' feedback on the contract template (Chapter 8)
4	To quantify the achievable amount of energy savings by assuming different take-up rates of EPC in Hong Kong.	• Literature review (Chapter 2) • Questionnaire surveys (Chapter 4) • Semi-structured interviews (Chapter 5) • Case Studies (Chapter 6)

10.4 Summary of the Main Findings

The main findings of this research study can contribute to the fulfilment of the knowledge gaps as identified in Chapter 1, and summarised as follows:

10.4.1 Concerns and understanding of local hosts and ESCOs on EPC

The findings of the latest development of EPC market in Hong Kong are presented in Chapter 2, 4 and 5. The survey findings indicate that most hosts have the awareness of the need to improve energy efficiency in their buildings, but they tend to carry out minor energy improvement works which often involve less capital and technological know-how. In general, the current take-up rate of EPC in Hong Kong is relatively low. Only few host respondents (less than 10%) have been involved in EPC projects. Regarding energy retrofitting works, it is found that retrofitting works on central air-conditioning and lighting systems are the most common ECMs which are implemented under EPC in Hong Kong because the improvement on central AC systems can achieve a significant amount of energy savings, whilst lighting upgrading requires relatively low upfront cost and has a short payback period.

In addition, it is observed that 'long payback period' and 'worry about its complexities' are the top two concerns of hosts in implementing EPC projects. The survey results also indicate that 'payment default of host after installation', 'not being sure if baseline measurement can be correctly established', and 'costs of installation increase' are the top three key risk factors in EPC projects, as perceived by ESCOs.

To enhance the wider adoption of EPC in Hong Kong, the respondents indicate that 'promoting successful examples of EPC projects', 'modification of government procurement practices to facilitate the use of EPC contracts', and 'government backing up a portion of

ESCOs' guarantee to lending banks' are the top three practical measures for better market development.

From the findings of twenty-six semi-structured interviews, it is found that apart from those common barriers which have been discussed by the previous researchers (e.g. procurement, M&V and legal issues), the absence of a clear market direction is also a reason leading to the hitherto low take-up rate of EPC in Hong Kong. Based on their work experience in EPC projects, the interviewees summarises the circumstances under which EPC projects would be more feasible to be implemented in Hong Kong: (1) Buildings with single or a few owners; (2) Hosts with strong engineering teams and legal backup; (3) Hosts lacking upfront capital; (4) Stable building operation patterns; and (5) A high expectation on energy savings.

It is observed that some ESCOs in Hong Kong are willing to bear both financial and performance risks when the hosts have a high credibility in repayment. In the Hong Kong market, the engagement of financial institutions for EPC project financing is very uncommon due to high interest rates being charged to both ESCOs and hosts caused by unfamiliarity.

It is worth noting that most EPC contracts being used in Hong Kong are in-house written, mostly by ESCOs, instead of adapting established overseas standard forms of EPC contract, as would be the case for new construction. The interviewees explain that most hosts are unfamiliar with the contract terms in those overseas standard documents, raising a question of fairness in risk allocation in those contracts. In addition, the ESCO interviewees indicate the difficulties in determining the amount of guaranteed energy savings in the tendering stage. The current method used for such determination is mainly based on simple engineering analysis and previous work experience.

10.4.2 Development of a risk assessment approach taking into account the probabilities of saving shortfalls

A risk assessment approach for evaluating the probabilities of energy saving shortfalls, taking into account variations in the influential parameters affecting energy savings, was developed. The method involves the use of a detailed building energy simulation programme (e.g. *EnergyPlus*), correlation analysis and Monte Carlo simulation technique. Three case studies with different retrofitting measures, including chiller replacement, change of heat rejection system and lighting upgrading, were used to demonstrate the application of this probabilistic method.

Based on those three case studies, it is found that for the chiller plant retrofitting, the key factors leading to saving uncertainties include (1) overall COP of chiller plant; (2) equipment load; (3) occupant density; (4) occupancy rate; (5) lighting load; (6) thermostat set point; and (7) AC operating hours. In order to mitigate the performance risks on chiller plant retrofitting, three approaches are suggested as follows: (1) frequent maintenance; (2) clear contractual stipulations; and (3) increase in risk premium. For instance, to ensure that the chiller plant is operating at the optimal conditions, the ESCO should review the operating data of a chiller plant from time to time. Once the operating performance of the chiller plant is not as expected, possible rectifications such as tube chemical cleaning and parts replacement should be carried out. Besides, a contractual approach may be used to limit the range of possible settings in thermostat set-points. When the host wishes to adjust the setting beyond the agreed limit, prior consent should be obtained from the ESCO for baseline adjustment. For the parameters of AC operating hours, lighting load, equipment load and occupancy rate, a baseline adjustment mechanism should be well developed prior to project implementation. For example, the energy baseline should be adjusted accordingly based on an agreed formula when the changes in these parameters are more than 5% of the original situation. For the parameter of occupant density, it may be very difficult to evaluate the occupant density, which changes from time to time. Therefore, one possible way of mitigating this type of risk would be to increase the risk premium at the bidding stage and/or provide a lower level of guarantee on energy savings (having known the possible range at a certain confidence level). These are possible ways to manage the risks of energy saving shortfalls for chiller plant retrofitting under an EPC project setting.

For lighting retrofitting, the key factors leading to saving uncertainties often involve four aspects: (1) daylight availability; (2) occupancy rates (3) lighting use pattern; and (4) lamp conditions. Since the variability in the parameter of daylight availability is an intrinsic risk, it is difficult for the ESCO to truly predict the actual variations in climatic conditions from year to year (e.g. cloudiness). Therefore, it is suggested that the ESCO should increase the risk premium at the bidding stage and/or provide a lower level of guarantee on energy savings (also based on a known range at a known confidence level). For the parameter of lamp conditions, the ESCO should obtain the information regarding lamp deterioration rate from the manufacturers or suppliers such that the estimated energy savings would not be too aggressive. For the parameters of occupancy rate and lighting use patterns, the baseline adjustment mechanism should be well established and agreed upon prior to project implementation.

10.4.3 Development of EPC contract template

A comparative study of nine standard forms of EPC contract in eight jurisdictions was conducted. The essential features of standard forms of EPC contract were identified, and the key differences between those contracts were highlighted to reflect various treatments of common contractual issues in EPC projects. The findings of this comparative study show that the guaranteed saving model is more common in those standard forms. For the sake of simplicity, most contracts only consider cost savings in energy and water consumption. Other types of cost savings such as operational cost savings are often not dealt with.

It is observed that several standard forms provide the ESCO with an incentive to achieve energy savings higher than the guaranteed level. For example, the amount of excess savings can be used (1) to offset the ESCO’s liability for future shortfalls; (2) as a ‘gain’ which is shared by the contracting parties; and (3) to shorten the guarantee period. Regarding payment arrangement, the host often starts to make payments when actual savings are materialised during the post-retrofit period, and most standard forms stipulate that actual payment will be adjusted based on the amount of excess savings and saving shortfalls in each M&V period. Although the ESCO often pays the upfront capital for project implementation, the ownership of equipment is usually transferred to the host upon the issue of acceptance certificate, instead of upon full payment made by the host. In addition, it is common that the ESCO is responsible for maintenance work during the contract period, whilst the host is responsible for system operation. However, in order to protect the interest of the ESCO, the host has to comply with the operational procedures laid down by the ESCO to ensure that the system operates at the expected efficiency.

Due to a concern of fairness in the tendering stage, modifications of installed ECMs may not be allowed in some standard forms when actual energy savings are less than the guaranteed level during the post-retrofit period. This is more common in the public EPC contracts. Regarding the clauses dealing with risk of changes, it is observed that a baseline adjustment mechanism is often negotiated by both contracting parties before the signing of a contract, and *the International Performance Measurement and Verification Protocol* (IPMVP) is the most popular guideline used as reference. However, several jurisdictions (e.g. Singapore, Taiwan and the U.S.) use their own M&V guidelines. In addition, restrictions on assignment are often stated in EPC contracts, especially for the public contracts where a public procurement process has been undertaken. The provision of termination for convenience is introduced in some standard forms, and this allows the host to terminate the contract without default during the post-retrofit period. As EPC projects involve the calculation of energy savings and baseline adjustment which are the common grounds of disputes, most standard forms stipulate alternative means of dispute resolution (e.g. mediation and arbitration) and their procedures when disputes occur, before litigation takes place.

Based on the findings of contract comparison and interviews, an EPC contract template and guidance notes were developed for common retrofitting work such as chiller replacement or lighting upgrading. As mentioned in Chapter 5, the guaranteed saving model is more preferable in Hong Kong in term of M&V arrangement and risk allocation, and therefore this contract template is based on the guaranteed saving model. This contract template is targeted at hosts who have not got strong in-house engineering teams and legal representatives. Therefore, the template is made simple to the extent that it covers the essential elements in EPC projects, and enables a lay person to understand the contractual obligations when the contracting parties agree to implement an EPC project.

10.4.4 Development of a model of EPC for Hong Kong

A generic model of EPC projects for Hong Kong was developed based on the extensive literature review, the findings from the questionnaire surveys, as well as the semi-structured interviews with key stakeholders from the public and private sectors in Hong Kong. The model has been presented in Chapter 8. The model comprises fourteen building blocks. To ensure that the model is practicable for use in Hong Kong, the model was validated by two groups of people: (1) experts who have intimate knowledge of EPC; (2) industry practitioners who have no hands-on experience with EPC, but are potential users (after making sure that the model is understandable to them) under five aspects, namely the 'degree of comprehensiveness', 'degree of practicality', 'degree of adaptability for different types of building retrofit', 'degree of replicability' and 'degree of objectivity'. (Score). In addition, the comments from the experts were obtained and incorporated.

10.4.5 Potential energy savings through EPC projects in Hong Kong

The achievable amount of energy savings under different take-up rates of EPC in Hong Kong was predicted. To illustrate the principles of estimation, the scope is only limited to private office buildings. It is found that among 1875 office buildings in Hong Kong, around 829 of them would be considered feasible to implement chiller replacement works. The total number of office buildings where lighting upgrading has not yet been implemented is 583. If the take-up rate of EPC in Hong Kong increases from the current level (5%) to 20% for both types of retrofitting works, this will contribute to energy savings of 399.6 TJ for chiller replacement (equivalent to 3.16% of the total electricity consumption in office buildings) and 191.8 TJ for lighting upgrading (equivalent to 1.51% of the total electricity consumption in office buildings). The detailed figures of estimated energy savings for both retrofitting works at different take-up rates of EPC were discussed in Chapter 9.

10.5 Recommendations on the wider use of EPC in Hong Kong

Based on the findings of this study, three recommendations for promoting the wider use of EPC in Hong Kong are made as follows:

I. Similar to the early stage of EPC market development in other overseas countries such as Australia, Singapore and the U.S., active government promotion is vital to the wider use of EPC in existing buildings. For example, the Taiwanese Government has launched the 'Subsidy Scheme for Promotion on the Use of Energy Performance Contracting' in the public sector since 2006. As a result, a significant increase of take-up rate of EPC in Taiwan is observed. From 2006 to 2012, more than ninety EPC projects were carried out in public buildings, universities and hospitals with the total project cost exceeding US$396 million. These experiences of EPC project implementation in the public sector can provide good opportunities for different parties, including hosts, ESCOs and financiers, to understand the concept of EPC in practice, as well as to identify problems such as M&V and contractual issues which may occur exclusively in the local market. Therefore, it is recommended that the HKSAR government should revisit its policy for enhancing energy efficiency and encourage the public sector to adopt EPC as a means for building energy retrofitting.

II. As discussed in Chapter 2, the high cost of project financing in Hong Kong is one of the reasons hindering the further use of EPC in the private sector. In order to build up the confidence of financial institutions in EPC projects and thereby lower transaction costs of project financing, it is recommended that the HKSAR Government should take a lead to back up a portion of ESCOs' guarantee to lending banks for private EPC projects. The Singaporean Government has lined up financial institutions to implement the pilot 'Building Retrofit Energy Efficiency Financing (BREEF)

Scheme'. In the scheme, both the government and banks share the risk of any possible loan default, and the participating financial institutions provide loans up to S$5 million with low interest rates to those hosts who have inadequate upfront cost for project implementation. The HKSAR Government may also consider launching a loss-sharing scheme similar to the one implemented in Singapore.

III. It is observed that the general practice of EPC project implementation in Hong Kong is based international guidelines such as the IPMVP. However, these guidelines only provide the general principles of M&V works and have little discussion on some local specific issues such as the methods for baseline adjustment on climatic variables under a sub-tropical climate. Therefore, both hosts and ESCOs still require much efforts and time to negotiate the work procedures before project implementation. In order to reduce the transaction costs in this aspect, it is recommended that local M&V guidelines should be developed by relevant organisations in Hong Kong, specifically for the retrofitting on air-conditioning and lighting systems.

10.6 Value and Significance of the Research

This research study has filled the knowledge gap through investigating the current EPC market in Hong Kong, developing a risk assessment approach as well as an EPC contract template. Although there are numerous studies focusing on the latest development of EPC market and ESCO activities in the world, only a few studies were conducted to discuss the EPC market in Hong Kong. This research study has investigated in-depth on the current development of EPC market in Hong Kong, including the hosts' concerns, the motivation factors, the risk perception inherent in EPC projects and the practicality of measures to enhance the use of EPC. Recommendations on how to promote the wider use of EPC were also made, based on the literature review, questionnaire surveys and structured interviews.

Although several attempts have been made to develop risk assessment methods which take into account variations in the post-retrofit conditions, there are still drawbacks in the existing methods such as over-simplified assumptions, insufficient real project data to develop a reliable actuarial database, as well as uncertainties arising from system degradation and climatic variations. This study has proposed a simulation-based approach which takes into account the influence of yearly variations in the parameters affecting energy savings, and eventually the method enables ESCOs and hosts to recognise a range of possible energy savings at a known confidence level when certain ECMs are implemented.

In addition, a number of standard forms of EPC contract have been used in several foreign countries. However, with over a decade of market development, no standard form of EPC contract has yet been developed in Hong Kong. Hence, this study has discussed the comparison results between nine standard forms of EPC contract in eight jurisdictions, which enables the stakeholders of EPC projects, including hosts, ESCOs, lawyers and financiers, to better understand the terms of EPC contracts and the various issues of concern in different jurisdictions. Besides, a set of EPC contract template and guidance notes, which is targeted at those hosts who have not got strong in-house engineering teams and legal representatives, have been developed such that a lay person can understand the contractual obligations when the parties agree to implement a EPC project.

