A MODEL FOR SUSTAINABLE BUILDING ENERGY EFFICIENCY RETROFIT (BEER) USING ENERGY PERFORMANCE CONTRACTING (EPC) MECHANISM FOR HOTEL BUILDINGS IN CHINA

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CERTIFICATE OF ORIGINALITY

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________________________________ (Signed)

Xu Pengpeng (Name of Student)

DEDICATION

To my beloved family

To Wu Qing

ABSTRACT

Among the building stocks in any country, there are more existing buildings than the new ones that are energy inefficient. Hotel building is one of the high-energy-consuming building types, and retrofitting hotel buildings is an untapped solution to help cut carbon emissions contributing towards sustainable development. Building Energy Efficiency Retrofit (BEER) not only provides excellent opportunities to reduce overall energy consumption of all buildings in a city but also improves environment protection, rational resources use, and occupants' health. Sustainable development (SD) strategy has embraced many aspects of human activities and sustainable BEER is integrating sustainable development concept into existing buildings and retrofit projects. For BEER projects to fulfill the sustainable development strategy, various delivery models should be considered. Energy Performance Contracting (EPC) has been promulgated as a market mechanism for the delivery of energy efficiency projects, and yet there is a lack of effective performance indicators to measure the sustainability of BEER projects. EPC mechanism has been introduced into China relatively recently, and it has not been implemented successfully in building energy efficiency retrofit projects.

The aim of this research is to develop a model for achieving the sustainability of Building Energy Efficiency Retrofit (BEER) in hotel buildings under the Energy Performance Contracting (EPC) mechanism. The objectives include:

(1) To critical review BEER and EPC from the perspective of sustainable development;

(2) To develop a conceptual framework for sustainable BEER projects under the EPC mechanism;
(3) To identify a set of Key Performance Indicators (KPIs) for measuring the sustainability of BEER in hotel buildings;
(4) To identify Critical Success Factors (CSFs) under EPC mechanism that have a strong correlation with identified KPIs and sustainable BEER project ;
(5) To develop a model explaining the relationships between the Critical Success Factors (CSFs) and the sustainability performance of BEER in hotel building.

Literature reviews revealed the essence of sustainable BEER and EPC, which help to develop a conceptual framework for analyzing sustainable BEER under EPC mechanism in hotel buildings. 11 potential KPIs for sustainable BEER and 28 success factors of EPC were selected based on the framework developed through literature review and in-depth interview.

A questionnaire survey was conducted to ascertain the importance of selected performance indicators and success factors. Fuzzy set theory was adopted in identifying the KPIs. The 6 identified KPIs are: (1) Quality performance, (2) Hotel energy management, (3) Cost benefit performance, (4) Energy consumption & resources saving, (5) Health and safety, and (6) Stakeholders' satisfaction. Through a questionnaire survey, out of the 28 success factors, 21 Critical Success Factors (CSFs) were also indentified. Using the factor analysis technique, the 21 identified CSFs in this study were grouped into six clusters to help explain project success of sustainable BEER. They are: Project organization process; EPC project financing for hotel retrofit; Implementation of SD strategy; Knowledge and innovation of EPC, SD, and M&V (Measurement and Verification); Contractual arrangement; and External economic environment. The results indicate that the EPC professional team, client, ESCOs (energy service companies), and other related departments, who are directly or indirectly involved in this work, should make joint efforts to deliver sustainable BEER projects successfully.

Finally, AHP/ANP approach was used in this research to develop a model to examine the interrelationships among the identified CSFs, KPIs, and sustainable dimensions of BEER. The findings indicate that the success of sustainable BEER in hotel buildings under the EPC mechanism is mainly decided by project objectives control mechanism, available technology, organizing capacity of team leader, trust among partners, accurate M&V, and team workers' technical skills.

This study has the significant value of contributing to the body of knowledge on theory and project practice in sustainable BEER and Energy Performance Contracting. The ANP model developed in this study itself is the first attempt to investigate the success factors of EPC mechanism affecting the sustainability performance of hotel retrofits for building energy efficiency. Findings in this study provide valuable reference for practitioners to conduct BEER projects using EPC mechanism successfully. Furthermore, based on the results of this study, governments and industry associates could propose relevant policies to implement EPC successfully for sustainable BEER of hotel buildings.

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CHAPTER 1 Introduction

1.1 Research Background

Today China is experiencing rapid development, with increasing levels of modernization and standard of living as well as increasing energy consumption. China has become the second largest energy consumer and carbon dioxide emitter (Wang et al, 2008). Buildings represent an important and increasing component of China's total energy consumption. For the past 20 years, Building Energy Consumption (BEC) in China has been increasing at more than 10% each year. In 2004, BEC alone constituted 20.7% of national energy consumption (Jiang and Yang, 2006; Liang et al, 2007; Chan et al, 2009). According to statistics from the International Energy Agency (IEA), existing buildings take up over 40% of the world's total final energy consumption and account for 24% of world CO_2 emissions (IEA, 2006). Much of this consumption could be avoided through improving the efficiency of building energy systems using current commercially viable technology. Energy efficiency projects, such as upgrading to newer, better-performing equipment and building renovations, are a very effective way to save on energy bills over the long term. Currently, there are nearly 40 billion m^2 buildings in China and the area of urban buildings is up to 14 billion m^2. More than 95% of existing buildings in China are "highly-energy-consuming" (Lin et al., 2005; Long, 2005). The potential energy savings from energy efficiency retrofits of existing building is very large. Both the central and local Chinese governments have proposed the "Energy Conservation and Emission Reduction" program in the building industry. For example, the Beijing government proposed to carry out energy efficient retrofitting on 25% of all existing buildings, a measure expected to reduce overall BEC by 17% during the 11th Five Year Plan (Beijing Government, 2006).

Energy efficiency improvement is a desirable way to deal with issues of sustainable development, pollutant emission reductions, high production costs, global climate change, energy resource shortages and other issues. Such projects also contribute to the health of the environment, improve indoor air quality, and contribute to employee morale and productivity. Building Energy Efficiency Retrofit (BEER) offers significant benefits to society, owners, and occupants of buildings from the following perspectives: (i) protect environment and reduce CO_2 emissions; (ii) stop losing money on utility bills and reduce maintenance cost; (iii) create jobs and career opportunities; (iv) improve comfort, safety and productivity in workplace and community spaces; (v) modernize buildings, bring operations in line with best practices, and upgrade staff credentials through training.

Despite the benefits, many energy efficiency projects remain unimplemented. Energy efficient facilities are a goal of facility managers, owners, and even governments, but achieving it is not always simple or affordable. Most energy efficiency projects stall due to one or a combination of the following perceived barriers (Zobler & Hatcher, 2003): (i) lack of money, (ii) lack of time or personnel to design and plan the projects, (iii) lack of internal expertise to implement the projects, and (iv) lack of policy support within the decision-making process. In addition to the above general barriers, there are other specific barriers to building energy efficiency retrofit in China, which include the lack of an energy consumption baseline for different types of buildings in China, which should be established through extensive surveys; the lack of clear ownership rights in many buildings; a low consciousness of energy efficiency projects in the general population; and limited implementation of new technologies for energy efficiency retrofit (Jia & Zhou, 2008; Yang et al., 2006; Lv & Wu, 2007, Xu et al., 2009). The most common challenge in both developed and developing countries for the implementation of BEER is finding the initial funding.

Energy Performance Contracting (EPC) is a financial package provided by Energy Service Companies (ESCOs) that includes energy savings guarantees and associated design and installation services for energy efficiency projects. EPC uses potential energy savings to pay for the capital investment costs of energy efficiency projects. The EPC principle has been applied in North America for over 20 years, and for a little less in some European countries; it was introduced into China in the 1990s (Shen, 2007). EPC in the ESCO business may be broadly defined as a contract between an ESCO and its client, involving an energy efficiency investment in the facilities, the performance of which is somehow guaranteed by the ESCO, with financial consequences for the ESCO (Taylor et al., 2007). Under an energy performance contract, the ESCO will provide financing for a specified set of building energy efficiency retrofit measures, along with associated design, engineering, and installation services.

1.2 Motivation of the Research

With the growing concern about global warming and environmental issues, the topic of “sustainability” or “sustainable development” has gained much more consideration and is frequently discussed by economists, industrialists, politicians, and academics. According to the Brundtland Report, sustainable development is needed to meet human needs without compromising the ability of future generations to meet their own needs (WCED, 1987). From then on, sustainable development principles have been reaching many spheres of human activity. Following this trend, the building sector welcomed a new term: sustainable building. As mentioned above, existing buildings have great potential for energy saving in China. Building Energy Efficiency Retrofit (BEER) provides excellent opportunities to reduce overall energy consumption of all buildings in a city and improves environmental protection, rational resources use, and occupants’ health.

The EPC mechanism has great advantages for building clients: to conduct BEER and to improve the sustainability of existing buildings (Zhao, 2007). Firstly, it can free up a client’s capital, transfer non-core staff from a client, and allow a client to focus on its primary business function. Secondly, it guarantees the performance of the project. The other advantage in an EPC is that ESCO companies undertake almost all the investment risk, technical risk, market risk and performance risk, leaving “zero risk” to customers.

Because the mechanism involves financing through future energy savings and provides a performance guarantee, and since the payback period is contained in a contract period, EPC projects are always long-term projects. The long-term nature of EPC projects gives rise to a number of future uncertainties, which will also cause higher risk for ESCOs. However, building clients and ESCOs are profit-oriented, which means that concerns about profit are likely to overshadow concerns about the environment, society, and sustainability. So, undertaking BEER projects, clients want to transfer all the responsibilities and risks to the ESCOs. The ESCOs often take simple retrofits with a short payback period by using mature and familiar technologies without any technical innovation - like a lighting retrofit - rather than comprehensive measures in energy efficiency projects. Sometimes, ESCOs with low creditability even use poor quality equipment to reduce cost, which leaves potential risk to the customer after project completion. Such conditions impede the sustainability of BEER projects, and can even result in project failure.

It is necessary to integrate the sustainable approach into BEER projects. Today, there is almost no integration of sustainability strategies and retrofit project organization, which tend to only focus on economic and technical issues. Current sustainable building systems for major refurbishment pay little attention to the retrofitting process and delivery business model. In order to achieve success and sustainability in BEER under the EPC mechanism, there is a need to understand the relationships between sustainable development strategy, BEER and the EPC mechanism, and to identify the sustainability performance of BEER projects as well as success factors for the EPC mechanism.

1.3 Scope of the Study

It is necessary to limit the scope of the study mainly because this research area of sustainable building retrofit is overly vast to comprehensively address within a single study. A clear statement of the scope of the study serves to concentrate research efforts. This research focuses on hotel buildings, for two reasons: firstly retrofit in hotel buildings has a large potential for energy saving, because of high energy consumption in hotel buildings; and secondly most hotels belong to a single owner, which makes it easier to partner with an ESCO for the delivery of an EPC.

Energy consumption related to the building industry includes energy consumption in construction material production and transportation, building construction and commissioning, and building operation and maintenance. In the life cycle of buildings, energy consumption embodied in construction materials and consumed in the construction process itself account for nearly 20% of the total life cycle energy consumption of buildings. Most energy is consumed in the building operation and maintenance phase, so the building energy consumption (BEC) is normally defined as the energy consumption in civil building operation and maintenance (THUBERC, 2007).

Energy usage is dramatically different in different types of buildings, which are normally divided into two main categories: industrial and civil. Because the energy consumption of industrial buildings is calculated into the industrial energy consumption, the BEC in this study only refers to the energy consumption in civil buildings. Civil buildings consist of residential buildings and public buildings. Energy consumption per unit of gross floor area also varies greatly according to the scale of the public buildings, so public buildings are further divided into common public buildings and large-scale public buildings (see Fig. 1.1). Large-scale public buildings are defined as those buildings with a central air-conditioning system and more than 20,000 m^2 gross floor area. Chinese public buildings include office buildings, schools, hotels, hospitals, retail places, and others, which are analogous to what are called commercial buildings in the US (Hong, 2009).

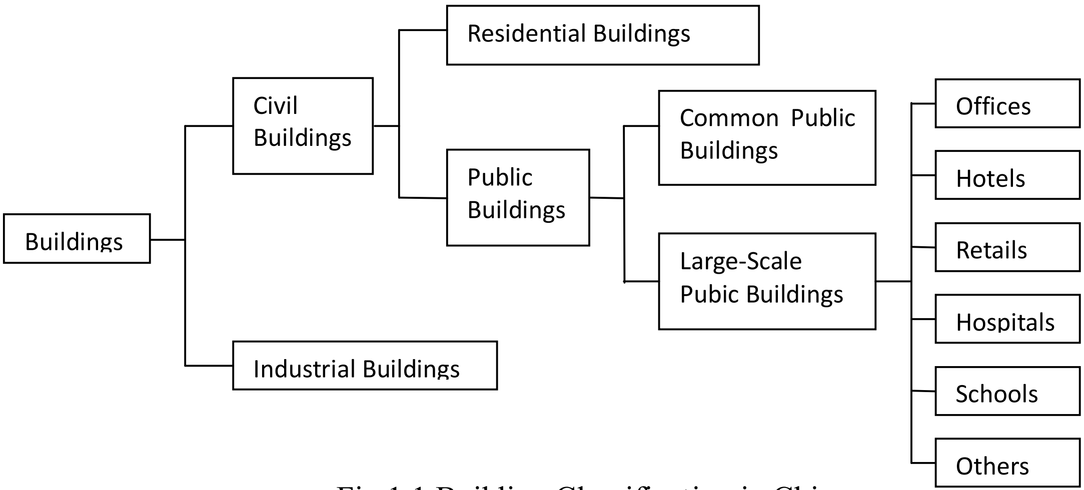

Fig.1.1 Building Classification in China

According to the Tsinghua University Building Energy Research Center (THUBERC) (2007), energy consumption in large-scale public buildings and commercial buildings, such as offices, hotels, retails, hospitals, and schools, may reach up to 300 kWh/m^2, which is eight times that of common public buildings and fifteen times that of energy consumption in urban residential buildings.

Hotel buildings are one type of large scale of public/commercial building. Energy consumption in starred hotels is unique as compared to other large-scale public buildings. It is influenced by different operating schedules for different functional facilities in a hotel building, such as restaurants, in-house laundry, business centre, etc. The variability of occupancy levels throughout the year and varied personal preferences for the indoor environment expected by guests, will lead to different operating schedules for building service systems and therefore different energy consumption situations in hotel buildings (Deng and Burnett, 2000). In hotels, the main energy consuming systems are heating, ventilation and air conditioning (HVAC); lighting; hot water provision; electricity (lifts, etc.); and cooking. There is a lack of statistical data of detailed energy consumption in China but researchers in different areas have made some energy surveys in hotel buildings. A survey in Beijing showed that the electricity consumption was 100-200 kWh/(m^2.a) (Xue, 2007). The range was 55-144.3 kWh/(m^2.a) in Chongqing in 2006 (Zhou et al, 2008). Another survey of nine starred hotels in Shanghai showed that the average energy consumption was 2.698GJ/(m^2.a) (Xue, 2007). Energy costs in hotels account for up to 6% of total running costs. For sake of comparison, in the US, the nation's 47,000 hotels spend an average of US$2,196 per available room each year on energy (EPA, 2009).

According to the OECD (2008), sustainable development is not only an end goal but also a process - a way of applying the principles of integration across space and time to all decisions. This research focuses on sustainability at the project level. The sustainability of building retrofit projects should be considered from two aspects: (i) from the perspective of the product as a facility, and (ii) from the perspective of the creation of the product as a process. In sustainable retrofit processes, both the resulting performance of building retrofit and the project organizational process for the delivery model are involved. In summary, this research focuses on the sustainability of building energy efficiency retrofit under the EPC mechanism, the type of existing buildings studies are hotel buildings in China.

1.4 Research Aim and Objectives

The primary aim of this research is to develop a model for achieving the sustainability of BEER in hotel buildings under the EPC mechanism.

The special objectives of this research are shown below:

(1) To critically review BEER and EPC from the perspective of sustainable development;

(2) To develop a conceptual framework for sustainable BEER projects under the EPC mechanism;

(3) To identify a set of key performance indicators (KPIs) for measuring the sustainability of BEER in hotel buildings;

(4) To identify critical success factors (CSFs) under the EPC mechanism that have a strong correlation with identified KPIs and sustainable BEER projects;

(5) To develop a model explaining the relationships between the CSFs and the sustainability performance of BEER in hotel building.

1.5 Research Methodology

The methodology was chosen to achieve the research objectives and to be consistent with the internal logic of the study. The main research methods include literature review, document analysis, interviews, questionnaire surveys, statistical analysis, group meetings, and decision-making methods. Two or more methods, either qualitative or quantitative, have been combined to achieve a certain objective.

In this study, a comprehensive literature review was undertaken in the first instance to identify a potential problem worthy of research and to formulate a research framework. Then, a further literature review and an interview method were employed to select the potential performance indicators/criteria for sustainable BEER, and to select success factors under the EPC mechanism. After that, a questionnaire was designed based on selected performance indicators and success factors. The target respondents were requested to complete questionnaires and the data collected was examined through a series of statistical analyses to identify the KPIs and CSFs. Finally, a multi-decision-making model was developed using the analytic network process (ANP) approach to explain the relationships between the CSFs and the sustainability performance of BEER in hotels. Details of the research methodology are discussed in Chapter 3.

1.6 Significance of Research

From an academic point of view, this research contributes to the knowledge of sustainable building and fills the knowledge gap in achieving sustainable BEER. It also provides contributions to knowledge regarding EPC project management and retrofit project management. The findings of this research could be applied to other types building, other industries, and other countries.

The findings of this research also have practical value. The result of the sustainability performance of these projects and the identification of project success factors could give incentive to industry practitioners to engage projects successfully. It can promote favorable practices in BEER projects for the development of sustainable buildings and “green hotels”. It also facilitates the implementation of the EPC mechanism in BEER projects and promotes the development of the ESCO industry in China.

1.7 Structure of the Thesis

This thesis consists of nine chapters. Chapter 1 is an overall introduction highlighting the background, motivation, scope, objectives, methodology, significance of the study, and the structure of the entire thesis.

Chapter 2 presents a review of the literature relating to the research project. Three streams of literature are reviewed: the concepts, process, and technologies of BEER; a detailed review of EPC; and an analysis of sustainable development and current sustainable BEER systems. Lastly, a theoretical framework is proposed based on the critical review.

Chapter 3 describes the methodology applied in this research. In this chapter, the research framework is first presented, followed by a discussion of data collection procedure, the samples used, data analysis methods, and the development of the decision-making model.

Chapter 4 develops a conceptual framework to analyze sustainable BEER under the EPC mechanism. This chapter first defines sustainable BEER, followed by a review of sustainable building retrofit and project management success factors. After that a primary analysis framework is developed based on the EFQM Excellence Model. This framework links the sustainable BEER with affecting factors together. After that, a series of structured interviews with experienced practitioners and professional researchers are discussed. This chapter then reports on the selection of critical performance indicators, and success factors, based on an interview and literature review method.

Chapter 5 identifies the KPIs for sustainable BEER in hotel buildings. A questionnaire was designed based on the potential performance indicators selected through interviews in Chapter 4. The questionnaires were delivered to three groups of experts from the hotel sector, ESCOs, and other areas. Finally, six KPIs are identified through use of the fuzzy set theory analysis.

Chapter 6 continues the analysis of the data collected from the questionnaire survey for indentifying the KPIs for sustainable BEER in hotel buildings and CSFs of the EPC, which is described in detail in Chapter 3 and Chapter 5. This chapter analyzes the data to identify the CSFs and makes a factor analysis to structure and explain them.

Chapter 7 implements the ANP approach. *SuperDecision* software was used to develop and calculate the ANP model. Two rounds of group meetings were conducted during March to April 2011 in Shenzhen. The first round of group meetings aimed to identify the relationship among sustainable dimensions, KPIs, and CSFs so as to structure an ANP model. The second round of group meetings involved carrying out AHP/ANP excises and conducting a pairwise comparison.

Chapter 8 highlights the relationships and explains how individual factors could contribute to sustainable development objectives. By adopting the ANP approach, the final priorities and relationships between CSFs and KPIs are revealed. A detailed discussion of how each of these factors affects the performance of sustainable BEER in hotel buildings is given in the following section.

Chapter 9 is an overall summary of the main research findings, the academic contributions, and the practical implications for practitioners as well as for researchers. The limitations of this research and potential areas for further study are also discussed.

CHAPTER 2 Literature Review

2.1 Introduction

This chapter presents a review of the literature relating to the research topic. Three streams of literatures are examined here. Firstly, this chapter reviews the concepts, technologies and process of BEER and the approach to sustainable building retrofit. Secondly, a detailed review of EPC is conducted. Thirdly, it undertakes an analysis essential of sustainable development and current sustainable BEER systems. Lastly, a theoretical framework is proposed based on the critical review.

2.2 Building Energy Efficiency Retrofit (BEER)

2.2.1 Introduction to BEER

Building energy efficiency retrofit (BEER) is defined as reducing building operation energy use by certain approaches of building envelope improvement and mechanical systems upgrading, while keeping the building indoor environment comfortable (Shanghai Construction and Transportation Commission, 2008). Besides retrofitting of building structures and the mechanical system, the improvement of operating and management practices should also be considered. Improvements to building energy efficiency typically include structural, mechanical, and control systems as well as conversion to renewable energy where appropriate. Staff training, new management and monitoring strategies are also required to ensure continued optimal operation and savings.

Building energy retrofits follow an AIM (audit-implement-monitor) process which includes the following steps (CMHC, 2002): (i) audit: an auditing of the building and the way it uses energy which leads to a definition of appropriate measures; (ii) implement: the implementation of the measures including engineering, project management, subcontracting, and commissioning; (iii) monitor: the monitoring and tracking of energy savings ensure that they are achieved as expected, and that they can be sustained. BEER can range from single system retrofits to a whole-building approach. The main retrofitting technologies are as follows:

- **Building Envelope:** The building envelope is what separates the indoor environment from outdoor elements and includes walls, ceilings, doors, and windows. Replacing insulation with better performing material is one of the best ways to improve energy efficiency. Other innovative technologies include high efficiency windows, foundations with insulated concrete slabs, advanced framing techniques, and cool or reflective roofs.
- **Heating, Ventilation and Cooling:** Energy efficiency in heating and cooling systems can be improved through the use of automatic thermostats and intelligent building system controls, natural ventilation techniques, duct insulation, and advanced technologies, such as desiccant dehumidification and radiant heating. For boiler systems, energy saving add-ons include economizers and air pre-heaters, or newer and more energy efficient systems. Water-based central heating is used in the north of China. In this case, retrofitting can address heating appliances and the supply system itself.

- **Water Heating:** Appropriate tank insulation can help to improve the energy performance of existing water heaters and older units can be replaced with newer, more efficient models. Significant energy savings can be achieved through the use of water conservation technologies such as aerated faucets and water-efficient shower heads.
- **Lighting:** Energy efficient compact fluorescent lights (CFL), as well as T-5 and T-8 lamps, can save significant amounts of energy in comparison to older incandescent or T-12 applications. Light-emitting diodes (LEDs) are an energy efficient choice for exit signs and other displays. The use of timers and occupancy sensors are also available for consideration. For new buildings or reconstruction projects, day-lighting techniques are available.
- **Whole Building Comprehensive Retrofit:** For reconstruction projects, this approach involves designing and integrating all building components and systems to maximize energy performance and minimize environmental impact. When updating building energy consumption systems, the renewable energy resources and new technologies should also be explored, such as, PV, solar heat, wind, earth heat, biomass etc.

Based on the above analysis, building retrofit for energy efficiency can address three aspects: building envelope, the equipment system, and the energy management and control system. Details are shown in Table 2.1.

Table 2.1 Building energy efficiency retrofit strategies

Building Energy Efficiency Retrofit	Building envelope	Walls, ceilings, windows, doors, and floor etc.
	Equipment system	HVAC, lighting, water heating, lift etc.
	Energy management	Staff training, new management and monitoring strategies.

2.2.2 Benefits & Obstacles

2.2.2.1 Benefits of BEER

BEER benefits the environment, society, building owners, and occupants. The benefits are discussed herein in greater detail.

Reduce CO_2 emission: Systematic action to dramatically increase building energy efficiency through retrofitting and other strategies can address the goal of reducing greenhouse gas emission. According to the *Pew Center on Global Climate Change*, buildings account for about 43% of the total carbon dioxide emissions in the U.S. (Living Cities, 2009).

Reduce utility bills and maintenance costs: A recent study of energy efficiency potential in several U.S. cities shows building energy efficiency gains of 50% or more are achievable through the application of measures that are cost-effective on 'simple' terms. Gains of 25% or more are achievable even assuming market costs of capital **(**Institute for Sustainable Communities, 2009**)**. New equipment can cost much less to operate than ageing systems. New systems also minimize risk for costly emergency repairs (GMF, 2009).

Create jobs and career opportunities: The Canadian government estimates that for every $50,000 invested in energy retrofits, one year of employment for one person is created. On a national scale, this represents an opportunity for between 5600 and 7840 person-years of employment (GMF, 2009). The *Center for American Progress* estimated in a report that $100 billion in green economic investment will translate into two million new jobs in two years (Pollin et al, 2008). And a 2008 report by the *Center on Wisconsin Strategies* suggests that about 8 to 11 jobs can be created for every $1 million invested in building energy efficiency retrofitting (Walsh and White, 2008).

Other benefits: A range of other benefits, including healthier indoor air quality; improved comfort, safety and productivity in the workplace and community spaces; the modernization of buildings; the implementation of best practice in building operations; and staff training (GMF, 2009; Institute for Sustainable Communities, 2009).

2.2.2.2 Obstacles to BEER in China

Despite the advantages of BEER, many potential projects remain unimplemented in both developed and developing countries. The reasons for delaying projects may vary, most energy efficiency projects stall due to one or a combination of the following perceived barriers (Zobler & Hatcher, 2003): (i) lack of money, (ii) lack of time or personnel to design and plan the projects because of higher priorities, (iii) lack of internal expertise to implement the projects, and (iv) lack of policy support within the decision-making process.

BEER’s benefit to society and the environment represent a valuable positive externality (Jin et al., 2007); therefore, promoting BEER should not only depend on the market but should also benefit from policy incentives. In order to clear barriers to BEER, promoting programs were implemented in different countries and areas, such as ‘Municipal Building Retrofits’ in Canada, the ‘Building Energy Efficiency Programme’ (BEEP) in London, and the ‘Energy Efficiency Building Retrofit Program’ (EEBRP) supported by the ‘Clinton Climate Initiative's’ (CCI) in the US. Obstacles to BEER vary because of different conditions in different countries. Because of the complicated energy consumption picture in China, there are many technological, managerial, and economical obstacles to implementing BEER in China. According to the literature (Wu et al., 2007; Han et al., 2006; Sun and Liu, 2007; Zhong et al, 2009), there are three main obstacles to BEER in China.

Lack of basic energy consumption statistics

Currently, the Chinese National Bureau of Statistics has neither classification statistics for buildings nor basic data addressing existing building and building energy consumption. Due to China’s lagging building management system, decision-makers lack appropriate data on building type distribution, building energy consumption, building energy systems, and the development trend of building energy consumption. Without the energy consumption baseline for different types of buildings, it is impossible to assess and conduct BEER. Besides, most standards and regulations about building energy efficiency apply to new buildings; there is little standardization and regulation of energy efficiency in existing buildings.

Lack of money

Most of the pilot retrofit projects in China and overseas indicate that energy efficiency projects are cost-effective with high return rates, but many energy efficiency projects remain unimplemented due to a lack of capital. Nearly 15 billion m^2 of existing buildings in urban areas have energy retrofit potential and could potentially be retrofitted before 2020 in China. The cost of energy efficiency retrofitting is about 100~300RMB/m^2 depending on the type of buildings and the total retrofit expense would amount to 2,000 billion RMB (Han et al., 2006). Currently, the main financing sources are government grants and subsidies, supplemented by building owners' investment.

Lack of policy support within the decision-making process

The lack of policy incentives are manifested in the inadequacy of laws, incentives, techniques, materials, and products (Zhong et al, 2009). A large-scale investigation of energy efficiency in China was carried out in 22 provincial capital cities and major cities in 2005 by the Ministry of Housing and Urban–Rural Development of China (MOHURD) (Wu et al., 2007). According to the results of the investigation, of 10,236 participants, 47% believed that a lack of policy incentives was the biggest barrier to the promotion of building energy efficiency, 58% were open to pursuing energy cost reductions through retrofit, and 74% were willing to accept costs of less than 10% of the total project costs (refer to Figs. 2.1 and 2.2).

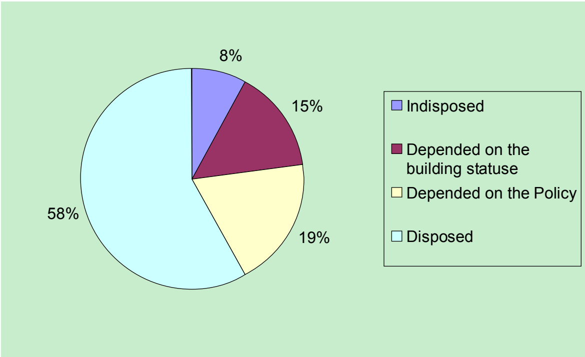

Fig. 2.1 Willingness to accept BEER (Zhong et al., 2009)

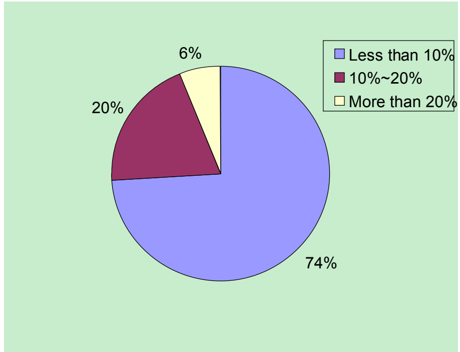

Fig. 2.2 Willingness to share the cost of BEER (Zhong et al., 2009)

Besides the above obstacles, there are many other impediments for BEER in China (Jia & Zhou et al, 2008; Yang et al., 2006; Lv & Wu, 2007). Property ownership rights are not clear for many buildings. For residential buildings, the property rights can be split amongst many different owners, which can make it difficult to reach agreement on BEER. New technologies and renewable energy sources for energy efficiency retrofit should be further explored. Most people have limited consciousness of energy efficiency projects. More pilot projects should be conducted and relevant information and education should be provided to allow more public participation in BEER.

2.2.3 BEER in Hotel buildings

As discussed in Chapter 1, energy retrofitting of hotel buildings has great potential energy savings. Energy costs in hotels represent up to 6% of total running costs. In the US, 47,000 hotels spend an average of $2,196 per available room each year on energy (EPA, 2009). In the hotel sector, reducing energy costs while continuing to meet the diverse requirements of customers is challenging. However, it is estimated that hotels could cut energy costs by 20% or more by adopting proven energy-efficiency measures.

Retrofit in hotel buildings has its special characteristics. Energy efficiency retrofit provides cost savings to hotel owners and operators. Efficiency also improves the service of capital equipment, enhances guest comfort, and demonstrates a commitment to climate stewardship. Consider a hotel or motel's largest energy loads when planning a retrofit strategy. Typically, nearly 75% of a hotel's or motel's total energy use can be attributed to space heating, water heating, lighting, and cooling combined. Cooling and lighting alone make up half of the building's electricity consumption (EPA, 2007).

2.3 Energy Performance Contracting (EPC)

2.3.1 The EPC mechanism

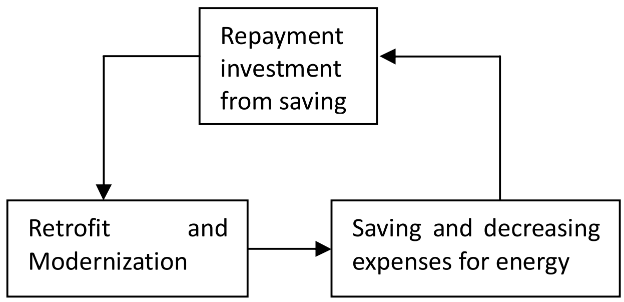

Fig. 2.3 EPC Mechanism

Energy Performance Contracting (EPC), also known as energy service performance contracting, is a financing package from Energy Service Companies (ESCOs) that include energy savings guarantees and associated design and installation services for energy efficiency projects. The system emerged in the US in the 1970s after the first oil crisis. EPC is a mechanism for procuring and implementing capital improvements today that are self-funded over time through guaranteed operational savings. Performance contracting uses operational savings and avoided capital expenditures from the owners to fund repayment of capital for building and infrastructure improvements (see Fig. 2.3).

However, the EPC principle not only is a financing tool but also a market mechanism for conducting energy efficiency projects. EPC in the ESCO business may be broadly defined as a contract between an ESCO and its client, involving an energy efficiency investment in the client's facilities, the performance of which is somehow guaranteed by the ESCO, with financial consequences for the ESCO (Taylor et al, 2007). Under an energy performance contract, the ESCO will provide financing for a specified set of energy efficiency retrofit measures, along with associated design, engineering, and installation services. The owner or user can enjoy high energy efficient facilities and potential savings with little or even no front investment. The basic concept of the EPC is shown in Fig. 2.4. The first bar represents the total utility costs of one facility before the EPC. In the second bar, after retrofitting, the energy savings are shared by the client and the ESCO during performance contract period. After the performance contract, all the cost savings belong to client, which is shown in the third bar.

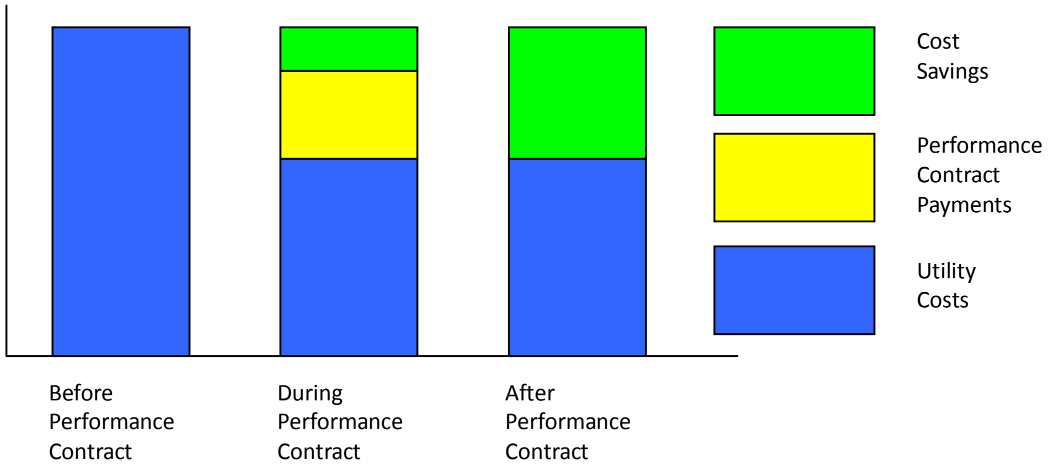

Fig 2.4 Basic Concept of Energy Performance

2.3.2 Terminology and Definition

There are several terms with the same meaning in the context of the EPC, such as energy saving performance contracting and contract energy management. Sometimes the ESCO and third party financing (TPF) are also defined as the business mechanism. In order to reduce confusion and understand this mechanism clearly, it is necessary to distinguish these definitions.

Energy Performance Contracting (EPC)

Energy performance contracting (EPC) is a turnkey service, sometimes compared to design/build construction contracting, which provides customers with a comprehensive set of energy efficiency, renewable energy, and distributed generation measures aiming at the guaranteed improvement of energy performance and cost efficiency of facilities. The service is paid out of saved energy costs, with most cases including financing services. (Friedrich Seefeldt, 2003; NAESCO, 2007)

Energy Service Company (ESCO)

An *ESCO,* or *energy service company,* is a business that develops, installs, and finances projects designed to improve the energy efficiency and maintenance costs for facilities over a 7- to 10-year time period. ESCOs generally act as project developers for a wide range of tasks and assume the technical and performance risk associated with the project (NAESCO, 2009). The term ESCO may mean different things to different people. ESCO not only refers to a company which provides energy efficiency services but also can refer to the energy efficiency business mechanism, having the same meaning as the term energy performance contracting (EPC). In this research, ESCOs are defined to include any companies using EPC as the main energy efficiency investment transaction.

Energy Service Provider Company (ESPC)

In contrast to an ESCO, *energy service provider companies (ESPCs)* are natural or legal persons that provide a service for a fixed fee or as added value to the supply of equipment or energy. Often the full cost of energy services is recovered in the fee, and the ESPC does not assume any (technical or financial) risk in case of underperformance. ESPCs are paid a fee for their advice and service rather than being paid based on the results of their recommendations (WEEA 1999).

Bertoldi and Rezessi (2005) distinguished between an ESPC and an ESCO. An ESPC can supply energy efficiency equipment, heat, energy, operations and maintenance, or facility management but at a fixed fee. They do not assume any ongoing performance risks beyond that of normal warranties relating to product quality; for example, a 12-month defects period. Sometimes ESCOs also offer these services; however, ESCOs' activities can be distinguished from ESPCs' activities in the following ways:

1) ESCOs guarantee the energy savings and/or the provision of the same level of energy service at a lower cost by implementing an energy efficiency project;
2) The remuneration of ESCOs is directly tied to the energy savings achieved;
3) ESCOs typically finance, or assist in arranging financing for, the installation of an energy project they implement by providing a savings guarantee;
4) ESCOs retain an ongoing operational role in measuring and verifying the savings over the financing term.

Third Party Financing

Third-party financing (TPF) refers solely to debt financing. As the name suggests, project financing comes from a third party, e.g. a finance institution, and not from the internal funds of the ESCO or of the customer. The finance institution may either assume the rights to the energy savings or may take a security interest in the project equipment (WEEA 1999).

