The Hong Kong Polytechnic University

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Contractor's Environmental Performance Assessment System (C-EPAS)

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CERTIFICTE OF ORIGINALITY

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Abstract

ABSTRACT

Construction activities have considerable impacts on both the natural and the built environment in various ways. Existing research works suggest that construction activity has adverse environmental effects, such as the loss of soil and agricultural land, the loss of forests, and the consumption of non-renewable energy resources. Construction activity also contributes to the environmental pollution through releasing dust, toxic fumes and noise during the construction process.

In line with the promotion of sustainable development, increasing research efforts have been devoted to investigating methods for mitigating the environmentally adverse effects caused during the process of implementing construction activities. One development is to assess the environmental performance of a construction product at different stages during its life cycle, thus proper action can be taken to mitigate the poor performance if identified. Various assessment systems have been developed for assessing the environmental performance of a construction project. However, it appears that little study has been conducted to find an appropriate way to assess a contractor's environmental performance. In fact, the contractor plays the key role in executing construction activities, and its environmental performance has a strong association with the overall environmental performance in the process of implementing a construction project. Thus the implementation of environmental management across a contractor's operational activities is considered an important contribution towards protecting the environment. To assist contractors understand the level of their environmental performance, a methodology to assess their

environmental performance is necessary.

This study develops an effective method for assessing a contractor's environmental performance to calculate a contractor's environmental performance index (C-EPI). In order to calculate the C-EPI, a contractor's environmental performance assessment system (C-EPAS) is built up through formulating various parameters and performance assessment benchmarks to present a calculation model. Parameters adopted in the system include the environmental performance factors affecting the contractor's environmental performance and the environmental performance indictors used to evaluate the contractor's environmental performance.

A detailed survey was conducted for collecting the data used for determining the weightings of the parameters applied in the assessment system C-EPAS. In applying the system C-EPAS, the value of assessment indicators needs to be allocated. For this, the benchmarks of the indicator values are formulated. In order to calculate the C-EPI, the relative weightings of environmental performance factors to individual performance indicator are determined with applying the Non-Structural Fuzzy Decision System (NSFDS) method.

Based on the establishment of the environmental performance factors, indicators, benchmarks and weightings, a quantitative formula is used in calculating the value of C-EPI. The operation procedures in applying C-EPAS have been programmed, leading to the development of the C-EPAS computing system. The principles and functions of the C-EPAS are defined and the procedures for operating the system are

flowcharted. The operation system of the C-EPAS has been developed to user-friendly software.

The adequacy of the principles embodied in the C-EPAS computing system and the applicability of the system operation procedures of the system have been tested and proven through conducting a case study.

Publications Arising from the Thesis

Publications arising from the thesis

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Chapter 1:

Introduction

CHAPTER 1: INTRODUCTION

1.1 Research Background

Buildings have considerable impacts on the natural and the built environment in a variety of ways. The influence of the development of construction projects on the environment has been increasingly attracting a great deal of research studies. Ofori (1992) contends that the environment protection should be the fourth goal in implementing construction projects, along with cost, quality and schedule. The environmental cost resulting from the construction process is substantial. For example, great deal of energy is used in the production of construction materials such as cement, steel, aluminous, wood products, plastic and paints; the environmental pollution is generated during the process in implementing a construction project, including air pollution, noise pollution, water pollution, and land pollution; various kinds of wastes are generated during construction process, and the energy consumption for delivering materials and components to sites, and running and operating various facilities on site.

The pollution from construction activities can also lead to health problem. Surveys have shown that the majority of victims who suffer from dermatitis are due to the allergy to chromate that is from the trace impurity in all cements. A study of 600 cement workers in north Kent of UK found that their death rate from stomach cancer was 75% higher than expected and chromates were suspected as the likely cause

(Hall & Warm, 1995a).

It has been found that the manufacture and use of synthetic paints and solvents contributes nearly as much pollution as that from the fumes of motorcar exhausts. For example, the statistics shows that in West Germany 1989, VOC (volatile organic compound) emissions from paints and solvents relating to construction activities were 550,000 tons, compared to the 650,000 tons of emissions from motor vehicles. These emissions are pollutants to the environment, which could only be reduced through rainfall (Hall & Warm, 1995b).

Waste from construction activities is another type of pollutant to the environment. McDonald (1996) found that 14 million tones of waste were put into landfill in Australia, of which, about 6.2 million tonnes (i.e. 44%) were produced by construction demolition activities. Construction wastes results in, inter alia, the waste of land resources and the pollution to the environmental ecologies. Solid waste produced during construction has traditionally been discarded and sent to landfill. The increasing generation of construction wastes adds to the general waste disposal problems of that dumping sites reach to limited capacity and that waste transport distance increases. The increase of construction waste generation also accelerates the rate of exhaustion of non-renewable resources.

The waste from construction activities is not only a major environmental pollutant but also potentially hazardous to human being health. The study by Hendrickson (2000) identifies the five largest toxic air emissions from construction, including sulphur dioxide (SO_2), nitric dioxide (NO_2), volatile organic compounds (VOC), toxic releases to air, and hazardous waste generated. The analysis was conducted to the impacts of these environmental emissions among the four largest construction sectors in the United States.

These four major construction sectors including (1) highway, bridge, and other horizontal construction; (2) industrial facilities and commercial and office buildings; (3) residential one-unit buildings and (4) other construction such as towers, sewer and irrigation systems, and railroads. It was found that the level of hazardous emissions from construction activities in USA is considerable, and their environmental impacts are significant.

Construction business is a major energy consumer. Bush (1995) estimated that 57% of electricity used in developed countries was consumed directly by buildings: 31% in residential buildings, and 26% in commercial buildings. There are some cases where half the energy is used in operating buildings. The study by Hall & Warm (1995c) shows that about 30% of the UK energy is used in houses and 20% in office. On-site construction activity requires energy for tools, lighting, hoists and so on. And other facilities such as cranes and mixers have to consume fossil fuels for play their functions. The waste from using various energy resources not only contributes to the environmental pollution but also mitigate the sustainability of these environmental resources.

There is an association between the level of economic development and the environmental performance. Baba (1998) investigated the environmental problems caused by the construction boom in Asia, particularly in developing countries in the Asia region, as developing countries are exempt from new commitments to the mitigation of global warming. It is noted that one of the most serious problems in promoting environmentally friendly construction is the big gap between the opinions of people from developing countries and those from developed countries. The opinion came from the developed countries regards that the function of environmentally friendly construction activities is to supply the comfortable living environment based on the energy and resources consumption, but in the developing countries, the people pay more attention to provide the basic living and life conditions through method of saving energy and resources as far as possible (Baba, 1998).

Previous researches have demonstrated that the impacts from construction activities on the environment are considerable and in multiple ways. (Bourdeau, 1998; Treloar, 1996; Ofori, 1998). Typical impacts include the loss of soil and agricultural land, the loss of forests and wild lands, and the loss of non-renewable energy sources and materials, competition for land with other activities such as agriculture; adverse effect on developed land and substantial consumption of both renewable and non-renewable resources; production of substantial volumes of waste; and consumption of large amounts of energy during the processing of materials. Furthermore, the construction process contributes to air pollution by releasing dust and toxic fumes during the production and transportation of materials and during construction operations. The pollution causes disruption to people living in the vicinity of a project because of traffic diversions, noise pollution and others environmental damages.

The construction-contributed environmental pollution is worsening particularly in those developing countries. For example, in China, the standards of major environmental indicators such as sulphur dioxide (SO_2) emissions and total air-suspended particulates (TSP) are far worse than international standards (Zhang & Shen, 2000). It is suggested that these problems have close association with its fast urban development in China since the early 1980s. It has been reported 72% of the major Chinese cities, including the municipalities and the provincial capitals, have TSP of over 200mg/m^3, whilst the international standard defined by the World Health Organization is 90 mg/m^3 (WB, 1998). These facts have caused the governmental concern with the impacts of construction activities on the environment. Accordingly, relevant laws and regulations have been legislated during previous few years for protecting the environment in the process of implementing construction projects.

Among those developed countries and regions, Hong Kong is a typical place where construction is one of the major economic sectors and at the same time is a major contributor for the environmental pollution. With a rapidly growing population in Hong Kong, which has increased by about one million people every decade over the last 30 years and is forecasted to be 8.9 million by 2016 –up 2.2 million from 1998 (EPD, 1999), Hong Kong has been implementing and will continue to implement ambitious construction programs. Nevertheless, these construction works have contributed largely to the continuing deterioration of the environment in the local territory. Unfortunately, protecting the environment has been given a low priority for many years. Until recent years, the Hong Kong Government has devoted significant amount of resources to implement environmental protection among all industries particularly including construction industry. Huge amount of investment has been spent on new sewers and sewage treatment facilities and new landfills. Various laws and legislations have been introduced for enforcing environmental protection (EPD, 1999).

The previous research works on environmental protection have led to the development of various management systems and methods. Typically, for example, ISO 14000 has been developed as an international standard for promoting environmental protection across all industries. A key element in the ISO 14000 system is the Environment Management System (EMS) (ISO, 1999), which is described in details in the Standard ISO 14001. ISO 14001 is considered as a market-driven framework for balancing environmental protection with socio-economic needs, which incorporates the principles of sustainable development (Ofori, 1998). The application of ISO 14000 is to promote environmental protection across all industrial sectors and allows issuing the ISO 14000 certificate to those business companies who have properly implemented EMS. The practice of ISO14000 is largely based on the establishment of a documentation system, which is similar to the practice of ISO9000 certification (HKPC, 1998). A typical limitation in the current practice in using the ISO14000 system is that the contractor's real environmental performance cannot be properly measured, and thus cannot be adequately communicated to the public or to construction clients (Shen & Zhang, 1999).

There are other systems developed for promoting environmental management. The Building Research Establishment Environmental Assessment Method (BREEAM) (Roger, 1998) was launched in UK in 1990. The system is designed to provide authoritative guidance on ways of minimizing the adverse effects of buildings process and building products on the environment.

The application of this system leads to the development of many other similar schemes adopted in other countries, such as the Green Building Tool (GBTool), Leadership in Energy and Environmental Design (LEED), Sustainable Building Assessment Tool (SBAT), and Hong Kong Building Environmental Assessment Method (HK-BEAM).

GBTool is an international initiative that set up an agenda for environmental assessment of buildings (BRI, 2001). It was developed to assess the environmental performance of commercial, residential and schools buildings. It is a very comprehensive assessment tool that focuses on the biophysical aspects of a building development.

The system LEED developed by US Green Building Council (USGBC) allows for a comprehensive assessment of building environmental performance by adopting a life-cycle approach. But it is limited to only assess and rate commercial office buildings (Todd & Lindsey, 2000).

The sustainable Building Group in South Africa developed the Sustainable Building Assessment Tool (SBAT). SBAT is a tool developed to assist in assessing the sustainable development, namely, social, economic and environmental aspects of a development, SBAT compromises a wide range of factors that effect the environmental performance (Kaatz, 2002).

The application of these systems has contributed significantly to promoting the environmental protection in construction activities. However, one of the major limitations of these management systems is considered as that less consideration has been given to the environmental performance of the concerned contractors who are the key players in implementing construction activities. For example, ISO 14000 system only provides guidelines for implementing environmental protection in the practice. It does not present a measurement for measuring the environmental performance committed by a contractor. In fact, contractors play essential roles in improving environmental performance along the whole construction process. It is considered of important significance to find a way for assisting contractors in understanding their environmental performance and identifying their weak areas in practicing environmental management. Therefore, it is the aim of this study to find an assessment approach for assessing the contractor's environmental performance. This approach is called as contractor's environmental performance assessment system (C-EPAS). This approach is designated as a quantitative model being able to calculate the contractor's environmental performance index (C-EPI), which means the level of environmental performance from a contractor's practice and identify the environmentally weak areas through a diagnosing process.

1.2 Research Objectives

This study is formulated with focusing on the following research objectives:

(1) To identify the key environmental performance factors affecting a contractor's environmental performance in construction activities

(2) To formulate the environmental performance indicators for measuring a contractor's environmental performance

(3) To select the benchmarks of assessing the level of environmental performance of individual environmental performance indicators

(4) To design the quantitative model to calculate the C-EPI

(5) To formulate the checklist for assisting contractors in diagnosing the causes of poor environmental performance

(6) To develop the operation procedures of using C-EPAS to computer aided programs, and test the validity of the system

1.3 Methodologies

This research is composed of extensive literature studies and practical surveys, which provide essential data for analysis. To achieve the objectives designed in this study, a number of methodologies are used. These methods are described in details as follows.

(1) A survey approach is adopted to collect practical data. Questionnaires are used for approaching professionals who are working in construction fields. Questionnaires are designed in the way that the data to be collected can assist in achieving planned study objectives of establishing the indicators of a contractor's environmental performance and identifying the key factors affecting the indictors. (2000 questionnaires were sent to respondents and more than 500 were returned, of which 511 are valid for analysis.) The results of the questionnaires survey were presented to

6 constructive interviews. Good comments were received from these in-depth interviews on the issues such as the weightings among various environmental performance factors and environmental performance indicators. And the final findings from the survey are used in identifying the factors affecting a contractor's environmental performance and building up the indicators.

(2) The statistical analysis package, namely, Statistics Package for Social Science (SPSS), is used to assist in generating results from the practical survey. SPSS has been proven an effective tool in assisting research analysis to produce the significant statistical results. The survey of this study has generated a great deal of both qualitative and quantitative data, and the application of SPSS can help the data processing.

(3) The analytic hierarchy process (AHP) method is used to determine the ultimate weightings among environmental performance factors and among environmental performance indicators. AHP is an effective method for ranking the importance among many parameters, which may be described in hierarchy (Saaty, 1979). Thus it is considered suitable to be used to determine weightings in this study where both the indicators and factors are presented in a multi-level hierarchy.

(4) A non-structural fuzzy decision system (NSFDS) method is used to calculate the level of a contractor's environmental performance, called as contractor

environmental performance index (C-EPI). The formulation of the environmental performance factors and environmental performance indicators provides the basis for calculating the level of contractor's environmental performance. A quantitative model is needed to process the calculation, and the method NSFDS is chosen for this purpose. NSFDS is an effective modeling method with the functions of decomposition, comparative judgment and synthesis of priorities among factors and indicators (CHEN, 1998). The decomposition principle is used to categorize the assessment indicators into different levels. The principle of comparative judgment concerns the pair-wise comparisons on the relative weightings among the factors and indicators. The synthesis of priorities ensures the propriety and consistency of priority setting in comparative judgments.

1.4 Structure of the thesis

Chapter 1 provides an overall introduction about this research study. It describes the research background, presents the research objectives, and describes the methodologies used for conducting the research.

Chapter 2 presents a comprehensive literature review for this study and builds up the structure of C-EPAS. The literature review establishes the theoretical basis for this study. The major areas covered in the review include the buildings' impact on the environment, construction activities' environmental impact, existing research work on the environmental factors affecting a contractor's environmental performance, related research results about the environmental performance indicators which can be used to assess a contractor's environmental performance and environmental assessment systems. The literature review demonstrates the lack of research works in the field chosen for this study, thus presents the significance of understanding this study. The structure of C-EPAS is built up with the several parts including environmental performance factors, environmental performance indicators, environmental assessment benchmarks for evaluating the contractor's specific environmental performance with individual environmental indicators and a quantitative model used to calculate the C-EPI.

Chapter 3 identifies the factors affecting contractor's environmental performance. The purpose of this identification is to establish an understanding on what factors should be controlled for improving contractor's environmental performance. These factors are classified under the categories of specialist works, site management, project management, technology and environmental policy. The identification of these factors involves dada collection from literatures and an extensive practical survey, more than 500 responses being collected from a questionnaire survey. The relative importance of the factors has been established, and the distributions of the weightings among the factors are formulated by using the Analytic Hierarchy Process (AHP) method.

Chapter 4 formulates the environmental performance indicators in multi-hierarchy structure, which can be used to evaluate a contractor's environmental performance.

Environmental performance indicators have been extensively investigated and analyzed. This formulation involves data collection from literatures and practical survey. The distributions of the weightings among the indicators are established by using the Analytic Hierarchy Process (AHP) method.

In chapter 5, the benchmarks for evaluating the contractor's environmental performance with individual environmental performance indicators are proposed. Existing systems on environmental performance assessment are widely referred to. By using the benchmarks, contractor's weak areas on environmental performance can be identified.

Chapter 6 presents a quantitative model to calculate a contractor's environmental performance index (C-EPI). In the calculating process, the Non-Structural Fuzzy Decision System (NSFDS) is adopted to determine the relative weightings between the environmental performance factors and the environmental performance indicators.

Chapter 7 presents a computer aided C-EPAS package for calculating the C-EPI. The operation procedures are presented and the data flow chart of C-EPAS are demonstrated as well. The package includes three main modules: input module, core module and output module. The diagnosis function of C-EPAS can be useful to assist the contractor's to improve the environmental performance.

In Chapter 8, the results of applying the package through a case study have been presented for testing the practical characters and effectiveness.

Chapter 9 presents the overall conclusions from the study. Major findings have been summarized and the potential areas for future other studies are identified.

Chapter 2:

Literature Review

CHAPTER 2: LITERATURE REVIEW

2.1 Impact of Construction to Environment

Any economic activity will have an effect on the environment in one way or another, and sometimes this effect can be a detrimental one. Best (1997) deemed that the erection of permanent structures for residential and other purposes was one of the major attributes of civilization. However, the construction, maintenance and use of these structures all have significant impacts on the environment, both locally and globally. These impacts may bring the actual effects in short or long term, for example, they can contribute to the air pollution locally or make changes in the world's climate, atmosphere and ecosystem.

It has been realized that global climate change is happening, and human building activity is considered one of the major causes for this (IPCC, 1995). Building at all stages of its life from construction to demolition, contributes in many ways to the impacts on the environment. It is considered a pressing issue to realize these impacts thus proper measures can be taken for protecting the environment.

2.1.1 Space Impact

Building activity will consume space environment, whether above or under the ground. In many developed cities it is hardly to find much spare open space apart from the built structures. The problem of crowded environment is growing in many developing countries or regions where the urbanization process is developing rapidly. Further, it is likely to be so crowded with largely unplanned developments that the designers of new buildings pay little attention to the existing built environment and instead design in isolation (Best, 1997).

2.1.2 Materials consumption

The consumption on building materials has the impacts on the environment in a number of ways, from the extraction of minerals such as iron, ore and bauxite, to the disposal of demolition materials at the end of building's life. Using materials for developing building will not only reduce materials resources but also consume energy resource. Energy is used to explore and transport raw materials, to process those materials, to fabricate components from the processed materials, to install components into built structures, to maintain the operation of the built building, to disassemble or remove those components at the stage of building demolition, and to recycle the wastes generated from building demolitions (Best, 1997).

The environmental impact of the processing and manufacture of building materials also include physical degradation around mines, loss of topsoil, loss of forests, destruction of habitat, loss of biodiversity, and depletion of non-renewable resources such as mineral reserves and rainforests. Manufacturing processes for building materials produce a variety of toxic and non-toxic wastes, many of which go to landfill or find their way into rivers and groundwater. On-site construction activities produce noise, dust and, sometimes, vibrations which may have significant, although generally short-term, local effects (Best, 1997).

The practice of logging timber materials for building framing, furniture and finishes is worsening in affecting the forests. It is reported that in tropical areas the pace of deforestation is alarming – about 42 million acres (approx. 17 million hectares) of forest disappear each year (Grant, 1996). The additional consequences of deforestation include the loss of water quality, destruction of habitat, degradation of soils and loss of species (which may contain substances which are potentially beneficial pharmaceuticals). In fact, forest is a vital environmental aspect, and any reduction in forest will directly reduce the capacity of the Environment to absorb carbon dioxide.

The impacts of using materials on the environment will continue after a building completed. Once installed many materials continue to affect the environment, particularly in respect of indoor air quality (IAQ). Paints, upholstery fabrics, carpets and manufactured wood products are examples of the range of materials, which can generate potentially toxic emissions for a considerable time after installation. There are ongoing research works (Bartlett & Prior, 1991a), aiming for establishing links between 'outgassing' from building materials and sick building syndrome (SBS).

Many insulating materials used in buildings are made from non-renewable petroleum resources and use Chlorofluorocarbons (CFCs) in their manufacture. Most of the CFCs used remain in the material and this present a risk of disposal or recovery when buildings are refurbished or demolished.

CFCs and, more recently, Hydrogen-Chlorofluorocarbon (HCFCs) have been widely used as refrigerants in chillers and other refrigeration plant inside a building. There are countries where the use of CFCs is strictly controlled. The Worldwide these substances are generally being phased out but their use will not be completely outlawed for some years yet. The USA, for example, aims to have eliminated the use of CFCs by the end of 1996, and of HCFCs by 2030.

2.1.3 Waste generation

Construction wastes are in the form of building debris, rubbles, earth, concrete, steel, timber and mixed site clearance materials, arising from various construction activities including land excavation or formation, civil and building construction, site clearance, demolition activities, roadwork and building renovation. Construction activities also generate chemical and other special wastes, which are normally regulated strictly for special treatment as they can easily cause pollution to the environment or become risks to health. Solid waste produced from construction and demolition works has traditionally been discarded and sent to landfills. This not only adds to the general problems of waste disposal as dumping sites reach capacity and transport distances increase but also accelerates the rate of exhaustion of non-renewable resources (McDonald, 1996).

2.1.4 Energy consumption

Buildings are major energy consumers. The building sector accounts for around one third of the delivered energy used in most countries, with an even greater portion of electricity use attributable to buildings. Janda and Busch (1994) estimate that 57 per cent of electricity used in developed countries is consumed directly by buildings: 31 per cent in residential buildings, and 26 per cent in commercial buildings.

On-site construction activity requires electricity for tools, lighting, hoists and so on; other items of equipment such as cranes and mixers use fossil fuels, which contribute directly to atmospheric pollution. In completed buildings, energy is used for multiple purposes including space heating and cooling, lighting, domestic hot water, and to operate various appliances. The majority of energy used in buildings is devoted to heating, cooling and lighting. In Australia heating, ventilating and air conditioning (HVAC) systems account for around 43 per cent of the energy consumed in commercial buildings, and a further 22 per cent is used for lighting (CBEC, 1994). Energy for hot water accounts for another 18 per cent of the total. Much of energy is in the form of electricity and therefore contributes to Greenhouse Gases (GHG) emissions. Furthermore, HVAC systems installed inside buildings also contribute to the pollution of urban environment. The rising in temperature in urban areas is becoming a major environmental problem, for a number or reasons including the crowded urban structures, which have higher ability in absorbing heat, and the extensive use of HVAC systems.

The above discussion demonstrates that the impacts of buildings and their multitude of components on the environment are not limited to the local or immediate environment surrounding a building but include regional and global effects. The construction industry includes regional and global effects. The construction industry including the key players of clients, designers, demolishers, developers and contractors, which has liability to deal with those problems and make contributions to sustainable environment. Management efforts should be devoted to all construction related activities, in particular, in the areas including materials selection, waste management, environmentally friendly construction operation, environmentally friendly technologies and other methods, which can be useful in implementing environmental management. Some advances have been made but much remains to be done if the environmental impact of built structures is to be reduced to a level where sustainable construction can become an achievable goal (Best, 1997).

2.2 Sustainable Construction

2.2.1 Implication of sustainable construction

Sustainable construction has been promoted in line with the mission of sustainable development. The key issue of sustainable construction is to adopt a practice that has the minimum environmental impacts. Arup and partners (1993a) pointed out that the first fundamental concept in attempting to minimize the impact on environment was to use less of everything. There is a clear benefit to be gained by consuming the minimum level of resources. Building activities can make contributions to this through a number of measures, such as proper control of construction procedures; minimize wastage across whole construction process. The implication of sustainable construction is multiple. It concerns that building materials or components should be re-used wherever possible, thus saving the material and energy cost needed for producing new materials. If re-use is not possible, re-cycling or refurbishment should be considered in preference to disposal. Nevertheless, much of the existing studies relate sustainable development to the subjects of energy efficiency or more specifically fuel efficiency, and less attention was given to the environmental impacts of materials. As discussed before that the impacts from developing buildings on the environment are through many activities including the production and transportation of materials and building components, their construction on site, the generation of construction wastes, etc. It is widely considered that the environmental impacts from building activities are more significant to that from other economic sectors. For example, Robert (1994) had suggested that 66% of total UK energy consumption was accounted for by buildings and building construction and services.

2.2.2 Development of Sustainable Construction

This recognition on the depletion of the environment was first discussed in the 1973 United Nations Conference on the Human Environment in Stockholm. Following that, the concept of sustainable development was described in the 1980 World Conservation Strategy (WCS), produced by the International Union for Conservation of Nature and Natural Resources (IUCN) in collaboration with the United Nations Environmental Programme (UNEP) and the World Wildlife Fund (WWF, now the World Wide Fund for Nature). Based on the World Conservation Strategy, the National Conservation Strategies for sustainable development were then prepared and adopted by the governments of fifty countries (Langston, 1997). It is widely quoted that sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs (CIB, 1998b). The World Commission on Environment and Development in 1987 adopts the definition in the report.

Hence the construction industry has a lot of direct and indirect links with the various aspects of sustainable development (CIB, 1998a). It is clear that the various activity of the construction sector have to be regarded and analyzed when considering sustainable development (CIB, 1998b). The concept of sustainable development has increasingly attracted the attention to both practice and the academic since 1980s when the growing concern about the depletion of the environment became obvious.

It is now widely accepted that environmental quality and the conservation of natural resources are among those priorities to be addressed in our business activities.

The First International Conference on Sustainable Construction held in Tampa in 1994, where the definition of sustainable construction was introduced as "the creation and responsible maintenance of a healthy built environment based on resource efficient and ecological principles" (Kibert, 1994). The research by CIB (1998c) investigates the relationship between sustainable development and the future of construction. It presents a conceivable sustainable construction road map, as shown in Figure 2.1.

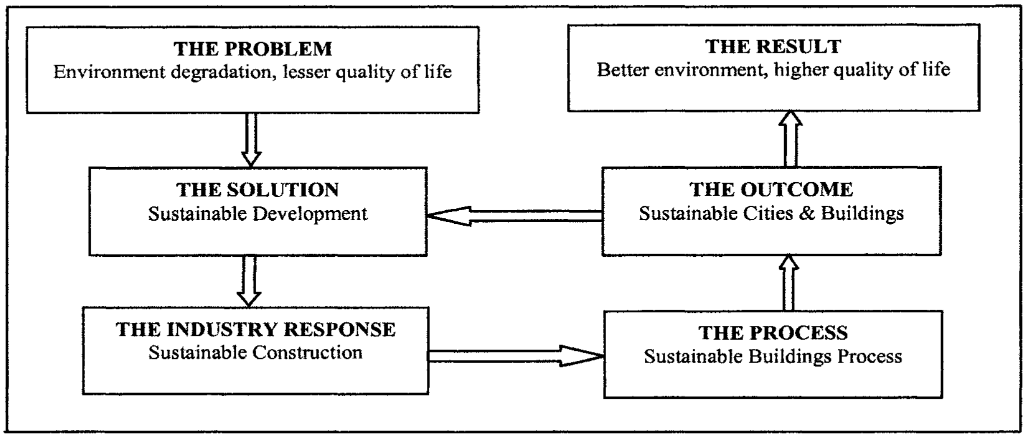


Figure 2.1 A conceivable Sustainable Construction Road Map

Questions are raised in applying the principle of sustainable construction. What kind of buildings will be built in 2010, and how will we adapt existing buildings? How will we design and construct them? What kind of materials, services and components will be used there? What kind of skills and standards will be required? And what kind of cities and settlements will we have then? These questions were opened for an extensive discussion among the delegates from different countries (CIB, 1998d). The discussion over the conference leads to the development of the principles of sustainable construction. These principles include three major aspects: (a) ecological principles (to eliminate resource depletion, to eliminate environmental degradation, and to create a healthy interior and exterior environment); (b) resources (four resources are concerned: land, energy, water and materials); (c) life-cycle phases of the construction process (five phases are defined: develop and plan, design, manufacture and construct, operate, deconstruct).

2.2.3 Promotion of Green Construction

The focus of sustainable construction on protecting the environment leads to the promotion of green construction which relates to all activities in the whole process of developing a construction product, including design, construction and project operation. Others relate green construction more to an architecture style. Sudjic (1996) assumed that buildings are green if they look hand-made and are built of natural materials but working in aluminum and glass might create a more genuinely sustainable architecture in the long run.

Sudjic's viewpoint comes from an attitude to architecture in which stylistic questions tend to be considered more important than environmental ones. But it reminds us the danger of assuming that because a building looks superficially green it is creating less damage to the environment than one that looks 'high tech' or post modern (Woolley, 1997).

The subject for a building to be green essentially concerns more about the environmental impact of all the building constituent parts, which will be largely determined in building design. This is a much more thorough exercise than simply adding a few green elements such as a grass roof or a solar panel.

Many people are reluctant in using the term green building or green construction, rather adopting of environmentally friendly buildings or sustainable construction. Are these terms euphemisms or do they mean something different? There is undoubtedly a need for some people to distance themselves from green activists who climb up trees or dig tunnels in the path of new roads. There are many who fear there is an association between green building or construction and some political implications.

Nevertheless, the term green building has been widely adopted. The implication of green building is multiple. Robert and Brenda (1991) suggested that a green approach to the built environment involved a holistic approach to the design of buildings, that all the resources that went into a building, including materials, flues or the contribution of the users needed to be considered if a sustainable architecture was to be produced. Sim and Cowan (1996) pointed out that we must infuse the design of products, buildings and landscapes with a rich and detailed understanding of ecology.

Whilst there are many similar concepts used, such as Green, Sustainable, Environmental and Ecological, they are practically used interchangeable. The nuances of their use depend on the context and the audience. For instance, the Building Services Research and Information Association (BSRIA), a mainstream construction industry body, defines "sustainable construction" as *"the creation and responsible management of a healthy built environment based on resource efficient and ecological principles.* " (BSRIA, 1996). It indicates that there are common principles in these concepts, namely, minimizing non-renewable resource consumption; enhancing the natural environment and eliminating or minimizing the use of toxins. Decisions about layout, relationship with site, the effects of wind and weather, possible use of solar energy, orientation, shading, ventilation, specification of materials and structural systems, must all be evaluated in terms of their impact on the environment and the occupants of buildings (Woolley, 1997).

Thus green building is not simply about protecting the biosphere and natural resources from over-exploitation or over-consumption, nor is it simply about saving energy to reduce our heating bills. It is about reducing energy use, minimizing external pollution and environmental damage, reducing embodied energy and resource depletion, and minimizing internal pollution and damage to health. Nevertheless, limitations exist in the application of green building. Dickens (1995) pointed the danger of suggesting that green design can "save the world", warning of a fetish of so-called environmentally friendly commodities, which were simply new forms of consumer product.

2.2.4 Environmental Management Systems

In line with promoting sustainable construction, building regulations have been improved to reduce energy consumption, and regulations also exist for reducing toxic emissions from building materials. But often these standards are watered down as a result of commercial pressures or fail to be properly enforced and will inevitably lag behind what is possible (Woolley, 1997). The implementation of these regulations has led to the developments of various environmental management systems, and those typical ones are listed as follows (Howard L., 1995):

- Building Research Establishment Environmental Assessment Method (BREEAM (UK)
- Building Research Establishment office Tool kit (BRE Office Tool kit) (UK)
- Home Energy Rating (UK)
- European Eco-labelling (Europe)
- Ecocerto (Italy)
- Ecolab (Netherlands)
- BREDEM (UK)
- SIB (Switzerland)

- BauBioDataBank (Germany)
- Waste/ Environmental Data Sheet (Europe)
- Athena (Canada)
- BEP AC (Canada)
- BMES Index (Australia)
- Hong Kong Building Environmental Assessment Method (HKBEAM) (HKSPR)

These techniques provide tools for conducting the assessments of individual buildings, materials and products. The applications of these techniques are promising. Many larger building and development projects are nowadays required by law to produce environmental impact statements (E.I.S.s) before planning permission is granted. In particular, Eco-labeling seems being well received by the industry and commercially adopted. A UK Eco-labeling board, based in London, is now issuing guidelines to industry for this voluntary scheme for consumer products (UKELB, 1995).

2.2.5 Critiques of Environmental Assessment Systems

There is also a significant body of literature, which is critical of current attempts to develop standardized systems of environmental criteria in implementing construction activities. Wozniak (1993) argued that several assessment systems were flawed in that they rely on an uneven collection of criteria that were not based on any logical evaluation. Often crucial environmental factors were left out simply because they couldn't fit them into the methodology. Shove (1995) pointed out the dangers of standardization in that such an attitude in the past with public housing had led to a failure to take account of the cultural variability of building occupants and their creative, multi dimensional interaction with the built environment. In other words, such standardization rules out opportunities for people to take responsibility for environmental standards and avoids variation between different circumstances. Rigidity can be dangerous as people fail to look behind the bland labelling to the criteria, which have been used to formulate them. If something has an eco-label, it will be assumed to be ok, when full awareness of the impact of the product may still lead many to question its use.

Furthermore, the difficulties of attempting to produce standardized and systematized solutions to environmentally friendly buildings are also because buildings are complex, requiring creativity, imagination and judgment exercised in collaboration with clients and building users. For instance, the introduction of highly insulated, draught sealed buildings to save energy has led to problems of condensation and health problems for occupants as insufficient attention has been paid to ventilation. Attempts to compensate for this by introducing ventilation and heat recovery systems have ended up increasing the energy costs beyond the original reductions (ECJRC, 1996). Environmental management systems will find difficulty to success without incorporating with design and other relevant issues. Unfortunately, some existing studies concerning the eco-labelling and environmental criteria contribute less attention to the building design process, the manufacturers of materials and the producers of constructing buildings (ECJRC, 1996). In a purely commercial environment, builders and developers may be concerned with creating the impression that they are being environmentally responsible whilst decisions about development and building procurement may be taken in a way that precludes proper consideration of environmental issues.

Woolley (1997) pointed out the danger that many people are concerned with finding a scientific, politically neutral, mathematical formula for awarding environmental credit points to particular materials, products and buildings, while making it possible for commercial manufacturers and developers to avoid the need to understand environmental issues themselves. Rather than attempting to achieve a mathematical, politically neutral set of standards, which then hold up the danger of being applied in an inflexible way, what are required are guidelines based on scientific research against a whole range of questions that green designers can find answers. Well-informed designers and clients through a process in which they take responsibility for the implementations of their decisions can then make judgment about what should and should not be used. Simply applying certain standards without investigating the reasoning behind them creates the danger of environmental criteria that are essentially cosmetic.

Of course this is controversial as there are many who believe that measures to protect the environment will never be taken unless stringent standards are applied through legislation. Woolley (1997) points out that here is much to say in support of this point of view and indeed many of the issues referred to in the digest are a result of

European legislation intended to protect industrial workers and the environment. Such base-line controls and requirements are necessary, but we cannot only rely on legislation to determine behaviour. It is still necessary to change attitudes and this must be done through education of professionals and others in the construction industry.

2.3 Review on the factors affecting the environmental performance in construction process

There are number of studies which have presented various factors affecting the environmental performance in construction process. The typical studies are discussed as follows.

2.3.1 Environmental performance factors applied in HK-PASS

Hong Kong Housing Authority (HK-PASS, 1990) has been implementing a Performance Assessment Scoring System (PASS) as the principal appraisal method for measuring contractor's quality performance. The assessment concerns many aspects including cost control performance, time management performance, environmental performance, and safety performance. PASS was introduced in 1990 by the HKHA for use on HKHA building contracts. The main principle of using the system is that contractors who perform to the required standard will have tendering opportunities. Thus it is important to have a set of proper performance standards and a set of practically applicable assessing procedures. HKHA applies rating methodology to assess contractors' overall performance on a number of attributes including structural works, architecture works, other obligations, site management and progress. Each of these attributes includes a number of factors and they formulate the basis for assessing contractor's environmental performance. These factors are listed out under individual attributes as follows (HK-PASS, 1990).

STRUCTURAL WORKS (SW)

Substructural formwork and formation

Substructural reinforcement and concreting

Substructural finished concrete

Formwork and false work

Reinforcement and concreting

Finished concrete

Construction quality and practice

ARCHITECTURE WORKS (AW)

Floor

Internal wall

Internal wall finish

External wall finish

Ceiling

Window opening

Window

Plumbing

Components

Spatter dash

Waterproofing

Precast components

Shop front

Watertightness test to window

Watertightness test to bathroom (washroom, balcony)

Watertightness test to precast façade

Builder's work

Earthwork

External drainage

Roads

Emergency access

Footpath

Pdestrian areas

OTHER OBLIGATIONS (OO)

General site safety

Site security & material

Health & other provision

Cleanliness and care of the finished works

Block related safety

SITE MANAGEMENT

Management & Organization of works

Management structure

Site planning

Resources

Labour

Plant

Mmaterials

Co-ordination and Control

General co-ordination

Environment control

Supervision

Communications

Ccompliance and cooperation

Other attendance

Completed works after sectional completion

PROGRESS

Documentation

Submission of temporary works instruction

Submission of materials' environment impact report

Submission of phase site environment report

Submission of monthly payment application for environment, environment documentation

Programming and Progress

Program

Progress

Milestone dates

2.3.2 Environmental performance factors applied in MALAYSIA MHLG

The MALAYSIA Ministry of Housing and Local Government (MALAYSIA MHLG) formulated a set of factors for assessing the building's environment performance in 1997 (CIB, 1998c). These factors are grouped into six categories: (1) building environment; (2) initiating and designing; (3) construction and demolition; (4) operating and maintenance; (5) components, materials, services and assembly; and (6) skills and standards. The impacts of these factors on the environment are related to the basic elements of the elements, namely, land, energy, water, and materials. MALAYSIA MHLG provides a valuable reference in undertaking this study.

2.4 Environmental Performance Indicators

Typical indicators used in the existing methodologies for assessing environmental performance include water pollution, noise, air pollution, emission, soil damage, solid wastes, loss of forests and wild lands, loss of non-renewable energy sources, sewage, loss of non-renewable materials, traffic, health hazards, loss of biodiversity (Cole, 1998; Treloar, 1996; Ofori, 1998). To verify the suitability and comprehensiveness of these indicators, this study will engage a practical survey to project clients, designers, project managers, contractors and subcontractors, focusing on the suitability, comprehensiveness and the importance of the indicators for measuring contractor's environmental performance.

The Hong Kong Building Environmental Assessment Method (HK-BEAM, 1999) has provided a valuable frame of the environmental performance indicators under the categories of Global Issues, Local Issues and Indoors Issues. The frame has been accepted and confirmed by the related official Departments of Hong Kong. This too provides important reference to this research study. Woolley (1997) has also established a system of the indicators, which can assess the building's environmental performance, for example, acid, global warming, air pollution, etc.

2.4.1 Environmental Performance Indicators in HK-BEAM

There is a growing concern about the quality of the local environment in Hong Kong. It is well realized that the environmental performance has a close association with building activities in the local territory (HK-BEAM, 1999). Both public and private sectors are urged to improve the environmental quality of the local building stocks. For promoting the environmental performance of building activities, the Hong Kong Building Environmental Assessment Method (HK-BEAM) has been developed to provide authoritative guidance to developers (and their consultants), owners, operators and users with the aim of minimizing the adverse effects of buildings on the global and local environments, whilst promoting a healthy indoor environment. In implementing the system, the environmental issues are grouped under three categories, namely, global issues and use of resources; local issues and indoor issues.

The HK-BEAM scheme is an initiative of The Real Estate Developers Association of Hong Kong. The first two versions were developed through a HK-BEAM Steering Committee with the assistance of the Department of Building Services Engineering, The Hong Kong Polytechnic University (BSE), the Welsh School of Architecture, University of Wales College of Cardiff (WSA), and ECD Energy and Environment Limited, UK (HK-BEAM, 1999).

The system HKBEAM includes various criteria for good environmental performance in buildings, which can be recognized through an independently issued certificate. Developers and creditors can use the system as the guidance in supervising contractors' environmental performance. There are three set of assessment indicators in HK-BEAM, aiming for three different objects: An Environment Assessment for New Residential Buildings, An Environment Assessment for New Office designs and An Environment Assessment for Existing Office Buildings. Whilst all the indicators adopted by the HK-BEAM are effective in describing the environment impact of the relative object, but it is not easy to generalize the common indicators for measure or estimate the environment impacts or performance. And there are also some doubts about the comprehensiveness of the indicators adopted in the systems.

2.4.2 Environmental performance indicators by others

In order to distinguish the impacts of different building products on the environment, Woolley (1997) used the indicators, which are more technical and can be used to measure the building's environmental performance. These indicators are shown in the following table.

Table 2.1 Indicators adopted by Woolley

Acid rain	Photochemical smog	Photochemical oxidant
Particulate	Global warming	Ozone depletion
Pollution of land	Pollution of air	Pollution of water
Toxics	Toxics in treatment process	Noise pollution
Liquid waste	Solid waste	Electric use
LPG use	Water use	Solar use
Gas use	Wind use	Resource depletion (bio)
Resource depletion	Thermal performance	Usage of recycled

(non-bio)		materials
Usage of renewable materials and energy	Reusing of the materials	Maintenance of materials
Site polite construction	Site safety	Community communication
Social image	Health hazard	Occupation health

In the study by Woolley (1997), these indicators are found effective in measuring the environmental impacts of construction activities from different aspects.

2.5 Review on the benchmarks for assessing environmental performance in construction

Proper criteria or benchmarks are needed for assessing environmental performance in construction activities. Existing research works present some useful references in building up these benchmarks.

2.5.1 The method adopted by FRANCE CSTB

The FRANCE CENTRE SCIENTIFIQUE ET TECHNIQUE DU BATIMENT (France CSTB, 1997) adopted 24 factors for examining the environmental performance of construction process, as listed in figure 2.2. By using these 24 factors, three phases of the life cycle of buildings (construction, operation and retrofit/demolition) are examined against a set of environmental performance criteria (or benchmarks), presented in Figure 2.2. The first phase involves the technical-economic optimization of the project, the site activities and the resources subtraction. The operation phase is to maintain the intended functions of the building, including proper interfaces with the surroundings and the contribution to the social and urban life. In the retrofit / demolition phase, activities such as retrofit and refurbishment, demolition and deconstruction are involved.

In applying FRANCE CSTB, the criteria are classified in two families: direct criteria and indirect criteria. The direct criteria involve impact factors in terms of physical pollution and have effects on resources depletion, area degradation and pollution growth. The indirect criteria are those of a socio-economic character, and they have only indirect influence on the life environment and the human relations.

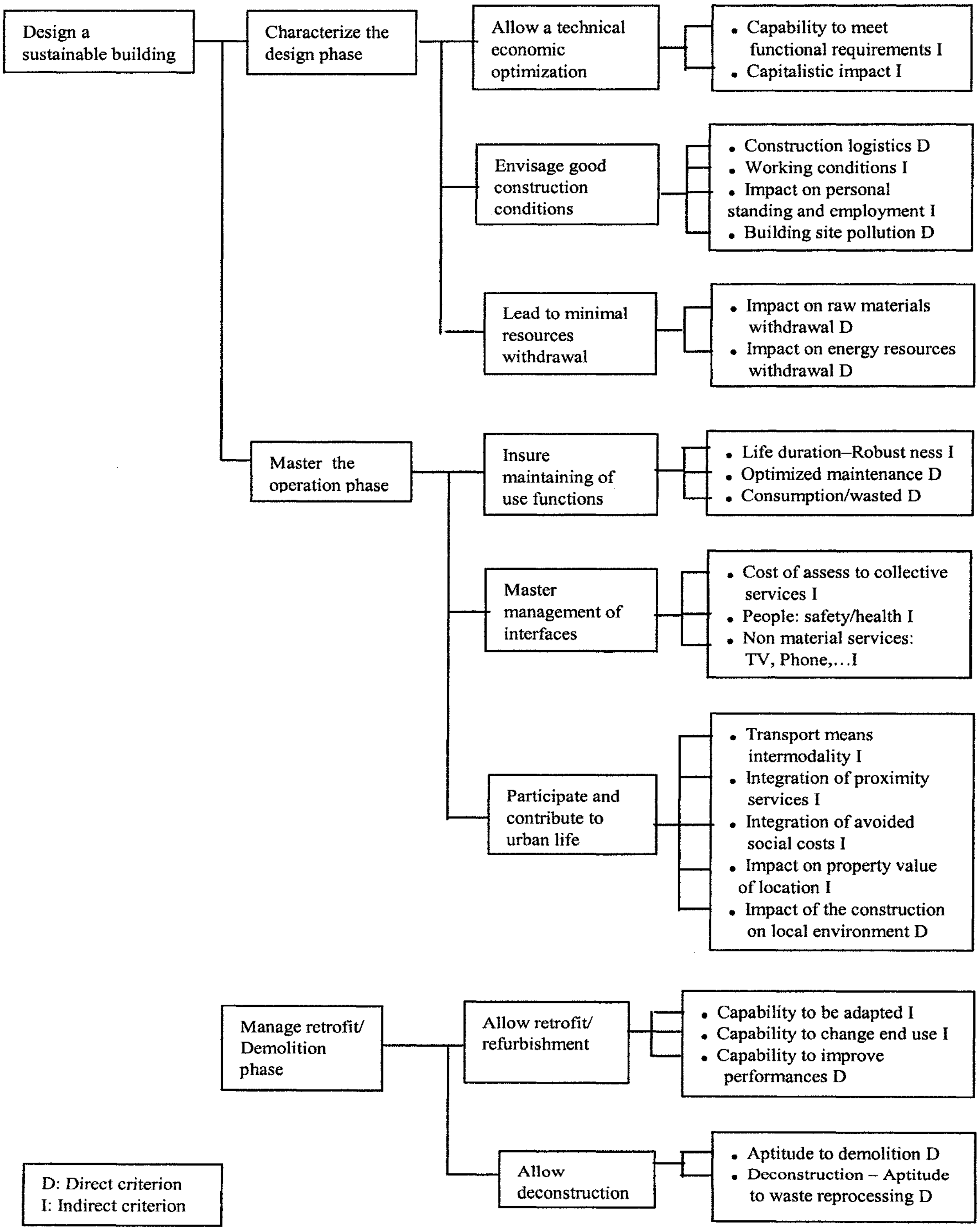


Figure 2.2 Flow diagram of the analysis of a sustainable building

2.5.2 Environment management standards, regulations and laws

ISO14000

The ISO 14000 series is a family of environmental management standards developed by the International Organization for Standardization (ISO) (Starkey, 1998). The ISO 14000 standards are designed to provide an internationally recognized framework for environmental management, measurement, evaluation and auditing. They do not prescribe environmental performance targets, but instead provide organizations with the tools to assess and control the environmental impact of their activities, products or services. The standards are designed to be flexible to be used by any organization of any size and in any field, including construction activities.

They major components of ISO14000 series are environmental management systems; environmental auditing; environmental labels and declarations; and environmental performance evaluation and life cycle assessment. The standards list of ISO14000 series is described in the Table 2.2.