This study has also introduced a generic model of EPC for Hong Kong, and it is expected that the model enables practitioners (both hosts and ESCOs) to identify and address the key issues and their relationships when implementing EPC projects, starting from the stage of pre-retrofit, through installation, to post-retrofit.

10.7 Limitations of the Research

It is noted that this research has the following limitations:

I. Despite over a decade of market development, the take-up rates of EPC in Hong Kong is still relatively low, resulting in difficulties in finding target respondents for EPC questionnaire surveys. Although the response rate of two questionnaire surveys are considered as acceptable for an exploratory study (18.9% for host questionnaire survey and 24.8% for ESCO questionnaire survey), the respondents with hands-on experience in EPC projects only account for 35.3% of the total respondents. However, most respondents still understand the concept of EPC since some of them were involved in the stage of energy audit and EPC project negotiation, but the projects were not implemented eventually. Despite the difficulties in finding target respondents, a meaningful analysis was still conducted after some efforts to identify them;

II. Since there were several unsuccessful experience in EPC projects in Hong Kong (e.g. disputes over the actual amount of energy savings), it is difficult to organise focus group meetings and panel discussion forums with different EPC stakeholders. Therefore, only semi-structured interviews (twenty-six interviewees in total on an individual basis) were conducted;

III. Unlike the Case Study I and II in Chapter 6 (which involve real buildings), the qualification of performance risks in the lighting retrofitting can be only demonstrated through a hypothetical office building, instead of using actual buildings. However, the use of this hypothetical building still serves the purpose of illustration since this building model was developed based on survey findings of sixty-four commercial buildings in Hong Kong, which summarise the representative design characteristics of a reasonably large number of existing commercial buildings;

IV. In this research, some empirical data (e.g. AC operating hours) involve the daily building operation data. Although the data providers were willing to provide the candidate with the data in relation to building information, system and equipment specifications, as well as the measured energy use data for building energy simulation, they were still hesitant to release some sensitive data (which would somehow reflect the profitability of their business) for the development of probability distribution functions (PDF). Therefore, the PDF of several influential parameters affecting energy savings were developed based on other research findings and third party database. For example, in Case Study I of Chapter 6, no empirical data to describe the variation in long-term AC operating hours in a single building is available. An alternative way to develop such a PDF is employed by using published data of a property consultant on AC operating hours in different office buildings in Hong Kong. In addition, it would be difficult to build algorithm to take into consideration the actual site conditions in building energy simulation. For example, there are some constraints on wiring issues in lighting retrofitting projects; and

V. The generic model of EPC projects for Hong Kong is qualitative in nature and exhibits a visual and systematic presentation, mainly to represent good practices. However, there is no real project to demonstrate the application of the model. Instead, the model was validated by two groups of related people: (1) experts who have intimate knowledge of EPC; (2) industry practitioners who have no hands-on experience in EPC, but are potential users. Therefore, the model serves more as a guide to the users and as a reminder for identifying and addressing the key issues and their relationships when implementing EPC projects, starting from the stage of pre-retrofit, through installation, to post-retrofit.

10.8 Suggestions for Future Research

This study has achieved all research objectives as set out in Chapter 1. To extend the knowledge base, future research work in relation to this study is recommended as follows:

I. The questionnaire surveys can be repeated in other jurisdictions for comparison purposes;

II. The financial benefits from EPC projects should not only include energy cost savings, but also avoided-cost savings (e.g. reductions in operation and maintenance costs). More research is needed to consider possible variations in such avoided-cost savings in the risk assessment method;

III. In this research, only the EPC contract template and guidance notes for the guaranteed saving model were developed with the experts' feedback. Since the findings of the questionnaire surveys indicate that both models (guaranteed savings and shared savings) may be used in EPC projects in Hong Kong, it is encouraged that a contract template for the shared saving model to be developed to suit the future market development; and

IV. Similar to other jurisdictions in overseas countries on the progress of industry evolution, it is expected that a standard form of EPC contract for use in Hong Kong will be developed eventually. Industry consensus is needed to adopt the standard form based on the contract template developed in this research study.

10.9 Chapter summary

This chapter reviews the aim and objectives of this research study. The results which fulfil the research objectives are also depicted. The main findings of the study are summarised together with the significance and value of the research. It is anticipated that this research study can provide a solid foundation for future EPC research, particularly on the risk assessment approach taking into account other cost savings (e.g. reductions in operation and maintenance costs), as well as the standard form of EPC contract for use in Hong Kong.

APPENDICES

Appendix A - Blank Survey Questionnaire to Hosts (English Version)

Department of Building and Real Estate, The Hong Kong Polytechnic University
Research Topic: An investigation into Energy Performance Contracting for enhancing its role in energy conservation in Hong Kong
Survey on Building Owners/Occupants/Facilities Managers (Pls. refer to the attached Chinese version)

Introduction: This research is aimed at collecting responses from building owners, occupants and facilities managers on an arrangement for improving the energy efficiency of buildings. You may or may not be familiar with the term **Energy Performance Contracting** (abbreviated as "EPC"), which means an Energy Services Company ("ESCO") provides a range of services to adopt energy efficient technologies and products, initially at no cost to the building owner, but will share the realized energy cost savings with the owner over a period of time.

You do not need prior experience with EPC or ESCO in answering many of the questions

I. General Information *(Only overall statistical data will be compiled, i.e., individuals not identifiable)*

1. Your role (you may tick more than one answer):
☐ Landlord ☐ Unit Property Owner ☐ Tenant ☐ Facilities Management (FM) On-site Staff
☐ Member of Owners' Corporation ☐ Member of Owners' Committee e ☐ FM Head Office Staff
☐ Occupier (as in the case of government departments in public buildings)
☐ Occupier (as in the case of government departments renting private buildings)
☐ Occupier (as in the case of a private organization or NGO using public buildings)
Others (please specify) ______

2. Type of use of the space owned/occupied/managed by yourself or your organization (you may tick more than one answer) :
☐ Residential ☐ Office ☐ Shop ☐ Eating Place ☐ Industrial ☐ Recreational
☐ Educational ☐ Hospital ☐ Hotel ☐ Aged People Accommodation
☐ Religious Place Others (please specify) ______

3. Which sector do you belong to (in relation to your primary role):
☐ Public ☐ Quasi-public (e.g., Housing Society or subvented bodies) ☐ Private ☐NGO

4. What is the age band of the building(s) that you own/occupy/manage? (you may tick more than one answer)
☐ Less than 5 years ☐ 5 – 10 years ☐ 11 – 15 years ☐ 16 – 20 years ☐ Over 20 years

5. Which arrangement(s) best describe(s) the payment of electricity in premises under your use? (you may tick more than one box)
☐ As landlord/unit owner, you pay your own electric bills ☐ As FM, your company arranges landlord/OC to pay electric bills
☐ As unit owner/tenant, you share cost of electric bills with someone ☐ As FM, your company collects payment from owners
☐ As tenant, your unit owner pays for electric bills ☐ As occupier, electric bills are settled by the government
☐ As tenant, you pay your own electric bills ☐ As occupier, you pay your own electric bills
Others (please specify) ______

6. Which method is used to apportion the electric bills?
☐ Based on meter readings ☐ Based on the area used ☐ Based on time of usage
Others (please specify) ______

7. Which arrangement best describe(s) the use of electricity in **common areas** of the building in Q.5?
☐ Owners' Corporation pays for the electric bills ☐ Landlord pays for the electric bills in common areas
☐ You share the cost of electric bills with someone ☐ Electric bills are settled by the government
☐ FM company is responsible for paying the cost of electric bills out of management fees collected
Others (please specify) ______

8. Which measure(s) have you considered/taken to save energy cost in your existing building (you may tick more than one choice)?
☐ Do nothing for the time being
☐ Adopt disciplined use (e.g. enforce switching off power when not in use or set air-con to around 25ºC)
☐ Advocate energy retrofitting using more energy efficient installations in your building(s)
☐ Replace with energy efficient appliances & luminaries (including portable time switches or sensors)
☐ Already carried out energy retrofitting works (excluding re-wiring) to your building(s) (e.g. Replacement of air-conditioning system from air to water cooling)
Which type of retrofitting (please specify)? ______
Others (please specify) ______

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9. If your building has carried out energy retrofitting works, who paid for the cost (May tick more than one box; pls. go to Q12 if not happened)?
☐ You (as tenant) shared with owner ☐ My organisation paid upfront as part of its operating cost
☐ FM/OC paid upfront out of sinking fund ☐ Landlord paid ☐ Owners' Corporation raised fund to pay
☐ Government paid upfront ☐ Owners shared the upfront cost ☐ With government subsidy/loan
☐ An energy services company (ESCO) paid first ☐ Owner paid, since you are tenant
☐ You paid out of a loan under guaranteed saving by an ESCO ☐ You paid under guaranteed saving by an ESCO
Others (please specify) ______

10. If your building has carried out energy retrofitting works, they were related to (Pls. skip if not happened; you may tick more than one box):
☐ Owned area ☐ Rent area ☐ Common areas

11. If your building has carried out some energy retrofitting works, how were they organized (pls. skip if not happened)?
☐ A consultant designed and a contractor installed ☐ A contractor designed and installed
Others (please specify) ______

12. Have **<u>you</u>** ever been involved with Energy Performing Contracting (EPC) to-date?
☐ Yes ☐ Know about it, but no experience (pls. go to Q15 directly) ☐ Not knowing EPC (pls. go to Q15)
Others (please specify) ______

13. Which of the following types of EPC projects have you been involved with? (You may tick more than one box)
☐ (Mode I) ESCOs finance, design, supply, install equipment for host in return for energy cost saving
☐ (Mode II) ESCOs design, supply, install equipment with host or 3rd party financing and ESCO's guarantee on energy saving
☐ (Mode III) Others (please specify) ______
13a It depends on individual cases, but Mode _____ (I, II or III) is the most common we have encountered
13b You prefer Mode_____ (I, II or III) most, reasons being: ______

14. If EPC project is used, would you prefer ESCO to undertake operation of the relevant facilities within the contract period to ensure that the promised saving is achieved?
☐ Yes ☐ No. Reason: ☐ Our own staff will handle this better ☐ That would make EPC costly
Other reasons (please specify) ______

Please indicate if your building has done the following items or its likelihood to carry out such works in future from 1 – 5, where **"1" represents "Least Likely"** and **"5" represents "Most Likely"**.

II. Retrofitting Works *(Please answer this section based on your own understanding, regardless of your EPC experience)*

15. Energy retrofitting works in building(s) under your control/management (In case of more than one building, please answer based on the oldest one)	**Already Done**		**To do in future** *(tick only if not done)*					**Don't know**
	Using EPC	**Not using EPC**	**Least likely ←** **1**	**2**	**3**	**4**	**→likely Most** **5**	
i) Lighting replacement to more efficient fluorescent lamps(e.g. replace T8 with T5)	☐	☐	☐	☐	☐	☐	☐	☐
ii) Lighting replacement to LED lamps	☐	☐	☐	☐	☐	☐	☐	☐
iii) Lighting replacement (replacing incandescent light bulbs with compact fluorescent lamps)	☐	☐	☐	☐	☐	☐	☐	☐
iv) Installation of time switches and sensors	☐	☐	☐	☐	☐	☐	☐	☐
v) Replacement of power switch gear at control room	☐	☐	☐	☐	☐	☐	☐	☐
vi) Improvement of existing air-conditioning system (other than cleaning)	☐	☐	☐	☐	☐	☐	☐	☐
vii) Replacement of air-conditioning system from air to water cooling	☐	☐	☐	☐	☐	☐	☐	☐
viii) Works involving heat pumps (machines capable of both heating and cooling)	☐	☐	☐	☐	☐	☐	☐	☐
ix) Change of energy source from gas to electric	☐	☐	☐	☐	☐	☐	☐	☐
x) Change of energy source from electric to gas	☐	☐	☐	☐	☐	☐	☐	☐
xi) Use of renewable energy (e.g. solar and biofuel)	☐	☐	☐	☐	☐	☐	☐	☐
xii) Lift & escalator improvement (change of motors, excluding interior decoration)	☐	☐	☐	☐	☐	☐	☐	☐
xiii) Building fabric improvement (e.g., insulation, double window, etc.)	☐	☐	☐	☐	☐	☐	☐	☐
xiv) Others, pls. specify: ______	☐	☐	☐	☐	☐	☐	☐	☐

(Please answer based on your own understanding, regardless of your EPC experience)

16. Your concern on EPC, assuming someone approaches you with this proposal (The answer scale is now on relative importance)	Least Important ← **1**	**2**	**3**	**4**	Most → Important **5**	**Don't know**
i) Lack of familiarity with EPC	☐	☐	☐	☐	☐	☐
ii) Worry about its complexities (e.g. procurement procedures, legal issues)	☐	☐	☐	☐	☐	☐
iii) Not convinced that EPC can achieve higher saving than conventional approach	☐	☐	☐	☐	☐	☐
iv) Worry about measurement & verification inaccuracies (assuming no fraud)	☐	☐	☐	☐	☐	☐
v) Not convinced that it is cost effective	☐	☐	☐	☐	☐	☐
vi) Worry about disruption to your normal business operation or use of property	☐	☐	☐	☐	☐	☐
vii) Worry about ESCOs' guaranteed saving not being achieved, causing problem in 3rd party financing	☐	☐	☐	☐	☐	☐
viii) Worry about integrity issues of ESCOs	☐	☐	☐	☐	☐	☐
ix) Long payback period	☐	☐	☐	☐	☐	☐
x) Others, pls. specify:	☐	☐	☐	☐	☐	☐

(Please answer based on your own understanding, regardless of your EPC experience)