However, studies in Europe lead to the conclusion that TPF and EPC are used very much interchangeably (Leutgöb et al, 2000). This is the case in a document from the World Energy Efficiency Association (WEEA, 1999). There are different traditions in North America and Europe regarding the similarities and differences between TPF and EPC. “Third party” has a different meaning in a Canadian definition (Langlois, 2001), where it refers to some party other than the owner or ESCO organization; a banker or financier, for example. In one European Union context, “third party” refers to the ESCO, the first party being the owner and the second party the user.

2.3.3 EPC Models

There are many ways to structure an EPC model. Two of the common EPC models are the guaranteed savings contract and shared savings contract (Silvia Rezessy, et al; Han, et al. 2006; Bertoldi and Rezessi, 2005; Hui, 2002; Hansen 2003, Poole and Stoner 2003).

Guaranteed savings contract: The ESCO designs and implements the project but does not finance it, although it may arrange for or facilitate financing. The ESCO guarantees that the energy savings will be sufficient to cover debt service payments (see Fig. 2.5).

Shared savings contract: The ESCO designs, finances and implements the project; verifies energy savings; and shares an agreed percentage of the actual energy savings over a fixed period with the customer. This is also referred to as the “full-service ESCO” (see Fig. 2.6).

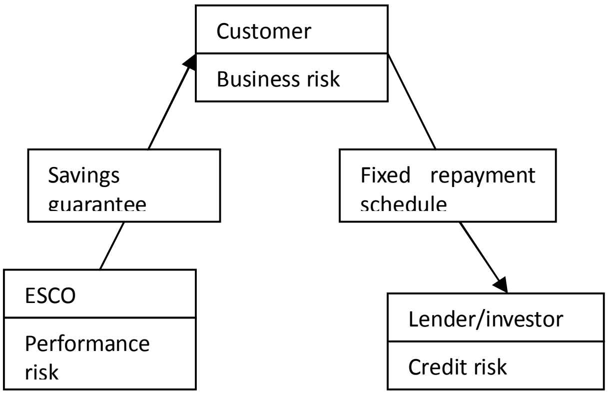

Fig.2.5 Guaranteed savings

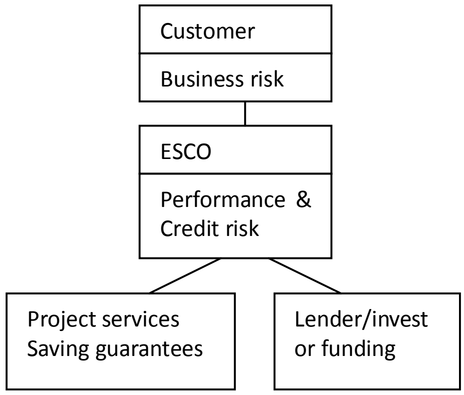

Fig. 2.6 Shared savings

(Dreessen 2003, Hansen 2003, Poole and Stoner 2003)

An important difference between the guaranteed and shared savings models is that in the former case the performance guarantee is the level of energy saved, while in the latter it is the cost of energy saved. Table 2.2 summarizes the features of the guaranteed and shared savings models.

Table 2.2 Guaranteed savings and shared savings: a comparison

Guaranteed savings	**Shared savings**
Performance related to level of energy saved	Performance related to cost of energy saved
Value of energy saved is guaranteed to meet debt service obligations down to a floor price	Value of payments to ESCO is linked to energy price
ESCO carries performance risk Energy user/customer carries credit risk	ESCO carries performance and credit risk as it typically carries out the financing. In some circumstances the customer may carry the credit risk due to contract termination provisions.
If the energy user/customer borrows,	Usually off the balance sheet of energy

then debt appears on its balance sheet	user/customer
Requires creditworthy customer	Can serve customers that do not have access to financing, but still requires a creditworthy customer
Extensive M&V	Extensive M&V
ESCOs can do more projects without getting highly leveraged.	Favors large ESCOs; small ESCOs become too leveraged to do more projects
More comprehensive project scope due to lower financing costs	Favors project with short payback due to higher financing costs

Sources of data: Dreessen 2003, Hansen 2003, Poole and Stoner 2003

From the above comparison, we find that the guaranteed savings concept is likely to function properly only in countries with a well-established banking structure, a high degree of familiarity with project financing and sufficient technical expertise, also within the banking sector, in order to understand energy-efficiency projects. So the guaranteed savings concept is difficult to use in introducing the ESCO concept in developing markets because it requires customers to assume investment repayment risk. The shared savings concept is a good introductory model in developing markets because customers assume no financial risk. However it may limit long-term market growth and competition between ESCOs and between financing institutions: small, new ESCOs with no previous experience in borrowing and limited resources are unlikely to enter the market if such agreements dominate because they will be unwilling to assume the investment repayment risk (CTI 2003, Dreessen 2003).

In addition to the two main models, other EPC models have emerged in different areas. The following is a summary of contracting models discussed in the literature from high service (shared savings contract) to low service (technical consultant) (see Table 2.3). All these models can help achieve energy savings. However, strictly speaking, the last two technical consultant models, without financing services, should not be group with EPC mechanisms.

Table 2.3 Business models of EPC

EPC Models	Description
Shared savings contract	The ESCO designs, finances and implements the project, verifies energy savings and shares an agreed percentage of the actual energy savings over a fixed period with the customer. This is also referred to as the "Full-Service ESCO" (Bertoldi and Rezessi, 2005; Hui, 2002; Hansen, 2003).
Chauffage	The ESCO takes over operation and maintenance of the equipment and sells the output (e.g., steam, heating/cooling, lighting) to the customer at an agreed price. Costs for all equipment upgrades, repairs, etc. are borne by the ESCO, but ownership typically remains with the customer. This model is also sometimes referred to as Contract Energy Management (Hui, 2002; ESCO feasibility study, 2007; Bertoldi and Rezessi, 2005).
Guaranteed savings contract	The ESCO designs and implements the project but does not finance it, although it may arrange for or facilitate financing. The ESCO guarantees that the energy savings will be sufficient to cover debt service payments (Bertoldi and Rezessi, 2005; Hui, 2002; Hansen 2003,).
First-out	All savings achieved under this type of contract belong to the contractor. Once the contractor

	recoups the expenses incurred during the project the contract ends or once the contract ends any future savings made belong to the client. An 'extreme' form of the shared savings is the 'first out' contract whereby the ESCO receives 100 % of the savings until the project costs, including the profit of the ESCO, are fully paid.
The Build-Own-Operate-Transfer (BOOT) contract	A BOOT model may involve an ESCO design, building, financing, owning and operating the equipment for a defined period of time and then transferring this ownership across to the client. The charge incurred by the client includes the recovery of operating costs, capital and project profit (ESCO feasibility study, 2007; Bertoldi and Rezessi., 2005).
Equipment Supplier Credit	The equipment supplier designs and commissions the project, verifying that the performance/energy savings matches expectations. Payment can either be made on a lump-sum basis after commissioning or over time (typically from the estimated energy savings). Ownership of the equipment is transferred to the customer immediately (World Bank, 2004).
Equipment Leasing	Similar to supplier credit, the equipment supplier receives fixed payments from the estimated energy savings. However, in this case the supplier owns the equipment until all the lease payments, and any transfer payments, are completed (World Bank, 2004; Bertoldi and Rezessi, 2005).
Technical Consultant (Performance-based Payments)	The ESCO conducts an audit and assists with project implementation. The ESCO and

	customer agree on a performance-based fee, which can include penalties for lower energy savings and bonuses for higher savings (World Bank, 2004).
Technical Consultant (Fixed Payments)	The ESCO conducts an audit, designs the project and either assists the customer to implement the project or simply advises the customer for a fixed, lump-sum fee (World Bank, 2004).

Adapted from: Examples of Different ESCO Business Models **(**World Bank, 2004)

2.3.4 Process of EPC project

Various approaches to the EPC process have been implemented for different projects in different areas. The general process is the same, comprising three phases. Phase I is contractor selection, phase II is “make an EPC agreement,” and phase III involves implementing EPC agreement. This research further divides the common process into the following seven steps: project identification; planning assessment; select a contractor; project design; arrange financing; negotiate EPC contract; construction and implementation; and measurement and verification of savings (see Fig. 2.7).

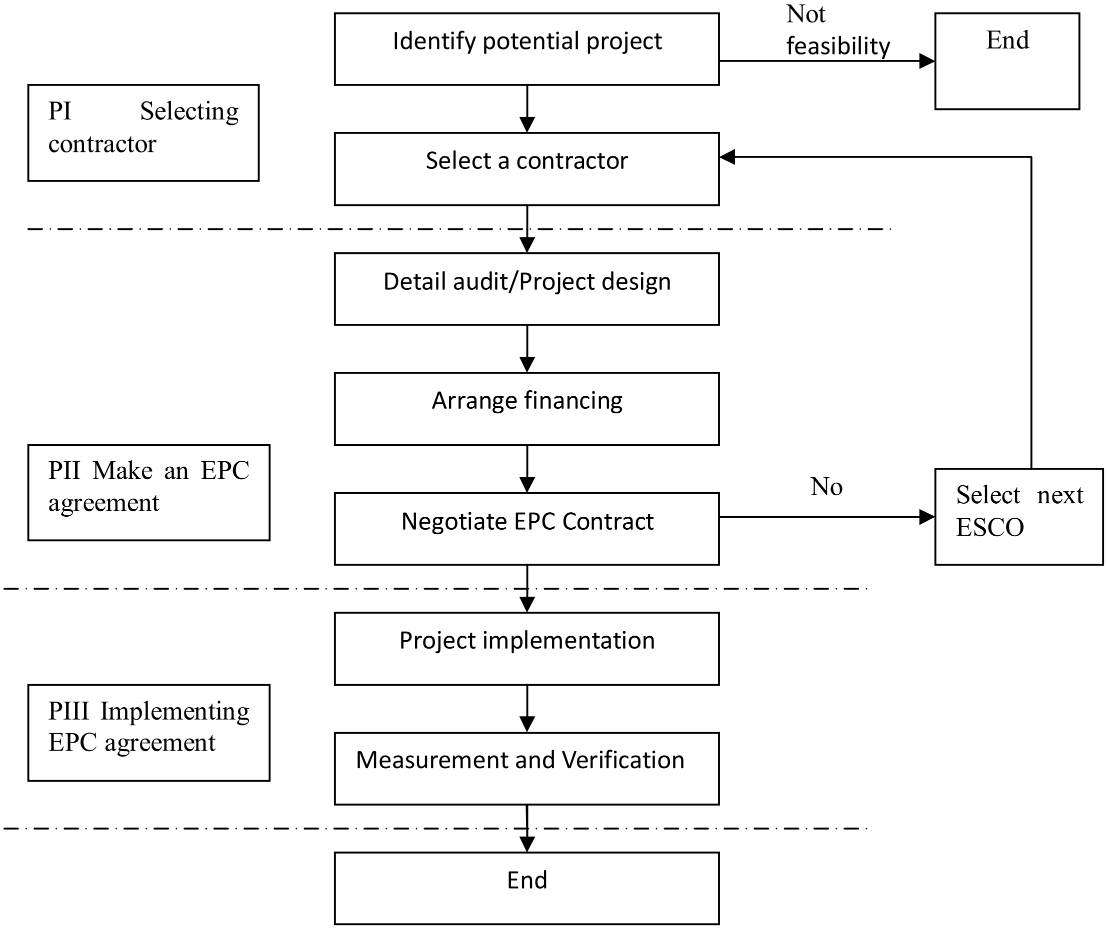

Fig. 2.7 EPC process

Phase I: Contractor selection

Step 1 Project identification

Any energy project begins with a preliminary analysis. This effort starts with the collection of utility cost and usage information along with general background information on facilities. The EPC project process normally begins with assembling a work team and project leader to gather and evaluate this preliminary information. Team members should represent a broad range of skill sets in technical, financial, purchasing, contractual, and project management.

Then, the team should further define the project by conducting a more in-depth facility profile. The facility profile information will help identify the boundaries and scope of the potential projects. This information will include facility operation information and basic background data on the major energy systems, including HVAC, controls/EMS, lighting, water fixtures, building envelope, O&M, new technologies, and renewable resources.

Step 2 Select an ESCO

Once the project team feels that they have a potential project that an EPC will likely be interested in pursuing, a request for proposal (RFP) will be drafted and issued. The RFP includes the owner's preliminary scope of work, project definition (boundaries), proposal response format, selection criteria, site visit, information collection logistics, timelines, and project expectations. After a pre-proposal meeting and a site visit, hopefully, two or more proposals will be received for competitive bidding. Based on the best overall program, proposal scoring, references, and presentations, an ESCO will be selected. Selection is not based solely on proposed project costs as with conventional procurement. In some markets, there is no need to select a contractor through the bidding process. The ESCO discusses the project planning with the client and makes an agreement to develop the project together.

Phase II: Making an EPC agreement

Step 3 Detailed energy audit and project design

The selected ESCO will carry out a "technical" or "investment grade" audit and establish all the details of the project. Terms of the technical audit are negotiated. The ESCO will develop a detail planning and project design which will include the identification of possible energy savings and efficiency improving actions.

Step 4 Arrange financing

This step can be incorporated into the previous step, as financing suggestions, cost, and payment analysis should be included in the “investment grade” audit. Also cost and payment analysis should be given in it. The ESCO arranges for long-term project financing that is provided by a third-party financing institute. Financing is typically in the form of an operating lease or municipal lease.

Step 5: Negotiate a contract

After the facility owner accepts the investment proposal, and financing sources are identified and secured, it is time to draft and sign the EPC. The final contract will include all contractual legal requirements, energy savings analysis, projected annual cash flows, measurement & verification (M&V), the technical audit report, project costs breakdown, and all construction process provisions, as well as a number of attachment “schedules” that define various project information, guarantee, responsibilities, insurance, warranties, M&V, commissioning, training, project costs and so on. The final contract will be negotiated by the owner and the ESCO.

Phase III: Implementing the EPC agreement

Step 6: Project implementation

Project construction follows the process of other capital construction projects. EPCs are used to purchase a wide variety of building equipment and services. Energy-efficient lighting; heating, air conditioning and ventilation systems; energy management control systems; motor replacements; variable-speed drives for pumps and fans; building envelope improvements; and water-efficient fixtures are commonly implemented improvements in buildings. Renewable energy and cogeneration systems may also be purchased. In addition to equipment installation, the ESCO may propose various repair and maintenance services.

Step 7: Measurement and Verification of Savings

The measurement and verification (M&V) of energy savings involves calculating cost savings. The most used protocol for the M&V of performance contacts is the International Performance and Measurement Verification Protocol (IPMVP). The schedule for conducting M&V and for issuing regular reports to the building owner should be clearly established in the EPC contract. In some cases, clients hire a third party to review and confirm the ESCO's M&V reports.

2.3.5 EPC Advantages

The EPC mechanism has numerous advantages for delivering energy efficiency projects compared with other traditional procurement systems. When mentioning the benefits of an EPC, previous research often confuses the benefits of the energy efficiency projects with that of the EPC mechanism, such as energy and cost savings and environmental benefits. However, EPC as a delivery method can assist clients in conducting energy efficiency projects.

Energy performance contracting offers a streamlined approach to making facility improvements because, with a single contract, clients can tackle multiple energy efficient projects throughout the contracting period for their facilities, rather than doing one project at a time. ESCO can provide a full range of services and continue working with clients once the projects are completed to ensure that clients get optimal long-term energy performance. EPC as a financing mechanism can provide financing that transfers non-core staff from a client's organization, and can free up a client's capital, allowing a client to focus on its primary business function (Zhao, 2007). EPC also provides technology and expertise support. Today's ESCOs use industry standard practices and proven energy saving technologies and have excellent track records for satisfying their customers. ESCOs can specialize in finding the best opportunities for improving energy efficiency (Alliance to Save Energy, 2006). The other advantage in an EPC is that ESCO companies shift risk away from the customer, assuming the totality of risk.

2.3.6 Barriers to EPC

Despite the fact that the business concept of EPC is very attractive from a theoretical perspective, there are many barriers to the EPC mechanism and the ESCO industry. Vine (2005) conducted an international survey of barriers to the ESCO industry faced in different countries. Painuly et al. (2003) classified the barriers to ESCOs growth in developing countries into three categories: market barriers, institutional barriers and financial barriers. The European Union's Energy Service Company and the International Energy Association's Demand-Side Management Implementing Agreement's Task X identified some major barriers: lack of information and understanding of the opportunities that energy efficiency offer; lack of culture for project financing; public procurement rules that prevent the use of ESCOs; "low" price of electricity; safety and reliability concerns that hinder the introduction of new technologies; burdensome administrative procedures that allow only very large projects to be carried out; limited understanding of energy efficiency and performance contracting by financial institutions; administrative hurdles; limited government support; lack of motivation; and misunderstanding of M&V protocols for assuring performance guarantees (Westling, 2003; Bertoldi and Rezessi 2005). Vine (2005) listed several key barriers to EPC from the end user aspect (see Table 2.4).

Table 2.4 Key barriers to end users

Key barriers	Elements of barrier
Financing	Lack of access to capital and financing and credit; high cost of money; limited financial capital of potential customers; unclear accounting and treatment of energy performance contracting (EPC) (e.g., operational costs); bias in financing for large enterprise compared to smaller ones (as reflected in interest rates)
Perception of risk	Includes both technical and business risk; need for risk management and business plan; short-term view of investment (e.g., short paybacks required); conservative behavior of customers and banking industry; risk that core production process may be affected.
Information/awarenes s/knowledge	Customers, suppliers, engineering companies, banks, finance sector, industry lack information (or are not

	aware or knowledgeable) of EPCs (as well as technology characteristics, economic and financial costs and benefits, energy savings potential, sources of finance, and installation services); lack of understanding and interest in EPC; lower priority for energy efficiency.
EPC expertise	Lack of expertise in EPC-technical, financial, education; key areas needing assistance: energy-efficiency measures, and design and negotiation of EPC; few energy managers (emphasis on purchasing energy, not on energy efficiency).
Access to energy-efficiency equipment and technology	Shortage of equipment; lack of affordable and appropriate technology; lack of measurement equipment (e.g., meters); need for imported technology-but import taxes increase the costs of equipment.
Administrative	High transaction costs for identifying, procuring, installing, operation, and maintaining energy-efficient equipment, and ESCOs (e.g., information searching); time delays in project implementation; time consuming process to agree on contracts; preparation costs for managing EPC; lack of time and manpower; management costs.
Reliability	Concerns about reliability of equipment (low energy performance of existing systems) and organizations (ESCOs) with poor track records (compounded by poorly performing energy-efficiency measures installed by ESCOs).
Credibility/confidence / trust	Lack of confidence of ESCO services and solutions, EPC; lack of credit history for ESCOs and customers (no credit history for small customers with banks and ESCOs); firms with few projects and references often viewed with skepticism.

Sourced from: Vine (2005)

The development of EPC is later in China. Many barriers encountered in the development of EPC industry in China have been discussed in previous studies (Fu, 1999; Wang, 2009; Yang et al, 2004; Xie, 2008; Shen, 2007; Wang, 2008; Zhang, 2008). Table 1 summarizes barriers to EPC in China.

Table 2.5 Barriers to EPC in China

Barriers	**Sources**
Information/awareness	Wang (2009), Fu (1999), Yang et al (2004), Xie (2008)
Financing	Wang (2009), Yang et al (2004), Xie (2008), Shen (2007), Wang (2008), Zhang (2008)
Measurement/verification	Yang et al (2004), Wang (2009), Zhang (2008)
Institutional barriers	Wang (2009), Fu (1999), Yang et al (2004), Xie (2008), Shen (2007), Wang (2008), Zhang (2008)
Risk	Yang et al (2004), Xie (2008)
Credibility/trust	Shen (2007), Yang et al (2004), Zhang (2008)
EPC expertise	Yang et al (2004)

Previous research mainly focuses on barriers to the EPC/ESCO industry development. This research engages more closely with barriers to implementing the EPC mechanism, which should be discussed at the project level. Such barriers differ by country, sector and other circumstances. The World Energy Council (WEC) and ADEME project on energy efficiency policies presented an overview of the different barriers that hinder the proliferation of the EPC concept in various sectors (Ürge-Vorsatz et al., 2007). These barriers are summarized in

Table 2.5.

Table 2.6 Barriers to EPC in various sectors (Ürge-Vorsatz et al., 2007)

Various sectors	Barriers to EPC
Barriers in public sector	• Loss of control over sourced system • Missing in regulatory framework • Less incentive if energy consumption reduced and budget will decrease • Public procurement rules have not included EPC
Barriers in industry sector	• Big companies can implement and finance energy efficiency improvement • Do not allow ESCOs to check the core industrial processes • Life-cycle costs are rarely taken into account • More risk to invest in private
Barriers in residential sector	• Projects are usually small with high relative transaction costs • Low level of information • Lack of interest among building owners • Complexity of the decision process
Barriers in commercial sector	• Lack of awareness and knowledge about EPC • Have sufficient funds to improve energy efficiency themselves • Unreliable clients

In summary, barriers to EPC/ESCO industry development are common. For the specific markets and projects, barriers to EPC vary by different countries, sectors and other circumstances.

2.3.7 EPC in China

2.3.7.1 Development of EPC/ESCO industry in China

EPC was introduced in China in 1996 in partnership with the World Bank and the Global Environment Fund. The program aims to introduce EPC, improve energy efficiency, reduce greenhouse gas emissions, and protect the global environment. The program is divided into two stages (Shen, 2007).

During Stage I (from 1998 to June 2003), three pilot energy service companies (ESCOs are also called energy management companies in China, abbreviated as EMCs or EMCos) were created: Beijing ESCO, Liaoning ESCO, and Shandong ESCO. These entities have established client-provider relationships with 405 users, implemented 475 projects, and invested 1.33 billion RMB. The project has garnered both energy conservation and environmental benefits: an annual energy saving of 1.49 million tce plus an annual carbon dioxide reduction of 1.45 million ton-c.

Stage II refers to the period from 2003 to 2008. The objective of Stage II was to promote the adoption of the EPC mechanism, foster and develop the energy conservation service industry, expand investment in energy efficiency projects, and reduce carbon dioxide emissions and other pollution. Stage II includes two subprojects: i) a Loan Guarantee Special Fund was established to help EMCos secure loans from commercial banks to implement energy efficiency projects; and ii) the Energy Management Company Association (EMCA) was created in

April 2004 to facilitate the operation of EPC and development of the energy conservation industry in China (Shen, 2007). As shown in Fig. 2.8, investment in energy conservation projects using energy performance contracting in 2007 was over USD 1 billion, four times the 2005 level. Meanwhile, the number of EMCA members had increased from 59 to 308 (including 185 ESCOs) by the end of 2007. By this time, many energy conservation projects had been commissioned in the nation's industrial, construction, and transportation sectors (see Fig. 2.9) (Taylor, 2009).

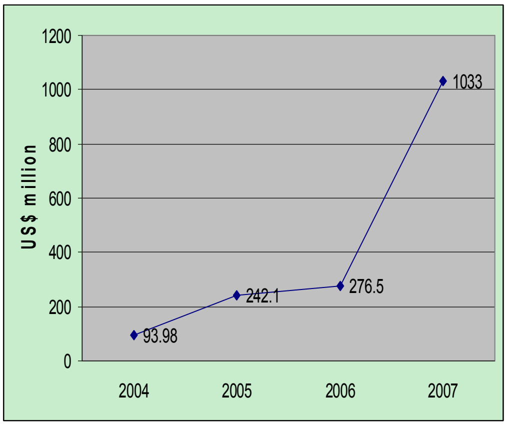

Fig. 2.8 Growth in EPC investment in China (Taylor, 2009)

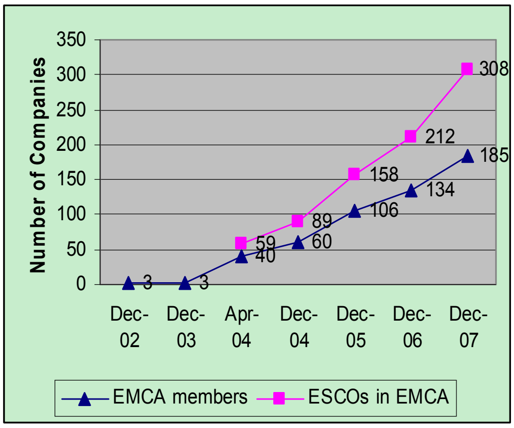

Fig. 2.9 Growth in EMCA members and ESCOS (Taylor, 2009)

A vibrant energy performance contracting industry had developed in China in the first ten years. After 2008, the size of China's ESCO industry experienced especially strong growth. Investment in energy conservation projects using energy performance contracting increased from RMB 11.7 billion in 2008 to RMB19.5 billion in 2009. The number of EMCA members also increased to 454 at the end of 2009. The output value of the ESCO industry was at RMB 58.8 billion in 2009. According to the EMCA's estimation, this value will approach

RMB 400 billion in future years (EMCA, 2010).

2.3.7.2 EPC models in China

There are three basic types of energy performance contracts currently in use in China, in addition to a variety of sub-variations (Shen, 2007). A common feature among them all is that the ESCO's compensation level is in some way dependent upon the actual achievement of the promised energy savings. The three basic types include:

1) shared savings contracts
2) guaranteed savings contracts
3) outsourcing of energy system management

Shared savings contracts and guaranteed savings contracts have been described in detail in the previous section. In the outsourcing of energy system management, which is similar to the Chauffage model, the host enterprise contracts the ESCO to manage all or part of its energy-use systems (e.g. air conditioning, lighting, boiler facilities, on-site power generation, etc.) for a specified fee (or fee formula). The resulting fee is lower than the expected energy cost to the enterprise (including facility upgrading, if relevant) without the ESCO's participation. The ESCO undertakes any agreed investment and renovation, manages the facilities, and covers the payment of energy supply costs. The ESCO is compensated through the difference between those costs and its fee, which results from energy efficiency gains. Besides the above models, Table 2.3 summarizes many other EPC models, which should also be explored in the

Chinese ESCO industry.

From the above review of EPC mechanisms, much research concerns the development of the ESCO/EPC industry. There exists little research on performance contracting mechanisms at the organizational level.

2.4 Sustainable development and sustainable BEER

This section gives an overview of the definitions of sustainable development/sustainability and explores the implications of these terms leading to a conceptual foundation of this study.

2.4.1 Overview of definitions of sustainability/sustainable development

The topic of "sustainability" or "sustainable development" has long been of concern and frequently discussed among economists, industrialists, politicians, and academics. A quick Google search for the term of 'sustainable development' returns over 46 million hits. By the 20th century, the industrial revolution had resulted in an exponential increase in the human consumption of resources and an increase in health, wealth, and population. By the close of the 20th century, ideas part and parcel to sustainability were being explored. In 1987, the United Nation's World Commission on Environment and Development in its report "Our Common Future," also known as the Brundtland Report, suggested that sustainable development was needed to meet human needs without compromising the ability of future generations to meet their own needs

(WCED,1987). Held in Rio in 1992, the UN Conference on "Environment and Development," also referred to as the World Summit, listed 27 principles of sustainability in its declaration (Christopher Wedding, 2008). A more recent and broader definition is the following of 1996: the concept of sustainability relates to the maintenance and enhancement of environmental, social and economic resources, in order to meet the needs of current and future generations. The three components of sustainability are environmental sustainability, social sustainability, and economic sustainability (Gilbert et al, 1996).

The broad nature of "sustainable development/sustainability" leaves it open to a variety of interpretations. Emrgnc (2003) summarised more than one hundred definitions of sustainability. Besides, research efforts made to define the concept of sustainability can also be found extensively in other publications. Here lists some typical and well known definitions (shown in Table 2.6).

Table 2.7 Definitions of sustainable development

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."
"Sustainable development involves devising a social and economic system, which ensures that these goals are sustained, i.e. that real incomes rise, that educational standards increase, that the health of the nation improves, that the general quality of life is advanced."
"Sustainable development, sustainable growth, and sustainable use have been used interchangeably, as if their meanings were the same. They are not. Sustainable growth is a contradiction in terms: nothing physical can grow indefinitely. Sustainable use is only applicable to renewable resources. Sustainable development is used in this strategy to mean: improving the quality of human life whilst living within the carrying capacity of the ecosystems."
"Sustainable development is base d on the principle that the right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations"
"The concept of sustainability relates to the maintenance and enhancement of

environmental, social and economic resources, in order to meet the needs of current and future generations. The three components of sustainability are:

- *Environmental sustainability – which requires that natural capital remains intact. This means that the source and sink functions of the environment should not be degraded. Therefore, the extraction of renewable resources should not exceed the rate at which they are renewed, and the absorptive capacity to the environment to assimilate wastes should not be exceeded. Furthermore, the extraction of non-renewable resources should be minimised and should not exceed agreed minimum strategic levels.*
- *Social sustainability – which requires that the cohesion of society and its ability to work towards common goals be maintained. Individual needs, such as those for health and well-being, nutrition, shelter, education and cultural expression should be met.*
- *Economic sustainability – which occurs when development, which moves towards social and environmental sustainability, is financially feasible."*

"The goal of sustainable development is to enable all people throughout the world to satisfy their basic needs and enjoy a better quality of life, without compromising the quality of life of future generations."

"Sustainable development means the will to follow a rational approach to economic policies; to show respect for future generations by integrating concern for environmental protection into decision-making; and progressively to evolve towards the full participation of all concerned actors."

"sustainable development means:

- *supporting economic growth for more prosperity in partner countries;*
- *ensuring equal opportunities for rich and poor, North and South, women and men;*
- *utilising natural resources for the benefit of present and future generations."*

"The concept of sustainability is interpreted here as integration and balance of the 3 fundamental domains i.e. economic development, environmental quality and social equity, through an on-going process of change and adaptation, to fulfill inter-generation and intra-generation needs."

"Sustainability is a means of configuring civilization and human activity so that society and its members are able to meet their needs and express their greatest potential in the present, while preserving biodiversity and natural ecosystems, and planning and acting for the ability to maintain these ideals indefinitely."

"Sustainability means living within the resources of the planet without damaging the environment now or within the future. It also means having an economic system that provides a genuine quality of life, rather than depending on increased consumption."

"Sustainability is defined as meeting the needs of current and future generations through simultaneous environmental, social and economic improvement."

"Sustainability is the economic and social changes that promote human prosperity and quality of life without causing ecological or social damage. It is a new way of thinking about an age-old concern: ensuring that our children and grandchildren inherit a tomorrow that is at least as good as today, preferably better. We want to make sure that the way we live our lives is sustainable - that it can continue and keep improving for a long, long time."

"Sustainable development is a dynamic process which enables all people to realize their potential and improve their quality of life in ways which simultaneously protect and enhance the Earth's life support systems."

(Rio Earth Summit, 1992; Emrgnc, 2003; GTZ, 2005; The UK Government, 1999; Gilbert et al, 1996; WCED, 1987; Lee, 2008)

These definitions reflect different interpretations of sustainability by various parties. From the definitions, it also can be noticed that economy, environment and society are the foremost ingredients of sustainability concept commonly recognized in the world. However, all the definitions are given in high level policy statements addressing global concerns which provided little useful advice for practical daily decision making (Christopher Wedding, 2008). A universal and exact definition of sustainability suitable for different levels (global, regional, and local), industries, and organization does not exist. In order to understand the essence of sustainability, deeper insights into the concept should be gained.

2.4.2 Insight into sustainability concept

The following paragraphs go beyond the definitions of sustainability in search of deeper insights into the concept. The essence of the sustainability concept is explored through components introduction, process and end result discussion, and different levels of analysis.

2.4.2.1 Components of sustainability

Sustainable development is often thought to have three dimensions: environment, society, and economy (Lee, 2008; Gilbert et al, 1996; Shearlock et al, 2000). The "triple bottom line" of sustainability is often the phrase used in business circles – economic vitality, environmental quality, and social equity (Christopher Wedding, 2008). Lee (2008) discussed the relationships between the foremost three dimensions under the concept of sustainability:

Economic Vitality

Economic conditions have a direct impact on social well-being. A weak economy can lead to business closure, a high level of unemployment, an increase in the crime rate, etc. The quality of life of the public further deteriorates during an economic recession. Consequently, every municipality aims to sustain long-term economic growth to retain acceptable living standards for citizens (Couch, 1990).

Environmental Quality

Destruction and depletion of natural resources such as forest, soil, water, air and fuel would adversely affect the human life of current and future generations. Sources that pollute the environment and lead to global warming/ climate change problem have to be controlled and measures protecting habitats and species have to be taken (Shearlock et al., 2000). In order to avoid negative impacts on the preservation of global environment, measures for natural resources are required.

Social Equity

Equity is a fundamental and essential dimension of social sustainability (Chiu, 2002). Social equity mainly implies consideration of the social, cultural and spiritual needs of various social groups to ensure that a more efficient and equitable allocation of limited resources can be achieved (Pincetl, 2001). Social sustainability is the idea that future generations should have the same or greater access to social resources as the current generation.

The three components are interconnected and mutually reinforced, and are often presented as three interconnected circles. Achieving sustainability involves reaching the overlapping areas of the three circles (see Fig. 2.10). Differences in interpretation mostly derive from how each of the three dimensions of sustainable development are emphasised.

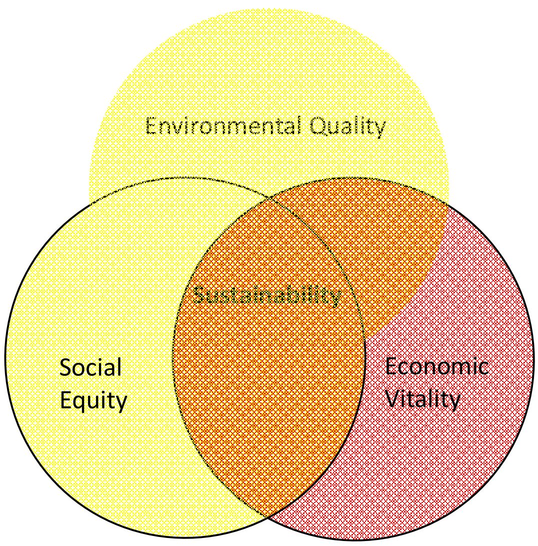

Fig. 2.10 Common three components of sustainability

2.4.2.2 Sustainability: process or end result?

There is a question about whether sustainability is a kind of guiding principle, as many of its supporters would argue, or rather a concrete goal or set of goals that can be measured, evaluated and “achieved.” Research referenced earlier reveals support for both points of view. In order to achieving sustainability as a goal, it needs a dynamic process to improve and change current development models (Lee, 2008; Berke and Conroy, 2000). According to the OECD (2008), sustainable development is: (i) a conceptual framework: a way of changing the predominant world view to one that is more holistic and balanced; (ii) a process: a way of applying the principles of integration across space and time to all decisions; and (iii) an end goal: identifying and fixing the specific problems of resource depletion, health care, social exclusion, poverty, unemployment, etc.

2.4.2.3 Levels analysis of sustainability

Ideas of sustainability can exist at different levels of analysis. Sustainability has been discussed in global, regional, national, and local levels. However, the concept is easy to understand but difficult to achieve. In order to do so, sustainable principles should also be applied in different contexts: municipalities, institutes, communities, individual lives, individual goods and services, occupations, lifestyles, behaviour patterns, and so on. In short, it can entail the full compass of biological and human activity or any part of it (MEA, 2003). From another point of view, sustainability can be implemented in industry, business/company level, and project/product levels. Sustainability cannot be well understood without referring to the distinctions between different levels of analysis.

2.4.3 Sustainable BEER under the EPC mechanism

2.4.3.1 Current sustainable system for building retrofit

Recently, much attention has been paid to the issue of sustainable retrofitting. Keeping and Shiers (1996) proposed the "green" refurbishment concept and analyzed the potential benefits of a "green" approach to building refurbishment. Sobotka and Wyatt (1998) applied the principles of "sustainable development" to a renovation of apartment buildings. Sitar et al. (2006) considered a model of sustainable renovation for multi-apartment buildings. The sustainable renovation of a building is presented in two scenarios, in which an energy efficiency renovation should examine the connections between possibilities of architectural design, renovation technologies, and energy efficiency heating of the building. Mickaityte et al. (2008) presented a concept model of sustainable building refurbishment, which provides excellent opportunities to reduce energy consumption and encourages the implementation of other sustainable refurbishment principles including citizen's health, environment protection, rational resource use, information about sustainable refurbishment dissemination and stakeholders groups' awareness. The EU launched a large research project SUREURO (Sustainable Refurbishment Europe) in 2000. SUREURO (2004) has developed models and systems that provide housing organizations, interested parties, local authorities, town planners, construction companies, etc. opportunities to perform refurbishment processes within a normal time schedule and budget. The SUREURO models and systems offer users considerable environmental improvement and energy savings. The effort of SUREURO is to combine an overview of usable and available SUREURO models and systems and the context on which housing people can use these tools and, furthermore, it helped to identify what kind of management and participation skills are required in order to be successful.

Many global organizations have developed comprehensive sustainability assessment systems to promote sustainability in building environments. Currently, the most well known assessment systems for green or sustainable building are LEED, developed by the US. Green Building Council, BREEAM developed by BRE Global in the UK, GBTool/SBTool developed by the Green Building Challenge (a collaboration of more than 20 countries), and HK-BEAM in Hong Kong (now called BEAM Plus). These sustainable systems have developed several versions and all of them have special versions for existing buildings. However, the existing building sustainability evaluation tools are mainly intended to assess the actual performance of a building and to give guidance on potential best performance. With reference to retrofit projects, BRE Global is developing a new standard to enable the sustainable refurbishment of existing housing titled BREEAM Domestic Refurbishment. Most versions for new constructions are also used where building have undergone major renovation. However, these sustainable systems only consider a construction project from physical perspectives and pay little attention to project organization and delivery method.