Table 2.2 Specific standards list of ISO 14000 series

ISO International Standards	
ISO Guide 64:1997	Guide for the inclusion of environmental aspects in product standards

ISO 14001: 1996	Environmental management systems - Specification with guidance for use
ISO 14004: 1996	Environmental management systems - General guide lines in principles, systems and supporting techniques
ISO 14010:1996	Guidelines for environmental auditing - General principles
ISO 14011: 1996	Guidelines for environmental auditing - Audit procedures: Auditing of environmental management systems
ISO 14012:1996	Guidelines for environmental auditing Qualification criteria for environmental auditors
ISO 14040:1997	Environmental management -Life cycle assessment: Principles and framework
Draft International Standards (DIS)	
ISO/DIS 14020	Environmental labels and declarations – General principles
ISO/DIS 14021	Environmental labels and declarations - Self declaration environmental claims: Guidelines and definition and usage of terms
ISO/DIS 14024	Environmental labels and declarations - Type 1 environmental labelling: Guiding principles and procedures
ISO/DIS 14041	Environmental management Life cycle assessment: Goal and scope definition and inventory analysis
ISO/DIS 14050	Environmental management - Vocabulary
Committee Drafts (CD)	
ISO/CD 14031	Environmental performance evaluation- Guidelines
ISO/CD 14042	Environmental management Life assessment: Life cycle impact assessment
ISO/CD 14043	Environmental management Life assessment: Life cycle interpretation
Working Drafts (WD)	
ISO/WD 14061	Guidance to assist forestry organizations in the use of ISO 14001 and ISO 14004 (future type 3 technical report)

New Proposals (NP)	
ISO/NP 14049	Environmental management Life cycle assessment: Examples for the application of ISO 14041 (future type 3 technical report)

Source: ISO, 1998

Eco-Management and Audit Scheme (EMAS)

The Eco-Management and Audit Scheme (EMAS) is a regulation introduced by European Union (Starkey, 1998). EMAS consists of 21 articles, described briefly in Table 2.3 (Hillary, 1993a). It is considered a major environment management system providing valuable references for establishing the benchmarks for measuring the contractor' environmental performance.

Table 2.3 Eco-management and audit scheme articles (Hillary, 1993a)

Article number	**Title and description of article**
Article 1	The Eco-management and audit scheme and its objectives Defines the scheme's aims and relationship with existing environmental laws
Article 2	Definitions Defines the 15 terms used in the Regulation, e.g. site, environmental audit, industrial activity and accredited environmental verifier
Article 3	Participation in scheme Explains the elements a site must undertake to become- registered on the scheme

Article 4	Auditing and validation Outlines who may conduct a site's internal environmental audit how and at what frequency, and details accredited environmental verifiers' activities
Article 5	Environmental statement Lists the information required in a statement and explains simplified annual statements
Article 6	Accreditation and supervision of environmental verifiers Defines accreditation systems for environmental verifiers which Member States are required to establish
Article 7	List of accredited environmental verifiers Define frequency of lists and where they should be published
Article 8	Registration of sites Explains site registration and de-registration by the competent body
Article 9	Publication of the list of registered sites Defines how lists of registered sites should be published in the EC ' s Official Journal
Article 10	Statement of participation Defines where sites may use the statement
Article 11	Costs and fees Allows member states to set up charges
Article 12	Relationship with national, European and international standards Explains under what conditions standards may be used in conjunction with the scheme
Article 13	Promotion of companies' participation, in particular of small and medium-sized enterprises States how Member States promote company involvement in the scheme
Article 14	Inclusion of other sectors Defines under what conditions other sectors may be included

Article 15	Information Defines how Member States may promote and publicize the scheme
Article 16	Infringements Gives Member States powers to act in case of non-compliance with the Regulation
Article 17	Annexes States that the Annexes may be adapted before the Regulation's review date
Article 18	Competent bodies Defines and ensures the neutrality of the competent body
Article 19	Committee bodies Sets up the structure and voting procedure for the Committee
Article 20	Revision Sets the time limit for the Commission review of the entire Regulation
Article 21	Entry into force Gives the dates when the regulation enters into force and when it will apply in the Member States

Legislation by Hong Kong Environmental Protection Department (EPD)

The Hong Kong Environment Protection Department (HK-EPD) has introduced various legislative measures for promoting the environmental protection across all industrial sectors including construction. The major legislations, as described below, will provide major references in studying the assessment benchmark for assessing contractor environmental performance.

(1) Legislation for Environmental Impact Assessment

Following the enactment of the Environmental Impact Assessment Ordinance (EIAO) (Cap.499) on 4 February 1997, the "Technical Memorandum on Environmental Impact Assessment Process" and two subsidiary laws on the appeal board and application fees were approved by the Provisional Legislative Council of Hong Kong in 1997 respectively. The EIAO was implemented on 1 April 1998. The purpose of the EIAO is to avoid, minimize and control the adverse impact on the environment of designated projects through the application of the environmental impact assessment (EIA) process and the environmental permit (EP) system (EPD, 1999). Public involvement in the EIA process is a major requirement in the Ordinance. The description of the Ordinance is given in Table 2.4.

Table 2.4 Legislation for Environmental Impact Assessment in Effect

Legislation	Description of Control
Environmental Impact Assessment Ordinance (Cap. 499)	Provides a statutory environmental impact assessment (EIA) process to avoid, minimize and control the adverse impacts of designated projects, through the application of the EIA process and the environmental permit (EP) system.
Environmental Impact Assessment (Appeal Board) Regulation	Provides for the setting up of an appeal mechanism and procedures of the Appeal Board.
Environmental Impact Assessment (Fees) Regulation	Prescribes the fees that are payable applications made under the EIA Ordinance

(2) Legislation for Management of Air

The principal ordinance for air quality management in Hong King is the Air Pollution Control Ordinance (APCO). Subsidiary legislations are made under the principal law to deal with specific types of air pollution. For example, the Air Pollution Control (Smoke) Regulations are to limit continuous dark smoke emission to three minutes, the Air Pollution Control (Fuel Restriction) Regulations are to restrict sulphur content of liquid fuel to 0.5 per cent, and the Air Pollution control (Furnaces, Ovens and Chimneys) (Installation and Alteration) Regulations are to require prior approval of plans and specifications before any furnace or chimney works are carried out. Table 2.5 provides a summary of these legislations.

A technical memorandum setting out the principles, methods and standards for assessing air pollution on issuing abatement notices came into effect in February 1994. The Air Pollution Control (Consolidation) Statement of Air Quality Objectives was repealed and the Air Quality Objectives for Hong Kong is now specified as a Technical Memorandum made under the APCO in June 1994. The Air Pollution Control (Open Burning) Regulation came into effect in February 1996, which prohibits open burning of construction wastes, tyres and cables for metal salvage. The Air Pollution Control (Asbestos) (Administration) Regulation came into operation in May 1996 for the registration of asbestos personnel (EPD, 1999). The import and sale of amosite and crocidolite asbestos are prohibited under the APCO since May 1996. The Air Pollution Control (Construction Dust) Regulation came into operation in June 1997, which requires notification before carrying out certain types of construction works and to adopt dust reduction measures while carrying out construction activities.

Table 2.5 Air pollution control related legislations in Hong Kong

Legislation	Description of Control
Air Pollution Control Ordinance (Cap. 311)	Provides for the control of air pollution from stationary sources and motor vehicles. Also enables promulgation of regulations (as below).
Air pollution Control (Asbestos) (Administration) Regulation	Provides for the qualifications and fees for registration of asbestos consultants, contractors, supervisors and laboratories.
Air Pollution Control (Construction Dust) Regulation	Requires construction contractors to adopt dust reduction measures when construction work is being carried out.
Air Pollution Control (Dust & Grit Emission) Regulations	Stipulates the emission standards, procedures and requirements for assessing particulate emissions from stationary combustion sources.
Air Pollution Control (Fuel Restriction) Regulations 1990	Provides for the prohibition on the use of liquid fuels of a sulphur content of more than 0.5 per cent by weight and of a viscosity of more than six centistokes at 40°C, or of solid fuels of a sulphur content of more than one per cent by weight in any relevant plant, except for Sha Tin where only gaseous fuel is allowed.
Air Pollution Control (Furnaces, Ovens & Chimneys) (Installation and Alteration) Regulations	Requires the submission of plans for the installation and alteration of furnaces, ovens and chimneys to ensure appropriate design.
Air Pollution Control (Open	Prohibits open burning of construction wastes,

Burning) Regulation	tyres and cables for metal salvage.
Air Pollution Control (Smoke) Regulations	Restricts emissions of dark smoke from stationary combustion sources.
Air Pollution Control (Specified Processes) Regulations	Provides for the licensing of new specified processes and registration of existing ones.
Air Pollution Control (Specified Processes) (Removal of Exemption) Order 1993, 1994 and 1996	Removes the exemption granted to the owner of premises for conduct of certain specified processes.
Air Pollution Control (Specified Processes) (Specification of Required Particulars and Information) Order 1993 and 1994	Provides for the supply of information and specifications by owners of certain existing specified processes to the Air Pollution Control Authority.
Building (Demolition Works) Regulations (Cap. 123)	Regulates building demolition, including prevention of nuisance

(3) Legislation for Management of Ozone Layer

The Ozone Layer Protection Ordinance in Hong Kong became effective in May 1993 to ban the import of certain products containing these substances from countries which are non-partiers to the Montreal Protocol, and to mandate the recovery of chlorofluorocarbons (CFCs) being used by large industrial and commercial refrigeration cooling plants and motor vehicle air conditioners. An amendment to the Ozone Layer Protection (Products Containing Scheduled Substances) (Import Banning) Regulation came into effect in December 1996 to include prohibition of import of portable fire extinguishers containing halons from all countries (EPD, 1999). The related legislations are included Table 2.6.

Table 2.6 Legislation for Management of Ozone Layer in Hong Kong

Legislation	Description of Control
Ozone Layer Protection Ordinance (Cap. 403)	Gives effect to Hong Kong's international obligations under the 1985 Vienna Convention, the 1987 Montreal Protocol and any amendments to control the manufacture, the import and the export of ozone depleting substances.
Ozone Layer Protection (Controlled Refrigerants) Regulation	Requires the conservation of controlled refrigerants used in large-scale installations and motor vehicles.
Ozone Layer Protection (Products Containing Scheduled Substances) (Import Banning) Regulation	Prohibits the import of portable fire extinguishers containing halons from all countries and other controlled products from a country or place not a party to the Montreal Protocol unless the Authority considers that it complies with the requirements of the Protocol.

(4) Legislation for Management of Noise

Noise is a typical kind of environmental pollution from construction activities. Noise Control Ordinance was implemented in Hong Kong in 1989 (EPD, 1999). The basic specifications of related legislations are described in Table 2.7.

Table 2.7 Noise control legislations in Hong Kong

Noise	Legislation	Description of Control	Control

Control			**Authority**
General Construction Work	Noise Control Ordinance (Cap. 400); Noise Control (General) Regulation; Noise Control (Construction Work) Regulation; Noise Control (Designated Area) Notice	Controls construction noise from (a) the use of powered mechanical equipment; and (b) the carrying out of certain noisy works in designated areas, between 7 p.m. and 7 a.m. and on general holidays by construction noise permits. Director of Environmental Protection issues permit in accordance with two relevant statutory Technical Memoranda.	Director of Environmental Protection and Commissioner of Police
Percussive Piling	Noise Control Ordinance (Cap. 400); Noise Control (General) Regulation; Noise Control (Appeal Board) Regulation	(a) Prohibits percussive piling between 7 p.m. and 7 a.m. and on general holidays; and (b) restricts the working hours of percussive piling at other times by construction noise permits. Director of Environmental Protection issues permit in accordance with a relevant statutory Technical Memorandum.	Director of Environmental Protection and Commissioner of Police
Industrial and Commercial Activities	Noise Control Ordinance (Cap. 400); Noise Control (General) Regulation;	Controls noise from industrial and commercial activities, including ventilation noise. through Noise Abatement Notices. Director of Environmental Protection issues Notices in accordance with a	Director of Environmental Protection

	Noise Control (Appeal Board) Regulation	relevant statutory Technical Memorandum.	

The Hong Kong government recognizes that the existing controls on environmental noise cannot meet the expectation from the community. Various new control measures are therefore proposed and these noise control legislation in effect as at 31 December 1998, listed in Table 2.8.

Table 2.8 New Noise Control Legislation in Hong Kong

Proposed Legislation/Control	**Features**	**Current Status**
Noise Control (Amendment) Ordinance - Phasing out of Diesel. Pneumatic and Steam Piling Hammers in Built-up Areas	Phases out noisy diesel, pneumatic and steam piling hammers in built-up areas in four stages over a period of two years.	Progressive phasing out of the noisy piling hammers in built-up areas started in April 98. By October 1999, noisy piling hammers will be completely phased out in built-up areas.
New control on the use of percussive powered equipment in daytime renovation work	Reduces noise from renovation work in domestic premises.	Drafting of the proposal is in progress. Consultation will be conducted in the second half of 1999.

(5) Legislation for Management of Wastes

The Waste Disposal Ordinance was enacted in 1980, along with its subsidiary regulations, for implementing waste management in Hong Kong, in particular, the wastes from construction activities. Additional legal measures are also available for dealing with special types of waste. For example, oily wastes from ships are regulated by the Merchant Shipping legislation. Waste management legislations are to ensure that vast volume of wastes is disposed in an environmentally acceptable manner. The related waste management legislations are listed out in Table 2.9

Table 2.9 Legislations for waste management in Hong Kong

Legislation	**Description of Control**
Waste Disposal Ordinance (Cap.354)	Provides for the licensing of collection services and disposal facilities for all types of waste the prohibition of livestock keeping in urban areas the control on livestock keeping in restriction areas the control on discharge or deposit of livestock waste in designated control areas the control scheme on chemical waste the control on illegal dumping of waste the control on import and export of waste and for the establishment of a system whereby specified wastes must be notified to the relevant authority who may give directions as to the method of disposal. Requires also the production of a comprehensive plan for the collection and disposal of wastes.
Waste Disposal (Chemical Waste)(General) Regulation	Provides for control of all aspects of chemical waste disposal including storage collection transport treatment and final disposal.

Waste Disposal (Permits and Licenses) (Forms and Fees) Regulation	Prescribes the forms and fees for application of licenses for waste collection and disposal and the permits for import and export of waste
Waste Disposal (Designated Waste Disposal Facility) Regulation	Provides for the maintenance of orderly conduct within sites used for waste disposal measures to counteract the evasion of payable in connection with the provision of waste disposal services at such sites; and proof of matters in proceedings before a court in relation to the provision of Waste disposal activities at such sites.
Dumping At Sea Ordinance (Cap. 466)	Provides for control on marine dumping extends controls on marine pollution gives legal effect to the Marine Dumping Action Plan.
Buildings Ordinance (Cap.123)	Allows the Building Authority to require adequate waste treatment facilities in any new building. Provides for control over the design of refuse chutes within buildings and oil storage facilities.
Buildings Ordinance (Application to the New Territories) (Cap.121)	Similar provisions to Cap.123.
Radiation Ordinance (Cap.303)	Controls the use and disposal of radioactive substances.

(6) Legislation for Management of Water Quality

The Water Pollution Control Ordinance was enacted in Hong Kong in 1980. The ordinance and its subsidiary legislations ensure that sewage and industrial wastewater will be discharged in an environmentally acceptable manner. The major specifications of these legislations are presented in Table 2.10.

Table 2.10 Legislations for water quality management in Hong Kong

Legislation	**Description of Control**
Water Pollution Control Ordinance (Cap, 358)	Provides for the designation of control zones within which discharges of effluent other than domestic sewage into a foul sewer must be licensed.
Water Pollution Control (General) Regulations	Gives practical effect to the ordinance.
Water Pollution Control (Appeal Board) Regulations	Imposes requirements on private lot owners to collect and convey wastewater to public sewers and provides for control over the operation and maintenance of private wastewater treatment facilities.
Buildings Ordinance (Cap.123)	Allows the Building Authority to require adequate waste treatment facilities in any new building. Provides for control over the design of refuse chutes within buildings private drainage works and oil storage facilities.
Buildings Ordinance (Application to the New Territories) (Cap.121)	Similar provisions to Cap.123.
Waste Disposal Ordinance (Cap.354)	Prohibits livestock keeping in urban areas and provides for control over the discharge or deposit of livestock waste in designated control areas.
Public Health and Municipal	Provides for control over the discharge of

Services Ordinance (Cap.132)	hazardous materials to sewers and for the control of littering. Also provides for the designation of bathing beaches and the control of pollution at such beaches together with Swimming pools and wells.
Dumping At Sea Ordinance (Cap. 466)	Provides for control on marine dumping extends control on marine pollution, gives legal effect to the Marine Dumping Action Plan.

2.5.3 Hong Kong Building Environmental Assessment Method (HK-BEAM)

HK-BEAM provides a set of criteria for assessing building environmental performance, and these criteria relate to building design, operation, maintenance and management of buildings. 'Credits' are awarded where the criteria are satisfied, whilst those poor areas will be identified. The results of the assessment in using HK-BEAM will be specified HK-BEAM certificate with a grade of Fair, or Good, or Very Good, or Excellent (HK-BEAM, 1999).

It is the intention that the criteria should be easily used during an examination on building aspects such as designs and maintenance of a building. In the current application of HK-BEAM, the assessment is mainly carried out at the design stage. Some information and data are also needed from construction process or upon the completion of the major building components and engineering services. The method identifies and credits the good design practice and good applications of construction techniques. In using the method, innovative design solutions are encouraged, but they do not necessarily gain the credit. Innovation must demonstrate environmental gains.

The criteria used in HK-BEAM are presented as checklists and recommended credits. The details of these checklists and recommended credits are listed in the following tables (Table 2.11, Table 2.12, Table 2.13).

Table 2.11 Checklist Credits in using HK-BEAM for Existing Offices (HK-BEAM (Existing Offices), 1999)

Global Issues And Use of Resources	
Credit requirement	**Obtainable Credit**
Overall Environmental Policy	1
Environmental Purchasing Policy	2
Energy Management Program	3
Electrical Energy Consumption	15
Ozone Depleting Substances	6
Facility for Recycling Materials	2
Total Credits Under Global Issues	**29**
Local Issues	
Electricity Maximum Demand	3
Water Conservation	2
Legionella Bacteria from Wet Cooling Towers	1
Noise from the Building	1
Transport and Pedestrian Access	2
Vehicular Access for Servicing and for Waste Disposal	2

Building Maintenance	1
Total Credits Under Local Issues	12
Indoor Issues	
Operations and Maintenance of Building Services Systems	2
Metering and Monitoring Equipment	3
Biological Contamination	2
Indoor Air Quality	6
Mineral Fibres	3
Radon	1
Hazardous Materials	2
Interior Lighting	2
Indoor Noise	1
Total Credits Under Indoor Issues	22
Total Credits Available	63

Table 2.12 Checklist and Credits in using HK-BEAM for New Offices (HK-BEAM (New Offices), 1999)

Global Issues and Use of Resources	
Credit requirement	**Obtainable Credit**
Electrical Energy Consumption	13
Ozone Depletion	5
Use of Timber	3
Facility for Recycling Materials	1
Total Credits Under Global Issues	22

Local Issues	
Credit requirement	**Obtainable Credit**
Electricity Maximum Demand	1
Construction Wastewater Discharge	2
Water Conservation	2
Legionella Bacteria from Wet Cooling Towers	1
Recycled Materials	4
Noise During Construction	1
Noise from the Building	1
Transport and Pedestrian Access	2
Vehicular Access for Servicing and for Waste Disposal	2
Total Credits Under Local Issues	17
Indoor Issues	
Metering and Monitoring Equipment	3
HVAC System Commissioning	3
Operations and Maintenance	2
Biological Contamination	1
Indoor Air Quality	4
Hazardous Materials	2
Interior Lighting	2
Indoor Noise	2
Total Credits Under Indoor Issues	**20**
Total Credits Available	**59**

Table 2.13 Checklist and Credits in using HK-BEAM for New Residential buildings (HK-BEAM (New Residential Buildings), 1999)

Global Issues	
Credit Requirement	**Obtainable Credit**
Transportation and Pedestrian Access	3
Overall Thermal Transfer Value	4
Flexible Design and Fit-Out	2
Clothes Drying Facilities	1
Energy Efficient Building Services and Equipment	2
Public Area Lighting	2
Exterior Lighting	2
Construction Materials	3
Use of Recycled Materials	3
Ozone Depleting Substances	1
Use of Permanent Timber	2
Timber for Temporary Works	3
Commissioning	2
Facilities	2
Total Credits Under Global Issues	32
Local Issues	
Contaminated land	1
Ecological Impact Assessment	1
Air Quality Assessment	2
Noise Impact Assessment	3
Water Pollution and Drainage	2
Microclimate Around Buildings	2

Landscaping	4
Planters on Building	1
Water Conservation	2
Recycling Facilities	2
Environmental Management Plan	1
Air Pollution During Construction	2
Noise During Construction	2
Water Pollution During Construction	2
Demolition Waste Management	1
Construction Waste Management	1
Total Credits Under Local Issues	29
Indoor Issues	
Solar Heat Gains	2
Daylighting Design	3
Natural Ventilation	2
Radon Mitigation Measures	2
Indoor Noise	2
Air Conditioning Units	3
Hazardous Materials	3
Uncontrolled Ventilation	1
Tenant/Owner's handbook	1
Total Credits Under Indoor Issues	19
Additional Credits: Innovative and unconventional designs	5
Total Credits Available	85

2.6 Existing methodologies for assessing the environmental performance in construction process

There are several methodologies developed for assessing the environmental performance in construction process. The examination on these methods is important for identifying focuses in undertaking this research study. Several typical methodologies for assessing the environmental performance in construction process are discussed as follows.

2.6.1 Environmental performance assessment method by FRANCE CSTB

The FRANCE CENTRE SCIENTIFIQUE ET TECHNIQUE DU BATIMENT used a Mutli-Dimension Analysis Matrix for analyzing the environmental impacts of various construction related factors and for investigating the relationship among the different factors and various environmental resources Life Cycle Phases (CIB, 1998e). This matrix approach uses environmental factors and construction life cycle process as two dimensions for constructing the matrix. The environmental factors are grouped under two categories, ecological principles and environmental resources. Ecological principles concern to eliminate resource depletion; to eliminate environmental degradation, and to create a healthy interior and exterior environment. Resources refer to four basic environmental resources including land, energy, water and materials. And life-cycle construction process is divided into five phases, namely, develop and plan, design, construct, operate, and deconstruct. The matrix structure adopted in the FRANCE CSTB can be described in the following table 2.14. It is a sample for construct stage.

Table 2.14 Multi-Dimension Analysis Matrix for Construction Stage

Construct	Resource			
Principle	Land	Energy	Water	Materials
Conserve				-Reduce squandering (plan right quantities, reuse offcuts, ...
Re-use				
Renewable/ Recylce				
Protect Nature	-Insure flora and wildlife protection -Increase waste management		-Insure ground water protection	
Non-toxic	-No air pollution -No soil pollution			
Excellent Quality				
Other aspects (human, finance,...)	-Building site without noise -Limit traffic needs -Decrease task hardness (definition of tasks and operating methods, adapted tools,...) -Secure tasks -Pleasure at work (good living conditions at site, site cleanness, ...) -Impact on self-actualization (interest at work, image,...) -Optimize building site logistics: supplying, delivering, executing, controlling			

2.6.2 Assessment method by DUTCH ECO-QUANTUM

The Dutch government introduced an environmental performance assessment method, called Eco-Quantum (EQ) to provide architects and project developers with an instrument to measure the environmental performance of buildings (CIB, 1998e). EQ is a quantitative method using Life Cycle Assessment (LCA) technique to produce quantitative information on the environmental impacts of buildings. The environmental impacts of a building during its entire life cycle are taken into account; from the moment the raw materials are extracted to the final demolition or reuse of the building wastes. These impacts concern the energy use, the environmental pollution, the maintenance during building operation, and the choice of demolition or renovation.

For different applications, there are two customized tools: Eco-Quantum Advanced and Eco-Quantum Quick (CIB, 1998e). Eco-Quantum Advance is used by building consultants, environmental researchers and large design offices to analyze their building concepts and to reduce the environmental impact of their designs. EQ-quick is a tool for designers, enabling to assess the environmental consequences from adopting different design layouts and using different building materials. A building client can use EQ-quick to set environmental performances at the start of design process. The tools EQ-quick and EQ-advanced can be used separately, although they have associations, as shown in Figure 2.3. EQ-advanced generates indicators for EQ-quick. These indicators can be updated or changed when different applications are considered.

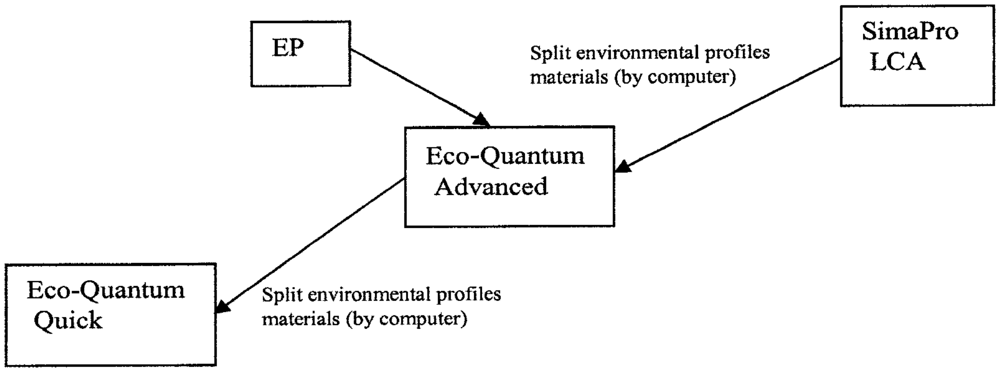


Figure 2.3 Structure of ECO-QUANTUM

The DUTCH ECO-QUANTUM is practicable but limited to assessing the environmental impacts from designing activities. It is unable to assess a contractor's environmental performance during construction stage.

2.6.3 Life Cycle Analysis (LCA) Rating Method by Woolley

Woolley (1997) introduced an environmental performance assessment method designed in an 'easy-to-read' format. A table format is adopted, as shown in table 2.15. This method adopts various symbols in representing the environmental impacts of various building materials. A circle in a column indicates that published comments on a particular aspect of a product's impact have been discovered. The larger the circle the worse an environmental impact is thought to be. Life Cycle or 'cradle-to-grave' analysis on a building's environmental impacts considers all stages including materials extraction, production of building, use and disposal. The benefits of using LCA in assessing building environmental impacts including the identification of major factors affecting the environmental performance in construction process. (Woolley, 1997).

Table 2.15 Environmental Impact Analysis of Materials

	Production										Use					
	Unit Price Multiplier	**Energy Use**	**Resource Depletion (bio)**	**Resource Depletion (non-bio)**	**Global warming**	**Ozone Depletion**	**Toxics**	**Acid Rain**	**Photochemical Oxidants**	**Other**	**Energy Use**	**Durability/Maintenance**	**Recycling/Reuse/Disposal**	**Health**	**other**	**ALERT!**
Bricks																
Ordinary lay	1.0	◕					●	●	●	●						
Flettons	0.8	•					@	◕	•	◕						
Soft Mud/Stocks	1.0	@					●	●	●	●						
Perforated clay	1.0	●					•	•	●	•						
Calcium Silicate	0.9	◕		●	●		●	●	●	◕						CFCs
Re-Used	1.4															
Concrete Blocks																
Ordinary Dense blocks	0.3	●	•	◕	@		◕	●	●	◕						
Lightweight Aggregate	?	●	•	●	@		◕	●	●	@				@		
Aerated	3.2	@	•	•	●		◕	●	●	◕						
Composite Insulating	1.4	●	•	◕	@	@	◕	●	●	◕						
Stone																
Local	3.2									●						

Imported	?	●								●						
Reclaimed	3.2															
Artificial	1.4	●	•	◕	@		◕	●	●	◕						
Mortar Ingredients																
Ordinary Portland Cement	N/a	@						●	●	◕			•	●		Haz.
Pure Lime	N/a	◕			@		●	●	•	◕				●		
Hydraulic Lime	N/a	◕			◕		●	●	•	◕				●		
OP Blastfurnace Cement	N/a	●		•	●		•	•	•	•			•	●		
OP lverised Fuel Ash	N/a	●		•	●		●	•	•	•			•	●		
Masonry Cement	N/a	◕		•	◕		●	•	•	◕			•	•		
Sand and Gravel	N/a		•	◕												

The study by Woolley adopts five scales of environmental impacts from various factors, namely, worst or biggest impact, next biggest impact, lesser impact, smaller but significant impact, and no significant impact. The following symbols are used to represent the scale of environmental impact:

@ … worst or biggest impact

◕ … next biggest impact

● … lesser impact

• … smaller but significant impact

[blank] no significant impact

There is a sample table of using the rating methods in assessing environmental impacts of applying building materials. The table 2.15 is shown as above.

2.7 Structure of C-EPAS

The literature review establishes the theoretical basis for this study and demonstrates the lack of research works in the field chosen for this study, thus presents the significance of undertaking this study. Various assessment systems have been developed for assessing the environmental performance of a construction project. However, it appears that little study has been conducted in finding a effective way to assess a contractor's environmental performance.

In fact, contractor plays the key role in executing construction activities, and its environmental performance has a strong association with the overall environmental performance in the process of implementing a construction project. Thus the implementation of environmental management across a contractor's operational activities is considered an important alternative in protecting the environment. To assist contractors understand the level of their environmental performance, a methodology to assess their environmental performance is necessary.

This study finds out an effective method for assessing a contractor's environmental performance, we called it as contractor's environmental performance assessment system (C-EPAS). A scoring model, namely, contractor's environmental performance index (C-EPI), is calculated for evaluating the contractor's environmental performance by adopting the non-structural fuzzy decision system (NSFDS) method.

The C-EPAS is built up with two types of parameters, assessment benchmarks, relative weightings of parameters and calculation model. The two types of parameters include the environmental performance factors affecting the contractor's environmental performance and the environmental performance indictors, which can be used to evaluate the contractor's environmental performance.

A set of benchmarks is proposed for allocating indicators' values. In order to calculate the C-EPI, the relative weightings of parameters need to be determined. The calculating method shall be designed to get the C-EPI score. The computer-aided technologies are adopted to develop the C-EPAS package, which is more convenient for conducting the assessment. The structure of C-EPAS can be figured as shown in figure 2.4.

In the figure 2.4, the C-EPI can be calculated with the calculating model and the formula can be expressed as follows:

$$C-EPI = f(W_{ji}, D_{ji}) \quad \text{-------Eqn. (2.1)}$$

Where

C-EPI means the contractor's environmental performance index

f is denoted as the function of data collected from the relative weightings of factor to individual indicators (W_{ji}) and the decision through benchmarks (D_{ji});

j is denoted as the symbol of environmental performance factor;

i is denoted as the symbol of environmental performance indicator.

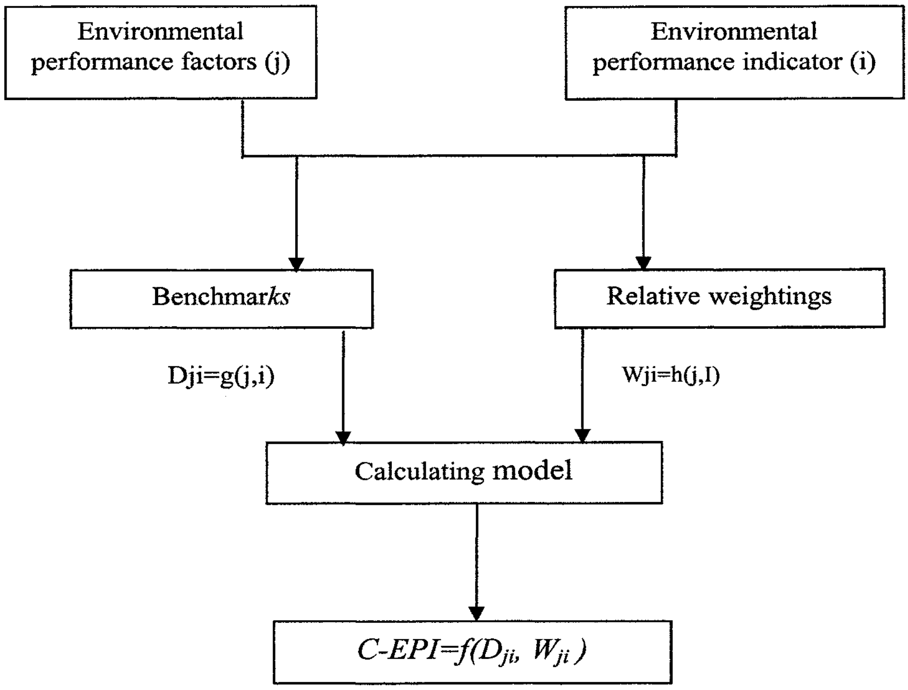


Figure 2.4 Structure of C-EPAS

In the formula (2.1), the D_{ji} and W_{ji} can be calculated with formula (2.2), (2.3).

$$D_{ji} = g(j,i) \qquad \text{------Eqn. (2.2)}$$

$$W_{ji} = h(j,i) \qquad \text{-------Eqn. (2.3)}$$

Where

g, h is function of environmental performance factor (j) and environmental performance indicator (i).

The following chapters in this study shall be implemented on the structure of figure 2.4. In the chapter 3, the environmental performance factors shall be formulated. The environmental performance indicators shall be demonstrated in the chapter 4. In the chapter 5, the benchmarks shall be determined. In the chapter 6, the NSFDS method is adopted to calculate the relative weightings of factors to individual indicators and the C-EPI shall be calculated with the designed calculating model. The chapter 7 shall develop the C-EPAS package for assisting the jury to conduct the assessment more conveniently. The functions of the package not only include calculating the C-EPI score, but also include analyzing the C-EPI distribution and diagnosis function. The case shall be tested in the chapter 8 for evaluating the practical use of C-EPAS.

2.8 Summary

This chapter not only provides a comprehensive literature review on theories, factors, environmental performance indicators, benchmarks and assessment methods for implementing environmental performance assessment for a contractor on sites, but also establishes the structure of this study. The specific results this chapter can be summarized as follows:

Based on the analysis of impacts of construction to environment, including analyzing the space impact, materials consumption, waste generation and energy consumption, the environmental performance assessment works are discussed with the view of sustainable development. Being as one important area of promoting sustainable development on construction, the environmental performance assessment for contractor is a significant work for increasing the government's role to supervise and control the contractor's environmental impacts.

The factors, indicators, benchmarks and assessment methods are main aspects of constructing the environmental performance assessment on contractors. The literatures concerning these four aspects are interviewed separately.

The Hong Kong Performance Assessment Scoring System (HK-PASS) applies a set of environmental performance factors, which have specific impacts on contractor's environmental performance. The MALAYSIA Ministry of Housing and Local Government formulates another set of factors for assessing the building's environment performance.

The Hong Kong Building Environmental Assessment Method (HK-BEAM) has provided a valuable frame of the environmental performance indicators under the categories of global issues, local issues and indoor issues. Tom Woolley establishes the indicators to distinguish the impacts of different building products on the environment, which can be effective to be used to measure the contractor's environmental performance.

France CSTB applies the benchmarks, which are classified in two families: direct criteria and indirect criteria. These criteria can be used to evaluate the environmental effects including not only the resource depletion, area degradation, pollution growth, but also life environment and human relations. ISO14000, Eco-Management and Audit Scheme (EMAS), legislations by Hong Kong Environmental Protection Department (HK-EPD) and HK-BEAM supply the strong support for establishing the benchmarks for assessing the contractor's environmental performance.

Several typical methodologies for assessing the environmental performance in construction process are examined and discussed. The FRANCE CSTB uses a Multi-Dimension Analysis Matrix method for analyzing the environmental impacts of construction. The DUTCH ECO-QUANTUM takes advantage of Life Cycle Assessment (LCA) method to produce quantitative information on the environmental impacts of buildings. Tom Woolley designs an 'easy-to-read' format with the Life Cycle Analysis Rating Method to analyze the impacts of buildings.

This chapter provides strong support for contractor's environmental performance assessment (C-EPAS) and the structure of C-EPAS has been designed just based on the reference of these important literatures. The following research works for this dissertation shall be conducted including choosing the factors, identifying the environmental indicators, establishing the benchmarks and designing the assessment method. The computer-aided package C-EPAS shall be developed for assisting the assessment work.

Chapter 3:

Identifications of the Factors Affecting Contractor's Environmental Performance

CHAPTER 3: IDENTIFICATIONS OF THE FACTORS AFFECTING CONTRACTOR'S ENVIRONMENTAL PERFORMANCE

3.1 Introduction

In Chapter 3, the theoretical framework for assessing contractors' environmental performance has been formulated. One of the major procedures in adopting the framework is to identify the factors affecting contractors' environmental performance during construction process. Various studies have been undertaken in examining the factors affecting construction environmental performance from the viewpoint of understanding the environmental impacts of construction. A review on these studies will build up a basis for correctly identifying these environmental factors.

Shen (2000) identified construction environmental factors through investigating the impacts of construction on the environment, including the extraction of environmental resources such as fossil fuels and minerals; extending consumption of generic resources, namely, land, waste, air, and energy; the production of waste that require the consumption of land for disposal; and pollution of the living environment with noise, odors, dust, vibrations, chemical and particulate emissions, and solid and sanitary waste. In the study by Best (1997), the major environmental impacts in implementing on-site construction activities are classified as noise, dust and sometimes vibrations. McDonald (1996) suggested that consumption on landfill for dumping construction wastes is a major environmental impact from construction activities, and it is reported that 14 million tones of construction waste were put into landfill in Australia.

The gas vented from construction activities is also considered a major environmental factor. Typically, there are five toxic air emissions generated from construction, including sulphur dioxide (SO_2), nitric dioxide (NO_2), volatile organic compounds (VOC), toxic releases to air, and hazardous waste (Hendrickson, 2000). It is demonstrated that significant part of environmental emissions in US is from the construction activities engaged by the four largest construction sectors, namely, highway, bridge, and other horizontal construction; industrial facilities and commercial and office buildings; residential buildings and other construction such as towers, sewer and irrigation systems, and railroads (Hendrickson, 2000).

The study by Bush (1995) demonstrates the impact of construction activities on energy consumption. It is estimated that 57% electricity used in developed countries was consumed directly by buildings, with about 31% by residential buildings and 26% by commercial buildings. Although the energy consumption for on-site construction activities may not be the major part of the total energy use in a project's life cycle, it needs energy, for example, in the form of oil or electricity, for operating tools, lighting, hoists and other machines. In fact, the operation of large plants or equipments such as cranes and mixers, which consume fossil fuels, can contribute to atmospheric pollution as well.

In line with the development of implementing sustainable construction, the implications of construction environmental performance have been extended. Various studies have been conducted on promoting sustainable construction (Shiva, 2000). The new development of sustainable construction is usually considered as the application of sustainable development in construction industry. In a typical study by Shiva (2000), sustainable development represents social progress, environmental quality, economic development and prudent use of natural resources. Measures for controlling environmental quality are suggested as follows:

- Making best use of land space and water by maximizing sustainable yields of agricultural crops without ignoring the needs for grazing land and wildlife habitat and the demands of human settlement and industry
- Controlling mineral extraction - for example to ensure hundreds of years' supplies from proven reserves, or thousands where there arc no possibilities of developing other sources
- Preservation of the less scientifically understood resources in an essentially undisturbed condition because ultimately they may have economic applications. amenity value or aesthetic appeal

In line with the mission of sustainable development, various studies have been conducted for formulating the principles of sustainable construction, and the major principles can be withdrawn as (Shiva, 2000):

- Use only of those raw materials for construction activities, of which there are ample reserves, in the ground or recycled from previous use, obtaining and processing them without excessive environmental impact
- Economical use of energy in the process of construction
- Emphasis on durability in structures so that they can serve their purpose effectively across the long term life of a project
- Emphasis on the adaptability, so that elements of the structure can be converted or extended to accommodate future changes in use and technology.
- Ease of demolition, when the structure finally becomes redundant, in a manner in which materials can be recycled and the site can be reassigned to another use or returned to a semi-natural state; where massive construction, as in a dam or breakwater, cannot be demolished then its ultimate existence as a stable landform should be anticipated.

Environmental pollution caused by construction activities is particularly evidenced in those developing countries such as China where there is a rapid development of construction industry but on the other hand little attention is given to the environmental management. In China, it is reported that the performance of sulphur dioxide (SO_2) emissions and total air-suspended particulates (TSP) is far from the international standards (Zhang, 2000). According to the report by World Bank (WB) (1998), 72% of the major Chinese cities, including the municipalities and the provincial capitals, have TSP of over 200mg/m^3, whilst the international standard defined by the World Health Organization is 90 mg/m^3 (WB, 1998). It is suggested that there is a close association of these environmental problems with the dramatic development of construction business in China. With recognizing the significance of the environmental impacts from construction, the Chinese government has started to implement various measures through regulations for improving the construction environmental performance.

The environmental pollution due to construction has also caused concerns in those densely populated cities such as Hong Kong. There is growing concern about the quality of the local environment in Hong Kong. Complains are often received about the environmental pollution from construction activities, such as noise, air pollution. Nevertheless, the management is more effective in controlling construction environmental impacts in those developed countries or cities such as Hong Kong. There are well established regulations and policies for controlling the environmental problems in the process of implementing construction works, both public sector and private sector projects.

3.2 The role of contractor in implementing environmental protection

Before identifying all the major factors affecting contractors' environmental performance, it is necessary to examine their roles in the process of implementing environmental protection. This examination will help understand contractors' major business activities and management procedures, which can have various impacts and influence on the environment. Thus the factors affecting the effectiveness of these activities and management procedures can be identified.

The participation of a contractor among other construction professionals in implementing environmental management in the implementation of a construction project is committed by performing the three functions: compliance with regulations set by environmental authorities; implementation of environmental protection measures designated in project designs and specifications; environmental protection initiatives taken by contractors.

Compliance with regulations set by environmental authorities

Compliance with environmental regulations is not only the responsibility to project clients, planners and designers, it is also the responsibility to construction contractor. The allocation of specific responsibilities among various professionals may be specified and agreed between all concerned parties, including project clients (called promoters sometime for infrastructure projects), designers, planning authorities and contractors.

Implementation of designed environmental protection measures

It is the contractors' responsibility to implement various environmental protection plans and measures. Project designers often provide guidelines and design plans for protecting the environment. Contractors have to incorporate these measures and principles into their operational programs. This commitment will usually be defined in project contract documents for ensuring that proper practical methods will be adopted and that environmental damage is avoided in the construction process. The design specifications can contain clauses dealing with protection of property and land or water conservation. The design drawings will define site boundaries and existing features or utilities, which provide guidelines for contractors to incorporate into their operational plans. Commitments defined in construction contract include the limitations on noise, working hours, access to sensitive areas and use of roads and haul routes. Contractors must adopt proper methods to ensure the compliance with these requirements or commitments, in addition to the requirements by local authorities on the matter of environmental protection.

Environmental protection initiatives by contractors

The environmental protection commitments defined in contract document only provide guidelines and demonstrate the major areas where attention must be given for protecting the environment. The details of implementation methods have to be initiated by contractors. For example, considerations should be given to choosing construction methods such as precast method or in-situ method, selecting subcontractors with good environmental performance, using environmentally friendly machines, and so on.

3.3 Examination on the major construction operations having environmental impacts

In order to examine the factors affecting the environment in construction activities, it is necessary to establish an understanding about the relations between construction operations and environmental performance. Major operations during construction process can be shown graphically in Figure 3.1, and the principal relations between these operations are illustrated as well. Those operations include the handling materials, operating machinery, earthworks, structures, site formation, and transportation. The discussions in the following sections will present the details of these areas, which have environmental impacts.

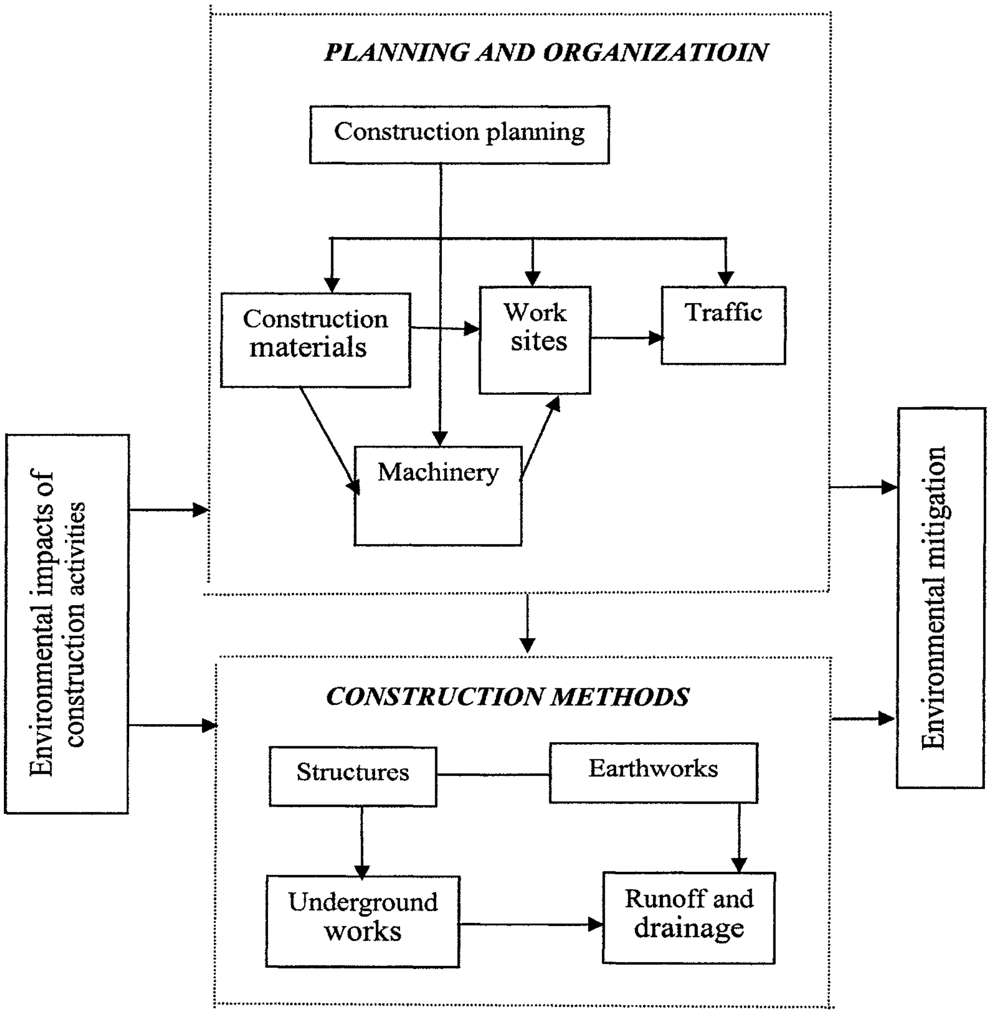


Figure 3.1 Major construction operations and environmental protection

3.3.1 Earthworks

Earthworks mainly concern with excavation and earth placement. They are among the basic operations in implementing a construction project. General operations of earthworks include the follows:

- Quarrying or dredging for construction raw materials, namely, rock, concrete aggregates, soils for fill, clay for bricks and clay or lime for cement manufacture. These activities have obvious environmental impacts, thus consideration should be given in these activities to procure the materials in a way, which has less environmental impacts.
- Excavation for foundations, basements, cuttings or tunnels and disposal of the excavated materials for backfill or site formation
- Earthwork for forming embankment, reclaimed land and support for structures
- Treatment of contaminated land during site formation for project development in order to improve the condition of project foundation.

As earthwork can affect the environment through consuming land and changing the characteristics of land geographies, it is important to adopt proper techniques thus the consumption on land during earthwork can be minimum. Consequently, earthwork usually is undertaken within a congested space, particularly, in those urban areas. The study by Preece (1991) points out that there is a close association between construction earthworks and environmental performance.

In general, earthworks are to construct landforms providing site access or meeting structural and aesthetic needs. For example, excavation creates space for foundation or basement construction. Earth-cuttings are undertaken for transport routes or access to tunnel entrances. Whilst these activities are inevitable during construction, consideration can be given to identifying better methods for earthworks thus the impacts to the environment can be mitigated to the minimum level, whilst the functional and aesthetic criteria can be met at the same time.

3.3.2 **Structures**

Structural works are also the major construction operations for implementing a construction project. Generally, structural works involve the demolition of old structures in the existing buildings in order to form the project site, and the building-up of the new structures such as foundation structure and superstructure. The implementation of these activities will apply various materials and plants and generate various environmental pollutants, such as wastes, noise, and air pollution.