17. Criteria for choosing ESCO, assuming you will adopt EPC	Least Important ← **1**	**2**	**3**	**4**	Most → Important **5**	**Don't know**
i) Company reputation and track record	☐	☐	☐	☐	☐	☐
ii) Lowest bid price (i.e., lowest outlay for the entire contract)	☐	☐	☐	☐	☐	☐
iii) Convincing energy saving proposal	☐	☐	☐	☐	☐	☐
iv) ESCO offers guarantee on energy saving level	☐	☐	☐	☐	☐	☐
v) ESCO bears all risks (including energy price, changes in weather & use pattern)	☐	☐	☐	☐	☐	☐
vi) ESCO provides financing	☐	☐	☐	☐	☐	☐
vii) ESCO provides energy saving solutions in different aspects (including building fabric improvement)	☐	☐	☐	☐	☐	☐
viii) ESCO has done separate energy audit before negotiating for EPC	☐	☐	☐	☐	☐	☐
ix) Use of innovative technology	☐	☐	☐	☐	☐	☐
x) Long time to pay off the contract sum to the ESCO (lower installment)	☐	☐	☐	☐	☐	☐
xi) ESCO capable of providing operation & maintenance during contract	☐	☐	☐	☐	☐	☐
xii) Short break-even period for upfront investment outlay	☐	☐	☐	☐	☐	☐
xiii) Others, pls. specify:	☐	☐	☐	☐	☐	☐

III. Please share your experience with past EPC or ESCO, if any, in respect of the following:

ESCO Selection Process:	
Negotiation with ESCO:	
Establishing the Baseline/ Measuring Energy Saving:	
Service Quality:	
Others (e.g. disagreement in contract):	

(End)

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Appendix B - Blank Survey Questionnaire to Hosts (Chinese Version)

香港理工大學建築及房地產學系
研究主題: 合同能源管理可提升本港能源效益之探討
問卷對象: 大廈業主/租戶/設施管理經理

簡介：此項研究目的是搜集大廈業主，住戶及設施管理經理對**合同能源管理**之意見。(你不需對**合同能源管理**有深入了解，也能完成這問卷。) **合同能源管理**(簡稱"EPC")的概念是能源服務公司，在不需前期工程費用情況下，提供多種節能技術和節能產品，從而改善建築物能源效益。當預期節能目標實現後，大廈業主與能源服務公司共同分享節能後的**費用**節省。

大部份問題，不需相關合同能源管理或能源服務公司的經驗。

I. 一般資料（所得資料只供整體統計分析之用，個人資料絕不泄漏）

1. 你現時擔當的角色（你可以選擇一個或以上答案）:
   ☐ 大業主 ☐ 小業主 ☐ 租戶 ☐ 設施管理公司職員(駐場)
   ☐ 業主立案法團成員 ☐ 業主委員會成員 ☐ 設施管理公司職員(駐總公司)
   ☐ 佔用人（政府部門使用公共建築物）
   ☐ 佔用人（政府部門租用私人樓宇）
   ☐ 佔用人（私人或非政府組織租用公共建築物）
   其他（請註明）

2. 下列選擇中，那些是你現時所擁有 / 使用 / 或管理的地方的地方（你可以選擇一個或以上答案）:
   ☐ 住宅 ☐ 辦公室 ☐ 商店 ☐食肆 ☐ 工業大廈 ☐ 休憩場所
   ☐ 教育 ☐ 醫院 ☐ 酒店 ☐老年住宿中心
   ☐ 宗教場所 其他（請註明）

3. 你屬於下列哪個類別（與你現時擔當的角色有關）:
   ☐ 公營 ☐ 半公營(如房屋協會或資助機構) ☐ 私營 ☐ 非政府組織

4. 你現時擁有 / 使用 / 或管理這座大廈的樓齡（你可以選擇一個或以上答案）:
   ☐ 少於 5 年 ☐ 5 – 10 年 ☐ 11 – 15 年 ☐ 16 – 20 年 ☐ 超過 20 年

5. 你是如何繳交你使用地方的電費帳單?（你可以選擇一個或以上答案）
   ☐ 作為大/小業主，自行繳交有關的電費帳單 ☐ 作為設施管理公司，安排大業主或法團繳交有關的電費帳單
   ☐ 作為小業主/租戶，你與別人分擔有關的電費帳單 ☐ 作為設施管理公司，收取各業主的電費支出，然後統一繳交
   ☐作為租戶，由小業主代你支付有關的電費帳單 ☐ 作為佔用人，由政府代你支付有關的電費帳單
   ☐作為租戶，自行繳交有關的電費帳單 ☐ 作為佔用人，自行繳交有關的電費帳單
   其他（請註明）

6. 你應繳交的電費是根據下列那些方法來計算的?
   ☐ 根據你使用的能源讀數來支付 ☐ 根據你使用的面積來支付 ☐ 根據你使用的時間來支付
   其他（請註明）

7. 你所在建築物的**公用地方**是用下列那種安排來支付有關的電費帳單?
   ☐ 業主立案法團支付 ☐ 大業主支付 ☐你與別人一同分擔費用 ☐ 政府支付
   ☐ 物業管理公司收取管理費用, 並負責支付有關電費開支
   其他（請註明）

8. 下列那些措施，你曾經或將會採用來減少建築物能源消耗?（你可以選擇一個或以上答案）
   ☐ 暫時沒有考慮
   ☐ 採用自律性節能措施（例如，關掉未被使用電器或將室溫設定約攝氏 25 度）
   ☐ 提倡使用具能源效益的節能裝置
   ☐ 改用具能源效益的電器及燈具（包括便攜式時間開關裝置或光感測量器）
   ☐ 已開展建築物節能改善工程（不包括重新佈線）（例如，空調機組改用淡水冷卻，取代風冷冷卻）
   請註明哪類建築物節能改善工程
   其他（請註明）

請將填妥問卷放入回郵信封，寄回本校　　1　　

9. 若你現時擁有 / 使用 / 或管理的建築物已進行一些節能改善工程，由誰支付有關費用（可選多個答案，如果從未發生，請跳去問題 12）?
☐ 租戶與業主一同分擔 ☐ 機構自行支付，這作為其經營成本的一部分
☐ 設施管理公司/法團從改善基金中支付有關費用 ☐ 大業主支付 ☐ 法團籌款支付
☐ 政府支付 ☐ 業主共同支付 ☐ 政府資助/貸款
☐ 能源服務公司預先支付 ☐ 作為租戶，由業主支付
☐ 在能源服務公司的保證下，你從貸款中支付 ☐ 在能源服務公司的保證下，你自行預先支付
其他（請註明）

10. 若你現時擁有 / 使用 / 或管理的建築物已進行一些節能改善工程， 這些工程在那些地方? (你可以選擇一個或以上答案）
☐ 自用地方 ☐租用地方 ☐公共地方

11. 若你現時擁有 / 使用 / 或管理的建築物已進行一些節能改善工程，是用下列那種模式來進行?
☐ 工程顧問設計，承包商安裝 ☐ 承包商設計及安裝
其他（請註明）

12. 你曾使用合同能源管理嗎?
☐ 是 ☐ 了解它，但沒有經驗(請跳去問題 15） ☐ 不認識 (請跳去問題 15）
其他（請註明）

13. 你曾接觸過下列那些類型的合同能源管理項目？（你可以選擇一個或以上答案）
☐ (模式 I) 能源服務公司提供融資，設計，供應，安裝主機設備，並**分享**節能效益
☐ (模式 II) 能源服務公司提供設計，供應，安裝主機設備，並**保證**節能效益，但由大廈業主或邀請第三方金融機構融資
☐ (模式 III) 其他（請註明）
13a 取決於個別情況, 但模式 _____ (I，II 或 III) 是我們最常遇見的。
13b 比較以上模式，我最喜歡模式_____ (I，II 或 III), 原因是:

14. 若使用合同能源管理，在合同期限內，你願意讓能源服務公司營運有關設備，以確保達至所承諾的節能成效?
☐ 是 ☐ 否，原因: ☐我們自己的員工能更好處理 ☐ 這會增加**合同能源管理**的費用
其他原因（請註明）

請選擇下列項目最合適的答案。“1”代表“最不可能”和“5”代表“最可能”。
II. 建築物節能改善工程 (請根據自己的認識，回答下列問題。沒有**合同能源管理**的經驗也可作答。)

15. 你現時擁有/使用/管理的建築物，曾否或將會進行以下節能改善工程: (如多於 1 幢建築物，則以樓齡較大者為準)	已完成		將會進行 (***未曾做才填寫***)					不知道
	使用 EPC 模式	沒有使用 EPC 模式	最不可能 ← **1**	**2**	**3**	**4**	→ 最可能 **5**	
i) 改用高能源效益的照明光管系統 (如 T5 光管取代 T8 光管)	☐	☐	☐	☐	☐	☐	☐	☐
ii) 改用 LED 照明系統	☐	☐	☐	☐	☐	☐	☐	☐
iii) 改用慳電膽取代鎢絲燈作照明系統	☐	☐	☐	☐	☐	☐	☐	☐
iv) 加裝時間掣及光感應器控制	☐	☐	☐	☐	☐	☐	☐	☐
v) 更換電力控制器，從而減少能源損失	☐	☐	☐	☐	☐	☐	☐	☐
vi) 提升現时空調機組效能 (除日常清潔外)	☐	☐	☐	☐	☐	☐	☐	☐
vii) 空調機組改用淡水冷卻，取代風冷冷卻	☐	☐	☐	☐	☐	☐	☐	☐
viii) 改用熱泵 (機組能同時提供熱能及冷卻效果)	☐	☐	☐	☐	☐	☐	☐	☐
ix) 改用電力取代煤氣	☐	☐	☐	☐	☐	☐	☐	☐
x) 改用煤氣取代電力	☐	☐	☐	☐	☐	☐	☐	☐
xi) 使用再生能源 (如太陽能及生物燃料)	☐	☐	☐	☐	☐	☐	☐	☐
xii) 改善升降機及自動電梯的能源效益（如改用變壓變頻式傳動裝置）	☐	☐	☐	☐	☐	☐	☐	☐
xiii) 改善建築物外牆（例如，隔熱，雙層窗等，以減少熱損耗）	☐	☐	☐	☐	☐	☐	☐	☐
xiv) 其他（請註明）:	☐	☐	☐	☐	☐	☐	☐	☐

(請根據自己的認識，回答下列問題。沒有**合同能源管理**的經驗也可作答。)

16. 你對**合同能源管理**的顧慮是: (假設有人建議你使用)	最不重要 ← 1	2	3	4	→最重要 5	不知道
i) 對**合同能源管理**的認識度不足	☐	☐	☐	☐	☐	☐
ii) 憂慮其複雜性（如採購程序，法律問題）	☐	☐	☐	☐	☐	☐
iii) 不相信**合同能源管理**比傳統方法能達到更高的節能成效	☐	☐	☐	☐	☐	☐
iv) 憂慮節能量度和核實的準確性 (假設沒有欺詐行為)	☐	☐	☐	☐	☐	☐
v) 不相信**合同能源管理**是符合成本效益	☐	☐	☐	☐	☐	☐
vi) 擔心影響大廈正常營運或對使用者構成不便	☐	☐	☐	☐	☐	☐
vii) 憂慮能源服務公司不能實現保證的節能成效，造成拖欠第三方貸款	☐	☐	☐	☐	☐	☐
viii) 憂慮能源服務公司的誠信問題	☐	☐	☐	☐	☐	☐
ix) 長投資回本期	☐	☐	☐	☐	☐	☐
x) 其他（請註明）:	☐	☐	☐	☐	☐	☐

(請根據自己的認識，回答下列問題。沒有**合同能源管理**的經驗也可作答。)

17. 選擇能源服務公司的準則 (假如你會採用**合同能源管理**)	最不重要 ← 1	2	3	4	→最重要 5	不知道
i) 該公司聲譽和過往記錄	☐	☐	☐	☐	☐	☐
ii) 最低投標價格（以整份合同計算）	☐	☐	☐	☐	☐	☐
iii) 令人信服的節能建議	☐	☐	☐	☐	☐	☐
iv) 能源服務公司提供節能保證水平	☐	☐	☐	☐	☐	☐
v) 能源服務公司承擔所有風險 (包括能源價格，天氣及使用模式變化等風險)	☐	☐	☐	☐	☐	☐
vi) 能源服務公司提供融資渠道	☐	☐	☐	☐	☐	☐
vii) 能源服務公司提供多種節能技術（包括改善建築物外牆隔熱能效）	☐	☐	☐	☐	☐	☐
viii) 在商議**合同能源管理**前，能源服務公司已進行能源審計	☐	☐	☐	☐	☐	☐
ix) 採用創新節能技術	☐	☐	☐	☐	☐	☐
x) 能提供長還款期（減低分期付款的金額）	☐	☐	☐	☐	☐	☐
xi) 在合同期間，能源服務公司能提供設施營運及維修保養服務	☐	☐	☐	☐	☐	☐
xii) 減短前期投資回報期	☐	☐	☐	☐	☐	☐
xiii) 其他（請註明）:	☐	☐	☐	☐	☐	☐

III. 請分享你過往接觸**合同能源管理**或能源服務公司的經驗： (如曾有)

能源服務公司的選擇過程：	
與能源服務公司的協商過程：	
建立能耗基線/ 如何量度節能成效：	
服務質素：	
其他（如合同中具爭議的地方）：	

(完)

Appendix C - Blank Survey Questionnaire to ESCOs

Department of Building and Real Estate, The Hong Kong Polytechnic University
Research Topic: An investigation into Energy Performance Contracting for enhancing its role in energy conservation in Hong Kong
Survey on Energy Services Companies

I. General Information *(Only overall statistical data will be compiled, i.e., individual information not disclosed)*

1a. Your work experience:
☐ Below 5 year ☐ 6 - 10 years ☐ 11 - 15 years ☐ 16 - 20 years ☐ Over 20 years

1b Years of your department having been established:
☐ Below 5 year ☐ 6 - 10 years ☐ 11 - 15 years ☐ 16 - 20 years ☐ Over 20 years

1c) Approximate staff number (both Head-Quarter and Site Office) in your department:
☐ Below 25 staff ☐ 26-50 staff ☐ 51-100 staff ☐ 101-150 staff ☐ Over 150 staff

2. Scope of work of your department and organization (you may tick more than one):
☐ Energy audit ☐ Renewable energy applications ☐ Power quality solutions
☐ Power supply ☐ Power transmission and distribution ☐ Facilities management
☐ Lighting services ☐ Manufacture and supply of equipment ☐ E & M Infrastructure
☐ Consultancy ☐ Energy Performing Contracting ☐ Energy retrofitting to client's design
Others (please specify) ☐

II. EPC Experience *(pls. go to Q14-18 directly after answering Q3 if you have no EPC experience or don't know about it)*

3. Have you ever been involved with Energy Performing Contracting (EPC) to-date?
☐ Yes ☐ Know about it, but no experience ☐ Not knowing EPC