2.4.3.2 Sustainable BEER

As mentioned above, BEER can improve energy efficiency and indoor environment quality. This helps existing buildings improve sustainability and achieve green building status (Papadopoulos et al., 2002; Gorgolewski, 1995; Hong et al., 2006). It is necessary to integrate the sustainable approach into BEER projects. Again, sustainable development not only is an end goal, but also a continuous process (OECD, 2008). AACPS Development Office (2005) also indicated that project sustainability involves two facets: (1) maintaining the outcomes, goals and products; (2) institutionalizing the process. Under sustainable development strategy, the analysis and understanding of sustainable projects should consider projects life cycle. Sustainable BEER is intended to be developed by applying the concept of sustainability to existing buildings and retrofit projects. A truly sustainable BEER should consider economic vitality, environmental quality, and social equity at the project level and should aim to achieve sustainability in those three dimensions. Economic sustainability of BEER includes cost-efficiency of retrofit project. Economic sustainability is improved by reducing the retrofitting capital costs and the running costs of the retrofitted building. As this research concerns hotel building, it also aims to increase the operating profit of hotels by improving the competitiveness and attractiveness after retrofit. BEER environmental sustainability is the main objective of these projects. Saving energy and, therefore, money, is the result of a successful project. Besides, environmentally friendly activities should be embraced in the project process. Social sustainability of BEER at the project level includes improving public awareness and education of energy efficiency, improving health and safety, and taking account of local cultural heritage etc.

Previous research has paid more attention to the retrofitting result, design, material choice, and technical process rather than focus on the project organizational process. The EPC mechanism as a delivery method has many advantages, one of which is to offer a streamlined approach to make facility improvements. An ESCO can provide a full range of services and continue working with clients once the projects are complete to ensure that clients get optimal long-term energy performance. According to the above analysis, in order to achieve the sustainable BEER, it is necessary to integrate sustainable development strategy into both the sustainability performance of BEER and the EPC mechanism itself.

2.4.3.3 Achieving sustainable BEER under EPC mechanism

In order to allow a better understanding of sustainable BEER under the EPC mechanism, Fig. 2.11 depicts the interrelationships between sustainable development, BEER, and the EPC mechanism. The process of BEER can be simplified into four phases: energy audit, design, executing, and operation. This study takes the EPC mechanism as the retrofit business model and focuses on hotel buildings in China. Understanding the relationship clearly can help to define sustainable performance of BEER and find success factors to achieve BEER sustainability under the EPC mechanism. Fig. 2.12 shows the theoretical framework for sustainable BEER under the EPC mechanism. The sustainability of each of the three dimensions can be measured using KPIs, which are quantifiable, for the BEER project. At the bottom level, critical success factors under the EPC mechanism affecting the KPIs are identified.

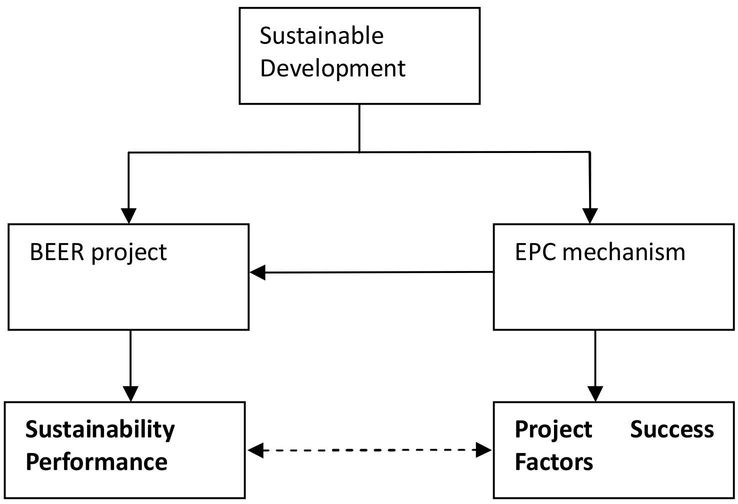

Fig. 2.11 Relationships among components in sustainable BEER projects

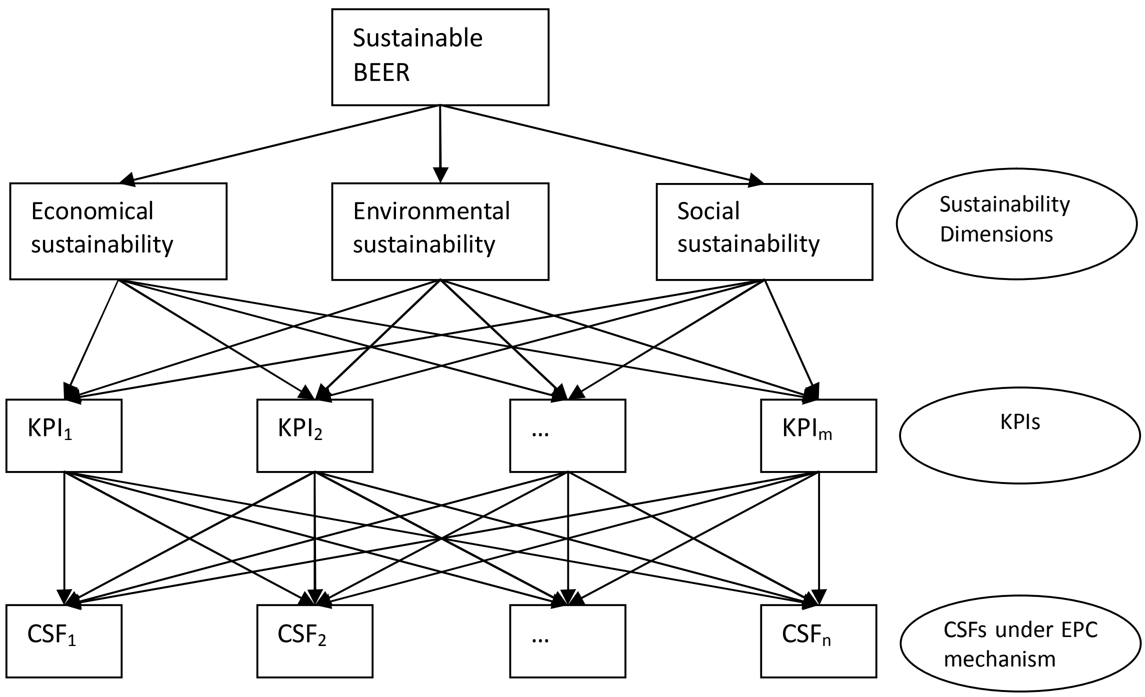

Fig. 2.12 A theoretical hierarchy of sustainable BEER under the EPC

2.5 Summary

A comprehensive review was conducted in the above section, which helps to clear the research boundaries and understand BEER projects and the EPC mechanism. Based on sustainable development theory, the nature of sustainable BEER under the EPC mechanism was defined. A theoretical framework of sustainable BEER under the EPC was developed for this research at the end of this chapter.

CHAPTER 3 Research Methodology

3.1 Introduction

3.2 Research framework and methodology

3.3 Literature review

3.4 Face-to-face interview

3.5 Questionnaire survey

3.6 AHP/ANP approach

3.7 Summary

3.1 Introduction

This chapter sets out the research design and methodology adopted in the current study. In this chapter, the research framework is first presented, followed by a discussion of data collection procedure, the samples used, data analysis methods, and development of decision-making model. A number of systematic research methodologies and strategies are discussed in this chapter.

3.2 Research framework and methodology

The methodology adopted herein largely depends on the research objectives and the logic of the study. As stated previously, the aim of this research is to develop a model for achieving the sustainability of Building Energy Efficiency Retrofit (BEER) using the Energy Performance Contracting (EPC) mechanism in hotel buildings, which consist of four research objectives, which are further divided into six steps. Fig. 3.1 shows the research framework of this study and research methodology in each step. The research methods adopted in this study consist of literature review, document analysis, face-to-face interviews, questionnaire surveys, group meetings, statistical analysis, fuzzy set theory, and analytic network process (ANP). Two or more methods, either qualitative or quantitative, may be combined to achieve a certain objective.

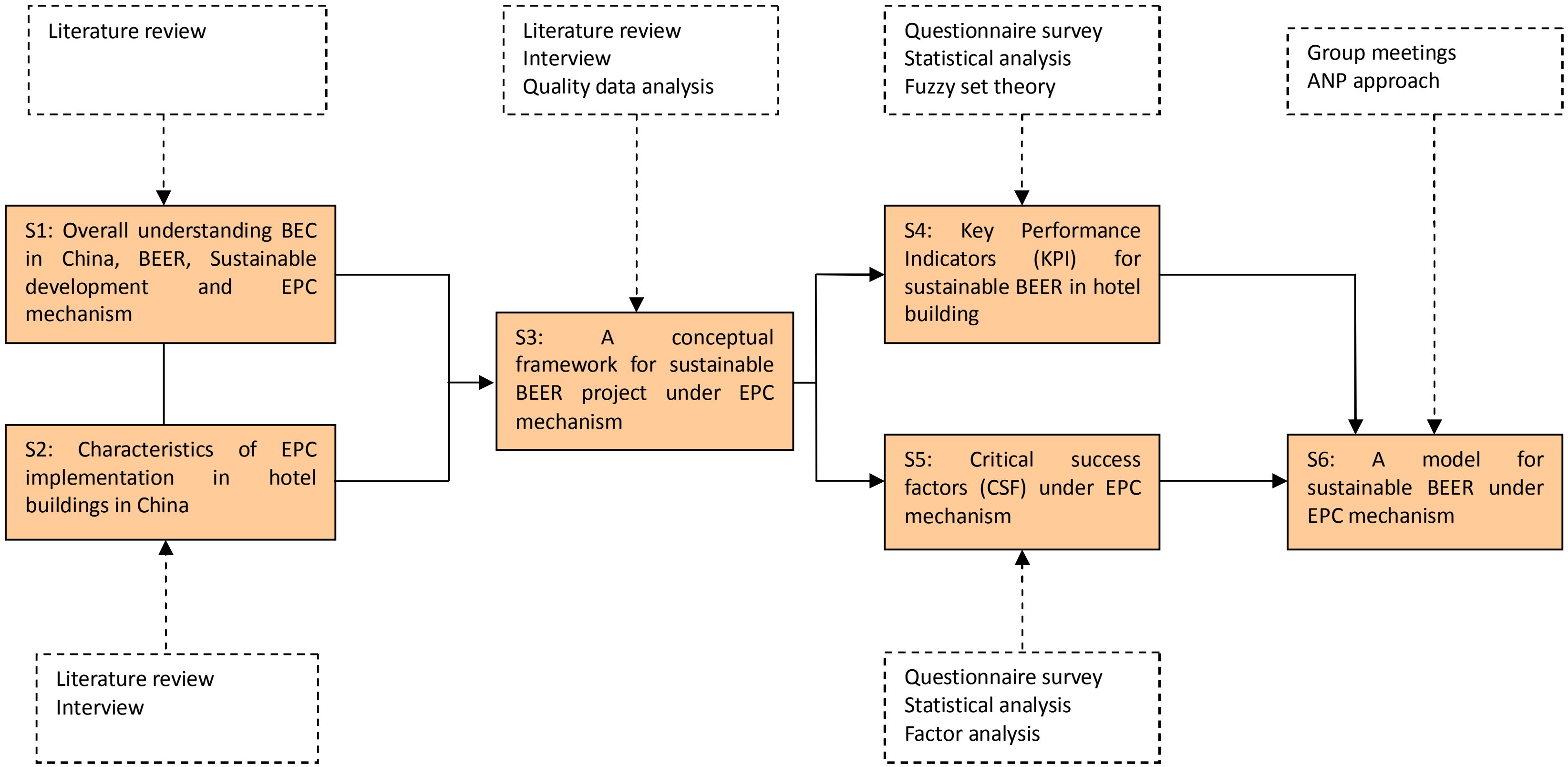

Fig. 3.1 the Research Framework and Research Methodology

Step 1: Overall understanding of BEER, sustainable development and the EPC mechanism

This research is a combination of BEER, sustainable development, and the EPC mechanism. Building energy consumption (BEC) also factors into the study. Conducting a comprehensive literature review of each topic at the commencement of the study elucidates the research underpinning these topics. A comprehensive literature review helps understand sustainable BEER and provide the basis for a theoretical hierarchy encompassing all these aspects.

Step 2: Characteristics of EPC implementation in hotel buildings in China and typical EPC models

This step followed Step 1 to investigate the current status of EPC application in hotel building retrofit in China. The main research methods in this step include literature review and interviews. A set of structured interviews was conducted to understand the current status of EPC implementation in hotel buildings in China. The result of this survey enabled the examination of characteristics for implementing EPC in hotel buildings in China and selecting the potential KPIs for sustainable BEER in hotel buildings, as well as CSFs of EPC.

S3: A conceptual framework for sustainable BEER project under EPC mechanism

This step developed a conceptual framework to link the sustainable BEER and affecting factors together. Then the potential performance indicators for sustainable

BEER and affecting factors for EPC success were examined based on literature review and face-to-face interviews.

S4: Key Performance Indicators for sustainable BEER

A questionnaire was designed based on the potential performance indicators and success factors selected through literature review and interviews. A questionnaire survey and statistical analysis was conducted to help identify the KPIs. In this part, the final KPIs were identified using fuzzy set theory.

S5: Critical Success Factors under EPC mechanism

The delivered questionnaire contains two parts. The first part is for KPIs and the second for CSFs of the EPC mechanism. CSFs were selected by the mean values of importance of each factor and then classified into several categories with similar characters through factor analysis.

S6: A model for sustainable BEER under EPC mechanism

After indentifying the KPIs for sustainable BEER and CSFs of the EPC mechanism, an ANP model was developed to explain the relationships between the KPIs and CSFs. In this step, two rounds of group meetings were conducted to collect data and make an ANP exercise.

3.3 Literature review

Literature review is the collection of background information of a research study. It aims to consolidate all previous studies related to the research by other researchers and understanding the current practice (Chow, 2005). A suitable literature review could help the researcher to dig out the research problems. Literature review is not just about reading the relevant publications but rather about presenting critiques of existing works in order to identify gaps in knowledge (Yeung, 2007; Xia, 2010).

A number of relevant texts were examined in order to obtain a holistic picture of each topic of this study including: BEER, EPC, and sustainable development. Firstly, the concept, technologies and process of building energy efficiency retrofit (BEER) and the approach to sustainable building energy efficiency retrofit were reviewed. Secondly, a detailed review of EPC was performed, including definitions, business models, EPC project procedure, barriers to EPC industry, and the development of EPC mechanism in China. Thirdly, another review examined the concept of sustainable development/sustainability and current sustainable BEER systems. After that, a theoretical framework for sustainable BEER under the EPC mechanism was formulated. The detail results of the reviews were reported in Chapter 2. After the overview of the BEER, EPC, and sustainable development, a comprehensive literature review and data collection were conducted to examine the potential performance indicators for sustainable BEER and success factors of EPC mechanism. Details can be found in Chapter 4.

3.4 Face-to-face interviews

Face-to-face interviews were adopted because of the synchronous communication in time and place. They offer the possibility of dispelling ambiguity because the interviewer is adjacent to the interviewee as the questions are being answered (Opdenakker, 2006). Another main reason of conducting face-to-face interviews lies in the quality of the data obtained. Since the EPC mechanism has not been commonly used in China, minimal prior research has been conducted on BEER at the project management level. It is necessary to conduct a set of interviews with experts to collect data.

A series of semi-structured interviews with 17 professionals were conducted to identify performance indicators for assessing the sustainability of BEER in hotel buildings and affecting factors of EPC project success. Nine of the professionals were engineering managers of hotels, five were project managers from contractors, and three were academic researchers. All of them had more than five years of experience in the area of energy efficiency. BEER is a relatively new business venture in China and there are not many professionals available who have a comprehensive view of BEER to hotel buildings. Details of the interviewees are shown in Table 3.1. As the interviewees were senior personnel who could provide first-hand diverse and rich information, the interviews were purposefully not structured to facilitate free flow of ideas. The interviews discussed six issues: i) energy consumption and retrofit measurements of hotel buildings; ii) understanding of sustainable development theory; iii) features of good retrofit projects; iv) EPC projects organization; v) problems in the EPC process; and vi) Participants' expectations and evaluation of the projects. The interviews were conducted between April and July 2010. Each of the interviews lasted from one to two hours and was tape recorded and fully transcribed.

After that, a qualitative data analysis (QDA) was conducted with respect to the collected information through interviews and secondary information from literature. The analysis process contains two steps: summarization and compilation. All the collected information and secondhand material from literature was summarized into items. Then, the items with the similar meaning were categorized together and compiled into a performance indicator.

Table 3.1 Details of the interviewees

Sector (No.)	**Current role**	**Company**	**Years of Exp.**
Hotel (9)	Engineering Manager	South Union Hotel	13
	Engineering Manager	Golden Coast Lawton Hotel	8
	General Manager	Bohua Harbour View Hotel	17
	Engineering Manager	Haikou Huitong Hotel	22
	Engineering Manager	Ye Hai Hotel	14
	Engineering Manager	Haikou Tower Hotel	25
	Engineering Manager	Leaguer Resort Sanya Bay	7
	Engineering Manager	Xinyuan Hot Spring Hotel	25
	Engineering Supervisor	Sanya Beautiful Spring Spa Garden Resort	12
ESCO (5)	General Manager	Bard Energy Saving Engineering Co., Ltd.	20
	General Manager	Yangpu Oasis Energy Saving Co., Ltd.	15
	Vice-general Manager	Shenzhen Guoneng Power investment Co., Ltd.	15
	Business Manager	Shenzhen LED industry Association	8
	Contracts Manager	IET Energy Technology Co.,Ltd.	5
Academic (3)	Professor	The Haikou College of Economics	20
	Post Doctor	The Hong Kong Polytechnic University	5

	Lecture	The Shenzhen University	6

3.5 Questionnaire survey

Questionnaire is an effective tool in conducting a survey research for observing and recording data beyond the physical reach of the observer, and for sampling the opinion of individuals in spatially diverse locations. This is because questionnaire is usually designed to get standardized data from the respondents by giving a set of choices for each question for them to select (Yeung, 2007).

3.5.1 Questionnaire survey in this study

In this study, potential performance indicators and success factors were selected based on information collected through interviews. In order to analyze importance of the selected indicators and factors and identify the KPIs for sustainable BEER and CSFs of EPC mechanism, a questionnaire was designed to deliver and collect data. The questionnaire is composed of three parts. The first part deals with the personal information of respondents. The second part is for identifying KPIs. The last contains questions for the CSFs in the third part. The level of importance is measured on a 5-point Likert scale in the questionnaire, where "Extremely Unimportant = 1" "Unimportant = 2", "Neutral = 3", "Important = 4", and "Extremely Important = 5". At the beginning of the questionnaire, personal basic information of respondents was also collected, such as their position, experience, type of enterprise, etc.

3.5.2 Data analysis techniques

The data collected in this section was analyzed by a number of statistical techniques including descriptive statistics, mean score ranking technique, reliability analysis, analysis of variance (ANOVA), fuzzy set theory, and factor analysis. Statistical Package for the Social Sciences (SPSS) was the primary tool employed for analyzing the raw data.

3.5.2.1 Descriptive Statistics

Useful information cannot be extracted unless raw data collected from various samples is well organized (Russo, 2003). Therefore, descriptive statistics that can organize, summarize, simplify and interpret data sets effectively should be used to analyze the sample data (Lee, 2008). In this research, descriptive statistical techniques were applied to both demographic and attitudinal data in order to identify the characteristics of particular groups and describe the similarities and differences among variables.

3.5.2.2 Mean score ranking technique

Ranking the relative importance of each variable was established by the "mean score" method. Rankings of various performance indicators and success factors were obtained by calculating the means for the overall sample as well as for separate groups of respondents. If two or more factors happened to have the same mean value, the one with lower standard deviation was assigned a higher rank.

3.5.2.3 Reliability Analysis

Reliability is concerned with the degree to which the results can be replicated. Reliability analysis is useful to measure the degree of stability or consistency of the measurement scales and the variables that make them up. A statistic called Cronbach's alpha (α) is the most widely used measure of reliability (Aron and Aron, 2002). According to Aron and Aron (2002), α with value from 0 to 1 was used to measure the internal consistency of the data collected; the greater the value (i.e. α closer to 1), the higher is the reliability of the data. Generally speaking, α at least 0.7 is the minimum requirement while α closer to 0.9 is preferable (Aron and Aron, 2002).

3.5.2.4 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) is a powerful statistical technique that involves partitioning the observed variance into different components to conduct various significance tests. ANOVA test statistics can be used to test if more than two groups' means are equal. In this study, in order to clarify whether the opinions of the experts from hotels, ESCOs, and other areas were the same for each of the nominated factors, one-way ANOVA tests of significance were conducted to explore the existence of any divergence in opinions between the different respondents' groups. The detail results of ANOVA for performance indicators and success factors were shown in Chapter 5 and Chapter 6, respectively. The results suggested that there is a consistent opinion for the three groups regarding success factors of EPC mechanism, but there are different opinions for the three groups on the performance indicators.

3.5.2.5 Fuzzy set theory

In order to identify the KPIs, the collected sample should be treated in three groups separately. Fuzzy set theory is an appropriate method to facilitate the selection process (Xia, 2010). Fuzzy set theory is therefore applied to assist in identifying the KPIs. Since Lotfi A. Zadeh (1965) introduced fuzzy set theory, it has been applied widely in many areas including engineering, management, and social science. Teodorovic (1994) used fuzzy set theory in solving complex traffic and transportation problems. Cornelissen et al. (2001) developed fuzzy mathematical models to assess sustainable development based on context-dependent economic, ecological, and social sustainability indicators. Lin et al. (2009) adopted fuzzy set theory to managerial contract analyses. Shen et al. (2010) applied it to establish the key assessment indicators (KAIs) for assessing the sustainability performance of infrastructure project.

Fuzzy set defines set membership as a possibility distribution. A fuzzy set is a pair

(A,m) where A is a set and m is degree of membership of the set A ($m: A \rightarrow [0,1] m: A \rightarrow [0,1]$). For each $x \in A x \in A$, m(x) is called the grade of membership of x in (A,m). If m(x) = 0, then x is called not included in the fuzzy set (A,m); if m(x) = 1, x is called fully included; and if 0 < m(x) < 1, x is called fuzzy member. For a finite set $A = \{x_1,...,x_n\}$, the fuzzy set (A,m) is often denoted by $\{m(x_1) / x_1,...,m(x_n) / x_n\}$. $m(x_i) / x_i$ means that the degree of membership of x_i in A is $m(x_i)$.

In this study, a selection model based on fuzzy set theory was designed to identify the KPIs for sustainability of BEER in hotel buildings. The details of this selection model are presented in Chapter 5.

3.5. 2.6 Factor analysis

Factor analysis refers to a variety of statistical techniques whose common objective is to represent a set of variables in terms of a smaller number of hypothetical variables (Kim and Mueller, 1978). It simplifies a large matrix of correlations and identifies a small number of factors that can explain most of the variables observed (Kline, 1994). Exploratory factor analysis is commonly used to identify the patterns of how the respondents reply to a set of questions and to explore the underlying structure of the patterns of responses (De Vaus, 2001). In order to obtain reliable results from this analysis, five major steps should be followed (Comrey and Lee, 1992):

(1) identify the variables;

(2) compute a correlation matrix for the variables;

(3) extract the unrotated factors to see whether the chosen model fits the data;

(4) rotate the factors to make them more interpretable; and

(5) interpret and label the rotated factors.

In this study, the success factors with means exceeding or equal to 4 were recognized as CSFs based on the consensus of the respondents in above questionnaire survey. Twenty-one factors were recognized as CSFs that significantly influenced the success of EPC for sustainable BEER. Factor analysis is used to investigate the underlying relationship among the identified CSFs to find out the clusters that can better represent all the CSFs. The details of factor analysis are presented in Chapter 6.

3.6 AHP/ANP approach

3.6.1 Analytic Hierarchic Process (AHP)

The Analytic Hierarchic Process (AHP) and the Analytic Network Process (ANP) are two decision making methods proposed by Saaty (Saaty, 1980, 1996, 2001, 2005). AHP developed by Saaty is one of the most widely used MCDM methods and has been widely applied in decision-making since its introduction. The AHP decomposes a problem into several levels making up a hierarchy in which each decision element is considered to be independent (Lee et al., 2009). A complex problem can be divided into several sub-problems based on the hierarchical level, where each level denotes a set of criteria or attributes related to each sub-problem. The top level of the hierarchy is the main goal of the decision problem. The lower levels denote the factors of the respective upper levels. AHP permits factors to be compared with the importance of individual factors relative to their effect on the problem solution.

The AHP provides an effective method to measure relative priorities of all elements within a cluster. Suppose e_1, e_2,…,e_n are n elements in a cluster; the pairwise comparison matrix of the cluster when measured with respect to a specific controlling principle is given as:

$$A = \begin{array}{c} \\ e1 \\ e2 \\ \vdots \\ en \end{array} \begin{array}{c} \begin{array}{cccc} e1 & e2 & \dots & en \end{array} \\ \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \end{array} \qquad (3.1)$$

Where the entry a_{ij} represents the relative importance of the column element e_i over the row element e_j with respect to one principle P, i.e., a_{ij} is the result of the evaluation to a question such as "how much more important is the column element e_i than the row element e_j under the criterion P?" As far as the measurement is concerned, Saaty (1980) suggested a 1-9 scale to measure the intensity of relative importance when comparing two elements. a_{ij}=1 represents equal importance for both elements e_i and e_j, while a_{ij}=9 indicates that the element e_i is extremely more important than the element e_j while with respect to criterion P. If the column element

e_i is less important than row element e_j, the scales of a_{ij} range from 1 to 1/9. The description of Saaty's 1-9 scales is given in Table 3.2. The pairwise comparison procedure will automatically generate a positive reciprocal matrix, i.e., a_{ji} is assigned to be equal to $1/a_{ij}$.

Table 3.2 Nine-point Scale for Pairwise Comparisons in AHP

Intensity of Importance	**Definition**	**Explanation**
1	Equal Importance	Two elements contribute equally to the level immediately above
3	Moderate Importance	Judgment slightly favors one element over another
5	Strong Importance	Judgment strongly favors one element over another
7	Very Strong Importance	One element is favored very strongly over another
9	Absolute/ Extreme Importance	There is evidence affirming that one element is favored over another
2, 4, 6, 8	Immediate values between above scale values	When compromise is needed
Reciprocals of above	If element *i* has one of the above non-zero numbers assigned on it when compared with activity *j*, *j* has the reciprocal value when compared to *i*	A reasonable assumption

(Saaty, 1980)

In order to calculate the priority weights of each criterion, each decomposed level with respect to a higher level forms a matrix and the pairwise comparison data are summarized in the absolute priority weights on the basis of Saaty's eigenvector procedure. The relative importance of the elements is established by solving the following formulae:

$A*w = \lambda_{max} * w$ （3.2）

Where A denotes the matrix of pair-wise comparison; w denotes the eigenvector, and λ_{max} denotes the largest Eigenvalue of A. If A denotes a consistency matrix, then eigenvector X can be determined using:

$(A-\lambda_{max}I)X=0$ （3.3）

To assess the reliability of the experts' judgments, Saaty (1980) advised the users to validate the judgments by studying their consistency in rating the relative importance of the criteria. AHP does not demand perfect consistency but it provides a measure of inconsistency in each set of judgments in terms of Consistency Index (CI) and Consistency Ratio (CR). The Consistent Index (CI) is defined as:

$CI = \frac{\lambda max - n}{n-1} CI = \frac{\lambda max - n}{n-1}$ (3.4)

Where n is the dimension of the square pairwise comparison matrix. The Consistent Index (CI) basically reflects the deviation by the amount that the eigenvalue λ_{max} deviates from n. The average CI, which depends on the matrix order in consideration over a large number of reciprocal matrices with random entries, is called the Random Index (RI), which is listed in Table 3.3.

Table 3.3 Average Random Index (RI) for corresponding matrix size

n	1	2	3	4	5	6	7	8	9	10	11
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

The ratio of Consistent Index CI to Random Index RI is defined as the Consistent Ratio:

$$CR = \frac{CI}{RI} CR = \frac{CI}{RI} \qquad (3.5)$$

If CR=0 then the pairwise comparison matrix is consistent; otherwise, it is not. In general, the standard is set at CR=0.1. If CR<0.1, the found priority vector is acceptable, otherwise, if CR>0.1, the priority weight is rejected.

3.6.2 Analytic Network Process (ANP)

The ANP is a generalization of the AHP also developed by Satty (Satty, 1996). The ANP extends the AHP to problems with dependence and feedback. The ANP allows for more complex interrelationships among decision elements by replacing the hierarchy in the AHP with a network, in which the relationships between levels are not easily classified simply as hierarchical versus non-hierarchical, or direct versus indirect (Meade & Sarkis, 1999). Hence, a hierarchical framework with a linear top-to-bottom form is not appropriate for complex systems. In addition to these merits of AHP, the ANP provides a more generalized model in decision-making without making assumptions about the independency of the higher-level elements from lower-level elements and also of the elements within their own level. A two-way arrow or arcs among different levels of criteria may graphically represent the interdependencies in an ANP model. If interdependencies are present within the same level of analysis, a looped arc may be used to represent such interdependencies (Jharkharia & Shankar, 2007). The influence of the elements in the network on other elements in that network can be represented with a supermatrix. The structure difference between an AHP hierarchy and a network is given in Fig. 3.2 (Hamza, 2006).

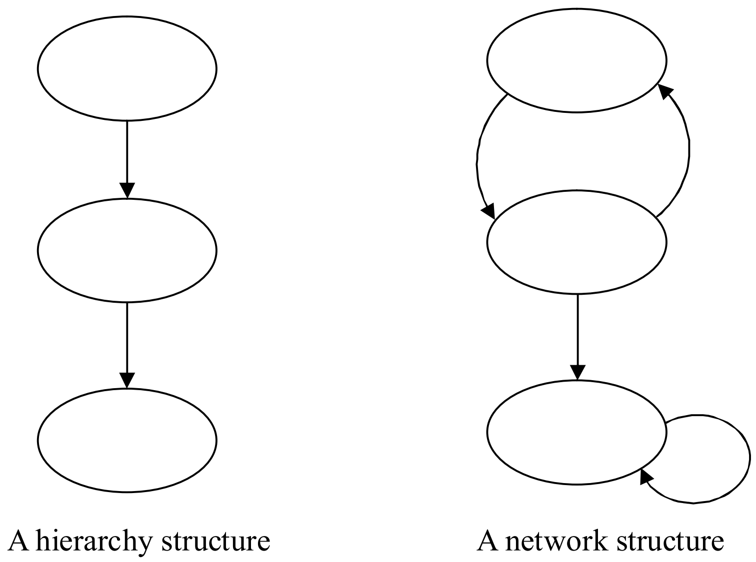

Fig. 3.2 Structural difference (Hamza, 2006)

The reasons for using an ANP-based decision analysis approach in this research are: (i) the sustainable BEER under EPC mechanism is a multi-criteria decision problem; (ii) there are dependencies among sustainable dimensions, performance criteria and groups of project success factors that have to be analyzed; (iii) the detailed analysis of the inter-relationships between clusters forces the decision-makers to carefully reflect on their project priority approach and on the decision-making problem itself. This helps to gain a better understanding of the problem and make a more reliable final decision.

The process of the ANP comprises the following four steps (Satty, 1996, 2001, 2005):

(i) Step 1 Model construction: A problem is decomposed into a network in which nodes corresponds to clusters. The elements in a component can interact with some or all of the elements of another cluster. Also, relationships among elements in the same cluster can exist. These relationships are represented by arcs with directions. In general, the ANP is a coupling of two parts. The first consists of a control hierarchy or network of criteria and sub-criteria that control the interactions in the system under study. The second is a network of influences among the elements and clusters. The network varies from criterion to criterion.

(ii) Step 2 Pairwise comparisons and local priority vectors: In this step, the elements are compared pairwisely with respect to their impacts on other elements. The way of conducting pairwise comparisons and obtaining priority vectors is the same as in the AHP. The relative importance values are determined on a scale of 1-9, where a score of 1 indicates equal importance between the two elements and 9 represents the extreme importance of one element compared with the other one. A reciprocal value is assigned to the inverse comparison; that is, $a_{ij}=1/a_{ji}$ where a_{ij} denotes the importance of the ith element compared with the jth element. Also, aii=1 is preserved in the pairwise comparison matrix. Then, the eigenvector method is employed to obtain the local priority vectors for each pairwise comparison matrix. Besides to test consistency of a pairwise comparison, a consistency ratio (CR) can be introduced with the consistency index (CI) and random index (RI). If the CR is less than 0.1, the pairwise comparison is considered acceptable.

(iii) Step 3 Supermatrix formation: The local priority vectors are entered into the appropriate columns of a supermatrix, which is a partitioned matrix where each segment represents a relationship between two clusters. Consider a network that has been decomposed into N clusters, represented by $C_1, C_2, \ldots, C_N$, and the elements in C_k, $1 \leq k \leq N$ are $e_{k1}, e_{k2}, \ldots, e_{knk}$, where nk is the number of elements in C_k clusters. The supermatrix has the following forms:

$$W = \begin{array}{cc} & \begin{array}{cccc} \begin{array}{c} C_1 \\ e_{11} \cdots e_{1n1} \end{array} & \begin{array}{c} C_2 \\ e_{21} \cdots e_{2n2} \end{array} & \cdots & \begin{array}{c} C_N \\ e_{N1} \cdots e_{NnN} \end{array} \end{array} \\ \begin{array}{cc} C_1 & \begin{array}{c} e_{11} \\ \vdots \\ e_{1n1} \end{array} \\ C_2 & \begin{array}{c} e_{21} \\ \vdots \\ e_{2n2} \end{array} \\ \vdots & \\ C_N & \begin{array}{c} e_{N1} \\ \vdots \\ e_{NnN} \end{array} \end{array} & \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1N} \\ W_{21} & W_{22} & \cdots & W_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ W_{N1} & W_{2N} & \cdots & W_{NN} \end{bmatrix} \end{array} \quad (3.6)$$

A matrix segment, W_{ij}, represents a relationship between the C_i cluster and the C_j cluster. Each column of W_{ij} is the local priority vector obtained from the corresponding pairwise comparison, representing the importance of the elements in the C_i to an element in the C_j. When there is no relationship between clusters, the corresponding matrix segment is a zero matrix. Then, pairwise comparisons should also be conducted on the clusters, which is to develop weights matrix. The supermatrix can be transformed into the weighted supermatrix, each of whose columns sums to one. Finally, the weighted supermatrix is transformed into the limit supermatrix by raising it to powers. The reason for multiplying the weighted supermatrix, is to capture the transmission of influence along all possible paths of the supermatrix.

(iv) Step 4 Final priorities: When the supermatrix covers the whole network, the final priorities of elements are found in the corresponding columns in the limit supermatrix. If there is not only one criterion in control hierarchy, repeat Step 3 to calculate other supermatrix. Finally, additional calculations should be made for obtaining final priorities.

According to Saaty (1996), making a group decision is preferable to an individual decision as brainstorming, sharing ideas, and discussion within the group can improve the final results and reduce bias against/towards a particular group of criteria. In this study, two rounds of meetings were conducted to structure the ANP model and make a set of ANP exercise. The details of the developed model are presented in Chapter 7.

3.7 Summary

This chapter provides a detailed account of the research framework for this study. The methods used to achieve the research objectives were described. The overall research design and process were first introduced, followed by the explanation of data analysis techniques and research models.

CHAPTER 4 A Conceptual Framework for Sustainable BEER Using EPC Mechanism for Hotel Buildings in China

4.1 Introduction

In this chapter, a conceptual framework is developed to provide insight into sustainable BEER and EPC mechanism. This framework contains two parts: result area and organizational area. Key result areas (KRA) for sustainable BEER and CSF categories of the EPC mechanism were identified based on the literature review, which provide an outline to select potential KPIs and CSFs. After that, a series of structured interviews with experienced practitioners and professional researchers was conducted. Potential KPIs for sustainable BEER in hotel buildings and CSFs of EPC were selected based on interview feedback.

4.2 A conceptual framework

A theoretical framework of sustainable BEER under EPC mechanism has been developed in Chapter 2, shown in Fig 2.12. This section aims to develop a conceptual framework to analyze sustainable BEER under EPC and provides an outline to select performance indicators and success factors.

4.2.1 Theoretical formulation of the framework: The EFQM Excellence Model

The EFQM Excellence Model is one of the most widely used organizational frameworks in Europe and is the basis for the majority of national and regional quality awards. The EFQM Excellence Model is a non-prescriptive framework based on 9 criteria. Five of these are 'enablers' and four are 'results'. The 'enabler' criteria cover what an organization does and how it does it. The 'results' criteria cover what an organization achieves. 'Results' are caused by 'enablers' and 'enablers' are improved using feedback from 'results'. The EFQM Model is presented in diagram form in Fig. 4.1. The arrows emphasize the dynamic nature of the model. They show innovation and learning, helping to improve enablers that in turn lead to improved results. The EFQM Model, which recognizes there are many approaches to achieving sustainable excellence in all aspects of performance, is based on the premise that excellent results with respect to performance, customers, people and society are achieved through leadership driving policy and strategy, which are themselves delivered through people partnerships and resources, and processes. The EFQM model is used to measure and improve the overall quality of an organization.