Demolition

Apart from safety implementation, demolition can also produce local disturbance and present the matter of waste material disposal. Demolition involves various technical activities. For example, individual units will be disconnected and removed by crane for possible reuse. Brickworks will be knocked down by impact of a swinging weight or excavator bucket. Concrete will be broken up more noisily with jackhammers. And burners cut steel reinforcements.

Usually, regulations impose limitations on the level of environmental pollutions during construction demolition, for example, alleviating dust by watering or screening. Regulations take into account the public interests. Furthermore, the extent to which materials can be wasted or recycled depends on the nature of the structure to be dismantled.

Foundation works

Foundation works involve extensive excavation operation and have significant environmental impacts. Foundation works are undertaken by adopting various techniques, depending on a number of factors, such as the construction of bentonite membranes, sheet piling or concrete diaphragm walls which are for containing adjacent foundations, soils and groundwater.

A typical environmental impact from foundation works is noise pollution. Noise will be generated from the vibration operation, operation of hammer piledriving, and other actions. Complains can be received from the public, and this is a typical environmental problem particularly in urban area. Mitigation on these environmental problems from foundation works can be gained through using proper methods such as quieter piling methods for boring or jacking. Furthermore, the wastes from excavation have to be disposed of properly. Special measures should be used when piles are driven down to the ground to ensure that the underground will not be contaminated for example by oil. Special techniques have to be devised for sinking piles without releasing any displaced spoil (Hayward, 2000).

Superstructure

The impacts of superstructure works on the environment are also multiple but are considered as more controllable in comparing that in conducting underground works. The major environmental impacts of superstructure include the noise pollution, the transportation congestion and interruption to the public activities. Transportation congestion is a major problem to those projects situated in urban areas in case that those large or pre-assembled units have to be brought to site. Other superstore actions can generate air pollution. For example, the application of stone masonry, cutting blocks into shapes, polishing marble or hard granite, shaping rocks, cleaning or renovation, all these actions can generate dust hazards and even silicosis to stonemasons. To mitigate the air pollution due to the dust hazards, usually water spraying has to be employed.

3.3.3 Machinery

Construction plant - both fixed and mobile – is used primarily to undertake the construction activities. However, the choice of equipment and the method of operating the equipment have influence to the atmospheric pollution or the level of noise during construction. The risks also exist where safety and health accidents happen due to improper operation of machines. Proper methods should be adopted to mitigate the environmental impacts and the risks of health and safety from operating mechanical machines. The following factors should be considered when choosing the measures to operate machines:

- The extent of interference to the public activities and the public transportation. For example, when there is a busy existing public transportation, the application of mechanical transportation should be less used.
- The noise levels that site activities will generate to the vicinity. Usually, regulations exist for regulating that different noise levels are allowed for different time periods. This policy must be complied in operating machines.
- Possible vibration from operating machines. Vibration my happen when drilling or piledriving are undertaken, so that warning should be given to the parties who may suffer, or precautions taken to protect particularly those delicate equipment in the nearby.
- Air pollution due to the emissions such as fumes and particulates from operating construction machinery. Measures should be taken to controlling the emissions from suing various machines or tools.
- Various liquid pollutants in operating machines. Liquid pollutions are mainly due to the loss of oil or fuel, and it is a common problem in construction sites due to the improper operation of machines. Actions should be taken as soon as liquid pollution happens.

Air pollution in operating machines is usually caused by engine fumes produced from excavation machines, generators and haulage vehicles. It is suggested that consideration still needs to be given although some studies suggest the emissions hazardous to healthy, the proportions of carbon monoxide, hydrocarbons and nitrogen oxides from diesel engineers (common on heavy vehicles and machinery) are substantially less than from petrol engines (which make up the bulk of road traffic) (Watkins, 1981). Thus the use of diesel is common in operating construction machineries.

Other visible emissions can be thrown into the air in certain processes. For instance, diesel pile hammers spew oil liberally, particularly in a high wind, causing damage to clothing of passers-by or on washing lines. For example, asphalt plants and asphalt lying can generate harmful fumes. Dusts are also produced from earthwork in dry conditions through operating vehicles on various activities such as rock crushing.

Fuel not only presents a fire risk and is also pollutant to health. Fuel tanks should be located within specially designated bunds. Machinery and vehicles should be refuelled upstream of drains where spillage is collected at safe sumps. Storm water and other runoff, which might be contaminated by running through waste cement, asphalt and toxic grouts or slurries, must be tested dealt with specific techniques before their disposal on site. Treatment of contaminated water may even be necessary if its discharge to groundwater aquifers or to surface streams cannot be avoided. Other causes of aquatic pollution include temporary blocking of watercourses or excessive extraction of water for construction purposes.

Acceptable noise levels are subject to legislation or negotiation with local authorities. Proper measures should be taken for mitigating noise. For example, noise barriers can be applied to those areas where excessive noise is not avoidable. On-site construction is a relatively short-term activity. Usually, measures for mitigating noise are taken only when there is a significant noise impact from construction operations. The typical operations, which can induce significant noise pollution, include:

- Piledriving (over 100 dB(A) at 7m)
- Aggregate plants, concrete mixers
- Jack hammers and rock drilling (85-95dB(A))
- Concrete vibrators
- Excavators, scrapers and bulldozers (94dB(A))
- Conveyor belts (90-95 dB (A))
- Vehicles of all types: alarms such as dump truck reverse gear warning horns

3.3.4 Construction transportation

Transportation in construction process concerns the transportation of building materials or components and the on-site delivering operation. Both two types of transportation have environmental impacts. The on-site delivering activities can generate air and noise pollution. When there is spacious site, quarries and construction yards can be planned on site to suit the topography. But certain level of noise and air pollution will be obvious. On the other hand, if the site is congested, the attention should be given to the size of machine, the capacity of the machine that can commit the operation function, and the protection of the nearby site from damage. Construction traffic on site can cause serious dust in dry weather. Spraying water can mitigate such problems. If water shortages presents and the construction period are protracted then temporary bituminous sealing may be justified (Edwards, 1999).

The delivery of building materials or components by using public roads can induce traffic congestion to public transportation and interfere the public activities. It also increases additional noise and possibly accident risks. Public highways have to be used for delivery of construction materials, equipment and personnel. Typical environmental impacts of the transportation for construction include the follows:

- Traffic congestion and delays to road users caused by construction vehicles which are normally large and by necessary traffic control measures when special construction materials or components are delivered
- The stoppages of public roads due to the access of large scale construction traffics
- Annoyance to householders from high level of noise due to construction related traffic, especially on roads to which extra traffic is temporarily diverted
- Splashing, mud or dust from construction vehicles on public roads, especially annoying the pedestrians in wet weather. Measures such as 'wheel spinners' should be carried out on site before entering public roads
- Accidents of collisions between vehicles or with pedestrians

3.3.5 Runoff and drainage

Construction activity will involve serious difficulties if natural drainage has to be temporarily interrupted. Water pollution will be generated if no proper measures are taken in construction process. In general, the following measures are considered in dealing with the potential of water pollution:

- Measures to accommodate watercourses or drains diverted during construction; The risk and consequences of floods should be identified beforehand, which may occur while temporary arrangements are in place, thus measures to prevent or reduce the damage to aquatic habitat can be taken
- Measures such as pumping or temporary drains to protect earthworks or foundations under construction from storm runoff
- Identification of any liquid pollution which may affect downstream water users and of any necessary measures to isolate and treat water which might become contaminated
- Avoidance of excessive water abstraction that would limit downstream flow

On the other hand, surface or groundwater can be contaminated by runoff through construction materials such as chalk or clay leachate in stockpiles as well as by spillage of fuels and lubricants. To mitigate this problem, those construction materials can be piled and covered with plastic membrane, and drainage is provided in the surrounding of materials to allow water flow away. Local government, conservation groups and river authorities have to be consulted about the disposal of runoff and the quality of effluents (Carpenter, 2001).

Attention should also be given to the water quality, which can be examined by pH level and the contents of other chemicals or suspended solids. The results of such examination can provided the information whether the effluents should be disposed of by special means. Permeable ground surfaces allow infiltration of rainfall as a normal element of natural drainage. This infiltration will be prevented by paving, hard standing or membranes provided as construction temporary works or as a result of compaction by the passage of heavy vehicles and plant. Accordingly, as soon as the works are completed, the impermeable elements should be removed, compacted surfaces scarified and such topsoil or vegetation replaced to restore more rapid ground seepage (Carpenter, 2001).

3.4 Construction materials and environmental performance

The application of construction materials makes significant contributions to the environmental performance of construction activities. Construction materials themselves are essential parts of construction activities and at the same time they affect the methods adopted for implementing construction activities. This section is to discuss the environmental implications of the major construction materials.

3.4.1 Implication of choosing construction materials to environmental performance

The choice of construction materials has environmental implication across a project's life cycle. Choosing construction materials involves has to consider not only a particular kind of materials itself but also the integration with all other types of materials to be used in a construction project. The integration of various materials should aim for a total betterment of the environmental performance of a construction project. Nevertheless, a particular kind of materials is often a dominant material in a particular application, for example, rock in the application of coastal protection, earthwork in the application of embankments, concrete in the application of project foundations, steel in the application to bridge girders and alloys or complex composites in pre-assembled components of buildings (Carpenter, 2001).

The application of each type of materials has particular environmental implication. In general, construction materials can be classified into two broad groups: metal and non-metal materials. Other classification suggests the groups of soils and rocks; and manufactured or organic construction materials. Typical manufactured construction materials include steel, polymers, fiberglass, ceramics and fabrics, bricks, dressed stone and sawn timber. Various types of materials are built into a construction product through a integrative construction process. Figure 3.2 illustrates the process of applying construction materials in various construction operations.

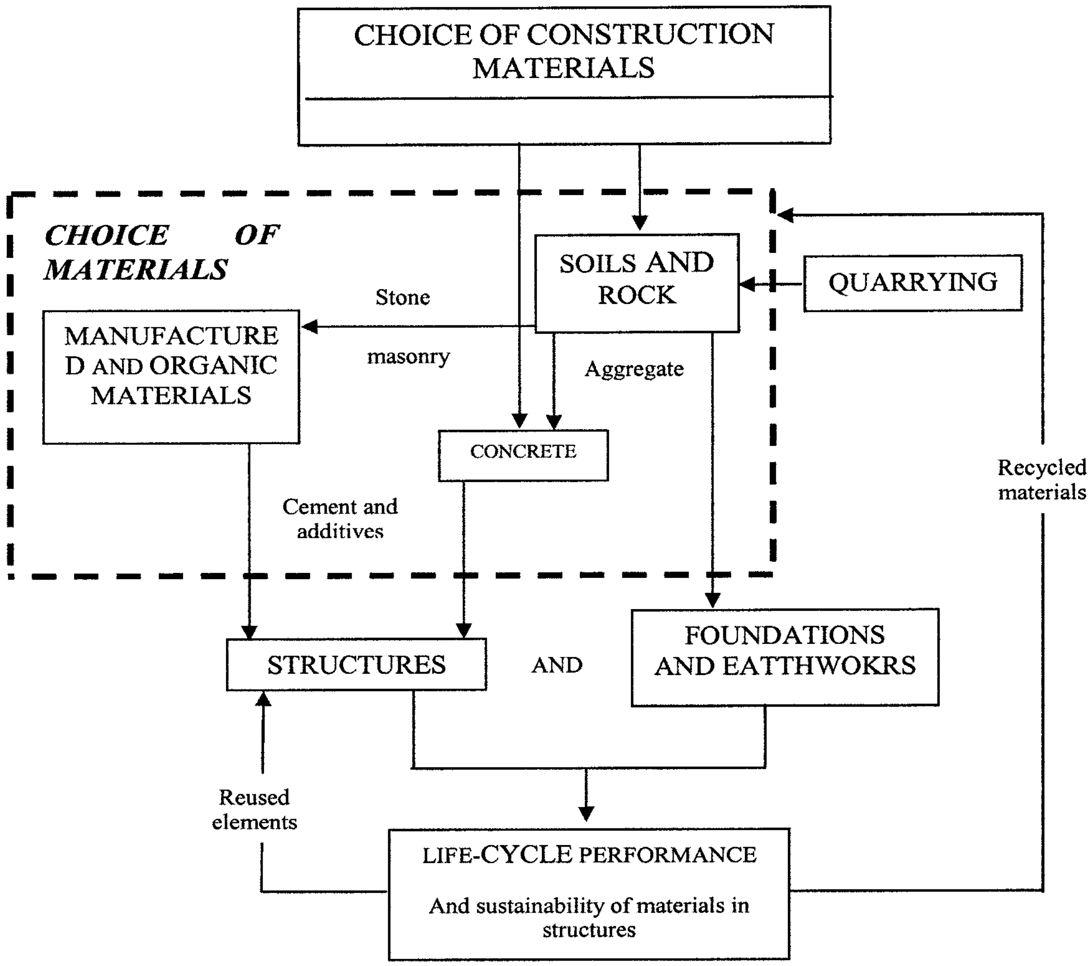


Figure 3.2 Planning for use of construction materials

3.4.2 Metal materials

Metal materials are usually from a manufactured process. According to CIRIA (1995) manufacture of metal materials is relatively energy-intensive compared with those non-metal materials used in construction. As an exception, the production of plastics also involves high-energy consumption.

Steel is most typical metal material used in construction. There are various types of applications in using steel materials, including the follows:

- Application to structural sections - plates, piles, stanchions, girders and tubes - as individual elements or within boxes, trusses or frameworks
- Application for high-strength cables for suspension or stays of bridges, buildings or masts
- Being used as long plain or ribbed bars to carry tensile loads in reinforced concrete
- Application for wires, pre-tensioned or post-tensioned in pre-stressed concrete
- Application for strips, ties and anchors for earth strengthening or the framework of gabion cages
- Being used for bearings and joint components
- Application for profiled and corrugated sheeting for roof, wall and soft cladding

The process of manufacturing steel materials involves considerable consumption on environmental resources in particular the energy. Thus the use of those steel materials used before for new construction projects is highly encouraged. Usually a recycling process is needed to modify the used steel into reusable steel materials. It is suggested that much reinforcing steel can be recycled if it can be effectively retrieved from demolished structures. There are some structural steel materials and most alloys materials, which cannot yet be efficiently recycled for the difficulty of modifying them into the exactly expected shape or application. Nevertheless, for the value of most the alloys, recycles have to be taken even with high costs in the recycling process. Alloys have wide applications such as the reinforcement to concrete pressure vessels (Cochrane, 1998).

Furthermore, non-ferrous metals are also used in construction, for example, aluminium. The lightness and durability of aluminium present the value of the materials even though the high energy required for its production. In the practical application, aluminium recycling is considered important in order to maximize the use of its value. Thus aluminium sheets and units are usually used so that they can be eventually recoverable for recycling.

3.4.3 Non-metal materials

Non-metal materials include those nature materials such as rock and timber, and those manufactured materials such as plastics. The application of both natural materials and manufactured materials will have impacts on the environment. The consumption on these materials implies the consumption on natural environment and the energy. However, these materials are essential to engage construction activities.

Concrete is one of the most popular construction materials in nowadays construction projects. Concrete is a kind of manufactured construction materials. It has wide range of applications including reinforced concrete beams, columns and slabs. Both in-situ and pre-cast concrete methods are adopted in the practice. When concrete is used for structure members, the choice between reinforced concrete, steel and composite structures is influenced by considering design features, susceptibility to corrosion, costs, availability of relevant materials and skills. There are varieties of advantages from using concrete. For example, a major advantage of concrete is that it can be made on or off the site. Disadvantages exist in using concrete, particularly, because of its rigidity. It is widely realized that the rigidity limits its application to adapt to the situations where flexibility is necessary (Pec, 1998).

Plastic is also a kind of popular construction materials with its good strength and flexibility. For example, strength and durability of plastics (mouldable synthetic polymeric compounds) have been proven and applied widely in construction products. The application functions of plastics materials in a construction product are multiple, include:

- Application for structural members
- Application for reinforcement (for example, carbon fibre)
- Protective panels, sprays or impregnation on surfaces susceptible to weathering or acidic or bacterial corrosion
- Adhesives
- Pipes
- Geotextiles

The production of plastics materials will consume various resources. Plastics are often considered pollutants thus proper application procedures must be taken. On the other hand, many plastics materials are recyclable, such as PVC (Coventry, 1998).

Ceramics are brittle materials but they can be immensely hard. They have the capacity of pressure resistance, which can be in excess of the capacity of some strong metals. Ceramics can be used for a considerable scope as a substitute for steel in various applications with little corrosion risks. Ceramics are within a range of products made with clay, such as bricks, earthenware pipes, industrial applications, various fine household applications and very delicate products. The production of ceramics involves the consumption on soil and the energy, thus having environmental impacts.

Fabric-reinforced polymer (FRP) is a newly developed construction materials. It is comparatively expensive but has the advantage of higher overall tensile strength even than steel, and has much higher strength-to-weight ratio. Alsayed (2000) pointed out that the value of FRP is to be used as structural repair sheets. This type of materials is particularly valuable in the application where the strength against brittle is necessary. Nevertheless, the production of this kind of new materials has significant environmental impacts.

Glass is also type of typical construction materials. There is a long history of making glass, about 150 years, being used as a major material for building walls and roofs within slender frameworks. There is an increasing scope for use of glass fibre as reinforcement in making plastics, concrete, and fabrics for enhancing the strength of the materials. The production of glass involves a complicated process where considerable amount of energy is consumed and environmental pollution is induced as well (Lewis, 1998).

In the development of construction materials, fabrics have been developed. Fabric materials can be manufactured from vegetable matter (such as cotton), from glass fibre or from synthetic polymers. As fabrics can be made into highly flexible rolls of thin materials, they have found wide application in construction products, for example, they are used as lightweight tension membranes, especially in roofing such as over London's Millennium Dome or large well-ventilated tent-like structures in hot countries (Alsayed, 2000), and as geotextiles to strengthen soils or ground surfaces or to provide barriers against vegetative growth or water flow. The production of fabric materials also involves a complicated process consuming considerable amount of energy and other type of environmental resources.

Other non-metal construction materials are from natural environment, such as timber. Timber is a very common construction materials used for a wide range of purposed in implementing a construction project. For example, timber is used for concreting frameworks, for window and door frameworks, for building roof, for floorboards, for variety of furniture, and so on.

Timber, in particular, tropical hardwood is considered as a kind of important environmental resources. It has multiple purposes in construction. However, for protecting this type of environmental resources, specifications for its use should be limited to temperate hardwoods and softwoods and with preservatives or other precautions, to the minimum quality necessary for the intended purpose.

Cork is another kind of important environmental resources. It has the properties of lightweight, impermeable, insulating, resilient, inflammable and durable. There is no synthetic alternative thus it is kind of very valuable environmental resources. The consumption on the materials should be controlled for the mission of implementing environmental protection.

The above discussions demonstrate the application of various construction materials have different environmental impacts. The choice of materials needs to incorporate the natures of these materials. Consideration should be given to both the environmental impacts from a single type of materials and the integrated environmental impacts of all kinds of materials used in a construction product.

3.5 Analytical framework presenting the construction environmental factors

The above discussions provide a basis to formulate an analytical framework presenting the construction environmental factors. It is the major objective of this section to formulate a framework presenting those factors, which have impacts on a contractor's environmental performance. The methods for examining the degree of the impacts of these factors will be presented.

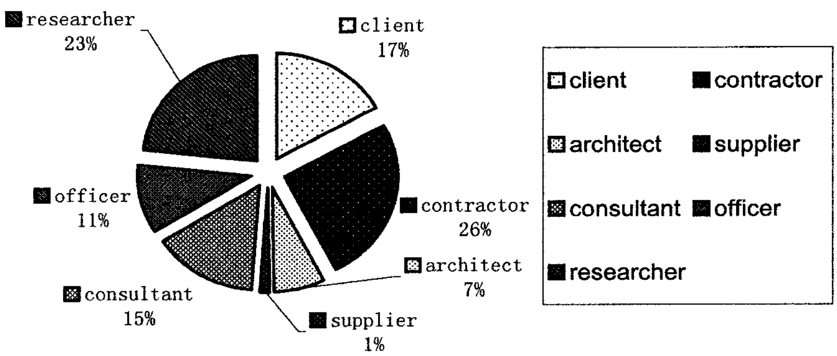
In fact, there have some existing studies examining the factors affecting a building's environmental performance. For example, the Malaysia Ministry of Housing and Local Government (MMHLG) in 1998 identified some factors for assessing the building's environment performance. By this approach, the environmental factors are sorted into six types according to the different sorts of resources, including land, energy, water, material and others (CIB report, 1998f). These factors are considered significant in measuring the environmental impact in operating a building.

In 1999, the HK-BEAM scheme is constituted to assess the environmental performance of a building's design, operation and maintenance and management (HK-BEAM, 1999). The Hong Kong Performance Assessment Scoring System (HK-PASS) (1997) identified a series of factors for assessing the building's performance including environment and quality. These factors are sorted into the categories such as: architecture works, structural work, site management, management & organization works, resources, co-ordination & control, documentation and programming & process, etc. All these factors can almost cover all the works and management activities in various construction stages.

Nevertheless, it appears that there is no existing study examining the factors affecting a contractor's environmental performance. It is one of the major tasks of this study to examine the factors affecting a contractor's environmental performance. The data used for this study are from a recent survey of the Mainland China and Hong Kong construction industry from December 2000 to June 2001, including clients, contractors, architects, suppliers, consultants, governmental officers and researchers in Universities and Institutes.

The distribution of respondents involved in the survey for factors is displayed in Figure 3.3. In the survey, questionnaires were sent to the selected respondents, 511 effective replies had been received. The responded clients take 17% in total effective replies, contractors take 26% of total, and environment researchers take 23%, some others such as officers 11%, consultants 15%, architects 7%, and material suppliers 1%.

Figure 3.3 Distribution of respondents involved in the survey for the factors



The survey was designed to collect the data for identifying the factors affecting contractors' environmental performance and the relative significance between these factors. A sample of the questionnaire is attached in appendix I in this dissertation. The correspondents are from the professionals who have good experience working on the construction activities, environment research and environmental quality management in various large construction companies and universities in China including Beijing, Shanghai, Guangzhou, Shenzhen, Chongqing and Chendu, and some are from the leading construction and real estate firms in Hong Kong including Henderson (China) Investment Co., Swire Properties, New World Development (China) Ltd., Hong Kong Land Ltd., China State Construction Engineering Co. (Hong Kong), Gammon Construction Ltd, etc. A summer investigation and in-depth interviews was conducted in August 2001 along Yangtze River from Chongqing to Shanghai that supported the survey analysis.

With considering the data collected from the survey and the review on the existing studies, all the factors affecting a contractor's environmental performance are classified in five categories:

- Specialist works (F_1)
- Site management (F_2)
- Project management (F_3)
- Technology (F_4)
- Environment policy (F_5)

For the easy of conducting the analysis on each group of factors, each category of environmental performance factors is subdivided into second level of environmental performance factors, and the factors at second level are further divided into the third level factors. The results of the subdivisions are shown in Table 3.1.

Table 3.1 Original framework of contractor environment factors

1st level factor (F_j)	2nd level factor ($F_{j-j'}$)	3rd level factor ($F_{j-j'-j''}$)
Specialist works (F_1)	Structural works (F_{1-1})	Earthwork and excavation (F_{1-1-1})
		Formwork and formation (F_{1-1-2})
		Reinforcement (F_{1-1-3})
		Concrete (F_{1-1-4})
		Waste treatment (F_{1-1-5})
	External & internal works (F_{1-2})	Wall, roofing and isolation (F_{1-2-1})
		Component instalments (F_{1-2-2})
		Plumbing and drainage (F_{1-2-3})
		Ornament and painting (F_{1-2-4})
		Surrounding landscaping (F_{1-2-5})
		Waste treatment (F_{1-2-6})
Site management (F_2)	Site performance (F_{2-1})	Site security (F_{2-1-1})
		Material storage and security (F_{2-1-2})
		Cleanliness and care (F_{2-1-3})
	Health & block Safety (F_{2-2})	Health & other provision (F_{2-2-1})
		Block related safety (F_{2-2-2})
Project Management (F_3)	Management & organization works (F_{3-1})	Management structure (F_{3-1-1})
		Site planning (F_{3-1-2})
		Environment engineering training (F_{3-1-3})
	Resources (F_{3-2})	Labour (F_{3-2-1})
		Plant (F_{3-2-2})
		Materials (F_{3-2-3})
	Co-ordination & Control (F_{3-3})	Co-ordination (F_{3-3-1})
		Control and supervision (F_{3-3-2})

		Co-operation (F_{3-3-3})
	Documentation (F_{3-4})	Submission (F_{3-4-1})
		Environment report (F_{3-4-2})
	Programming & progress (F_{3-5})	Program (F_{3-5-1})
		Progress (F_{3-5-2})
		Milestone (F_{3-5-3})
Technology (F_4)	Information technology (F_{4-1})	Software package (F_{4-1-1})
		Intranet (F_{4-1-2})
		Internet (F_{4-1-3})
	Construction technology (F_{4-2})	Energy & resource saving technology (F_{4-2-1})
		Pollution reducing technology (F_{4-2-2})
		Waste reducing technology (F_{4-2-3})
	Human skill (F_{4-3})	Environment engineer (F_{4-3-1})
		Environment knowledge (F_{4-3-2})
Environment policy (F_5)	Government policy (F_{5-1})	Environmental law (F_{5-1-1})
		Building regulation (F_{5-1-2})
	Company policy (F_{5-2})	Environment management system (F_{5-2-1})
		ISO14000 (F_{5-2-2})

Table 3.1 is the analytical framework presenting the factors affecting a contractor's environmental performance. The major factors will be identified through analyzing the data collected from the survey in the next section, followed by establishing the relative significance between these major factors. The establishment of the major environmental performance factors and their relative significances or weightings will provide a basis for establishing a scoring model for calculating a contractor's environmental performance index (C-EPI).

3.6 Relative significance between environmental performance factors

The formulation of the analytical framework of the environmental performance factors in the previous section provides the basis for analyzing the relative significance between all the factors presented in Table 3.1. The relative significance is measured by the significance score. The data used for calculating the significance score is from the questionnaire survey, which has been described before.

In the survey, for each environmental performance factor (as shown in Table 3.1), the respondents were requested to judge the significance level by selecting one of ten grades, namely, grade 1, 2, ... and 10, as shown in Table 3.2. Grade 1 indicates that the concerned factor has no impact on the environment, and grade 10 indicates the most essential. The middle grades indicate the difference from less important to more important. The survey results are summarized in Table 3.3. The figures in the table represent the number of respondents who gave specific grade to each environmental performance factor. For example, the figure 48 in the top-left corner indicates that 48 respondents considered that the factor has most essential impacts to the environment.

Table 3.2 Grades for judging the significance level of environmental performance factors

Numerical grade	Implication	Numerical grade	Implication
10	Most Essential (ME)	5	Slightly Important (SlI)
9	Most Important (MtI)	4	Less Important (LeI)
8	Very Important (VI)	3	Some Impact (SoI)
7	More Important (MeI)	2	Little Impact (LiI)
6	Commonly Important (CI)	1	No Impact (NI)

Table 3.3 Summarized results of significance level for environment factors

Factor	ME	MtI	VI	MeI	CI	SlI	LeI	SoI	LiI	NI
1st level factor										
Specialist works	48	115	144	94	62	25	14	6	3	
Site management	56	95	117	112	85	35	8	2	1	
Project management	80	102	139	94	49	35	11	1		
Technology	30	50	113	134	95	46	30	12	1	
Environment policy	51	70	123	100	97	30	25	11	2	2
2nd level factor										
Structural works (F_{1-1})	57	110	114	136	70	18	4	1	1	
External & internal works	75	105	126	107	84	8	3	2	1	
Site performance	106	117	120	105	31	18	4	5	3	2
Health & block safety	75	103	135	68	65	55	6	2	2	
Management &organization works	97	115	136	89	48	18	4	1	1	2
Resources	60	98	145	99	32	31	25	12	5	4
Co-ordination & control	44	110	130	85	66	51	18	6	1	
Documentation	18	49	71	112	85	65	77	32	2	
Programming & progress	30	70	90	102	97	68	40	10	4	
Information technology	6	79	84	88	81	56	41	43	23	10
Construction technology	80	138	117	69	32	31	21	18	3	2

Human skill	45	68	98	102	78	56	32	25	5	2
Government policy	128	148	124	58	27	17	8	1		
Company policy	156	179	130	24	12	6	4			
3rd level factor										
Earthwork and excavation	85	115	111	81	48	41	19	8	3	
Formwork and formation	28	89	109	81	80	56	40	22	6	
Reinforcement	18	75	88	99	97	60	41	19	14	
Concrete	40	101	125	109	83	22	22	5	4	
Waste treatment	69	100	138	118	69	8	6	2	1	
Wall, roofing and isolation	44	88	109	103	85	35	22	19	6	
Component installment	29	92	85	85	45	71	56	32	15	1
Plumbing and drainage	13	100	145	123	56	41	25	6	1	
Ornament and painting	71	89	123	123	65	26	6	6	2	
Surrounding landscaping	80	106	115	108	57	42	1	2		
Waste treatment	91	113	125	105	71	4	1	1		
Site security	55	116	158	99	25	16	20	20	2	
Material storage and security	42	92	125	100	72	42	25	7	6	
Cleanliness and care	76	109	105	97	88	30	3	2	1	
Health & other provision	81	90	127	108	78	15	7	2	3	
Block related safety	68	95	111	95	88	20	15	12	4	3
Management structure	60	100	129	88	115	8	3	4	4	
Site planning	49	126	146	78	88	5	6	9	2	2
Environment engineering training	90	150	76	87	44	49	10	4	2	
Labor	49	102	147	87	55	30	21	10	8	2
Plant	55	89	127	99	65	41	24	8	2	1
Materials	40	102	121	125	69	25	16	12	1	
Co-ordination	32	99	105	134	86	25	15	10	4	1
Control and supervision	42	95	166	125	58	10	9	5	1	
Co-operation	49	88	101	125	110	26	10	2		
Submission	10	65	100	92	86	68	54	11	16	9
Environment report	18	45	157	108	96	35	49	2	1	

Program	22	92	93	125	131	25	12	10	1	
Progress	21	85	100	114	118	68	3	2		
Milestone	12	48	88	105	89	68	58	36	7	
Software package	121	115	134	95	35	8	1	1	1	
Intranet	93	92	110	101	90	15	6	3	1	
Internet	45	75	99	123	89	55	17	8		
Energy & resource saving technology	162	153	108	70	9	6	2	1		
Pollution reducing technology	189	145	136	25	13	1	1	1		
Waste reducing technology	198	168	114	19	5	5	1	1		
Environment engineer	185	158	115	21	12	9	8	3		
Environment knowledge	134	155	135	41	25	10	9	2		
Environmental law	199	190	103	15	2	1	1			
Building regulation	185	177	102	25	10	7	4	1		
Environment management system	279	210	21	1						
ISO14000	361	147	3							

To examine the relative significance level among these factors, an alternative approach is to calculate the average significance score (S_{xyz}) between 511 responses to each factor through the following model:

$$S_{xyz} = \frac{1}{n}\sum_{i=1}^{n} R_i \qquad \text{------Eqn.(3.1)}$$

where

x denotes for that the consideration is given at the first level in the analytical framework shown in Table 3.1;

y for that the consideration is given at the second level;

z for that the consideration is given at the third level;

S_{xyz} denotes for the average significance score to a particular factor (if y, z=0, x $\neq$0, the significance value is for the factor which is at first level, denoted as S_x; if z=0, but y and x$\neq$0, the significance value is for the factor at second level, denoted as S_{xy}; if all z, y and x$\neq$0, the significance value is for the factor at third level, namely, S_{xyz});
R_i denotes for the specific score allocated by a specific respondent;
n for the total number of the questionnaire responses, namely, n=511.

By adopting these numerical values included in Table 3.3 to the formula (3.1), the average significance scores for all the environmental performance factors are calculated in Table 3.4.

Table 3.4 Average significance scores for all the environmental performance factors from survey

Factor	**Important rate score (S)**
1st level factor	
Specialist works (F_1)	7.64
Site management (F_2)	7.55
Project management (F_3)	7.84
Technology (F_4)	6.95
Environment policy (F_5)	7.23
2nd level factor	
Structural works (F_{1-1})	7.74
External & internal works (F_{1-2})	7.86
Site performance (F_{2-1})	8.07
Health & block safety (F_{2-2})	7.69
Management &organization works (F_{3-1})	8.06
Resources (F_{3-2})	7.50
Co-ordination & control (F_{3-3})	7.45

Documentation (F_{3-4})	6.29
Programming & progress (F_{3-5})	6.82
Information technology (F_{4-1})	6.21
Construction technology (F_{4-2})	7.74
Human skill (F_{4-3})	6.89
Government policy (F_{5-1})	8.40
Company policy (F_{5-2})	8.80
3rd level factor	
Earthwork and excavation (F_{1-1-1})	7.71
Formwork and formation (F_{1-1-2})	6.88
Reinforcement (F_{1-1-3})	6.62
Concrete (F_{1-1-4})	7.42
Waste treatment (F_{1-1-5})	7.84
Wall, roofing and isolation (F_{1-2-1})	7.18
Component installment (F_{1-2-2})	6.59
Plumbing and drainage (F_{1-2-3})	7.27
Ornament and painting (F_{1-2-4})	7.67
Surrounding landscaping (F_{1-2-5})	7.81
Waste treatment (F_{1-2-6})	8.05
Site security (F_{2-1-1})	7.68
Material storage and security (F_{2-1-2})	7.29
Cleanliness and care (F_{2-1-3})	7.75
Health & other provision (F_{2-2-1})	7.78
Block related safety (F_{2-2-2})	7.48
Management structure (F_{3-1-1})	7.65
Site planning (F_{3-1-2})	7.73
Environment engineering training (F_{3-1-3})	7.89
Labor (F_{3-2-1})	7.45
Plant (F_{3-2-2})	7.40
Materials (F_{3-2-3})	7.44

Co-ordination (F_{3-3-1})	7.30
Control and supervision (F_{3-3-2})	7.69
Co-operation (F_{3-3-3})	7.44
Submission (F_{3-4-1})	6.41
Environment report (F_{3-4-2})	6.95
Program (F_{3-5-1})	7.16
Progress (F_{3-5-2})	7.12
Milestone (F_{3-5-3})	6.30
Software package (F_{4-1-1})	8.30
Intranet (F_{4-1-2})	7.80
Internet (F_{4-1-3})	7.20
Energy & resource saving technology (F_{4-2-1})	8.70
Pollution reducing technology (F_{4-2-2})	8.90
Waste reducing technology (F_{4-2-3})	9.00
Environment engineer (F_{4-3-1})	8.80
Environment knowledge (F_{4-3-2})	8.50
Environmental law (F_{5-1-1})	9.10
Building regulation (F_{5-1-2})	8.90
Environment management system (F_{5-2-1})	9.50
ISO14000 (F_{5-2-2})	9.70

3.7 Weightings between environmental performance factors

This section is to establish weightings between environmental performance factors. There are two types of weightings: (a) relative weightings among the factors within the same groups, and (b) absolute weightings for individual factors.

Relative weightings among the factors within the same groups

The relative weightings can be calculated by adopting the following model:

(a) for the third level groups

$$RW_{xyz} = \frac{S_{xyz}}{\sum_{z} S_{xyz}} \qquad \text{-------Eqn.(3.2)}$$

$$\begin{cases} x=1,\ y=1,\ z=\{1,2,\ldots,5\};\ x=1,\ y=2,\ z=\{1,2,\ldots,6\} \\ x=2,\ y=1,\ z=\{1,2,3\};\ x=2,\ y=2,\ z=\{1,2\} \\ x=3,\ y=1,\ z=\{1,2,3\};\ x=3,\ y=2,\ z=\{1,2,3\};\ x=3, y=3,\ z=\{1,2,3\}; \\ x=3,\ y=4,\ z=\{1,2\} \\ x=4,\ y=1,\ z=\{1,2,3\};\ x=4, y=2,\ z=\{1,2,3\};\ x=4, y=3,\ z=\{1,2\}; \\ x=5, y=\{1,2\}, z=\{1,2\} \end{cases}$$

RW_{xyz} denotes for the relative weightings between the factors, which are at the third level but within a same group; and S_{xyz} denotes for the average significance score to a particular third level factor.

(b) for the second level groups

$$RW_{xy} = \frac{S_{xy}}{\sum_{y} S_{xy}} \qquad \text{-------Eqn.(3.3)}$$

$$\begin{cases} x=1,\ y=\{1,2\} \\ x=2,\ y=\{1,2\} \\ x=3,\ y=\{1,2,\ldots,4\} \\ x=4,\ y=\{1,2,3\} \\ x=5,\ y=\{1,2\} \end{cases}$$

The relative-weighting (RW_x) (z and y=0, x≠0) for the first level specific factor can be calculated with the Eqn.(3.4) as that:

(c) for the first level groups

$$RW_x = \frac{S_x}{\sum_x S_x} \qquad \text{------Eqn.(3.4)}$$

x={1, 2, …,5}

The calculation results by using the equations (3.2), (3.3) and (3.4) are in Table 3.5

Table 3.5 Relative weighting (RW) for all the environmental performance factors from survey

Factor	Relative weighting (RW)
1st level factor	
Specialist works (F_1)	0.205
Site management (F_2)	0.203
Project management (F_3)	0.211
Technology (F_4)	0.187
Environment policy (F_5)	0.194
2nd level factor	
Structural works (F_{1-1})	0.496
External & internal works (F_{1-2})	0.504
Site performance (F_{2-1})	0.512
Health & block safety (F_{2-2})	0.488
Management &organization works (F_{3-1})	0.223

Resources (F_{3-2})	0.208
Co-ordination & control (F_{3-3})	0.206
Documentation (F_{3-4})	0.174
Programming & progress (F_{3-5})	0.189
Information technology (F_{4-1})	0.298
Construction technology (F_{4-2})	0.371
Human skill (F_{4-3})	0.331
Government policy (F_{5-1})	0.488
Company policy (F_{5-2})	0.512
3rd level factor	
Earthwork and excavation (F_{1-1-1})	0.211
Formwork and formation (F_{1-1-2})	0.189
Reinforcement (F_{1-1-3})	0.182
Concrete (F_{1-1-4})	0.203
Waste treatment (F_{1-1-5})	0.215
Wall, roofing and isolation (F_{1-2-1})	0.161
Component installment (F_{1-2-2})	0.148
Plumbing and drainage (F_{1-2-3})	0.163
Ornament and painting (F_{1-2-4})	0.172
Surrounding landscaping (F_{1-2-5})	0.175
Waste treatment (F_{1-2-6})	0.181
Site security (F_{2-1-1})	0.338
Material storage and security (F_{2-1-2})	0.321
Cleanliness and care (F_{2-1-3})	0.341
Health & other provision (F_{2-2-1})	0.510
Block related safety (F_{2-2-2})	0.490
Management structure (F_{3-1-1})	0.329
Site planning (F_{3-1-2})	0.332
Environment engineering training (F_{3-1-3})	0.339
Labor (F_{3-2-1})	0.334

Plant (F_{3-2-2})	0.332
Materials (F_{3-2-3})	0.334
Co-ordination (F_{3-3-1})	0.325
Control and supervision (F_{3-3-2})	0.343
Co-operation (F_{3-3-3})	0.332
Submission (F_{3-4-1})	0.480
Environment report (F_{3-4-2})	0.520
Program (F_{3-5-1})	0.348
Progress (F_{3-5-2})	0.346
Milestone (F_{3-5-3})	0.306
Software package (F_{4-1-1})	0.356
Intranet (F_{4-1-2})	0.335
Internet (F_{4-1-3})	0.309
Energy & resource saving technology (F_{4-2-1})	0.327
Pollution reducing technology (F_{4-2-2})	0.335
Waste reducing technology (F_{4-2-3})	0.338
Environment engineer (F_{4-3-1})	0.509
Environment knowledge (F_{4-3-2})	0.491
Environmental law (F_{5-1-1})	0.506
Building regulation (F_{5-1-2})	0.494
Environment management system (F_{5-2-1})	0.495
ISO14000 (F_{5-2-2})	0.505

Absolute weightings for individual factors

The absolute-weighting for first level factor (AW_x) (when z and y=0, but x≠0) can be obtained from the formula:

$$AW_x = \frac{S_x}{\sum_x S_x} \qquad \text{------Eqn.(3.5)}$$

For the second level factor, the absolute-weighting, denoted as AW_{xy} (when z=0, but y and x$\neq$0), can be obtained from the formula:

$$AW_{xy} = RW_x \times RW_{xy} = \frac{S_x}{\sum_x S_x} \times \frac{S_{xy}}{\sum_y S_{xy}} \qquad \text{------Eqn.(3.6)}$$

The absolute-weighting for third level factor, AW_{xyz} (when all z, y and x$\neq$0), can be calculated from:

$$AW_{xyz} = RW_x \times RW_{xy} \times RW_{xyz} = \frac{S_x}{\sum_x S_x} \times \frac{S_{xy}}{\sum_y S_{xy}} \times \frac{S_{xyz}}{\sum_z S_{xyz}} \qquad \text{------Eqn.(3.7)}$$

The calculation results by using the equations (3.5), (3.6) and (3.7) are in Table 3.6. In fact, the absolute-weightings for the first level factors are the same as their relative weightings, namely, $AW_x=RW_x$. It can be seen in the table that the relative weightings between the first level factors, namely, specialist works, site management, project management, technology, and environment policy are 0.205, 0.203, 0.211, 0.187 and 0.194 respectively. This distribution is also illustrated in Figure 3.4. The factor "project management" assumes 0.211 and is the most important factor among these five first level factors.

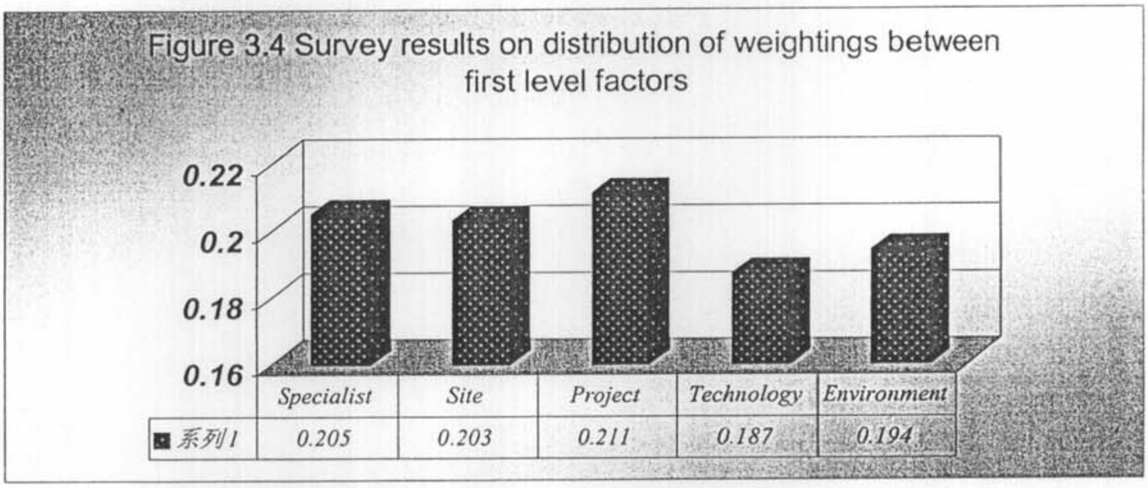
Table 3.6 Absolute weighting (AW) for all the environmental performance factors from survey

Factor	**Absolute weighting (AW)**

1st level factor	
Specialist works (F_1)	0.205
Site management (F_2)	0.203
Project management (F_3)	0.211
Technology (F_4)	0.187
Environment policy (F_5)	0.194
2nd level factor	
Structural works (F_{1-1})	0.102
External & internal works (F_{1-2})	0.103
Site performance (F_{2-1})	0.104
Health & block safety (F_{2-2})	0.099
Management &organization works (F_{3-1})	0.047
Resources (F_{3-2})	0.044
Co-ordination & control (F_{3-3})	0.044
Documentation (F_{3-4})	0.037
Programming & progress (F_{3-5})	0.040
Information technology (F_{4-1})	0.056
Construction technology (F_{4-2})	0.069
Human skill (F_{4-3})	0.062
Government policy (F_{5-1})	0.095
Company policy (F_{5-2})	0.099
3rd level factor	
Earthwork and excavation (F_{1-1-1})	0.022
Formwork and formation (F_{1-1-2})	0.019
Reinforcement (F_{1-1-3})	0.019
Concrete (F_{1-1-4})	0.021
Waste treatment (F_{1-1-5})	0.022
Wall, roofing and isolation (F_{1-2-1})	0.017
Component installment (F_{1-2-2})	0.015
Plumbing and drainage (F_{1-2-3})	0.017

Ornament and painting (F_{1-2-4})	0.018
Surrounding landscaping (F_{1-2-5})	0.018
Waste treatment (F_{1-2-6})	0.019
Site security (F_{2-1-1})	0.035
Material storage and security (F_{2-1-2})	0.033
Cleanliness and care (F_{2-1-3})	0.035
Health & other provision (F_{2-2-1})	0.050
Block related safety (F_{2-2-2})	0.049
Management structure (F_{3-1-1})	0.015
Site planning (F_{3-1-2})	0.016
Environment engineering training (F_{3-1-3})	0.016
Labor (F_{3-2-1})	0.015
Plant (F_{3-2-2})	0.015
Materials (F_{3-2-3})	0.015
Co-ordination (F_{3-3-1})	0.014
Control and supervision (F_{3-3-2})	0.015
Co-operation (F_{3-3-3})	0.015
Submission (F_{3-4-1})	0.018
Environment report (F_{3-4-2})	0.019
Program (F_{3-5-1})	0.014
Progress (F_{3-5-2})	0.014
Milestone (F_{3-5-3})	0.012
Software package (F_{4-1-1})	0.020
Intranet (F_{4-1-2})	0.019
Internet (F_{4-1-3})	0.017
Energy & resource saving technology (F_{4-2-1})	0.023
Pollution reducing technology (F_{4-2-2})	0.023
Waste reducing technology (F_{4-2-3})	0.023
Environment engineer (F_{4-3-1})	0.032
Environment knowledge (F_{4-3-2})	0.030

Environmental law ($F_{5\text{-}1\text{-}1}$)	0.048
Building regulation ($F_{5\text{-}1\text{-}2}$)	0.047
Environment management system ($F_{5\text{-}2\text{-}1}$)	0.049
ISO14000 ($F_{5\text{-}2\text{-}2}$)	0.050



3.8 Application of AHP for the adjustments of the weightings between the environmental performance factors

The establishment of weightings between those environmental performance factors will provide an important basis for further establishing the contractor's environmental performance scoring system in later chapters. Therefore, the adequacy of the weighting establishment is important. The weightings obtained in the previous section are according to the data collected from the practical survey. Nevertheless, the responses from survey do not directly provide the data about the relative importance between factors. Therefore, the quality of the weighting establishment may be affected.

In order to improve the quality of weighting establishment, the analytic hierarchy process (AHP) method is employed in this section to help adjusting these weightings between factors. AHP is a decision-aiding method developed by Saaty (1979). It aims at quantifying relative priorities for a given set of alternatives on a ration scale, based on the judgment of decision-maker, and stresses the importance of the intuitive judgment of a decision-maker as well as the consistency of the comparison of alternatives in decision-making process.

It is considered as an effective method for establishing weightings between factors, which are levelled in hierarchy. By using this approach, the first step is to establish the relative weightings between the first level factors through pair-wise comparison.

In applying AHP in establishing the weightings between the five first-level factors discussed in previous section, the results of pair-wise comparison among the factors is obtained through 6 professional interviews and presented in a pair-wise comparison matrix, as shown in Table 3.7. Usually, it is recommended to use a nominal-ratio scale from 1 to 9 in conducting the pair-wise comparison between the first level factors (Saaty, 1979).