4. How many EPC projects have you ever been involved with?
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ above 4

5. Which type(s) of EPC projects have you been involved with? (You may tick more than one box)
☐ (Mode I) We finance, design, supply, install equipment for host in return for a share of energy cost saving
☐ (Mode II) We design, supply, install equipment with host or 3rd party financing and our guarantee on energy saving
☐ (Mode III) We provide consultancy service only for clients
☐ (Mode IV) Others (please specify) ☐
5a. It depends on individual cases, but Mode ______(pls. indicate I, II, III or IV) is the most common we have encountered.
5b: Our organization prefers Mode _____(pls. indicate I, II, III or IV) , reasons being: ☐

6. Do you maintain/operate the equipment for the EPC projects within the contract periods? (You may tick more than one box)
☐ (Mode A)Yes, we carry out maintenance and operation
☐ (Mode B)We carry out maintenance only, with operation by host's own staff
☐ (Mode C)We carry out maintenance only, with operation by property management companies
☐ (Mode D) We carry out operation only, with maintenance by others
☐ (Mode E) Host carries out their own maintenance and operation, with our advice and training
☐ (Mode F) Others (please specify) ☐
6a. It depends on individual cases, but Mode_____(pls. indicate A, B, C, D, E or F) is the most common we have encountered.
6b: Our organization prefers Mode_____(pls. indicate A, B, C, D, E or F), reasons being: ☐

7. How about ownership of the equipment installed under the EPC projects? (You may tick more than one box)
☐ (Mode i) Ownership by host
☐ (Mode ii) Ownership by our organization, with leasing to host within the contract period.
☐ (Mode iii) Ownership by financier until loan is paid off
☐ (Mode iv) Others (please specify) ☐
7a. It depends on individual cases, but Mode _____(pls. indicate i, ii, iii or iv) is the most common we have encountered.
7b: Our organization prefers Mode______(pls. indicate i, ii, iii or iv), reasons being: ☐

8. Is there any energy audit carried out before negotiation for EPC (You may tick more than one box)?
☐ (Mode 1) Yes, the energy audit is conducted by 3rd party
☐ (Mode 2) Yes, the energy audit is conducted separately from EPC by our organization as different but linked contracts
☐ (Mode 3) Yes, the energy audit is conducted by our organization as a part of EPC package
☐ (Mode 4) No, the negotiation for EPC is done solely based on the data available from host
☐ (Mode 5) Others (please specify) ☐
8a. It depends on individual cases, but Mode _____(pls. indicate 1, 2, 3, 4 or 5) is the most common we have encountered.
8b: Our organization prefers Mode______(pls. indicate 1, 2, 3, 4 or 5), reasons being: ☐

1

9. Which method have you used to develop the baseline of energy consumption on EPC projects? (You may tick more than one box)
   ☐ (Mode a) Based on electricity bills
   ☐ (Mode b) Based on short-term measurements
   ☐ (Mode c) Based on BMS data provided by host or host's FM Company
   ☐ (Mode d) Based on long-term measurements
   ☐ (Mode e) Based on energy audit report carried out by 3rd party
   ☐ (Mode f) Others (please specify) ______
   9a. It depends on individual cases, but Mode _____(pls. indicate a, b, c, d, e or f) is the most common we have encountered.
   9b: Our organization prefers Mode_____(pls. indicate a, b, c, d, e or f), reasons being: ______

10. In your EPC contracts, what are the bases of the payment terms? (You may tick more than one box)
   ☐ (Mode i) Fixed payment schedule, with deduction for performance shortfall at interim periods
   ☐ (Mode ii) Fixed payment schedule, with deduction for performance shortfall at contract end
   ☐ (Mode iii) Strictly based on measured cost saving
   ☐ (Mode iv) Others (please specify) ______
   10a. It depends on individual cases, but Mode _____(pls. indicate i, ii, iii or iv) is the most common we have encountered
   10b: Our organization prefers Mode _____(pls. indicate i, ii, iii or iv), reasons being: ______

11. Which method(s) have you adopted in estimating energy saving? (You may tick more than one box)
   ☐ (Mode A) Simplified engineering method (e.g. power rating x operating hours for lighting retrofit)
   ☐ (Mode B) Regression analysis model
   ☐ (Mode C) Building energy simulation program (e.g. EnergyPlus)
   ☐ (Mode D) Others (please specify) ______
   11a. It depends on individual cases, but Mode _____(pls. indicate A, B, C or D) is the most common we have encountered
   11b: Our organization prefers Mode _____(pls. indicate A, B, C or D), reasons being: ______

12. Do you follow any measurement & verification guidelines for calculating energy saving? If so, which guideline(s) have you used? (You may tick more than one box)
   ☐ (Guideline 1) EVO International Performance M&V Protocol
   ☐ (Guideline 2) ASHRAE Guideline 14 Measurement of Energy and Demand Savings
   ☐ (Guideline 3) FEMP M&V Guidelines: M&V for Federal Energy Projects
   ☐ (Guideline x) Others (please specify) ______
   12a. It depends on individual cases, but Mode _____(pls. indicate Guideline No.) is the most common we have encountered
   12b: Our organization prefers Guideline _____(pls. indicate Guideline No.) , reasons being: ______

13. Which basis have you encountered in preparing an EPC contract? (you may tick more than one box)
   ☐ (Mode A) Contract written in-house and agreed with the client
   ☐ (Mode B) Modified from a standard construction contract
   ☐ (Mode C) Modified from a standard M&E contract
   ☐ (Mode D) Direct use of an overseas standard form of EPC contract (e.g. ESPC in U.S., EPC in Canada, GESP in S'pore)
   ☐ (Mode E) Modified from an overseas standard form of EPC contract (same examples as above)
   ☐ (Mode F) Others (please specify) ______
   13a. It depends on individual cases, but Mode _____(pls. indicate A, B, C, D, E or F) is the most common we use
   13b: Our organization prefers Mode_____(pls. indicate A, B, C, D, E or F), reasons being: ______

14. [Optional Question] Which method(s) have you used for EPC project financial evaluation? (you may tick more than one box)
   ☐ (Mode 1) Net Present Worth
   ☐ (Mode 2) Internal Rate of Return (IRR)
   ☐ (Mode 3) Benefit Cost Ratio
   ☐ (Mode 4) Payback Period
   ☐ (Mode 5) Others (please specify) ______
   14a. It depends on individual cases, but Mode _____(pls. indicate 1, 2, 3, 4 or 5) is the most common we use
   14b: Our organization prefers Mode_____(pls. indicate 1, 2, 3, 4 or 5), reasons being: ______

III Ranking Questions ***(Please answer this section based on your understanding, regardless of your EPC experience)***
Please rate the relative frequencies of the following items from 1 – 5, where **"1" represents "Least Frequent** and **"5" represents "Most Frequent"**.

15. Potential energy retrofitting works in Hong Kong *(The following items may be carried out by EPC or traditional contracting arrangement)*	Least Frequent ← 1	2	3	4	Most →Frequent 5	Don't know
i) Lighting replacement to more efficient fluorescent lamps(e.g. replace T8 with T5)	☐	☐	☐	☐	☐	☐
ii) Lighting replacement to LED lamps	☐	☐	☐	☐	☐	☐
iii) Lighting replacement (replacingincandescent light bulbs with compact fluorescent lamps)	☐	☐	☐	☐	☐	☐
iv) Installation of time switches and sensors	☐	☐	☐	☐	☐	☐
v) Replacement of power switch gear at control room	☐	☐	☐	☐	☐	☐
vi) Improvement of existing air-conditioning system (other than cleaning)	☐	☐	☐	☐	☐	☐
vii) Replacement of air-conditioning system from air to water cooling	☐	☐	☐	☐	☐	☐
viii) Works involving heat pumps (machines capable of both heating and cooling)	☐	☐	☐	☐	☐	☐
ix) Change of energy source from gas to electric	☐	☐	☐	☐	☐	☐
x) Change of energy source from electric to gas	☐	☐	☐	☐	☐	☐
xi) Use of renewable energy (e.g. solar and biofuel)	☐	☐	☐	☐	☐	☐
xii) Lift & escalator improvement (change of motors, excluding interior decoration)	☐	☐	☐	☐	☐	☐
xiii) Building fabric improvement (e.g., insulation, double window, etc.)	☐	☐	☐	☐	☐	☐
xiv) Others, pls. specify: ____________________	☐	☐	☐	☐	☐	☐

Please rate the relative importance of the following items from 1 – 5, where **"1" represents "Least Important"** and **"5" represents "Most Important"**.

16. Motivation of Building Owners towards use of EPC, if they would consider it	Least Important← 1	2	3	4	Most → Important 5	Don't know
i) Lack of capital to implement energy saving measures on their own	☐	☐	☐	☐	☐	☐
ii) Provision of turnkey services as all-in-one package including energy audit, retrofit and financing	☐	☐	☐	☐	☐	☐
iii) Use of energy saving for other purposes may yield better return	☐	☐	☐	☐	☐	☐
iv) A quick way to comply with legislation requirements	☐	☐	☐	☐	☐	☐
v) Transfer the technical/performance risk from clients to ESCOs	☐	☐	☐	☐	☐	☐
vi) Reliance on ESCOs' expertise	☐	☐	☐	☐	☐	☐
vii) ESCOs provide staff training for better system operation and control	☐	☐	☐	☐	☐	☐
viii) Budgeting of energy consumption taken care of by ESCOs	☐	☐	☐	☐	☐	☐
ix) Expect higher energy efficiency than design-bid-build	☐	☐	☐	☐	☐	☐
x) More comfortable environment after installation or upgrading	☐	☐	☐	☐	☐	☐
xi) EPC is a cost effective solution to achieve energy saving	☐	☐	☐	☐	☐	☐
xii) Others, pls. specify: ____________________	☐	☐	☐	☐	☐	☐

Please rate the likelihood of the following items from 1 – 5, where **"1" represents "Least Likely"** and **"5" represents "Most Likely"**.

17.Likely reasons for Building Owners NOT considering EPC	Least Unlikely← 1	2	3	4	Very → Likely 5	Don't know
i) Lack of familiarity with EPC	☐	☐	☐	☐	☐	☐
ii) Worry about its complexities (e.g. procedures, legal issues)	☐	☐	☐	☐	☐	☐
iii) Not convinced that EPC can achieve higher saving than design-bid-build	☐	☐	☐	☐	☐	☐
iv) Worry about measurement & verification inaccuracies (assuming no fraud)	☐	☐	☐	☐	☐	☐
v) Not convinced that it is cost effective	☐	☐	☐	☐	☐	☐
vi) Worry about disruption to their normal business operation or use of property	☐	☐	☐	☐	☐	☐
vii) Worry about ESCOs' guaranteed saving not being achieved, causing problem to 3rd party financing	☐	☐	☐	☐	☐	☐
viii) Worry about integrity of ESCOs	☐	☐	☐	☐	☐	☐
ix) Long payback period	☐	☐	☐	☐	☐	☐
x) Others, pls. specify: ____________________	☐	☐	☐	☐	☐	☐

(Please answer this section based on your understanding, regardless of your EPC experience)

Please rate the relative importance of the following items from 1 – 5, where **"1" represents "Least Important"** and **"5" represents "Most Important"**.

18. Please rank the relative importance of risk factors relevant to EPC as perceived by ESCO	Least Important← 1	2	3	4	→ Most Important 5	**Don't know**
i) Not sure if expected performance can be achieved (e.g. due to change in baseline condition such as weather, occupancy, room usage etc.)	☐	☐	☐	☐	☐	☐
ii) Not sure if baseline measurement can be correctly established (e.g. due to incomplete and poor quality of data obtained from energy audit)	☐	☐	☐	☐	☐	☐
iii) Not sure if energy saving determination method is accurate (e.g. system modeling error)	☐	☐	☐	☐	☐	☐
iv) Not sure if measurement after installation is accurate	☐	☐	☐	☐	☐	☐
v) Not sure if host would change use pattern without informing ESCO	☐	☐	☐	☐	☐	☐
vi) Not sure if host would operate plant as advised during contract period	☐	☐	☐	☐	☐	☐
vii) Not sure if actual maintenance cost is smaller than the expected budget	☐	☐	☐	☐	☐	☐
viii) Not sure if actual M&V cost is smaller than the expected budget	☐	☐	☐	☐	☐	☐
ix) New installed equipment perform poorly due to improper design (e.g. oversizing)	☐	☐	☐	☐	☐	☐
x) New equipment deteriorate much faster than expected	☐	☐	☐	☐	☐	☐
xi) Payment default of host after installation	☐	☐	☐	☐	☐	☐
xii) Costs of installation increase (e.g. exchange rate, equipment cost, labour cost)	☐	☐	☐	☐	☐	☐
xiii) Interest rate fluctuation (if the 3rd party finances the project)	☐	☐	☐	☐	☐	☐
xiv) Energy price fluctuation	☐	☐	☐	☐	☐	☐
xii) Others, pls. specify: ____________________	☐	☐	☐	☐	☐	☐

Please rate the relative importance of the following items from 1 – 5, where **"1" represents "Least Important"** and **"5" represents "Most Important"**.

19. Practicality of measures to enhance the adoption of EPC in Hong Kong	Least Important← 1	2	3	4	→ Most Important 5	**Don't know**
i) Promote successful examples of EPC projects	☐	☐	☐	☐	☐	☐
ii) Establishment of awards for ESCOs based on transparent criteria	☐	☐	☐	☐	☐	☐
iii) Public sector takes a leading role in adopting EPC	☐	☐	☐	☐	☐	☐
iv) Modification of government procurement practices to facilitate the use of EPC contracts	☐	☐	☐	☐	☐	☐
v) Promote the value for money of EPC amongst building owners	☐	☐	☐	☐	☐	☐
vi) Publication of clear guidelines on EPC procedures	☐	☐	☐	☐	☐	☐
vii) Further strengthen the requirement of Building Energy Code and efficiency standards	☐	☐	☐	☐	☐	☐
viii) Use of a standard consultancy agreement for energy audit	☐	☐	☐	☐	☐	☐
ix) A suit of standard EPC contracts for use with major types of energy retrofitting	☐	☐	☐	☐	☐	☐
x) Standard M & V procedures for major types of energy retrofitting	☐	☐	☐	☐	☐	☐
xi) Government backs up a portion of ESCOs' guarantee to lending banks (as in Singapore)	☐	☐	☐	☐	☐	☐
xii) A joint fund by gov't, investment banks & oil companies to guarantee majority of financings obtained by ESCOs, with suppliers, equipment leasers, ESCOs and banks bearing rest of payment default risk by owners.	☐	☐	☐	☐	☐	☐
xiii) Accreditation and maintenance of a register of ESCOs (as in Singapore)	☐	☐	☐	☐	☐	☐
xiv) Insurance against energy efficiency shortfall (as in the US)	☐	☐	☐	☐	☐	☐
xv) Development of new technologies and energy efficient products	☐	☐	☐	☐	☐	☐
xvi) Others, pls. specify: ____________________	☐	☐	☐	☐	☐	☐

(End)

Thank you for your kind cooperation and
valuable assistance in participating in this survey

Appendix D - Sample List of Interview Questions

The Hong Kong Polytechnic University

RGC Research Project

Background:

With the support of the Research Grants Council, HKSAR, a research team from the Hong Kong Polytechnic University is now conducting the research project “An Investigation into Energy Performance Contracting for enhancing its role in energy conservation in Hong Kong”. In order to have a better understanding of EPC development in HK, we would like to seek your consent for a face-to-face interview.