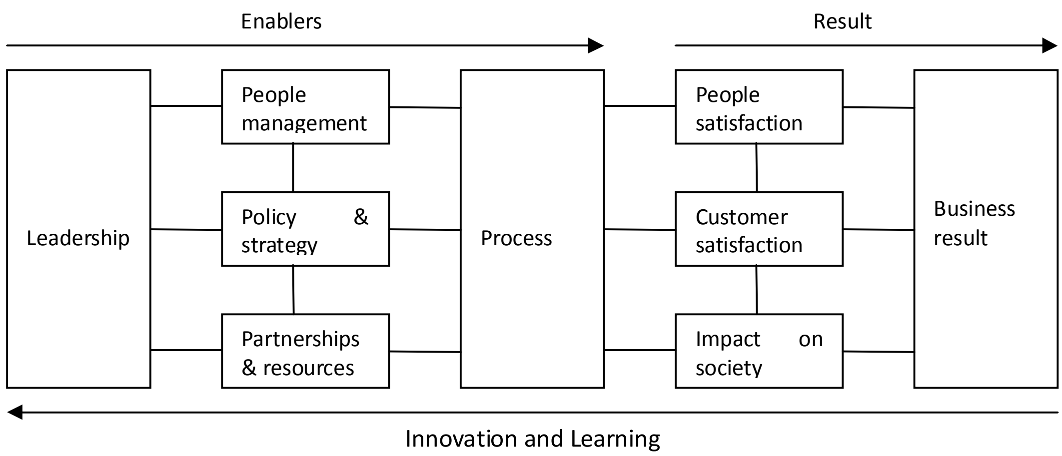

Fig. 4.1 EFQM Excellence model (www.efqm.org)

The model can be used for improving sustainability performance. However, it is suitable for business organizations in enterprises rather than at a project level. To adapt the model to the purposes of this study, it is necessary to make some further modification and improvement. Some researchers have tried to use it for construction projects. Bassioni et al (2005) built a conceptual framework for measuring business performance in construction based on the EFQM excellence model and a balanced scorecard. Westerveld (2003) modified the EFQM excellence model into project form and established the Project Excellence Model. One of the essential characteristics of the EFQM model is that it distinguishes results ("what" the organization achieved) from organization ("how" it achieved it) (Westerveld, E., 2003). In order to implement the EFQM model at the project level, the performance criteria of sustainable BEER projects could be seen as result areas and the CSFs under EPC as organizational areas:

- Result areas: Performance criteria of sustainable BEER projects
- Organizational areas: Critical success driving factors under the EPC mechanism

4.2.2 Key result areas of sustainable BEER

One objective of this research is to identify the KPIs for sustainable BEER. Cox et al (2003) defined KPIs as compilations of data measures used to evaluate the performance of an operation. They are tools that management uses to assess employee performance of a particular task. These evaluations typically compare the actual and estimated performance in terms of efficiency, effectiveness, and quality of both product and workmanship. KPIs are commonly referred to as determining the “Key Result Areas” (KRAs). Once the KRAs are agreed upon, then measures (KPIs) can be developed to support them (Yeung, 2007). KRAs refer to general areas of outcome or outputs for which a role is responsible. Before developing a set of KPIs for sustainable BEER, it is necessary to analyze the KRAs. Previous performance measurement frameworks and systems in building retrofit and sustainable construction could be useful in finding KRAs.

There are a wide variety of sustainability performance measurement tools for existing buildings and retrofits. Most of them are decision-making tools for selecting retrofit scenarios and retrofit actions. Reddy et al. (1993) offered a frame-based decision support model for building refurbishment. Rosenfiels and Shohet (1999) developed a decision support model for semi-automated selection of renovation alternatives. Alanne (2004) proposed a multi-criteria “knapsack” model to help designers select the most feasible refurbishment actions in the conceptual phase of a refurbishment project. Dascalaki and Balaras (2004) introduced a new XENIOS methodology for assessing refurbishment scenarios and the potential of applying renewable energy sources and rational use of energy in the hotel sector. Flourentzou et al. (2002), Caccavelli and Gugerli (2002) presented a retrofit decision-making model for existing buildings. This model brings energy, indoor environment quality (IEQ), scenarios, and cost analysis in the decision making process. Matinaitis et al. (2004), Matinaitis et al. (2007), and Zavadskas et al. (2008) proposed methods for appraising building renovation and energy efficiency improvement projects from an economic perspective. Juan et al. (2010) developed a hybrid decision support system for sustainable office building renovation and energy performance improvement. All the above models are decision-making tools before conducting retrofit. Another tool named IPMVP (International Performance Measurement & Verification Protocol) is the most commonly used tool in retrofit project to verify and measure the energy savings result of a retrofit project. Many global organizations have developed comprehensive sustainability assessment systems to promote sustainability in building environments. Current famous comprehensive assessment systems for green or sustainable building are LEED developed by US. Green Building Council, BREEAM developed by BRE Global in the UK, GBTool/SBTool developed by the Green Building Challenge (a collaboration of more than 20 countries), and HK-BEAM in Hong Kong. These sustainable systems have been developed into several versions, all of them have special version for existing buildings. However, the existing building sustainable evaluation tools are mainly assessing the actual performance of a building and giving guidance on potential best performance that can be obtained. Referring to retrofit project, BRE Global is developing a new standard to enable the sustainable refurbishment of existing housing entitled BREEAM Domestic Refurbishment.

In summary, these previous sustainable models for building retrofit can be mainly classified into two categories: decision tools for decision-making at the primary stage of a retrofit project and label tools for existing buildings. Previous research on performance measurement for construction project mainly considered the performance from project management objectives, such as three project management triangles - time, cost, quality, and satisfactions of people. This study intends to examine the KPIs from three areas:

- KRA_1: Project result – energy savings, project profit, etc.
- KRA_2: Project life cycle sustainability – environmental quality, health and safety, etc.
- KRA_3: Project management objectives – cost, quality, time, satisfaction etc.

4.2.3 Categories of EPC project Critical Success Factors (CSF)

This section aims to develop the CSFs of EPC mechanisms. The term "CSFs" in context of project management was first used by Rockart in 1982 and is defined as those factors predicting success on projects (Chan, 2004). Sanvido et al. (1992) indicated that the CSFs are those few things that must go well to ensure success for a manager or organization, and therefore, they represent those managerial or enterprise areas that must be given special and continual attention to bring about high performance.

There has been no systemic research to investigate the CSFs of EPC in delivering sustainable BEER projects. However, there are many lists of critical success factors for construction projects introduced by various researchers in the previous decades. Contractual arrangement, which defines the contracting parties' obligations and rights in various ways, has been identified as one major factor for the success of construction projects (Chan & Yu 2005, Chan & Suen 2005). Chua et al. (1999) maintain that success of a construction project is determined by four aspects: project characteristics, contractual arrangements, project participants, and interactive processes. Belassi & Tukel (1996) classified the factors into five distinct groups according to which element they relate to: the project manager, the project team, the project itself, the organization, and the external environment. Chan et al (2004) identified five groups of factors: project-related factors, procurement-related factors, project management factors, project participants-related factors, and external factors. All the above classification methods have some similarity. The critical success factors can be divided into five categories: external factors, project-related factors, leadership and team factors, contracting factors, and project management factors. The external environment can include the political, economic, socio-culture and technological (PEST) context in which the project is executed. Factors like the weather, work accidents or the government's favorable or unfavorable legislation can affect the project in all phases (Dimitrios, 2009). Project type and size underline some factors that are important to success. The capability of project manager and team members influences project success. The contracting factors consist of contract type, contract award method, tasks and risk allocation. Equitable risk allocation dictates both the content and the type of the contract (Gordon 1994; Diekmann and Girard 1995; Chan & Yu 2005). Project management factors are related to the communication, planning, monitoring and control, and project organization to facilitate effective coordination throughout the project life (Chua et al, 1999).

Kellen (2003) and Flanagan (2005) argued that critical success factors need to be identified in order to provide focus for performance management and measurement.

Haktanir and Harris (2005) support their views and have highlighted the discernible link between critical success factors, industry context and performance measurement. CSFs should be discussed in the context of performance measurement. This research focus on the sustainability of BEER projects and sustainable development strategy should be considered when organizing the EPC mechanism. Although, most categories of CSFs for general construction projects may suit the EPC projects, some specific success factors and their importance under each category will be changed. For example, because more organizations are involved with an existing building and new technologies are introduced, external environment and project characteristics have greater influence to the success and performance of energy efficiency projects. The most critical element for success in an EPC project is developing a mutually beneficial contract for both the owner and the ESCO. Human factors and organizational factors indeed have impacts upon project results. Besides these factors, some special issues require more efforts to consider the characteristics of an EPC projects. There is not much research on the CSFs for EPC or retrofit projects. Sanvido and Riggs (1991) named ten success factors for retrofit project management: project team characteristics, team member characteristics, contracting, information management, planning, communications, time management, space management, management of working environment, and resources/support. Zhang et al (2008) identified four categories of CSF for EPC in China: external factors, internal technology factors, internal management factors, and internal financing factors. The financing package and arrangement is a key task in EPC project, which alone can affect success of a project. Besides, partnership between a client and ESCO will be a fundamental ingredient for project success as a good partnership is conducive to the success of performance contracting (Yik & Lee, 2004). Davies and Chan (2001) also indicate that partnership is one of key ingredients for performance contracting success. In China, statistical data about energy consumption is lacking and hotel energy consumption varies from one building to another; thus, reference standards for measuring energy performance could be problematic. After retrofit, measurement and verification (M&V) is concerned with quantifying the result of a retrofit project. In summary, this part of review provides an outline for selecting nominated success factors of EPC for sustainable BEER projects. According to above analysis, there are eight the categories of CSFs for EPC in energy efficiency project:

1) external environment,
2) project self characteristic,
3) leadership and team,
4) sustainable development strategy,
5) financing package,
6) contracting,
7) partnership,
8) process management.

4.2.4 The developed framework

Fig. 4.2 shows the conceptual analysis framework for sustainable BEER under the EPC mechanism. The logic of the framework starts with leadership and team as the main driver in EPC organizations. Leadership and team, external environment and project self-characteristics together guide the approach for the financing, contracting, and partnership of a project and they are transferred into processes for implementation. The sustainable retrofit result could be performed through project result, project life cycle sustainability, and project management objectives. This proposed framework links the sustainable BEER performance and CSFs of EPC.

Because of the lack of pre-existing research, this study conducted a set of interviews with industry and academic experts to help select potential KPIs for sustainable BEER in hotel buildings and CSFs of the EPC. This developed framework contains two parts: KRAs in the result part and CSFs categories in the organizational part, which provides a guideline for selecting the potential success factors during future interviews.

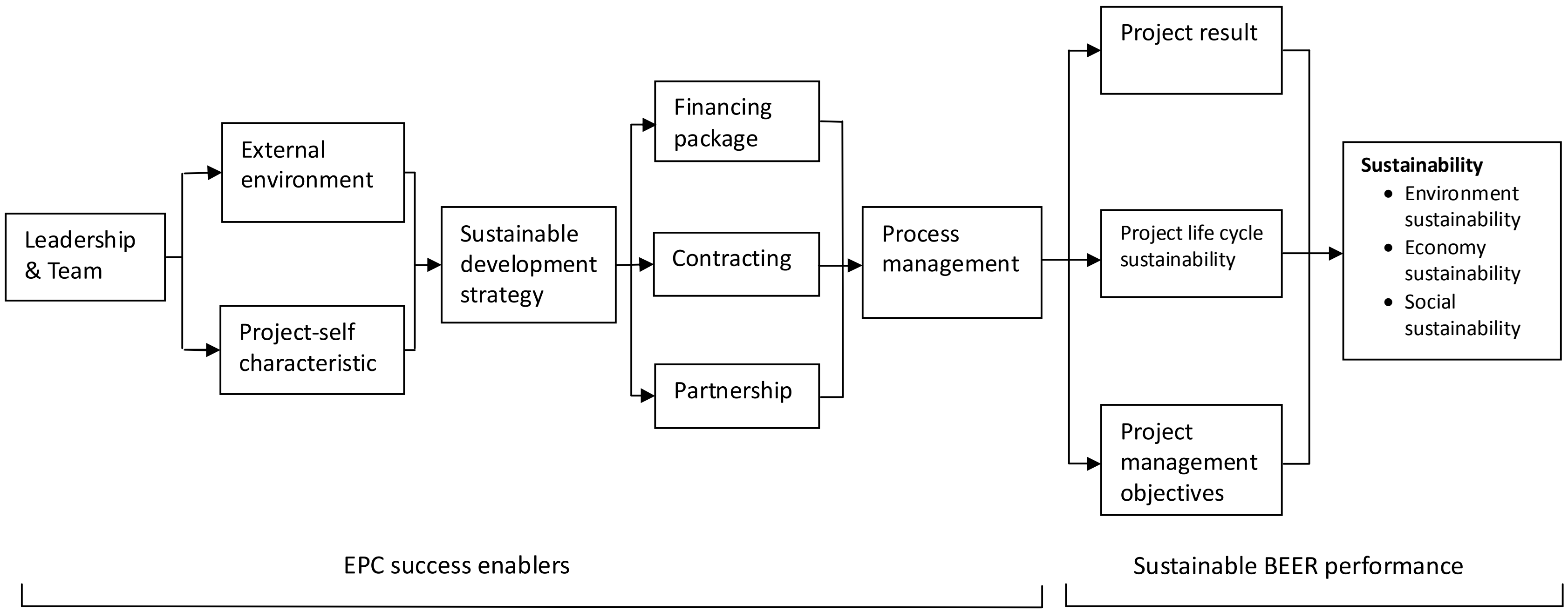

Fig 4.2 A conceptual framework for analyzing sustainable BEER under EPC mechanism

4.3 Potential KPIs and CSFs

In order to select performance indicators for assessing the sustainability of BEER in hotel buildings and affecting factors of EPC project success, a series of semi-structured interviews with 17 professionals were conducted. Nine of the professionals were engineering managers of hotels, five were project managers with the contractor, and three were academic researchers. All had more than five years experience in energy efficiency. BEER is a relatively a new business venture in China and there are not many professionals available who have a comprehensive view of BEER to hotel buildings. The details of all the interviewed experts have been described in Table 3.1 in Chapter 3. The interviews were conducted between April and July 2010. Each of the interviews lasted between one and two hours were tape recorded and fully transcribed.

As the interviewees were senior personnel who could provide first-hand, diverse, and rich information, the interviews were purposefully not structured to facilitate free flow of ideas. The interviews discussed six issues:

1) Energy consumption and retrofit measurements of hotel buildings,

2) Understanding of sustainable development theory,

3) Features of good retrofit projects,

4) EPC projects organization,

5) Problems in EPC process,

6) Participants' expectations and evaluation toward the projects.

Questions were open and interviewees were encouraged to add any details they considered relevant. During the interview, three KRAs and eight categories for selecting potential KPIs and CSFs were also presented to the experts. Questions were open and interviewees were encouraged to add any details that they considered relevant.

After that, a Qualitative Data Analysis (QDA) of the information was conducted to the collected information through interview and second information from literature. The analysis process contains two steps: summarization and compilation. Firstly, all the collected information and secondhand material from literature was summarized into items. In this process, transcribed data was read carefully line by line divided into meaningful analytical units, and then coded. Coding is defined as marking the segments of data with symbols and descriptive words. Secondly, the items with similar meaning were categorized together and compiled into one indicator or factor. The details of selected performance indicators and success factors were listed in Table 4.1 and 4.2 respectively.

Table 4.1 Selected performance indicators for sustainable BEER in hotel buildings

Code	Indicators	Descriptions
SPI-1	Cost benefit performance	This indicator is an economic indicator that reflects the project investment and project profitability.
SPI-2	Time performance	Refers to both contract period and the duration from project planning to retrofitting finish.
SPI-3	Quality performance	The total features required by product or service of the project to satisfy a given purpose.
SPI-4	Hotel function improvement	Hotel function improvement through energy efficiency retrofit, which is one project business result.
SPI-5	Health and safety	This indicator measures health and safety of all the participants during the retrofit process.
SPI-6	Energy consumption & resource savings	It one of most important project objectives. It is the real energy conservation after the hotel retrofit.
SPI-7	Hotel energy management	This indicator deals with operation of an energy management system. It reflects the convenience and efficiency improvement of energy management system after building retrofit.
SPI-8	Innovation and improvement	Refers to innovation during the project process, i.e. new technologies application and project management innovation.
SPI-9	Environmental loading	Quality of indoor and outdoor environment during the life cycle of the project.
SPI-10	Culture protection and transmission	Culture protection and transmission during project, especially for retrofitting with building envelope.
SPI-11	Stakeholders' satisfaction	The degree of satisfaction of all the participants and stakeholders.

Table 4.2 Selected success factors of EPC for sustainable BEER in hotel buildings

Groups	Factors
External factors	Economic environment
	Social environment
	Policy support
	Nature environment
	Available technology
Project-self factors	Hotel operation status
	Project complexity
	Building age
	Site and location limitation
	Tourism season and operating time limitation
Leadership & Team factors	Clients' awareness of EPC
	Organizing skill of leader
	Team members' technical background
	Communication skill
Sustainable development factors	Clients' and ESCOs' awareness of SD principles
	Sustainable development strategy planning
	Control mechanism of sustainable development strategy
Financing factors	Available financing market
	financing institute awareness of EPC
	Credit of ESCOs and clients
	Project financial status
Contracting factors	Savings share
	Task and risk allocation
Partnership factors	Trust
	Effective coordination
Project process factors	Develop appropriate organization structure
	Project objectives control mechanism
	Accurate M&V

4.4 Summary

A conceptual framework for analyzing sustainable BEER under the EPC mechanism in hotel buildings was developed. The framework modified from EFQM model, which contains two parts: result area and organizational area. The 11 potential KPIs for sustainable BEER and 28 CSFs of EPC were selected based on the developed framework through in-depth interview.

CHAPTER 5 Key Performance Indicators (KPIs) for Sustainable BEER in Hotel Buildings

5.1 Introduction

This chapter identifies the KPIs for sustainable BEER in hotel buildings. A questionnaire was designed based on the potential performance indicators selected through the interviews in the previous chapter. The questionnaires were delivered to three groups of experts and six KPIs were identified through fuzzy set theory analysis.

5.2 Questionnaire survey

In this study, 11 performance indicators and 28 success factors were selected based on information collected through interviews. In order to analyze importance of the selected indicators and factors, a questionnaire was designed to deliver and collect data. The questionnaire is composed of three parts. The first part is about the personal information of respondents. The second part is for identifying KPIs, which contains 11 questions. Similarly, there are 28 questions for the CSFs in the third part. A cover letter and a questionnaire are attached as Appendix A and Appendix B.

In responding to the questionnaire, respondents were invited to indicate the level of significance of each performance indicator and success factor. The level of importance is measured on a 5-point Likert scale, where Extremely Unimportant = ’1’, Unimportant = ’2’, Neutral = ’3’, Important = ’4’ and extremely Important = ’5’. At the beginning of the questionnaire, personal basic information of respondents was also collected, such as their position, experience, type of enterprise, etc. The questionnaire survey was conducted from Oct. to Nov. 2010.

The questionnaires were distributed via e-mail, MSN, and by hand to increase the response and sample representation. The questionnaires were delivered to three groups of people: participants in hotel engineering department, participants in ESCOs, and other people with expertise about building energy efficiency and EPC mechanisms from governments, consultancies, financing institutes, and academics. The main consideration for determining the target population was that they were all familiar with building energy efficiency and EPC mechanism. A total of 400 questionnaires were delivered to the respondents. Table 5.1 shows that 91 valid copies were retrieved, a 22.75% response rate, which is acceptable and higher than the average response rate for online surveys, which is 10%-15% (Survey Academic, 2010). Among the respondents, 22 (24.2%) were from hotels (project owners), 39 (42.8%) from energy service companies (ESCOs) (project contractors), and 30 (33.0%) were professionals from governments, academics, consultancies etc.

Table 5.1 the summary of responses in the survey

Type of group	Number	Percentage (%)
Hotel	22	24.2
Contractor (ESCO)	39	42.8
Other professionals	30	33.0
Total	91	100

5.3 Data analysis

The data were analyzed using the Statistical Package for the Social Sciences (SPSS). The reliability of the five-point scale used in the survey was determined using Cronbach's coefficient alpha, which measures the internal consistency among the factors. Previous study suggests that a value of Cronbach's alpha of 0.7 or above normally indicates a reliable set of items (Ceng and Huang, 2005). The value of this test was 0.761, which was greater than 0.7, indicating that the five-point scale measurement was reliable. Three statistical analyses, namely, scale ranking, ANOVA, and fuzzy set theory analysis, were undertaken. The analysis procedure and findings of the study are detailed in the following sections.

5.3.1 Ranking of performance indicators

Ranking of various performance indicators was obtained by calculating the means for the overall sample as well as for separate groups of respondents. If two or more factors happened to have the same mean value, the one with lower standard deviation was assigned a higher rank. The ranking results are shown in Table 5.2. It is evident that all respondents were conscious about quality performance (SPI-3), cost-benefit performance (SPI-1), health and safety (SPI-5), energy consumption and resources saving (SPI-6), and stakeholders' satisfaction (SPI-11). There are some noticeable differences between the rankings of performance indicators across various groups. For example, hotel energy management (SPI-7) is higher on the agenda of experts in the hotel industry than other groups, presumably because hotel experts are more focused on hotel operation and management.

5.3.2 Analysis of variance (AVONA)

In order to clarify whether or not the opinions of the experts were the same for each of the nominated factors, a one-way ANOVA test of significance was conducted to explore the existence of any divergence in opinion between the different respondents' groups. A probability value p below 0.05 or even 0.01 suggests a high degree of difference of opinion between the groups. The significance levels derived from the one-way ANOVA test for this study are also indicated in Table 5.2. Most of the indicators obtain the significance levels from the one-way ANOVA test being higher than 0.05, except three indicators, two of which are lower than 0.01: Hotel energy management (0.022<0.05), Innovation and improvement (0.006<0.01), and Hotel function improvement (0.006<0.01). This suggests that there is a consistent opinion for the three groups regarding most performance indicators, and there are different opinions for the three groups to the above three indicators. Therefore, the collected sample should be treated in three groups separately in the following analysis of fuzzy set theory.

Table 5.2 Ranks and ANOVA for different classification of respondents

	Performance indicators	Total (N=91)			Hotel（N=22）			ESCO（N=39）			Professionals（N=30）			ANOVA	
		Mean	*Sd*	*Rank*	*Mean*	*Sd*	*Rank*	*Mean*	*Sd*	*Rank*	*Mean*	*Sd*	*Rank*	*F*	*Sig.*
SPI-3	Quality performance	4.59	0.59	1	4.59	0.49	1	4.69	0.56	1	4.47	0.67	2	1.222	0.300
SPI-1	Cost benefit performance	4.47	0.63	2	4.36	0.77	6	4.54	0.59	2	4.47	0.56	1	0.524	0.594
SPI-5	Health and safety	4.31	0.67	3	4.45	0.66	3	4.28	0.71	3	4.23	0.62	3	0.720	0.490
SPI-6	Energy consumption & resource savings	4.27	0.55	4	4.43	0.43	4	4.25	0.57	4	4.17	0.58	4	1.495	0.230
SPI-11	Stakeholders' satisfaction	4.15	0.54	5	4.31	0.43	7	4.13	0.61	5	4.04	0.47	6	1.555	0.217
SPI-7	Hotel energy management	4.13	0.85	6	4.55	0.50	2	3.92	1.00	8	4.10	0.75	5	3.968	0.022*
SPI-9	Environmental loading	4.07	0.67	7	4.23	0.63	8	4.06	0.66	6	3.95	0.68	7	1.084	0.343
SPI-8	Innovation and improvement	3.89	0.91	8	4.41	0.72	5	3.79	0.88	9	3.63	0.91	9	5.452	0.006**
SPI-2	Time performance	3.87	0.71	9	3.91	0.73	10	3.95	0.71	7	3.73	0.68	8	0.806	0.450
SPI-4	Hotel function improvement	3.66	0.89	10	4.18	0.78	9	3.49	0.84	10	3.5	0.89	10	5.404	0.006**
SPI-10	Culture protection and transmission	3.51	0.92	11	3.91	0.73	11	3.44	0.90	11	3.3	0.97	11	3.092	0.050

*Significant at the 0.05 level ($p<0.05$), ** Significant at the 0.01 level ($p<0.01$)

5.3.3 Analysis of KPIs based on fuzzy set theory

In the questionnaire, the significance of a particular indicator is scored between 1 and 5, with the score 3 as a natural level and score 4 as an important level. Therefore, if the mean of an indicator's score is more than 4, the possibility for the indicator to be among the KPI set is high. Moreover, the value of standard deviation (Sd) should also be given consideration. When determining whether an indicator belongs to the KPI set, the larger Sd is, the less significant the indicator will be. The scoring result from the questionnaire survey is usually not in a standard normal distribution. Here, a parameter Z can be introduced to standard normalize the distribution and calculate a value for determining whether an indicator should be included in KPI set.

$$Z = (\mathrm{Mean} - 4)/\mathrm{Sd} \qquad (5.1)$$

According to statistics theory, when Z=1.65, a 95% probability of an indicator's score will fall within the range [4,+∞]. This result can be found in Standard Normal Distribution Table, $P(X \leq 1.65) = 0.95$. Fig. 5.1 shows the normal distribution of one indicator's score. According to fuzzy set theory, the degree of membership for each indicator can be described as follows:

$$m(x_i) = \int_4^{\infty} f(x_i)\, dx = 1 - P_f = P(X \leq Z) \qquad (5.2)$$

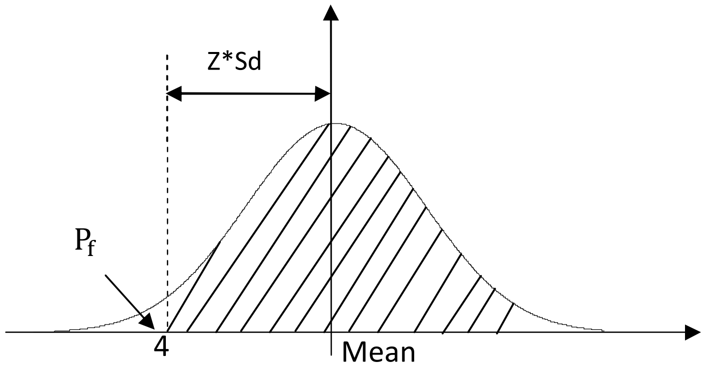

Fig. 5.1 The normal distribution of one indicator's score

The degree of membership for each indicator can be calculated by using Eq. 5.2. In order to decide whether or not an indicator is a KPI, a benchmark value should be preset. The $m(x_i)$ should meet a certain given value (λ), then the indicator X_i will be considered as a key performance indicator.

As the survey data comes from three groups of experts, different groups will produce different means, Sds, Z values, and fuzzy sets, which are represented by A_H, A_E, and A_P respectively. According to Eq. 5.1 and Eq. 5.2 and data in Table 5.2, the parameter Z and the degree of membership m of each indicator in each group can be calculated. The results of Z_H, Z_E, Z_P, $m_H(x_i)$, $m_E(x_i)$, and $m_P(x_i)$, are shown in Table 5.3.

The final integrated fuzzy set for performance indicators should be calculated from the union of three fuzzy sets derived from three groups of data. According to the definition of the union operator on fuzzy theory by Yager (1980), KPIs' fuzzy set can be described as follows (Shen et al., 2010):

$$A = A_H \cup A_E \cup A_P = \{x,\ m_{A_H \cup A_E \cup A_P}(x)/x \in X\} \quad (5.3)$$

where

$$m_{A_H \cup A_E \cup A_P}(x) = \min\left\{1, \left(m_{A_H}(x)^n + m_{A_E}(x)^n + m_{A_P}(x)^n \right)^{1/n}\right\} \quad (5.4)$$

It should be noted that n, the number of indicators, must be equal or greater than 1. In this study, the number of indicators was n=12. Therefore, the integrated result $m_A(x_i)$ was obtained from the union $m_H(x_i)$, $m_E(x_i)$, and $m_P(x_i)$ based on Eq. 5.4. The results of $m_A(x_i)$ are also shown in Table 5.3.

In order to identify the KPIs for sustainability of BEER projects, the λ-cut set approach is adopted. The λ-cut set method can transfer a fuzzy set to a classical set. The optimistic outcome is λ=1 and the worst outcome is λ=0. When λ=0.5, it means that the outcome is neither optimistic nor pessimistic. In this study, λ=0.75 is adopted as the criterion to select KPIs. Considering the indicator x_i, if m is equal or greater than 0.75, x_i is selected as KPI. In this study, eight KPIs for sustainability of BEER in hotel buildings are selected and ranked by their degree of membership (see Table 5.3). These are Quality performance (KPI1), Hotel energy management (KPI2), Cost benefit performance (KPI3), Energy consumption & resources saving (KPI4), Health and safety (KPI5), and Stakeholders' satisfaction (KPI6).

Table 5.3 The degree of membership of indicators for KPIs

Indicator set		Hotel				ESCO				Professionals				Integrated	
X		M_H	Sd_H	Z_H	$m_H(x_i)$	M_E	Sd_E	Z_E	$m_E(x_j)$	M_P	Sd_P	Z_P	$m_P(x_k)$	$m(x_i)$	
SPI-3	Quality performance	4.59	0.49	1.202	0.885	4.69	0.56	1.232	0.891	4.47	0.67	0.697	0.757	0.947*	**KPI1**
SPI-7	Hotel energy management	4.55	0.50	1.095	0.863	3.92	1.00	-0.077	0.469	4.10	0.75	0.134	0.553	0.864*	**KPI2**
SPI-1	Cost performance	4.36	0.77	0.471	0.681	4.54	0.59	0.909	0.818	4.47	0.56	0.831	0.797	0.861*	**KPI3**
SPI-6	Energy consumption & resources saving	4.43	0.43	1.010	0.844	4.25	0.57	0.437	0.669	4.17	0.58	0.288	0.613	0.849*	**KPI4**
SPI-5	Health and safety	4.45	0.66	0.693	0.756	4.28	0.71	0.395	0.654	4.23	0.62	0.379	0.648	0.774*	**KPI5**
SPI-11	Stakeholders' satisfaction	4.31	0.43	0.709	0.761	4.13	0.61	0.219	0.587	4.04	0.47	0.089	0.535	0.765*	**KPI6**
SPI-8	Innovation and improvement	4.41	0.72	0.570	0.716	3.79	0.88	-0.232	0.408	3.63	0.91	-0.402	0.344	0.716	
SPI-9	Environmental loading	4.23	0.63	0.358	0.640	4.06	0.66	0.097	0.539	3.95	0.68	-0.074	0.470	0.647	
SPI-4	Hotel function improvement	4.18	0.78	0.234	0.593	3.49	0.84	-0.608	0.272	3.50	0.89	-0.565	0.286	0.593	
SPI-2	Time performance	3.91	0.73	-0.124	0.451	3.95	0.71	-0.072	0.471	3.73	0.68	-0.392	0.347	0.490	
SPI-10	Culture protection and transmission	3.91	0.73	-0.124	0.451	3.44	0.90	-0.627	0.265	3.30	0.97	-0.721	0.236	0.451	

***the degree of membership is more than 0.75**

5.4 Key Performance Indicators (KPIs)

5.4.1 KPI1-Quality performance

Quality performance was ranked both by experts in hotels and ESCO as the top criterion for sustainability of BEER, while other experts ranked it as the second most important criterion (see Table 5.2). Parfitt and Sanvido (1993) defined quality in the construction industry as the totality of features required by a product or services to satisfy given needs, or fitness for purposes. Moreover, quality is the guarantee of fitness of products that convinces customers or end users to purchase or use them (Chan and Chan, 2004). In hotel building energy efficiency retrofit projects, project quality is directly decided by the renewed energy consumption equipment. The interviewees have also emphasized the importance of quality performance and mentioned that some energy efficiency retrofit projects are “energy-saving but not money-saving” because of high maintenance or replacement cost for poor quality equipment.

5.4.2 KPI2-Hotel energy management

The second key performance indicator is hotel energy management. This involves project operation management after completing energy efficiency retrofit. In BEER projects, operation management encourages an appropriate level of hotel building services operating in an environmentally sound manner in terms of resource use, energy consumption and pollution. This operation management criterion has been introduced into the sustainable building tool, BREEAM, as one of main assessment criteria (BREEAM 2008). Xu and Chan

(2010) indicated there are three retrofit measures for building energy efficiency improvement projects: building envelope refurbishment, energy consumption equipment replacement, and energy management system improvement. Energy management is more important in BEER projects as compared to other types of projects.

However, the ranking of this criterion is not high, even though hotel experts ranked it as the second most important criterion. In ANOVA, this criterion has a significance level of 0.022<0.05 (Table 5.2), which also indicated their different opinions of this indicator. Hotel clients and owners of BEER projects have a vested interest in the cost of hotel operations and will operate energy systems in the long-term operation management period. That is why hotel experts put a higher emphasis on energy management.

5.4.3 KPI3-Cost benefit performance

Cost benefit performance is another key performance indicator for economic sustainability. It is defined as the degree to which the general conditions promote the completion of a project within the estimated budget (Bubshait and Almohawis, 1994). Cost benefit performance was ranked first by ESCO experts and second by other professionals, but it was ranked seventh by hotel experts (see Table 5.2). This pattern of ranking would seem to reflect that hotel clients do not seems to be too concerned with the project delivery cost. Cost indeed is very important both for clients and contractors. However, because of some market mechanisms (such as energy performance contracting-EPC mechanism) and competition of energy-saving products, the contractor and equipment supplier will invest the capital in BEER project and derive compensation from future energy savings, suggesting that contractors are more concerned about cost than clients.

This indicator also reflects the profitability of a project. Both clients and contractors, like most private organizations, are profit-oriented. There is a perception that "sustainable" business practices can sometimes entail profit sacrifices. To the extent that they do not increase profitability, however, and perhaps even sacrifice profits, sustainable business efforts go against the ingrained corporate principle of shareholder-wealth maximization (Judd F. Sneirson, 2009).

5.4.4 KPI4- Energy consumption & resource savings

All sustainable assessment tools consider energy as an important criterion (BREEAM, LEED, SBTool, HK-BEAM, China-GBS etc.). The three groups in this survey consider energy consumption and resource savings as a critical important indicator. Saving energy and reducing emission of CO_2 is the final goal of these projects. Besides the project mission, energy and resource savings should also be considered during the retrofit process. The same reasons for the importance of the KPI of "Hotel energy management", apply to "Energy consumption & resource savings", hotel clients are more interested in the energy cost of hotel operation compared with the other two parties.

5.4.5 KPI5-Health and safety

Health and safety is the fifth key performance indicator (see Table 5.3). Construction is a high-risk activity. Safety, health, and well-being of workers are of paramount importance to retrofit projects. Safety programs should be guaranteed to minimize hazards in the workplace and continually monitor safety progress to ensure that project programs are working as effectively as possible. Besides on-site safety management, the health and safety of occupants needs extra attention in hotel retrofit because of the mobility of hotel customers, who take the hotel as their "home away from home".

5.4.6 KPI6-Stakeholders' satisfaction

Stakeholders' satisfaction has been proposed as an important measure for project success in the last decade (Chan and Chan, 2004; Torbica and Stroh, 2001; Cheung et al., 2000; Liu et al., 1998; Parfitt and Sanvido, 1993; Sanvido et al., 1992). Key stakeholders in a typical construction project include: client, contractor, and end users (the public). Under sustainable development principles, the result of a project should balance and satisfy all the stakeholders' needs and expectations. In this study all groups consider this performance indicator important.

5.4.7 Other performance indicators

According to the fuzzy theory model, another four selected performance indicators, having the integrated $m(x_i)$ of less than 0.75, were not considered as key performance indicators (see Table 5.3): time performance, hotel function improvement, environmental loading, innovation and improvement, and culture protection and transmission. Time performance is one criterion within the Project Management Iron Triangle; however, the BEER projects in hotels are normally small and simple, which will not impact upon the normal operation of the hotel. Either the stakeholders pay little attention to this criterion or their concerns are embedded in the cost factor. Hotel function is affected by many other issues beyond the performance of a building and hence, it will stay the same or change little after the BEER retrofit. For the environmental loading, the workplace of these projects is in the equipment room of a hotel building, which will cause minimal environmental impact to the indoor and outdoor environment. For the indicator of innovation and improvement, the p value is $0.006<0.01$ (Table 5.2), which indicates the existence of disparities among the respondent groups. According to previous interviews, it can be summarized that hotel clients expect a new product after the BEER retrofit and get the potential energy savings fully using new technologies, while contractors prefer to apply mature technologies and simple retrofit measures because contractors provide project capital and take a high risk. This can explain why hotel experts gave a higher ranking to this indicator than other experts. Without refurbishment of the building envelope or interior decoration, the indicator, culture protection and transmission may not be affected that much and hence this indicator is considered to the interviewees to be not significant to these projects.

5.5 Summary

Building Energy Efficiency Retrofit (BEER) projects play major roles in energy and cost savings, carbon reduction, and environmental protection, particularly in hotel buildings. This chapter identified and ranked the KPIs for the sustainability of BEER in hotel buildings according to their importance, which is based on the views of experts with experience in BEER. Fuzzy set theory was adopted in identifying the KPIs. 6 KPIs were selected from primary 11 selected performance indicators. They were collected based on in-depth interview and literature review. They are: (1) Quality performance, (2) Hotel energy management, (3) Cost benefit performance, (4) Energy consumption & resources saving, (5) Health and safety, and (6) Stakeholders' satisfaction. This study focuses on sustainability at project level. The traditional project management pays attention to project performance of "iron triangle" - cost, schedule, and quality. Quality and cost performances still have higher priorities in this study's findings. Other indicators related to energy, environment, and people's satisfaction are proposed for sustainable objectives.

CHAPTER 6 Critical Success Factors of the EPC Mechanism for Sustainable BEER in Hotel Buildings

6.1 Introduction

This chapter continues to analyze the data collected from the questionnaire survey for indentifying the KPIs for sustainable BEER in hotel buildings and CSFs of EPC mechanism to achieve sustainable BEER in hotel buildings, which was described in detail in Chapter 3 and Chapter 5. This chapter analyzes this part of data to identify the CSFs and utilizes a factor analysis to structure and explain them.