For ensuring the consistence of the values in the pair-wise comparison matrix given by the surveyed professionals, necessary judgment measure is needed. In applying AHP method, an eigenvector λ_{max} is used. The calculation of the value of the eigenvector, named as eigenvalue, is illustrated in Table 3.8. b_{ij} in the table stands for the value of the matrix elements in Table 3.7.

Table 3.7 Pair-wise comparison matrix for experience

Exp	Specialist works	Site management	Project management	Technology	Environment policy
Specialist works	1	2	1/4	½	1/3
Site management	1/2	1	1/5	1/3	¼
Project management	4	5	1	2	2
Technology	2	3	1/2	1	½
Environment policy	3	4	1/2	2	1

Table 3.8 Weighting and the Maximum eigenvalue

$M_i = \prod_{j=1}^{5} b_{ij}$	$\overline{W_i} = \sqrt[5]{M_i}$	$w_i = \dfrac{\overline{W_i}}{\sum_{i=1}^{5} \overline{W_i}}$	$\lambda_{\max} = \sum_{i=1}^{5} \dfrac{(BW)_i}{nw_i}$
0.083	0.608	0.099	
0.008	0.381	0.062	
80	2.402	0.393	5.073
1.5	1.084	0.177	
12	1.644	0.269	

In order to check whether the values in the pair-wise comparison matrix were consistent or not, consistency ratio (C.R.) is used. When C.R <0.1, it is suggested that the consistency of the pair-wise comparison matrix from survey can be accepted (Saaty, 1979).

The calculation of CR is through the following formula:

$$C.R. = \frac{C.I.}{R.I.}$$ ------Eqn.(3.8)

Where C.I is a consistency index, which needs to be established by using the equation:

$$C.I. = \frac{\lambda_{\max} - n}{n - 1}$$ ------Eqn.(3.9)

And R.I is a random index (R.I.) recommended in Table 3.9 (Saaty, 1979). In our application, there are only five factors at the first level, thus RI =1.12, according to Table 3.9

Table 3.9 Average random index (R.I.)

No. of dimension for matrix	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54	1.56	1.58	1.59

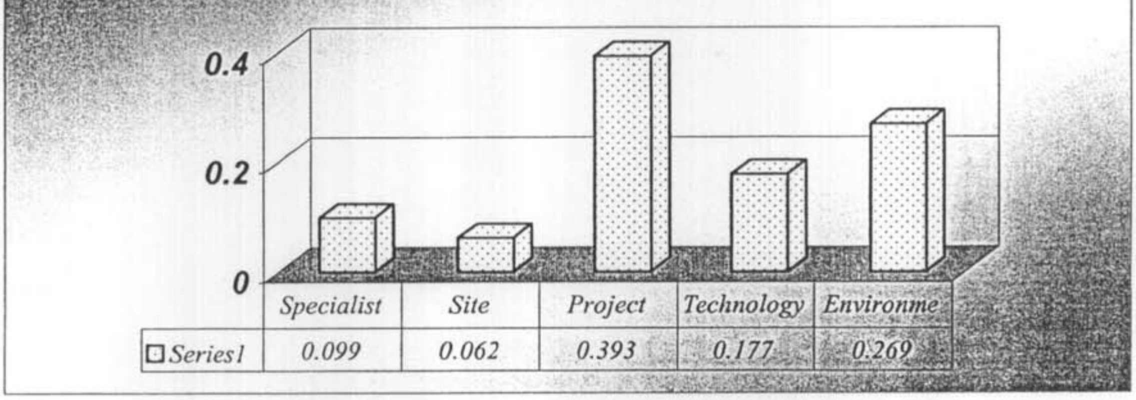
In Table 3.5, the eigenvalue λ_{max} has been calculated as 5.073, namely, λ_{max}=5.073. Also it is know that n=5.

By applying the above values to equations (3.8) and (3.9), the following values can be gained:

C.I.=0.018; C.R.=0.016

According to the criteria mentioned before that when C.R <0.1, the consistency of the pair-wise comparison matrix from survey can be accepted, consistency of the pair-wise comparison matrix in Table 3.7 is accepted as C.R.=0.016<0.1. It also suggests that the weightings in Table 3.8 is acceptable. It can be seen in this table that the relative weightings between the five first level factors (specialist works, site management, project management, technology, and environment policy) are 0.099, 0.062, 0.393, 0.177 and 0.269 respectively. The distribution of these weightings is also illustrated in Figure 3.5. This result is obtained through AHP approach and is considered a more proper distribution of weighting distribution between the factors. According to the new weighting distribution, the factor "project management" assumes 0.393 and is still the most important factor among these five first level factors.

Figure 3.5 Distribution of modified weightings between first level environmental performance factors



In order to modify the weightings between the factors at second and third levels, the weighting distribution between the five factors in Table 3.8 will be used to replace the weighting values obtained in previous section (namely specialist works 0.205, site management 0.203, project management 0.211, technology 0.187, and environment policy 0.194). When such replacement is incorporated into the equations (3.2)~(3.7), the modified weightings between factors at second and third levels can be calculated, and the results are shown in Table 3.10 and 3.11.

Table 3.10 Modified weightings between the environmental performance factors at 3rd level

Factor	Relative weighting (RW)	Absolute weighting (AW)
Earthwork and excavation ($F_{1\text{-}1\text{-}1}$)	0.211	0.010
Formwork and formation ($F_{1\text{-}1\text{-}2}$)	0.189	0.009
Reinforcement ($F_{1\text{-}1\text{-}3}$)	0.182	0.009
Concrete ($F_{1\text{-}1\text{-}4}$)	0.203	0.010
Waste treatment ($F_{1\text{-}1\text{-}5}$)	0.215	0.011
Wall, roofing and isolation ($F_{1\text{-}2\text{-}1}$)	0.161	0.009
Component installment ($F_{1\text{-}2\text{-}2}$)	0.148	0.007
Plumbing and drainage ($F_{1\text{-}2\text{-}3}$)	0.163	0.008
Ornament and painting ($F_{1\text{-}2\text{-}4}$)	0.172	0.009
Surrounding landscaping ($F_{1\text{-}2\text{-}5}$)	0.175	0.009
Waste treatment ($F_{1\text{-}2\text{-}6}$)	0.181	0.009
Site security ($F_{2\text{-}1\text{-}1}$)	0.338	0.010
Material storage and security ($F_{2\text{-}1\text{-}2}$)	0.321	0.010
Cleanliness and care ($F_{2\text{-}1\text{-}3}$)	0.341	0.011

Health & other provision ($F_{2\text{-}2\text{-}1}$)	0.510	0.015
Block related safety ($F_{2\text{-}2\text{-}2}$)	0.490	0.015
Management structure ($F_{3\text{-}1\text{-}1}$)	0.329	0.030
Site planning ($F_{3\text{-}1\text{-}2}$)	0.332	0.029
Environment engineering training ($F_{3\text{-}1\text{-}3}$)	0.339	0.030
Labor ($F_{3\text{-}2\text{-}1}$)	0.334	0.027
Plant ($F_{3\text{-}2\text{-}2}$)	0.332	0.027
Materials ($F_{3\text{-}2\text{-}3}$)	0.334	0.027
Co-ordination ($F_{3\text{-}3\text{-}1}$)	0.325	0.026
Control and supervision ($F_{3\text{-}3\text{-}2}$)	0.343	0.028
Co-operation ($F_{3\text{-}3\text{-}3}$)	0.332	0.027
Submission ($F_{3\text{-}4\text{-}1}$)	0.480	0.033
Environment report ($F_{3\text{-}4\text{-}2}$)	0.520	0.035
Program ($F_{3\text{-}5\text{-}1}$)	0.348	0.026
Progress ($F_{3\text{-}5\text{-}2}$)	0.346	0.026
Milestone ($F_{3\text{-}5\text{-}3}$)	0.306	0.023
Software package ($F_{4\text{-}1\text{-}1}$)	0.356	0.019
Intranet ($F_{4\text{-}1\text{-}2}$)	0.335	0.018
Internet ($F_{4\text{-}1\text{-}3}$)	0.309	0.016
Energy & resource saving technology ($F_{4\text{-}2\text{-}1}$)	0.327	0.022
Pollution reducing technology ($F_{4\text{-}2\text{-}2}$)	0.335	0.022
Waste reducing technology ($F_{4\text{-}2\text{-}3}$)	0.338	0.022
Environment engineer ($F_{4\text{-}3\text{-}1}$)	0.509	0.030
Environment knowledge ($F_{4\text{-}3\text{-}2}$)	0.491	0.030
Environmental law ($F_{5\text{-}1\text{-}1}$)	0.506	0.066
Building regulation ($F_{5\text{-}1\text{-}2}$)	0.494	0.065
Environment management system ($F_{5\text{-}2\text{-}1}$)	0.495	0.068
ISO14000 ($F_{5\text{-}2\text{-}2}$)	0.505	0.070

Table 3.11 Modified weightings between the environmental performance factors at 2^{nd} level

Factor	Relative weighting (RW)	Absolute weighting (AW)
Structural works (F_{1-1})	0.496	0.049
External & internal works (F_{1-2})	0.504	0.050
Site performance (F_{2-1})	0.512	0.032
Health & block safety (F_{2-2})	0.488	0.030
Management &organization works (F_{3-1})	0.223	0.088
Resources (F_{3-2})	0.208	0.082
Co-ordination & control (F_{3-3})	0.206	0.081
Documentation (F_{3-4})	0.174	0.068
Programming & progress (F_{3-5})	0.189	0.074
Information technology (F_{4-1})	0.298	0.053
Construction technology (F_{4-2})	0.371	0.066
Human skill (F_{4-3})	0.331	0.059
Government policy (F_{5-1})	0.488	0.131
Company policy (F_{5-2})	0.512	0.138

From Table 3.10, it can be seen that those important factors at the 3^{rd} level include ISO14000 (F_{5-2-2}), Environment management system (F_{5-2-1}), Environmental law (F_{5-1-1}), Building regulation (F_{5-1-2}), Environment report (F_{3-4-2}), and so on. It is suggested that effectiveness of improving contractors' environmental performance will be gained if more attention is given to those more important factors.

3.9 Summary

With the assistance of a practical survey (WU, 2002), this chapter has systematically examined the major factors affecting contractor's environment performance in construction stage. Data are collected from both and professional interviews, and the identifications of the environment factors provide a comprehensive understanding about the relevance various construction aspects to contractor's environmental performance.

The application of AHP method in modifying the weightings between factors has enhanced the quality of the establishment of the weightings, which will be used in later chapters for establishing models for calculating the value of contractor's environmental performance. The establishment of weightings between factors also helps contractors to understand those more important factors or areas where the effectiveness of improving environmental performance can be achieved. Thus adequate strategies can be adopted accordingly.

Chapter 4:

Establishment of the Indicators Measuring Contractor's Environmental Performance

CHAPTER 4: ESTABLISHMENT OF THE INDICATORS MEASURING CONTRACTOR'S ENVIRONMENTAL PERFORMANCE

4.1 Introduction

Improving construction environmental performance is in line with the mission of sustainable development. Various technologies and management methods have been developed in previous studies for improving environmental performance during construction process (Woolley, 1997; BRI, 2001). However, few studies have been undertaking on how to measure the environmental performance delivered by the contractor during construction. It is considered that a appropriate method for the assessment of construction environmental performance is important for gaining an adequate understanding about the progress of the performance, thus further improvements can be made by contractors through adopting more effective methods. Consequently, the establishment of a set of suitable assessment indicators is the key for engaging the assessment of construction environmental performance. And it is the main objective of this chapter to establish this set of environmental performance assessment indicators.

There are several methodologies developed for assessing environmental performance of a building or a construction product, mainly concerning with environmental (green) criteria. Typical methods include the Building Research Establishment Environmental Assessment Method (BREEAM), the Leadership in Energy and Environmental Design (LEED) and Green Building Tool (GBTool), and Hong Kong

Building Environmental Assessment Method (HK-BEAM) (HK-BEAM, 1999). These assessment methods are applicable in evaluating the environmental performance of a construction project at different levels, for example, at the global, regional and local level. In the application of these methods, a wide range of assessment indicators are used, and focuses are given to the amount of consumed resources (i.e. energy, water, land and materials) and the availability of environmental management systems concerning environmental policy, resources consumption targets, and monitoring procedures for environmental performance.

BREEAM, designed as an eco-labelling system, was developed by Building Research Establishment and private sector researchers (Larsson, 2001). This system allows for a relatively comprehensive assessment on the environmental performance of a construction product. Nevertheless, this approach is criticized that it doesn't consider a number of key issues including waste management, waste recycling as well as disposal of toxic waste (McDonald, 1996). LEED is a design-support tool and a tool for marketing green construction products, launched by the US Green Building Council (USGBC, 2002). LEED provides the measures for assessing the impacts of onsite disturbance, erosion and sedimentation processes of a construction product. But the system concerns little about the specific environmental performance of construction activities. Furthermore, Green Building Tool (GBTool) is a product produced by Green Building Challenge (GBC), which is an international initiative setting up the agenda for conducting environmental assessment on buildings (BRI, 2001). However, GBTool mainly emphasized on the sanitary waste management systems without detailing the requirements for waste management measures. The method concerns more about the adaptability and flexibility of building structures and systems, with little consideration given to the on-site construction activities. HKBEAM is considered a development of previous methods in assessing building environmental performance, with a focus of examining environmental performance of building works.

Although these methods are mainly developed for conducting environmental performance assessment of buildings or other types of construction products, they provide valuable references in studying the proper indicators in assessing contractors' environmental performance.

4.2 Theoretical framework for establishing construction environmental performance indicators

Before studying the environmental performance indicators in contractors' business activities, it is useful to gain an understanding about the implications of assessing contractors' environmental performance. In fact, pursuing better environmental performance is the commitment of any businesses including construction for contributing to the global mission of sustainable development. In recent years, the principle of sustainable development has been promoted to construction activities, leading to the development of sustainable construction.

The subject of sustainable construction is often described as consisting of a wide range of aspects that interact with construction process, including environmental, socio-economic, cultural, biophysical, and technical aspects (Hill et al., 1997). It aims for contributing to a balanced development in social, economic, technical and environmental aspects through a whole process of a construction development, including urban planning, project design, manufacturing, construction, operation and decommissioning (Hill et al., 2001). The mission of sustainable construction particularly emphasizes on the reduction of the environmental impacts from construction activities. Thus, improving environmental performance by contractors is a significant contribution to sustainable construction. Consequently, the principles of sustainable construction are considered as the guidelines for establishing the indicators for assessing contractors' environmental performance.

Sustainable construction practice shifts the traditional focus of construction practitioners from product provision to service provision. Yashiro (2000) suggests that such service includes benefits from building functioning, performance and psychological perceptions embodied with buildings. Therefore, buildings are not the end products of the construction process but the devices for supplying service. This indicates that sustainable construction is a practical methodology for implementing a life-cycle management approach. Since the late 1960s, life cycle analysis (LCA) has become an increasingly important tool for environmentalists (Eaton, 1998). LCA enables the effects that products, processes and activities have on local, regional or global environments to be assessed. It is necessary to consider the impact that raw material extraction, energy production, manufacturing processes, transportation needs and waste disposal requirements have on both social and natural environments.

The major principle of sustainable construction is to contribute to a balanced development among economic, social and environmental aspect. The economic contribution from construction activities is obvious. Implementation of construction projects will not only bring economic benefits to contractors themselves, but also to the local and national economy by means of tax-payment and improvement of economic conditions.

A sustainable construction practice should be able to contribute social development, for example, through improving social infrastructures and environment, and providing opportunities for employments of both individual construction work forces and specialist construction trades. Proper developments of construction activities can also contribute on promoting the development of small and medium enterprises. On the other hand, a contractor engaging a sustainable construction practice can build up its competitive advantage as it improves its good image among the public and gains social value.

According to the study by Rampele (1991), the implementation of sustainable construction calls for "a more integrated, people centred, participatory approach to ecological concerns". The process of engaging a construction project should include the participation of all interested and affected parties in the decision-making process during all project stages including project planning, design and operation. It is pointed out in the study by Hill & Bowen (1997) that sustainable construction practice must take on social responsibility and focus on the empowerment of local communities through skill training, as well as respond to their needs.

Nevertheless, the contribution of construction activities to the protection of the natural environment has been given less attention. In fact, construction business has very close relation with the environment. The impacts of construction activities on the environment are multiple. Typically, for example, implementation of a construction project will consume environmental resources, cause environmental pollutions, and produce various types of wastes. The principle of sustainable construction is for engaging an environmentally friendly construction process, which has the minimum environmental impacts. There is a significant development that the public is becoming more environmental conscious and appealing for strict enforcement of environmental regulations to reduce the environmental impacts of constructions activities. Thus the attendance of the public is one of important impulses for promoting the environmental performance by contractors.

The above discussions demonstrate that the establishment of environmental performance indicators should be in line the principle of sustainable construction. By this principle, the indicators for assessing a contractor's environmental performance should be investigated from the three-macro dimensions, namely, the society (S), the history (H), and the nature (N). These three dimensions form a three-dimensional coordinate as shown in figure 4.1. This coordinate presents a generic theoretical frame for establishing the indicators of contractors' environmental performance.

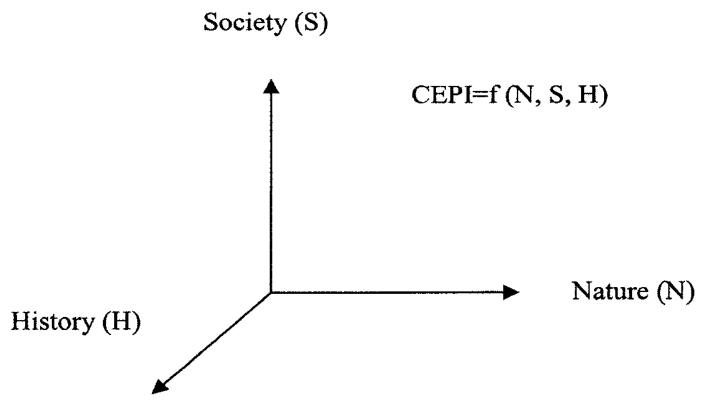


Figure 4.1 Three-dimensional coordinates for identifying construction environmental performance indicator

The three dimensions in the coordinate in Figure 4.1, namely, society (S), History (H) and Nature (N), can be considered as independent variables. These three macro variables represent three dimensions from which all construction environmental performance indicators will be identified. The integrated impacts from all these indicators can be called as contractor's environmental performance index (CEPI). This can be described in an analytical model as follows:

$CEPI = f(N, S, H)$

Where

CEPI denotes for contractor's environmental performance index, indicating the integrated value of all construction environmental performance indicators;

f for the functional relation between the variables (N, S, and H) and the value of CEPI.

4.3 Establishment of environmental assessment indicators

4.3.1 Categories of environmental assessment indicators

As discussed before, there are existing methods for assessing the environmental performance of building. Typical indicators used in these methods include water pollution, noise, air pollution, emission, soil damage, solid wastes, loss of forests and wild lands, loss of non-renewable energy sources, sewage, loss of non-renewable materials, traffic, health hazards, loss of biodiversity (Cole, 1998; Treloar, 1996; Ofori, 1998). In the Hong Kong Building Environmental Assessment Method (HK-BEAM, 1999), the frame of the environmental performance indicators was established with considering Global Issues, Local Issues and Indoors Issues. The system has been endorsed and promoted by the local government.

In particular, HKBEAM has been well received in the practice. This is in line with the development that concerns are growing about the construction-related environmental pollution in the local community. The promotion is encouraged from the government and the public and environmental impacts should be minimized and people should be provided with a better environment quality. Professionals are aware of the environmental impacts from building activities, and have been urged to improve their environmental performance. The HK-BEAM provides effective guidance particularly to building developers (and their consultants), owners, operators and users. Criteria for good environmental performance in buildings performance have been established. By using the guidance, good environmental performance can be recognized with receiving a certificate. Project developers are encouraged to use the guidance when selecting contractors or suppliers. The implementation of the guidance aims to minimize the adverse effects of buildings on the environment across all levels, including global, local and indoor environment.

The consideration to the global issues in HKBEAM suggests that building activities have the impacts on the planet, such as on the atmosphere beyond the local region. Indicator measuring the global impacts includes climate change due to greenhouse gas emission; stratospheric ozone depletion; deforestation and loss of biodiversity; depletion of natural resources; deterioration of water resources, and diminished capacity for food production.

Local issues relating to the environmental performance of buildings concern the impacts of buildings to the Hong Kong environment in general and the immediate surroundings of buildings. The specific indicators included in this category are ecological impacts and mitigation measures; noise pollution during construction and from the building equipment; air pollution; and waste conservation, water pollution and sewage, etc.

The indoor environmental performance is also considered important. Indicators used in HKBEAM for assessing indoor environmental performance concern all the aspects of building design, installation, finishes and operations which affect the health, comfort or well-being of the occupants. These indicators include thermal comfort; indoor air quality; lighting quality; noise and vibration; and hazardous materials, etc. In another typical study by Woolley (1997), the indicators used to measure the building's environmental performance are listed in the following table (Table 4.1)

Table 4.1 Indicators for measuring building's environmental performance (Woolley, 1997)

Acid rain	Photochemical smog	Photochemical oxidant
Particulate	Global warming	Ozone depletion
Pollution of land	Pollution of air	Pollution of water
Toxics	Toxics in treatment process	Noise pollution
Liquid waste	Solid waste	Electric use
LPG use	Water use	Solar use
Gas use	Wind use	Resource depletion (bio)
Resource depletion (non bio)	Thermal performance	Usage of recycled materials
Usage of renewable materials and energy	Reusing of the materials	Maintenance of materials
Site polite construction	Site safety	Community communication
Social image	Health hazard	Occupation health

Although these literatures concern more on built construction, they provide valuable basis for selecting indicators to assess contractor's environment performance in construction stage. By incorporating these references to the theoretical framework displayed in Figure 5.1, this research classifies various construction environmental performance indicators under the categories:

- Ecology category
- Embodied energy category
- Sustainability category
- Public aspect category
- Human aspect category

In the process of formulating a full set of construction environmental performance indicators, a comprehensive practical survey study was undertaken. The survey study was planned to identify properly the indicators and evaluate the propriety of the identification. Survey respondents include construction project clients, designers, project managers, contractors and subcontractors.

4.3.2 Structure of construction environmental performance indictors

As pointed early in this study, the major objective of this study is to develop a contractor environmental performance assessment system (C-EPAS). The importance of establishing a set of suitable indicators for C-EPAS is obvious. The theoretical framework for establishing these indicators and the five major categories of the indicators (namely, ecology, embodied energy, sustainability, public and human) have been discussed in previous sections.

In applying the theoretical framework of environmental performance indicators (shown previously in Figure 4.1), there are three dimensions: society, history and nature. The relationships between these three dimensions and the five main categories of indicators can be shown in Figure 4.2.

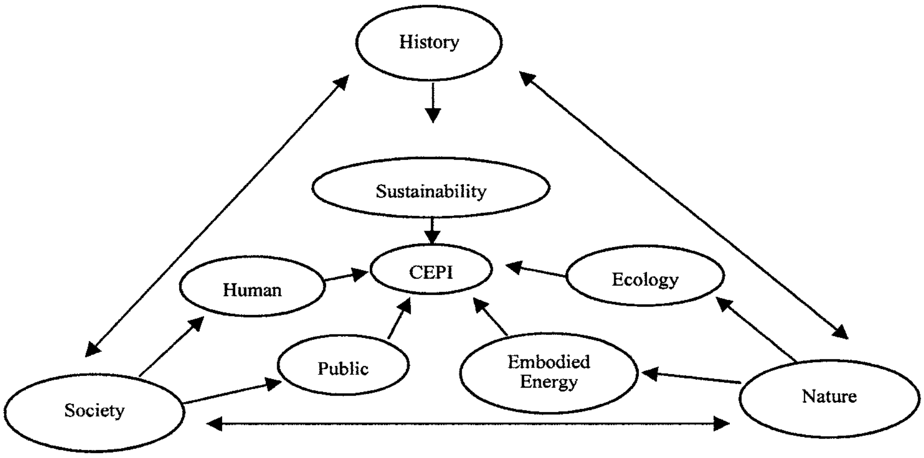


Figure 4.2 Revised subdivisions of the three-dimension coordinates

The dimension "nature" is described with the indicator categories of ecology and embodied energy, dimension "history" with the indicator category of sustainability, and the dimension "society" with the indicator categories of human and public aspect. However, it can be seen that these five indicator categories are too broad for engaging proper analysis. They need to be further divided into sublevel indicators in order to evaluate properly the environmental performance committed by contractors. Existing literatures provide valuable references for these subdivisions. For example, Woolley (1997) points out that the ecology performance can be described with following parameters: acid rain, particulate, global warming, ozone depletion, toxics, waste, air pollution, land pollution, water pollution, noise pollution, photochemical pollution, etc. In conducting the energy use in construction process, Yohanis (2002) related the energy used in the construction phase to a number of indicators including the extraction of materials, manufacture of components, transportation to site and construction process.

There are still other studies providing findings about the indicators for assessing environmental performance in construction process. The category of sustainability is related to the usage of recycled materials, reusing of materials, maintenance of materials, usage of renewable materials and usage of renewable energy (Woolley, 1997). Based on these discussions, the subdivisions of these five indicator categories can be established as shown in figure 4.3, figure 4.4, figure 4.5, figure 4.6 and figure 4.7.

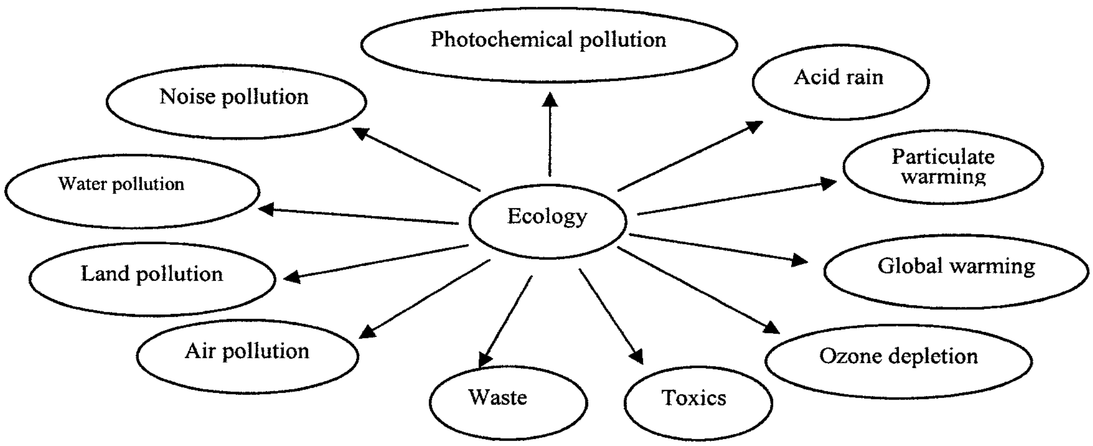


Figure 4.3 Subdivision of ecology category

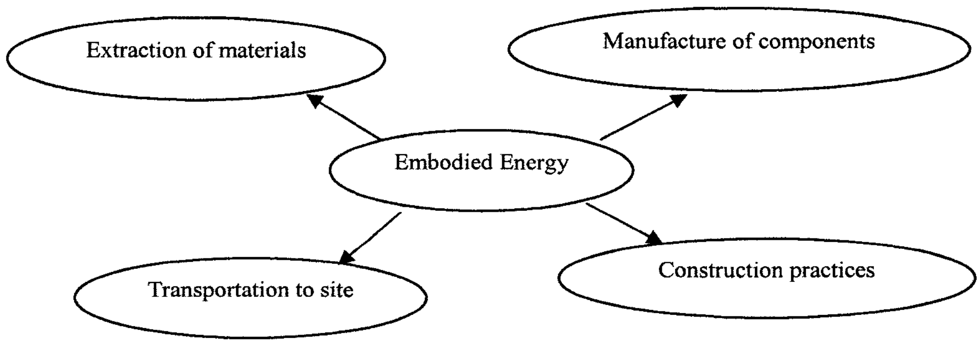


Figure 4.4 Subdivision of embodied energy category

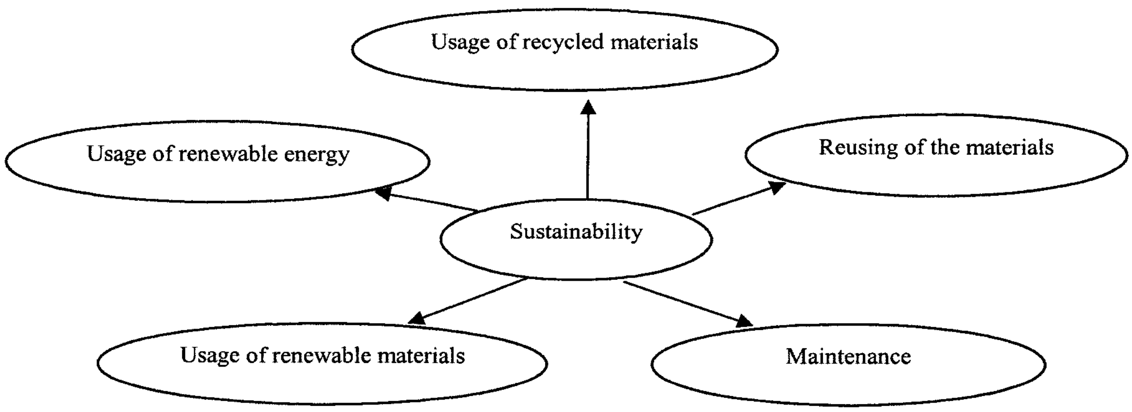


Figure 4.5 Subdivision of sustainability category

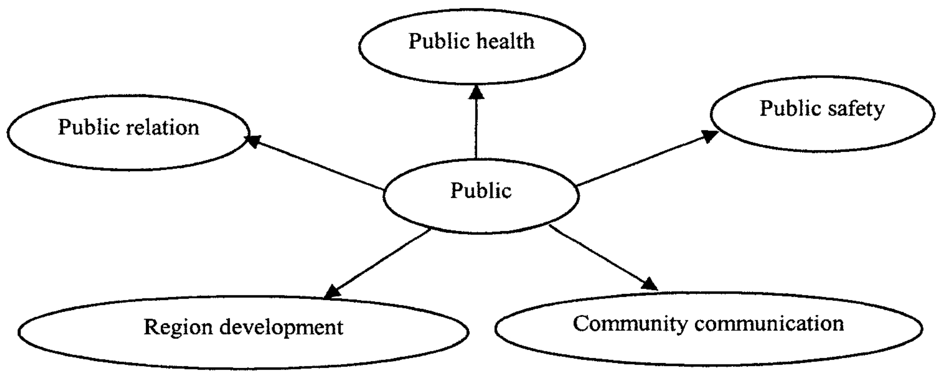


Figure 4.6 Subdivision of public category

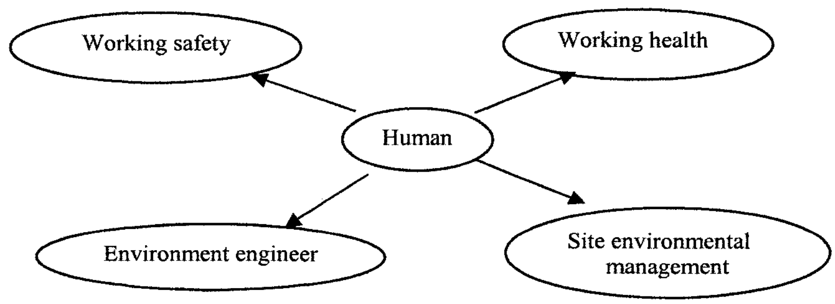


Figure 4.7 Subdivision of human category

These subdivisions of environmental performance indicators under the five major categories can be summarized in Table 4.2.

Table 4.2 Classification of environmental performance indicators

1st level indicator	2nd level indicator
Ecology	Acid rain
	Particulate
	Global warming
	Ozone depletion
	Toxics
	Waste
	Air Pollution
	Land Pollution
	Water Pollution
	Noise Pollution
	Photochemical pollution
Embodied energy	Extraction of materials
	Manufacture of components
	Transportation to site
	Construction practices
Sustainability	Usage of recycled materials
	Reusing of materials
	Maintenance
	Usage of renewable materials
	Usage of renewable energy
Public Aspect	Public health
	Public safety
	Community communication

	Region development
	Public relationship
Human Aspect	Environment engineer
	Working health
	Working safety
	Site environmental management

4.4 Analysis of the implications of environmental performance indicators

The implications of these environmental performance indicators under the five major categories in Table 4.2 will be described in this section.

4.4.1 Ecology

Ecology is a major environmental aspect. The quality of ecology can be indicated by many factors. For example, carbon dioxide (CO_2) has influences on the environment by causing global warming. It is considered that much of the CO_2 in the atmosphere is a direct result of fossil fuel burning. The other two major sources of producing CO_2 include cement manufacturing and using tropical land (Callander, 1995). Some gases, such as chlorofluorocarbons (CFCs), which have been regarded as the primary destroyer for Ozone layer, are one of the productions of burning the building waste materials. The paint used in the fitment can cause high-energy consumption, fire hazard, and pollution of land, air and water (Bradley, 1995a).

Construction practice affects the quality of ecology through various formats. For example, the earthwork and excavation in construction process can affect the quality of ecology through polluting the ground water and air. Construction activities also make noises through using heavy construction equipments and disturbing the environment nearby. The major ecologic impacts from construction activities can be analyzed as follows:

Acid rain

Construction activities provide sources causing acid rain. In 1972, at the United Nations Conference on Human Environment, Sweden presented a study that scientifically assessed the growing public concern with acid rain (Cowling, 1982). This was the first time acid rain was raised as an international pollution problem (Kowalok, 1993). The National Atmospheric Deposition Program was formed in the United States, and during the 1980s, consensus gradually emerged in Europe and North America that acid deposition was a real threat to the health of the environment.

In Europe, emission reduction targets were established for each country, and controls were mandated by law to be installed on the major sources of pollution that led to acidification (Hordijk, 1991). It was also found to be efficacious to apply lime to acidified lakes and soils, in restricted areas, to counteract the effects of acidification (McCormick, 1985). Today, emissions of SO_2 are on the decline in the West and the environment is recovering. In contrast, there is growing concern that Asia is headed for serious ecological and human health damage resulting from emissions of both SO_2 and NO_X.

Growth in the consumption of fossil fuels may be at the heart of this problem, as many Asian countries have experienced extremely rapid economic growth. Over 80% of all commercial energy used in Asia is derived from fossil fuels. Coal is the dominant energy source, and its use is expanding at a rate of almost 7% per year. At current rates, Asian energy demand doubles every 12 years. The demand for electricity is growing even faster. The amount of new investment in the Asian power sector during the 1990s was two thirds of the world's total power investment during this period.

These increases are driven by the rapid growth of Asian economies, the inefficiency of energy use, the reliance on coal as the major energy supply, and the rapid growth of motor vehicle transportation. Furthermore, the emergence/growth of the transportation sector is expected to result in an increase in NO_x emissions. (Fujita, 1999).

Large quantities of materials and components adopted in the construction processes have some special roles in impacting the environment, especially for causing the acid rain. Just during the production, transportation and demolition process of these raw materials and components, the emission of SO_2, and NO_x are so heavy and they are the major reason for causing the acid rain.

These materials life cycle impact to environment shall be expressed ultimately in the construction and these impacts shall be the core content for assessing the construction environmental impact. This thought shall be considered in evaluating another environmental indicators, such as global warming, ozone depletion, toxics and some others. There are so many raw materials and components that have impacts to the acid rain and are listed in the following table 4.3.

Table 4.3 List and content of raw materials causing acid rain

Aluminium	SO_2 and NOx are released when fossil fuels are burned at all stages of manufacture, to produce electricity and in gas-fired furnaces (Howard, N., 1995)
Asphalt Tiles (fiberglass matting)	Sulphur and nitrogen oxides, which form acid rain, are produced during fibreglass manufacture (Clough, 1995).
Asphalt tiles (organic matting)	Oil extraction and petrochemical refining are major sources of SO_2 and NOx, which form acid rain (Tolba, 1992).
Biomass fuel	Air pollution, from emissions that contribute to Acid Rain and Photochemical Smog, as well as Particulates and Toxics emissions, are the major concern with the burning of biomass fuels (Borer, 1994).
Blockboard/laminboards	See ' Synthetic resins '
Carpet fibres – polyester	See ' Synthetic fibres, foams & sheeting '
Cast iron	Emissions of sulphur dioxide and nitrogen oxides are associated with iron and steel production (HMSO (metal), 1991).
Cement bound boards --- (a) wood-cement particleboard/ (b) wood-wool cement slabs	Sulphur Dioxide is produced in the cement kiln both as part of the chemical reaction of the raw material and as a product of burning fossil fuel. Normally, however, this is mostly reabsorbed into the cement by chemical combination and only a small amount escapes. Nitrogen

	oxides from the fuel are not absorbed (CEC, 1990).
Clay tiles	SO_2 and NOx, which contribute to acid rain, are released during firing of clay products (Clough, 1995).
Coal	Coal burning is the major cause of acid rain, causing around 75% of SO_2 emissions in the UK (HMSO, 1992).
Concrete tiles	Burning fuels to heat cement kilns releases NOx and SO_2 (CEC, 1990).
Decorative laminates	See 'Synthetic resins'
Fibres in fibre-cement - synthetic polymer fibre	Petrochemicals refining and synthetic polymer manufacture are major sources of SO_2 and NOx (Tolba, 1992).
Fibres in fibre-cement - glass Fibre	Glass fibre manufacture contributes to acid rain formation, mainly through the fuels used to melt the ingredients (Clough, 1995).
Flettons	Sulphur and nitrogen oxides are top of the list of pollutants associated with the fletton industry (HMSO (ceramic), 1992).
Glass wool	Emissions of oxides of sulphur and nitrogen are linked with glass production (HMSO (glass), 1991).
Glass-reinforced polyester	Petrochemical refineries are major polluters with the acid rain forming gases SO_2 and NOx. Glass fibre production also contributes to acid rain pollution, mainly through the burning of fossil fuels to melt the ingredients (HMSO (glass), 1992).
Natural gas	Natural gas contributes very little to acid rain: SO_2 emissions are virtually zero; and NO_x emissions are very small compared to other fossil fuels (UNEP, 1991).
Ordinary portland cement	Sulphur dioxide is produced in the cement kiln, both as part of the chemical reaction of the raw materials, and as a product of burning fossil fuel. Normally, however, it is mostly re-absorbed into the cement by chemical

	combination, and only a small amount escapes. Nitrogen oxides from fuel burning are not absorbed (CEC, 1990).
Ordinary solid clay	The sulphur content of clays, and therefore the potential for emissions of sulphur dioxide from brick kilns, varies widely, but may be as high as for flettons (CEC, 1990).
Organic coatings for steel sheet ---roofing	High levels of dioxins have been found around PVC manufacturing plants and the waste sludge from PVC manufacture going to landfill has been found to contain significant levels of dioxins and other highly toxic compounds (Tolba, 1992).
Plastic foams (general)	Petrochemical refineries are major polluters with the acid rain forming gases SO_2 and NO_x (Tolba, 1992).
Plywood	See 'Synthetic resins'
Polymer modified cement --- slates	Synthetic polymer manufacture is a major source of SO_2 and NOx (Tolba, 1992).
Pure Lime	Similar comments apply to lime production as to ordinary portland cement. (HMSO (lime), 1992)
Resin and polymer bonded --- slates	Synthetic polymer manufacture is also a major source of SO_2 and NOx (Tolba, 1992).
Sheet metal roofing -- aluminium sheet	SO_2 and NOx are released when fossil fuels are burned at all stages of manufacture, to produce electricity and in gas-fired furnaces (Howard, N., 1995).
Sheet metal roofing -- copper sheet	SO_2 and NOx emissions will be substantial due to the fuels consumed during copper manufacture (UNEP, 1991).
Sheet metal roofing -- lead sheet	Emissions of SO_2 and NOx can be substantial due to the fuels consumed in lead manufacture (Howard, N., 1995).
Sheet metal roofing -- stainless steel sheet	SO_2 and NOx arise from fuels consumed in production. The smelting of molybdenum and other alloying metals results in the emission of sulphuric acid fumes, which can lead to local problems of acid deposition (Chris,

	1995).
Sheet metal roofing --- steel sheet	Combustion emissions from ore refinement, blast furnace and oxygen furnace operations include greenhouse- and acid rain forming gases (HMSO (metal), 1991).
Sheet metal roofing --- zinc galvanizing layer	SO_2 and NOx emissions will be "substantial" owing to the fossil fuels consumed during zinc manufacture (Howard, N., 1995).
Smooth floor coverings -- PVC (vinyl)	See ' Synthetic fibres, foams & sheeting '
Steel	Combustion emissions from ore refinement, blast furnace and oxygen furnace operations include greenhouse- and acid rain forming gases (Howard, N., 1995).
Synthetic fibres, foams & sheeting	Petrochemicals refining is a major source of SO_2 and NOx, the gases responsible for acid deposition (Tolba, 1992).
Synthetic foams and rubbers – general --- butadiene-styrene co-polymers	See ' Synthetic fibres, foams & sheeting '
Synthetic foams and rubbers – general --- polyurethane foam	See ' Synthetic fibres, foams & sheeting '
Synthetic resins	Nitrogen oxides and sulphur dioxide, involved in the formation of acid rain, are produced during refining and synthetic resin production (Bradley, 1995b).
Synthetic-solvent-borne	Petrochemical refineries are major polluters with the acid rain forming gases SO_2 and NOx (Tolba, 1992).
uPVC	Petrochemical refineries, the source of may of the raw materials for PVC, are major polluters with the acid rain

	forming gases SO_2 and NOx (Tolba, 1992).

Global warming

Through analyzing the concept of EEI, the impact of construction has closely relations with the global warming. For the large quantity of wood and wood production have been used during the process and the earthwork is another huge damage to the forest, too. It is sometimes claimed that planting trees might be the answer to the global warming crisis, because they will 'soak up' the CO_2 from fossil fuel burning, the picture is in fact more complex.

Overall, an ecosystem such as a tropical forest will absorb very little CO_2 - but it will have a regional cooling effect on the climate through evaporation, releasing water vapour into the air and creating cloud cover (James, 1991). Greenpeace estimates that tropical deforestation (from all causes) contributes to around 18% of all global warming (30% of CO_2 emissions). In temperate regions, conversion of old-growth forest to plantation also causes a net increase in greenhouse gas levels - from release of carbon and methane in soils - as does the draining of peatlands (Leggett, 1990).

For the aerated concrete used in construction, it can absorb a large amount of CO_2 from the atmosphere, which reduces the overall global warnling impact. The cement industry is the only significant CO_2 polluter other than fossil fuel burning responsible for about 450 million tonnes, or about 8-10% of the global total. It is estimated that CO_2 emissions from Synthetic polymer manufacture production plant, quarry transport and electricity during slate production are of the order of 0.53 tonnes CO_2 per tonne of finished product, although this is likely to be less for crushed aggregate where there is less wastage of material (Tolba, 1992). This figure does include transport to the point of use. (See table 4.4)

Table 4.4 List and content of materials causing global warming

Aerated concrete	Ordinarily, concrete does not carbonate significantly, but aerated concrete with its open texture does absorb a significant amount of CO_2 from the atmosphere. This reduces the overall global warnling impact (Tolba, 1992).
Aluminium	One tonne of aluminium produced consumes energy equivalent to 26 to 37 tonnes of CO_2 - but most imported aluminium is produced by hydroelectric power with very low CO_2 emission consequences (Hall, 1992).
Asphalt tiles (fiberglass matting)	Gaseous emissions from fiberglass production include the 'greenhouse' gases NOx, CO_2 and carbon monoxide (Clough, 1995).
Asphalt tiles (organic matting)	Oil extraction and petrochemical refining are major sources of CO_2, NOx, methane and other 'greenhouse' gases (Clough, 1995).
Blockboard/laminboards	See 'Synthetic resins '
Carpet fibres -- nylon	Nitrous oxide is the third most important greenhouse gas, after CO_2 and methane (Pearce, 1991).
Carpet fibres – polyester	See 'Synthetic fibres, foams and sheets'
Cast iron	CO_2 emissions from iron & steel production are significant, although much smaller than those from

	burning fossil fuels (about 1.5%) and CO_2 emissions incurred during global transport of raw materials should also be considered (Neill, 1993).
Cement based tiles -- concrete tiles	The manufacture of Portland cement releases around 500kg CO_2 per tonne and is the only significant producer of CO_2 other than fossil fuel burning, responsible for 8-10% of total emissions (EBN, 1995a).
Cement bound boards -- (a) wood-cement particleboard / (b) wood-wool cement slabs	CO_2 is given off during chemical reaction with calcium/magnesium carbonate materials (i.e. chalk or limestone) (Tolba, 1992).
Clay tiles	NOx, a greenhouse gas, is released during firing (Clough, 1995).
Decorative laminates	See 'Synthetic resins '
Fibres in fibre-cement - glass fibre	Gaseous emissions from fiberglass production include the 'greenhouse' gases NOx and CO_2 (Clough, 1995).
Fibres in fibre-cement - synthetic polymer fibre	Petroleum refining and synthetic polymer manufacture are major sources of NOx, CO_2, methane and other 'greenhouse' gases (Clough, 1995).
Foams & sheeting	See 'synthetic fibres, foams and sheets'
Hydraulic lime	It is responsible for a similar amount of CO_2 in production (Doran, 1992)
Ordinary portland cement	The manufacture of cement from chalk or limestone involves a chemical reaction in which carbon dioxide is given off at a rate of 500kg tonne (Tolba, 1992).
Organic coatings for steel sheet - roofing	Petroleum refining and synthetic polymer manufacture are major sources of NOx and CO_2 (Clough, 1995).
Plywood	See 'Synthetic resins '

Polymer modified cement - slates	Synthetic polymer manufacture is also a major source of 'greenhouse' gases (Tolba, 1992).
Polystyrene (extruded)	HFCs, one of the possible replacement blowing agents for CFCs have a global warming potential 3200 times that of CO_2 (Doran, 1992).
Pure lime	The manufacture of lime from chalk or limestone involves a chemical reaction in which carbon dioxide is given off in large quantities (BRE, 1975).
Resin and polymer bonded - slates	See 'slate'
Sheet metal roofing - aluminium sheet	See 'aluminium'
Sheet metal roofing - copper sheet	About 7 tonnes of CO_2 are produced per tonne of copper produced from ore, and 1-6 tonnes per tonne of recycled copper (Howard, N., 1995).
Sheet metal roofing - lead sheet	CO_2 emissions are estimated at 16 tonnes per tonne of lead produced (Howard, N., 1995).
Sheet metal roofing - stainless steel sheet	About 1.6 tonnes of CO_2 is emitted per tonne of stainless steel produced from recycled scrap (Howard, N., 1995).
Sheet metal roofing - steel sheet	See 'steel'
Sheet metal roofing - zinc galvanizing layer	CO_2 emissions are estimated at 6 tonnes per tonne of zinc produced (Howard, N., 1995).
Slates	It is estimated that CO_2 emissions from production plant, quarry transport and electricity are of the order of 0.53 tonnes CO_2 per tonne of finished product. This figure does include transport to the point of use (Clough, 1995).
Smooth floor coverings -- PVC (vinyl)	See 'Synthetic Fibres, Foams and Sheets'

Steel	About 3 tonnes of CO_2 are emitted per tonne of steel produced from ore, and 1.6 tonnes per tonne of recycled steel (Howard, N., 1995).
Stone (a) local	See 'slates'
Synthetic fibres, Foams and sheets	Petrochemicals manufacture is a major source of NOx, CO_2, methane and other 'greenhouse' gases (Tolba, 1992).
Synthetic foams and rubbers – general --- butadiene-styrene co-polymers	See 'Synthetic Fibres, Foams and Sheets'
Synthetic foams and rubbers – general --- latex (natural) rubber & foam	Latex foams should be treated with more caution than rubber sheet or tile, as they require the use of blowing agents such as HFCs and ammonia, most of which are environmentally damaging (Arup, 1993a).
Synthetic foams and rubbers – general --- polyurethane foam	See 'Synthetic Fibres, Foams and Sheets'
Synthetic resins	Petrochemicals manufacture is a major source of NOx, CO_2, methane and other 'greenhouse' gasses (Tolba, 1992).
Timber	Tropical deforestation from all causes is responsible for a large proportion (18%) of global warming (Leggett, 1990).