Face-to-Face Interview Aim:

The interview objectives are summarised as follows:

- To understand the concerns of stakeholders of commercial and institutional facilities about EPC.
- To understand the business scope of ESCOs in Hong Kong, their EPC experience and ranking of risk factors.

Interview Questions:

EPC market

1. What do you think about EPC market in Hong Kong? Are the stakeholders aware of it and do they have confidence on adoption of EPC contract?

   (Note: Dr. Sam C.M. Hui discussed in the conference paper that the ESCO industry is still developing in Hong Kong and many people (like building owners, bank officers, contractors, lawyers) are not familiar with EPC and its financing method.)

2. What is your view on the suitability of the 2 types of EPC model (namely, shared saving model and guaranteed saving model)?

3. As for guaranteed savings, they can be reckoned based on energy cost (i) or plant efficiency(ii)? Which one is more realistic to be adopted in EPC market in HK?

   (Note:

   (i) ESCO guarantees that saving is achieved in terms of final energy cost. (e.g. the utility bills)

   (ii) ESCO guarantees that saving is achieved in terms of plant efficiency. (e.g. the efficiency of central chiller plant system is operated not less than 1kW/ton throughout any year. If the ESCO is unable to perform the agreed requirement, then the client may claim for performance damage.)

   The main difference between these two approaches is that in (ii), ESCO is not required to bear the risk of change of building loads & operation if the guarantee of plant efficiency is adopted.)

Retrofitting Works

4. What type of retrofitting work is the most feasible to form an energy performance contract with clients/ building owners?

   (e.g. Power saving, Chiller Replacement, Lighting System Replacement, Lift system Improvement)

Measurement and Verification

5. What difficulties do you have when carrying out M&V work in EPC projects in HK?

   (E.g., the possible concern/difficulties may be dispute of M&V, mistrust between contractual parties etc.)

6. As there are different M&V guidelines published to determine energy saving for retrofit projects, do you think that these guidelines are applicable to HK market? If not, what improvement should we make?

   (PS: The common M&V guidelines such as International Performance Measurement and Verification Protocol & ASHRAE guideline 14 Measurement of Energy and Demand Savings)

7. Do you think that existing energy measurement technology is reliable and accurate enough to quantify the energy saving?

   (PS: Apart from using utility bills as a tool to quantity the saving, using direct measurement on the retrofitting system is the other common approach to determine the saving. However, some practitioners are concerned with the reliability of measurement data.)

Financing

8. Do you have any difficulty to obtain financing from financial institutions or banks for EPC projects? Are they keen on providing this kind of financing to either ESCOs or Hosts?

Procurement Process

9. Is there any difficulty to find suitable ESCOs for tendering and providing a comprehensive proposal for EPC projects?

   (Note: EPC requires a different approach from conventional contract and tendering procedures. In many cases, a new specification, especially for the M&V procedure, is necessarily drafted prior to negotiation of EPC projects, which hinders the adoption of EPC contract.)

Risk Perception of EPC

10. What is your major concern for the adoption of EPC contract?

    (e.g. Not sure if energy saving estimation is accurate, host may change use pattern without informing ESCO)

Appendix E - Experts' comments on the contract template and associated guidance notes as well as the responses

I.D.	Designation	Role	Years of experience
1	Director	Building Owner	≥ 20 years
2	Director	ESCO	≥ 20 years
3	Manager	ESCO	≥ 15 years

Comments from Expert 1	Response to Expert 1
Comments: 1. In Clause 4 (Ownership of Contractor-installed Equipment), would the equipment become a fixture and thus become part of the land? How to deal with property transaction? How can owner sell the property without the equipment	The Contractor first retains the ownership of equipment during the installation period. Upon the substantial completion certificate being issued by the Client, the ownership of equipment would be handed over to the Client. If the contract is terminated during the installation period, the Client would appoint an independent claim adjuster to ascertain the value of installation completed and materials delivered to-date. The Client should also pay the Contractor the ascertained value after due adjustment of the cost of employing the claim adjuster.
2. What if the client fails to comply with the operation procedures made by the contractor?	If the Client does not strictly follow the operation procedures of ECM as set forth in Schedule 8 (Operation Procedures of ECM) and thereby lead to shortfall in energy saving in any M&V period, the Contractor should forthwith notify the Client and estimate the impact on energy saving due to improper operation of ECM, and the Client shall compensate in the next payment due the ascertained loss, if any, to the Contractor once the impact on energy saving is mutually agreed.
Comments from Expert 2	**Response to Expert 2**
1. It is expected that the purpose of the template is to enable building owners to implement EPC projects without involving other consultants such as legal consultants. However, in Note 5 of cover page of the template, it mentions that "independent legal advice should be sought by both parties before entering	This template may be used without the involvement of legal consultant unless the building owner does not fully understand the meaning and the implications of each clause. In order to protect the interest of building owners in such case, it is advisable that independent legal advice be sought by both parties before entering into contract.

into contract", and this may violate the original purpose of drafting this template.	
2. In Clause 5c, it is not clear to state that the client has the right to reject and ask for re-submission if the submission is not up to the standard.	Clause 5c is revised as "the Contractor shall submit as-fitted drawings and Operation & Maintenance manuals to the satisfaction of the Client or his designated representatives".
3. Clause 6 may become complicated when two or more ECMs are involved in one EPC project. For example, the installation period of lighting retrofit is much shorter than that of chiller replacement. It may be unfair if there is only one performance guarantee commencement date for two or more ECMs involved.	When two or more ECMS are implemented in one single project but with substantial difference in their completion dates, it is recommended to sign two separate EPC contracts to avoid the argument on the performance guarantee commencement date. This recommendation is now highlighted in the Guidance Note.
4. In Clause 7, it is better to emphasise that the measured data should be shared between both parties to prevent the Contractor from manipulating the data.	Noted. "Identical copies of such reading shall be kept by both the Contractor and the Client" is added in Clause 7b.
5. In Clause 11c, it should be highlighted that the Contractor shall report immediately to the Client if the recommended operation procedures are not strictly followed.	Clause 11c is revised as 'If the Client does not strictly follow the operation procedures of ECM in any M&V period, the Contractor shall forthwith notify the Client and estimate the impact on energy saving due to improper operation of ECM.'
6. In Clause 14, the meaning of performance bond may be confusing, and this needs more clarification.	For better clarification, the purpose of performance bond has been described in the Guidance Notes.
7. In Schedule 1 'Project Description', more information requirements should be provided, for examples, equipment rating, sizes or number of equipment.	The suggested information requirements such as equipment rating, sizes and number of equipment are now added in Schedule 1.
8. The industry at present found the baseline adjustment as the most difficult part to deal with. It would be better if some simple forms of baseline adjustment (e.g. if increase 1 degree in temperature in n days, then this would mean x% increment in energy use) are included in Schedule 3.	Unfortunately, there is no generality in baseline adjustment since the influential factors affecting energy use are highly dependent on building operation patterns, building physical characteristic, etc. However, Schedule 5 highlights the general principle of baseline adjustment, for example, both parties should determine which factor and the degree of variations in those factor(s) to trigger baseline adjustment.

9. Liquidated Damages (LD) in some cases may be unnecessary. For example, if the Client suffers losses due to project delay of chiller replacement (lots of complaints from the end users), then by common law, the Contractor has to reimburse for any justifiable loss.	In this contract design, the Contractor's obligation on performance guarantee would commence only when the Client issues the certification of substantial completion. That means that the Client cannot seek compensation for saving shortfalls before the expected completion date. In addition, the merit of having LD provision is to enable both parties to clearly recognise the consequences of project delay before entering into the contract.
Comments from Expert 3	**Response to Expert 3**
1. In practice, the Contractor first conducts an energy audit on the Client's building, and proposes the retrofit measure in the engineering proposal. Such a proposal often forms a part of the contract document in EPC projects. It is better if your contract is able to cater for this provision.	The name of Schedule 1 (originally it is "Project Description") has been revised as "Project Proposal" to suit the industry practice.
2. It may be unfair to the Client if the calculation of amount of saving shortfall/ excess savings is based on the energy tariff as at the contract award date. It is because there are various types of energy tariff in Hong Kong. After retrofitting, the type of energy tariff may change accordingly, and this may put the Client in an unfavourable position. Besides, it is expected that the unit rate of electricity will be going up in Hong Kong, and the Client will incur more losses in the event of saving shortfall if the energy tariff is fixed at the contract award date.	Clause 9 and 10 are revised as "the amount shall be calculated based on the tariff structure applicable on the date of the latest M&V result".

Appendix F - EPC Model Validation Form

<u>EPC Model Validation Form</u>

I. Introduction

A model of Energy Performance Contracting (EPC) for Hong Kong has been developed based on extensive literature review, questionnaire survey findings, as well as semi-structured interviews with key stakeholders. To ensure that this proposed model is suitable for use in Hong Kong, the model will be validated in terms of five aspects, namely, 'Comprehensiveness', 'Practicality', 'Degree of adaptability for different types of building retrofits', 'Replicability', and 'Objectivity' by experienced personnel.

II. General Information

Your role: ______________________

Years of work experience (approx.): ______________________

III. Validation Criteria

Please rate the level of satisfaction with the model in the following items from 1 – 5, where "1" represents "Poor" and "5" represents "Excellent".

Validation Criteria	Poor ←		→ Excellent		
	1	2	3	4	5
1. Degree of Comprehensiveness	☐	☐	☐	☐	☐
2. Degree of Practicality	☐	☐	☐	☐	☐
3. Degree of Adaptability for different types of building retrofits	☐	☐	☐	☐	☐
4. Degree of Replicability	☐	☐	☐	☐	☐
5. Degree of Objectivity	☐	☐	☐	☐	☐

IV. Comments (optional)

____

____

Explanatory Notes of Validation Criteria:

1. Degree of Comprehensiveness: Whether the model includes all essential elements for implementing EPC projects and provides the users with necessary explanations.
2. Degree of Practicality: Whether the components (called "Building Blocks") of the model are realistic in nature and can be used in practice.
3. Degree of Adaptability for different types of building retrofits: Whether the model can provide users with guidance and is implementable in different types of building energy retrofits.
4. Degree of Replicability: Whether the model will provide similar outcomes when an identical project is implemented again.
5. Degree of Objectivity: Whether the model avoids biased or misleading elements in favour of a particular choice for project implementation.

Appendix G - Proposed Energy Performance Contract Template (Guarantee Energy Saving Model) for the Private Sector in Hong Kong SAR

Energy Performance Contract Template (Guarantee Energy Saving Model) for the Private Sector in Hong Kong SAR

Notes:

1. Please refer to the accompanying Guidance Notes, which do not form part of the Contract.
2. Options within the Contract conditions (as identified by * in the content list) should be selected and initialised by the Parties to indicate agreement.
3. No more than one option is allowed in each clause.
4. Please complete Schedule 1 to Schedule 8.
5. It is advisable that independent legal advice be sought by both parties before entering into contract.
6. The Hong Kong Polytechnic University and the research team providing this draft template for comments do not accept any liability arising from the use of this document.
7. Any comment and/or application for permission to use this template should be addressed in writing via e-mail: pan.lee@connect.polyu.hk. Acknowledgement will be sent regarding the application.
8. The research producing this draft template was fully supported by a grant from the General Research Fund of the Hong Kong SAR Government (Project No. PolyU5188/11E).
9.

Contents
(* indicates that options exist for the choice of the contracting parties;
 # indicates that data insertion is required)

Part A: Articles of Agreement

This Agreement is made on the ………………………………………………………………… day of………………………………………………………………………..………………………..

between

…………………….……………..………………………………………………………………….
of ……………………………………………………………………………………………….
…………………….……………..………………………………………………………………….

(hereinafter called "the Client") and

…………………….……………..………………………………………………………………….
of ……………………………………………………………………………………………….
…………………….……………..………………………………………………………………….

(hereinafter called "the Contractor")

Whereas the Client wishes to implement certain Energy Conservation Measures ("ECMs" and hereinafter called "the Works"), described in Schedule 1 (Project Proposal) for……………………(Hong Kong Dollars …………only) (hereinafter called "the Contract Price")
at
(address).………………………………………………………….……………………………………
…………………………………………………………………………….........

and has agreed with the contents of this document comprising:

Part A: Articles of Agreement
Part B: General Provisions

Schedule 1: Project Proposal
Schedule 2: Energy Savings Guarantee
Schedule 3: Energy Use Baseline
Schedule 4: Measurement & Verification Plan
Schedule 5: Savings Calculation and Baseline Adjustment
Schedule 6: Installation Schedule
Schedule 7: Payment Schedule
Schedule 8: Operation Procedures of ECM

Whereas the Contractor has expertise in the design, installation, implementation, operation and monitoring of ECMs and has been made aware of the purpose of the Works.

The Contract Documents shall comprise this document and all pre-award written correspondences between the Client (including any consultant(s) acting on his/her/its behalf) and the Contractor.

HENCE, in consideration of the mutual promises as set forth in this Contract, the parties agree as follows:

Authorised Signatures

IN WITHNESS WHEREOF, the parties have executed this Contract on the date as written above.