6.2 Identifying CSFs

The first analysis of the collected data is reliability analysis. Reliability is concerned with the degree to which the results can be replicated and is useful to measure the degree of stability or consistency of the measurement scales and the variables that make them up. Cronbach's alpha (α) was used to measure the consistency of the data. According to Aron and Aron (2002), α in value from 0 to 1 was used to measure the internal consistency of the data collected. The greater the value (i.e. α closer to 1) is, the higher is the reliability of the data. Generally speaking, α at least 0.7 is the minimum requirement while α closer to 0.9 is preferable (Aron and Aron, 2002). The data collected for CSFs were analyzed using the Statistical Package for the Social Sciences (SPSS). The value of Cronbach's coefficient alpha was 0.879, which was greater than 0.7, indicating that the five-point scale measurement was reliable. Two statistical analyses, namely, scale ranking and factor analysis, were undertaken on the data. The procedure, findings, and relevant discussion of the analyses are detailed in the following sections.

Like the identification of KPIs, in order to clarify whether or not the opinions of the experts were the same for each of the nominated factors, a one-way ANOVA test of significance was conducted to explore the existence of any divergence in opinion between the different respondents' groups. A probability value p below 0.05 or even 0.01 suggests a high degree of difference of opinion between the groups. The significance levels derived from the one-way ANOVA test for this study are also indicated in Table 6.1. All the factors have one-way ANOVA test levels higher than 0.05. This suggests that there is no significant difference in the opinion among the three groups and that the collected sample could be treated in together.

Table 6.1 also ranked the nominated factors according to their mean values of the responses. If two or more factors happened to have the same mean value, the one with the lowest standard deviation would be assigned the highest importance ranking among these factors. The factors with means exceeding or equal to 4 were recognized as CSFs based on the consensus of the respondents. Twenty-one factors were recognized as CSFs that significantly influenced the success of EPC for sustainable BEER. Table 6.1 shows the ranking of these factors based on mean values.

Table 6.1 Ranking of CSFs for EPC in sustainable BEER in hotel buildings

	Success factors	Total (N=91)			ESCO（N=39）			Hotel（N=22）			Professionals（N=30）			ANOVA	
		Mean	*Sd*	*Rank*	*Mean*	*Sd*	*Rank*	*Mean*	*Sd*	*Rank*	*Mean*	*Sd*	*Rank*	*F*	*Sig*
CSF1	Accurate M&V	4.45	0.68	1	4.62	0.63	1	4.41	0.67	4	4.27	0.74	3	2.30	0.11
CSF2	Trust	4.32	0.75	2	4.28	0.86	7	4.32	0.72	9	4.37	0.67	1	0.10	0.90
CSF3	Control mechanism of sustainable development strategy	4.27	0.74	3	4.23	0.81	10	4.45	0.51	1	4.20	0.81	5	0.85	0.43
CSF4	Available technology	4.27	0.79	4	4.33	0.87	3	4.27	0.70	10	4.20	0.76	4	0.24	0.79
CSF5	Effective coordination	4.26	0.69	5	4.15	0.74	15	4.36	0.66	7	4.33	0.66	2	0.86	0.43
CSF6	Sustainable development strategy planning	4.25	0.70	6	4.26	0.79	9	4.41	0.59	3	4.13	0.68	7	0.96	0.39
CSF7	Savings share	4.25	0.76	7	4.28	0.76	6	4.41	0.80	6	4.10	0.76	10	1.08	0.34
CSF8	Project financial status	4.23	0.76	8	4.44	0.75	2	4.18	0.59	14	4.00	0.83	26	2.96	0.06
CSF9	Credit of ESCOs and clients	4.21	0.82	9	4.21	0.86	12	4.41	0.73	5	4.07	0.83	12	1.10	0.34
CSF10	Task and Risk allocation	4.20	0.71	10	4.18	0.68	13	4.45	0.51	1	4.03	0.85	14	2.27	0.11
CSF11	Project objectives control mechanism	4.19	0.68	11	4.28	0.69	5	4.09	0.61	17	4.13	0.73	8	0.69	0.51
CSF12	Hotel operation status	4.18	0.72	12	4.26	0.68	8	4.36	0.66	7	3.93	0.78	18	2.77	0.07
CSF13	Economic environment	4.18	0.82	13	4.23	0.87	11	4.23	0.81	11	4.07	0.78	11	0.39	0.68
CSF14	Clients' and ESCOs' awareness of SD theory	4.12	0.72	14	4.31	0.95	4	4.23	0.81	11	3.80	0.81	23	3.09	0.05
CSF15	Policy support	4.12	0.89	15	4.10	0.82	17	4.18	0.59	14	4.10	0.71	9	0.10	0.91
CSF16	Clients' awareness of to EPC	4.09	0.91	16	4.15	0.81	16	4.23	1.02	13	3.90	0.96	19	0.99	0.38
CSF17	Organizing skill of leader	4.04	0.75	17	4.03	0.71	20	3.86	0.77	21	4.20	0.81	5	1.27	0.28
CSF18	Technical background of project team	4.03	0.70	18	4.18	0.76	14	4.05	1.00	19	3.83	0.75	21	1.52	0.22
CSF19	Appropriate organization structure	4.03	0.78	19	4.03	0.74	21	4.05	0.79	18	4.03	0.85	14	0.00	1.00
CSF20	Financing institutes' awareness of EPC	4.03	0.82	20	4.05	0.76	19	4.00	0.69	20	4.03	0.67	13	0.04	0.96
CSF21	Availability of financing market	4.00	0.78	21	4.08	0.70	18	4.14	0.94	16	3.80	0.76	22	1.49	0.23
	Communication skill	3.95	0.75	22	4.03	0.81	23	3.77	0.69	22	3.97	0.72	17	0.81	0.45
	Social environment	3.92	0.81	23	4.03	0.78	22	3.77	0.87	23	3.90	0.80	19	0.71	0.50
	Project complexity	3.78	0.87	24	3.95	0.92	24	3.59	0.85	25	3.70	0.79	25	1.40	0.25
	Nature environment	3.52	0.99	25	3.64	0.90	25	3.36	0.95	28	3.47	1.14	27	0.60	0.55
	Tourism season and operating time limitation	3.51	0.89	26	3.26	0.88	28	3.64	0.66	24	3.73	0.98	24	2.89	0.06
	Building age	3.47	0.84	27	3.49	1.02	26	3.55	0.60	26	3.40	0.72	28	0.20	0.82
	Site and location limitation	3.45	0.76	28	3.31	0.77	27	3.36	0.58	27	3.70	0.84	26	2.50	0.09

As indicated by Table 6.1, it was found that the five most important factors are Accurate M&V, Trust, Control mechanism of sustainable development strategy, Available technology, and Effective coordination. Measurement and Verification (M&V) is to identify the project result and energy savings. The reliable and undisputable M&V is very important for EPC projects success (Xu & Chan, 2010). During the interviews, nearly all the interviewees mentioned M&V as one of the most important factors. Trust is an important success factor for partnering (Cheng & Li, 2002; Chan et al., 2008). The EPC mechanism is one type of partnering between clients and ESCOs in nature. Both experts from hotels and ESCOs worried about their partners' credit. There is still a lack of credit history for ESCOs and customers in China. This will impact project financing from third party entities. Lack of credit and trust during project organization also causes project failure. As there is no reliable standard for M&V, it is also difficult to agree with each other about the result of energy savings (Xu & Chan, 2011). All the respondents from the three categories gave a high priority to this factor. The goal of sustainable BEER is to achieve sustainability at the project level. The control mechanism of sustainable development strategy as a success factor was proposed by an expert in academics during interviews. However, it was only given higher priorities by experts from ESCOs and hotels as opposed to other professionals. Retrofit technologies reflect new equipment, new energy resources, new energy audit technologies, and new technologies of improvement measures. Affordable and appropriate technologies in BEER decide the feasibility of these projects and the energy savings potential, which is indeed a key factor for EPC project success. Effective coordination is another import success factor for achieving sustainable BEER under the EPC mechanism. Coordination is a tool to eliminate gaps and duplication in service, which determines an appropriate division of responsibility and establishes a framework for information sharing, policy agreements, program collaboration and joint planning (IFRC, 2000). The study also found that the top five success factors in the ESCO category and hotel category were same as the general top five success factors. Only the order of these factors is different. However, for other professionals, apart from effective coordination and trust, those factors, including organizing skill of leader, project objectives control mechanism, and policy support, were given much higher priorities than other factors. This is probably because people of the other professions (governments, academics, consultancies, etc.) paid more attention to the macro factors rather than micro factors preferred by experts from the industry.

6.3 Factor analysis

A long list of 21 CSFs is not very helpful to succinctly explain the success of a project. Factor analysis was used to explore and detect the underlying relationships among the identified CSFs. This statistical technique can recognize a relatively small number of factors that can be used to represent relationships among sets of many interrelated variables. The appropriateness of the factor analysis for the factor extraction needs to be tested in various ways. Factor analysis can be used either in hypothesis testing or in searching for constructs within a group of variables (Bartholomew and Knott 1999). Factor analysis is a series of methods for finding clusters of related variables and hence an ideal technique for reducing a large number of items into a more easily understood framework (Norusis, 2000). It focuses on a data matrix produced from the collection of a number of individual cases or respondents. In this paper, factor analysis is applied to explore the underlying constructs of the identified CSFs of EPC for sustainable BEER in hotel buildings.

Basic principles of factor analysis

Norusis (2000) succinctly describes factor analysis as a series of method for finding clusters of related variables. It concerns manipulation of a data matrix produced from the collection of a number of responses (that is, measures of different variables) from many individual cases or respondents. In the research questionnaire the measure are the scores on the five-point scale for each of 21 items.

A "factor" is defined by Jackson (1981) as "any linear combination of variables in a data matrix". Hence,

$$z_1=w_{11}x_1+w_{12}x_2+w_{13}x_3+ \ldots\ldots +w_{1n}x_n$$

$$z_2=w_{21}x_1+w_{22}x_2+w_{23}x_3+ \ldots\ldots +w_{2n}x_n$$

$$\ldots \ \ldots \ \ldots$$

$$z_m=w_{m1}x_1+w_{m2}x_2+w_{m3}x_3+ \ldots\ldots +w_{mn}x_n$$

Where, w_{ij} signifies the weighting to be applied to each item score (x_1 to x_n). The weightings w_{11} to w_{mn} are derived by the use of factor analysis methods. The factor score z relates to an underlying phenomenon in the variables to x_1 to x_n. It is of particular interest if this "common factor" is specific to a collection of items.

Several methods have been developed to calculate the linear relationships making up each factor and differ in the criteria adopted to develop the factor model. The factor score (z) arising from the linear relationships can be correlated with the original loadings to create a correlation matrix. The correlations (between factors and variables) in such a matrix are termed factor loadings (Jackson, 1981) and are used in deciding which variables are most important in defining each factor.

Principle components analysis

The main aim of the study was to reduce the data set of 21 variables into a manageable set of constructs on the basis of a scientifically repeatable method. Principle components analysis is regarded as the most suitable procedure for data reduction of this nature (Johnson, 1998).

Principle components analysis involves the generation of linear combinations of variables in such a way that they account for as much of the variance present in the data as possible. Such an analysis summarizes the variability in the observed data by means of a series of linear combinations or “factors”. Each factor can, therefore, be viewed as a “super variable” comprising a specific combination of the actual variables examined in the survey (Liu, 2003). The advantage of principle components analysis over other factor analysis approaches is that the mathematical representation of the derived linear combinations avoids the use of questionable causal models (Johnson, 1998).

Analysis

In order to achieve the research objective, the analysis requires the following procedures to be performed:

1) An extraction of factors to produce a factor matrix, which shows correlations of items with each factor.

2) Rotation of the resultant factor structure into its simplest form, where items which correlate most highly with each factor can be identified.

3) Naming each of the factors in order to provide a label for each of those specific phenomena.

In this research, 21 CSFs were subjected to factor analysis using principal components analysis and varimax rotation. The first stage of the factor analysis is to determine the strength of the relationship among the variables, namely, the 21 identified CSFs, measured by the correlation coefficients of each pairs of the variables. Table 6.2 gives the matrix of the correlation coefficients among the CSFs. The correlation coefficients show that the CSFs share common factors. The Bartlett test of sphericity is 798.044 and the associated significance level is 0.000, suggesting that the population correlation matrix is not an identity matrix. The value of the Kaiser-Meyer-Olkin measure of sampling accuracy is 0.728, which is higher than 0.5 and hence is considered acceptable. The results of these tests show that the sample data is appropriate for factor analysis.

Table 6.2 Correlation matrix of CSFs for EPC in sustainable BEER in hotel buildings*

	CSF1	CSF2	CSF3	CSF4	CSF5	CSF6	CSF7	CSF8	CSF9	CSF10	CSF11	CSF12	CSF13	CSF14	CSF15	CSF16	CSF17	CSF18	CSF19	CSF20	CSF21
CSF1	1.000																				
CSF2	.169	1.000																			
CSF3	-.006	.413	1.000																		
CSF4	.158	.409	.417	1.000																	
CSF5	-.019	.554	.458	.311	1.000																
CSF6	-.031	.303	.624	.450	.291	1.000															
CSF7	.161	.184	-.026	.159	.040	.045	1.000														
CSF8	.054	.314	.337	.318	.198	.282	.222	1.000													
CSF9	.028	.355	.321	.253	.271	.232	.197	.631	1.000												
CSF10	.088	.189	.188	.354	.094	.184	.432	.302	.305	1.000											
CSF11	.245	.356	.357	.172	.340	.200	.142	.430	.405	.264	1.000										
CSF12	-.094	.200	.156	.128	.282	.086	.239	.369	.609	.210	.180	1.000									
CSF13	.172	.229	.246	.062	.344	.056	.139	.289	.109	.185	.198	.264	1.000								
CSF14	.001	.238	.083	.173	.055	.180	.036	.269	.283	.240	.072	.207	.122	1.000							
CSF15	.134	.332	.225	.309	.090	.349	-.035	.230	.291	-.046	.111	-.020	-.073	.148	1.000						
CSF16	.325	.424	.241	.320	.155	.291	.126	.226	.256	.024	.169	.077	.082	.109	.468	1.000					
CSF17	.132	.400	.292	.221	.461	.454	-.076	.252	.270	.025	.263	.087	.059	-.090	.272	.331	1.000				
CSF18	.131	.268	.257	.174	.159	.233	.110	.449	.564	.158	.266	.419	.073	.191	.346	.528	.300	1.000			
CSF19	.158	.620	.480	.345	.678	.266	.041	.267	.387	.186	.593	.147	.181	.026	.267	.245	.522	.292	1.000		
CSF20	.129	.437	.425	.322	.456	.427	-.077	.254	.255	.075	.356	.032	.104	-.077	.252	.391	.557	.208	.461	1.000	
CSF21	-.020	.130	.151	.161	.182	.239	.202	.296	.359	.294	.145	.370	.376	.347	.135	.185	.167	.479	.054	.060	1.000

*Note: Kaiser-Meyer-Olkin Measure of Sampling Adequacy = 0.728; Bartlett's Test of Sphericity = 798.044; degree of freedom = 210; significance = 0.00

In order to avoid confusion between the extracted factors and the CSFs, it is necessary to rename the extracted factor as a “cluster” in the interpretation of the results. Six clusters with eigenvalues greater than 1 are extracted. Table 6.3 lists the cluster matrix after varimax rotation. Table 6.4 shows the final statistics of the principal component analysis, and the clusters extracted account for 66.209% of the variance. The six extracted principal components accounts for 66.209% of the variance. It is indeed a bit low because some researchers recommend that the cumulative percentage of principal components should be more than 80% or even 85%. The other method for indentifying the Principal Components is to select components with eigenvalue exceeding 1 as the Principal Components. This research follows this method. Sometimes the two criteria could be both satisfied. Some references are also found showing that their percentages are not very high, such as: 72.148% (Shen and Liu, 2003), 69.24% (Li, et al., 2005), and 62% (Ng and Tang, 2010).

Table 6.3 Cluster Matrix after Varimax Rotation

	Component					
	Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**	**Cluster 6**
CSF19	.846					
CSF5	.771					
CSF18	.680					
CSF17	.639					
CSF11	.613					
CSF2	.606					
CSF9		.826				
CSF12		.740				
CSF20		.709				
CSF8		.619				
CSF6			.774			
CSF4			.624			
CSF3			.556			
CSF15			.399			
CSF16				.791		
CSF1				.651		
CSF14				.605		
CSF15					.740	
CSF7					.735	
CSF10						.840
CSF13						.593

Table 6.4 Final statistic of principle component analysis

Clusters	Eigenvalues	Percentage of Variance	Cumulative Percentage of Variance
1	6.055	28.835	17.923
2	2.355	11.215	31.297
3	1.655	7.881	41.237
4	1.428	6.801	50.780
5	1.318	6.277	59.257
6	1.092	5.200	66.209

6.4 Discussion and interpretation of CSFs

Once the clusters have been established as a reliable measure, they should be labeled in such a manner as to be of practical use in terms of further research of VM. Rummel (1970) gives a clear account on interpretation and labeling:

1) Descriptive perspective – where the cluster describes the interrelationships between its variables.
2) Causal perspective – where the cluster is the underlying cause of the interrelationship between its variables.
3) Symbolic perspective – where the cluster describes a new, undefined concept, usually labeled algebraically.

Rummel (1970) also provides a number of criteria to be applied when developing factor labels:
1) Surplus meaning – where one must avoid using a label that implies more meaning than the group of variables themselves imply.
2) Reification – where one must avoid the cluster becoming an embodiment of the label.

Based on an examination of the inherent relationships among the CSFs under each of the clusters, the six extracted clusters can be reasonably interpreted as follows: project organization process, EPC project financing for hotel retrofit, knowledge and innovation of EPC, SD and M&V, implementation of SD strategy, contracting, and external economic environment. The six clusters and their respective constituents are presented in Table 6.5. The associated explanations regarding these clusters in order of importance are as follows.

Table 6.5 Six clusters extracted based on Factor Analysis

Clusters	**CSFs**
Cluster1 Project organization process	e_{11} Appropriate organization structure e_{12} Effective coordination e_{13} Technical background e_{14} Organizing skill of leader e_{15} Project objectives control mechanism e_{16} Trust
Cluster2 EPC project financing for hotel retrofit	e_{21} Credit of ESCOs and clients e_{22} Hotel operation status e_{23} Financing institutes' awareness of EPC e_{24} Project financial status
Cluster3 Implementation of SD strategy	e_{31} Sustainable development strategy planning e_{32} Technology available e_{33} Control mechanism of sustainable development strategy e_{34} Policy support
Cluster4 Knowledge and innovation of EPC, SD, and M&V	e_{41} Clients' awareness of to EPC e_{42} Accurate M&V e_{43} Clients' and ESCOs' awareness of SD theory
Cluster5 Contracting	e_{51} Savings share e_{52} Task and Risk allocation
Cluster6 External economic environment	e_{61} Economic environment e_{62} Availability of financing market

Cluster 1: Project organization

The six extracted CSFs significant for Cluster 1 are all related to the requirements of project organization, including appropriate organization structure, effective coordination, team members' technical background, organizing skill of leaders, trust, and the project objectives control mechanism. The ingredients required for EPC project success are similar to those required for most construction projects. The first step to organize a project is to establish a team. A team leader (here, a project manager) provides guidance, instruction, direction, leadership to a group of other individuals for the purpose of achieving a key result or group of aligned results. Effective project managers are essential to project success (Belassi & Tukel, 1996; Chua et al., 1999; Chan, et al., 2004). The project manager is in charge of the project and has sufficient authority, personality, and reputation to ensure that everything that need to be done for the benefit of the project is done (Chua et al., 1999). Additionally, technical background and skill of team members is stressed by researchers as one of the key reasons for project success (Belassi & Tukel, 1996; Chan, et al., 2004).

The EPC model is meant to create a win-win situation in energy efficiency projects. Collaboration and partnership are crucial for project success organization, which need trust and effective coordination. Trust can be defined as the belief that a party can reliably fulfill its obligations in an exchange relationship (Chen and Chen, 2007). One reason for partnering failure is poor coordination of activities. In order to achieve project objective, effective coordination is necessary, which is also a requirement to project manager's organizing skill. A project manager's organizing skill plays a role in this respect. In the questionnaire, each of these two factors was considered to have a high level of significance.

Good planning and objective control are obviously important for project organization. Chua et al. (1999) indicated “interactive process” as one project success factor and refers to planning, communication, monitoring and control, and project organization throughout the project life. Identifying the project organization structure and the project objectives control mechanism is the key mission of project organization, which directly affects project success performance.

Cluster 2: EPC project financing for hotel retrofit

The four CSFs in this cluster indicate financing package for an EPC project in hotel retrofit, including the credit of ESCO and the client, hotel operation status, awareness of financing institute by EPC, and project financial status. EPC is itself a financing mechanism. A number of financial instruments may be used, such as debt, equity, mezzanine finance, contractor and client’s credit, or sureties.

The development of the EPC industry has come relatively late in China and financing institutes are not familiar with this mechanism. Lack of awareness and lack of credit history for clients and ESCOs are impediments to financing. Another CSF, hotel operation status, is a long-term financial situation and operation status. Although project capital is recovered by energy and cost savings after building retrofit, the long-term operation situation of the hotel itself is an important economic factor for success of these long-term performance contracts. This factor was proposed by several interviewed experts, which is related to investment risk and project financing.

Cluster 3: Implementation of SD strategy

This cluster contains sustainable development strategy planning, available technology, the control mechanism of sustainable development strategy, and policy support. In order to achieve sustainable development of EPC projects, the sustainable development principle should be taken as a strategy to organize these projects. Business strategy management consists of strategic planning and control of strategy plans. Strategy management for sustainable projects is a tool to guarantee sustainable objectives of the project through sustainable development strategic planning and control mechanisms.

Retrofit technologies reflect new equipment, new energy resources, new energy audit technologies, and new technologies of improvement measures. Affordable and appropriate technologies in BEER decide the feasibility of these projects and the energy savings potential. Lack of policy incentive is a main barrier confronted by energy efficiency improvement of existing buildings (Zhong et al, 2009). Although some incentive policies for EPC projects have been implemented in some areas of China, none of them is suitable for such a small-scale project in hotel buildings. More policy support should be put forth to clear legal, tax, and financial institution barriers.

Cluster 4: Knowledge and innovation of EPC, SD, and M&V

This cluster consists of awareness of clients of EPC, accurate M&V, and awareness of clients and ESCOs of sustainable development theory. This cluster is named knowledge and innovation of EPC, SD, and M&V. Measurement and Verification (M&V) is one of most important parts of EPC procedure, which is to identify the project result and energy savings. The reliable and undisputable

M&V is one of the very key success factors of EPC, which was selected as the most important success factor in the questionnaire survey.

In China, customers, suppliers, engineering companies, banks, the finance sector, and industry are all lacking in awareness of EPC (Wang, 2009; Fu, 1999; Yang et al, 2004; Xie, 2008). According to collected information from interviews, most owners of hotels have a willingness to reduce energy consumption, but few of them have heard about EPC. Lack of understanding of EPC on the part of hotel managers impedes implementing EPC in hotel retrofit or contributes to its failure.

This research is about delivering sustainable BEER in hotel buildings. Highlighting and promotion awareness of clients and ESCOs to concept of sustainability could make project success with sustainable development principles in planning, designing and building retrofit.

Cluster 5: Contractual arrangement

The two extracted CSFs, savings share and task and risk allocation, in cluster 5 are related to contractual arrangement. These two CSFs are also selected as one category during previous interview. The contractual arrangement is the key mission of EPC. The identification and allocation of risks are an important issue in contractual arrangement (Gordon 1994, Chan & Yu 2005), which include both the type and content of the contract. There are several contracting models for EPC mechanism as mentioned above. Equitable risk allocation and savings share are required for delivering sustainable and successful projects.

Cluster 6: External economic environment

Cluster 6 deals with the external economic environment, which contains the economic environment and available financing market. Strictly speaking, the available financing market belongs to economic environment. This factor is related to project financing. Table 5 only lists the maximum loadings of each CSF on each cluster. According to factor analysis, the loading of this factor on cluster 6 is 0.539 and on cluster 2 is 0.532. Hence, this factor could also be clustered into Cluster 2. Belassi and Tukel (1996) suggested that some factors that are external to the organization still have an impact on project success or failure. Various researchers support "economic environment" as a factor affecting project success (Belassi and Tukel, 1996; Chua et al, 1999; Chan et al, 2004; Zhang et al, 2008). Economic environment factors exert their impact on the function and decisions of businesses or projects and include inflation, interest rates, economic policy, level of income, unemployment, energy price, etc. The economic environment is very dynamic and complex in nature.

6.5 Summary

This Chapter identifies and ranks the CSFs of sustainable building energy efficiency retrofit (BEER) in hotel buildings according to their importance, which is measured based on the views of experts with experience in EPC and hotel energy management in China. Firstly, 28 nominated factors were selected based on literature review and experts in-depth interviews. Then 21 Critical Success Factors (CSFs) were indentified based on questionnaire survey.

According to the data collected in questionnaire survey, importance ranking of the CSFs was presented. It was found that the most important five factors are Accurate measurement and verification (M&V), Trust, Control mechanism of sustainable development strategy, Available technology, and Effective coordination. After that, using the factor analysis technique the 21 identified CSFs in this study were grouped into six clusters. These are Project organization process, EPC project financing for hotel retrofit, Implementation of SD strategy, Knowledge and innovation of EPC, SD, and M&V, Contractual arrangement, and External economic environment. The results indicate that EPC team, client, ESCO, and other related departments who are directly or indirectly involved in this work all can significantly influence the success of delivering a sustainable BEER project.

CHAPTER 7 An ANP Model for Sustainable BEER Using the EPC Mechanism

7.1 Introduction

The procedure of ANP application was introduced in Chapter 3. This chapter implements the ANP approach into this system. SuperDecision Software was used to develop and calculate the ANP model. Two rounds of group meetings were conducted from March to April 2011 in Shenzhen. The first round sought to identify the relationship among sustainable dimensions, KPIs, and CSFs, so as to structure ANP model. The second round served to conduct AHP/ANP excises and conduct pairwise comparison.

7.2 Model development

The network model shows the dependencies among the goal, criteria and the nodes (sub criteria) formulated. In general, the ANP is a coupling of two parts. The first consists of a control hierarchy or network of criteria and sub-criteria that control the interactions in the system under study. The second is a network of influences among the elements and clusters. The network varies from criterion to criterion. The elements in one cluster can interact with some or all of the elements of another cluster. Also, relationships among elements in the same cluster can exist. These relationships are represented by arcs with directions.

A concept model has been developed in Fig. 2.12 in Chapter 2. This figure proposed the hierarchies of structure. The higher the level, the more encompassing or strategic the criteria are. At the top of this hierarchy is sustainable BEER; the second level are the three dimensions of sustainability; and the third level deals with KPI, which consists of 6 key performance criteria to demonstrate sustainable BEER. The bottom level is the CSF level. Twenty-one CSFs are grouped into 6 clusters in this level, which determine the upper level. Because the CSFs are not independent, this level is a subnet level. For each KPI, different CSF clusters compose a subnet to contribute it, so there are six subnets in this structure.

In order to identify the detailed interrelationships among these hierarchy, criteria, and CSFs, the first round group meeting was carried out in Shenzhen. Six experts took part in this group meeting: one from the hotel industry, three from ESCOs, and two academics. The interrelationship tables (Table 7.1-7.3) were completed after group discussions. If the indicators in the vertical column can affect or demonstrate those in the horizontal row, the blank is filled with 1; if not, it is 0. Table 6.1 shows the relationships between the six key performance criteria and the sustainable dimensions. This table shows that the economic sustainability of BEER is contributed by KPI1 (Quality), KPI2 (Energy system management), KPI3 (Cost-benefit performance), and KPI4 (Energy savings and resource conservation). Environmental sustainability of BEER could be measured by KPI1 (Quality), KPI2 (Energy system management), and KPI4 (Energy saving and resource conservation). For the social sustainability of BEER, KPI 1 (Quality), KPI4 (Energy saving and resource conservation), KPI5 (Health and safety), and KPI6 (Stakeholders' satisfaction) are considered. In the same vein, Table 7.2 presents the relationships between CSF clusters and the key performance criteria. Table 7.3 shows the relationships among the 21 CSFs.

Table 7.1 Relationships between performance criteria and sustainable dimensions

	Ec	En	Sc
KPI1 Q	1	1	1
KPI2 HEM	1	1	0
KPI3 CB	1	0	0
KPI4 ES	1	1	1
KPI5 HS	0	0	1
KPI6 Sa	0	0	1

Table 7.2 Relationships between CSF clusters and the key performance criteria

	KPI1 Q	KPI2 HEM	KPI3 CB	KPI4 ES	KPI5 HS	KPI6 Sa
C1 Project management	1	1	1	1	1	1
C2 Project financing	0	0	1	0	0	1
C3 Implementation of SD strategy	1	1	1	1	1	1
C4 Knowledge and innovation of EPC, SD, and M&V	1	1	1	1	1	1
C5 Contracting	1	1	1	0	0	1
C6 External economics	0	0	1	0	0	1

Table 7.3 Relationships among the 21 CSFs

	e_{11}	e_{12}	e_{13}	e_{14}	e_{15}	e_{16}	e_{21}	e_{22}	e_{23}	e_{24}	e_{31}	e_{32}	e_{33}	e_{34}	e_{41}	e_{42}	e_{43}	e_{51}	e_{52}	e_{61}	e_{62}
e_{11}	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e_{12}	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
e_{13}	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
e_{14}	1	1	0	0	1	1	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0
e_{15}	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
e_{16}	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0
e_{21}	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e_{22}	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
e_{23}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
e_{24}	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0
e_{31}	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
e_{32}	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	0
e_{33}	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e_{34}	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1
e_{41}	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
e_{42}	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
e_{43}	1	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0
e_{51}	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
e_{52}	1	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
e_{61}	0	0	0	0	1	0	0	1	0	1	0	0	0	1	0	0	0	1	0	0	1
e_{62}	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0

According to the relationships identified in Tables 7.1-7.3, the ANP model is structured in Fig. 7.1. There are two parts in this model, the control hierarchy and networks. The control hierarchy with the AHP approach is shown in Fig. 7.1. For the networks part, because not all the CSF clusters contribute to each KPI (see Table 7.2), the sub-networks under each KPI will be different. With the data collected from group meetings, the ANP model is constructed. Fig. 7.2-7.7 show the subnets, which are built by the aforementioned software.

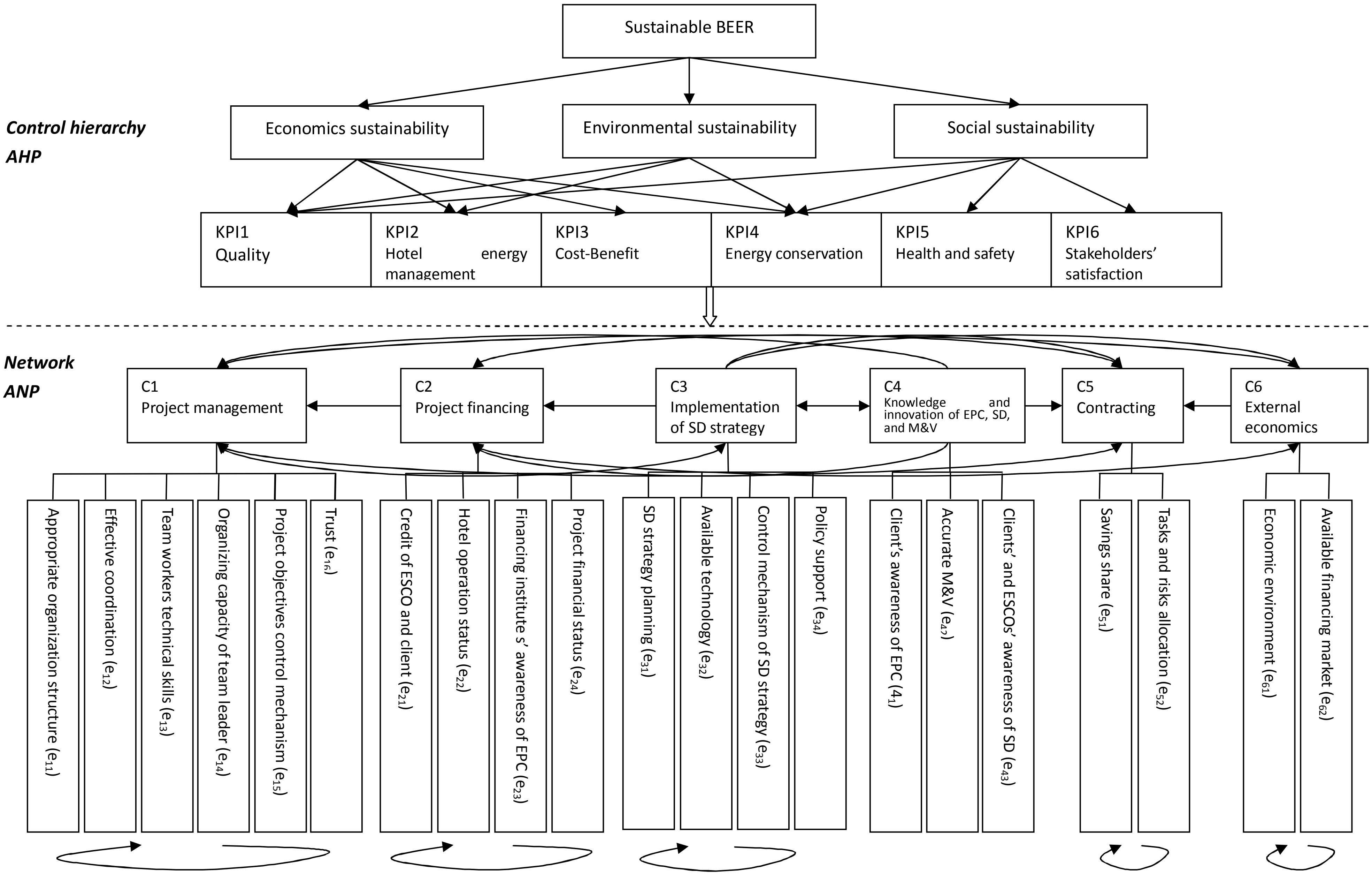

Fig. 7.1 Structure of the developed ANP model

Subnet under KPI1 (Quality): the sub-goal of this subnet is to improve quality performance of sustainable BEER projects in hotel buildings. Four CSF clusters contribute to this sub-goal, which are Cluster 1 (project process management), Cluster 3 (Implementation of sustainable development strategy, Cluster 4 (Knowledge of EPC, SD theory, and M&V), and Cluster 5 (Contracting) (see Fig. 7.2).

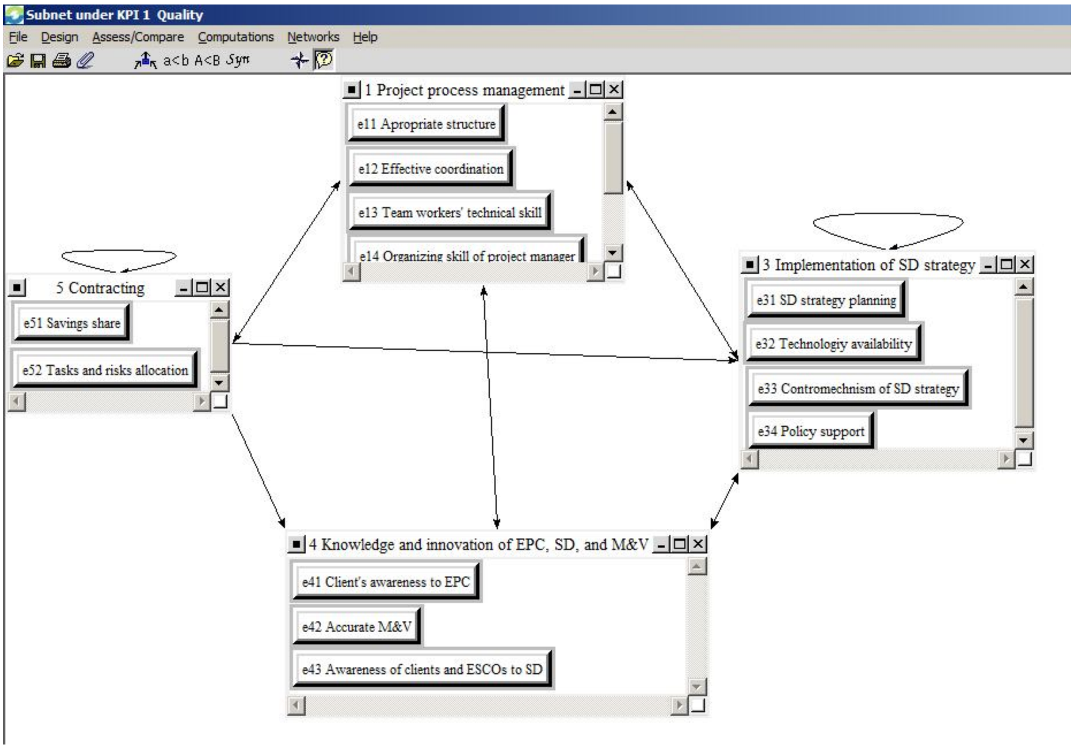

Fig. 7.2 Sub-network under KPI1

Subnet under KPI2 (Hotel energy management): the structure of this subnet is same as that under KPI1 (see Fig 7.3). Improvement of energy management is one important mission of BEER projects, which relate the project organization, energy system renewable technologies, contract contents, etc.