Ozone depletion

The first major environmental concern to strike the refrigeration-based industries was depletion of the ozone layer as the result of the emission of man-made chemicals into the atmosphere. Over 25 years ago, Rowland proposed that the emission of chlorinated man-made chemicals to the atmosphere could damage the stratospheric ozone layer (Rowland, 1974). Subsequently, and extensive worldwide programme of stratospheric ozone monitoring has confirmed that there is a pattern of depletion which is most pronounced over the Antarctic during springtime.

As a consequence, a series of intergovernmental agreements have been formulated, beginning in 1985 with the Vienna Convention on the Protection of the Ozone Layer and the Montreal Protocol on Substances that Deplete the Ozone Layer in 1987 (UNEP, 1999).

Consequent upon the Montreal Protocol and its Adjustments came measures to reduce the production and use of materials with high ozone depletion potentials (ODPs). First, the halons were banned, then the chlorofluorocarbons (CFCs), and now there is a push to ban the gydrochlorofluorocarbons (HCFCs) on a time scale which becomes shorter with each new amendment to the protocol. Methyl bromide is also included in the Protocol, but is not of concern here. These actions are interpreted differently in different parts of the world and there are different requirements for the developing and the industrialized countries.

The current official position is that halon and CFC production and use have already been phased out in the industrialized countries (except for "essential applications" and "the use of ozone depleting substances as feed stocks for other chemical production"). All production is to cease by the year 2006. However, CFC production remains well above target levels – to the extent that 2010 would now appear too be a more realistic phase-out date that 2006. This excess production is being driven by the continued sale of CFC-based systems in developing counties, and the export of used equipment from industrialized to developing countries. These actions are reinforcing CFC-dependency and enhancing demand.

Another factor is the black market in CFCs in the industrialized countries, and the associated illegal traffic. This is being supplied by the continuing legal production in developing countries and by a degree of illegal non-compliance with the provisions of the Protocol in other areas. At Montreal, the parties to the Protocol introduced a report-based licensing system to try to control this trade (UNEP, 1999). It does not seem likely that this will succeed.

For HCFCs, the official phase-out dates are 2030 for the industrialized countries and 2040 for the developing countries. In Montreal, the EU pushed for an earlier HCFC phase-out date of 2015, but this was defeated following opposition by the United States, Canada, and some developing countries. The EU proposal was based on the increasing availability of non-depleting substitutes for HCFCs and on recent evidence that many HCFCs are acutely toxic following regular exposure. Meanwhile, different countries are adopting their own phase-out strategies. For example, Germany has banned the use of HCFC-22 in new plants after the year 2000 (McMullan, 2002). There are some materials that can impact the ozone depletion. These materials can be evaluated by the indicators in the C-EPSS (see table 4.5).

Table 4.5 List and content of materials causing ozone depletion

Carpet fibres -- nylon	NOx also contributes to ozone depletion (Pearce, 1991).
Composite insulating Blocks	According to the AECB, there are no blocks available with attached insulation that is made without ozone-depleting chemicals such as CFCs (Hall, 1992).
Rigid urethane foams	Rigid urethane foams used to be blown with CFCs. There is still a possibility that HCFCs are used, possibly in conjunction with CO2 or other gases (Butler, 1989).
Smooth floor coverings -- PVC (Vinyl)	PVC (Vinyl) causes the ozone depletion (Tolba, 1992).
Synthetic foams and rubbers – general --- butadiene-styrene co-polymers	Butadiene-styrene co-polymers can cause the ozone depletion (Tolba, 1992).
Synthetic foams and rubbers – general --- latex (natural) rubber & foam	Latex foams should be treated with more caution than rubber sheet or tile, as they require the use of blowing agents such as HFCs and ammonia, most of which are environmentally damaging (Arup, 1993b).
Synthetic foams and rubbers – general --- polyurethane foam	Polyurethane foam contributes to ozone depletion (Tolba, 1992).

Toxics

Material used on the building that has strong impact on the environment, especially for the toxics impact. Coal smoke contains a wide range of harmful chemicals, some of which are carcinogenic. It is worth noting that more and more softwood timber is being pre-treated with toxic preservatives, possibly in an attempt to make up for inferior quality, poor seasoning and bad design (AECB, 1995). Some studies indicate that there has been a risk of lung cancer in workers in both the rock and glass wool sectors of the industry amounting to some 25% above normal 30 years after first employment (Clough, 1995).

Aluminium plants in the UK have been frequently criticized for high levels of discharge of toxic heavy metals to sewers. Emissions of dioxins have also been associated with secondary aluminium smelting (HMSO (aluminium), 1991). Until the discovery of its carcinogenic properties, all synthetic slates were produced using cement bonded with asbestos fibres. Synthetic fibres or natural fibres such as sisal, and filling compounds have replaced asbestos.

Steel smelting is listed as a major source of dioxin, as a result of the recycling of scrap steel with PVC and other plastic coatings (GI, 1994). Iron ores are relatively innocuous, but toxic metals are released in low concentrations as solid and liquid waste during refining. Copper mining also yields large amounts of heavy metal contaminated solid waste, and emissions to air.

Petrochemical industries are responsible for over half of all emissions of toxics to the environment. Though associated with toxic emissions, the effects from the manufacture of polyester resins are relatively small compared to PVC. High levels of dioxins have been found in the environment around PVC production plants. PVC is manufactured from the vinyl chloride monomer and ethylene dichloride, both of which are known carcinogens and powerful irritants. Despite high standards in emissions monitoring and control, large amounts of these chemicals end up released into the environment (GI, 1992).

Her Majesty's Inspectorate of Pollution guidelines indicate that all plastics making processes cause emissions of their raw materials and waste by-products to air, water and land, but PVC production is top of the list for toxic emissions to all three.

Organophosphates, used in sheep dips, have been linked to a range of physical illness, depression and mood swings. The suicide rate amongst sheep farmers is double the national average, which has lead to tight controls on their use since April 1995. Wool, however, requires far fewer chemicals to treat it compared to other fibres (see table 4.6).

Table 4.6 List and content of materials causing toxics

Aluminium	Bauxite refining yields large volumes of mud containing trace amounts of hazardous materials (HMSO (aluminium), 1991).
Asphalt Tiles (Fiberglass Matting)	Emissions to air from fiberglass manufacture include fluorides, chlorides and particulates (including glass fibres) (Clough, 1995).
Asphalt Tiles (Organic Matting)	The petrochemicals industry is responsible for over half of all emissions of toxics to the environment. Solid wastes from refining and extraction include polynuclear aromatics and heavy metals (Clough,

	1995).
Blackboard / laminboards	See 'synthetic resins'
Carpet Fibres -- Acrylic	It is a suspected carcinogen (Kruger, 1991).
Carpet Fibres -- Polyester	It has a relatively small impact on toxic when compared with PVC (HMSO, 1993).
Carpet Fibres -- Wool	Organophosphates, used in sheep dips, have been linked to a range of physical illness, depression and mood swings (Tolba, 1992).
Cast Iron	Metal smelting industries are second only to the chemicals industry in terms of total emissions of toxics to the environment (ENDS, 1995).
Cement based tiles -- concrete tiles	See 'ordinary portland cement'
Cement bound boards— (a) wood-cement particleboard /(b) wood-wool cement slabs	See 'ordinary portland cement'
Clay tiles	Emissions to air during production include fluorine and chlorine compounds (DE, 1991).
Decorative laminates	See 'synthetic resins'
Fibres in fibre-cement - glass fibre	Emissions to air from fiberglass manufacture include fluorides, chlorides and particulates (including glass fibres). Solid wastes include organic solvents, alkalis and 'alkali earth' metals (Clough, 1995).
Fibres in fibre-cement - synthetic polymer fibre	The petrochemicals industry is responsible for over half of all emissions of toxics to the environment (Dadd, 1986).
Flettons	The impurities in fletton clay burnt in the kiln result in the potential emission of a wide range of toxic and other pollutants (ENDS, 1993).
Foamed glass	Glass manufacture is associated with the emissions of

	fluorides, chlorides and particulate matter (HMSO (glass), 1991).
Glass-reinforced polyester	Emissions of particulates, oils, phenols, heavy metals and scrubber effluents are all associated with petrochemical manufacture (GD, 1989).
Medium density fibreboard (MDF)	There may be some pollution of watercourses from effluents unless the plant is fitted with a closed water system (EBN, 1995b).
Ordinary portland cement (OPC)	OPC contains heavy metals, of which a high proportion is lost to the atmosphere on firing (CEC, 1990).
Ordinary solid clay	Firing bricks often causes toxic gases and vapours to be given off, unless materials are very carefully chosen (Harland, 1993).
Organic solvent- borne	Fire & Explosion/ environment/ non-renewable resource (Hall, 1992)
Particleboards --chipboard	Chipboard plants release large quantities of volatile organic compounds (VOCs) largely as a result of their dryers (EBN, 1995b).
Particleboards--oriented strandboard (OSB)	OSB plants can emit large quantities of volatile organic compounds (VOCs) largely as a result of their dryers (EBN, 1995b).
Phenolic foam	Phenols are highly toxic aromatic organic compounds (Porteus, 1992).
Plant-based ---water-borne	Without toxic solvents such as turpentine, these paints involve the least toxics in production (Tolba, 1992).
Plant-based---solvent-borne	Plant-based chemicals are not necessarily non-toxic. Wastes from plant -based production processes are much less of a problem than with petrochemical processes (Birkin, 1989).
Plastic foams (general)	Petrochemical industries are responsible for over half

	of all emissions of toxics to the environment (Tolba, 1992).
Plywood	Plywood plants may emit large quantities of volatile organic compounds, largely as a result of their dryers (EBN, 1995b).
Polymer modified cement - slates	The petrochemicals industry, from which the synthetic binders are derived, is responsible for over half of an emission of toxics to the environment (Kruger, 1991).
Pure lime	Carbon monoxide and fluorine compounds can be present in emissions (HMSO (lime), 1992).
Resin and polymer bonded -- slates	See 'polymer modified cement - slates'
Sheet metal roofing -- aluminium sheet	Emissions of dioxins have also been associated with secondary aluminium smelting (HMSO (aluminium), 1991).
Sheet metal roofing -- copper sheet	Heavy metals are often leached into watercourses from mine drainage and spoil tips, with associated acidification of water (HMSO (copper), 1991).
Sheet metal roofing --lead sheet	Lead is toxic and tends to bioaccumulations (Howard, N., 1995).
Sheet metal roofing -- stainless steel sheet	Nickel, vanadium, molybdenum and chromium released in scrubber effluents can be toxic and phytoxic (toxic to plants) (Howard, N., 1995).
Sheet metal roofing --- steel sheet	The early stage of iron and steel production is one of the largest sources of dioxin emissions (Howard, N., 1995)
Sheet metal roofing --- zinc galvanizing layer	These solutions produce highly toxic waste products (HMSO (iron), 1991).
Smooth floor coverings -- PVC (Vinyl)	PVC is manufactured from the vinyl chloride monomer and ethylene dicWoride, both of which are known carcinogens and powerful irritants. PVC also

	contains a wide range of additives such as fungicides, pigments, plasticizers and heavy metals, which adds to the toxic waste production (Curwell, 1990).
Smooth floor coverings - wood floors	Fine wood dust, released during installation/maintenance is a suspected carcinogen, and tropical wood dusts may have respiratory effects (Curwell, 1986).
Steel	The refining of steel from iron is associated with further emissions of carbon monoxide, dust, metal fume, fluoride and heavy metals (GI, 1994).
Synthetic fibres, foams & sheeting	The most important impacts are particulates, organic chemicals, heavy metals and scrubber effluents (Tolba, 1992).
Synthetic foams and rubbers – general - butadiene-styrene co-polymers	Both butadiene and styrene are possible carcinogens (Arup, 1993b).
Synthetic foams and rubbers – general - polyurethane foam	A by-product of polyurethane production is the highly toxic phosgene gas (Brooks, 1985).
Synthetic resins	The petrochemicals industry is responsible for over half of all emissions of toxics to the environment, releasing particulates, heavy metals, organic chemicals and scrubber effluents. Volatile organic compounds released during oil refining and further conversion into resins contribute to ozone formation in the lower atmosphere with consequent reduction in air quality (Tolba, 1992).
Synthetic --water-borne	A number of toxic chemicals are likely to be used in water-borne paints (Hall, 1992).
Synthetic-solvent-borne	Many individual ingredients of synthetic paints are

	toxic (BRE, 1993).
Timber	Plantation-grown timber may well have been the subject of toxic pesticide treatments (AECB, 1995).
uPVC	PVC is manufactured from the vinyl chloride monomer and ethylene dichloride, both of which are known carcinogens and powerful irritants (GI, 1992).
WC + sewer & public treatment plant	The chlorination of water may combine with other chemicals to produce cancer-causing agents and chloroform in drinking water (Sim, 1995).
Wool	Organophosphates, used in sheep dips, have been linked to a range of physical illness, depression and mood swings (FV, 1996).

Photochemical pollution

Some materials have the impact of photochemical pollution. These materials are significant for evaluating the photochemical pollution by indicators. Photochemical Smog is the major concern with the burning of biomass fuels. The actual amounts and types of pollutants vary widely, depending on the type of fuel, its state (wet or dry, fresh or decomposed etc.) and the burning conditions. Biogas is essentially methane, the same as natural gas, but other impurities may be present. Coal burning is responsible for significant quantities of oxides of nitrogen, hydrocarbons and carbon monoxide, the photochemical smog gases. Emissions of the Photochemical Smog gases are likewise low from the combustion of natural gas. Likewise with emissions causing Photochemical Smog, oil combustion falls between coal and gas. Some materials are main causes for photochemical pollution (see table 4.7).

Table 4.7 List and content of raw materials causing photochemical pollution

Aluminum	The Nitrous Oxide emissions associated with aluminum production also contribute to photochemical smog (HMSO (metal), 1991).
Flettons	Nitrogen oxides result from the burning of fuel and from other high temperature reactions (HMSO (ceramic), 1992).
Foamed glass	Nitrogen oxides emission is serious (HMSO (glass), 1991).
Glass wool	See 'foamed glass'
Glass-reinforced polyester	Petrochemical refineries are responsible for significant emissions of photochemical oxidants such as hydrocarbons (HMSO (glass), 1991).
Ordinary portland cement	Nitrogen oxides result from the burning of fuel and from other high temperature reactions (CEC, 1990).
Ordinary solid clay	See 'Ordinary portland cement'
Plant-based - water-borne	With no solvent content, the volatile organic compound (VOCs) rating is low (Tolba, 1992).
Plant-based--solvent-borne	Although organic paint solvents are derived from plant sources (e.g. turpentine), these are still that contribute to photochemical smog (Tolba, 1992).
Plastic foams (general)	See 'Glass-reinforced polyester'
Synthetic - water-borne	Water-borne synthetic paints tend to have lower VOC contents (but not usually zero) (Hall, 1992).
Synthetic-solvent-borne	It is the emissions of VOCs (volatile organic compounds) associated with synthetic paints that is the prominent issue (Tolba, 1992).
uPVC	See 'Glass-reinforced polyester'

Pollution of land, water and air

The use of sewage sludge on agricultural land is closely regulated to ensure that the build up of pollutants does not pose unacceptable risks (HMSO (agricultural), 1989). Both the sludge and the soil must be regularly sampled and analyzed, and there are limits on applying sludge to crops such as soft fruit and vegetables. Presumably this sludge is too toxic for use on agricultural land. Sewage effluent standards for the UK were set in 1915 but in 1989 up to 20% of sewage treatment plants did not meet these. Sewage treatment works may produce phosphorus inputs to fresh water responsible for blue green algal blooms (Porteus, 1992).

7% of sewage sludge in the UK is currently incinerated. Pollution caused by the incineration of sewage sludge includes: particulates, heavy metals, sulphur, nitrogen and carbon oxides, halogen compounds, dioxins and organic compounds to air; mercury and cadmium in effluents to water; halogens, organ-metallic compounds, dioxins and furans and other heavy metal compounds in ashes and residues taken to landfills (HMSO (sewage), 1991). Sewage incineration can cause air pollution - the following are controlled by legislation: Carbon monoxide, 'organic compounds', particulates, heavy metals, chloride, fluoride and sulphur dioxide.

4.4.2 Embodied energy

Energy use during the lifespan of buildings consists of embodied energy, operational energy and demolition energy. Embodied energy may be divided into two parts: initial and recurring embodied energy. The initial embodied energy of a building is the energy used in producing a building whereas the recurring embodied energy is the energy used in maintaining and repairing of the building over its effective life (Chen, 2001). Embodied energy is the term used to describe the total amount of energy used in the raw materials and manufacture of a given quantity of product. For products specifically made for their insulating properties, it is true that all will probably save many times more energy during their life than is consumed in their production. Most will achieve energy break-even in months or years when compared to an un-insulated structure. From this viewpoint the embodied energy is relatively insignificant.

Conversely, given that all buildings should be (and must if new-build) properly insulated whatever they are made with, then the embodied energy of insulating may still be considered relevant (Woolley, 1997). The energy embodied in a building is that used to extract, process, manufacture and transport building materials and components. As improvements in the operational energy efficiency of buildings are made, the relative significance of embodied energy forms a higher proportion of the total amount of energy used over the lifetime of a building. Achieving a truly energy-optimized design requires the ability to investigate both operational and embodied energy implications of alternative design options including all inter-related inputs, processes and outputs (Yohanis, 2002).

The total energy used in a building over its life is the sum of the operational energy and the life cycle embodied energy as illustrated in Fig 4.8, the latter is sum of initial embodied energy, recurring energy and demolition energy.

	Construction	Use	Refurbishment	Use	Demolition
Embodied energy	. Extraction of materials . Manufacture of components . Transport to site construction process	. Replacement of materials and components	. Extraction of materials . Manufacture of components . Transport to buildings	. Replacement of materials and components	. Demolition process . Transport
Operational energy		. Heating and / or cooling . Lighting . Appliances	. Power tools . Energy loads for any on-going use	. Heating and / or cooling . Lighting . Appliances	

Building Life

Figure 4.8 Indicative components of embodied and operational energy over an illustrative building life cycle

The initial embodied energy increases from zero to a maximum during the construction phase as shown in Fig 4.9. During this phase as the building is not occupied, there is no operating energy requirement. Any energy requirement by construction personnel is assumed to be part of the initial embodied energy. During the operational phase, the increase in embodied energy is due to repainting, re-carpeting, replacement of lamps and systems, and major periodic modeling and refurbishment due to changes in tenancy of function.

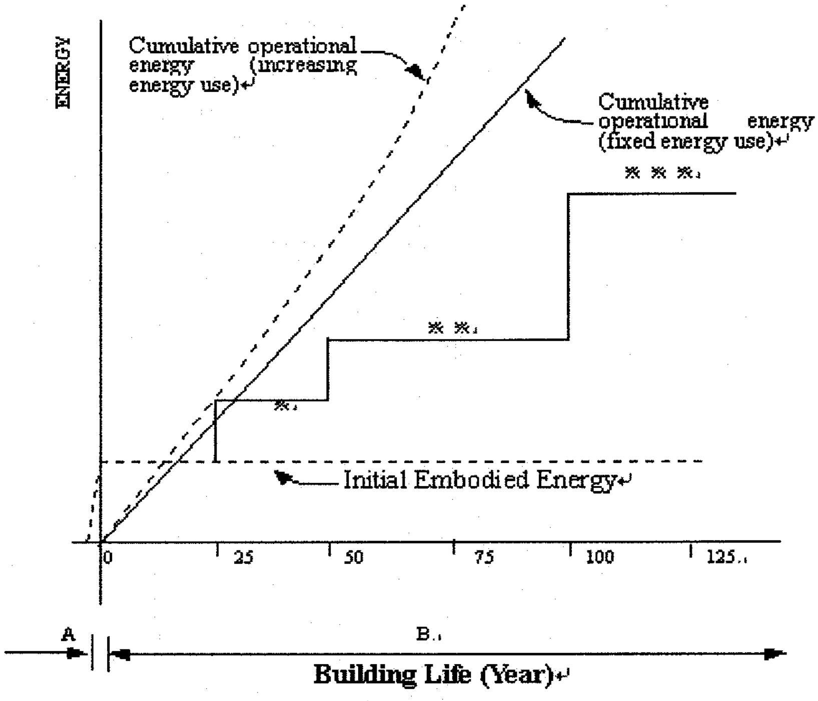


Fig. 4.9 Operational and embodied energy as a function of building life

※ Initial embodied energy plus recurring embodied energy over 25 years, ※※ 50 years, ※※※ 100 years.
A, Construction phase; B, Operation Phase

Major refurbishment may involve substantial reconstruction amounting to 0.10 to 0.17 GJ m^{-2}, 0.13 to 0.23 GJ m^{-2} or 0.17 to 0.34 GJ m^{-2} for basic, medium or top-grade office fit-out, respectively (Howard, 1994). Estimates for the additional energy associated with typical replacement and repair over various building lives, for the case of a building with a wood structure, are shown in Table 4.8.

Table 4.8 Additional embodied energy and increase in embodied energy during life of a building compared with initial embodied energy

Building life (year)	Additional embodied energy ($GJ\ m^{-2}$)	Percentage increase compared with initial embodied energy
25	2.52	59
50	6.32	148
100	14.4	339

Although these figures are illustrative and cannot be applied universally, they nevertheless show clearly that recurring embodied energy is significant in life-cycle energy analysis. At the end of the useful life of a building, energy is used for demolition and transport. This component is very difficult to assess due to difficulty in predicting the useful life of a building, the methods of demolition and the energy implications of any materials and/or component reuse and /or recycling at a future date. Initial embodied energy is estimated to account for about 70% of the total energy used in building construction and about 20% of the total energy requirement for UK industry (Atkinson, 1996). For some new well-insulated buildings, embodied energy could be as much as 50% of the operational energy over a 25-year period. Estimates for the initial embodied energy and for the sum of the initial and recurring embodied energy in relation to the operating energy over various building lives are shown in Table 4.9.

Table 4.9 Initial and recurring embodied energy as a percentage of operating energy (Cole & Kernan, 1996)

Building life (year)	Initial embodied energy as a percentage of operating energy	The sum of initial embodied energy and recurring embodied energy as a percentage of operating energy
25	67	105
50	34	87
100	17	71

Chen (2001) calculated the embodied energy consumed in Hong Kong and made conclusion that the energy use in the process during the production and demolition of buildings accounted for less than 2% of the total embodied energy, while the production of building materials consumed more 90%. Energy use in transportation of building materials and products for HK is about 7%, which is higher the average 5% assumed by others (Cole & Wong, 1996).

The embodied energy of an object represents the total amount of primary energy consumed in its manufacture and delivery to site, including extraction of the raw materials required. As a guide to understanding these quantities, we have also listed the embodied energy figures of some other common building materials in the table 4.10. But remember that this is not a direct comparison of like for like – one tonne of timber is not usually a substitute for one tonne of concrete or glass – and these sorts of figures are always very approximate. Also bear in mind that embodied energy is only one area of environmental impact – all other materials have significant impacts in a number of other areas.

Table 4.10 Embodied Energy for some materials

Material	Embodied Energy (GJ/Tonne)
Concrete	1.0
Brick	3.1
Glass	33.1
Steel	47.5
Aluminum	97.1
Plastics	162.0

(Source: GBD calculations from figures I Review of UK Statistical Sources – Sea Transport by Derrick Mort (Royal Statistical Society and SSRC, Pergamon Press) and in the Times Atlas. of the World.)

It has been estimated that the embodied energy in the production of building materials in the U.K. amounts to 430 PJ of primary energy per year, roughly 5% of the total U.K. primary energy use (CIRIA TR, 1994), a small but not insignificant percentage when compared with the total of 50% used in buildings. As energy performance of buildings improves, the energy embodied in the materials of construction will clearly become more important. The embodied energy associated with construction is typically understood as being a relatively small portion of that required to initially produce buildings, but they are also poorly discussed in the technical literature. European and U.S. figures estimate the construction portion to be about 7-10% of total embodied energy based on analyses undertaken 15-20 years ago

(Kohler, 1991).

Whilst the main energy input in tree production may be from sunlight via photosynthesis, transport energy, supplied by fuel oil, is the most important energy cost for timber in terms of environmental impact. Timber is very much a worldwide trade commodity, and some literally does come to the UK from the other side of the globe. The table shows an approximation of the energy used in fuel oil to transport timber to the UK from various parts of the world. Whilst container ships are a relatively energy efficient means of bulk transport, the vast distances involved mean that the 'embodied energy' of imported timber can add up to a significant amount (See table 4.11)

Table 4.11 Transport Energy from other countries to UK

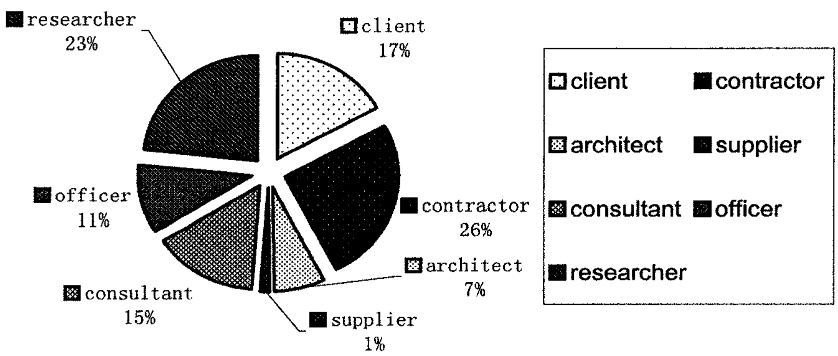
Country of Origin	Energy Cost of transport to UK via container ship (GJ/tonne)
Papau New Guinea	2.4
Indonesia	2.2
British Colombian	1.0
Brazil	0.7
Ghana	0.6
Siberia	0.5
Finland	0.3
Sweden	0.1

(Source: GBD calculations from figures I Review of UK Statistical Sources – Sea Transport by Derrick Mort (Royal Statistical Society and SSRC, Pergamon Press) and in the Times Atlas. of the World.)

4.5 Relative significance between environmental performance indicators

The discussions in previous sections establish the framework of the environmental performance indicators and analyzes the relevance between the environmental performance indicators and construction activities and materials. It is the major objective of this section to measure the relative significance of these indicator presented in table 4.1. The relative significance is measured by the significance score. The data used for this study are from a recent survey of the Mainland China and Hong Kong construction industry from December 2000 to June 2001, including clients, contractors, architects, suppliers, consultants, governmental officers and researchers in Universities and Institutes. The survey results are displayed in Figure 4.10. In the survey, more than 2000 copies of the questionnaire are faxed or mailed to the selected respondents, 511 effective replies had been received. The responded clients take 17% in total effective replies, contractors take 26% of total, and environment researchers take 23%, some others such as officers 11%, consultants 15%, architects 7%, and material suppliers 1%.

Figure 4.10 Distribtion of respondents involved in the survey for indicators



The survey was designed to collect the data for identifying the indicators, which can be used to assess the contractors' environmental performance and the relative significance between these indicators. A sample of the questionnaire is attached in appendix II in this dissertation. The correspondents are from the professionals who have good experience working on the construction activities, environment research and environmental quality management in various large construction companies and universities in China including Beijing, Shanghai, Guangzhou, Shenzhen, Chongqing and Chendu, and some are from the leading construction and real estate firms in Hong Kong including Henderson (China) Investment Co., Swire Properties, New World Development (China) Ltd., Hong Kong Land Ltd., China State Construction Engineering Co. (Hong Kong), Gammon Construction Ltd, etc. A summer investigation and in-depth interviews was conducted in August 2001 along Yangtze River from Chongqing to Shanghai that supported the survey analysis.

With considering the data collected from the survey and the review on the existing studies, all the environmental performance indicators assessing a contractor's environmental performance are classified in five categories:

- Ecology (I_1)
- Embodied energy (I_2)
- Sustainability (I_3)
- Public aspect (I_4)
- Human aspect (I_5)

For the easy of conducting the analysis on each group of indicators, each category of environmental performance indicators is subdivided into second level of environmental performance indicators. The results of the subdivisions are shown in Table 4.1.

Table 4.1 is the analytical framework presenting the indicators assessing a contractor's environmental performance. The major indicators will be identified through analyzing the data collected from the survey in this section, followed by establishing the relative significance between these major indicators. The establishment of the major environmental performance indicators and their relative significances or weightings will provide a basis for establishing a scoring model for calculating a contractor's environmental performance index (C-EPI).

In the survey, for each environmental performance indicator (as shown in Table 4.1), the respondents were requested to judge the significance level by selecting one of ten grades, namely, grade 1, 2, ... and 10, as shown in Table 4.12. Grade 1 indicates that the concerned indicator has no impact in assessing the contractor's environment performance, and grade 10 indicates the most essential. The middle grades indicate the difference from less important to more important. The survey results are summarized in Table 4.13.

The figures in the table represent the number of respondents who gave specific grade to each environmental performance indicator. For example, the figure 182 in the top-left corner indicates that 182 respondents considered that the indicator is most essential important in assessing the contractor's environment performance.

Table 4.12 Grades for judging the significance level of environmental performance indicator

Numerical grade	**Implication**	**Numerical grade**	**Implication**
10	Most Essential (ME)	5	Slightly Important (SlI)
9	Most Important (MtI)	4	Less Important (LeI)
8	Very Important (VI)	3	Some Impact (SoI)
7	More Important (MeI)	2	Little Impact (LiI)
6	Commonly Important (CI)	1	No Impact (NI)

Table 4.13 Summarized results of significance level for environment performance indictors

Indicator	ME	MtI	VI	MeI	CI	SlI	LeI	SoI	LiI	NI
1st level indicator										
Ecology	182	245	45	23	10	2	2	2		
Embodied energy	150	210	100	25	8	12	6			
Sustainability	113	105	117	87	65	12	8	4		
Public Aspect	10	11	42	68	89	143	102	32	14	
Human Aspect	5	29	76	103	131	104	41	14	8	
2nd level indicator										
Acid rain	15	117	119	96	78	56	18	9	2	1
Particulate	2	8	10	16	34	64	89	107	123	58
Global warming	13	42	92	113	118	75	42	14	2	
Ozone depletion	2	11	19	89	102	112	96	52	23	5
Toxics	102	116	101	88	51	30	15	7	1	
Waste	54	93	130	93	75	45	16	5		
Air pollution	119	152	102	72	32	20	10	3	1	
Land pollution	48	105	101	93	71	61	30	2		
Water pollution	115	138	118	64	34	30	5	4	2	1
Noise pollution	59	115	123	95	65	38	9	5	2	
Photochemical pollution	4	11	22	47	97	114	129	50	25	12
Extraction of materials	127	155	84	56	48	22	12	6	1	
Manufacture of components	28	67	86	111	106	71	27	9	5	1
Transportation to site	36	93	136	109	84	28	13	9	2	1
Construction practices	28	69	93	105	88	52	47	12	11	5
Usage of recycled materials	88	139	132	74	37	32	22	11	6	2
Reusing of the materials	63	135	122	97	46	18	14	11	5	
Maintenance	43	82	87	95	102	49	32	16	5	
Usage of renewable materials		1	5	16	22	34	63	110	126	134

Usage of renewable energy		1	13	20	38	66	87	95	102	89
Public health	2	5	12	25	21	55	92	99	115	85
Public safety	99	123	116	95	42	29	6	1		
Site polite construction			1	3	8	23	32	114	158	172
Community communication	70	103	98	96	79	28	16	12	7	1
Region development	22	59	85	91	92	59	52	31	19	1
Public relationship				1	7	10	15	45	193	240
Environment engineer	27	65	90	123	108	46	32	15	3	2
Working health	2	10	44	83	93	99	85	65	27	3
Working safety	15	16	68	112	103	75	64	31	19	8
Site environmental management		1	7	13	39	63	105	126	118	39

To examine the relative significance level among these indicators, an alternative approach is to calculate the average significance score (S_{xy}) between 511 responses to each indicator through the following model:

$$S_{xy} = \frac{1}{n}\sum_{i=1}^{n} R_i \qquad \text{------Eqn.(4.1)}$$

Where

x denotes for that the consideration is given at the first level in the analytical framework shown in Table 4.1;

y for that the consideration is given at the second level;

S_{xy} denotes for the average significance score to a particular indicator (if y=0, x $\neq$0, the significance value is for the indicator which is at first level, denoted as S_x; if z=0 if both y and x$\neq$0, the significance value is for the indicator at second level, namely, S_{xy});

R_i denotes for the specific score allocated by a specific respondent;

n for the total number of the questionnaire responses, namely, n=511.

By adopting these numerical values included in Table 4.13 to the equation (4.1), the average significance scores for the entire environmental performance indicator are calculated in Table 4.14.

Table 4.14 Average significance score for environmental performance indicators

Indicator	Important rate score (S)
Ecology	9.06
Acid rain	7.20
Particulate	3.50
Global warming	6.52
Ozone depletion	5.20
Toxics	7.88
Waste	7.48
Air pollution	8.26
Land pollution	7.32
Water pollution	8.17
Noise pollution	7.65
Photochemical pollution	4.94
Embodied energy	8.80
Extraction of materials	8.21
Manufacture of components	6.82
Transportation to site	7.39
Construction practices	6.69
Sustainability	**8.05**
Usage of recycled materials	8.03
Reusing of the materials	7.76

Maintenance	6.99
Usage of renewable materials	2.80
Usage of renewable energy	3.40
Public aspect	**5.28**
Public health	3.36
Public safety	8.05
Site polite construction	2.25
Community communication	7.46
Region development	6.37
Public relation	1.80
Human aspect	6.20
Environment engineer	6.84
Working health	5.26
Working safety	5.89
Site environmental management	3.48

If the average significance score for environmental performance indicator is lower than 4, the indicator must be deleted just for its unimportance. Those indicators deleted from the tentative C-EPAS indicator system are particulate, usage of renewable materials, usage of renewable energy, public health, site polite construction, public relation and working condition.

Then the revised environment performance indicators system and their symbolization can be shown in table 4.15.

Table 4.15 Revised environment performance indicators system for C-EPAS

Indicator	Symbolizing
Ecology	I_1
Acid rain	I_{1-1}
Global warming	I_{1-2}
Ozone depletion	I_{1-3}
Toxics	I_{1-4}
Waste	I_{1-5}
Air pollution	I_{1-6}
Land pollution	I_{1-7}
Water pollution	I_{1-8}
Noise pollution	I_{1-9}
Photochemical pollution	I_{1-10}
Embodied energy	I_2
Extraction of materials	I_{2-1}
Manufacture of components	I_{2-2}
Transportation to site	I_{2-3}
Construction practices	I_{2-4}
Sustainability	I_3
Recycling energy & resources	I_{3-1}
Reusing energy & resources	I_{3-2}
Maintenance	I_{3-3}
Public aspect	I_4
Public health & safety	I_{4-1}
Community communication	I_{4-2}
Region development	I_{4-3}

Human aspect	I_5
Environment engineer	$I_{5\text{-}1}$
Working health & safety	$I_{5\text{-}2}$
Site environmental management	$I_{5\text{-}3}$

4.6 Weightings between environmental performance indicators

This section is to establish weightings between environmental performance indicators. There are two types of weightings: (a) relative weightings among the indicators within the same groups, and (b) absolute weightings for individual indicators.

Relative weightings among the indicators within the same groups

The relative weightings can be calculated by adopting the following model:

(a) for the second level groups

$$RWI_{xy} = \frac{S_{xy}}{\sum_{y} S_{xy}} \qquad \text{-------Eqn.(4.2)}$$

$$\begin{cases} x=1,\ y=\{1,2\ \ldots,\ 10\} \\ x=2,\ y=\{1,2\ldots,\ 4\} \\ x=3,\ y=\{1,\ 2,3\} \\ x=4,\ y=\{1,\ 2,\ 3\} \\ x=5,\ y=\{1,\ 2,3\} \end{cases}$$

RWI_{xy} denotes for the relative weightings between the indicators, which are at the second level but within a same group; and S_{xy} denotes for the average significance score to a particular second level indicator.

(b) for the first level groups

The relative-weighting (RWI_x) (If y=0, but x≠0) for the first level specific indicator can be calculated with the Eqn.(4.3) as that:

$$RWI_x = \frac{S_x}{\sum_x S_x} \qquad \text{------Eqn.(4.3)}$$

x={1, 2, …,5}

RWI_x denotes for the relative weightings between the indicators, which are at the first level but within a same group; and S_x denotes for the average significance score to a particular first level indicator.

The calculation results by using the equations (4.2) and (4.3) are in Table 4.16

Table 4.16 Relative-weightings for environmental performance indicators

Indicator	**Relative weighting (RWI_{x-y})**
1st level indicator	
Ecology (I_1)	0.242
Embodied energy (I_2)	0.235
Sustainability (I_3)	0.215
Public Aspect (I_4)	0.141
Human Aspect (I_5)	0.166
2nd level indicator	
Acid rain (I_{1-1})	0.102
Global warming (I_{1-2})	0.092
Ozone depletion (I_{1-3})	0.074
Waste (I_{1-4})	0.112

Toxics (I_{1-5})	0.106
Air pollution (I_{1-6})	0.117
Land pollution (I_{1-7})	0.104
Water pollution (I_{1-8})	0.116
Noise pollution (I_{1-9})	0.108
Photochemical pollution (I_{1-10})	0.070
Extraction of materials (I_{2-1})	0.282
Manufacture of components (I_{2-2})	0.234
Transportation to site (I_{2-3})	0.254
Construction practices (I_{2-4})	0.230
Recycling energy & resources (I_{3-1})	0.353
Reusing energy & resources (I_{3-2})	0.341
Maintenance (I_{3-3})	0.307
Public health & safety (I_{4-1})	0.368
Community communication (I_{4-2})	0.341
Region development (I_{4-3})	0.291
Environment engineer (I_{5-1})	0.380
Working health & safety (I_{5-2})	0.292
Site environment management (I_{5-3})	0.327

Absolute weightings for individual indicators

The absolute-weighting for first level indicator (AWI_x) (when y=0 but x≠0) can be obtained from the formula:

$$AWI_x = \frac{S_x}{\sum_x S_x} \qquad \text{------Eqn.(4.4)}$$

For the second level indicator, the absolute-weighting, denoted as AWI_{xy} (when both y and x≠0), can be obtained from the formula:

$$AWI_{xy} = RWI_x \times RWI_{xy} = \frac{S_x}{\sum_x S_x} \times \frac{S_{xy}}{\sum_y S_{xy}}$$ ------Eqn. (4.5)

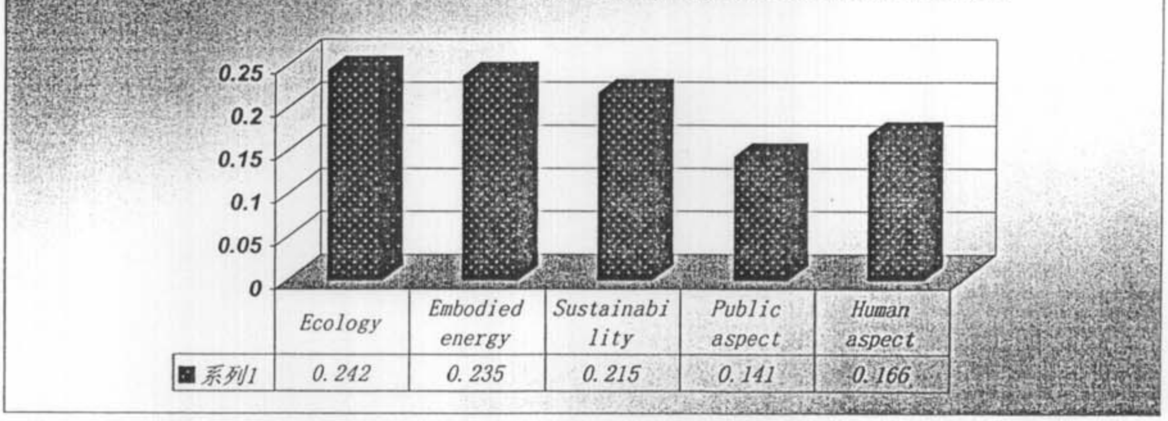
The calculation results by using the equations (4.4) and (4.5) are in Table 4.17. In fact, the absolute-weightings for the first level indicators are the same as their relative weightings, namely, $AWI_x = RWI_x$. It can be seen in the table that the relative weightings between the first level indicators, namely, ecology, embodied energy, sustainability, public aspect and human aspect are 0.242, 0.235, 0.215, 0.141 and 0.166 respectively. This distribution is also illustrated in Figure4.11. The indicator "ecology" assumes 0.242 and is the most important indicator among these five first level indicators.

Table 4.17 Absolute-weightings for environmental performance indicators

Indicator	**Absolute weighting (AWI_{x-y})**
1st level indicator	
Ecology (I_1)	0.242
Embodied energy (I_2)	0.235
Sustainability (I_3)	0.215
Public Aspect (I_4)	0.141
Human Aspect (I_5)	0.166
2nd level indicator	
Acid rain (I_{1-1})	0.025
Global warming (I_{1-2})	0.022
Ozone depletion (I_{1-3})	0.018
Waste (I_{1-4})	0.027

Toxics (I_{1-5})	0.026
Air pollution (I_{1-6})	0.028
Land pollution (I_{1-7})	0.025
Water pollution (I_{1-8})	0.028
Noise pollution (I_{1-9})	0.026
Photochemical pollution (I_{1-10})	0.017
Extraction of materials (I_{2-1})	0.066
Manufacture of components (I_{2-2})	0.055
Transportation to site (I_{2-3})	0.060
Construction practices (I_{2-4})	0.054
Recycling energy & resources (I_{3-1})	0.076
Reusing energy & resources (I_{3-2})	0.073
Maintenance (I_{3-3})	0.066
Public health & safety (I_{4-1})	0.052
Community communication (I_{4-2})	0.048
Region development (I_{4-3})	0.041
Environment engineer (I_{5-1})	0.063
Working health & safety (I_{5-2})	0.049
Site environment management (I_{5-3})	0.054

Figure 4.11 Survey results on distribution of weightings between first level indictors



4.7 Application of AHP for the adjustments of the weightings between the environmental performance indicators

The establishment of weightings between those environmental performance indicators will provide an important basis for further establishing the contractor's environmental performance scoring system in later chapters. Therefore, the adequacy of the weighting establishment is important. The weightings obtained in the previous section are according to the data collected from the practical survey. Nevertheless, the responses from survey do not directly provide the data about the relative importance between indicators. Therefore, the quality of the weighting establishment may be affected.

In order to improve the quality of weighting establishment, the analytic hierarchy process (AHP) method is employed in this section to help adjusting these weightings between factors. AHP introduced by Saaty (1979) is a decision-aiding method. It aims at quantifying relative priorities for a given set of alternatives on a ratio scale, based on the judgment of the decision-maker, and stresses the importance of the intuitive judgments of a decision-maker as well as the consistency of the comparison of alternatives in the decision-making process. AHP method is considered as an effective method for establishing weightings between indicators, which are levelled in hierarchy. By using this approach, the first step is to establish the relative weightings between the first level indicators through pair-wise comparison. And then the relative weightings between those indicators at lower levels will be calculated by using certain equations.

In applying AHP in establishing the weightings between the five first-level indicators discussed in previous section, the results of pair-wise comparison among the indicators is obtained through 6 professional interviews and presented in a pair-wise comparison matrix, as shown in Table 4.18. Usually, it is recommended to use a nominal-ratio scale from 1 to 9 in conducting the pair-wise comparison between the first level factors (Saaty, 1979).

For ensuring the consistence of the values in the pair-wise comparison matrix given by the surveyed professionals, necessary judgment measure is needed. In applying AHP method, an eigenvector λ_{max} is used. The calculation of the value of the eigenvector, named as eigenvalue, is illustrated in Table 4.19. b_{ij} in the table stands for the value of the matrix elements in Table4.18.

Table 4.18 Pair-wise comparison matrix for experience

Exp	Ecology	Embodied energy	Sustainability	Social	Human
Ecology	1	3	4	6	7
Embodied energy	1/3	1	2	5	6
Sustainability	1/4	1/2	1	4	5
Public aspect	1/6	1/5	1/4	1	2
Human aspect	1/7	1/6	1/5	1/2	1

Table 4.19 Weighting and the Maximum eigenvalue

$M_i = \prod_{j=1}^{5} b_{ij}$	$\overline{W_i} = \sqrt[5]{M_i}$	$w_i = \frac{\overline{W_i}}{\sum_{i=1}^{5}\overline{W_i}}$	$\lambda_{\max} = \sum_{i=1}^{5}\frac{(BW)_i}{nw_i}$
504	3.471	0.481	
20	1.821	0.252	
2.5	1.201	0.166	5.215
0.017	0.443	0.061	
0.002	0.289	0.040	

In order to check whether the values in the pair-wise comparison matrix were consistent or not, consistency ratio (C.R.) is used. When C.R <0.1, it is suggested that the consistency of the pair-wise comparison matrix from survey can be accepted (Saaty, 1979).

The calculation of CR is through the following formula:

$$C.R. = \frac{C.I.}{R.I.} \qquad \text{------Eqn. (4.6)}$$

Where C.I is a consistency index, which needs to be established by using the equation:

$$C.I. = \frac{\lambda_{\max} - n}{n-1} \qquad \text{------Eqn. (4.7)}$$

And R.I is a random index (R.I.) recommended in Table 4.20 (Saaty, 1979). In our application, there are only five factors at the first level, thus RI =1.12, according to Table 4.20

Table 4.20 Average random index (R.I.)

No. of dimension for matrix	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54	1.56	1.58	1.59

In Table 4.19, the eigenvalue λ_{max} has been calculated as 5.215. Also it is know that n=5.

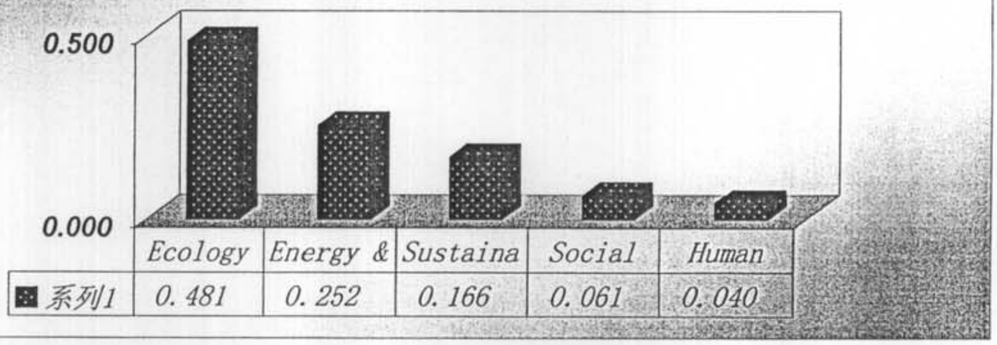
By applying the above values to equations (4.6) and (4.7), the following values can be gained:

C.I.=0.054

C.R.=0.048

According the criteria mentioned before that when C.R <0.1, the consistency of the pair-wise comparison matrix from survey can be accepted, consistency of the pair-wise comparison matrix in Table 4.18 is accepted as C.R.=0.048<0.1. It also suggests that the weightings in Table 4.19 are acceptable. It can be seen in this table that the relative weightings between the five first level indicators (ecology, embodied energy, sustainability, public aspect and human aspect) are 0.481, 0.252, 0.166, 0.061 and 0.040 respectively. The distribution of these weightings is also illustrated in Figure 4.12. This result is obtained through AHP approach and is considered a more proper distribution of weighting distribution between the indicators. According to the new weighting distribution, the indicator "ecology" assumes 0.481 and is still the most important indicator among these five first level indicators.