Signed for and on behalf of the Client

(Signature of authorised representative for the Client)	(Signatory of witness)
(Name and title of Client's representative)	(name and occupation of witness)

Signed for and on behalf of the Contractor

(Signature of authorised representative for the Contractor)	(Signatory of witness)
(Name and title of Contractor's representative)	(name and occupation of witness)

Part B: The General Conditions

1. Definitions

The following terms carry the meanings as stated below:

"Installation Schedule" means the Contractor's installation schedule for the Work that includes, without limitation, a schedule related to the entire Project and for each ECM, and that provides for expeditious and practicable execution of all aspects of the Work.

“Contract Price” is defined in Schedule 7 (Payment Schedule).

“Measurement and Verification” means those works and services carried out by the Contractor as stipulated in Schedule 4 (Measurement and Verification Plan).

“Energy Use Baseline” means the energy consumption related to the scope of the ECM in the existing facilities prior to the installation of ECM.

“Guaranteed Savings” means the Guaranteed Annual Savings or Guaranteed Total Savings as provided herein.

“Guarantee Period” is a period that the Contractor is liable to the contractual obligation under the clause of Guaranteed Savings.

“Performance Commencement Date” is defined in Clause 6.

“Energy Conservation Measure” or “ECM” means any measures which are intended for an improvement of building energy efficiency or conversion of energy sources. All related services are described in Schedule 1 (Project Proposal).

“Substantial Completion Date” means the date stated on the Certificate of Substantial Completion issued by the Client, after the Contractor gives the Client a written notice that the ECM are substantially completed, including the completion of satisfactory testing and commissioning.

“Certificate of Substantial Completion” means following satisfactory joint site inspection by the representatives of the Client and the Contractor, the Client shall issue a Certificate of Substantial Completion to the Contractor. After this process, the Contractor-installed ECM shall be handed over to the Client and shall remain the property of the Client.

“Day” means calendar day.

2. Responsibilities of the Contractor

2.1 Energy Use Baseline Establishment

Energy use baseline shall compose all existing conditions including climatic conditions; building and system operation patterns, level of occupancy, operating hours, and operating loads of equipment or systems. The energy use baseline for this Contract shall be documented in Schedule 3 (Energy Use Baseline) and established before the award of this Contract.

2.2 ECM Design and Installation

The Contractor shall be responsible for design, procurement of equipment and installation of the Works with due care, fitting the intended purpose of the premises as informed by the Client.

Within fourteen (14) days of the award of this Contract, the Contractor shall prepare and submit ECM installation plans (with face-to-face presentations as and when required) to the Client for review and approval before the beginning of ECM installation. The installation plans shall be agreed in writing by the Client as specified in Clause 3.1.

2.3 Notice of Completion

The Contractor shall proceed regularly and diligently with the Works in accordance with this Contract and notify the Client when the ECM is substantially completed through a written request for inspection. Both the Client and the Contractor representatives shall jointly inspect the ECM to determine jointly if the ECM is operating with satisfactory performance. The Client shall respond to the Contractor with the scheduled date and time for joint inspection within seven (7) days of receipt of inspection request. Upon satisfactory inspection, the Client shall issue a Certificate of Substantial Completion.

2.4 Regular Maintenance and Repair of ECM (for normal wear and tear)

☐ If the preceding box is ticked, the Client shall be responsible for regular maintenance and repair of the ECM installed after the Substantial Completion Date. The Contractor only provides the warranties of Contractor-installed ECMs and fulfils obligations under Clause 2.5.

☐ If the preceding box is ticked, the Contractor shall be responsible for maintenance and repair of the ECM installed during the contract period. The Contractor shall ensure the benefits of equipment warranties would pass to the Client in the event that the warranty period(s) exceed the contract period.

2.5 Operation and Maintenance Manuals and Staff Training

a. The Contractor shall provide operation and maintenance manuals for operation and maintenance of the ECM within fourteen (14) days after the Substantial Completion Date.

b. Within thirty (30) days after the Substantial Completion Date, the Contractor shall provide training to the Client's designated representatives as required to operate, and where relevant, to maintain, and repair the ECM equipment and systems.

2.6 Measurement and Verification

Unless previously agreed otherwise, all measurement and verification activities shall follow the methods and procedures laid down in Schedule 4 (Measurement & Verification Plan).

3. Responsibilities of the Client

3.1 Sample Reviews and Approvals

The Client shall review and respond to the Contractor whether the samples of submitted materials are approved or not in writing (to be provided free of charge) within fourteen (14) days of receipt of the materials. When the Client does not approve the submitted materials, the Client shall indicate the reasons of dissatisfaction for re-submission by the Contractor.

3.2 Equipment Space and Access

a. The Client shall provide the Contractor with mutually agreed space for the installation of the ECM.

b. The Client shall allow the Contractor unrestricted access to the premises for performing the Contractor's obligations under this Contract.

4. Ownership of Contractor-installed Equipment

a. The Contractor shall retain the ownership of all equipment installed as part of the ECM during the installation period. The Client shall use its best endeavours to protect all equipment installed by the Contractor before handover.

b. At the end of the installation period, the Client shall issue the Certificate of Substantial Completion to the Contractor to certify the date upon which the Contractor-installed ECM have been handed over to the Client and shall become the property of the Client.

c. Regular operation of the ECM by the Client independent of the Contractor after installation shall be deemed Substantial Completion.

5. Installation of ECM

a. Work Schedule – The installation work shall be carried out as set forth in Schedule 6 (Installation Schedule).The Contractor shall notify the Client of the schedule and proposed sequence of work not less than fourteen (14) days in advance. The Contractor shall use his best efforts to keep interferences to the existing use of the premises to a minimum when the Contractor designs work schedule and handle materials under this Contract.

b. Changed or Unusual Conditions – The Contractor shall promptly notify the Client in writing in the event of an unexpected condition happening at the work site.

c. ECM Documentation – Within thirty (30) days after the Substantial Completion Date, the Contractor shall submit as-fitted drawings and Operation & Maintenance manuals to the satisfaction of the Client or his designated representatives.

6. Performance Guarantee Commencement Date

The Performance Guarantee Commencement Date shall be one (1) day after the Substantial Completion Date. It is also the date on which the Contractor starts to provide the performance guarantee and maintenance services (subject to Clause 2.4). The performance guarantee commencement date is also regarded as the first day of the M&V period. The period of guarantee shall be as stated in Schedule 2 (Energy Savings Guarantee).

7. Measurement & Verification

a. All measurement and verification activities shall follow the methods and procedures laid down in the Schedule 4 (Measurement & Verification Plan).

b. The interval of M&V period shall be annual, during which the Client may request the Contractor to report on the on-going performance of the installed ECMs. Towards the end of each M&V period, the Client shall grant the Contractor access to the facility premises for the collection of any necessary readings which are used to prepare an annual M&V report and calculate savings. Identical copies of such readings shall be kept by both the Client and the Contractor.

c. The Contractor shall maintain and repair all necessary metering. In the event of failure of any necessary metering, the Client shall notify the Contractor of the said event within seven (7) days of the date on which the event becomes known to the Client.

d. Within fourteen (14) days after the date for each annual M&V activity, the Contractor shall calculate the energy savings realised at the premises in that M&V period and provide to the Client a M&V report setting out the saving results.

8. Saving Guarantee

☐ If the preceding box is ticked, the following clauses (8a to 8c) apply:

a. The Contractor guarantees that the Client will achieve energy savings at the premises in each guarantee year of not less than the Guaranteed Annual Savings.

b. The level of Guaranteed Annual Saving and Guarantee Period are as set forth in Schedule 2 (Energy Savings Guarantee).

c. Energy savings are determined in accordance with Schedule 5 (Savings Calculation and Baseline Adjustment), and such saving calculation shall take into consideration the adjusted baseline as necessary under Clause 12 for the premises.

☐ If the preceding box is ticked, the following clauses (8d to 8f) apply:

d. The Contractor guarantees that the Client will achieve energy savings at the premises at the end of the total guarantee period of not less than the Guarantee Total Savings.

e. The level of Guaranteed Total Saving and Guarantee Period are as set forth in Schedule 2 (Energy Savings Guarantee).

f. Energy savings are determined in accordance with Schedule 5 (Savings Calculation and Baseline Adjustment), and such saving calculation shall take into consideration the adjusted baseline as necessary under Clause 12 for the premises.

9. Saving Shortfall

In any of the following cases, the amount shall be calculated based on the tariff structure and rates applicable at the date of the latest M&V result:-

☐ If the preceding box is ticked, the Contractor shall pay or allow to the Client the amount of the shortfall when the Guaranteed Annual Savings are not achieved in any guarantee year (applicable to Clauses 8a to 8c). The Contractor shall investigate and attempt to remedy the shortfall situation by improvement to the ECMs at his own cost.

☐ If the preceding box is ticked, the Contractor shall pay or allow to the Client the amount of the shortfall when the Guaranteed Total Savings are not achieved at the end of the whole contract period (applicable to Clauses 8d to 8f).

10. Excess Savings

In any of the following cases, the amount shall be calculated based on the tariff structure and rates applicable at the date of the latest M&V result:-

☐ If the preceding box is ticked, no excess savings is accounted for in this Contract.

☐ If the preceding box is ticked, the Client shall pay the Contactor for (in words and numerals) %[19] (to be filled in before contract award) of the excess when the actual savings in energy consumption in any subsequent guarantee year exceed the Guaranteed Savings for that year (applicable to Clauses 8a to 8c).

☐ If the preceding box is ticked, the excess savings shall be used to offset the Contractor's liability for any accumulated shortfall when the actual savings in energy consumption in any subsequent guarantee year fall below the Guaranteed Savings for that year.Net surplus saving, if any, shall accrue to the Client and net shortfall in saving, if any, shall be dealt with in accordance with Clause 9 (applicable to Clauses 8a to 8c).

☐ If the preceding box is ticked, the Client shall pay the Contactor for (in words and numerals) %[1] (to be filled in before contract award) of the excess when the actual total savings in energy consumption at the end of the guarantee period exceed the Guaranteed Total Savings (applicable to Clauses 8d to 8f).

11. Operation of ECM

a. The energy conservation procedures and methods of ECM operation shall be implemented in accordance with Schedule 8 (Operation Procedures of ECM).

b. The Client shall grant access to the Contractor monthly to the premises to determine whether the Client is complying with the operation procedures in accordance with Schedule 8 (Operation Procedures of ECM). The Client shall retain the right to witness each inspection and the Contractor's recording.

c. If the Client does not strictly follow the operation procedures of ECM as set forth in Schedule 8 (Operation Procedures of ECM) and thereby lead to shortfall in energy saving in any M&V period, the Contractor shall forthwith notify the Client and estimate the impact on energy saving due to improper operation of ECM, and the Client shall compensate in the next payment due the ascertained loss, if any, to the Contractor once the impact on energy saving is mutually agreed.

[19] The percentage to be inserted may range from 1 to 100%.

12. Significant Changes and Baseline Adjustment

a. The Contractor shall incorporate a checklist in Schedule 5 (Savings Calculation and Baseline Adjustment) setting out the key elements of up-to-date building and system operation conditions. The checklist shall be completed by the Client and returned to the Contractor at (in words and numerals) intervals[20] (to be filled in before contract award), highlighting any significant change(s), if any. The completed checklists shall be used as reference documents to determine whether baseline adjustment would be necessary.

b. The degree of variations which trigger a baseline adjustment shall be clearly stated in Schedule 5 (Savings Calculation and Baseline Adjustment). When necessary, the baseline shall be adjusted under the conditions as set forth in Schedule 5 (Savings Calculation and Baseline Adjustment). In the event of a significant change not being listed in Schedule 5 (Savings Calculation and Baseline Adjustment) or the checklist, but expected to affect energy savings being achieved by the Contractor, the Baseline Adjustment shall be agreed between the Client and the Contractor.

13. Payments

Alternative 1:
☐ If the preceding box is ticked, the following clauses shall apply:-

a. The Client shall pay the Contractor the invoiced amount representing the Equipment and Installation Costs as set forth in Schedule 7 (Payment Schedule) after the Substantial Completion Date.

b. Payment of the priced maintenance fees, if applicable, to the Contractor shall be due at the end of each year after the Substantial Completion Date, subject to the contract conditions being complied with.

c. The Contractor shall conduct the Measurement and Verification as described in Schedule 4 (Measurement & Verification Plan). Based on the results of the M&V, the Contractor shall compute the annual savings based on Schedule 4 (Measurement & Verification Plan), and submit an annual M&V report to the Client each year. The report shall contain the amount of payment to be made or allowed, as the case may be related to saving shortfall and excess savings, if any.

d. Upon the delivery of the annual M&V report, the Client shall accept or reject the report with reasons in writing (in which case the Contractor shall resubmit).

[20] Suggested to be quarterly, or as otherwise stated.

e. Upon agreement of M & V results, the Client shall pay the amounts for excess savings to the Contractor (if applicable) or the Contractor shall pay or allow the amounts for saving shortfall to the Client (if applicable). All adjustments for saving shortfall or excess savings shall be subject to the Clause 9 and 10 and be incorporated in the next applicable payment period after agreement. For M & V results agreed at the end of the contract period, adjustments shall be made in the last payment.

Alternative 2:
☐ If the preceding box is ticked, the following clauses shall apply:-

f. The Client shall pay the Contractor the invoiced amount as stated in Schedule 7 (Payment Schedule), subject to the contract conditions being complied with.

g. The Contractor shall conduct the Measurement and Verification as described in Schedule 4 (Measurement & Verification Plan). Based on the results of the M&V, the Contractor shall compute the annual energy savings based on Schedule 4 (Measurement & Verification Plan), and submit an annual M&V report to the Client each year and also on an accumulated basis. The report shall contain the amount of payment to be made or allowed, as the case may be, related to saving shortfall and excess savings, if any.

h. Upon the delivery of the annual M&V report, the Client shall accept or reject the report with reasons in writing (in which case the Contractor shall resubmit).

i. Upon agreement of M & V results, the Client shall pay the amounts for excess savings to the Contractor (if applicable) or the Contractor shall pay or allow the amounts for saving shortfall to the Client (if applicable). All adjustments for saving shortfall or excess savings shall be subject to the Clause 9 and 10 and be incorporated in the next applicable payment period after agreement. For M & V results agreed at the end of the contract period, adjustments shall be made in the last payment.

Whenever an amount is payable by one party to another (except in the case of termination), it shall be made within the Honouring Period as stated in Schedule 7 (Payment Schedule).