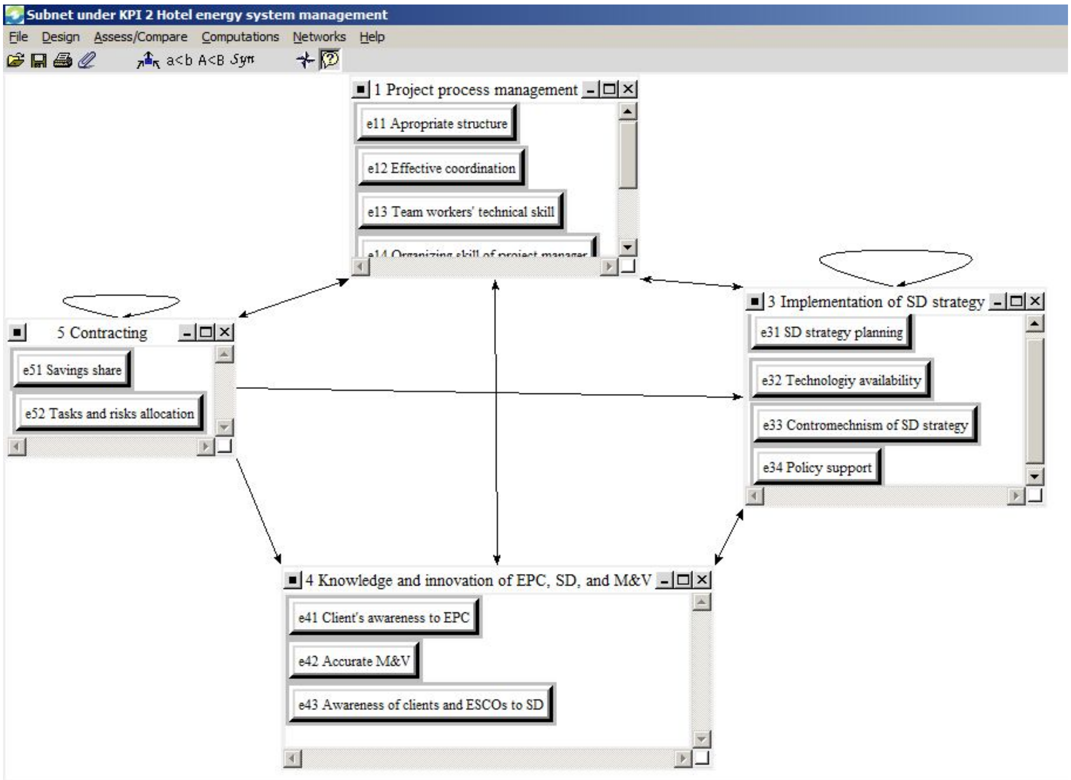

Fig. 7.3 Sub-network under KPI2

Subnet under KPI3 (Project cost-benefit) (Fig 7.4): The sub-goal of this subnet is to minimize the project cost and maximize the project profit. All six clusters of CSFs will impact the performance of this indicator.

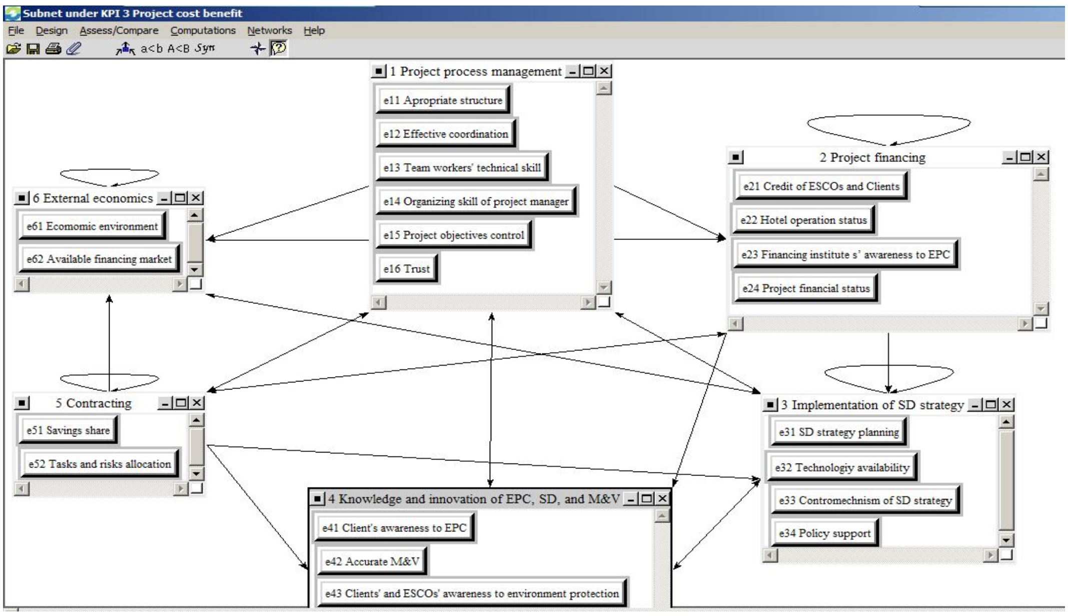

Fig. 7.4 Sub-network under KPI3

Subnet under KPI4 (Energy and resources conservation) (Fig 7.5): Three clusters contribute to this KPI: Cluster 1 (Project process management), Cluster 3 (Implementation of sustainable development strategy), and Cluster 4 (Knowledge of EPC, SD theory, and M&V.)

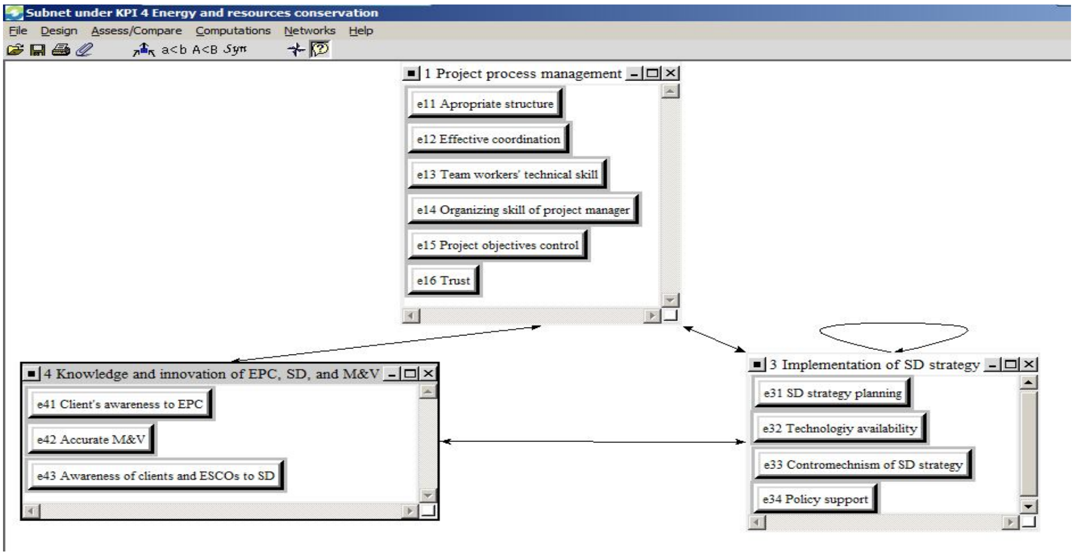

Fig. 7.5 Sub-network under KPI4

Subnet under KPI5 (Health and safety) (Fig 7.6): The goal of this subnet is to guarantee participants' safety during the project period and ensure the health of occupants after retrofitting.

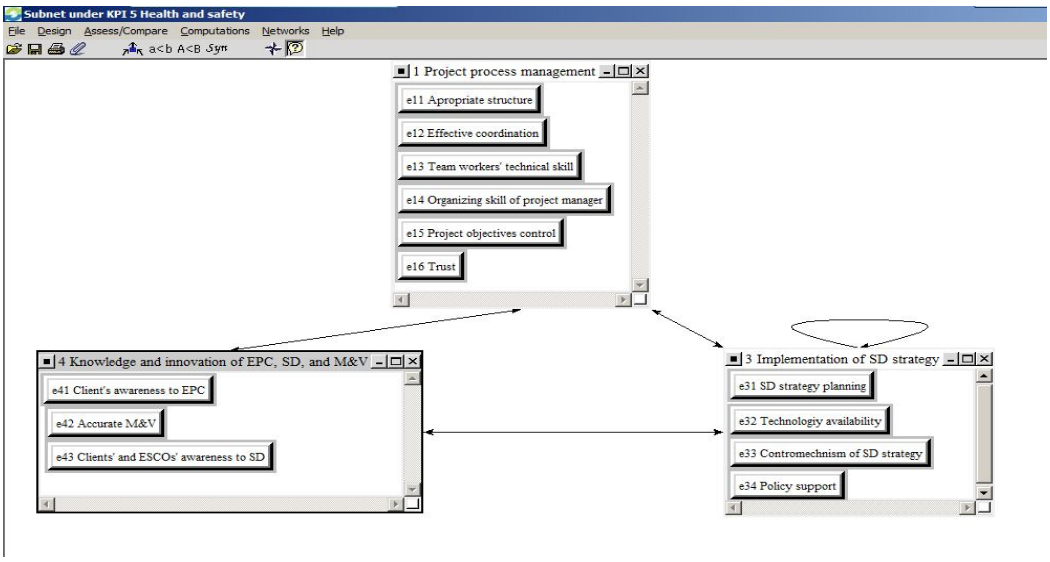

Fig. 7.6 Sub-network under KPI5

Subnet under KPI6 (Stakeholders' satisfaction) (Fig. 7.7): BEER project stakeholders include the project manager, the project team members, the funding sponsor, the hotel customers, the user group, etc. All the CSFs clusters contribute to stakeholders' satisfaction.

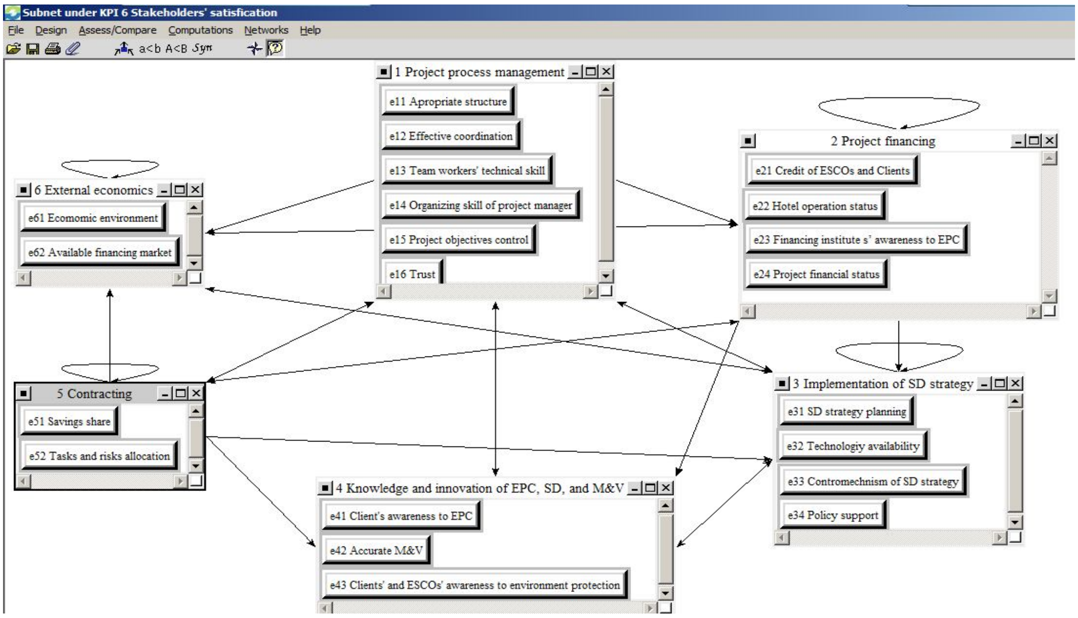

Fig. 7.7 Sub-network under KPI6

7.3 Pairwise comparison

In this step, the second round of group meetings with the same experts was conducted in April 2011 to format the pairwise comparison matrix. Group decision-making may be used to avoid the biased attitude of the decision-maker towards a particular provider (Jharkharia & Shankar, 2007). The pairwise comparison matrices were developed based on the ANP structure through group discussion. The way of conducting pairwise comparisons and obtaining priority vectors is the same as in the AHP. The relative importance values are determined on a scale of 1-9, where a score of 1 indicates equal importance between the two elements and 9 represents the extreme importance of one element compared with the other one. A reciprocal value is assigned to the inverse comparison; that is, aij=1/aji where aij denotes the importance of the ith element compared with the jth element. Also, aii=1 is preserved in the pairwise comparison matrix. Then, the eigenvector method is employed to obtain the local priority vectors for each pairwise comparison matrix. Besides to test consistency of a pairwise comparison, a consistency ratio (CR) can be introduced with consistency index (CI) and random index (RI). If the CR is less than 0.1, the pairwise comparison is considered acceptable. The SuperDecision software was also used to deal with the raw data. Users can instantaneously verify the priorities of the alternatives with respect to the criterion and at the same time check the consistency of the comparisons (see Fig 7.8.)

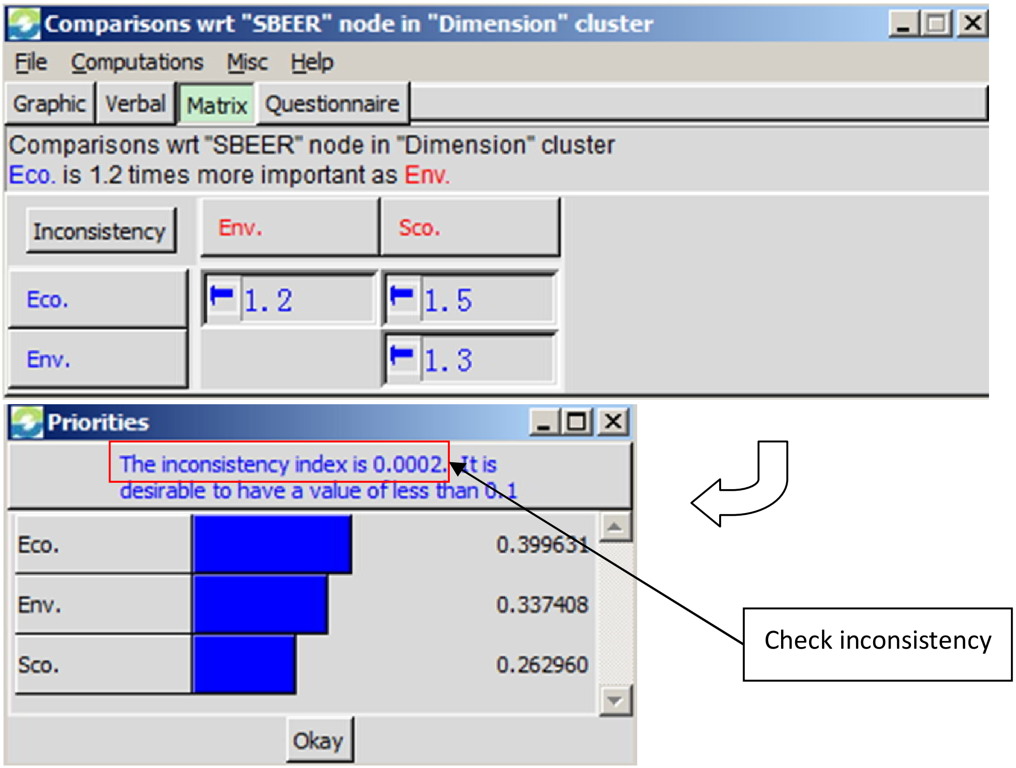

Fig. 7.8 Priorities and inconsistency check

According to the ANP structure developed above, there are four comparison matrices in control hierarchy: one matrix involves sustainable dimensions with respect to the goal of sustainable BEER and the other three are key performance criteria with respect with each sustainable dimension. The relative importance of each sustainable dimension with respect to the goal and performance criterion with respect to each dimensions are pairwised perspectively. These four pairwise comparison matrices and the resulting priority vectors are shown in Table 7.4-7.7.

Table 7.4 Pairwise comparison matrix among sustainable dimensions with respect to SBEER

SBEER	Eco	Env	Sco	Priority
Eco	1	1.2	1.5	0.400
Env		1	1.3	0.337
Sco			1	0.263

CR=0.0002

Table 7.5 Pairwise comparison matrix among performance criteria with respect to Eco

Eco	KPI1 Q	KPI2 HEM	KPI3 CB	KPI4 ES	Priority
KPI1 Q	1	2	1/3	1/2	0.154
KPI2 HEM		1	1/6	1/3	0.083
KPI3 CB			1	2	0.496
KPI4 ES				1	0.267

CR=0.0039

Table 7.6 Pairwise comparison matrix among performance criteria with respect to Env

Env	KPI1 Q	KPI2 HEM	KPI4 ES	Priority
KPI1 Q	1	1/2	1/2	0.196
KPI2 HEM		1	1/2	0.311
KPI4 ES			1	0.493

CR=0.0516

Table 7.7 Pairwise comparison matrix among performance criteria with respect to Sco

Sco	KPI1 Q	KPI4 ES	KPI5 HS	KPI6 Sa	Priority
KPI1 Q	1	1/3	1/6	1/9	0.052
KPI4 ES		1	1/2	1/3	0.155
KPI5 HS			1	1/2	0.290
KPI6 Sa				1	0.503

CR=0.0039

In the networks aspects, pairwise comparisons were also conducted to measure interdependency among the CSFs. There will be a lot of pairwise comparisons matrices developed in an ANP model. In theory, the maximum number of pairwise comparisons matrices could approach:

$$M = \sum_{i=1}^{m} n_i N_i \qquad (7.1)$$

Where, m is the total amount of the principles (sub-goals) in one ANP model. There are N_i clusters and n_i elements under the ith principle. In this research, there are six sub-goals in the structure. Because not all the elements under each principle are dependent, a total of 80 pairwise comparison matrices were made with respect to the impact on the given elements among elements under their performance criteria. The pairwise comparison matrix for elements in C1 with respect to e11 under KPI1 (Quality) is shown as an example in Table 7.8. The resulting priority vectors will be entered into a supermatrix.

Table 7.8 Pairwise comparison matrix among CSFs with respect to e11 under KPI1 Quality

e_{11}	e_{13}	e_{14}	e_{16}	Priority
e_{13}	1	1/2	1/3	0.163
e_{14}		1	1/2	0.297
e_{16}			1	0.540

CR=0.0000

Then, comparisons among CSF clusters were carried out with respect to one cluster as sub-criteria underlying performance criteria, which aim to identify the weights matrix. For example, the pairwise comparison matrix with respect to C1 PM under KPI1 is shown in Table 7.9. The resulting priority vectors will be entered into a weights matrix. There were total 26 clusters in this structure. The additional comparisons were also made for the other clusters and additional five performance criteria.

Table 7.9 Pairwise comparison matrix among clusters with respect to C1 under KPI1

C1	C1	C3	C4	C5	Priority
C1	1	2	2	2	0.400
C3		1	1	1	0.200
C4			1	1	0.200
C5				1	0.200

CR=0.0039

7.4 Supermatrix

Consider a system that has been decomposed into N clusters, represented by $C_1, C_2, \ldots, C_N$, and the elements in C_k, $1 \leq k \leq N$ are $e_{k1}, e_{k2}, \ldots, e_{knk}$, where n_k is the number of elements in C_k cluster. The interaction between different clusters may be given through a supermatrix, which is composed of the relative importance weights from each cluster of a network hierarchy. The local priority vectors are entered into the appropriate columns of a supermatrix, which is a partitioned matrix where each segment represents a relationship between two clusters. The supermatrix has the following forms:

$$
W = \begin{array}{cc} & \begin{array}{cccc} \begin{array}{c} C_1 \\ e_{11} \cdots e_{1n1} \end{array} & \begin{array}{c} C_2 \\ e_{21} \cdots e_{2n2} \end{array} & \cdots & \begin{array}{c} C_N \\ e_{N1} \cdots e_{NnN} \end{array} \end{array} \\ \begin{array}{c} C_1 \; \begin{array}{c} e_{11} \\ \vdots \\ e_{1n1} \end{array} \\ C_2 \; \begin{array}{c} e_{21} \\ \vdots \\ e_{2n2} \end{array} \\ \vdots \\ C_N \; \begin{array}{c} e_{N1} \\ \vdots \\ e_{NnN} \end{array} \end{array} & \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1N} \\ W_{21} & W_{22} & \cdots & W_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ W_{N1} & W_{2N} & \cdots & W_{NN} \end{bmatrix} \end{array} \qquad (7.2)
$$

Where the entry W_{ij} is a $n_i \times n_j$ sub-matrix representing the impact importance of elements in the cluster C_i with respect to the elements in the cluster C_j. The sub-matrix W_{ij} is given by:

$$
W_{ij} = \begin{bmatrix} w_{i1}^{j1} & w_{i1}^{j2} & \cdots & w_{i1}^{jn_j} \\ w_{i2}^{j1} & w_{i2}^{j2} & \cdots & w_{i2}^{jn_j} \\ \vdots & \vdots & \ddots & \vdots \\ w_{in_i}^{j1} & w_{in_i}^{j1} & \cdots & w_{in_i}^{jn_j} \end{bmatrix} \qquad (7.3)
$$

The k^{th} column vector in W_{ij} represents the relative important weight or eigenvector of the elements in the cluster set C_i with respect to the element e_{jk} in the cluster C_j. The column vectors could be determined from the eigenvectors of the pairwise comparison matrix of elements through the traditional AHP method (see Fig. 7.9). The element in each cluster may or may not interact with the elements in other clusters in the hierarchy. If there is no direct interaction between two clusters, the corresponding sub-matrix is a zero matrix.

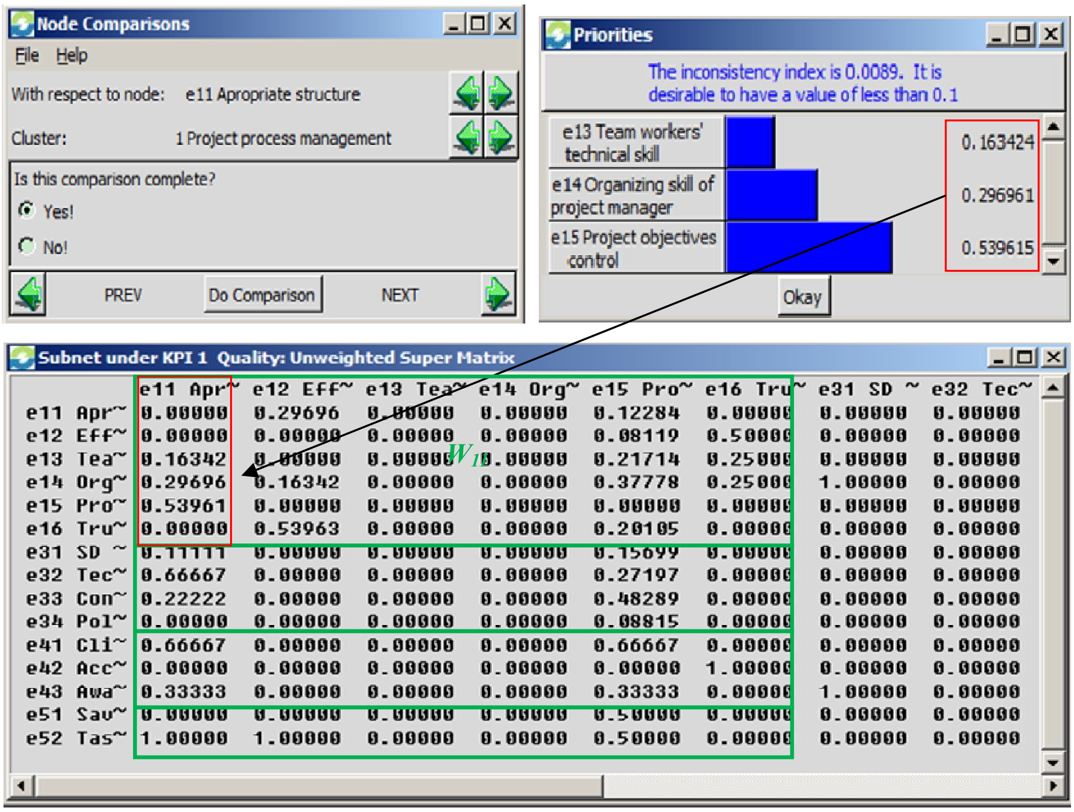

Fig. 7.9 A supermatrix developed by SuperDecision

There are three supermatrices associated with each network: the unweighted supermatrix, the weighted supermatrix and the limit supermatrix. The unweighted supermatrix contains the local priorities derived from the pairwise comparisons throughout the network as shown in Fig.7.9. All the local priority information can be read directly from the unweighted supermatrix. In this research, there are six sub-networks in the ANP structure, so there are six supermatrices developed. Consider the subnet under KPI1 (Quality) as an example. Table 7.10 shows the unweighted supermatrix under KPI1.

Table 7.10 Unweighted Supermatix under KPI1

		C1						C3				C4			C5	
		e11	e12	e13	e14	e15	e16	e31	e32	e33	e34	e41	e42	e43	e51	e52
C1	e11	0.0000	0.2970	0.0000	0.0000	0.1228	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	e12	0.0000	0.0000	0.0000	0.0000	0.0812	0.5000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3333	0.0000
	e13	0.1634	0.0000	0.0000	0.0000	0.2171	0.2500	0.0000	0.0000	0.0000	0.0000	0.0000	0.3333	0.0000	0.0000	0.4000
	e14	0.2970	0.1634	0.0000	0.0000	0.3778	0.2500	1.0000	0.0000	0.1429	0.0000	0.0000	0.0000	0.0000	0.0000	0.4000
	e15	0.0000	0.5396	0.0000	0.0000	0.2011	0.0000	0.0000	0.0000	0.2857	0.0000	0.0000	0.0000	0.0000	0.6667	0.2000
	e16	0.5396	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5714	0.0000	0.0000	0.6667	0.0000	0.0000	0.0000
C3	e31	0.1111	0.0000	0.0000	0.0000	0.1570	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	e32	0.6667	0.0000	0.0000	0.0000	0.2720	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.8000
	e33	0.2222	0.0000	0.0000	0.0000	0.4829	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	e34	0.0000	0.0000	0.0000	0.0000	0.0882	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2000
C4	e41	0.6667	0.0000	0.0000	0.0000	0.6667	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1000	0.6667
	e42	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9000	0.0000
	e43	0.3333	0.0000	0.0000	0.0000	0.3333	0.0000	1.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3333
C5	e51	0.0000	0.0000	0.0000	0.0000	0.5000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	e52	1.0000	1.0000	0.0000	0.0000	0.5000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000

The weighted supermatrix is obtained by multiplying all the elements in a component of the unweighted supermatrix by the corresponding cluster weight matrix, which makes each column therein add up to 1. The column vectors of the cluster weight matrix could be determined from the eigenvectors of the pairwise comparison of clusters. Fig. 7.10 shows the example of weight matrix under KPI1. Table 7.11 shows the weighted supermatrix under KPIs, which is calculated by multiplying the un-weighted supermatrix in Table 7.10 by the cluster weight matrix in Fig. 7.10.

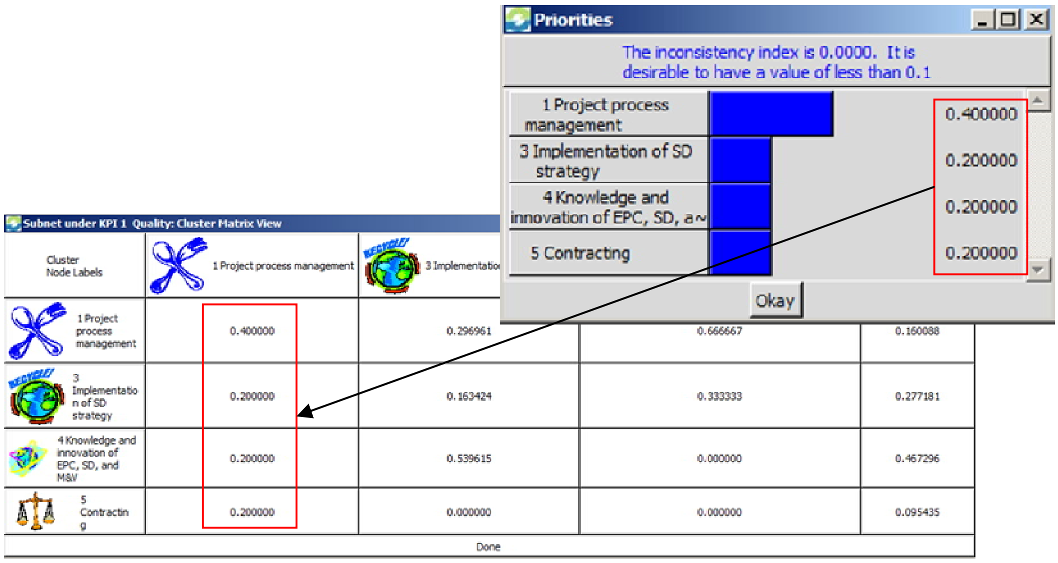

Fig. 7.10 Weight matrix under KPI1

The limit supermatrix is obtained by raising the weighted supermatrix to powers by multiplying it with itself. When the column of numbers is the same for every column, the limit matrix has been reached and the matrix multiplication process is halted.

$$W' = \lim \left(\frac{1}{N}\right) \sum_{k=1}^{N} W^k \qquad (7.4)$$

Where W' is the limit supermatrix, W is the weighted supermatrix, N indicates the sequence, and k is the exponent determined by iteration. After a limit supermatrix is calculated, repeat this process for other networks. Tables 7.12-7.17 show the six limit supermatrices in this study.

Table 7.11 Weighted supermatix under KPI1

		C1						C3				C4			C5	
		e11	e12	e13	e14	e15	e16	e31	e32	e33	e34	e41	e42	e43	e51	e52
C1	e11	0.0000	0.1980	0.0000	0.0000	0.0491	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	e12	0.0000	0.0000	0.0000	0.0000	0.0325	0.3333	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0738	0.0000
	e13	0.0654	0.0000	0.0000	0.0000	0.0869	0.1667	0.0000	0.0000	0.0000	0.0000	0.0000	0.2222	0.0000	0.0000	0.0708
	e14	0.1188	0.1089	0.0000	0.0000	0.1511	0.1667	0.3550	0.0000	0.0424	0.0000	0.0000	0.0000	0.0000	0.0000	0.0708
	e15	0.0000	0.3598	0.0000	0.0000	0.0804	0.0000	0.0000	0.0000	0.0848	0.0000	0.0000	0.0000	0.0000	0.1477	0.0354
	e16	0.2158	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1697	0.0000	0.0000	0.4444	0.0000	0.0000	0.0000
C3	e31	0.0222	0.0000	0.0000	0.0000	0.0314	0.0000	0.0000	0.0000	0.1634	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	e32	0.1333	0.0000	0.0000	0.0000	0.0544	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3333	0.0000	0.0000	0.2451
	e33	0.0444	0.0000	0.0000	0.0000	0.0966	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	e34	0.0000	0.0000	0.0000	0.0000	0.0176	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0613
C4	e41	0.1333	0.0000	0.0000	0.0000	0.1333	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0646	0.3444
	e42	0.0000	0.0000	0.0000	0.0000	0.0000	0.3333	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5818	0.0000
	e43	0.0667	0.0000	0.0000	0.0000	0.0667	0.0000	0.6450	0.0000	0.5396	0.0000	0.0000	0.0000	0.0000	0.0000	0.1722
C5	e51	0.0000	0.0000	0.0000	0.0000	0.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	e52	0.2000	0.3333	0.0000	0.0000	0.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1320	0.0000

Table 7.12 Limit supermatix under KPI1

		C1						C3				C4			C5	
		e11	e12	e13	e14	e15	e16	e31	e32	e33	e34	e41	e42	e43	e51	e52
C1	e11	0.0351	0.0351	0.0000	0.0000	0.0351	0.0351	0.0000	0.0000	0.0351	0.0000	0.0000	0.0351	0.0000	0.0351	0.0351
	e12	0.0628	0.0628	0.0000	0.0000	0.0628	0.0628	0.0000	0.0000	0.0628	0.0000	0.0000	0.0628	0.0000	0.0628	0.0628
	e13	0.0955	0.0955	0.0000	0.0000	0.0955	0.0955	0.0000	0.0000	0.0955	0.0000	0.0000	0.0955	0.0000	0.0955	0.0955
	e14	0.1037	0.1037	0.0000	0.0000	0.1037	0.1037	0.0000	0.0000	0.1037	0.0000	0.0000	0.1037	0.0000	0.1037	0.1037
	e15	0.0779	0.0779	0.0000	0.0000	0.0779	0.0779	0.0000	0.0000	0.0779	0.0000	0.0000	0.0779	0.0000	0.0779	0.0779
	e16	0.0937	0.0937	0.0000	0.0000	0.0937	0.0937	0.0000	0.0000	0.0937	0.0000	0.0000	0.0937	0.0000	0.0937	0.0937
C3	e31	0.0151	0.0151	0.0000	0.0000	0.0151	0.0151	0.0000	0.0000	0.0151	0.0000	0.0000	0.0151	0.0000	0.0151	0.0151
	e32	0.1146	0.1146	0.0000	0.0000	0.1146	0.1146	0.0000	0.0000	0.1146	0.0000	0.0000	0.1146	0.0000	0.1146	0.1146
	e33	0.0219	0.0219	0.0000	0.0000	0.0219	0.0219	0.0000	0.0000	0.0219	0.0000	0.0000	0.0219	0.0000	0.0219	0.0219
	e34	0.0138	0.0138	0.0000	0.0000	0.0138	0.0138	0.0000	0.0000	0.0138	0.0000	0.0000	0.0138	0.0000	0.0138	0.0138
C4	e41	0.0965	0.0965	0.0000	0.0000	0.0965	0.0965	0.0000	0.0000	0.0965	0.0000	0.0000	0.0965	0.0000	0.0965	0.0965
	e42	0.0767	0.0767	0.0000	0.0000	0.0767	0.0767	0.0000	0.0000	0.0767	0.0000	0.0000	0.0767	0.0000	0.0767	0.0767
	e43	0.0913	0.0913	0.0000	0.0000	0.0913	0.0913	0.0000	0.0000	0.0913	0.0000	0.0000	0.0913	0.0000	0.0913	0.0913
C5	e51	0.0193	0.0193	0.0000	0.0000	0.0193	0.0193	0.0000	0.0000	0.0193	0.0000	0.0000	0.0193	0.0000	0.0193	0.0193
	e52	0.0823	0.0823	0.0000	0.0000	0.0823	0.0823	0.0000	0.0000	0.0823	0.0000	0.0000	0.0823	0.0000	0.0823	0.0823

Table 7.13 Limit supermatix under KPI2

		C1						C3				C4			C5	
		e11	e12	e13	e14	e15	e16	e31	e32	e33	e34	e41	e42	e43	e51	e52
C1	e11	0.0333	0.0333	0.0000	0.0000	0.0333	0.0333	0.0000	0.0000	0.0333	0.0000	0.0000	0.0333	0.0000	0.0333	0.0333
	e12	0.0832	0.0832	0.0000	0.0000	0.0832	0.0832	0.0000	0.0000	0.0832	0.0000	0.0000	0.0832	0.0000	0.0832	0.0832
	e13	0.0750	0.0750	0.0000	0.0000	0.0750	0.0750	0.0000	0.0000	0.0750	0.0000	0.0000	0.0750	0.0000	0.0750	0.0750
	e14	0.0636	0.0636	0.0000	0.0000	0.0636	0.0636	0.0000	0.0000	0.0636	0.0000	0.0000	0.0636	0.0000	0.0636	0.0636
	e15	0.1050	0.1050	0.0000	0.0000	0.1050	0.1050	0.0000	0.0000	0.1050	0.0000	0.0000	0.1050	0.0000	0.1050	0.1050
	e16	0.1114	0.1114	0.0000	0.0000	0.1114	0.1114	0.0000	0.0000	0.1114	0.0000	0.0000	0.1114	0.0000	0.1114	0.1114
C3	e31	0.0115	0.0115	0.0000	0.0000	0.0115	0.0115	0.0000	0.0000	0.0115	0.0000	0.0000	0.0115	0.0000	0.0115	0.0115
	e32	0.0812	0.0812	0.0000	0.0000	0.0812	0.0812	0.0000	0.0000	0.0812	0.0000	0.0000	0.0812	0.0000	0.0812	0.0812
	e33	0.0065	0.0065	0.0000	0.0000	0.0065	0.0065	0.0000	0.0000	0.0065	0.0000	0.0000	0.0065	0.0000	0.0065	0.0065
	e34	0.0213	0.0213	0.0000	0.0000	0.0213	0.0213	0.0000	0.0000	0.0213	0.0000	0.0000	0.0213	0.0000	0.0213	0.0213
C4	e41	0.1017	0.1017	0.0000	0.0000	0.1017	0.1017	0.0000	0.0000	0.1017	0.0000	0.0000	0.1017	0.0000	0.1017	0.1017
	e42	0.1152	0.1152	0.0000	0.0000	0.1152	0.1152	0.0000	0.0000	0.1152	0.0000	0.0000	0.1152	0.0000	0.1152	0.1152
	e43	0.0781	0.0781	0.0000	0.0000	0.0781	0.0781	0.0000	0.0000	0.0781	0.0000	0.0000	0.0781	0.0000	0.0781	0.0781
C5	e51	0.0303	0.0303	0.0000	0.0000	0.0303	0.0303	0.0000	0.0000	0.0303	0.0000	0.0000	0.0303	0.0000	0.0303	0.0303
	e52	0.0826	0.0826	0.0000	0.0000	0.0826	0.0826	0.0000	0.0000	0.0826	0.0000	0.0000	0.0826	0.0000	0.0826	0.0826