Figure 4.12 The adjusted weighting distribution of the first level environmental performance indicators



In order to modify the weightings between the indicators at second level, the weighting distribution between the five indicators in Table 4.19 will be used to replace the weighting values obtained in previous section (namely ecology 0.242, embodied energy 0.235, sustainability 0.215, public aspect 0.141, and human aspect 0.166). When such replacement is incorporated into the equations (4.2)~(4.5), the modified weightings between indicators at second level can be calculated, and the results are shown in Table 4.21.

Table 4.21 Modified weightings between the environmental performance indicators

Indicator	Relative weighting (RWI_{x-y})	Absolute weighting (AWI_{x-y})

1st level indicator		
Ecology (I_1)	0.481	0.481
Embodied energy (I_2)	0.252	0.252
Sustainability (I_3)	0.166	0.166
Public Aspect (I_4)	0.061	0.061
Human Aspect (I_5)	0.040	0.040
2nd level indicator		
Acid rain (I_{1-1})	0.149	0.072
Global warming (I_{1-2})	0.190	0.091
Ozone depletion (I_{1-3})	0.084	0.040
Waste (I_{1-4})	0.330	0.159
Toxics (I_{1-5})	0.082	0.039
Air pollution (I_{1-6})	0.019	0.009
Land pollution (I_{1-7})	0.027	0.013
Water pollution (I_{1-8})	0.038	0.018
Noise pollution (I_{1-9})	0.013	0.006
Photochemical pollution (I_{1-10})	0.068	0.033
Extraction of materials (I_{2-1})	0.245	0.062
Manufacture of components (I_{2-2})	0.607	0.153
Transportation to site (I_{2-3})	0.048	0.012
Construction practices (I_{2-4})	0.101	0.025
Recycling energy & resources (I_{3-1})	0.324	0.054
Reusing energy & resources (I_{3-2})	0.602	0.100
Maintenance (I_{3-3})	0.075	0.012
Public health & safety (I_{4-1})	0.258	0.016
Community communication (I_{4-2})	0.105	0.006
Region development (I_{4-3})	0.637	0.039
Environment engineer (I_{5-1})	0.731	0.029
Working health & safety (I_{5-2})	0.188	0.008
Site environment management (I_{5-3})	0.081	0.003

Chapter 5:

Proposed Benchmarks of Environmental Performance Indicators

CHAPTER 5: PROPOSED BENCHMARKS OF ENVIRONMENTAL PERFORMANCE INDICATORS

5.1 Introduction

As previously discussed, the main objective of this study is to develop a contractor's environmental performance assessment system (C-EPAS), the core of the system is to establish a model for calculating contractor's environmental performance index (C-EPI). In the real application of C-EPAS, the calculation of C-EPI will request for the input of the values of environmental performance indicators, assessed by the analysts in specific applications. Put simply, indicators' values are different in different contractors' applications.

However, there is a need for a mechanism that can provide guidelines or benchmarks for allocating indicators' values. This chapter proposes a set of guidelines or benchmarks for this purpose. Whilst the adequacy of the benchmarks is subject to further discussions, the intention of this study is to investigate an alternative methodology for solving the problem of such. It is a pioneering work in this area and weakness and shortcomings are expected for further improvements. In fact, three group interviews were conducted between the author and relevant professionals, two in Shenzhen and one in Beijing, for obtaining the comments about the benchmarks.

A major consideration in developing the benchmarks for indicators is that the achievement of each benchmark requests for the contributions from various environmental performance factors that have been identified in Chapter 4. These performance factors are grouped into five categories including site management, specialist works, project management, technology and environmental management policy listed. For example, good performance in specific works such steel works, ornament and painting, concreting, component installment and earthworks can contribute to the good performance of the indicator 'acid rain'. Otherwise, the contractor's performance will contribute to the problem of 'acid rain'. Therefore, there are two major tasks for establishing the indicator benchmarks: (a) to build up a list of benchmarks for each environmental performance indicator; (b) to identify what are the factors contributing to each item of benchmark.

5.2 Existing Methods

There are existing methods for assessing environmental performance of a building. Typical methods include, as discussed before, LEED (Leadership in Energy & Environmental Design), Green Building Rating System, BREEAM (Building Research Establishment Environmental Assessment Method), HPBG (High Performance Building Guidelines), HK-BEAM (Hong Kong Building Environmental Assessment Method) and GGCP (A Guide to Green Construction Practice).

LEED is a design supporting tool and product marketing tool launched by the US

Green Building Council (USGBC) to rate commercial office buildings. It aims at stimulating green competition and transforming the marketplace. LEED is mainly used for the assessment of commercial and high-rise residential new constructions and major renovation. This assessment method allows for a comprehensive assessment of building environmental performance and uses a life-cycle approach. LEED comprises a checklist of credits that are linked to design strategies (Todd, 2000). Thus, it promotes integrated design and construction process.

BREEAM, designed as an eco-labelling system, was developed by the British Research Establishment (BRE) and private sector researchers (Larsson, 2001). This tool provides a relatively comprehensive assessment of building performance. BREEAM may be used to assess new and existing office buildings, residential and industrial units as well as retail superstores and supermarkets (Baldwin, 1998).

HPBG, designed as a guideline for public sector capital designer and planners to increase their knowledge on energy and environmentally efficient construction technologies and practices, was developed by the Department of Design and Construction (DDC) of New York (DDC, 1999).

HK-BEAM scheme is a significant private sector initiative in Hong Kong to promote environmentally friendly design, construction and management practices for existing office buildings, new residential buildings and new office buildings. It is not at present practical to assess all the issues covered in HK-BEAM on a common scale (HK-BEAM, 1999).

The Hong Kong Productivity Council prepares GGCP. This guidebook presents practicable measures on how to develop a green culture in the management and operation of construction sites. Its preparation involved an examination of existing practices within Hong Kong and around the world to ensure its comprehensiveness (GGCP, 2001).

The above methods have established various benchmarks for conducting the assessment, but these establishments are designed for assessing a building rather than a contractor. Nevertheless, they provide valuable references to this study, and many benchmarks in these existing methods are incorporated in developing the benchmarks for assessing contractor's environmental performance, which will be presented in next section.

5.3 Establishing Benchmarks of Environmental Performance Indicators

Contractors' environmental performance indicators are structured in a two-level system, as shown in Table 4.15. It is considered that benchmarks should be provided to all the second-level indicators.

The procedures of developing the benchmarks for each second-level indicator include: (a) to build up a list of specific benchmarks; (b) to identify the contribution factors for each item of benchmark. The results of implementing these procedures are a full list of specific benchmarks for all the indicators, as shown in the following tables 5.1~5.23.

In applying these benchmarks in a particular application, the assessor will consider whether the concerned contractor has met the requirements defined in a specific benchmark, and a credit is given if this is met (for example, by ticking the corresponding box). After the examination to all benchmarks under all indicators is completed, the assessment results can be inputted to the C-EPI calculation model, which will be presented in the next Chapter.

Table 5.1 Benchmarks for assessment indicator 'acid rain'

Eco	EE	Sus	PA	HA
8 optional credits				

Acid Rain

	INTENT	**Credit**
	To reduce the release of oxides of nitrogen (NO_x) and sulphur dioxide (SO_2) into the atmosphere on the site and reduce the use of materials that have high emission during the extraction and production.	
Contribution Factor	**BENCHMARKS**	
Project management (F_3) Environment policy (F_5)	The content of sulphur in fuels of machines doesn't surpass 0.5% (CNEPB).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3)	Don't burn the waste of plastic foams, PVC, uPVC, plywood, resin and polymer bonded slates, organic coating, synthetic fibres, carpet fibres, rubbers, etc on the site (Woolley, 1997).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Advocate using the cements produced from New-Style-Dry-Method-Kiln (CNEPB).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4) Environment policy (F_5)	Don't use ordinary solid clay brick (CNEPB).	☐

Specialist works (F_1) Project management (F_3) Technology (F_4)	Advocate using the glass produced in 'Luoyang-Fufa' Method (CNEPB).	☐
Site management (F_2) Project management (F_3)	Don't burn the coals on the site directly (HMSO, 1992).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	The boilers supplying the main heating load are of the low NO_x emitting type with burner emissions of less than 200 mg/kWh of fuel consumed, when running at full-load output (BREEAM).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Advocate using flue-gas desulphurization (FGD) gypsum (HPBD).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	

Table 5.2 Benchmarks for assessment indicator 'global warming'

Eco	EE	Sus	PA	HA
6 optional credits				

Global Warming

Contribution Factor	INTENT / BENCHMARKS	Credit
	INTENT	**Credit**
	To reduce the release of carbon dioxide (CO_2) into the atmosphere as a result of energy use in on site and reduce using the materials that has high CO_2 emissions during the extraction and production.	
Contribution Factor	**BENCHMARKS**	
Specialist works (F_1) Project management (F_3) Technology (F_4)	Reduce to use the timbers and replace the timbers with the bamboo and other materials (Leggett, 1990).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Avoid using the insulation materials made with polystyrene production on the sites (Doran, 1992).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Advocate using the cements produced from New-Style-Dry-Method-Kiln (CNEPB).	☐
Specialist works (F_1) Project management (F_3)	Reduce or avoid using the materials made of synthetic polymer such as fibre reinforced cement roofing and advocate using the alternative roofing materials such as: wooden	☐

Technology (F_4)	shakes & shingles, used tyres, recycled PVC & wood shingles, thatching, bamboo, plastic panels, planted roofs, hotovoltaic roofing panels, etc (Tolba, 1992).	
Specialist works (F_1) Project management (F_3) Technology (F_4)	Avoid to use nylon carpet and advocate using the wool carpet; avoid to use synthetic foams underlay and advocate using Hessian/felt under materials; avoid to use vinyl/PVC smooth coverings and advocate using linoleum, cork, timber and stone materials; avoid to use solvent-based blues for fixings and advocate using grippers/tacks (Woolley, 1997).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Advocate using the roofing made of reclaimed tiles/slates certified wooden shingles and reduce to use the metal sheets (Woolley, 1997).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	

Table 5.3 Benchmarks for assessment indicator 'ozone depletion'

Eco	EE	Sus	PA	HA
7 optional credits				

Ozone Depletion

		Credit
	INTENT	**Credit**
	To reduce the release of CFCs (Chlorofluorocarbons), HCFCs (Hydro chlorofluorocarbons) and halons into the atmosphere and thus reduce damage to the earth's stratospheric ozone layer.	
Contribution Factor	**BENCHMARKS**	
Site management (F_2) Project management (F_3) Technology (F_4)	Either no air conditioning is installed or the refrigerants employed in the air conditioning have an ozone depletion potential of less than 0.06 (HREEAM).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	A comprehensive automatic refrigerant detection system has been installed to detect leaks from refrigeration plant (HREEAM).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	A fixed or portable refrigerant recovery unit is provided permanently on site for systems with a refrigerant charge of greater than 15 kg in weight (HREEAM).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	There are no halon-based fixed or portable fire protection systems on the sites (HREEAM).	☐

Environment policy (F_5)		
Project management (F_3) Technology (F_4) Environment policy (F_5)	A schedule of maintenance and testing of fixed halon fire protection systems has been drawn up with the specific aim of minimizing unnecessary emissions of halon (HREEAM).	☐
Project management (F_3) Technology (F_4)	A maintenance agreement which has been established to ensure regular inspection for refrigerant leaks and, if instead, a management system is in place to deal promptly with any alarms raised by an automatic refrigerant detection system (HREEAM).	☐
Specialist works (F_1) Project management (F3) Technology (F_4)	The thermal insulation on sites fabric and services are made only from materials with zero ozone depletion potential (HK-BEAM).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the HVAC&R systems do not use CFC-based refrigerants and specific fire suppression systems use no HCFCs or Halons.	

Table 5.4 Benchmarks for assessment indicator 'toxics'

Eco	EE	Sus	PA	HA
10 optional credits				

Toxics

Contribution Factor		Credit
	INTENT	**Credit**
	Reduce the quantity of indoor air contaminants that are odorous, potentially irritating and/or harmful to the comfort and well-being of installers and occupants.	
Contribution Factor	**BENCHMARKS**	
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Specifying particleboard, fibreboard, and similar composite boards conforming to European Standard EN 321-1, or alternative equivalent standards (HK-BEAM).	☐
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Excluding use of treated timber where it is not recommended in any relevant codes and stands (HK-BEAM).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Specifying all preserved timber shall be industrially pre-treated ready for finishing on site (HK-BEAM).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4) Environment policy (F_5)	The paints contain no lead (HK-BEAM).	☐
Specialist works (F_1)		

Project management (F_3) Environment policy (F_5)	Paint containing volatile organic compounds (VOC) conforms to British Standards BS 245:5358:1993 relating to solvent (HK-BEAM).	
Site management (F_2) Project management (F_3) Technology (F_4)	Don't burn the waste of plastic foams, PVC, uPVC, plywood, resin and polymer bonded slates, organic coating, synthetic fibers, carpet fibres, rubbers, etc on the site (Wooley, 1997).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3) Technology (F_4)	Reduce the workers absorbing the vapours of components chemicals during in-situ foaming (Curwell, 1990).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3) Technology (F_4)	Reduce the workers the risks associated with insulation fibres such as glass fibre, which come in much smaller sizes than structural glass fibres (Curwell, 1990).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3) Technology (F_4)	Avoid the workers to breath the particulates of cement, which contains heavy metals and some suspected carcinogen (Hall, 1992).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3) Technology (F_4) Environment policy (F_5)	Don't use any asbestos productions on sites (Arup, 1993).	☐
	Submittals	Total

Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the noted requirements.	

Table 5.5 Benchmarks for assessment indicator 'waste'

Eco	EE	Sus	PA	HA
27 optional credits				

Waste

	INTENT	Credit
	Divert construction, demolition and land clearing debris from landfill disposal. Redirect recyclable recovered resources back to the manufacturing process. Redirect reusable materials to appropriate sites.	
Contribution Factor	**BENCHMARKS**	
Specialist works (F_1) Project management (F_3) Technology (F_4) Environment policy (F_5)	Develop and implement a waste management plan, quantifying material diversion goals (LEED).	☐
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Recycle and/or salvage at least 50% of construction, demolition and land clearing waste. Calculations can be done by weight or volume, but must be consistent throughout (LEED).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3) Technology (F_4)	Eliminate unnecessary finishes and other products on sites where they are not required (HPBG).	☐
Specialist works (F_1) Project management (F_3)	Use modular materials on sites (HPBG).	☐

Technology (F_4) Environment policy (F_5)		
Specialist works (F_1) Project management (F_3) Technology (F_4)	Advocate using the products for durability (HPBG).	☐
Project management (F_3) Environment policy (F_5)	List materials to be salvaged for reuse in the project in the contract documents (HPBG).	☐
Project management (F_3) Technology (F_4) Environment policy (F_5)	Identify local haulers for salvaged materials and products that will not be reused in the project. List additional materials that are economically feasible for salvaging in the project (HPBG).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3) Technology (F_4)	Educate workers on waste prevention goals and the proper handling and storage of materials (HPBG).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Where applicable, reuse salvaged material at the site (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Coordinate ordering and delivery of materials among all contractors and suppliers to ensure that the correct amount of each material is delivered and stored at the optimum time and place (HPBG).	☐

Specialist works (F_1) Site management (F_2) Project management (F_3)	Providing access for delivery vehicles to the service area of the building which lies within the site boundary and which are enclosed and/or segregated from pedestrian access routs (HK-BEAM).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3)	Providing access for waste collection vehicles which lies within the site boundary and which are enclosed and/or segregated from pedestrian routes (HK-BEAM).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3) Technology (F_4)	Providing facilities for the sorting of waste and recovery of recyclable materials (HK-BEAM).	☐
Site management (F_2) Project management (F_3)	Purchase materials in a manner that minimizes waste and unnecessary costs (GGCP).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Implement measures to minimize over-ordering and then wastage of materials such as concrete, mortars and cement grouts (GGCP).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Check consistency of drawings and specifications to avoid unnecessary hacking-off of concrete or unwanted work (GGCP).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Use durable, reusable hoarding to replace timber hoarding (GGCP).	☐

Specialist works (F_1) Project management (F_3) Technology (F_4)	Use precast concrete units produced at a casting yard with high degree of quality control (GGCP).	☐
Specialist works (F_1) Project management (F_3)	Use steel formworks as far as possible (GGCP).	☐
Specialist works (F_1) Project management (F_3)	Use standard wooden panels for high reuse level if timber formworks are unavoidable (GGCP).	☐
Specialist works (F_1) Project management (F_3)	Use interior drywall partition that requires low level of skill and is easy to install (GGCP).	☐
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Deliver by licensed waste contractors inert materials to approved public filling areas (GGCP).	☐
Specialist works (F_1) Project management (F_3)	Ensure that excavation works are carried out in a controlled manner to avoid excessive excavated materials (GGCP).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Research alternative products and practices, which generate reduced quantities or less dangerous types of chemical waste (GGCP).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Use products and materials with reduced packaging and/or encourage manufactures to reuse or recycle their original packaging materials (GGCP).	☐

Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Implement clean-up work of contaminated land in accordance with the appropriate procedures as laid down in any remediation action plan endorsed by the Environmental Protection Department (GGCP).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3) Environment policy (F_5)	If asbestos waste is identified during construction works, it should be handled and disposed of in accordance with the Environmental Protection Department's Code of Practice on the Handling, Transportation and Disposal of Asbestos Waste (GGCP).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the requirements have been met.	

Table 5.6 Benchmarks for assessment indicator 'air pollution'

Eco	EE	Sus	PA	HA
31 optional credits				

Air Pollution

	INTENT	Credit
	To minimize air pollution during the construction of buildings and the infrastructure serving buildings.	
Contribution Factor	**BENCHMARKS**	
Specialist works (F_1) Project management (F_3) Technology (F_4) Environment policy (F_5)	Apply adequate mitigation measures for dust and air emissions during the construction as the recommended by CIRIA and Air Pollution (Construction Dust) Regulation (HK-BEAM).	☐
Project management (F_3) Technology (F_4) Environment policy (F_5)	Demonstrate compliance with the air quality management guidelines as detailed in the Environmental Monitoring and Audit Manual (HK-BEAM).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Install mains-operated smoke alarms with battery back-up at appropriate locations (BREEAM).	☐
Specialist works (F_1) Project management (F_3)	There is no visible freestanding water in the duct work (BREEAM).	☐
Specialist works (F_1) Project management (F_3)	There has no visible gaps allowing air to bypass the filter (BREEAM).	☐

Specialist works (F_1) Site management (F_2) Project management (F_3)	Prevent loss of soil during construction by storm water and /or wind erosion (LEED).	☐
Site management (F_2) Project management (F_3) Technology (F_4) Environment policy (F_5)	Install a permanent carbon dioxide (CO_2) monitoring system that provides feedback on space ventilation performance in a form that affords operational adjustments. (LEED).	☐
Site management (F_2) Project management (F_3) Technology (F_4) Environment policy (F_5)	During construction meet or exceed the recommended Design Approaches of the Sheet Metal and Air Conditioning National Contractors Association (SMACNA) IAQ Guideline for Occupied Buildings under Construction, 1995, Chapter 3 (LEED).	☐
Site management (F_2) Project management (F_3)	Protect stored on-site or installed absorptive materials from moisture damage (LEED).	☐
Site management (F_2) Project management (F_3)	The site should offer support facilities for bicycling, mass transit, electric vehicles, carpooling, and other less polluting means of transportation (LEED).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	If air handlers must be used during construction, filtration media with a Minimum efficiency Reporting Value (MERV) of 8 must be used at each return air grill, as determined by ASHRAE	☐

Environment policy (F_5)	52.2-1999 (LEED).	
Site management (F_2) Project management (F_3) Technology (F_4) Environment policy (F_5)	Replace all filtration media immediately prior to occupancy. Filtration media shall have a Minimum Efficiency Reporting Value (MERV) of 13, as determined by ASHRAE 52.2-1999 for media installed at the end of construction (LEED).	☐
Site management (F_2) Project management (F_3) Technology (F_4) Environment policy (F_5)	After construction ends and prior to occupancy conduct a minimum two-week building flush-out with new Minimum Efficiency Reporting Value (MERV) 13 filtration media at 100% outside air. After the flush out, replace the filtration media with new MERV 13 filtration media, except the filters solely processing outside air (LEED).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3) Technology (F_4)	Evaluate sources of contamination from neighbouring buildings and soil contamination, such as radon, methane, and excessive dampness. Incorporate measures to prevent soil gas from being drawn into the building. Waterproof the slab-on-grade to limit moisture transport (HPBG).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Reduce potential pollution sources through effective moisture control (HPBG).	☐

Specialist works (F_1) Project management (F_3) Technology (F_4)	Specify materials with low volatile organic compounds (VOCs) and low odour emissions (HPBG).	☐
Site management (F_2) Project management (F_3)	Avoid occupant exposure to airborne pollutants; perform cleaning and pest control activities when the building is largely unoccupied (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Prevent storage of soft products on site during wet processes, unless separated and sealed; e.g., 'shrink-wrapped.' (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Schedule installation of wet materials (sealants, caulking, adhesives) and allow them to dry or cure before installing dry materials that could serve as 'sink,' and absorbents of VOCs (HPBG).	☐
Site management (F_2) Project management (F_3)	Ensure that construction materials such as concrete are dry before they are covered (e.g., with floor tile or carpeting) or enclosed in wall cavities (HPBG).	☐
Specialist works (F_1) Project management (F_3)	Ensure that the contractor uses metal ductwork instead of substituting fiberglass (HPBG).	☐
Site management (F_2)	Control fibre or particle release during	

Project management (F_3)	installation of insulation and require general area cleanup prior to building occupancy (HPBG).	
Site management (F_2) Project management (F_3) Environment policy (F_5)	Flush the building with 100% outside air for a period of mot less than 30 days beginning as soon as systems are operable and continuing throughout installation of furniture, fitting, and equipment. A delay in building occupancy can significantly reduce odour and irritancy complaints (HPBG).	☐
Site management (F_2) Project management (F_3) Environment policy (F_5)	Where a site boundary adjoins a road, service lane or other area accessible to the public, provide hoarding of not less than 2.4m on height along the entire length of that portion of the site boundary (GGCP).	☐
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Provide effective dust screen, sheeting or netting to enclose any scaffolding built around the perimeter of a building (GGCP).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Use fixed or mobile water sprays of watering of unpaved areas, access roads, construction areas and dusty stockpiles regularly to keep dusty surfaces wet. If necessary, use suitable wetting agents such as dust suppression chemicals during dry seasons (GGCP).	☐
Site management (F_2)		

Project management (F_3) Environment policy (F_5)	Inspect vehicles regularly to ensure that exhaust emissions are not causing nuisance, such as dark smoke emission (GGCP).	
Specialist works (F_1) Project management (F_3) Technology (F_4)	Ensure that wire meshes, gunny sacks, sandbags, blast nets and other appropriate covers are used on top of the blast area on each shot to prevent the flying off of rocks and to suppress dust generation (GGCP).	☐
Site management (F_2) Project management (F_3) Environment policy (F_5)	Do not carry out open burning for the purpose of clearance of a site in preparation for construction work or for the disposal of construction waste (GGCP).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Consider the use of low emission products and materials (GGCP).	☐
Site management (F_2) Project management (F_3) Environment policy (F_5)	If a power generation is used on-site, maintain it regularly and properly to avoid dark smoke emission (GGCP).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	

Table 5.7 Benchmarks for assessment indicator 'land pollution'

Eco	EE	Sus	PA	HA
7 optional credits				

Land Pollution

Contribution Factor	INTENT / BENCHMARKS	Credit
	INTENT	**Credit**
	Rehabilitate damaged sites where development is complicated by real or perceived environmental contamination, reducing pressure on undeveloped land.	
Contribution Factor	**BENCHMARKS**	
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Develop on a site documented as contaminated OR on a site classified as a brownfield by a local, state or federal government agency. Effectively remediate site contamination (LEED).	☐
Project management (F_3) Technology (F_4)	Locate project within 1/2 mile of a commuter rail, light rail or subway station or 1/4 mile of two or more public or campus bus lines usable by building occupants (LEED).	☐
Specialist works (F_1) Site management (F_2)	On greenfield sites, limit site disturbance including earthwork and clearing of vegetation to 40 feet beyond the building perimeter, 5 feet beyond primary roadway curbs, walkways and main utility branch trenches, and 25 feet beyond constructed areas with permeable surfaces (such as pervious paving areas, storm water detention	☐

Project management (F_3) Technology (F_4)	facilities and playing fields) that require additional staging areas in order to limit compaction in the constructed area; OR, on previously developed sites, restore a minimum of 50% of the site area (excluding the building footprint) by replacing impervious surfaces with native or adaptive vegetation (LEED).	
Site management (F_2) Project management (F_3) Technology (F_4)	Analyze planting soil and implement on-site soil remediation measures such as introducing earthworms if they are sparse, adding organic matter and micro organisms to break down pollutants, and removing toxic materials (HPBG).	☐
Site management (F_2) Project management (F_3)	Provide space and bins for composting of landscape materials (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Select textured paving (rather than smooth surfaces) for outside approaches, so that soils are scraped off shoes prior to building entry. Plantings bordering walkways should not be of the type that drops flowers or berries that can be tracked into the buildings (HPBG).	☐
Site management (F_2) Project management (F_3)	Minimize introduction of diet with appropriately sized, recessed metal grating within vestibules. Consider installing additional 'walk-off' mats in	☐

Technology (F_4)	entryways to further prevent dirt from entering the building (HPBG).	
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	

Table 5.8 Benchmarks for assessment indicator 'water pollution'

Eco	EE	Sus	PA	HA
16 optional credits				

Water Pollution

Contribution Factor	INTENT / BENCHMARKS	Credit
	INTENT	**Credit**
	To reduce wastage of water, which is a valuable resource.	
Contribution Factor	**BENCHMARKS**	
Site management (F_2) Project management (F_3)	Prevent loss of soil construction by storm water runoff and prevent sedimentation of storm sever or receiving streams (LEED).	☐
Site management (F_2) Project management (F_3) Environment policy (F_5)	If existing imperviousness is less than or equal to 50%, implement a storm water management plan that prevents the post-development 1.5 year, 24 hour peak discharge rate from exceeding the pre-development 1.5 year, 24 hour peak discharge rate. OR, if existing imperviousness is greater than 50%, implement a storm water management plan that results in a 25% decrease in the rate and quantity of storm water runoff (LEED).	☐
Site management (F_2) Project management (F_3)	Construct site storm water treatment systems designed to remove 80% of the average annual post-development total suspended solids (TSS) and 40% of the average annual post-development total phosphorous (TP) based on the average	☐

Environment policy (F_5)	annual loadings from all storms less than or equal to the 2-year/24 hour storm (LEED).	
Site management (F_2) Project management (F_3) Technology (F_4)	Use only captured rain or recycled site water to eliminate all potable water use for site irrigation, OR do not install permanent site irrigation systems (LEED).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3) Technology (F_4)	Undertake measures to reduce water pollution during construction, through adequately designed sediment retention and removal facilities, treatment of wastewater from concrete construction activities such as concreting, batching, etc., as outline in ProPECC PN 1/94 (HK-BEAM).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Provide an arrangement of water meters, which permits the monitoring of fresh water consumption by the Owner/Operator for each of the major engineering services (HK-BEAM).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Install an on-site grey water treatment system, to treat grey water for reuse in toilet flushing where seawater is not available (HK-BEAM).	☐
Site management (F_2) Project management (F_3) Environment policy (F_5)	Specify and install any two of the prescribed, or equivalent low flow devices (HK-BEAM).	☐

Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Undertake audits of water use during construction, implementing water conservation measures through reduced waste and leakage and recycling (HK-BEAM).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Install flow restrictors, automatic shut off systems and appliances for reduced water use during construction (GGCP).	☐
Site management (F_2) Project management (F_3) Environment policy (F_5)	Install secondary containment for hazardous material storage areas (e.g. fuel tanks) with a capacity equal to 110% of the volume of the large tank (GGCP).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Provide a site drainage system that may comprise temporary ditches, drainage pipes and/or culvers to collect site run-off for treatment (GGCP).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Provide adequate sanitary facilities (e.g. portable chemical toilets, septic tanks for holding discharge form toilets, bathrooms and kitchens) and employ licensed contractor to collect contents of these toilets/septic tanks for disposal (GGCP).	☐
Site management (F_2) Project management (F_3)	Cover the open stockpiles of construction materials (e.g. aggregates, excavated materials, sand and fill materials) with tarpaulin or similar fabric during rainstorms or arrange for other	☐

Technology (F_4)	measures to prevent the washing away of construction materials, soil, silt or debris into any nearby drainage system (GGCP).	
Specialist works (F_1) Project management (F_3) Technology (F_4)	Ensure that all manholes at the sites are adequately covered and temporarily sealed to prevent washing down of silt or debris into the drainage system (GGCP).	☐
Site management (F_2) Project management (F_3) Environment policy (F_5)	Provide an adequately designed wheel washing bay which should have a wash water collection basin for removal of settle and silt at every site exit (GGCP).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	

Table 5.9 Benchmarks for assessment indicator 'noise pollution'

Eco	EE	Sus	PA	HA
24 optional credits				

Noise Pollution

Contribution Factor	INTENT	Credit
	To reduce the nuisance caused by noise from building services plant and equipment, disturbing neighbouring householders, particularly at night.	
Contribution Factor	**BENCHMARKS**	
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Comply with the acceptable noise levels for neighbouring sensitive receivers in accordance with the Technical Memorandum for the Assessment of Noise from places Other Than Domestic Premises, Public Places or Construction Sites (HK-BEAM).	☐
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Apply the criteria and requirement laid down in the Environmental Protection Department Practice Note ProPECC PN 2/93 for minimizing nuisance to neighbours caused by noise during construction (HK-BEAM).	☐
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	The rating level outside the nearest exposed noise sensitive receive greater than 5 dB below the background level during any period of the day or evening (07:00 to 23:00 h) and does not exceed the background level during any period of the night (23:00 to .7:00 h) (HK-BEAM).	☐

Project management (F_3) Environment policy (F_5)	Demonstrate compliance with the noise management guidelines as detailed in the Environmental Monitoring and Audit Manual (HK-BEAM).	☐
Project management (F_3) Technology (F_4)	Either with no external warning device OR, where an external audible warning device is fitted, the period of sounding of the device is limited to not more than 20 minutes (BREEAM).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	The staff is trained in the operation of the system and keyholders or security personnel is appointed to alarm calls during unoccupied periods (BREEAM).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	To reduce noise nuisance by distance or by topographic features or walls (HPBG).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Select mechanical and plumbing devices, ductwork, and piping that generate less noise and dampen the noise generated (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Locate noisy mechanical equipment, office equipment, and functions away from noise-sensitive uses. Avoid locating mechanical equipment above or adjacent to noise-sensitive spaces (HPBG).	☐

Site management (F_2) Project management (F_3) Technology (F_4)	Prevent noise transmission by absorbing noise and vibrations at the source. Consider placing vibrating equipment on isolation pads, and enclosing equipment in sound-absorbing walls, floors, and ceilings (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Place acoustic buffers, such as corridors, lobbies, stairwells, electrical/janitorial closets, and storage rooms, between noise-producing and noise-sensitive spaces. This will alleviate the need for more complex acoustic separation solutions (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Prevent transmission of sound through the building structure through use of floating floor slabs and sound-insulated penetrations of walls, floors, and ceilings (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Prevent transmission between exterior and interior by ensuring appropriate fabrication and assembly of walls, windows, roofs, ground floor, and foundations (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Prevent transmission between rooms by wall, floor, and ceiling assemblies by specifying materials with appropriate sound transmission class ratings. Consider using set-off studs with sound-attenuating insulation, floating floor slabs, and sound-absorbent ceiling systems (HPBG).	☐
Specialist works (F_1)	Situate mechanical room across from non-critical	☐

Project management (F_3) Technology (F_4)	building areas. Consider the use of sound-rated acoustic doors and acoustic seals around these doors (HPBG).	
Site management (F_2) Project management (F_3) Technology (F_4)	Avoid locating outside air intake or exhaust air discharge openings near windows, doors, or vents where noise can re-enter the building (HPBG).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Advocate wrapping or enclose rectangular ducts with sound isolation materials (HPBG).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Advocate using the sound attenuators ('duct silencers' or 'sound traps') and acoustic plenums to reduce noise in ductwork (HPBG).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Employ off-site concrete batching plant rather on-site production, whenever appropriate (GGCP).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Dispose of rubble through plastic (rubber) chutes instead of metal chutes (or use rubber linings in chutes and dumpers to reduce impact noise) (GGCP).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Erect noise barriers either close to sources or receivers that can achieve a noise reduction of 5-10dB (A) (GGCP).	☐
Site management (F_2)	Locate equipment away from receives (doubling	

Project management (F_3) Technology (F_4)	distance will result in a 6dB(A) reduction) (GGCP).	
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Restrict nighttimes working to low noise activities to ensure no exceedance of acceptable noise level (GGCP).	☐
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Schedule noisy activity at times when dwellings are more likely to remain unoccupied (GGCP).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	

Table 5.10 Benchmarks for assessment indicator 'photochemical pollution'

Eco	EE	Sus	PA	HA
5 optional credits				

Photochemical Pollution

Contribution Factor	INTENT	Credit
	To eliminate light trespass from the building and site, improve night sky access and reduce development impact o nocturnal environment.	
Contribution Factor	**BENCHMARKS**	
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Meet or provide lower light levels and uniformity ratios than those recommended by the Illuminating Engineering Society of North America (IESNA) Recommended Practice Manual: Lighting for Exterior Environments (RP-33-99) (LEED).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Design exterior lighting such that all exterior luminaries with more than 1000 initial lamp lumens are shielded and all luminaries with more than 3500 initial lamp lumens meet the Full Cut-off IESNA Classification (LEED).	☐
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	The maximum candela value of all interior lighting shall fall within the building (not out through windows) and the maximum candela value of all exterior lighting shall fall within the property (LEED).	☐

Specialist works (F_1) Project management (F_3) Technology (F_4)	Any luminaries within a distance of 2.5 times its mounting height from the property boundary shall have shielding such that no light from that luminaries crosses the property boundary (LEED).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Don't burn the coals on the site directly (HMSO, 1992).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that project site meets requirements.	

Table 5.11 Benchmarks for assessment indicator 'extraction of materials'

Eco	EE	Sus	PA	HA
6 optional credits				

Extraction of Materials

	INTENT	**Credit**
	To increase demand for building materials and products that is extracted within the region, thereby supporting the regional economy and reducing the environmental impacts.	
Contribution Factor	**BENCHMARKS**	
Project management (F_3) Technology (F_4) Environment policy (F_5)	Of the regionally manufactured materials documented for MR Credit 5.1, use a minimum of 20% of building materials and products that are extracted, harvested or recovered (as well as manufactured) within 500 miles (LEED).	☐
Project management (F_3) Technology (F_4) Environment policy (F_5)	Of the regionally manufactured materials documented for MR Credit 5.1, use a minimum of 50% of building materials and products that are extracted, harvested or recovered (as well as manufactured) within 500 miles (LEED).	☐
Project management (F_3) Technology (F_4) Environment policy (F_5)	Use salvaged, refurbished or reused materials, products and furnishings for at least 5% of building materials (LEED).	☐
Project management (F_3) Technology (F_4)	Use salvaged, refurbished or reused materials, products and furnishings for at least 10% of	☐

Environment policy (F_5)	building materials (LEED).	
Project management (F_3) Technology (F_4) Environment policy (F_5)	Use materials with recycled content such that post-consumer recycled content constitutes at least 5% of the total value of the materials in the project OR combined post-consumer and 1/2 post-industrial recycled content constitutes at least 10%. (LEED).	☐
Project management (F_3) Technology (F_4) Environment policy (F_5)	Use materials with recycled content such that post-consumer recycled content constitutes at least 10% of the total value of the materials in the project OR combined post-consumer and 1/2 post-industrial recycled content constitutes at least 20% (LEED).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	

Table 5.12 Benchmarks for assessment indicator 'manufacture of components'

Eco	EE	Sus	PA	HA
12 optional credits				

Manufacture of Components

	INTENT	Credit
	To increase demand for building materials and products that is manufactured within the region, thereby supporting the regional economy and reducing the environmental impacts.	
Contribution Factor	**BENCHMARKS**	
Site management (F_2) Project management (F_3) Technology (F_4)	Locate project within 1/2 mile of a commuter rail, light rail or subway station or 1/4 mile of two or more public or campus bus lines usable by building occupants (LEED).	☐
Project management (F_3) Technology (F_4) Environment policy (F_5)	Of the regionally manufactured materials documented for MR Credit 5.1, use a minimum of 20% of building materials and products that are extracted, harvested or recovered (as well as manufactured) within 500 miles (LEED).	☐
Project management (F_3) Technology (F_4) Environment policy (F_5)	Of the regionally manufactured materials documented for MR Credit 5.1, use a minimum of 50% of building materials and products that are extracted, harvested or recovered (as well as manufactured) within 500 miles (LEED).	☐
Project management (F_3)	Use salvaged, refurbished or reused materials,	

Technology (F_4) Environment policy (F_5)	products and furnishings for at least 5% of building materials (LEED).	
Project management (F_3) Technology (F_4) Environment policy (F_5)	Use salvaged, refurbished or reused materials, products and furnishings for at least 10% of building materials (LEED).	☐
Project management (F_3) Technology (F_4) Environment policy (F_5)	Use materials with recycled content such that post-consumer recycled content constitutes at least 5% of the total value of the materials in the project OR combined post-consumer and 1/2 post-industrial recycled content constitutes at least 10%. (LEED).	☐
Project management (F_3) Technology (F_4) Environment policy (F_5)	Use materials with recycled content such that post-consumer recycled content constitutes at least 10% of the total value of the materials in the project OR combined post-consumer and 1/2 post-industrial recycled content constitutes at least 20% (LEED).	☐
Site management (F_2) Project management (F_3) Technology (F_4) Environment policy (F_5)	Maintain at least 75% of existing building structure and shell (exterior shin and framing, excluding window assemblies) (LEED).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Maintain an additional 25% (100% total) of existing building structure and shell (exterior shin and framing, excluding window assemblies)	☐

Environment policy (F_5)	(LEED).	
Site management (F_2) Project management (F_3) Technology (F_4) Environment policy (F_5)	Maintain 100% of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material) AND at least 50% of non-shell areas (interior walls, doors, floor coverings and ceiling systems) (LEED).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4) Environment policy (F_5)	Develop and implement a waste management plan, quantifying material diversion goals. Recycle and/or salvage at least 50% of construction, demolition and land clearing waste. (LEED).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4) Environment policy (F_5)	Develop and implement a waste management plan, quantifying material diversion goals. Recycle and/or salvage an additional 25% (75% total) of construction, demolition and land clearing waste. (LEED).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	

Table 5.13 Benchmarks for assessment indicator 'Transportation to site'

Eco	EE	Sus	PA	HA
10 optional credits				

Transportation to site

Contribution Factor	INTENT	Credit
	To reduce the environmental impacts by transport to site.	
Contribution Factor	**BENCHMARKS**	
Site management (F_2) Project management (F_3) Technology (F_4)	Locate project within 1/2 mile of a commuter rail, light rail or subway station or 1/4 mile of two or more public or campus bus lines usable by building occupants (LEED).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Provide alternative fuel vehicles for 3% of building occupants AND provide preferred parking for these vehicles, OR install alternative fuel refuelling stations for 3% of the total vehicle parking capacity of the site. Liquid or gaseous fuelling facilities must be separately ventilated or located outdoors (LEED).	☐
Site management (F_2) Project management (F_3)	Size parking capacity to meet, but not exceed, minimum local zoning requirements AND provide preferred parking for carpools or vanpools capable of serving 5% of the building occupants; OR add no new parking for rehabilitation projects AND provide preferred	☐

Environment policy (F_5)	parking for carpools or vanpools capable of serving 5% of the building occupants (LEED).	
Site management (F_2) Project management (F_3) Environment policy (F_5)	The site should offer support facilities for bicycling, mass transit, electric vehicles, carpooling, and other less-polluting means of transportation (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	No car parking provided (HK-BEAM).	☐
Project management (F_3) Technology (F_4) Environment policy (F_5)	Use a minimum of 20% of building materials and products that are manufactured regionally within a radius of 500 miles (LEED).	☐
Project management (F_3) Technology (F_4) Environment policy (F_5)	Use a minimum of 50% of building materials and products that are manufactured regionally within a radius of 500 miles (LEED).	☐
Project management (F_3) Technology (F_4) Environment policy (F_5)	Maintain at least 75% of existing building structure and shell (exterior shin and framing, excluding window assemblies) (LEED).	☐
Project management (F_3) Technology (F_4) Environment policy (F_5)	Maintain an additional 25% (100% total) of existing building structure and shell (exterior shin and framing, excluding window assemblies) (LEED).	☐

Project management (F_3) Technology (F_4) Environment policy (F_5)	Maintain 100% of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material) AND at least 50% of non-shell areas (interior walls, doors, floor coverings and ceiling systems) (LEED).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	

Table 5.14 Benchmarks for assessment indicator 'construction practices'

Eco	EE	Sus	PA	HA
7 optional credits				

Construction Practices

	INTENT	Credit
	To reduce the energy consumption during construction practices.	
Contribution Factor	**BENCHMARKS**	
Project management (F_3) Technology (F_4) Environment policy (F_5)	In all construction efforts, strive to improve energy performance well beyond the basic requirements of the NYS Energy Code, applicable regulations, and consensus standards. Determine the overall environmental impact of building energy consumption. Energy performance analysis shall account for energy losses incurred during delivery from the point of generation to the point of use, as well as for the emissions generated by energy production (on and off-site) (HPBG).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3) Technology (F_4) Environment policy (F_5)	An energy management system should be established for controlling all the energy consumption during the construction practices (HPBG).	☐
Project management (F_3) Technology (F_4) Project management (F_3)	Provide simple back up controls so that equipment can function if the energy management system goes down. (HPBG).	☐

Site management (F_2) Project management (F_3) Technology (F_4)	For larger boilers, oxygen trim controls to improve combustion efficiency; draft control inducers which reduce off-cycle losses; demand control for larger boilers, based on variations in heating demand; water reset control keyed to outside air temperature; burner flame control; for small renovation projects, provide a time clock for night and weekend set backs (HPBG).	☐
Project management (F_3) Technology (F_4)	Generate energy consumption profiles that identify occurrences of peak loads and develop responsive management strategies for reducing utility bills (HPBG)	☐
Project management (F_3) Technology (F_4)	Limit electrical demand during peak hours by turning off non-essential equipment (HPBG)	☐
Project management (F_3) Technology (F_4)	Set up the HVAC building control system to operate based on need. If multiple sources are available, minimize simultaneous heating and cooling, and supply thermal conditioning form the most appropriate/efficient sources (HPBG).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	

Table 5.15 Benchmarks for assessment indicator 'recycling energy & resources'

Eco	EE	Sus	PA	HA
17 optional credits				

Recycling Energy & Resources

	INTENT	Credit
	Facilitate the reduction of waste generated by building occupants that is hauled to and disposed of in landfills.	
Contribution Factor	**BENCHMARKS**	
Site management (F_2) Project management (F_3) Technology (F_4) Environment policy (F_5)	Provide an easily accessible area that serves the entire building and is dedicated to the separation, collection and storage of materials for recycling including (at a minimum) paper, corrugated, glass, plastics and metals (LEED).	☐
Site management (F_2) Project management (F_3) Environment policy (F_5)	Use materials with recycled content such that post-consumer recycled content constitutes at least 5% of the total value of the materials in the project OR combined post-consumer and 1/2 post-industrial recycled content constitutes at least 10%. (LEED).	☐
Site management (F_2) Project management (F_3) Environment policy (F_5)	Use materials with recycled content such that post-consumer recycled content constitutes at least 10% of the total value of the materials in the project OR combined post-consumer and 1/2 post-industrial recycled content constitutes at least 20% (LEED).	☐

Project management (F_3) Technology (F_4) Environment policy (F_5)	Develop and implement a waste management plan, quantifying material diversion goals. Recycle and/or salvage at least 50% of construction, demolition and land clearing waste. Calculations can be done by weight or volume, but must be consistent throughout (LEED).	☐
Project management (F_3) Technology (F_4) Environment policy (F_5)	Develop and implement a waste management plan, quantifying material diversion goals. Recycle and/or salvage an additional 25% (75% total) of construction, demolition and land clearing waste. (LEED).	☐
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	The U.S. EPA has identified (and continually updates) a listing of products with recycled content in its Comprehensive Procurement Guidelines (CPGs), including Structural Fibreboard, Laminated Paperboard, Rock Wool Insulation, Fiberglass Insulation, Cellulose Insulation, Perlite composite Board Insulation, Plastic Rigid Foam Insulation, Foam-in-Place Insulation, Glass-Fibre Reinforced Insulation, Phenolic Rigid Foam Insulation, Floor Tiles, Patio Blocks, Polyester Carpet Fibre Face, Latex Paint, Shower and Restroom Dividers, Parking Stops, Plastic Fencing, Playground Surfaces, Running Tracks, Garden and Soaker Hoses, Lawn and Garden Edging, and Yard Trimming Compost (HPBG)	☐

Project management (F_3) Technology (F_4) Environment policy (F_5)	Based on total materials cost, between 20-50% of the materials (excluding costs for mechanical and electrical systems, plumbing systems, labour, overhead fees etc.) shall contain at least 20% post-consumer recycled content OR a minimum of 49% pre-consumer recycled content. Document the materials and corresponding percentages accordingly (HPBG).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Identify licensed haulers of recyclables and document costs for recycling and frequency of pick-ups. Confirm with haulers what materials will and will not be accepted (HPBG).	☐
Project management (F_3) Technology (F_4)	Identify manufactures and reclaimers who recover construction/demolition scrap of their products for recycling (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Advocate providing the multiple recycling facilities for site use (BREEAM).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Specify timber and timber products for use as an integral part of the building (e.g. structural wood, window frames, architraves) which are entirely EITHER form well managed, regulated sources OR of suitable reused timber (BREEAM).	☐
Specialist works (F_1)	Specify timber and timber products for use other than as an integral part of the building (for	☐

Project management (F_3) Technology (F_4)	example decorative work or fixed furnishings such as wardrobes and fitted kitchens), which are entirely EITHER from well managed, regulated sources OR of suitable reused timber (BREEAM).	
Specialist works (F_1) Project management (F_3) Technology (F_4)	Specify the majority (i.e. over 50%) of material in roof covering to be recycled or reused. Roof covering means the tiles or slates, not the supporting elements or insulations (BREEAM).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Specify the majority (i.e. over 50%) of masonry material (e.g. brick, concrete block and stone) in walls to be recycled or reused (BREEAM).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Specify suitable uncontaminated demolition materials wherever appropriate in fill and hard-core (BREEAM).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Incorporate separate storage facilities for recyclable materials (BREEAM).	☐
Project management (F_3) Technology (F_4) Environment policy (F_5)	A high proportion of the existing structure and façade are retained, where use is made of recycled materials, and where there are facilities and active policies for storage and collection of office waste for recycling (BREEAM).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the	

environment engineering or responsible party, declaring that the project site meets the requirements.	