14. Performance bonds

☐ If the preceding box is ticked, no performance bond or security deposit is needed.

☐ If the preceding box is ticked, the Contractor shall provide a performance bond within twenty-one (21) days of the contract award in the sum of HK$ (in words and numerals)[21] (to be filled in before contract award) from an approved insurer or bank. The bond shall be released and returned to the Contractor upon Substantial Completion.

☐ If the preceding box is ticked, the Contractor shall deposit a sum of HK$ (in words and numerals)[17] (to be filled in before contract award) with the Client, which shall be refunded to the Contractor upon Substantial Completion without interest.

15. Force Majeure

a. If either party is unable to perform its obligation under this Contract due to unforeseeable causes outside the reasonable control of and in the absence of fault or negligence of the parties, including fire, flood and acts of God (hereinafter called a "force majeure event"), then the non-performing party shall promptly notify the other in writing of reasonable particulars of the force majeure event.

b. The non-performing party shall not suspend performance of its obligations longer than the duration of the force majeure event.

c. The non-performing party shall take all practicable measures to overcome the force majeure event as soon as possible.

d. When the party affected by the force majeure event is able to resume performance of its obligations under this Contract, that party shall give the other a written notice within fourteen (14) days of resumption of performance.

16. Time for Completion

The Contractor shall complete the Works within the Time for Completion stated in Schedule 6 (Installation Schedule). Time for completion of work is of the essence in this Contract.

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[21] If this option is selected, 5% of the Contract Price or as otherwise stated.

17. Liquidated Damages

In the event of late completion of installation beyond the time for completion or extended time of completion, the Contractor shall pay or allow to the Client liquidated damages as stated in Schedule 6 (Installation Schedule). The payment of liquidated damages shall not lessen the Contractor's responsibilities to complete the Works under this Contract.

18. Extension of time

The time within which the Works is to be completed may be extended by the Client before or after the Time for Completion by such further period or periods of time as may reasonably reflect justifiable and unavoidable delay in completion of the Works which will or might be or has been caused by any of the following events:

i. A significant increase in the work to be carried out, thereby causing actual delay, provided that variance was not apparent from the Contract Drawings;

ii. The postponement of possession of the entire work area;

iii. The Client's failure to provide or provide on time goods, materials, plant or equipment that he undertakes to provide for the Works;

iv. An act of prevention, a breach of this contract or other default by the Client or persons for whom he is responsible.

19. Safety and Avoidance of Nuisance

a. The Contractor shall throughout the installation and maintenance periods have full regard for the safety and regular activities (unless otherwise agreed) of all persons permitted to enter the site.

b. The Contractor shall keep the site and all works orderly so as to avoid any danger or nuisance to such persons.

20. Damage to or Failure of Equipment (not arising from normal wear and tear)

a. During the contract period, the Contractor shall be responsible for repairing or replacing all equipment installed by the Contractor if such is damaged or destroyed. In an event of damage or loss resulting from negligence or improper operation by the Client's personnel, the Client shall repair such equipment or reimburse the Contractor for such repairs.

b. The Contractor shall effect insurance (in joint name with the Client as an insured party) against loss or damage to the ECM equipment. The Contractor is responsible for repair or replacement to avoid delay in completion, subject to the provision of Clause 20.

21. Indemnity and Insurances

a. Each party shall indemnify the other from losses associated with the works and third parties (including personal injuries and property loss) arising from negligence or misconduct of personnel or subcontractors for whom they are responsible.

b. The Contractor shall effect his own Employee's Compensation insurance and Contractor's All Risk Insurance (in joint names with the Client and sub-contractors as insured parties). The Client shall have no liability in respect of any damages or compensation under the Employees' Compensation Ordinance or in consequence of any accident or injury to any workman or other person in the employment of the Contractor, and the Contractor shall indemnify the Client against any related claim, damage, liability and loss.

c. For the avoidance of doubt, the Client shall be responsible for insurance of the parts of the premises which are not handed over to the Contractor during the installation period. The Client is deemed to have informed his insurer on the works to be carried out.

22. Choice of Law

The laws of the Hong Kong SAR shall be the only applicable laws for the interpretation and enforcement of this Contract and any litigation arising from this Contract shall be brought and resolved by its courts in Hong Kong.

23. Assignment

a. No party is allowed to assign its rights and obligations under this Contract to any person or corporation unless a prior written consent of the other party is given.

b. Either party shall not unreasonably withhold the consent from the other if:

i. The Contractor intends to assign its rights and obligations to a wholly owned subsidiary of the Contractor or of the Contractor's parent company, or intends to assign its rights to receive payment hereunder to a lender of the Contractor's choice; or

ii. The Client intends to assign its rights and obligations to a transferee that enters into an agreement with the Contractor in substantially identical terms to this Contract and the Contractor is satisfied that such transferee is of at least equal financial standing as the Client.

24. Notices

All notices to be given by either party to the other under this Contract shall be in writing and shall be either delivered personally or by courier service, return receipt requested, addressed to be registered addresses of the Client or Contractor as the case may be.

25. Termination for Default

a. Either party may terminate the employment of the Contractor under this Contract immediately by a written notice to the other party ("the defaulting party") before expiry of this Contract if:

i. (1) The defaulting party fails to make any payment of balance due after the Honouring Period; and

(2) The non-defaulting party gives a notice in writing to the other requiring the defaulting party to pay the overdue amount; and

(3) The defaulting party fails to pay the overdue amount within fourteen (14) days of receipt of the notice without invoking the dispute resolution procedure as laid down in this contract, or

ii. Either party becomes bankrupt; makes a composition or arrangement with his creditors; undergoes voluntary or compulsory winding up (except due to reconstruction); or has a provisional liquidator or receiver appointed.

b. The Client may give a written notice of default to the Contractor if the Contractor wholly suspends the Works without justifiable reasons. The Client may terminate the employment of the Contractor under this Contract if the Contractor does not respond by resuming the Works within fourteen (14) days after the Client's notice.

c. Upon termination of this Contract:

i. Both parties' further obligations under this Contract shall cease;

ii. If the termination is on a date before the Substantial Completion Date, the non-defaulting party shall appoint an independent claim adjuster to ascertain the value of installation completed and materials delivered to-date. The Client shall pay the Contractor the ascertained value after due adjustment of the cost of employing the claim adjuster (such cost to be responsible by the defaulting party) within fourteen (14) days of the date of ascertainment.

iii. If the termination is on a date after the Substantial Completion Date, the non-defaulting party shall have the right to invoice the other for the Termination Value as laid down below, together with any net amount related to saving shortfall or excess savings (if applicable), which shall be payable within fourteen (14) days of the notice of termination.

(Termination Value = Contract Price – Previous Payment made to the Contractor before the termination date – unused maintenance costs on a pro-rata basis)

26. Disputes

a. Reference to mediation: In the event of a dispute arising between the Client and the Contractor (whether before or after any alleged termination of the contract), either party may give a notice to the other party by recorded mail to refer the dispute to a mediator to be agreed between the parties. Should the agreement on mediator cannot be reached within twenty-one (21) days of the notice, either party may request the Hong Kong International Arbitration Centre (HKIAC) to appoint a suitable mediator. The mediation shall be conducted in Hong Kong in accordance with the Hong Kong International Arbitration Centre Mediation Rules then in force.

b. Reference to arbitration: If the dispute is not settled by mediation within thirty (30) days after the mediation commences, either party may give a notice by recorded mail to the other to refer the dispute to an arbitrator to be appointed by the Hong Kong International Arbitration Centre. The arbitration shall be carried out in accordance with the Arbitration Ordinance (Chapter 341, Laws of Hong Kong SAR) under a domestic setting. The hearing of all matters referred to arbitration shall not commence until after Substantial Completion (actual or alleged) or determination (actual or alleged) of the Contractor's employment, unless the matter in dispute relates to non-payment of amount due under this contract, or when both parties agree in writing to have an earlier hearing.

c. Notwithstanding a dispute notice being served by either party, the Contractor shall continue to carry out the Works diligently unless and until the mediation agreement or arbitration award provides otherwise. Such continuation shall not prejudice the Contractor's other rights and remedies under the Contract.

Schedule 1: Project Proposal

(This schedule should describe project background and each ECM implemented by the Contractor to achieve targeted energy savings in the Client's premises.)

(The proposed design specification of major equipment, including equipment brand, size, rating, numbers, etc., should be listed in this schedule. Sufficiently detail drawings showing the ECM system design, scope of work and builder's work requirements for the proposed ECM(s) should also be attached. Works excluded in this contract and to be carried out by others must be stated clearly.)

Schedule 2: Saving Guarantee

Alternative 1: (applicable to Clauses 8a to 8c)

The Contractor guarantees that the Client will realize energy savings at the premises in each guarantee year of not less than the Guaranteed Annual Savings. The actual energy savings shall be calculated in accordance with Schedule 5 (Savings Calculation and Baseline Adjustment), and such saving calculation shall take into consideration the adjusted baseline as necessary under Clause 12 for the premises.

The Guarantee Period is as follows:

Guarantee Period	________years

The Guaranteed Annual Savings are as follows:

Period	Guaranteed Annual Savings (kWh)
Year 1	
Year 2	
Year 3	
Year 4	
etc.	
[final year]	
Total	

Alternative 2: (applicable to Clauses 8d and 8f)

The Contractor guarantees that the Client will realize energy savings at the premises at the end of the total guarantee period of not less than the Guarantee Total Savings.The actual energy savings shall be calculated in accordance with Schedule 5 (Savings Calculation and Baseline Adjustment), and such saving calculation shall take into consideration the adjusted baseline as necessary under Clause 12 for the premises.

The Guarantee Period is as follows:

Guarantee Period	________years

The Guarantee Total Savings are as follows:

Period	Guarantee Total Savings (kWh)
The Entire Guarantee Period	

Schedule 3: Energy Use Baseline

(This Schedule should contain the procedures and methods to develop the energy use baseline by the Contractor. All supporting documents for baseline development, including the previous metering records, should also be attached in this Schedule.)

Schedule 5: Savings Calculation and Baseline Adjustment

(This schedule should describe the basis for calculation of energy savings to be achieved by the Contractor. The calculation method should take into account any adjustment to the baseline condition. Besides, the savings should be calculated in terms of kWh, instead of HK$.)

(The mechanism for baseline adjustment should be clearly described. Both contracting parties should determine which factor and the degree of variations in those factor(s) to trigger baseline adjustment. The factors which are justifiable to account for baseline adjustment may include weather conditions, operation hours, occupancy level, etc.)

(A checklist setting out the key elements of up-to-date building and system operation conditions should be included in this Schedule. The completed checklist shall be returned by the Client to the Contractor at an interval as stipulated in this Contract. Any significant change shall be recorded by the Client.)

Schedule 6: Installation Schedule

(This Schedule should contain the timetables and milestones for installation system, startup, commissioning and handover.)

(If there are planned interruptions in any utility services for the Client's premises for carrying out the Works, the details of such interruption, including the length of the interruption, its time, locations, etc. should be clearly described in this Schedule.)

State the Liquidated Damages for late completion of installation: HK$ (*in words and numerals*) per day.
(to be agreed by the contracting parties and inserted before contract award)

(Note: this amount should be a genuine pre-estimate of the possible loss which may be incurred by the Client due to a delay for which the Contractor is responsible.)

Schedule 7: Payment Schedule

The payment shall be adjusted to incorporate all saving shortfall and excess savings (if applicable

Alternative 1: (an option applicable to Clauses 13a – 13e)
Terms of payment are agreed and fixed as below:

Equipment and Installation Costs upon Substantial Completion	HK$
Annual Maintenance Costs (if applicable)	HK$
Total Maintenance Costs (if applicable)	HK$________ x ____ years = HK$
Contract Price	HK$

Alternative 2: (an option applicable to Clauses 13f – 13i)
Terms of payment are agreed and fixed as below:

Before completion of installation (1st payment at _____% of Works completed	HK$
Before completion of installation (2nd payment at _____% of Works completed	HK$
……	
……	
End of one (1)month after Substantial Completion	HK$
End of six (6) months after Substantial Completion	HK$
End of twelve (12) months after Substantial Completion	HK$
End of eighteen (18) months after Substantial Completion	HK$
……	
……	
Annual Maintenance Costs (if applicable)	HK$
Total Maintenance Costs (if applicable)	HK$________ x ____ years = HK$
Contract Price	HK$

Honouring Period of Payment(s):

Payment (s) stated as payable by either party shall be made within (in words and numerals) (to be filled in before contract award) days of the date of invoice issued by the party demanding payment.

(Note: The above schedules assume that energy audit fees, if applicable, are subsumed in the amounts entered or are paid for separately.)

Schedule 8: Operation Procedures of ECM

(This schedule should contain the proper operation procedures of the ECM as required by the Contractor to ensure that the ECM operates at the optimal efficiency.)

Appendix H – Proposed Guidance Notes for the Energy Performance Contract Template – (Guaranteed Energy Saving Model)

Guidance Notes for the Energy Performance Contract Template –

(Guaranteed Energy Saving Model)

Background

With the support of the Research Grants Council, HKSAR, a research team from the Hong Kong Polytechnic University is conducting a research project entitled "An Investigation into Energy Performance Contracting (EPC) for enhancing its role in energy conservation in Hong Kong". In order to promote the wider use of EPC in Hong Kong, an Energy Performance Contract Template is developed for reference by private building owners in implementing energy efficiency retrofit projects in their existing buildings after seeking independent legal advice.

The Concept of EPC

Energy Performance Contracting (EPC) is a contracting model between building owners (the Client) and energy service companies (the Contractor), whereby the Contractor provides an all-in-one package, including identification of energy saving potential, design, installation, ongoing performance monitoring of energy conservation measures (ECMs), as well as staff training for better system operation. To ensure that the expected energy savings can be actually realised, the Contractor usually guarantees the Client for an agreed level of energy savings. In case of a shortfall in savings, the Contractor will compensate the losses incurred by the building owner under the contract agreement.

Main advantages of EPC arrangement

The main advantages of EPC arrangement are as follows:

- The Contractor pays upfront costs for project implementation (if needed).
- The Contractor provides an ongoing performance monitoring of energy conservation measures (ECMs).
- The Contractor provides maintenance and staff training to ensure that the installed ECMs are operating at optimal efficiency.
- The Contractor guarantees the energy performance of installed ECMs during the contract period.
- The payment to the Contractor is aligned to the actual energy savings being achieved by the Contractor during the post-retrofit period, and no interim payment will be made by the building owner for the work done by the Contractor during the installation stage (if the Contractor pays the upfront costs).