Table 7.14 Limit supermatix under KPI3

KPI3		C1						C2				C3				C4			C5		C6	
		e11	e12	e13	e14	e15	e16	e21	e22	e23	e24	e31	e32	e33	e34	e41	e42	e43	e51	e52	e61	e62
C1	e11	0.0027	0.0027	0.0000	0.0000	0.0027	0.0027	0.0000	0.0027	0.0000	0.0027	0.0000	0.0000	0.0027	0.0000	0.0000	0.0027	0.0000	0.0027	0.0027	0.0000	0.0000
	e12	0.0075	0.0075	0.0000	0.0000	0.0075	0.0075	0.0000	0.0075	0.0000	0.0075	0.0000	0.0000	0.0075	0.0000	0.0000	0.0075	0.0000	0.0075	0.0075	0.0000	0.0000
	e13	0.0418	0.0418	0.0000	0.0000	0.0418	0.0418	0.0000	0.0418	0.0000	0.0418	0.0000	0.0000	0.0418	0.0000	0.0000	0.0418	0.0000	0.0418	0.0418	0.0000	0.0000
	e14	0.0172	0.0172	0.0000	0.0000	0.0172	0.0172	0.0000	0.0172	0.0000	0.0172	0.0000	0.0000	0.0172	0.0000	0.0000	0.0172	0.0000	0.0172	0.0172	0.0000	0.0000
	e15	0.0120	0.0120	0.0000	0.0000	0.0120	0.0120	0.0000	0.0120	0.0000	0.0120	0.0000	0.0000	0.0120	0.0000	0.0000	0.0120	0.0000	0.0120	0.0120	0.0000	0.0000
	e16	0.0699	0.0699	0.0000	0.0000	0.0699	0.0699	0.0000	0.0699	0.0000	0.0699	0.0000	0.0000	0.0699	0.0000	0.0000	0.0699	0.0000	0.0699	0.0699	0.0000	0.0000
C2	e21	0.0133	0.0133	0.0000	0.0000	0.0133	0.0133	0.0000	0.0133	0.0000	0.0133	0.0000	0.0000	0.0133	0.0000	0.0000	0.0133	0.0000	0.0133	0.0133	0.0000	0.0000
	e22	0.0417	0.0417	0.0000	0.0000	0.0417	0.0417	0.0000	0.0417	0.0000	0.0417	0.0000	0.0000	0.0417	0.0000	0.0000	0.0417	0.0000	0.0417	0.0417	0.0000	0.0000
	e23	0.0063	0.0063	0.0000	0.0000	0.0063	0.0063	0.0000	0.0063	0.0000	0.0063	0.0000	0.0000	0.0063	0.0000	0.0000	0.0063	0.0000	0.0063	0.0063	0.0000	0.0000
	e24	0.1752	0.1752	0.0000	0.0000	0.1752	0.1752	0.0000	0.1752	0.0000	0.1752	0.0000	0.0000	0.1752	0.0000	0.0000	0.1752	0.0000	0.1752	0.1752	0.0000	0.0000
C3	e31	0.0023	0.0023	0.0000	0.0000	0.0023	0.0023	0.0000	0.0023	0.0000	0.0023	0.0000	0.0000	0.0023	0.0000	0.0000	0.0023	0.0000	0.0023	0.0023	0.0000	0.0000
	e32	0.1002	0.1002	0.0000	0.0000	0.1002	0.1002	0.0000	0.1002	0.0000	0.1002	0.0000	0.0000	0.1002	0.0000	0.0000	0.1002	0.0000	0.1002	0.1002	0.0000	0.0000
	e33	0.0020	0.0020	0.0000	0.0000	0.0020	0.0020	0.0000	0.0020	0.0000	0.0020	0.0000	0.0000	0.0020	0.0000	0.0000	0.0020	0.0000	0.0020	0.0020	0.0000	0.0000
	e34	0.0309	0.0309	0.0000	0.0000	0.0309	0.0309	0.0000	0.0309	0.0000	0.0309	0.0000	0.0000	0.0309	0.0000	0.0000	0.0309	0.0000	0.0309	0.0309	0.0000	0.0000
C4	e41	0.0379	0.0379	0.0000	0.0000	0.0379	0.0379	0.0000	0.0379	0.0000	0.0379	0.0000	0.0000	0.0379	0.0000	0.0000	0.0379	0.0000	0.0379	0.0379	0.0000	0.0000
	e42	0.0981	0.0981	0.0000	0.0000	0.0981	0.0981	0.0000	0.0981	0.0000	0.0981	0.0000	0.0000	0.0981	0.0000	0.0000	0.0981	0.0000	0.0981	0.0981	0.0000	0.0000
	e43	0.0207	0.0207	0.0000	0.0000	0.0207	0.0207	0.0000	0.0207	0.0000	0.0207	0.0000	0.0000	0.0207	0.0000	0.0000	0.0207	0.0000	0.0207	0.0207	0.0000	0.0000
C5	e51	0.0756	0.0756	0.0000	0.0000	0.0756	0.0756	0.0000	0.0756	0.0000	0.0756	0.0000	0.0000	0.0756	0.0000	0.0000	0.0756	0.0000	0.0756	0.0756	0.0000	0.0000
	e52	0.1127	0.1127	0.0000	0.0000	0.1127	0.1127	0.0000	0.1127	0.0000	0.1127	0.0000	0.0000	0.1127	0.0000	0.0000	0.1127	0.0000	0.1127	0.1127	0.0000	0.0000
C6	e61	0.1224	0.1224	0.0000	0.0000	0.1224	0.1224	0.0000	0.1224	0.0000	0.1224	0.0000	0.0000	0.1224	0.0000	0.0000	0.1224	0.0000	0.1224	0.1224	0.0000	0.0000
	e62	0.0095	0.0095	0.0000	0.0000	0.0095	0.0095	0.0000	0.0095	0.0000	0.0095	0.0000	0.0000	0.0095	0.0000	0.0000	0.0095	0.0000	0.0095	0.0095	0.0000	0.0000

Table 7.15 Limit supermatix under KPI4

KPI4		C1						C3				C4		
		e11	e12	e13	e14	e15	e16	e31	e32	e33	e34	e41	e42	e43
C1	e11	0.1000	0.1000	0.0000	0.0000	0.1000	0.1000	0.0000	0.0000	0.1000	0.0000	0.0000	0.1000	0.0000
	e12	0.0835	0.0835	0.0000	0.0000	0.0835	0.0835	0.0000	0.0000	0.0835	0.0000	0.0000	0.0835	0.0000
	e13	0.0959	0.0959	0.0000	0.0000	0.0959	0.0959	0.0000	0.0000	0.0959	0.0000	0.0000	0.0959	0.0000
	e14	0.1337	0.1337	0.0000	0.0000	0.1337	0.1337	0.0000	0.0000	0.1337	0.0000	0.0000	0.1337	0.0000
	e15	0.1128	0.1128	0.0000	0.0000	0.1128	0.1128	0.0000	0.0000	0.1128	0.0000	0.0000	0.1128	0.0000
	e16	0.1081	0.1081	0.0000	0.0000	0.1081	0.1081	0.0000	0.0000	0.1081	0.0000	0.0000	0.1081	0.0000
C3	e31	0.0170	0.0170	0.0000	0.0000	0.0170	0.0170	0.0000	0.0000	0.0170	0.0000	0.0000	0.0170	0.0000
	e32	0.1061	0.1061	0.0000	0.0000	0.1061	0.1061	0.0000	0.0000	0.1061	0.0000	0.0000	0.1061	0.0000
	e33	0.0193	0.0193	0.0000	0.0000	0.0193	0.0193	0.0000	0.0000	0.0193	0.0000	0.0000	0.0193	0.0000
	e34	0.0034	0.0034	0.0000	0.0000	0.0034	0.0034	0.0000	0.0000	0.0034	0.0000	0.0000	0.0034	0.0000
C4	e41	0.0920	0.0920	0.0000	0.0000	0.0920	0.0920	0.0000	0.0000	0.0920	0.0000	0.0000	0.0920	0.0000
	e42	0.0745	0.0745	0.0000	0.0000	0.0745	0.0745	0.0000	0.0000	0.0745	0.0000	0.0000	0.0745	0.0000
	e43	0.0535	0.0535	0.0000	0.0000	0.0535	0.0535	0.0000	0.0000	0.0535	0.0000	0.0000	0.0535	0.0000

Table 7.16 Limit supermatix under KPI5

KPI4		C1						C3				C4		
		e11	e12	e13	e14	e15	e16	e31	e32	e33	e34	e41	e42	e43
C1	e11	0.1360	0.1360	0.0000	0.0000	0.1360	0.1360	0.0000	0.0000	0.1360	0.0000	0.0000	0.1360	0.0000
	e12	0.0908	0.0908	0.0000	0.0000	0.0908	0.0908	0.0000	0.0000	0.0908	0.0000	0.0000	0.0908	0.0000
	e13	0.1138	0.1138	0.0000	0.0000	0.1138	0.1138	0.0000	0.0000	0.1138	0.0000	0.0000	0.1138	0.0000
	e14	0.1277	0.1277	0.0000	0.0000	0.1277	0.1277	0.0000	0.0000	0.1277	0.0000	0.0000	0.1277	0.0000
	e15	0.1252	0.1252	0.0000	0.0000	0.1252	0.1252	0.0000	0.0000	0.1252	0.0000	0.0000	0.1252	0.0000
	e16	0.0854	0.0854	0.0000	0.0000	0.0854	0.0854	0.0000	0.0000	0.0854	0.0000	0.0000	0.0854	0.0000
C3	e31	0.0581	0.0581	0.0000	0.0000	0.0581	0.0581	0.0000	0.0000	0.0581	0.0000	0.0000	0.0581	0.0000
	e32	0.0314	0.0314	0.0000	0.0000	0.0314	0.0314	0.0000	0.0000	0.0314	0.0000	0.0000	0.0314	0.0000
	e33	0.0482	0.0482	0.0000	0.0000	0.0482	0.0482	0.0000	0.0000	0.0482	0.0000	0.0000	0.0482	0.0000
	e34	0.0067	0.0067	0.0000	0.0000	0.0067	0.0067	0.0000	0.0000	0.0067	0.0000	0.0000	0.0067	0.0000
C4	e41	0.0186	0.0186	0.0000	0.0000	0.0186	0.0186	0.0000	0.0000	0.0186	0.0000	0.0000	0.0186	0.0000
	e42	0.0368	0.0368	0.0000	0.0000	0.0368	0.0368	0.0000	0.0000	0.0368	0.0000	0.0000	0.0368	0.0000
	e43	0.1214	0.1214	0.0000	0.0000	0.1214	0.1214	0.0000	0.0000	0.1214	0.0000	0.0000	0.1214	0.0000

Table 7.17 Limit supermatix under KPI6

KPI6		C1						C2				C3				C4			C5		C6	
		e11	e12	e13	e14	e15	e16	e21	e22	e23	e24	e31	e32	e33	e34	e41	e42	e43	e51	e52	e61	e62
C1	e11	0.0427	0.0427	0.0000	0.0000	0.0427	0.0427	0.0000	0.0427	0.0000	0.0427	0.0000	0.0000	0.0427	0.0000	0.0000	0.0427	0.0000	0.0427	0.0427	0.0000	0.0000
	e12	0.0923	0.0923	0.0000	0.0000	0.0923	0.0923	0.0000	0.0923	0.0000	0.0923	0.0000	0.0000	0.0923	0.0000	0.0000	0.0923	0.0000	0.0923	0.0923	0.0000	0.0000
	e13	0.0419	0.0419	0.0000	0.0000	0.0419	0.0419	0.0000	0.0419	0.0000	0.0419	0.0000	0.0000	0.0419	0.0000	0.0000	0.0419	0.0000	0.0419	0.0419	0.0000	0.0000
	e14	0.0362	0.0362	0.0000	0.0000	0.0362	0.0362	0.0000	0.0362	0.0000	0.0362	0.0000	0.0000	0.0362	0.0000	0.0000	0.0362	0.0000	0.0362	0.0362	0.0000	0.0000
	e15	0.0668	0.0668	0.0000	0.0000	0.0668	0.0668	0.0000	0.0668	0.0000	0.0668	0.0000	0.0000	0.0668	0.0000	0.0000	0.0668	0.0000	0.0668	0.0668	0.0000	0.0000
	e16	0.1090	0.1090	0.0000	0.0000	0.1090	0.1090	0.0000	0.1090	0.0000	0.1090	0.0000	0.0000	0.1090	0.0000	0.0000	0.1090	0.0000	0.1090	0.1090	0.0000	0.0000
C2	e21	0.0363	0.0363	0.0000	0.0000	0.0363	0.0363	0.0000	0.0363	0.0000	0.0363	0.0000	0.0000	0.0363	0.0000	0.0000	0.0363	0.0000	0.0363	0.0363	0.0000	0.0000
	e22	0.0487	0.0487	0.0000	0.0000	0.0487	0.0487	0.0000	0.0487	0.0000	0.0487	0.0000	0.0000	0.0487	0.0000	0.0000	0.0487	0.0000	0.0487	0.0487	0.0000	0.0000
	e23	0.0025	0.0025	0.0000	0.0000	0.0025	0.0025	0.0000	0.0025	0.0000	0.0025	0.0000	0.0000	0.0025	0.0000	0.0000	0.0025	0.0000	0.0025	0.0025	0.0000	0.0000
	e24	0.1154	0.1154	0.0000	0.0000	0.1154	0.1154	0.0000	0.1154	0.0000	0.1154	0.0000	0.0000	0.1154	0.0000	0.0000	0.1154	0.0000	0.1154	0.1154	0.0000	0.0000
C3	e31	0.0049	0.0049	0.0000	0.0000	0.0049	0.0049	0.0000	0.0049	0.0000	0.0049	0.0000	0.0000	0.0049	0.0000	0.0000	0.0049	0.0000	0.0049	0.0049	0.0000	0.0000
	e32	0.0442	0.0442	0.0000	0.0000	0.0442	0.0442	0.0000	0.0442	0.0000	0.0442	0.0000	0.0000	0.0442	0.0000	0.0000	0.0442	0.0000	0.0442	0.0442	0.0000	0.0000
	e33	0.0060	0.0060	0.0000	0.0000	0.0060	0.0060	0.0000	0.0060	0.0000	0.0060	0.0000	0.0000	0.0060	0.0000	0.0000	0.0060	0.0000	0.0060	0.0060	0.0000	0.0000
	e34	0.0328	0.0328	0.0000	0.0000	0.0328	0.0328	0.0000	0.0328	0.0000	0.0328	0.0000	0.0000	0.0328	0.0000	0.0000	0.0328	0.0000	0.0328	0.0328	0.0000	0.0000
C4	e41	0.0150	0.0150	0.0000	0.0000	0.0150	0.0150	0.0000	0.0150	0.0000	0.0150	0.0000	0.0000	0.0150	0.0000	0.0000	0.0150	0.0000	0.0150	0.0150	0.0000	0.0000
	e42	0.0735	0.0735	0.0000	0.0000	0.0735	0.0735	0.0000	0.0735	0.0000	0.0735	0.0000	0.0000	0.0735	0.0000	0.0000	0.0735	0.0000	0.0735	0.0735	0.0000	0.0000
	e43	0.0198	0.0198	0.0000	0.0000	0.0198	0.0198	0.0000	0.0198	0.0000	0.0198	0.0000	0.0000	0.0198	0.0000	0.0000	0.0198	0.0000	0.0198	0.0198	0.0000	0.0000
C5	e51	0.0580	0.0580	0.0000	0.0000	0.0580	0.0580	0.0000	0.0580	0.0000	0.0580	0.0000	0.0000	0.0580	0.0000	0.0000	0.0580	0.0000	0.0580	0.0580	0.0000	0.0000
	e52	0.0855	0.0855	0.0000	0.0000	0.0855	0.0855	0.0000	0.0855	0.0000	0.0855	0.0000	0.0000	0.0855	0.0000	0.0000	0.0855	0.0000	0.0855	0.0855	0.0000	0.0000
C6	e61	0.0651	0.0651	0.0000	0.0000	0.0651	0.0651	0.0000	0.0651	0.0000	0.0651	0.0000	0.0000	0.0651	0.0000	0.0000	0.0651	0.0000	0.0651	0.0651	0.0000	0.0000
	e62	0.0033	0.0033	0.0000	0.0000	0.0033	0.0033	0.0000	0.0033	0.0000	0.0033	0.0000	0.0000	0.0033	0.0000	0.0000	0.0033	0.0000	0.0033	0.0033	0.0000	0.0000

7.5 Final priorities

The final priorities are calculated by the desirability index approach by Meade and Sarkis (1999). The desirability index (DI) for the elements is defined as the following:

$D_i = \sum_{j=1}^{j} \sum_{k=1}^{k_j} P_j A_{kj} S_{ikj}$ (7.5)

Where:

Pj is the relative importance of principle j,

A_{kj} is the relative importance weight for attribute k of principle j,

S_{ikj} is the relative impact of element i on attribute k of principle j,

Kj is the index set of attributes for principle j,

and J is the index set of principles.

According to the equation 7.5, the composite priorities of the KPIs were determined by the AHP approach in the control hierarchy; the results were shown in Table 7.18.

Table 7.18 Composite priorities of the sustainable dimensions and KPIs

		KPI1	**KPI2**	**KPI3**	**KPI4**	**KPI5**	**KPI6**
SBEER 1.000	**Eco** 0.400	0.154	0.083	0.496	0.267	/	/
	Env 0.337	0.196	0.311	/	0.493	/	/
	Sco 0.263	0.052	/	/	0.155	0.290	0.503
Total	1.000	0.1413	0.1380	0.1984	0.3137	0.0763	0.1323

There is a network under each KPI in the developed ANP model. Six supermatrices were constructed with priority vectors obtained from pairwise comparisons for interdependencies among the CSFs. The final priorities of this

ANP model are shown in Table 7.19.

Table 7.19 Final priorities of the ANP model

CSFs		Final priorities
C1	e_{11} Appropriate organization structure	**0.0575**
	e_{12} Effective coordination	**0.0672**
	e_{13} Team workers technical skills	**0.0765**
	e_{14} Organizing capacity of team leader	**0.0833**
	e_{15} Project objectives control mechanism	**0.0827**
	e_{16} Trust	**0.0962**
C2	e_{21} Credit of ESCO and client	**0.0074**
	e_{22} Hotel operation status	**0.0147**
	e_{23} Financing institute s' awareness of EPC	**0.0016**
	e_{24} Project financial status	**0.0500**
C3	e_{31} SD strategy planning	**0.0146**
	e_{32} Available technology	**0.0888**
	e_{33} Control mechanism of SD strategy	**0.0149**
	e_{34} Policy support	**0.0169**
C4	e_{41}Client's awareness of EPC	**0.0674**
	e_{42} Accurate M&V	**0.0821**
	e_{43} Clients' and ESCOs' awareness of SD	**0.0565**
C5	e_{51} Savings share	**0.0296**
	e_{52} Tasks and risks allocation	**0.0567**
C6	e_{61} Economic environment	**0.0329**
	e_{62} Available financing market	**0.0023**

The result of this model shows that the weight of the economic sustainability objective is higher than the other two objective, and that at the KPI level, KPI4 (Energy consumption and resources savings) has the highest weight, followed by KPI 3 (Project cost benefit). For the CSF network, the most important five CSFs are e15 (project objectives control mechanism), e32 (available technology), e14 (organizing capacity of team leader), e16 (trust), and e42 (M&V). A detailed analysis of these findings is presented in Chapter 8.

7.6 Summary

Sustainable BEER under EPC mechanism is a comprehensive system. Because there are dependencies among sustainable dimensions, performance criteria and groups of project success factors, it is a difficult multi-criteria decision. This chapter used AHP/ANP to facilitate such the problem solving process. It focuses on how to structure a hierarchical decision model (by breaking down the decision problem into levels) and how to weight the decision criteria (by means of pairwise comparisons). From two rounds of group meetings, the relationships among sustainable BEER performance and success factors of EPC mechanism were identified. Meanwhile, the pairwise comparisons were conducted through expert group discussion. The ANP structure and final priorities of this system is built using the SuperDecision software.

CHAPTER 8 Discussions

8.1 Introduction

In Chapter 7, an ANP model for sustainable BEER in hotel buildings was developed. A set of relationships between the KPIs for sustainable BEER and the success factors under the EPC mechanism were examined. This chapter will highlight the relationships and explain how individual factors could contribute to sustainable development objectives. In this research, six KPIs for sustainable BEER and 21 CSFs of the EPC mechanism were identified. In adopting an ANP approach, the final priorities and relationships between CSFs and KPIs are revealed. A detailed discussion of each of these factors affects the performance of sustainable BEER in hotel buildings is given in the following section.

8.2 Priority of KPIs for sustainable BEER

The composite priorities of the KPIs have been determined by AHP approach in the control hierarchy; the results were shown in Table 7.18. From the table, it can be observed that the weight of the economic sustainability objective, which is 0.400, is higher than that of the other two objectives. Social sustainability (0.263) is the lowest weight. Environmental sustainability has a mean weight of 0.337. Economic sustainability for a BEER project means balancing project expenditures and revenues during a long-term period. This is the precondition of these projects. Not surprisingly for this result, the experts group emphasized economic sustainability and environment sustainability, which coincide with the objectives of BEER.

In this research, six key performance indicators were selected to measure the sustainable performance of BEER. The final weights of KPIs are shown in Table 7.18. KPI4 (Energy consumption and resource savings, 0.3137) and KPI3 (Project cost benefit, 0.1984) are the most two important indicators to evaluate sustainable BEER. The weight of these two indicators is more than half of the total weight of sustainable BEER. Besides the project mission of saving energy and reducing emission of CO_2, energy and resource savings should also be considered during the retrofit process. Energy saving and resources conservation is benefit to environment, meanwhile it also causes energy bills reduction. This task contributes to all three dimensions of sustainability. The KPI3 (Project cost benefit) is the most important indicator for economic sustainability. The third most important KPI is KPI1 (Quality, 0.1413), followed by KPI2 (Hotel energy system management, 0.1380) and KPI6 (Stakeholders' satisfactions, 0.1323). These three performance indicators have a similar weight for measuring sustainable BEER in hotel buildings. The last performance indicator is KPI5 (Health and safety, with a weight of 0.0763). When conducting a real BEER project in hotel building, more efforts should be given to improve the high-ranking sustainable dimensions and KPIs.

Not all the KPIs contribute to each sustainable dimension. Economic sustainability is measured by KPI1 (Quality), KPI2 (Hotel energy system management), KPI3 (Project cost benefit), and KPI4 (Energy consumption and resource savings.) The weight of KPI4 is up to 0.496, which is much higher than the other KPIs. It is not difficult to understand the importance of cost-benefit to the economic sustainability of BEER projects. KPI4 is another important performance indicator whose weight is 0.267. Environmental sustainability pertains to three KPIs: KPI1 (Quality), KPI2 (Hotel energy system management), and KPI4 (Energy consumption and resource savings.) KPI4 takes up the largest proportion of weight of environmental sustainability, which is 0.493. For social sustainability, four KPIs contribute to this dimension: KPI1, KPI4, KPI5 and KPI6. The most important KPI is KPI6, whose weight is 0.503. KPI5's weight is 0.29, which is another measurement indicator of social sustainability.

8.3 Factors affecting KPIs

This section serves to clarify the relationship between the CSFs of the EPC mechanism and KPIs for sustainable BEER in hotel buildings. There is a network under each KPI in the ANP model. Six supermatrices were constructed with priority vectors obtained from pairwise comparisons for interdependencies among the CSFs. Table 8.1 shows the priorities of CSFs under each KPI and the final priority of CSFs.

Table 8.1 Final priorities of CSFs

		KPI1 0.1413	KPI2 0.1380	KPI3 0.1984	KPI4 0.3137	KPI5 0.0763	KPI6 0.1323	Total
C1	e_{11} Appropriate organization structure	0.0351	0.0333	0.0027	0.1000	0.1360	0.0427	**0.0575**
	e_{12} Effective coordination	0.0628	0.0832	0.0075	0.0835	0.0908	0.0923	**0.0672**
	e_{13} Team workers technical skills	0.0955	0.0750	0.0418	0.0959	0.1138	0.0419	**0.0765**
	e_{14} Organizing capacity of team leader	0.1037	0.0636	0.0172	0.1337	0.1277	0.0362	**0.0833**
	e_{15} Project objectives control mechanism	0.0937	0.1114	0.0699	0.1128	0.1252	0.0668	**0.0962**
	e_{16} Trust	0.0779	0.1050	0.0120	0.1081	0.0854	0.1090	**0.0827**
C2	e_{21} Credit of ESCO and client	0	0	0.0133	0	0	0.0363	**0.0074**
	e_{22} Hotel operation status	0	0	0.0417	0	0	0.0487	**0.0147**
	e_{23} Financing institute s' awareness to EPC	0	0	0.0063	0	0	0.0025	**0.0016**
	e_{24} Project financial status	0	0	0.1752	0	0	0.1154	**0.0500**
C3	e_{31} SD strategy planning	0.0151	0.0115	0.0023	0.0170	0.0581	0.0049	**0.0146**
	e_{32} Available technology	0.1146	0.0812	0.1002	0.1061	0.0314	0.0442	**0.0888**
	e_{33} Control mechanism of SD strategy	0.0219	0.0065	0.0020	0.0193	0.0482	0.0060	**0.0149**
	e_{34} Policy support	0.0138	0.0213	0.0309	0.0034	0.0067	0.0328	**0.0169**
C4	e_{41}Client's awareness to EPC	0.0965	0.1017	0.0379	0.0920	0.0186	0.0150	**0.0674**
	e_{42} Accurate M&V	0.0767	0.1152	0.0981	0.0745	0.0368	0.0735	**0.0821**
	e_{43} Clients' and ESCOs' awareness to SD	0.0913	0.0781	0.0207	0.0535	0.1214	0.0198	**0.0565**
C5	e_{51} Savings share	0.0193	0.0303	0.0756	0	0	0.0580	**0.0296**
	e_{52} Tasks and risks allocation	0.0823	0.0826	0.1127	0	0	0.0855	**0.0567**
C6	e_{61} Economic environment	0	0	0.1224	0	0	0.0651	**0.0329**
	e_{62} Available financing market	0	0	0.0095	0	0	0.0033	**0.0023**

8.3.1 Factors affecting KPI1 (Quality)

Table 8.1 shows that there are four clusters and 15 CSFs under the subnet of KPI1 (Quality). The relative importance of CSFs for KPI1 (Quality) is presented in Fig. 8.1, with the weights normalized so that the most important factor is given a unit value. The most two important CSFs for KPI1 (Quality) are e_{32} (available technology) and e_{14} (organizing capacity of team leader.) Advanced technology could guarantee the quality of energy equipment used in a project. Application of innovative of management technique could increase the quality performance of a construction project (Chan, 2004). Besides, e_{41} (client's awareness of EPC), e_{13} (team workers' technical skills), e_{15} (project objectives control mechanism), and e_{43} (clients' and ESCOs' awareness of SD) are also at a high level. On the other hand, e_{33} (control mechanism of SD strategy), e_{51} (savings share), e_{31} (SD strategy planning), and e_{34} (policy support) are four factors considered least important for quality performance of sustainable BEER in hotel buildings.

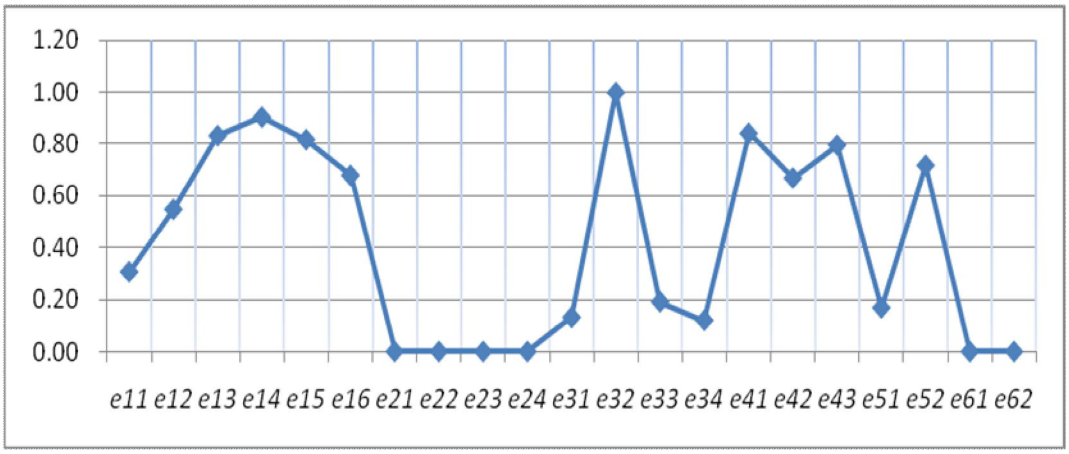

Fig. 8.1 Relative importance of CSFs for KPI1 (Quality)

The result shows that quality can be improved by drawing on better technology available, the organizing capacity of the team leader, the client's awareness of EPC, team workers' technical skills, project objectives control mechanism, and clients' and ESCOs' awareness of SD. Amongst these variables, "available technology" and "capacity of team leader" are found to be the most two powerful contributors for better quality.

8.3.2 Factors affecting KPI2 (Hotel energy management)

Hotel energy management measures operation management of a hotel energy system after completing energy efficiency retrofit. There are also four clusters and 15 CSFs under the subnet of KPI2. The relative importance of the CSFs is shown in Fig. 8.2. There are four factors at the first order of significance level. These are e_{42} (accurate M&V), e_{15} (project objectives control mechanism), e_{16} (trust), and e_{41} (client's awareness of EPC). Accurate M&V of the whole energy system in a hotel is the technical support for hotel energy management. Energy system management in the operation management stage is a task of this type of project. The project objectives control mechanism should be expanded from the retrofit process to the operation stage. A client's awareness of EPC and trust can promote the collaboration between clients and contractors during the operation management stage.

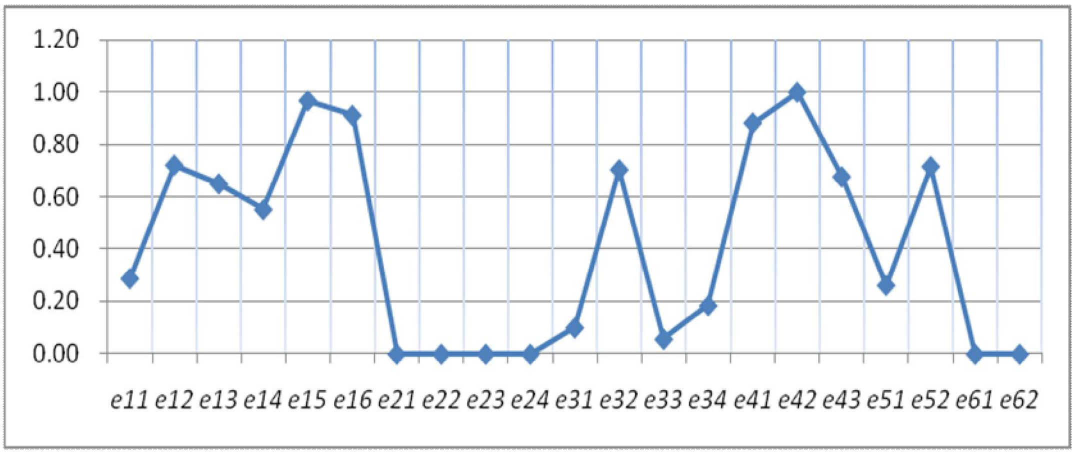

Fig. 8.2 Relative importance of CSFs for KPI2 (Hotel energy management)

The strongest contributors for hotel energy management performance are accurate M&V, project objectives control mechanism, trust, and client's awareness of the EPC mechanism. "Accurate M&V" is the most important factor affecting hotel energy management.

8.3.3 Factors affecting KPI3 (Project cost-benefit performance)

Cost-benefit performance is a variable expressed by the project profitability and the final contract sum under-run or over-run with respect to the original contract budget. All 21 CSFs in the six clusters contribute to this key performance indicator. Fig. 8.3 presents the relative importance of these 21 CSFs. e_{24} (project financial status) is the most important factor for cost-benefit performance and is a prerequisite to conduct the project. Four others - e_{61} (economic environment), e_{52} (tasks and risks allocation), e_{32} (available technology), and e_{42} (accurate M&V) are also at a high significance level. The total weight of these five factors is up to 0.6 (see Table 8.1).

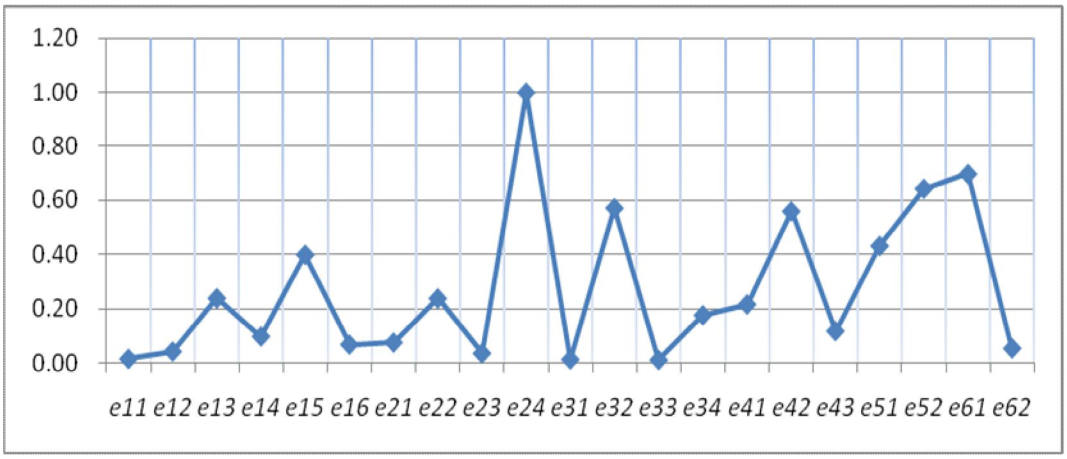

Fig. 8.3 Relative importance of CSFs for KPI3

It was found that better cost-benefit performance of sustainable BEER projects in hotel buildings is mainly determined by better project financial status, better economic environment, reasonable allocation of tasks and risks, advanced technology, and accurate M&V techniques and methods. Of these factors, "project financial status" is the most powerful predictor of the cost-benefit performance of the project.

8.3.4 Factors affecting KPI4 (Energy saving and resources conservation)

Energy saving is one of the most critical tasks of an energy efficiency project, this indicator reflect the performance of energy and resources conservation in the sustainable BEER project in hotel building. There are three clusters and 13 CSFs under this performance indicator. The relative importance of these factors is shown in Fig. 8.4. With respect to the KPI4, e_{14} (organizing capacity of team leader) has been considered the most significant factor. All the factors in Cluster 1 (Project organization) have high importance levels for the performance of KPI4

(Energy savings and resource conservation). When available resources used in a project are identified, the capacity of project manager and project organization has a dominant impact on the final result. Another important factor is e_{32} (available technology). It is not difficult to understand that the energy efficiency improvement technologies used directly affect the potential energy conservations. It also was found that the factor e_{34} (policy support) is insignificant for energy saving performance.

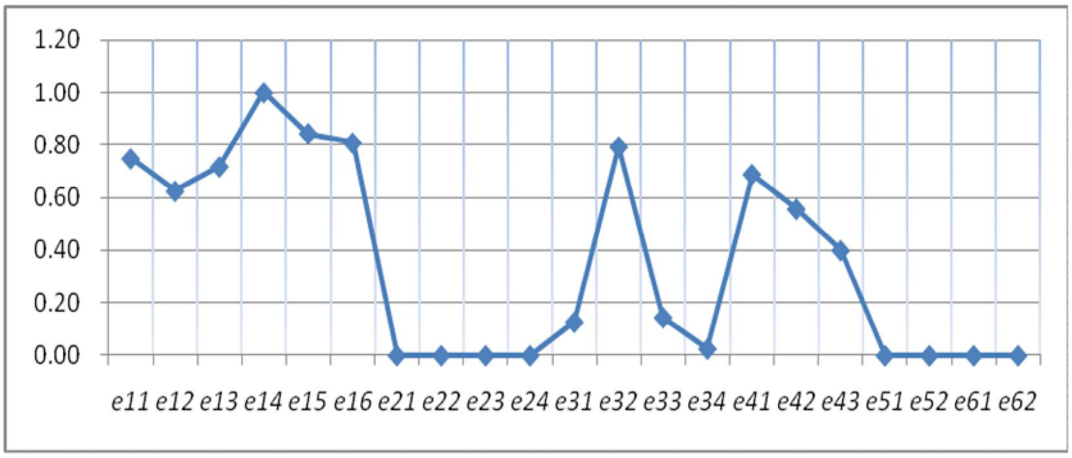

Fig. 8.4 Relative importance of CSFs for KPI4

Thus, in order to improve energy savings and resource conservation, more effort should be given to the improvement of a project manager's capacity, better project objective control mechanism, trust, and advance technologies.

8.3.5 Factors affecting KPI5 (Health and safety)

Health and safety involves three clusters and 13 CSFs, which are the same as KPI4 (energy saving and resources conservation.) Fig. 8.5 presents the relative significance of the 13 CSFs. From the figure, it was deduced that e_{11} (appropriate organization structure), e_{15} (project objectives control mechanism), e_{14} (organizing capacity of team leader), and e_{43} (clients' and ESCOs' awareness of SD) are the most important factors. All the factors in Cluster 1 (Project organization) get a higher significance with respect to health and safety performance. On the other hand, e_{34} (policy support) is insignificant for this indicator.