Table 5.16 Benchmarks for assessment indicator 'reusing energy & resources'

Eco	EE	Sus	PA	HA
15 optional credits				

Reusing Energy & Resources

Contribution Factor	INTENT / BENCHMARKS	Credit
	INTENT	**Credit**
	Extend the life cycle of existing building stock, conserve resources, retain cultural resources, reduce waste and reduce environmental impacts of new buildings as they relate to materials manufacturing and transport.	
Contribution Factor	**BENCHMARKS**	
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Maintain at least 75% of existing building structure and shell (exterior skin and framing, excluding window assemblies) (LEED).	☐
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Maintain an additional 25% (100% total) of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material) (LEED).	☐
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Maintain 100% of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material) AND at least 50% of non-shell areas (interior walls, doors, floor coverings and ceiling systems) (LEED).	☐
Specialist works (F_1)	Use salvaged, refurbished or reused materials,	☐

Project management (F_3) Technology (F_4)	products and furnishings for at least 5% of building materials (LEED).	
Specialist works (F_1) Project management (F_3) Technology (F_4)	Use salvaged, refurbished or reused materials, products and furnishings for at least 10% of building materials (LEED).	☐
Project management (F_3) Technology (F_4) Environment policy (F_5)	Incorporate salvaged or refurbished materials whenever possible. Early in the process, identify materials from existing buildings (e.g., doors, brick) that can be re-used and stockpiled in architectural salvage. Identify local suppliers of additional reusable material (HPBG).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Encourage on-site reuse of scrap material (HPBG).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3) Technology (F_4)	Consider construction assemblies that allow for disassembly of materials at the end of their useful life. This encourages the reuse of valuable materials and may simplify renovations and repairs (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Collect and use rainwater for landscape irrigation, urban gardening, toilet/urinal flushing, roof cooling (for un-insulated roofs), and for other purposes as appropriate (HPBG).	☐
Site management (F_2)	Plant roof areas to reduce the discharge of storm	☐

Project management (F_3) Technology (F_4)	water and to reap the benefits of increased green space (recreation, bird habitat, roof shading, etc.) (HPBG).	
Site management (F_2) Project management (F_3) Technology (F_4)	Collect and use graywater for water closet and urinal flushing, as well as for washdown of floor drains (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Recover excess groundwater from sump pumps for use as a source of recycled water (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Collect and use utility district steam system condensate for toilet/urinal flushing cooling tower make-up, and other non-potable uses (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Consider a 'vacuum-assist' system (in lieu of a standard system) for flushing of water closets and urinals (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Reduce rainwater runoff from the site, roofs, and building surfaces to minimize stress on NYC combined sewer system and to divert and reduce water pollution (HPBG).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	

Table 5.17 Benchmarks for assessment indicator 'Maintenance'

Eco	EE	Sus	PA	HA
12 optional credits				

Maintenance

Contribution Factor	INTENT	Credit
	Extent the life cycle of existing building, conserve resources, retain cultural resources, reduce waste and reduce environmental impacts of new buildings as they relate to materials manufacturing and transport.	
Contribution Factor	**BENCHMARKS**	
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Maintain at least 75% of existing building structure and shell (exterior skin and framing, excluding window assemblies) (LEED).	☐
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Maintain an additional 25% (100% total) of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material) (LEED).	☐
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Maintain 100% of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material) AND at least 50% of non-shell areas (interior walls, doors, floor coverings and ceiling systems) (LEED).	☐

Specialist works (F_1) Project management (F_3) Environment policy (F_5)	A planned programme of regular maintenance, cleaning and inspection of the building's fabric is in operation supported by a comprehensive and easy-to-follow manual (BREEAM).	☐
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	A planned programme of regular maintenance, cleaning and inspection of the building's services in operation supported by a comprehensive and easy-to-follow manual (BREEAM).	☐
Site management (F_2) Project management (F_3) Environment policy (F_5)	An ease-to-follow, regularly updated manual detailing the operating methods, instructions and standard control settings for HVAC services equipment (HK-BEAM).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Select healthy and environmentally preferable cleaning products. Obtain material safety data sheet and post in prominent, assessable locations (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Consider the use of portion control devices such as mechanical dispensers, which help ensure safe mixing of cleaning solutions, save packaging, and reduce chemical consumption (HPBG).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Coordinate housekeeping and custodial operations with building ventilation schedules to ensure that adequate ventilation is provided, both during and after these activities (HPBG).	☐

Site management (F_2) Project management (F_3) Technology (F_4)	Since carpets tend to act as 'sinks' for dirt and dust, a vacuum with high-efficiency vacuum bags or high efficiency particle air filters should be used. When shampooing carpets, avoid over-wetting and allow sufficient time for thorough drying. Water-damaged carpets can harbour mold and bacteria (HPBG).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Develop an integrated pest management plan. This is especially important in facilities where children are housed or spend significant amount of time (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Ensure that custodial staff are adequately trained and educated in the use of cleaning products and procedures. Foster a sense of pride, and provide performance incentives for custodial staff (HPBG).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	

Table 5.18 Benchmarks for assessment indicator 'public safety & health'

Eco	EE	Sus	PA	HA
18 optional credits				

Public Safety & Health

	INTENT	Credit
	To reduce the possibility which may present risk on public safety & health.	
Contribution Factor	**BENCHMARKS**	
Site management (F_2) Project management (F_3)	The site doesn't have evaporative cooling towers or condensers (BREEAM).	☐
Site management (F_2) Project management (F_3) Environment policy (F_5)	45 dB L_{Aeq} in private offices, small conference rooms (BREEAM).	☐
Site management (F_2) Project management (F_3) Environment policy (F_5)	50 dB L_{Aeq} in large offices (BREEAM).	☐
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	All furnishings thoroughly cleaned or shown to be clean (BREEAM).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Use of non-static carpets (BREEAM).	☐

Specialist works (F_1) Project management (F_3) Technology (F_4)	No tinted windows (BREEAM).	☐
Site management (F_2) Project management (F_3) Environment policy (F_5)	Smoking ban or smoking allowed only in designated and separately ventilated rooms, which make up less than 5% of the floor space (BREEAM).	☐
Site management (F_2) Project management (F_3) Environment policy (F_5)	Policy to minimize the use of polluting processes, equipment and materials including adhesives, floor waxes, stains, polishes, spray cans, deodorizers, detergents, etc (BREEAM).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Carpet cleaning specification requiring high performance, regularly maintained vacuum cleaners with high efficiency, hot water extraction (steam) cleaning (with minimum operating temperatures of 70 ℃) or liquid nitrogen treatment at least once a year and, where papers are stored for more than 2 years, cleaning them (BREEAM).	☐
Site management (F_2) Project management (F_3)	No air conditioning (except in computer suites, secure and other special high heat load situations) and building designed to avoid overheating (BREEAM).	☐
Site management (F_2) Project management (F_3)	Wet cooling towers are not used (HK-BEAM).	☐

Site management (F_2) Project management (F_3) Technology (F_4)	The wet cooling towers use seawater (HK-BEAM).	☐
Site management (F_2) Project management (F_3) Environment policy (F_5)	The wet cooling towers use water from an acceptable source and are designed and maintained as specified in the Code of Practice for the Prevention of legionnaires Disease (HK-BEAM).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Design kitchen areas and restrooms for ease of maintenance. Specifically, restroom stall partitions should be suspended from the ceiling or extended from walls to expedite floor cleaning and eliminate soil build-up on legs and supports. Sinks should be recessed into counter tops or molded as a single unit with a front lip that keeps water form spilling onto the floor (HPBG).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Select healthy and environmentally preferable cleaning products. Obtain material safety data sheet and post I prominent, assessable locations (HPBG).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Consider the use of portion control devices such as mechanical dispensers, which help ensure safe mixing of cleaning solutions, save packaging, and reduce chemical consumption (HPBG).	☐

Site management (F_2) Project management (F_3) Technology (F_4) Environment policy (F_5)	Develop an integrated pest management plan. This is especially important in facilities where children are housed or spend significant amount of time (HPBG).	☐
Site management (F_2) Project management (F_3) Environment policy (F_5)	Ensure that custodial staff are adequately trained and educated in the use of cleaning products and procedures. Foster a sense of pride, and provide performance incentives for custodial staff (HPBG).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	

Table 5.19 Benchmarks for assessment indicator 'community communication'

Eco	EE	Sus	PA	HA
5 optional credits				

Community Communication

Contribution Factor	INTENT / BENCHMARKS	Credit
	INTENT	**Credit**
	Advocate communicating with the local community.	
Contribution Factor	**BENCHMARKS**	
Site management (F_2) Project management (F_3)	Visit the site neighbours (e.g. local schools, residential blocks, local groups, etc) and explain to their representatives detail of the construction project and environmental measures adopted by the construction company to minimize nuisance to them (GGCP).	☐
Site management (F_2) Project management (F_3)	Establish an Environmental Hotline to receive environmental complaints and suggestions for improvement in environmental performance (GGCP).	☐
Site management (F_2) Project management (F_3)	Get involved and support local initiatives. Organize tree-planting campaigns (GGCP).	☐
Site management (F_2) Project management (F_3)	Report on your environmental initiatives within magazines and other publications (GGCP).	☐
Site management (F_2) Project management (F_3)	Apply for awards to gain formalized recognition of your efforts (GGCP).	☐

Submittals	Total
Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	

Table 5.20 Benchmarks for assessment indicator 'region development'

Eco	EE	Sus	PA	HA
9 optional credits				

Region Development

	INTENT	Credit
	To increase the chances of economy development and improve the transportation condition and enhance local ecology.	
Contribution Factor	**BENCHMARKS**	
Project management (F_3) Environment policy (F_5)	Building on land, which meets defined criteria for low ecological value or, in the case of ecologically valuable land, designing in compliance with recommendations form, an audit by the RSNC (Royal Society for Nature Conservation – the Wildlife Trusts Partnership) in order to minimize ecological damage (BREEAM).	☐
Specialist works (F_1) Project management (F_3) Environment policy (F_5)	Building can enhance the site ecology in accordance with advice from the RSNC positively (BREEAM).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	All WCs with a maximum flushing capacity of 6 liters or less (BREEAM).	☐
Specialist works (F_1) Project management (F_3)	The contractor provides a description of the available local public transport as part as the	☐

Environment policy (F_5)	assessment (BREEAM).	
Project management (F_3) Technology (F_4) Environment policy (F_5)	The sites is previously built up or used for industrial purposes and for reclaimed contaminated land (BREEAM).	☐
Specialist works (F_1) Project management (F_3)	The predicted or actual water consumption is less than specific targets (BREEAM).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3) Technology (F_4)	A high proportion of the existing structure and façade are retained, where use is made of recycled materials (BREEAM).	☐
Project management (F_3) Technology (F_4)	Building has access to good public transport (BREEAM).	☐
Project management (F_3) Technology (F_4) Environment policy (F_5)	The building can make the local and region an attractive place for technology companies to reside and can produce indirect economic benefits through development of the nascent clean and efficient technologies industry (HPBG).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	

Table 5.21 Benchmarks for assessment indicator 'environment engineer'

Eco	EE	Sus	PA	HA
11 optional credits				

Environment Engineer

	INTENT	Credit
	Enhance the environmental protection with the instruction of the Environmental engineer.	
Contribution Factor	**BENCHMARKS**	
Specialist works (F_1) Site management (F_2) Project management (F_3) Technology (F_4) Environment policy (F_5)	Ensure all employees are acquainted with the organization's environmental policy and environmental initiatives (GGCP).	☐
Project management (F_3) Environment policy (F_5)	Harness a commitment to the implementation of an organization's environmental policy (GGCP).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3)	Secure co-operation in the functioning of the environmental initiatives (GGCP).	☐
Project management (F_3) Environment policy (F_5)	Ensure all staffs are aware of the legal liabilities associated with their activities, both to themselves and their employers (GGCP).	☐
Specialist works (F_1) Site management (F_2)	Improve environmental performance and encourage a responsible attitude to	☐

Project management (F_3) Technology (F_4)	environmental protection (GGCP).	
Specialist works (F_1) Site management (F_2) Project management (F_3) Technology (F_4) Environment policy (F_5)	Encourage the development of practices that can reduce environmental impacts (GGCP).	☐
Project management (F_3) Technology (F_4) Environment policy (F_5)	Identify and collect legal information from corporate sources, relevant government authorities and industry associations (GGCP).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3)	Establish a register of environmental requirements relevant to your operation based on the information collected (GGCP).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3)	Establish a procedure to ensure that relevant staffs have continuous access to the legal requirements (GGCP).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3)	Establish a procedure to ensure relevant information on legal requirements is communicated to employees effectively (GGCP).	☐
Specialist works (F_1) Site management (F_2)	Establish a procedure to keep track of changes to environmental requirements and to update the	☐

Project management (F_3) Technology (F_4) Environment policy (F_5)	environmental requirements accordingly (GGCP).	
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	

Table 5.22 Benchmarks for assessment indicator 'working health & safety'

Eco	EE	Sus	PA	HA
15 optional credits				

Working Health & Safety

	INTENT	**Credit**
	Protect the construction workers from pollutants and health damage during construction.	
Contribution Factor	**BENCHMARKS**	
Specialist works (F_1) Site management (F_2) Project management (F_3) Technology (F_4)	Adequate separation and protection of occupied areas from construction areas (HPBG).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3) Technology (F_4)	Protection of ducts and airways form accumulating dust, moisture, particulates, VOCs and microbial resulting from construction/ demolition activities (HPBG).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Increased ventilation/ exhaust air at the construction site (HPBG).	☐
Specialist works (F_1) Project management (F_3)	Scheduling of construction procedures to minimize exposure of absorbent building materials to VOC emissions. For example, complete 'wet' construction procedures such as painting and sealing before storing or installing	☐

Technology (F_4) Environment policy (F_5)	'dry', absorbent materials such as carpets and ceiling tiles. These porous components act as a 'sink', retaining contaminants and releasing them over time (HPBG).	
Specialist works (F_1) Site management (F_2) Project management (F_3)	Posting of materials safety data sheets in high traffic, accessible locations (HPBG).	☐
Specialist works (F_1) Project management (F_3)	A flush-out period, beginning as soon as systems are operable and before or during the furniture, fittings, and equipment installation phase. The process involves flushing the building with 100% outside air for a period of not less than 20 days (HPBG).	☐
Site management (F_2) Project management (F_3) Environment policy (F_5)	Appropriate steps to control vermin (HPBG).	☐
Site management (F_2) Project management (F_3) Technology (F_4) Environment policy (F_5)	Prevention of pest infestation once the building or renovated portion is occupied using integrated pest management (HPBG).	☐
Specialist works (F_1) Site management (F_2)	Non-toxic interventions will be emphasized at all times on sites (HPBGF).	☐

Project management (F_3) Technology (F_4) Environment policy (F_5)		
Site management (F_2) Project management (F_3)	Place construction trailers and other production outbuildings on concrete or gravel pads that will prevent rodent burrowing and construction trailers should be situated without skirts (e.g., plywood, sheet metal) that could provide harborage for rodents or other pests/ vectors (HPBG).	☐
Site management (F_2) Project management (F_3)	Establish clearly defined 'break' areas where workers will eat meals and snacks (HPBG).	☐
Site management (F_2) Project management (F_3)	Supply enough containers to hold all wastes generated, and without overflow, between collection days (HPBG).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3)	Waste management procedures will ensure that all containers are emptied frequently enough to prevent open, loose-fitting lids or overflowing conditions. Daily emptying is most desirable; weekly emptying is the minimum frequency (HPBG).	☐
Specialist works (F_1) Site management (F_2)	Wherever possible, construction materials should be stored on racks approximately 18 in/46cm above ground (or floor) in order to prevent	☐

Project management (F_3)	creation of rodent (or other) pest harbourage, and to enhance inspection procedures (HPBG).	
Specialist works (F_1) Site management (F_2) Project management (F_3)	Frequency of inspections should be approximately monthly, increased or decreased as deemed necessary by inspection results, species present, and area of concern (e.g., basement, manhole, public walkway) (HPBG).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	

Table 5.23 Benchmarks for assessment indicator 'site environment management'

Eco	EE	Sus	PA	HA
8 optional credits				

Site Environment Management

Contribution Factor	INTENT	Credit
	To improve the appearance and condition of the construction sites and reduce the impacts on the environment as a whole.	
Contribution Factor	**BENCHMARKS**	
Site management (F_2) Project management (F_3)	Post signs to inform site workers of good practices for handling and storing materials (GGCP).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3)	Provide dedicated areas on the construction site for the storage of materials. This is particularly important for materials with the potential to harm people and the environment. Signage indicating the storage of potentially harmful materials should also be displayed in these areas (GGCP).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	Store potentially harmful materials with roofed, secondary containment to ensure that any spills are contained and to minimize contaminated storm water run-off (GGCP).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3)	Keep an inventory of all products stored on-site. This is particularly important for products with the potential to harm people and the environment	☐

Technology (F_4) Environment policy (F_5)	(GGCP).	
Specialist works (F_1) Project management (F_3)	Obtain Material Safety Data Sheets (MSDS) from material suppliers and keep them on-site where employees can access them (GGCP).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3) Environment policy (F_5)	Concern the direct habitat loss of the habitants or disturbance of the habitats due to increased human activities (GGCP).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3) Technology (F_4) Environment policy (F_5)	Concern the direct or indirect impact to the wildlife inhabiting the areas (GGCP).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3) Technology (F_4) Environment policy (F_5)	Concern the potential damage of any heritage resources (GGCP).	☐
	Submittals	Total
	Provide C-EPSS template, signed by environment engineering or responsible party, declaring that project site meets requirements.	

Chapter 6:

Methodology for Calculating C-EPI

CHAPTER 6: METHODOLOGY FOR CALCULATING C-EPI

6.1 Introduction

This chapter is to present a quantitative model for calculating the value of contractor's environmental performance index (C-EPI). In fact, the value of C-EPI is a total score from all concerned assessment indicators. These indicators for calculating C-EPI have been structured in two-level system, and there are five groups at the first-level, namely, ecology, embodied energy, sustainability, social aspect and human aspect. Detail indicators are withdrawn from the first-level indicators, and in tall there are 23 second-level indicators employed for analysis. Through the process of assessing contractor's environmental performance, a certain value will be gained for each second-level indicator. Therefore, C-EPI is the sum of the 23 indicators' values. This can be expressed as follows:

$$C - EPI = \sum_{i=1}^{23} D_i \qquad \text{-----Eqn. (6.1)}$$

Where D_i is the value gained for the second-level indicator i.

To gain the value D_i for a particular second-level indicator, there are three assumptions to be taken into account:

(1) First, all benchmarks designed for this indicator have to be applied to assess the actual performance. As demonstrated in previous chapter, that the performance of each second-level indicator will be judged by a number of benchmarks.

(2) Second, whether a specific benchmark is met or not will depend on the performance of a number of environmental factors, called contribution factor.

(3) Different contribution factors have different significance of contribution to a particular indicator.

The value of Di is weighted contribution from those factors, which will have the impacts to this particular indicator, and this can be expressed as follows:

$$D_i = \sum_{j=1}^{5} w_{ji} F_{ji} \qquad (i = 1, \cdots 23) \quad (j = 1, \cdots 5) \qquad \text{-----Eqn. (6.2)}$$

Where

w_{ji} is relative weighting value that factor j has to the indicator i;

F_{ji} is the contribution value of the that factor j to the indicator i;

The calculation for the values F_{ji} and w_{ji} will be conducted through employing a quantitative method, namely, Non-Structural Fuzzy Decision System (NSFDS), discussed in the later section in this chapter.

6.2 The application of Non-structure fuzzy decision system (NSFDS) for analyzing the value of an indicator

In using NSFDS method, there are three procedures: (a) decomposition, (b) comparative judgment, and (c) synthesis of priorities (CHAN, 1998).

Decomposition

In the decomposition stage in using NSFDS, an objective variable will be decomposed into a number of a number of detail variables forming a hierarchy. For example, in calculating C-EPI, it consists of the values of 23 second-level indicators, which are grouped under five categories: ecology environment, energy & resource consumption, sustainable environment, social aspect and human aspect. From each of the five first-level indicators, more specific indicators are developed. For example, the first-level indicator 'ecology' is subdivided into 'acid rain', 'global warming', 'ozone depletion', etc. The first-level variables will be more broad and general, and second level or even lower level variables will be more specific. An example of decomposition is given in Figure 6.1

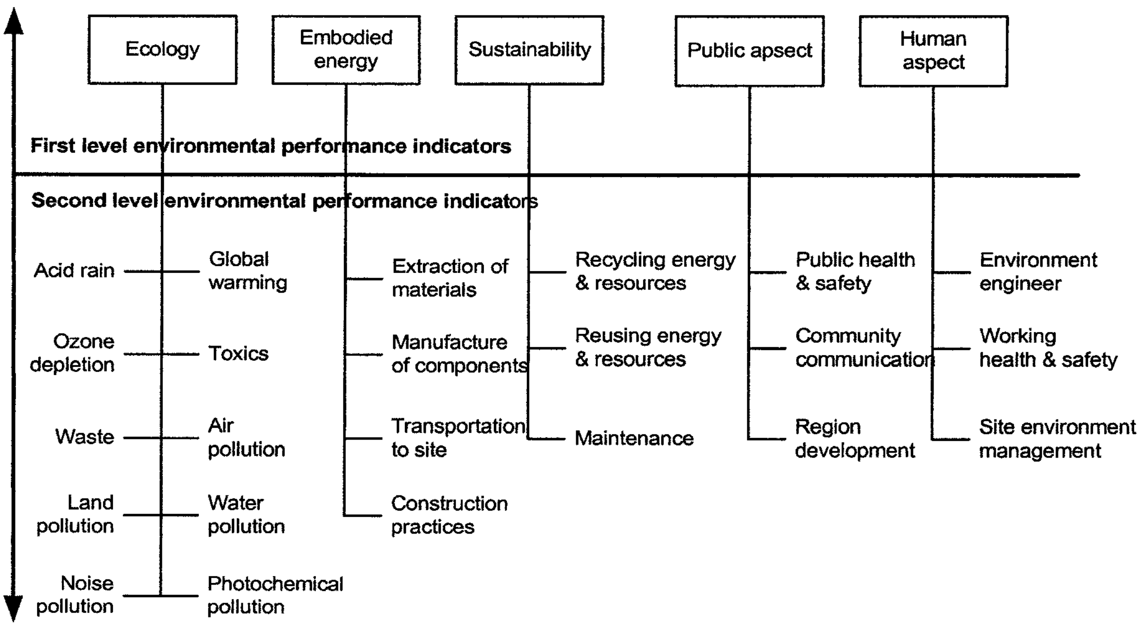


Figure 6.1 Decomposition structure of two-level framework of indicators

Comparative judgment

In the application of NSFDS method, comparative judgment will be made to the relative significance or importance through pair-wise comparisons between the variables, which are in the same group and at the same level in the variable hierarchy. In fact, through comparative judgment, weightings have been established among these environmental performance factors and performance assessment indicators in previous chapters. These weightings have been summarized in Table 6.1 and 6.2.

Table 6.1 Relative weighting for environmental performance factors

Factor	**Relative weighting (RW_{x-y})**
Specialist works (F_1)	
Structural works (F_{1-1})	0.496
Earthwork and excavation (F_{1-1-1})	0.211
Formwork and formation (F_{1-1-2})	0.189
Reinforcement (F_{1-1-3})	0.182
Concrete (F_{1-1-4})	0.203
Waste treatment (F_{1-1-5})	0.215
External & internal works (F_{1-2})	0.504
Wall, roofing and isolation (F_{1-2-1})	0.161
Component installment (F_{1-2-2})	0.148
Plumbing and drainage (F_{1-2-3})	0.163
Ornament and painting (F_{1-2-4})	0.172
Surrounding landscaping (F_{1-2-5})	0.175
Waste treatment (F_{1-2-6})	0.181

Site management (F_2)	
Site performance (F_{2-1})	0.512
Site security (F_{2-1-1})	0.338
Material storage and security (F_{2-1-2})	0.321
Cleanliness and care (F_{2-1-3})	0.341
Health & block safety (F_{2-2})	0.488
Health & health provision (F_{2-2-1})	0.510
Block related safety (F_{2-2-2})	0.490
Project management (F_3)	
Management &organization works (F_{3-1})	0.223
Management structure (F_{3-1-1})	0.329
Site planning (F_{3-1-2})	0.332
Environment engineering training (F_{3-1-3})	0.339
Resources (F_{3-2})	0.208
Labor (F_{3-2-1})	0.334
Plant (F_{3-2-2})	0.332
Materials (F_{3-2-3})	0.334
Co-ordination & control (F_{3-3})	0.206
Co-ordination (F_{3-3-1})	0.325
Control and supervision (F_{3-3-2})	0.343
Co-operation (F_{3-3-3})	0.332
Documentation (F_{3-4})	0.174
Submission (F_{3-4-1})	0.480
Environment report (F_{3-4-2})	0.520
Programming & progress (F_{3-5})	0.189
Program (F_{3-5-1})	0.348
Progress (F_{3-5-2})	0.346
Milestone (F_{3-5-3})	0.306

Technology (F_4)	
Information technology (F_{4-1})	0.298
Software package (F_{4-1-1})	0.356
Intranet (F_{4-1-2})	0.335
Internet (F_{4-1-3})	0.309
Construction technology (F_{4-2})	0.371
Energy & resource saving technology (F_{4-2-1})	0.327
Pollution reducing technology (F_{4-2-2})	0.335
Waste reducing technology (F_{4-2-3})	0.338
Human skill (F_{4-3})	0.331
Environment engineer (F_{4-3-1})	0.509
Environment knowledge (F_{4-3-2})	0.491
Environment policy (F_5)	
Government policy (F_{5-1})	0.488
Environmental law (F_{5-1-1})	0.506
Building regulation (F_{5-1-2})	0.494
Company policy (F_{5-2})	0.512
Environment management system (F_{5-2-1})	0.495
ISO14000 (F_{5-2-2})	0.505

Table 6.2 Relative weighting for environmental indicators

Indicator	**Relative weighting (RW I_{x-y})**
Ecology (I_1)	0.481
Acid rain (I_{1-1})	0.149
Global warming (I_{1-2})	0.190
Ozone depletion (I_{1-3})	0.084
Toxics (I_{1-4})	0.330
Waste (I_{1-5})	0.082

Air pollution (I_{1-6})	0.019
Land pollution (I_{1-7})	0.027
Water pollution (I_{1-8})	0.038
Noise pollution (I_{1-9})	0.013
Photochemical pollution (I_{1-10})	0.068
Embodied energy (I_2)	0.252
Extraction of materials (I_{2-1})	0.245
Manufacture of components (I_{2-2})	0.607
Transportation to site (I_{2-3})	0.048
Construction practice (I_{2-4})	0.101
Sustainability (I_3)	0.166
Recycling energy & resources (I_{3-1})	0.324
Reusing energy & resource (I_{3-2})	0.602
Maintenance (I_{3-3})	0.075
Social aspect (I_4)	0.061
Public safety & health (I_{4-1})	0.258
Community communication (I_{4-2})	0.105
Region development (I_{4-3})	0.637
Human aspect (I_5)	0.040
Environment engineer (I_{5-1})	0.731
Working health & safety (I_{5-2})	0.188
Site Environmental management (I_{5-3})	0.081

Synthesis of priorities

The function of synthesis of priorities in using DSFDS is to establish relative weightings between variables, which are in different groups under the decomposition hierarchy. The adequacy of these weightings can also be validated. In our calculation for the value of D_i, in formula (6.2), the weighting w_{ji} is relative weighting between a factor j and an indicator i, in which factor j and indicator i are in different groups. Thus the method DSFDS is selected for this purpose. The interrelation between factor and indicator can be illustrated graphically in Figure 6.2. The process of establishing these relative weightings between factors and indicators will be discussed in next section.

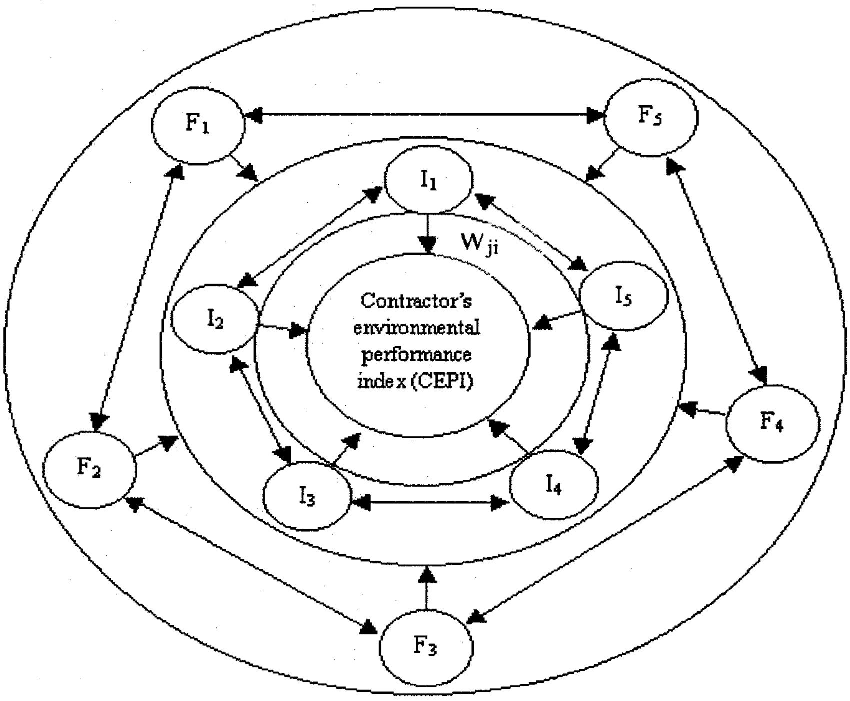


Figure 6.2 Overall structure of CEPI

6.3 Relative weightings between environmental factors and performance indicators

In applying DSFDS to establishing the relative weightings w_{ji} between environmental factors and performance indicators, the environmental factors used are Specialist works (F_1), Site management (F_2) Project management (F_3), Technology (F_4) and Environment policy (F_5). The full discussion has been given to the implications of these factors in Chapter 3. On the other hand, the indicators I_i used include those 23 second-level indicators under five groups, as shown in Table 6.2. The use of DSFDS methodology will help to generate a table of weightings w_{ji}, as formatted in Table 6.3. The detail calculations for these values w_j, in Table 6.3 will be discussed as follows.

Table 6.3 Format of the relative weightings w_{ji} between F_j and I_i

	F_1	**F_2**	**F_3**	**F_4**	**F_5**
I_1	W_{11}	W_{21}	W_{31}	W_{41}	W_{51}
...					
I_i	W_{1i}	W_{2i}	W_{3i}	W_{4i}	W_{5i}
...					

The method NSFDS is similar to the analytical hierarchy process (AHP) in the way that it breaks down the objective variable into multi-levels variables and compares these detail variables by pairs (TAM, 2002). The major difference between the two methodologies is that in applying NSFDS, three discrete options are given when comparison in pairs is conducted:

- A_1 is better than A_2; or
- A_1 is equally important as A_2; or
- A_1 is worse than A_2

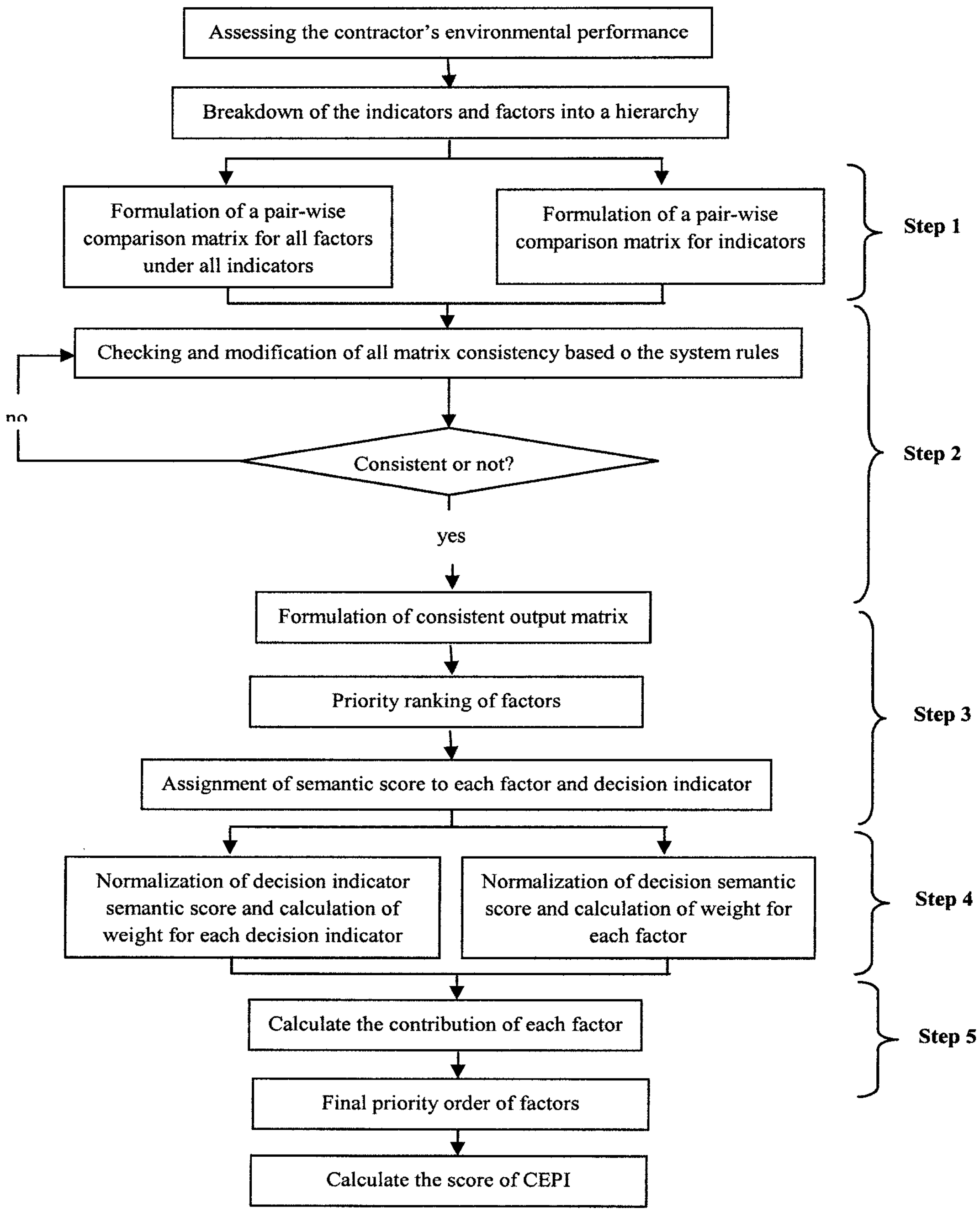
The overall structure of applying NSFDS to calculate weighting values w_j, (between factors F_j and indicators I_i) is flow-charted in Fig 6.3.

Step 1 --- pair-wise comparison matrix

The step 1 in using NSFDS is to formulate tow matrices: the pair-wise comparison matrix for all factors under all indicators, and the pair-wise comparison matrix for indicators.

Pair-wise comparison matrix for all factors under all indicators

The purpose of formulating the pair-wise comparison matrix is to judge the relative significance between groups of factors to individual indicators. For example, when considering the relative significance between 5 factors (F_1, F_2, ...F_5) and a indicator Ii, a judgment matrix can be used, as shown in Table 6.4.



Mark for x to y	Scale
	In considering a particular environmental decision indicator (I_n)
0	= Factor x is worse than factor y
0.5	= Two are the same
1	= Factor x is better than factor y

Figure 6.3 Flow chart of the NSFDS

The generation of these relative significance is based on the three discrete options recommended in NSFDS as mentioned before:

- A_1 is better than A_2; or
- A_1 is equally important as A_2; or
- A_1 is worse than A_2

Table 6.4 Example of relative significance between five factors to an indicator Ii

Factor	**Factor**				
	F_1	F_2	F_3	F_4	F_5
F_1	0.5	1	1	1	0.5
F_2		0.5	0	0	0
F_3			0.5	0	0
F_4				0.5	0
F_5					0.5

It is recommended in NSFDS that values can be allocated to these three options according to:

- When $A_i>A_j$, the value 0 is allocated to the concerned element in the matrix (for example, in Table 6.4, 0 is given to the element (F_2, F_3) as it is judged that the significance of F_2 to the indicator Ii is larger than the influence from F_3).
- When $A_i<A_j$, the value 1 is allocated to the concerned element in the matrix
- When $A_i=A_j$, the value 0.5 is allocated to the concerned element in the matrix

The methodology NSFDS also suggests to check the consistency of the values generated through above procedures. The example in Table 6.4 is used to show the testing procedures.

Step 2 --- consistency checking

The procedures of checking the consistency of the values generated in the pair-wise comparison matrix have been recommended in NSFDS (TAM, 2002). The implementation of the checking procedures includes building a matrix in Eqn.(6.3) and Eqn.(6.4).

$$
{}_iE = \begin{bmatrix} {}_ie_{11} & {}_ie_{12} & \cdots & {}_ie_{1n} \\ {}_ie_{21} & {}_ie_{22} & \cdots & {}_ie_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ {}_ie_{n1} & {}_ie_{n2} & \cdots & {}_ie_{nn} \end{bmatrix} = ({}_ie_{kl}) \qquad \text{------Eqn. (6.3)}
$$

$k = 1,2,\ldots,n; l = 1,2,\ldots,n.$

Where

$$
\left.\begin{array}{ll} \text{(1) When } {}_ie_{hk} > {}_ie_{hl} & {}_ie_{kl}=0 \\ \text{(2) When } {}_ie_{hk} < {}_ie_{hl} & {}_ie_{kl}=1 \\ \text{(3) When } {}_ie_{hk} = {}_ie_{hl}=0.5 & {}_ie_{kl}=0.5 \end{array}\right\} \qquad \text{-------Eqn. (6.4)}
$$

Where

h=1,2,...n, which is the reference factor.

When ${}_ie_{kl}$ is the logical parameter of pair-wise comparison of factor 'k' and 'l'; n is the number of factor to be considered. The sample evaluation matrix in Table 6.4 is transformed into the ${}_iE$ form of output matrix in table 6.5.

Table 6.5 ${}_iE$ form of output matrix for I_i (referring to Table 6.4)

Factor	Factor				
	F_1	F_2	F_3	F_4	F_5
F_1	${}_ie_{11}$=0.5	${}_ie_{12}$=1	${}_ie_{13}$=1	${}_ie_{14}$=1	${}_ie_{15}$=0.5
F_2	${}_ie_{21}$=0	${}_ie_{22}$=0.5	${}_ie_{23}$=0	${}_ie_{24}$=0	${}_ie_{25}$=0
F_3	${}_ie_{31}$=0	${}_ie_{32}$=1	${}_ie_{33}$=0.5	${}_ie_{34}$=0	${}_ie_{35}$=0
F_4	${}_ie_{41}$=0	${}_ie_{42}$=1	${}_ie_{43}$=1	${}_ie_{44}$=0.5	${}_ie_{45}$=0
F_5	${}_ie_{51}$=0.5	${}_ie_{52}$=1	${}_ie_{53}$=1	${}_ie_{54}$=1	${}_ie_{55}$=0.5

When matrix ${}_iE$ complies with the consistency checking of priority ordering, it is named as the priority matrix with consistent parameters. There are five conditions to check whether matrix ${}_iE$ satisfies the consistency checking of priority ordering (TAM, 2002), namely:

(1) If ${}_ie_{hk} > {}_ie_{hl}$, then ${}_ie_{kl} \equiv 0$ ('greater than one' condition) where: ${}_ie_{hk}$ is the logical parameter of pair-wise comparison of factor E_h and E_k; ${}_ie_{hl}$ is the logical

parameter of pair-wise comparison of factor E_h and E_l; and ${}_i e_{kl}$ is the logical parameter of pair-wise comparison of factor E_k and E_l. For example, in Table 6.5;

(a) ${}_i e_{14}=1$, that is factor no.1 >factor no.4.

(b) ${}_i e_{15}=0.5$, that is factor no.1=factor no.5.

(c) Therefore, factor no.5>factor no.4, that is ${}_i e_{54}=1$.

(2) If ${}_i e_{hk} < {}_i e_{hl}$, then ${}_i e_{kl} \equiv 1$ ('smaller than one' condition).

(3) If ${}_i e_{hk}=0.5$ and ${}_i e_{hl}=0.5$, then ${}_i e_{kl} \equiv 0.5$('equal to 0.5'condition).

(4) If ${}_i e_{hk}=1$ and ${}_i e_{hl}=1$, then ${}_i e_{kl}=\{0,0.5,1\}$.

(5) If ${}_i e_{hk}=0$ and ${}_i e_{hl}=0$, then ${}_i e_{kl}=\{0,0.5,1\}$.

Therefore, in table 6.5, we can check the consistency as that: begin with the second line of matrix ${}_i E$. Because $ie_{23}=0$, where ${}_i e_{12}= {}_i e_{13}=1$, then is true of condition 4; because ${}_i e_{24}=0$, where ${}_i e_{12}= {}_i e_{14}=1$, then is true of condition 4; because ${}_i e_{25}=0$, where ${}_i e_{12}$ (=1)> ${}_i e_{15}$=(0.5), then is true of condition 1.

Then check the third line of matrix ${}_i E$. Because $ie_{34}=0$, where $ie_{13}= ie_{14}=1$, then is true of condition 4; because ${}_i e_{35}=0$, where ${}_i e_{13}$ (=1)> ${}_i e_{15}$=(0.5), then is true of condition 1.

Then check the fourth line of matrix ${}_iE$. Because ie_{45}=0, where ${}_ie_{14}$ (=1)> ${}_ie_{15}$=(0.5), then is true of condition 1.

Therefore, in table 6.5, the ${}_ie_{kl}$ is valid and not necessary to be revised.

Formulating all pair-wise comparison matrices for all factors under all indicators

By using the methodologies discussed in above step one and step two, pair-wise comparison matrices between the five environmental factors under all indictors can be developed. Considering the complexity if all 23 indicators are considered individually, the pair-wise comparison matrices are established only for these five first-level indicators.

The data used in the establishment of these matrices are collected from 6 professional interviews. The results of these pair-wise comparison matrices are shown in table 6.6 ~ 6.10. For example, the values in table 6.6 represent the relative significance between the five major environmental factors when the environmental performance indicator 'ecology' is concerned. Validity of the values in these tables has been tested, and they are valid. In these tables (6.6)~(6.10), the values in the right-side column indicate the relative significance between the five factors in referring to a specific indicator. For example, in table 6.6, considering the indicator I_1 (Ecology), factor 3 (F_3) is most important with the total value in the column of 4.5, F_4 assuming second, F_1 and F_2 assuming third, and F_5 is least important.

Table 6.6 Output matrix for I_1 after consistency

For I_1						
Factor	F_1	F_2	F_3	F_4	F_5	Sum
F_1	0.5	0.5	0	0	1	2
F_2	0.5	0.5	0	0	1	2
F_3	1	1	0.5	1	1	4.5
F_4	1	1	0	0.5	1	3.5
F_5	0	0	0	0	0.5	0.5

Table 6.7 Output matrix for I_2 after consistency

For I_2						
Factor	F_1	F_2	F_3	F_4	F_5	Sum
F_1	0.5	0	0	0	0	0.5
F_2	1	0.5	0	0	0	1.5
F_3	1	1	0.5	0.5	0.5	3.5
F_4	1	1	0.5	0.5	0.5	3.5
F_5	1	1	0.5	0.5	0.5	3.5

Table 6.8 Output matrix for I_3 after consistency

For I_3						
Factor	F_1	F_2	F_3	F_4	F_5	Sum
F_1	0.5	0.5	0	0	0.5	1.5
F_2	0.5	0.5	0	0	0.5	1.5
F_3	1	1	0.5	1	1	4.5
F_4	1	1	0	0.5	1	3.5
F_5	0.5	0.5	0	0	0.5	1.5

Table 6.9 Output matrix for I_4 after consistency

For I_4						
Factor	F_1	F_2	F_3	F_4	F_5	Sum
F_1	0.5	0	0	0.5	0.5	1.5
F_2	1	0.5	0	1	1	3.5
F_3	1	1	0.5	1	1	4.5
F_4	0.5	0	0	0.5	0.5	1.5
F_5	0.5	0	0	0.5	0.5	1.5

Table 6.10 Output matrix for I_5 after consistency

For I_5						
Factor	F_1	F_2	F_3	F_4	F_5	Sum
F_1	0.5	0.5	0	1	1	3
F_2	0.5	0.5	0	1	1	3
F_3	1	1	0.5	1	1	4.5
F_4	0	0	0	0.5	0.5	1
F_5	0	0	0	0.5	0.5	1

Pair-wise comparison matrix for indicators

By using the methodologies discussed in above step one and step two, pair-wise comparison matrix the five first-level performance indicators can be developed, as shown in Table 6.11. the values in the table represent the relative significance between the indicators. Similarly, the data used in the establishment of these matrices are from 6 professional interviews. Validity of the values in the table has been tested, and they are valid.

Table 6.11 Output matrix for indicators after consistency

For decision indicator						
	I_1	I_2	I_3	I_4	I_5	Sum
I_1	0.5	0	0	0	1	1.5
I_2	1	0.5	0	0	1	2.5
I_3	1	1	0.5	1	1	4.5
I_4	1	1	0	0.5	1	3.5
I_5	0	0	0	0	0.5	0.5

The values in table 6.11, right-side column indicate the relative significance between the five indicators in assessing a contractor's environmental performance. Namely, indicator I_3 (project management) is most important in these five first level indicators.

Step 3 --- priority setting to factors and indicators

The priority between factors in referring to individual indicators

In fact, the priority between factors in referring to individual indicators can be gained through the values in the right-side column in tables 6.6~6.10. However, by using NSFDS, these values need to be transferred to relative weightings, in which the sum of weightings between the factors should be equal to 1. This transformation needs to employ a semantic score. The process of generating the semantic score is described as follows.

The priority between factors in referring to individual indicators are identified, showing in the left-side column in Table 6.13-6.17, according to the values in the right-side column in tables 6.6~6.10. Based on this priority order, analyst can assign semantic operator, each represented by a number in the range of 1-21 steps (see table 6.12) for the generating a semantic score (TAM, 2002). The semantic score to each factor is obtained by comparing each factor to the one with the highest value (the bottom –up approach). The semantic scores are listed in the right-side column in Table 6.13~6.17.