Targeted Users of this template

This template is targeted towards building owners (including Incorporated Owners) who may lack upfront capitals and technological know-how, but there is a need to undertake the retrofit projects, e.g., towards the end of equipment lifespan and operation at low energy efficiency of system performance, in their existing buildings in Hong Kong.

As it is assumed that the building owners have no strong in-house engineering team and legal representatives, this template is simple to the extent covering the essential elements in EPC projects, and enables a lay person to understand the contractual obligations when both contracting parties agree to implement EPC projects.

It is also assumed that a separate energy audit is carried out prior to the use of this contract template to establish the baseline of existing energy consumption.

Users of this template are recommended to make this template part of the invitation documentation sent to potential Contractors. Contractors should incorporate these conditions in their offers upon which acceptance is based.

The Client may engage independent consultants (technical and legal) for advice on design, installation and the use/modification of this contract template. Adoption of the contract template is entirely voluntary upon the agreement of the contracting parties. The provision of the contract template and these guidance notes are for reference ONLY and should not be construed as a consultancy or legal service.

Options to be Agreed

Both parties have to agree on the choice of several options in the EPC template as follows:

- Two options are given to both contracting parties on payment arrangement of upfront costs (Option 1: “Equipment and Installation Costs” is paid by the Client after an issue of Certificate of Substantial Completion.; Option 2: payment according to an agreed schedule to the Contractor during the post-installation period.)
- Two options are given that the Contractor guarantees the Client for a certain level of energy savings either in terms of “Guaranteed Annual Savings” or “Guaranteed Total Savings”
- Two options are given for the treatment of savings shortfalls
- Four options are given for the treatment of excess savings
- Two options are given for the treatment of maintenance responsibility (for normal wear and tear of ECM)
- Two options are given for the arrangement of termination without default
- Three options are given for the arrangement of performance bond or security deposit

Important Events During the Entire EPC Project

Pre-Installation Period	• Establishment of Energy Use Baseline • Determination of Installation Schedule • Determination of Measurement & Verification Plan • Determination of Baseline Adjustment Mechanism • Development of a Checklist for updating the Conditions of Building and System Operation
Installation Period	• Handover of work area to Contractor • ECM Design (included in the overall contract period) by Contractor • ECM Installation by Contract • Joint Inspection upon completion • Issue of Certificate of Substantial Completion by Client
Post-Installation Period	• Commencement of Performance Guarantee • Provision of Operation and Maintenance Manuals by Contractor • Training for Client's staff on ECM operation by Contractor • Annual Measurement and Verification (M&V) by Contractor • Regular maintenance and repair of ECM by Contractor • Contractor's inspection for Client's operation compliance • Regular (e.g. quarterly) completion of Checklist for Updated Conditions of Building and System Operation by Client for possible Baseline Adjustment • Annual Report on the Actual Energy Savings by Contractor

Responsibilities of the Client and Contractor

	Client	Contractor
Pre-Installation Period	• Grant the Contractor access to the facility premises	• Establish energy use baseline • Establish a measurement & verification plan • Determine a baseline adjustment mechanism • Develop a checklist for updating conditions of building and system operation
Installation Period	• Review and approve the Contractor's design work • Grant the Contractor access to the facility premises • Issue a Certificate of Substantial Completion upon satisfactory completion of installation	• Design ECMs • Present the ECM proposals and seek approval to go ahead • Install ECMs • Demonstrate to the Client that the installation is completed to his satisfaction • Submit the as-fitted drawings for approval
Post-Retrofit Period	• Grant the Contractor access to the facility premises for inspection of compliance of ECM operation • Complete and submit a checklist of updated building and system operation to the Contractor regularly as agreed • Notify the Contractor in an event of failure of any necessary metering • Pay the Contractor the amount as agreed in Schedule 7	• Submit operation and maintenance manuals • Train Client's staff on operation of the installed equipment • Inspect the Client's premises for operation compliance • Request the Client for the submission of Checklist on updated building and system operation and check for irregularities. • Carry out the M&V work • Report on the actual energy savings to the Client • Maintain and repair the installed equipment

Summary of the Main Clauses in EPC template

Since there are substantial differences between EPC contracts and construction contracts, the summary provides a concise overview of the essential clauses in EPC projects and describes the treatment of risk allocation inherent in EPC projects.

Ownership of Contractor-installed Equipment (Clause 4)

Purpose	In EPC projects, an issue regarding ownership of equipment often arises due to the possible scenario of upfront costs being paid by the Contractor for project implementation. This clause mainly sets forth the time for transfer of ownership from the Contractor to the Client.
Description	**The treatment of ownership of equipment (regardless of who pays the upfront costs)** The general principle is as follows: • During the installation period, all equipment installed by the Contractor remains the property of the Contractor. • At the end of the installation period, the Client retains the ownership of equipment once the Certificate of Substantial Completion is issued to the Contractor.

Performance Guarantee Commencement Date (Clause 6)

Purpose	A clear definition of the Performance Guarantee Commencement Date is vital in EPC projects as it implies that the Contractor starts to provide the performance guarantee and maintenance services.
Description	**The Performance Guarantee Commencement Date** The Performance Guarantee Commencement Date is defined as one (1) day after Substantial Completion, and this date is also regarded as the first day of the M&V period.

Measurement &Verification and Baseline Adjustment (Clause 7 and 12)

Purpose	This clause stipulates the methodologies and procedures for conducting regular M&V work.
Description	**M&V method and procedures** The M&V method and procedures should be laid down in Schedule 5 (Savings Calculation and Baseline Adjustment). When determining such procedures, both parties can refer to well-established guidelines, such as the *International Performance Measurement & Verification Protocol Concepts and Options for Determining Energy and Water Savings Volume I* (a Chinese version is also available at http://www.evo-world.org/index.php?lang=en) **The interval of M&V period** The interval of M&V period should be annual regardless of any payment arrangement. **Completion of Checklist for Updated Building and System Operation** The Client should complete and return the checklist, which sets out the key elements of up-to-date building and system operation, to the Contractor on an agreed regular basis. **Maintenance of all necessary metering** The Contractor is responsible for maintenance and repair of all necessary metering. The Client should notify the Contractor in the event of damage or failure of any necessary metering. **Calculation of energy savings:** The Contractor should calculate the energy savings realized by the ECM in each annual M&V period and provide to the Client an M&V report setting out the saving results. **Baseline adjustment:** Both parties should adjust the baseline under the conditions as set forth in Schedule 5. The degree of baseline adjustment should also be clearly stated in Schedule 5.

Saving Guarantee (Clause 8)

Purpose	This clause describes the Contractor's obligations as to the performance of installed ECMs during the post-retrofit period.
Description	There are two alternatives for the Contractor to provide a guarantee on energy savings during the post-installation period: 1. The Contractor guarantees energy savings in each guarantee year of not less than the Guaranteed Annual Savings. 2. The Contractor guarantees energy savings at the end of the total guarantee period of not less than the Guaranteed Total Saving. Please note that the calculation of actual energy saving should take into consideration the adjusted baseline, if any.

Saving Shortfalls (Clause 9)

Purpose	This clause stipulates the Contractor's liability when the actual saving is less than the level of guaranteed savings.
Description	There are two alternatives for the treatment of saving shortfalls: 1. The Contractor should pay or allow to the Client the amount of the shortfall when the Guaranteed Annual Savings are not achieved in any guarantee year (applicable to Clauses 8a to 8c). 2. The Contractor should pay or allow to the Client the amount of the shortfall when the Guaranteed Total Savings are not achieved at the end of the whole contract period (applicable to Clauses 8d to 8f). The calculation of amounts should be based on the energy tariff as at the date of latest M&V result Please note that the selection of saving shortfall options should be consistent with the "Saving Guarantee" Clause.

Excess Savings (Clause 10)

Purpose	The purpose of this clause is to cater for the situation in which the Contractor achieves energy savings more than the guaranteed level.
Description	There are four alternatives for the treatment of excess savings: 1. No excess savings is accounted for in payment. 2. The Client should pay the Contactor for the agreed percentage of the excess when the actual savings in energy consumption in any subsequent guarantee year exceed the Guaranteed Savings for that year (applicable to Clauses 8a to 8c). 3. The excess savings should be used to offset the Contractor's liability for any accumulated shortfall when the actual savings in energy consumption in any subsequent guarantee year fall below the Guaranteed Savings for that year. Net surplus saving, if any, should accrue to the Client and net shortfall in saving, if any, should be dealt with in accordance with Clause 9 (applicable to Clauses 8a to 8c). 4. The Client should pay the Contactor for the agreed percentage of the excess when the actual total savings in energy consumption at the end of the guarantee period exceed the Guaranteed Total Savings (applicable to Clauses 8d to 8f). Similarly, the selection of excess saving options should be consistent with the "Saving Guarantee" Clause. The calculation of amounts should be based on the energy tariff as at the date of latest M&V result.

Operation of ECM (Clause 11)

Purpose	Since the operation method of ECMs significantly affects the actual energy savings, this clause sets out the related procedures for system operation to ensure the installed ECMs are operating at optimal efficiency.
Description	**<u>General Principle</u>** The Client should operate the installed ECMs in accordance with Schedule 8 (Operation Procedures of ECM). **<u>Regular checking of operation compliance</u>** The Client should grant the Contractor access to the premises to determine whether the Client is complying with the operation procedures in accordance with Schedule 8 (Operation Procedures of ECM). The Client should have the right to witness each inspection and the Contractor's recording. **<u>Consequences when the Client does not strictly follow the required operation procedures</u>** The Contractor should estimate the impact on energy saving due to improper operation of ECM. The Client should compensate the ascertained loss, if any, to the Contractor once the impact on energy saving is mutually agreed.

Payments (Clause 13)

Purpose	Since the Contractor pays the upfront capital at the beginning, the payment arrangements can be significantly different from the conventional installation project. This clause is to allow for a choice of an agreed payment arrangement during the contract period.
Description	There are two alternatives to determine the payment method in this template. The features of alternative 1 are as follows: • The Contractor pays the upfront capitals. • The Clients pays the Equipment and Installation Costs to the Contractor after a Certificate of Substantial Completion is issued. • The Clients only pays the annual maintenance costs during the post-installation period. The features of alternative 2 are as follows: • The Contractor pays the upfront capitals. • Payment to the Contractor by the Client will be made in accordance with Schedule 7. • Payment is made with the fixed amount in each payment term according to a pre-agreed schedule. • All agreed adjustment for saving shortfall or excess savings should be subject to Clause 9 and 10 and be incorporated in the next applicable payment period after agreement.

Performance Bond (Clause 14)

Purpose	The requirement on Performance Bond is to ensure that the Contractor would complete the installation of ECM works on or before the scheduled date
Description	There are three alternatives for the arrangement of performance bond 1. No performance bond or deposit is needed (Please note that the Client faces the risk of no protection in an event of termination.). 2. The Contractor should provide a performance bond in the agreed sum from an approved insurer or bank. The bond should be released and returned to the Contractor upon Substantial Completion. 3. The Contractor should deposit an agreed sum with the Client, which should be returned to the Contractor upon Substantial Completion without interest. Please note that when the EPC contract involves two or more ECMs to be implemented, but each with significant differences in its completion dates (e.g. lighting retrofit plus chiller replacement), it is advisable that separate contracts are used for each ECM to avoid the argument on Performance Guarantee Commencement Date of individual ECM.

Extension of time (Clause 18)

Purpose	The clause allows the Contractor to extend the installation period due to specific events.
Description	The delay caused by the following events will lead to an extension of time: • A significant increase in the work to be carried out, thereby causing actual delay, provided that variance is not apparent from the Contract Drawings; • The postponement of the Date for Possession of the entire work area; • The failure of the Client to supply or supply on time materials, goods, plant or equipment that he agrees to provide for the Works; • An act of prevention, a breach of contract or other default by the Client or any person for whom the Client is responsible.

Damage to or Failure of Equipment (Clause 20)

Purpose	This clause describes the situation when damage(s) occurs to the ECMs (not arising from normal wear and tear)
Description	<u>**General Principle**</u> • The Contractor should effect insurance against loss or damage to the ECM equipment. The Contractor is responsible for repair or replacement to avoid delay in completion, subject to the provision of Clause 20. • The Contractor should be responsible for repairs during the contract period, when Contractor-installed equipment is damaged or destroyed, unless the damage is caused by the Client.

Assignment (Clause 23)

Purpose	This clause describes the conditions for both contracting parties to exercise the assignment clause.
Description	Neither party may assign, sell or transfer its interest under this Contract without the other party's prior written consent, such consent not to be unreasonably withheld if: c. The Contractor wishes to assign its rights and obligations to a wholly owned subsidiary of the Contractor or of the Contractor's parent company, or wishes to assign its rights to receive payment hereunder to a lender of the Contractor's choosing; or d. The Client wishes to assign its rights and obligations to a transferee that enters into an agreement with the Contractor in substantially identical terms to this Agreement and the Contractor determines that such transferee is of at least equal financial standing as the Client.

Termination for Default (Clause 25)

Purpose	This clause describes the conditions which lead to a termination of the Contract
Description	The following events will lead to a termination of the Contractor's employment: • Non-payment of either party • Insolvency of either party • Suspension of the Works without justifiable reasons by the Contractor Settlement upon the termination: • Both parties' further obligations under this Contract shall cease If the termination is on a date before the Substantial Completion Date, • The non-defaulting party should appoint an independent claim adjuster to ascertain the value of installation completed and materials delivered to-date. • The Client should pay the Contractor the ascertained value after due adjustment of the cost of employing the claim adjuster (such cost to be responsible by the defaulting party) If the termination is on a date after the Substantial Completion Date, • The non-defaulting party should be entitled to invoice the other for the Termination Value as laid down below, together with any net amount related to saving shortfall or excess savings (if applicable) *(Termination Value = Contract Price – Previous Payment made to Contractor before the termination date – unused maintenance costs on a pro-rata basis)*

Disputes (Clause 26)

Purpose	Similar to all construction projects, disputes may happen in EPC projects, especially in respect of the determination of actual energy savings being achieved by the Contractor. This clause provides a way-out when disputes occur between both contracting parties.
Description	There are two approaches to deal with disputes, if any, between the Client and Contractor • Reference to mediation • Reference to arbitration

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