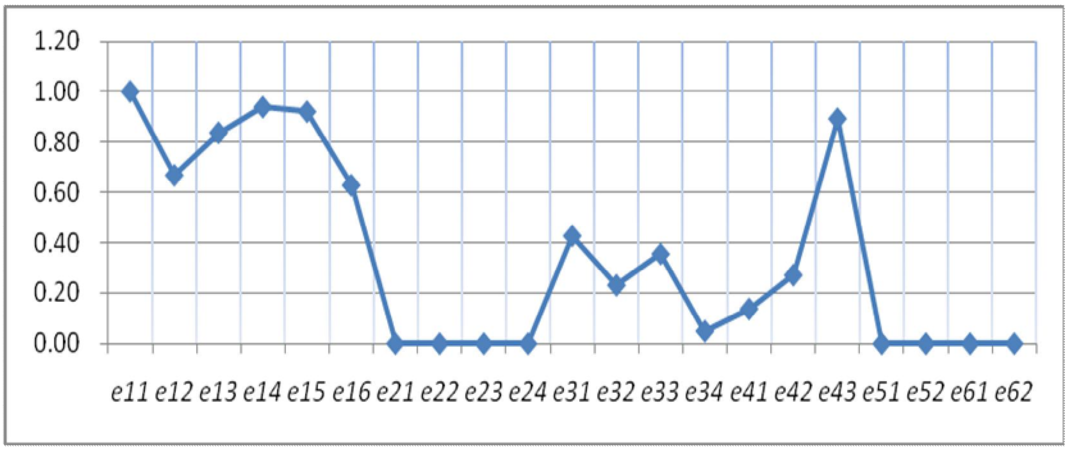

Fig. 8.5 Relative importance of CSFs for KPI5

The increase in health and safety performance can be best achieved through better organization structure, better project objectives control mechanism, improving the organizing capacity of team leader, and improving clients' and ESCOs' awareness of SD.

8.3.6 Factors affecting KPI6 (Stakeholders' satisfaction)

"Stakeholders' satisfaction" is a subjective measure of the satisfaction felt by the stakeholders in the hotel building retrofit projects. All 21 CSFs in the six clusters influence this key performance indicator. The relative importance of these 21 CSFs is presented in Fig. 8.6. The most important three factors for the performance of stakeholders' satisfaction are e_{24} (project financial status), e_{16} (trust), and e_{12} (effective coordination.) The main stakeholders in a typical BEER project under EPC mechanism include the client, the EPC contractor, and the end users (public/hotel customers). Both clients and contractors are profit-oriented. The project financial status is the most powerful contributor to stakeholders' satisfaction. Trust between client and contractor can promote collaboration and reduce conflict. The effective coordination is an effect way to settle problems and disputes. These factors give large part of contribution to the performance stakeholders' satisfactions. However, not all the factors in the subnet contribute to the sub-goal. Four factors e_{33} (control mechanism of SD strategy), e_{31} (SD strategy planning), e_{62} (available financing market), and e_{23} (financing institute's awareness of EPC) are insignificant for the performance of stakeholders' satisfaction with the project.

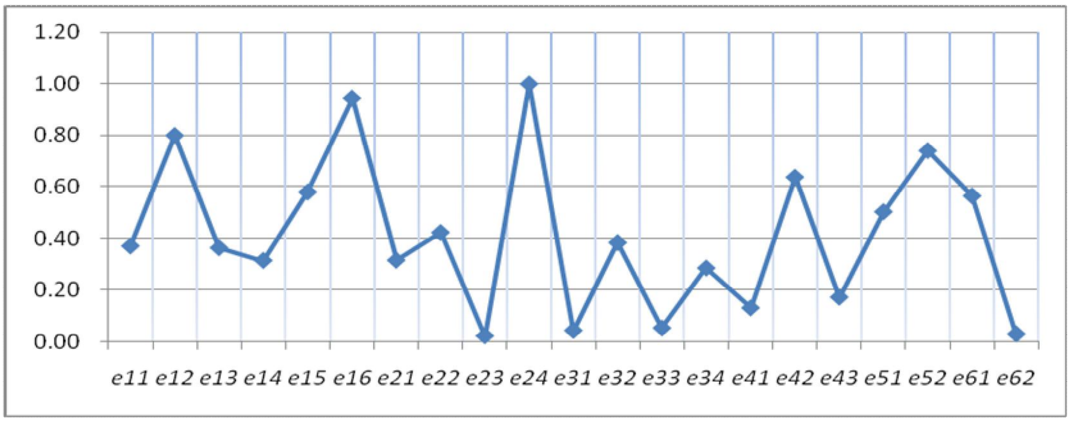

Fig. 8.6 Relative importance of CSFs for KPI6

The result reveals that stakeholders' satisfaction is mainly driven by project financial status, trust, and effective coordination.

8.4 Factors affecting sustainable BEER

Factors affecting each KPI were discussed above. The most important factors for each KPI were extracted. The final priorities of CSFs for sustainable BEER are also shown in Table 8.1. The relative importance of the CSFs for sustainable BEER is presented in Fig. 8.7. From the figure, e_{15} (project objectives control mechanism) is considered the most important factor. Additionally, e_{32} (available technology), e_{14} (organizing capacity of team leader), e_{16} (trust), e_{42} (accurate M&V), e_{13} (team workers' technical skills) are at a high level of significance. Project objectives control is obviously important for project organization, which directly affects project conducting process, results, and sustainable performance. Retrofit technologies reflect new equipment, new energy resources, new energy audit technologies, and new technologies of improvement measures. Affordable and appropriate technologies in BEER decide the feasible of these projects and the energy savings potential. Project manager is the person who provides guidance, instruction, direction, and leadership to a group of other individuals for the purpose of achieving a key result or group of aligned results. Effective project managers are essential to project success (Belassi & Tukel, 1996; Chua et al., 1999; Chan, et al., 2004). EPC model is meant to create a win-win situation in energy efficiency projects. Collaboration and partnership are crucial for EPC project, which need clients and contractors to trust each other. Measurement and Verification (M&V) is one of most important parts of EPC procedure, which is to identify the project result and energy savings. The reliable and undisputable M&V is important to achieve sustainable BEER. Team members with better technical background and skills are easier to be organized, which will improve efficiency of project delivery. In the other hand, e_{62} (available financing market) and e_{23} (financing institute s' awareness of EPC) are insignificant for sustainable BEER.

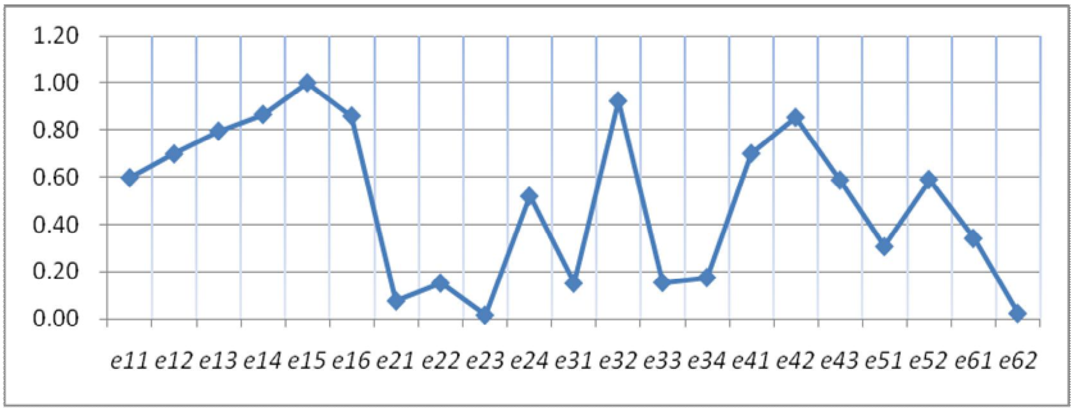

Fig. 8.7 Relative importance of CSFs for sustainable BEER

This result shows that sustainable BEER in hotel buildings under the EPC mechanism is mainly decided by project objectives control mechanism, available technology, organizing capacity of team leader, trust, accurate M&V, and team worker technical skills.

Sometimes, energy efficiency projects under different conditions emphasis on different objectives. In the follow sections factors affecting different sustainable dimensions were discussed.

8.4.1Factors affecting economic sustainability

Economic sustainability is measured by KPI1 (Quality), KPI2 (Hotel energy system management), KPI3 (Project cost benefit), and KPI4 (Energy consumption and resource savings). Table 8.2 shows the priorities of the CSFs. The relative importance of the CSFs for economic sustainability is presented in Fig. 8.8.

Table 8.2 Priorities of CSFs for economic sustainability

		KPI1 0.154	**KPI2** 0.083	**KPI3** 0.496	**KPI4** 0.267	Total
C1	e_{11} Appropriate organization structure	0.0351	0.0333	0.0027	0.1000	**0.0362**
	e_{12} Effective coordination	0.0628	0.0832	0.0075	0.0835	**0.0426**
	e_{13} Team workers technical skills	0.0955	0.0750	0.0418	0.0959	**0.0673**
	e_{14} Organizing capacity of team leader	0.1037	0.0636	0.0172	0.1337	**0.0655**
	e_{15} Project objectives control mechanism	0.0937	0.1114	0.0699	0.1128	**0.0555**
	e_{16} Trust	0.0779	0.1050	0.0120	0.1081	**0.0884**
C2	e_{21} Credit of ESCO and client	0	0	0.0133	0	**0.0066**
	e_{22} Hotel operation status	0	0	0.0417	0	**0.0207**
	e_{23} Financing institute s' awareness to EPC	0	0	0.0063	0	**0.0031**
	e_{24} Project financial status	0	0	0.1752	0	**0.0869**
C3	e_{31} SD strategy planning	0.0151	0.0115	0.0023	0.0170	**0.0090**
	e_{32} Available technology	0.1146	0.0812	0.1002	0.1061	**0.1024**
	e_{33} Control mechanism of SD strategy	0.0219	0.0065	0.0020	0.0193	**0.0101**
	e_{34} Policy support	0.0138	0.0213	0.0309	0.0034	**0.0201**
C4	e_{41}Client's awareness to EPC	0.0965	0.1017	0.0379	0.0920	**0.0667**
	e_{42} Accurate M&V	0.0767	0.1152	0.0981	0.0745	**0.0899**
	e_{43} Clients' and ESCOs' awareness to SD	0.0913	0.0781	0.0207	0.0535	**0.0451**
C5	e_{51} Savings share	0.0193	0.0303	0.0756	0	**0.0430**
	e_{52} Tasks and risks allocation	0.0823	0.0826	0.1127	0	**0.0754**
C6	e_{61} Economic environment	0	0	0.1224	0	**0.0607**
	e_{62} Available financing market	0	0	0.0095	0	**0.0047**

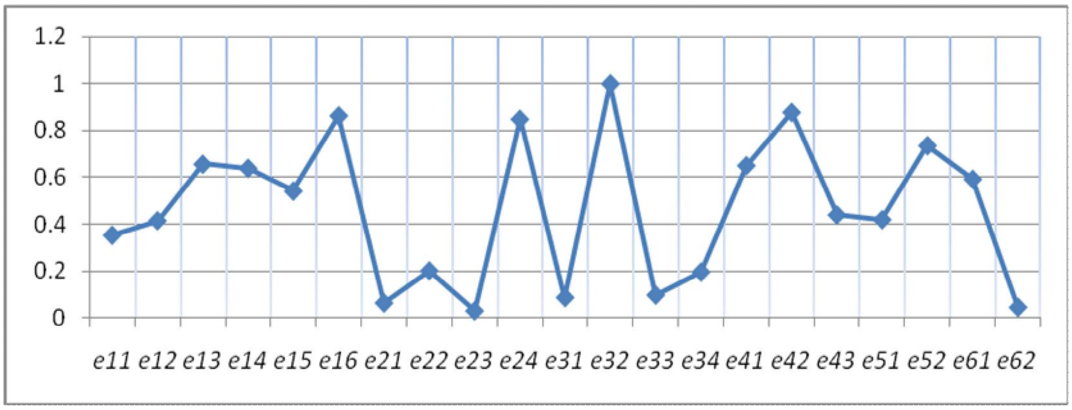

Fig. 8.8 Relative importance of CSFs for Economic sustainability

The most important factors are e_{32} (available technology), e_{42} (accurate M&V), e_{16} (trust), and e_{24} (project financial status). Five factors e_{33} (control mechanism of SD strategy), e_{31} (SD strategy planning), e_{21} (credit of ESCO and client), e_{62} (available financing market), and e_{22} (hotel operation status) are insignificant for economic sustainability. This result indicates that in order to improve economic sustainability, more efforts should be given to available advanced technologies, accurate M&V, trust, and project financial status.

8.4.2 Factors affecting Environmental sustainability

Environmental sustainability is measured by KPI1 (Quality), KPI2 (Hotel energy system management), and KPI4 (Energy consumption & resources saving). Four clusters and 15 factors under them contribute to the environmental sustainability. Table 8.3 shows the priorities of the CSFs under Economic sustainability of BEER project in hotel buildings. The relative importance of the CSFs for economic sustainability is presented in Fig. 8.9.

Table 8.3 Priorities of CSFs for environment sustainability

		KPI1 0.196	**KPI2** 0.311	**KPI4** 0.493	Total
C1	e_{11} Appropriate organization structure	0.0351	0.0333	0.1000	**0.0665**
	e_{12} Effective coordination	0.0628	0.0832	0.0835	**0.0793**
	e_{13} Team workers technical skills	0.0955	0.0750	0.0959	**0.0893**
	e_{14} Organizing capacity of team leader	0.1037	0.0636	0.1337	**0.1060**
	e_{15} Project objectives control mechanism	0.0937	0.1114	0.1128	**0.1086**
	e_{16} Trust	0.0779	0.1050	0.1081	**0.1012**
C3	e_{31} SD strategy planning	0.0151	0.0115	0.0170	**0.0149**
	e_{32} Available technology	0.1146	0.0812	0.1061	**0.1000**
	e_{33} Control mechanism of SD strategy	0.0219	0.0065	0.0193	**0.0158**
	e_{34} Policy support	0.0138	0.0213	0.0034	**0.0110**
C4	e_{41}Client's awareness to EPC	0.0965	0.1017	0.0920	**0.0959**
	e_{42} Accurate M&V	0.0767	0.1152	0.0745	**0.0876**
	e_{43} Clients' and ESCOs' awareness to SD	0.0913	0.0781	0.0535	**0.0686**
C5	e_{51} Savings share	0.0193	0.0303	0	**0.0132**
	e_{52} Tasks and risks allocation	0.0823	0.0826	0	**0.0418**

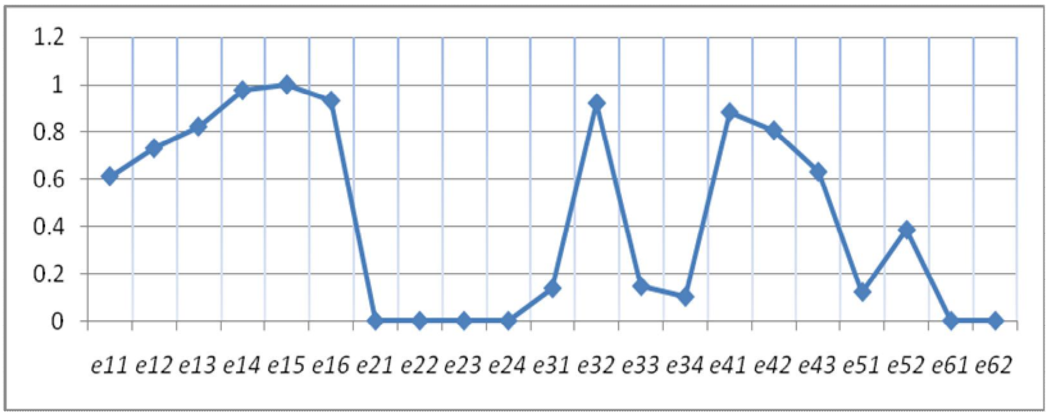

Fig. 8.9 Relative importance of CSFs for Environmental sustainability

The most important factors are e_{15} (project objectives control mechanism), e_{14} (organizing capacity of team leader), e_{16} (trust), e_{32} (available technology), e_{41} (client's awareness of EPC). This result shows that better environment sustainability performance of hotel building energy efficiency retrofit is mainly driven by better project objectives control mechanism, improving team leader's organizing capacity of, trust, and advanced technologies.

8.4.3 Factors affecting Social sustainability

Social sustainability is measured by KPI1 (Quality), KPI4 (Energy consumption & resources saving), KPI5 (Health and safety), and KPI6 (Stakeholders' satisfaction). Table 8.4 shows the priorities of the CSFs under economic sustainability of BEER projects in hotel buildings. The relative importance of the CSFs for economic sustainability is presented in Fig. 8.10.

Table 8.4 Priorities of CSFs for social sustainability

		KPI1 0.052	**KPI4** 0.155	**KPI5** 0.290	**KPI6** 0.503	Total
C1	e_{11} Appropriate organization structure	0.0351	0.1000	0.1360	0.0427	**0.0782**
	e_{12} Effective coordination	0.0628	0.0835	0.0908	0.0923	**0.0890**
	e_{13} Team workers technical skills	0.0955	0.0959	0.1138	0.0419	**0.0739**
	e_{14} Organizing capacity of team leader	0.1037	0.1337	0.1277	0.0362	**0.0814**
	e_{15} Project objectives control mechanism	0.0937	0.1128	0.1252	0.0668	**0.0923**
	e_{16} Trust	0.0779	0.1081	0.0854	0.1090	**0.1004**
C2	e_{21} Credit of ESCO and client	0	0	0	0.0363	**0.0183**
	e_{22} Hotel operation status	0	0	0	0.0487	**0.0245**
	e_{23} Financing institute s' awareness to EPC	0	0	0	0.0025	**0.0013**
	e_{24} Project financial status	0	0	0	0.1154	**0.0580**
C3	e_{31} SD strategy planning	0.0151	0.0170	0.0581	0.0049	**0.0227**
	e_{32} Available technology	0.1146	0.1061	0.0314	0.0442	**0.0537**
	e_{33} Control mechanism of SD strategy	0.0219	0.0193	0.0482	0.0060	**0.0211**
	e_{34} Policy support	0.0138	0.0034	0.0067	0.0328	**0.0197**
C4	e_{41}Client's awareness to EPC	0.0965	0.0920	0.0186	0.0150	**0.0322**

	e_{42} Accurate M&V	0.0767	0.0745	0.0368	0.0735	**0.0632**
	e_{43} Clients' and ESCOs' awareness to SD	0.0913	0.0535	0.1214	0.0198	**0.0582**
C5	e_{51} Savings share	0.0193	0	0	0.0580	**0.0302**
	e_{52} Tasks and risks allocation	0.0823	0	0	0.0855	**0.0473**
C6	e_{61} Economic environment	0	0	0	0.0651	**0.0327**
	e_{62} Available financing market	0	0	0	0.0033	**0.0017**

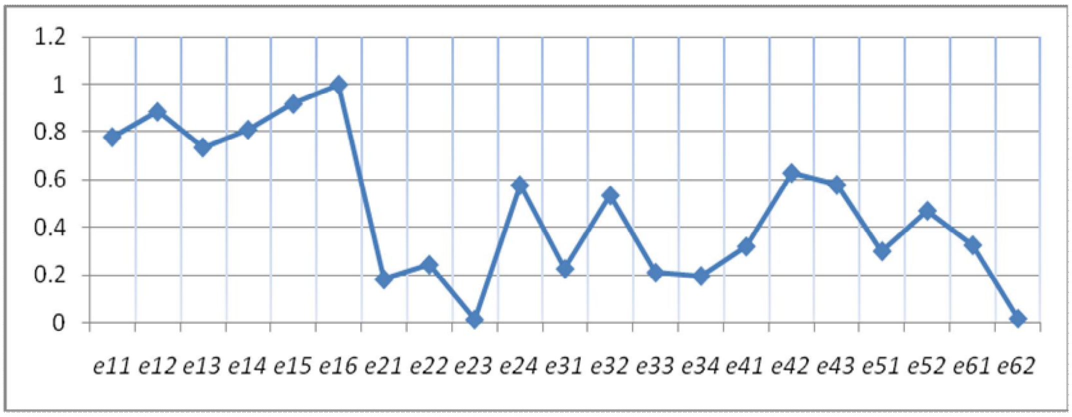

Fig. 8.10 Relative importance of CSFs for Social sustainability

All the factors in Cluster 1 project organization have a higher priority than other factors. The most important factor is e_{16} (trust). Two factors e_{62} (available financing market) and e_{23} (financing institute s' awareness of EPC) has no significance for social sustainability. This result shows that social sustainability performance of hotel building energy efficiency retrofit is mainly decided by project organization aspects, such as trust, project objective control mechanism, and effective coordination.

8.5 Model Validation

This research tried to find a real life hotel BEER project to validate the developed model. Though the development of EPC industry is fast in China, it is relatively new for us to see good example projects completed. Over the past 5 years, the number of EPC contractors is booming according to literature review. Hundreds of ESCOs were established in China. During the research process, the research team attended two training conference of ESCOs and tried to find some suitable EPC contractors with experiences in hotel energy efficiency projects. However, only several big ESCOs have the ability to apply EPC mechanism, and all of them prefer to conduct energy efficiency projects in industrial sector. Most of EMCA (Energy Management Company Association) members are transferred from traditional energy saving companies, such as equipment suppliers, which are not familiar with the EPC market and have conducted very few EPC projects successfully.

From other respect, the researcher has also tried to find a genuine project during the previous interview with hotel energy or engineering managers. All the hotel managers had willingness to conduct BEER and save energy costs bill. Because of the obstacles to BEER projects as presented in the literature review, few BEER projects were conducted in hotel buildings. Most of the energy efficiency projects in hotel buildings were implemented in traditional methods with the addition of simple energy efficiency measures. There is no real EPC used in these retrofitting, and most hotel managers interviewed had little awareness to EPC mechanism. There is a limited chance to learn from industrial projects or interview. That is why this research was proposed and hoped to contribute to industry from research led by academic. Hence, it is unrealistic to find a real life projects to validate the developed model.

In this study, the developed model was justified with cross-referencing between the initial questionnaire results and the basis for developing the model. Though the basic data to develop the model based on the data collected in the questionnaire, the relative importance of each factor was redefined in the ANP model. Hence, the comparison between them is feasible. Base on above questionnaire survey, CSFs were identified. According to the significance level of the CSFs given by respondents, the Top 5 CSFs are *Accurate M&V, Trust, Control mechanism of sustainable development strategy, Available technology*, and *Effective coordination* (see Table 8.5). Comparing with the model result, in the most five important CSFs for sustainable BEER, there are 3 same factors with the TOP 5 in questionnaire survey. For the two different CSFs, it is mainly because the interrelationships among factors were considered in the ANP model. From this test, it was believe that the results of the developed model are reasonable and reliable.

Table 8.5 Model justification

	Questionnaire Survey	**ANP Model**
1	Accurate M&V	Project objectives control mechanism
2	Trust	Available technology
3	Control mechanism of sustainable development strategy	Organizing capacity of team leader
4	Available technology	Trust
5	Effective coordination	Accurate M&V

8.6 Implications of findings

In order to achieve EPC success for sustainable BEER projects in hotel building, joint efforts should be made by all the involved participants in the following items:

(1) *Demonstration programs, education programs, and training.* Demonstration projects publicize successful examples of hotel building retrofit, which could publicly exhibit EPC project organization and delivery. Education programs should be provided by government, ESCO associations, and hotel associations, which could transmit knowledge of these projects and improve awareness. Training in energy efficiency technologies could improve the skill of team members.

(2) *Economic incentives.* Some economic incentive or policy support, such as special funding, tax preferences, and loan warrants, could make the investment environment and project financial status better.

(3) *Develop new technologies and energy efficiency products.* This item could make more advanced technologies and products available and affordable. The above results have shown that available technology has a high priority in the CSFs ranking.

(4) *Establish credit system*. Most ESCOs and hotel clients lack a credit history for building retrofit projects (Xu & Chan, 2011). A credit system of ESCOs and clients should be established through accreditation of qualification by a third party. This could promote trust between contractors and clients.

(5) *Standard contract procedure and M&V protocol*. A standard contract procedure could share risk, task, and profit reasonable. A M&V protocol agreed upon by clients and contractors could improve M&V. These would

reduce disputes and make coordination easier during the project process.

8.7 Summary

This chapter discussed the result of ANP model for sustainable BEER in hotel buildings developed in Chapter 7. A set of relationships between the KPIs for sustainable BEER and the success factors under EPC mechanism were examined. In this research, six KPIs for sustainable BEER and 21 CSFs of the EPC mechanism were identified. By adopting an ANP approach, the final priorities and relationships between CSFs and KPIs were revealed.

The final result of the ANP model indicates that sustainable BEER in hotel buildings under the EPC mechanism is mainly decided by project objectives control mechanism, available technology, organizing capacity of team leader, trust, accurate M&V, and team workers technical skills. More efforts should be given to these issues by decision-makers.

Weightings and relative importance of all the CSFs were identified in this section. However, the relative importance of all the CSFs for the sustainable BEER under EPC mechanism does not mirror the ranking identified in Chapter 6. The research aims are what distinguishes these two approaches. Factors ranking in Chapter 6 used the mean value approach, whose purpose is to select critical success factors and discard some factors with low mean value of importance. The ANP approach is used for identifying the weights of CSFs, which is a much more comprehensive and systematic method. Because the dependent relationships among CSFs were considered, the final priorities identified using the ANP approach in this chapter are more scientific.

CHAPTER 9 Conclusions

9.1 Introduction

This chapter summarizes conclusions and presents recommendations for further studies. The research aim and objectives are first reviewed, followed by a summary of the general conclusions of this study, which shows how the aim and objectives of this research have been met. It also presents the contributions, significance and limitations of the research. Finally, it concludes the study by suggesting potential areas for future research.

9.2 Review of research aim and objectives

Hotel building is a high energy consumption building, and most existing hotel buildings in China need energy efficiency improvements. BEER is an effective way to improve the energy efficiency of existing high energy consumption buildings and also encourages environmental protection, rational resource use, and occupant health. Sustainable development strategy has been reaching many spheres of human activities, and sustainable BEER involves integrating sustainable development techniques into existing buildings and retrofit projects. The delivery model is important when considering the implementation of BEER. EPC is a market mechanism to deliver energy efficiency projects and is considered a win-win system for organizing BEER projects. Studies have suggested various methods for assessing sustainable development in construction projects. However, there is a lack of effective performance indicators to assess and measure sustainability of BEER projects. The EPC mechanism has been introduced into China relatively recently and many EPC have not been successful.

The overall aim of this research is to develop a model for achieving the sustainability of Building Energy Efficiency Retrofit (BEER) in hotel buildings under the Energy Performance Contracting (EPC) mechanism. In order to achieve the primary aim of this research, the following objectives were established:

(1) A set of critical review of the BEER and the EPC from the perspective of sustainable development was conducted in Chapter 2;

(2) A conceptual framework for energy retrofitting under the EPC mechanism was developed in Chapter 4;

(3) Key Performance Indicators for measuring the sustainability of retrofitting projects in hotel buildings were identified were put forth in Chapter 5;

(4) Critical Success Factors of the EPC mechanism that have a strong co-relationship with the identified performance indicators were identified in Chapter 6;

(5) A model was developed to explain the relationships between the success factors and sustainability performance in Chapters 7 and 8**.**

9.3 Findings and conclusions: KPIs, CSFs, and ANP model

A theoretical hierarchy for sustainable retrofitting under the EPC mechanism was developed in Chapter 2. According to this hierarchy, a conceptual framework for analyzing the sustainability of retrofit projects was developed in Chapter 3. The framework was modified to be consistent with the energy framework quality model. This model contains two parts: result area and organizational area. This framework helps to analyze sustainable BEER under EPC and provide a guideline to select performance indicators and success factors. Eleven potential KPIs for sustainable BEER and 28 success factors of EPC are selected based on the developed framework through literature review and in-depth interviews.

Six critical concerns requiring performance indicators were identified from an initial set of eleven. The selection of these six areas of concern follows from the literature review and the in-depth interviews. The six concerns, which can be used as a basis for making performance indicators, are: (1) quality performance, (2) hotel energy management, (3) cost-benefit performance, (4) energy consumption and resource savings, (5) health and safety, and (6) stakeholders' satisfaction. Twenty one Critical Success Factors were identified based on the importance rankings. The five most important factors are: accurate measurement and verification, trust, control mechanisms, available technology, and efficacy of project coordination.

As described in chapter 3, an AHP/ANP approach was used in this research to develop a model to examine the interrelationships among success factors, performance indicators, and sustainable dimensions.

The following conclusions can be drawn based on the developed model:

1) Success factors affecting the performance indicators are:

- The quality performance of retrofitting is linked to the technology available, the organizing capacity of the team leader, the client's awareness of EPC, team workers' technical skills, project control mechanisms, and clients' and ESCOs' awareness of sustainable development in the project process.
- The strongest contributors for hotel energy management performance are accurate M&V, project objectives control mechanism, trust, and the client's awareness of the EPC mechanism.
- The cost-benefit performance of projects is related to project financial status, the economic environment, the allocation of tasks and risks, technology advances, and accurate M&V techniques and methods.
- In order to conserve energy and resources, more effort should be given to the improvement of the project manager's capacity, project control, trust, and technology.
- Health and safety performance is related to factors of organizational structure, project control, the organizing capacity of the team leader, and clients' and ESCOs' awareness of sustainable development.
- Stakeholder satisfaction is mainly driven by project financial status, trust, and efficacy of coordination.

2) Success factors particularly affecting the sustainability of retrofitting are:

- The sustainability of retrofitting is mainly decided by project control, available technology, the organizing capacity of the team leader, trust, accurate M&V, and team workers' technical skills.
- In order to improve the economic sustainability of retrofitting, more efforts

should be given to accessing new technologies, performing accurate M&V, trust, and financial management.

- The environmental sustainability of retrofitting is mainly driven by project control, the team leader's organizing capacity, trust, and technology.
- Social sustainability is driven by project organization, control, coordination, and trust.

9.4 Contributions

The ANP model adopted in this research will be very helpful for deepening the understanding of researchers and decision-makers of the complicated mechanism inherent in the sustainable BEER system.

This study identified key performance indicators for sustainable BEER project in hotel buildings. These factors can be used to develop an assessment system in future studies. It fulfills the knowledge gap of sustainability of building retrofit projects. By investigating the CSFs of the EPC mechanism, this study has added to the body knowledge of EPC project management and retrofit project management. It can help to set a benchmark to determine the success of the EPC mechanism and sustainability performance of BEER projects. The developed model itself is a first attempt to investigate the success factors of the EPC mechanism affecting the sustainability performance of hotel building energy efficiency retrofit, which contributes to the knowledge of sustainable building in general.

Moreover, the findings of this research are also constructive in practical usage. The result of sustainability performance of these projects and EPC project success factors could incentivize project practitioners to conduct these projects successfully. According to the developed model, decision-makers can invest their efforts for the different goals of project emphasis on economics, environment, and social sustainability. It also helps the implementation of the EPC mechanism in BEER projects and promotes the development of the ESCO industry in China. Additionally, governments and associates could propose relevant policies to implement EPC successfully in sustainable BEER in hotel buildings.

Finally, this study has academic value with its findings and research methodology, which can be adopted for an assessment system. The study focused on hotel buildings in China, but the research approach and analytical framework could be applied to investigate other building types. In this regard, the study provides a platform for further studies and debate.

9.5 Limitations of the study

There are two main limitations in this study:

- Firstly, due to limited time, the research data were confined to China and research findings were developed from a foundation of hotel buildings in China. Thus, the understanding and applications of these findings have to refer to the Chinese hotel building retrofits. The model developed in this research cannot be applied to other buildings and areas directly. However, it can be used after modification according to different statuses. This research focuses on the hotel buildings in China. In literature review, barriers to EPC in various building sectors were listed in Table 2.6, which reflects different characteristics of applying EPC to different types of buildings. For example in residential buildings, the projects scale is usually small with high transaction costs and decision process will be complexity because of multi-ownerships. The obstacles to BEER in China and barriers to EPC in China (see, Table 2.5) were also examined, which are the macro environment for identifying the KPIs and CSFs. In different countries, the policy systems, information and awareness, and contract and credible system are different. When applying EPC to other types of buildings and other countries, different KPIs and CSFs should be considered. However, the KPIs and CSFs identified in this research could provide references for selecting the KPIs and CSFs in other type of buildings and other areas.

- Secondly, due to current status of BEER in hotel buildings and EPC development in China, it is unrealistic to find a real case to validate the model developed in this research. It is noted that this model could be further improved and refined by applying it to real-life hotel building retrofit projects.

9.6 Directions for future research

This study provides a platform for further studies and debate. The possible directions for future research are listed as follows:

- KPIs of sustainable BEER in hotel buildings were identified. A rating system could be developed to measure the sustainability performance of BEER projects.

- Based on the model developed, a suitable business model for EPC could be investigated for building energy retrofit.
- This research could be expanded to other types of buildings, which could help make a comparative study involving sustainable BEER.

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APPENDICES

Appendix A: Cover letter of the questionnaire

尊敬的专家：

您好，

非常感谢您能在百忙之中抽出时间来做此问卷，这次研究的课题是“基于合同能源管理的酒店建筑可持续节能改造”。可持续发展是实现经济、社会与环境的协调发展，这一理论已经应用到各个领域的不同层面上，在建筑领域中被称为可持续建筑或绿色建筑。本研究根据可持续发展理论，提出了***可持续节能改造***的概念。采用合同能源管理机制（EPC）对既有建筑进行节能改造本身就是一种提高既有建筑的能效，实现绿色建筑的途径。在合同能源管理项目开展的过程中，也应当充分考虑可持续发展的原则做到可持续改造。本研究以酒店建筑为例，探讨在合同能源管理机制下实现酒店可持续节能改造的关键成功因素。

此次调研除了 Word 版问卷之外还采用了在线问卷，请任意选择您喜欢的方式，问卷的网址是：http://www.my3q.com/go.php?url=xupp/46027

您的看法对这一研究课题将有非常重要的启发和帮助，因此冒昧邀请您参与此次问卷调查，对给您带来的不便我深感抱歉。如果您需要，我们将为您提供本次调查的汇总和分析结果，以便您了解其他专家对这些问题的看法。请您尽量于 11 月 15 日之前将此问卷返回至 ______@gmail.com。

敬祝 身体健康、工作顺利

徐鹏鹏

香港理工大学建筑及房地产学系

2010 年 11 月

Appendix B: A questionnaire for sustainable BEER under EPC mechanism

第一部分 专家信息

姓　　名：________________________________职称/职务：____________________

单位名称：________________________________

单位性质：☐ 节能服务企业；☐ 酒店；☐ 政府部门；☐ 银行或融资机构；

☐ 科研机构/高等院校；☐ 其他能耗企业

从事节能领域工作的时间：

☐ 5 年以下；☐ 5-10 年；☐ 10-20 年；☐ 20 年或以上

您对合同能源管理（EPC/EMC）的了解程度：

☐ 不了解；☐ 了解一些；☐ 了解很多；☐ 非常了解

电邮地址: ________________________________联系电话：_____________________

第二部分 调查问卷表

一、 （酒店建筑）可持续节能改造的绩效评价指标

可持续节能改造：在节能改造项目中，综合平衡经济、环境、社会三方面的目标，在项目层面上实现经济、环境与社会的可持续性。

下表列出用于评价节能改造项目可持续性的绩效指标,根据您对可持续节能改造的理解，请分别判断各项指标对于可持续改造评判的重要性。重要程度说明：采用 5 分制方法评分；**1-很不重要；2-不重要；3-一般重要；4-重要；5-很重要。**

绩效评价指标（KPI）：	**重要性**
1）成本效益	请选择
2）改造持续时间	请选择
3）质量	请选择
4）酒店功能提升	请选择
5）健康与安全	请选择
6）能耗与资源节约	请选择
7）酒店能耗管理	请选择
8）创新与提高	请选择
9）环境负荷	请选择
10）文化的保护与继承	请选择
11）利益相关者满意度	请选择
其他指标（请补充）：	
	请选择

二、 基于合同能源管理（EPC）机制实现可持续改造的成功因素

下表列出了在合同能源管理机制下实现可持续改造的影响因素，请判断各因素影响可持续改造的重要性。重要程度说明：采用 5 分制方法评分；**1-很不重要；2-不重要；3-一般重要；4-重要；5-很重要。**

EPC 项目成功因素	重要性
外部因素:	
1）经济状况	请选择
2）社会环境	请选择
3）政策扶持	请选择
4）自然环境/气候	请选择
5）技术的获取（改造技术、检测技术、新能源等）	请选择
（酒店）项目自身因素:	
6）酒店自身经营状况	请选择
7）项目的复杂程度 （综合改造、单一改造）	请选择
8）建筑年限	请选择
9）建筑位置与场地空间限制	请选择
10）旅游季节与经营时间限制	请选择
领导与团队因素:	
11) 业主对 EPC 的认知	请选择
12) 领导的组织能力	请选择
13) 人员的技术背景	请选择
14）沟通能力	请选择
可持续发展战略因素：	
15）业主与能源公司对可持续发展理论的认知	请选择
16）项目绿色设计、改造方案	请选择
17）项目可持续方案实施的控制机制	请选择
融资因素:	
18）可获取的金融市场	请选择
19）融资机构对 EPC 的认知度	请选择
20）业主与能源公司的资信状况	请选择
21）项目自身的财务状况	请选择
合同因素:	
22）效益分享方式	请选择
23）任务及风险的分配	请选择
合作关系因素:	
24）相互信任	请选择
25）有效的协调	请选择
项目过程管理因素:	
26）合理的组织结构	请选择
27）项目目标控制机制	请选择
28）节能量的认证	请选择
其他因素（请补充）：	
	请选择

十分感谢您的热情参与！