Table 6.12 Semantic operators, scores and transformed priority scores

Semantic operators	step	ia_{1j}	ir_j
Same	1	0.5	1
In-between	2	0.525	0.905
Marginally different	3	0.55	0.818
In-between	4	0.575	0.739
Slightly different	5	0.6	0.667
In-between	6	0.625	0.6
Quite different	7	0.65	0.538
In-between	8	0.675	0.481
Markedly different	9	0.7	0.429
In-between	10	0.725	0.379
Obviously different	11	0.75	0.333
In-between	12	0.775	0.29

Very different	13	0.8	0.25
In-between	14	0.825	0.212
Significantly different	15	0.85	0.176
In-between	16	0.875	0.143
Very significantly different	17	0.9	0.111
In-between	18	0.925	0.081
Extremely different	19	0.95	0.053
In-between	20	0.975	0.026
Absolutely incomparable	21	1	0

Table 6.13 Priority ordering and assignment of semantic score for I_1

	For I_1	
Factor	Sum	Score
F_3	4.5	1
F_4	3.5	0.6
F_1	2	0.379
F_2	2	0.379
F_5	0.5	0.176

Table 6.14 Priority ordering and assignment of semantic score for I_2

	For I_2	
Factor	Sum	Score
F_3	3.5	1
F_4	3.5	1
F_5	3.5	1
F_2	1.5	0.212
F_1	0.5	0.212

Table 6.15 Priority ordering and assignment of semantic score for I_3

For I_3		
Factor	Sum	Score
F_3	4.5	1
F_4	3.5	0.667
F_1	1.5	0.333
F_2	1.5	0.333
F_5	1.5	0.333

Table 6.16 Priority ordering and assignment of semantic score for I_4

For I_4		
Factor	Sum	Score
F_3	4.5	1
F_2	3.5	0.379
F_1	1.5	0.250
F_4	1.5	0.250
F_5	1.5	0.250

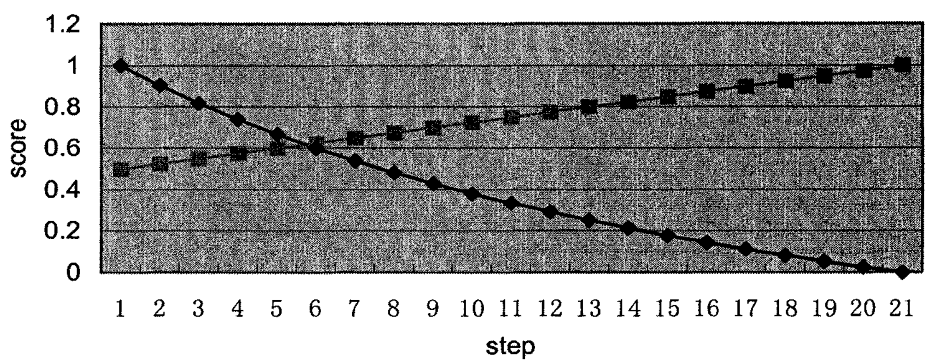
Table 6.17 Priority ordering and assignment of semantic score for I_5

For I_5		
Factor	Sum	Score
F_3	4.5	1
F_1	3	0.667
F_2	3	0.667
F_4	1	0.250
F_5	1	0.250

The process of generating the semantic scores for these factors can be explained as follows. For example, in the table 6.13, their difference is judged by experts who then assign a semantic operator of ‘absolutely incomparable’ to describe their relative importance. For factor 1, compared with the factor 3, the priority score of ‘0.379’ is assigned and the same process is repeated for all factors.

The value of semantic score (ia_{ij}) and priority (ir_j) in Table 6.12 is calculated through the following analytical processes. Each semantic operator (like marginally different, quite different, etc) is assigned a score. These scores, ia_{ij}, within the range of [0.5,1] (0.5=same; 1=different) are mapped into a priority score, ir_j, in the range of [1,0] as shown in Figure 6.4 by applying the fuzzy set theory through the following Eqn. (6.5).

Figure 6.4 Mapping of semantic score to priority score



$${}_i r_j = \frac{1 - {}_i a_{ij}}{{}_i a_{1j}}, 0.5 \le {}_i a_{1j} \le 1 \qquad \text{------Eqn. (6.5)}$$

Where ia_{1j} is the semantic score and ir_j is the priority score.

The priority between the five first-level indicators

In fact, the priority between the first-level indicators can be gained through the values in the right-side column in tables 6.11. However, by using NSFDS, these values need to be transferred to relative weightings, in which the sum of weightings between the indicators should be equal to 1. By using the similar procedures to those adopted above, the priority between indicators is shown in the left-side column in the table 6.18, and the semantic scores of the indicators are listed in the right-side column in Table 6.18.

Table 6.18 Priority ordering and assignment of semantic score for indicators

For decision indicator		
	Sum	Score
F_3	4.5	1
F_4	3.5	0.538
F_2	2.5	0.379
F_1	1.5	0.212
F_5	0.5	0.053

Step 4 --- establishing weightings by normalizing semantic scores

According to the semantic scores obtained for factors and indicators, weightings between factors in referring to indicators and the weighting between indicators in referring to a contractor's environmental performance can be calculated. These weightings can be developed from normalization of the semantic scores.

The weightings between indicators in referring to assessing a contractor's environmental performance are given in Table 6.19. And the weightings between factors in referring to individual first-level indicators are shown in Table 6.20-6.24, and Table 6.25 provides a summary of factor weightings.

Table 6.19 Normalization of decision indicator priority scores into weighting

I_n	Priority score	Normalization	Weighting (w)
F_1	0.212	0.212/2.182	0.097
F_2	0.379	0.379/2.182	0.174
F_3	1	1/2.182	0.458
F_4	0.538	0.538/2.182	0.247
F_5	0.053	0.053/2.182	0.024
Total	2.182		

Table 6.20 Normalization of factor for I_1 priority scores into weighting

F_n	Priority score	Normalization	Weighting (w)
F_1	0.379	0.379/2.534	0.15
F_2	0.379	0.379/2.534	0.15
F_3	1	1/2.534	0.395
F_4	0.6	0.6/2.534	0.237
F_5	0.176	0.176/2.534	0.069
Total	2.534		

Table 6.21 Normalization of factor for I_2 priority scores into weighting

F_n	Priority score	Normalization	Weighting (w)
F_1	0.026	0.026/2.977	0.009
F_2	0.212	0.212/2.977	0.071
F_3	1	1/2.977	0.336
F_4	1	1/2.977	0.336
F_5	0.739	0.739/2.977	0.248
Total	2.977		

Table 6.22 Normalization of factor for I_3 priority scores into weighting

F_n	Priority score	Normalization	Weighting (w)
F_1	0.333	0.333/2.666	0.125
F_2	0.333	0.333/2.666	0.125
F_3	1	1/2.666	0.375
F_4	0.667	0.667/2.666	0.25
F_5	0.333	0.333/2.666	0.125
Total	2.666		

Table 6.23 Normalization of factor for I_4 priority scores into weighting

F_n	Priority score	Normalization	Weighting (w)
F_1	0.250	0.250/2.129	0.117
F_2	0.379	0.379/2.129	0.178
F_3	1	1/2.129	0.47
F_4	0.250	0.250/2.129	0.17
F_5	0.250	0.250/2.129	0.117
Total	2.129		

Table 6.24 Normalization of factor for I_5 priority scores into weighting

F_n	Priority score	Normalization	Weighting (w)
F_1	0.667	0.667/2.834	0.235
F_2	0.667	0.667/2.834	0.235
F_3	1	1/2.834	0.353
F_4	0.250	0.250/2.834	0.088
F_5	0.250	0.250/2.834	0.088
Total	2.834		

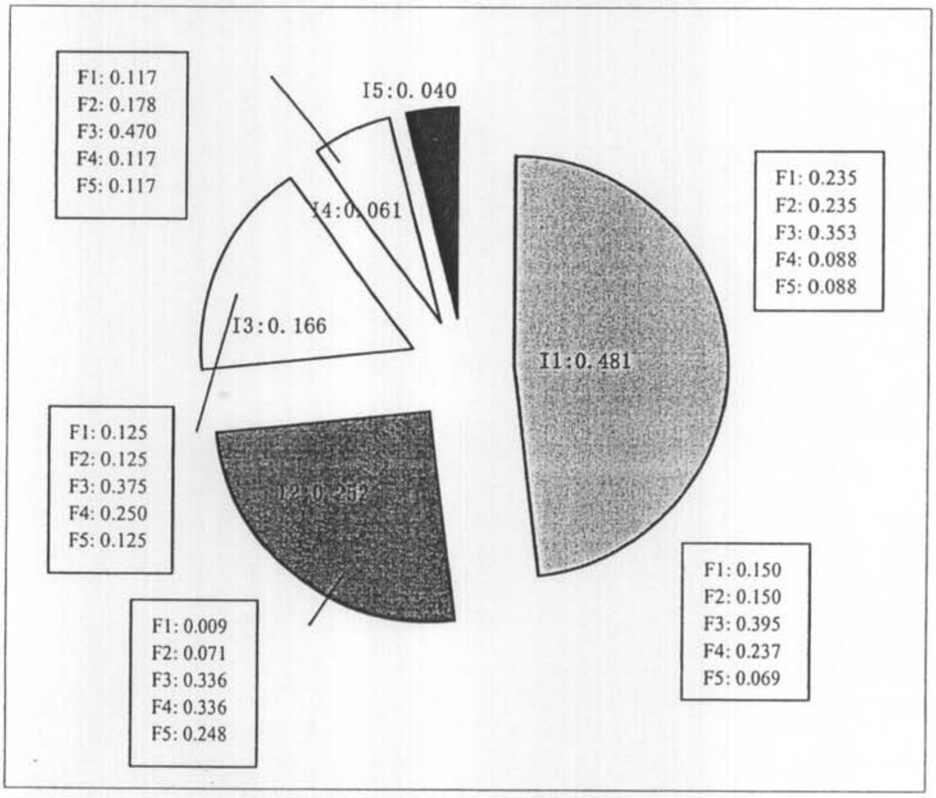
Table 6.25 Weighting of each factor after normalization

Factor/indicator	I_1	I_2	I_3	I_4	I_5
F_1	0.150	0.009	0.125	0.117	0.235
F_2	0.150	0.071	0.125	0.178	0.235
F_3	0.395	0.336	0.375	0.470	0.353
F_4	0.237	0.336	0.250	0.117	0.088
F_5	0.069	0.248	0.125	0.117	0.088

Step 5 --- Formulation of the relative weightings w_{ji} between F_j and I_i

In referring to Table 6.3, we need to find out all the relative weightings w_{ji} between F_j and I_i. An alternative method is to distribute the weightings in Table 6.25 to all the 23 second-level indicators according to the relative weightings between indicators in a same group, which have been established in Chapter 4, and the results are summarized in Table 6.2. The distribution of these values is graphically presented in Figure 6.5.

To distribute the weightings in Table 6.25 into relative weightings w_{ji}, it is suggested to covert the figures in the table into percentages, as shown in Table 6.26, for the sake of convenience of discussion. By multiplying the percentages in Table 6.26 with the relative weightings in Table 6.2, the values of relative weightings w_{ji} between F_j and I_i are established in Table 6.27.



Legends:

1. Pie chart: weighting of decision indicator (I_n) in contractor's environmental performance assessment
2. Callous: weighting of factors (F_n) in each decision indicator

Figure 6.5 Weighting allocation diagram of F_n under each I_n

Table 6.26 Distribution percentage of each factor for 1st level indicators

	I_1	I_2	I_3	I_4	I_5	Total
F_1	7.22%	0.23%	2.08%	0.71%	0.94%	11.17%
F_2	7.22%	1.79%	2.08%	1.09%	0.94%	13.11%
F_3	19.00%	8.47%	6.23%	2.87%	1.41%	37.97%
F_4	11.40%	8.47%	4.15%	0.71%	0.35%	25.08%
F_5	3.32%	6.25%	2.08%	0.71%	0.35%	12.71%
	48.15%	25.20%	16.60%	6.09%	4.00%	
Total	100%					

Table 6.27 Relative weightings (w_{ji}) of each factor to 2nd level indicators

	F_1	F_2	F_3	F_4	F_5	Subtotal
I_{1-1}	0.0108	0.0108	0.0283	0.0170	0.0049	0.4815
I_{1-2}	0.0137	0.0137	0.0361	0.0217	0.0063	
I_{1-3}	0.0061	0.0061	0.0160	0.0096	0.0028	
I_{1-4}	0.0238	0.0238	0.0627	0.0376	0.0110	
I_{1-5}	0.0059	0.0059	0.0156	0.0093	0.0027	
I_{1-6}	0.0014	0.0014	0.0036	0.0022	0.0006	
I_{1-7}	0.0019	0.0019	0.0051	0.0031	0.0009	
I_{1-8}	0.0027	0.0027	0.0072	0.0043	0.0013	
I_{1-9}	0.0009	0.0009	0.0025	0.0015	0.0004	
I_{1-10}	0.0049	0.0049	0.0129	0.0078	0.0023	
I_{2-1}	0.0006	0.0044	0.0207	0.0207	0.0153	0.2524
I_{2-2}	0.0014	0.0109	0.0514	0.0514	0.0379	
I_{2-3}	0.0001	0.0009	0.0041	0.0041	0.0030	
I_{2-4}	0.0002	0.0018	0.0086	0.0086	0.0063	
I_{3-1}	0.0067	0.0067	0.0202	0.0134	0.0067	0.1663
I_{3-2}	0.0125	0.0125	0.0375	0.0250	0.0125	

I_{3-3}	0.0016	0.0016	0.0047	0.0031	0.0016	
I_{4-1}	0.0018	0.0028	0.0074	0.0018	0.0018	
I_{4-2}	0.0007	0.0011	0.0030	0.0007	0.0007	0.0605
I_{4-3}	0.0045	0.0069	0.0183	0.0045	0.0045	
I_{5-1}	0.0069	0.0069	0.0103	0.0026	0.0026	
I_{5-2}	0.0018	0.0018	0.0027	0.0007	0.0007	0.0403
I_{5-3}	0.0008	0.0008	0.0011	0.0003	0.0003	
Subtotal	0.1117	0.1311	0.3797	0.2508	0.1271	

6.4 Calculation of a contractor's environmental performance index (CEPI)

As discussed earlier in this chapter, the calculation of a contractor's environmental performance index (C-EPI) can be obtained through formula (6.1) and (6.2), namely,

$$C-EPI=\sum_{i=1}^{23}D_i \qquad \text{-----Eqn. (6.1)}$$

Where D_i can be calculated from the formula (6.2), namely,

$$D_i=\sum_{j=1}^{5}w_{ji}F_{ji} \qquad (i=1,...,23) \quad (j=5) \qquad \text{------Eqn. (6.2)}$$

Then the C-EPI can be calculated with formula (6.6), namely,

$$C-EPI=\sum_{i=1}^{23}\sum_{j=1}^{5}w_{ji}F_{ji} \qquad \text{------Eqn. (6.6)}$$

The above discussions have produced the values of all w_{ji}, as shown in Table 6.27. Thus if the values of F_{ji} are known, the value C-EPI will be calculated.

The values F_{ji} will depend on specific applications, allocated by analysts in the actual situation with considering the environmental performance committed by a contractor. When judging the performance, the analyst needs to use the table5.1~5.23 in Chapter 5, where a specific box can be ticked if the contractor concerned meets the requirement defined in that specific benchmark.

To demonstrate the calculation of C-EPI in this study, the assumption is given that all the requirements have been met in a contractor's practice. The contribution value of a factor to a second-level indicator, namely Fji, is suggested to be measured by the number of contributions that the factor I give to the indicator j. For example, the factor F_1 has appears 5 times influencing the indicator $I_{1\text{-}1}$ (acid rain). These 5 times of appearance indicates that the factor F_1 influences the indicator $I_{1\text{-}1}$ when different benchmark requirements are judged.

By assessing the influences of the five factors to all the 23 second-level indicators listed in Table 6.2, the number of contributions that all factors to all 23 indicators can be counted and summarized in Table 6.28.

Table 6.28 Calculated times for factors during the C-EPSS evaluation

	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Subtotal**
Acid rain (I_{1-1})	5	3	8	5	2	23
Global warming (I_{1-2})	5	1	6	6	0	18
Ozone depletion (I_{1-3})	1	4	7	7	2	21
Toxics (I_{1-4})	9	5	10	7	5	36
Waste (I_{1-5})	22	9	27	15	8	81
Air pollution (I_{1-6})	11	21	31	16	13	92
Land pollution (I_{1-7})	2	5	7	5	1	20
Water pollution (I_{1-8})	3	14	16	9	6	48
Noise pollution (I_{1-9})	12	10	24	18	6	70
Photochemical pollution (I_{1-10})	4	1	5	3	2	15
Extraction of materials (I_{2-1})	0	0	6	6	6	18
Manufacture of components (I_{2-2})	2	4	12	12	11	41
Transportation to site (I_{2-3})	0	5	10	8	7	30
Construction practice (I_{2-4})	1	2	7	7	3	20
Recycling energy & resource (I_{3-1})	7	5	17	14	8	51
Reusing energy & resource (I_{3-2})	7	8	15	12	4	46
Maintenance (I_{3-3})	8	4	12	6	6	36
Public health & safety (I_{4-1})	6	12	18	8	8	52
Community communication (I_{4-2})	0	5	5	0	0	10
Region development (I_{4-3})	5	1	9	5	5	25
Environment engineer (I_{5-1})	8	8	11	5	6	38
Working health & safety (I_{5-2})	10	12	15	6	4	47
Site Environmental management (I_{5-3})	6	6	8	4	4	28
Subtotal	134	145	286	184	117	866

By multiplying the figures in Table 6.28 with the relative weightings in Table 6.27, the value of C-EPI can be gained as:

$$C-EPI=\sum_{i=1}^{23}\sum_{j=1}^{5}w_{ji}F_{ji}$$

$$=8.77$$

The value of C-EPI of 8.77 is based on the assumption that a contractor meets all the requirements defined under all benchmarks used for assessing contractors' environmental performance. Thus this index can be called the Perfect Index, denoted as P-CEPI, then

P-CEPI=8.77

By converting the P-CEPI into a score, the score 100 is applied. When the Perfect score 100 is adopted, the relative weightings in Table 6.27 can be converted accordingly by applying the following formula:

$$w_{ji}{}' = \frac{100}{8.77}\times w_{ji} = 11.40\times w_{ji} \qquad \text{------Eqn. (6.7)}$$

Where

$w_{ji}{}'$ is denoted as the converted relative weightings.

The converted relative weightings are shown in Table 6.29.

Table 6.29 Converted relative weightings of factor to 2nd level indicators

	F_1	F_2	F_3	F_4	F_5
I_{1-1}	0.123	0.123	0.323	0.194	0.056
I_{1-2}	0.156	0.156	0.412	0.247	0.072
I_{1-3}	0.069	0.069	0.182	0.109	0.032
I_{1-4}	0.272	0.272	0.715	0.429	0.125
I_{1-5}	0.068	0.068	0.178	0.107	0.031
I_{1-6}	0.016	0.016	0.041	0.025	0.007
I_{1-7}	0.022	0.022	0.059	0.035	0.010
I_{1-8}	0.031	0.031	0.082	0.049	0.014
I_{1-9}	0.011	0.011	0.028	0.017	0.005
I_{1-10}	0.056	0.056	0.147	0.088	0.026
I_{2-1}	0.006	0.050	0.237	0.237	0.175
I_{2-2}	0.016	0.124	0.586	0.586	0.433
I_{2-3}	0.001	0.010	0.046	0.046	0.034
I_{2-4}	0.003	0.021	0.098	0.098	0.072
I_{3-1}	0.077	0.077	0.230	0.153	0.077
I_{3-2}	0.143	0.143	0.428	0.285	0.143
I_{3-3}	0.018	0.018	0.053	0.036	0.018
I_{4-1}	0.021	0.032	0.084	0.021	0.021
I_{4-2}	0.009	0.013	0.034	0.009	0.009
I_{4-3}	0.052	0.079	0.208	0.052	0.052
I_{5-1}	0.078	0.078	0.118	0.029	0.029
I_{5-2}	0.020	0.020	0.030	0.008	0.008
I_{5-3}	0.009	0.009	0.013	0.003	0.003

Nevertheless, in the actual application, the situation of full compliance to the requirements defined by all benchmarks is rare. In practice, the values Fji will vary between different contractors' performance. In other words, the contribution figures in Table 6.28 will be different between different applications, thus different contractors will be measured with different value of C-EPI.

A calculation table can be designed for assisting actual application. In conducting the value C-EPI, the contribution times for each factor to each second-level indicator is only needed to be input into a table, as shown in Table 6.30. The calculation formula can be expressed as formula (6.8).

$$C-EPI=\sum_{i=1}^{23}\sum_{j=1}^{5}w_{ji}{}'F_{ji}$$ ------Eqn. (6.8)

Table 6.30 Calculating form for C-EPI

	F_1		**F_2**		**F_3**		**F_4**		**F_5**		**Total**
I_{1-1}	0.123		0.123		0.323		0.194		0.056		
I_{1-2}	0.156		0.156		0.412		0.247		0.072		
I_{1-3}	0.069		0.069		0.182		0.109		0.032		
I_{1-4}	0.272		0.272		0.715		0.429		0.125		
I_{1-5}	0.068		0.068		0.178		0.107		0.031		
I_{1-6}	0.016		0.016		0.041		0.025		0.007		
I_{1-7}	0.022		0.022		0.059		0.035		0.010		
I_{1-8}	0.031		0.031		0.082		0.049		0.014		
I_{1-9}	0.011		0.011		0.028		0.017		0.005		

I_{1-10}	0.056		0.056		0.147		0.088		0.026		
I_{2-1}	0.006		0.050		0.237		0.237		0.175		
I_{2-2}	0.016		0.124		0.586		0.586		0.433		
I_{2-3}	0.001		0.010		0.046		0.046		0.034		
I_{2-4}	0.003		0.021		0.098		0.098		0.072		
I_{3-1}	0.077		0.077		0.230		0.153		0.077		
I_{3-2}	0.143		0.143		0.428		0.285		0.143		
I_{3-3}	0.018		0.018		0.053		0.036		0.018		
I_{4-1}	0.021		0.032		0.084		0.021		0.021		
I_{4-2}	0.009		0.013		0.034		0.009		0.009		
I_{4-3}	0.052		0.079		0.208		0.052		0.052		
I_{5-1}	0.078		0.078		0.118		0.029		0.029		
I_{5-2}	0.020		0.020		0.030		0.008		0.008		
I_{5-3}	0.009		0.009		0.013		0.003		0.003		
										C-EPI=	$\sum_{i=1}^{23}\sum_{j=1}^{5} w_{ji}' F_{ji}$

6.5 Summary

This chapter demonstrates a systematic method to evaluate the importance of each factor affecting contactor environmental performance to individual performance assessment indicators. The non-structural fuzzy decision system (NSFDS) is used to assist in establishing the relative weightings between environmental performance factors and environmental assessment indicators.

The establishment of these weightings enables the calculation of a contractor's environmental performance index (C-EPI). The process of calculating C-EPI has been fully demonstrated. The calculation results by using this system provide a scientific guideline for analysts (who can be contractors themselves, or clients, or consultants, or officers to assessing a contractor's environmental performance, thus help the contractor to effectively allocate necessary resource for improving their environmental management.

It is noted that this process is rather complicated without the assistance of computing facilities. Therefore, a computing tool is to be developed in supporting the application of this system in the next chapter.

Chapter 7:

Development of Computer Aided System of C-EPAS

CHAPTER 7: DEVELOPMENT OF COMPUTER AIDED SYSTEM OF C-EPAS

7.1 Introduction

C-EPAS is a system for assessing a contractor's environmental performance, and the core of this system is to calculate the contractor's environmental performance index (C-EPI). Chapter 6 have presented a model for calculating C-EPI. It has been shown that the process of calculating C-EPI involves a number of complicated calculation procedures. It is considered that the application of these procedures in practices will not be effectively received without the assistance of computing facilities. Therefore, it is the main objective of this chapter to develop a computing system for supporting the application of C-EPAS. This system will be mainly presented in various flow charts. The results of applying this system will be shown in next Chapter where the case study is used.

The objectives of the computing system C-EPAS will not only provide a tool for conducting all calculations, but also assist to identify and diagnose those areas where a contractor's environmental performance is poor. Therefore, the computing system C-EPAS will be designed to serve for the following functions:

- To record and sort out data
- To conduct calculations, which is core function

- To produce the results of using the system, including (1) the calculation result of C-EPI; (2) the distribution charts presenting a contractor's environmental performance between major performance indicators; and (3) diagnosis results on poor performance areas.

7.2 Structure of C-EPAS package

The structure of C-EPAS computing system will be designed to achieve three functions described in the introduction of this chapter through establishing three modules: data input module, core module and output module. The operation of these three modules will be in logics, as shown in Figure 7.1.

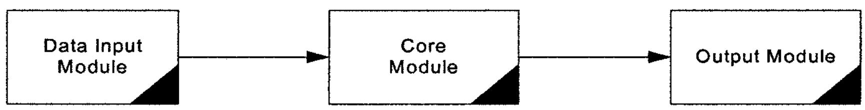


Figure 7.1 Basic structure of C-EPAS

Each module will serve for a system function, thus figure 7.1 can be elaborated to Figure 7.2.

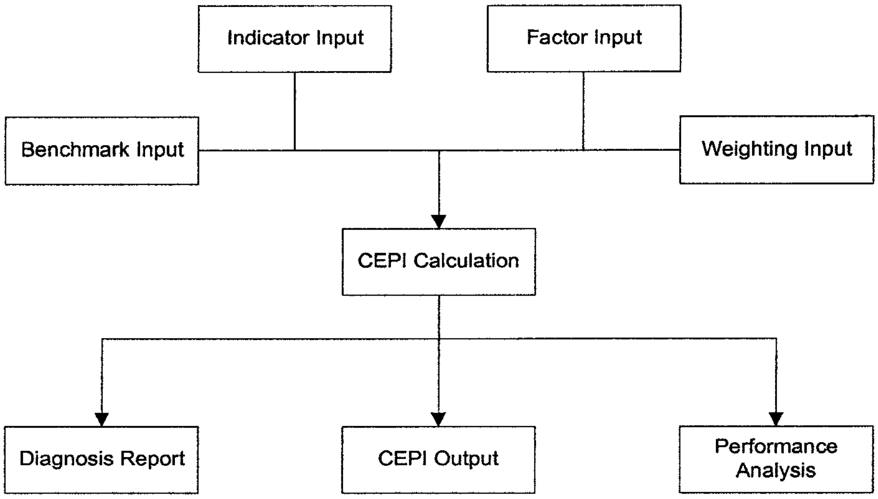


Figure 7.2 Expanded structure of C-EPAS

7.2.1 Data input module

The data input module is a basic module of the C-EPAS computing system. It serves for recording and sorting data inputs. The module also enables modifications of inputted data. Thus this module has two main functions including data input and data renew.

Data to be input and recorded include four groups:

- Data about the indicators measuring a contractor's environmental performance during construction process, which are structured in two levels;
- Data about the factors affecting a contractor's environmental performance during engaging various construction activities, which are structured in three levels;

- Data about the benchmarks used to judge whether various requirements defined in performance indicators have been met in a contractor's actual performance;
- Data about the weightings presenting the relative importance between environmental performance factors in referring to individual indicators

The structure of data input module can be shown in Figure 7.3.

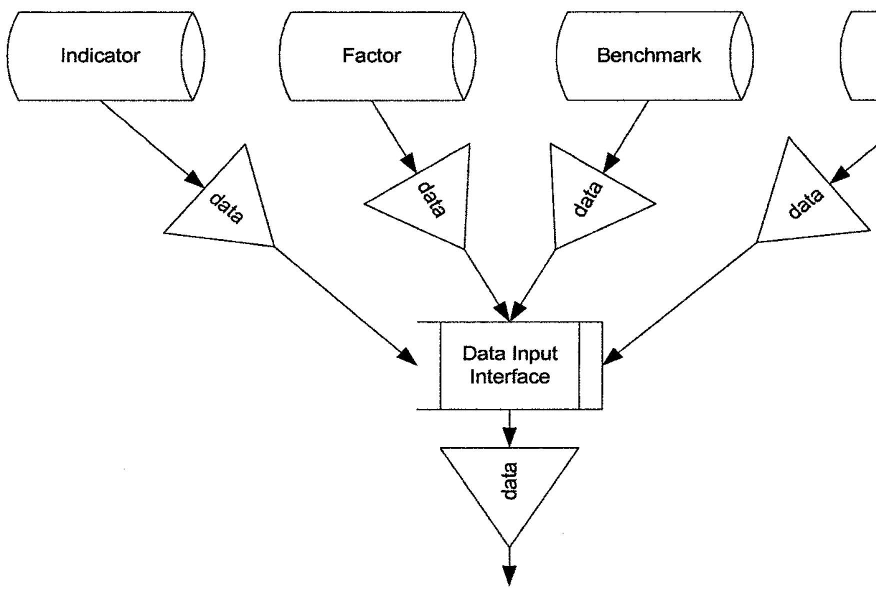


Figure 7.3 Date flow of data input module

7.2.2 Core module

The core module of the C-EPAS computing system serves for calculating the values of various parameters. The calculation models developed through employing USFDS method in Chapter 6 have been built in the core module. Thus when data are received from operating the first module (data input module), various calculations can be run. The process of operating the core module can be illustrated in Figure 7.4.

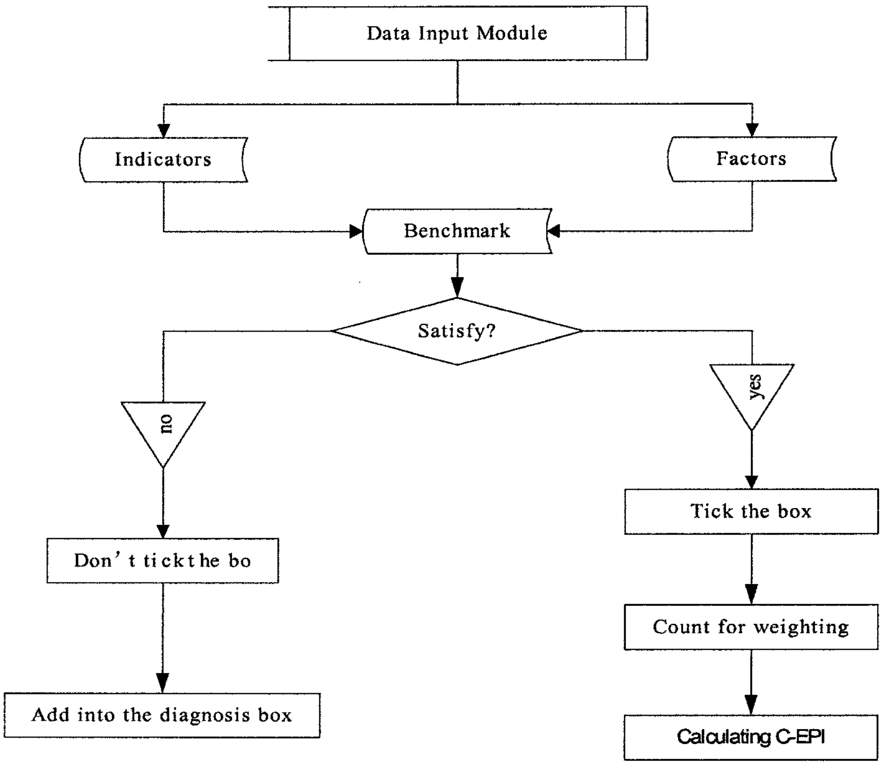


Figure 7.4 Date flow of core module

The flow chart of the module involves a number of operations, including the collection of those benchmarks, which have been satisfactorily met in contractor's practice, and calculating weightings and calculating the value of C-EPI. Those benchmarks, which have not been satisfied in the practice, will be marked and recorded in the diagnosis list. The diagnosis list includes those areas where the concerned contractor's environmental performance is not satisfied according to benchmarks proposed.

7.2.3 Output module

The output module in C-EPAS computing system serves for producing reports about: (1) the calculation result of C-EPI; (2) the distribution charts presenting a contractor's environmental performance between major performance indicators; and (3) diagnosis results on poor performance areas. The samples of these reports will be presented in next chapter where a case study is conducted for demonstrating the use of C-EPAS.

The operation procedures of the output module can be illustrated in Figure 7.5.

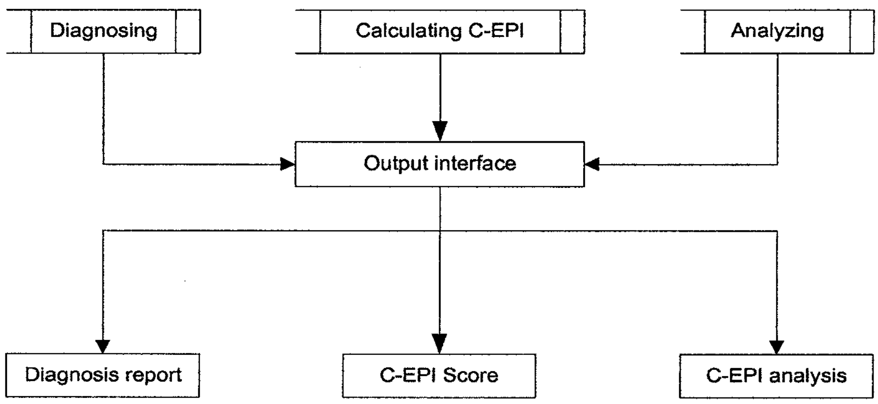


Figure 7.5 Data flow of output module

By linking the three modules, an integrated structure of C-EPAS can be formulated as shown in Figure7.6.

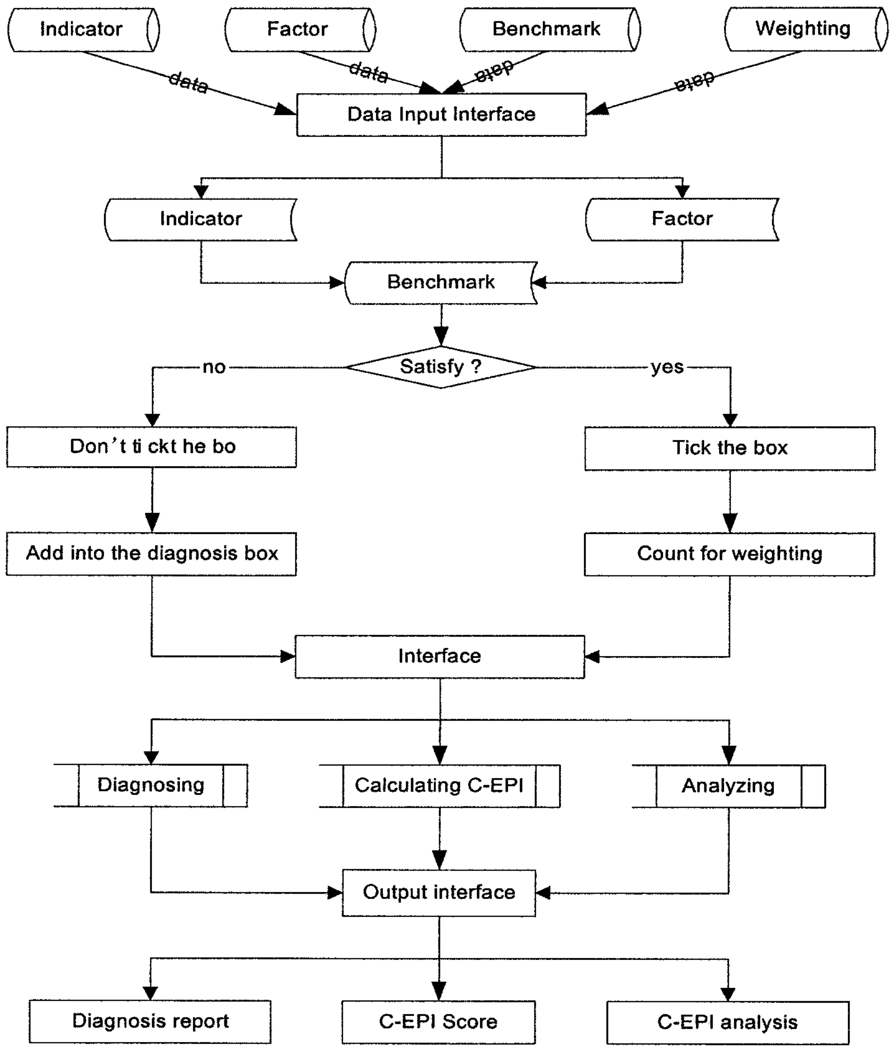


Figure 7.6 Data flow of general structure

7.3 Database in C-EPAS

The PARADOX database technique is adopted for formulating databases in C-EPAS. PARADOX is widely used in the program languages Borland Delphi and Visual Basic, which are used to develop C-EPAS in this research.

Like all the other familiar database types such as dBase, Informix, Oracle, the PARABOX database can be operated by SQL (Structural Query Language), which provide a mechanism to operate different types of database and now become a universal database operating language.

The structure recording data is designed to table format, as shown in Table 7.1. After the input of the into table-format database (shown in Table 7.1), data will be stored in computer. The layout of the database in computer can be shown in Figure 7.7, 7.8 and 7.9.

Figure 7.7 is the computer layout of the database for indicators; Figure 7.8 is the data base layout for benchmarks; and figure 7.9 is the data base layout for storing weightings.

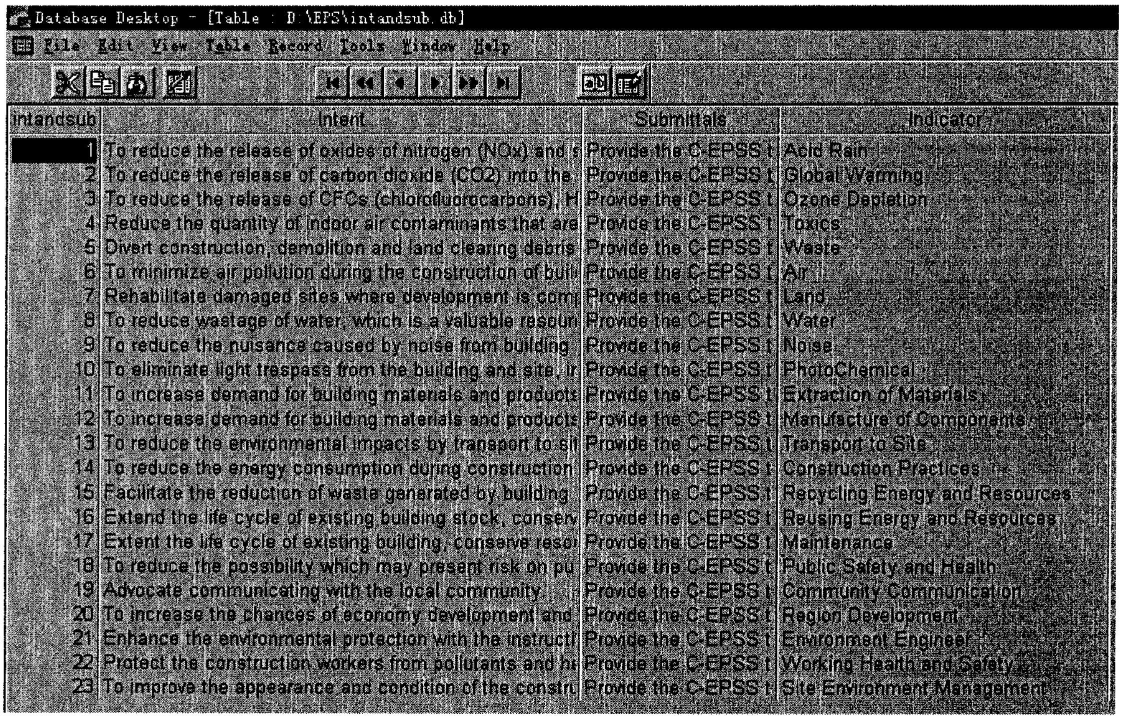
Table 7.1 Sample table format for recording data

Eco	EE	Sus	PA	HA
8 optional credits				

Acid rain

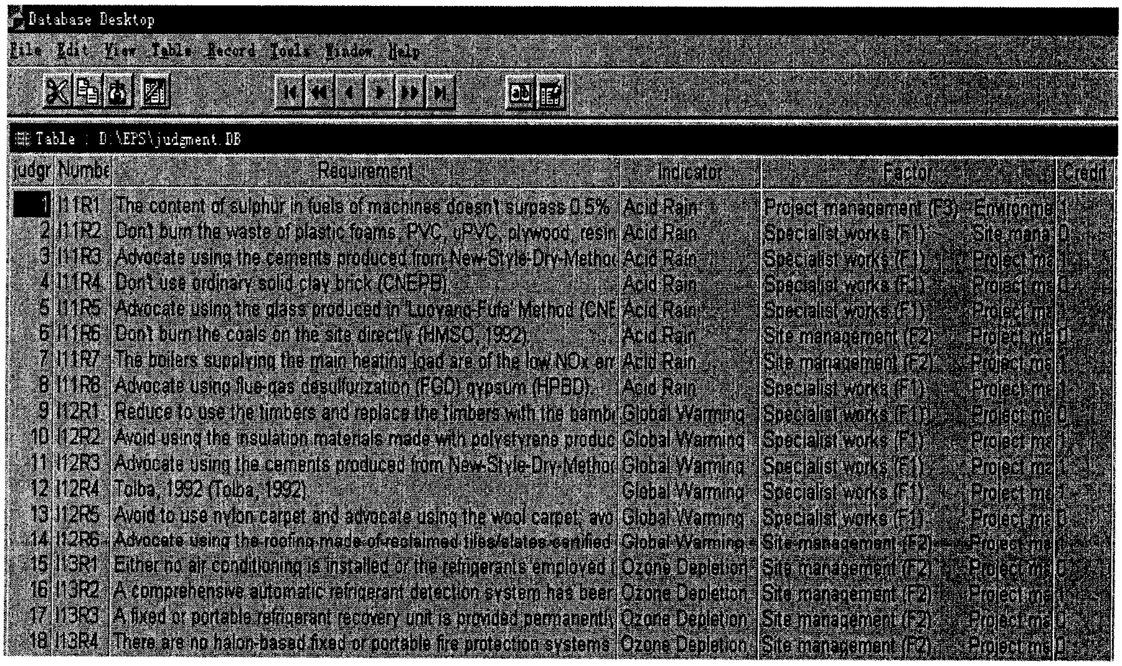
Contribution Factor	INTENT	Credit
	To reduce the release of oxides of nitrogen (NO_x) and sulphur dioxide (SO_2) into the atmosphere on the site and reduce the use of materials that have high emission during the extraction and production.	
Contribution Factor	**BENCHMARKS**	
Project management (F_3) Environment policy (F_5)	The content of sulphur in fuels of machines doesn't surpass 0.5% (CNEPB).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3)	Don't burn the waste of plastic foams, PVC, uPVC, plywood, resin and polymer bonded slates, organic coating, synthetic fibres, carpet fibres, rubbers, etc on the site (Woolley, 1997).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Advocate using the cements produced from New-Style-Dry-Method-Kiln (CNEPB).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4) Environment policy (F_5)	Don't use ordinary solid clay brick (CNEPB).	☐

Specialist works (F_1) Project management (F_3) Technology (F_4)	Advocate using the glass produced in 'Luoyang-Fufa' Method (CNEPB).	☐
Site management (F_2) Project management (F_3)	Don't burn the coals on the site directly (HMSO, 1992).	☐
Site management (F_2) Project management (F_3) Technology (F_4)	The boilers supplying the main heating load are of the low NO_x emitting type with burner emissions of less than 200 mg/kWh of fuel consumed, when running at full-load output (BREEAM).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Advocate using flue-gas desulphurization (FGD) gypsum (HPBD).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	



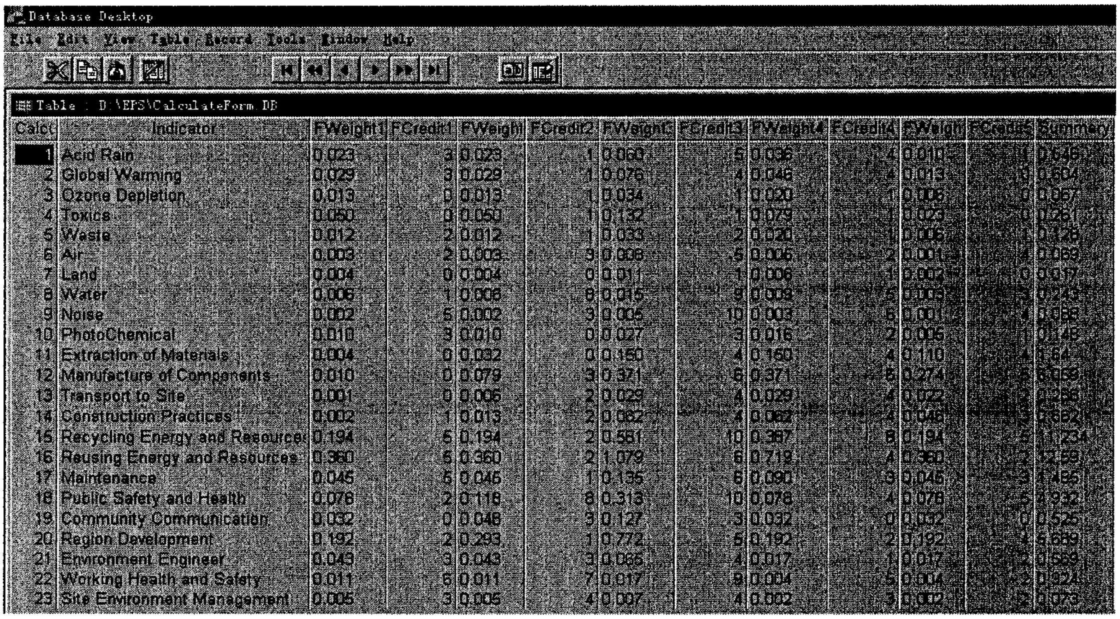
intandsub	Intent	Submittals	Indicator
1	To reduce the release of oxides of nitrogen (NOx) and s	Provide the C-EPSS t	Acid Rain
2	To reduce the release of carbon dioxide (CO2) into the	Provide the C-EPSS t	Global Warming
3	To reduce the release of CFCs (chlorofluorocarbons), H	Provide the C-EPSS t	Ozone Depletion
4	Reduce the quantity of indoor air contaminants that are	Provide the C-EPSS t	Toxics
5	Divert construction, demolition and land clearing debris	Provide the C-EPSS t	Waste
6	To minimize air pollution during the construction of buil	Provide the C-EPSS t	Air
7	Rehabilitate damaged sites where development is com	Provide the C-EPSS t	Land
8	To reduce wastage of water, which is a valuable resour	Provide the C-EPSS t	Water
9	To reduce the nuisance caused by noise from building	Provide the C-EPSS t	Noise
10	To eliminate light trespass from the building and site, ir	Provide the C-EPSS t	PhotoChemical
11	To increase demand for building materials and products	Provide the C-EPSS t	Extraction of Materials
12	To increase demand for building materials and products	Provide the C-EPSS t	Manufacture of Components
13	To reduce the environmental impacts by transport to sit	Provide the C-EPSS t	Transport to Site
14	To reduce the energy consumption during construction	Provide the C-EPSS t	Construction Practices
15	Facilitate the reduction of waste generated by building	Provide the C-EPSS t	Recycling Energy and Resources
16	Extend the life cycle of existing building stock, conserv	Provide the C-EPSS t	Reusing Energy and Resources
17	Extent the life cycle of existing building, conserve reso	Provide the C-EPSS t	Maintenance
18	To reduce the possibility which may present risk on pu	Provide the C-EPSS t	Public Safety and Health
19	Advocate communicating with the local community.	Provide the C-EPSS t	Community Communication
20	To increase the chances of economy development and	Provide the C-EPSS t	Region Development
21	Enhance the environmental protection with the instructi	Provide the C-EPSS t	Environment Engineer
22	Protect the construction workers from pollutants and h	Provide the C-EPSS t	Working Health and Safety
23	To improve the appearance and condition of the constru	Provide the C-EPSS t	Site Environment Management

Figure 7.7 Typical data segment for storing indicators



judgr	Numbe	Requirement	Indicator	Factor		Credit
1	I11R1	The content of sulphur in fuels of machines doesn't surpass 0.5%	Acid Rain	Project management (F3)	Environme	1
2	I11R2	Don't burn the waste of plastic foams, PVC, uPVC, plywood, resin	Acid Rain	Specialist works (F1)	Site mana	0
3	I11R3	Advocate using the cements produced from New-Style-Dry-Metho	Acid Rain	Specialist works (F1)	Project ma	1
4	I11R4	Don't use ordinary solid clay brick (CNEPB).	Acid Rain	Specialist works (F1)	Project ma	0
5	I11R5	Advocate using the glass produced in 'Luoyang-Fufa' Method (CNE	Acid Rain	Specialist works (F1)	Project ma	1
6	I11R6	Don't burn the coals on the site directly (HMSO, 1992).	Acid Rain	Site management (F2)	Project ma	0
7	I11R7	The boilers supplying the main heating load are of the low NOx an	Acid Rain	Site management (F2)	Project ma	1
8	I11R8	Advocate using flue-gas desulfurization (FGD) gypsum (HPBD).	Acid Rain	Specialist works (F1)	Project ma	1
9	I12R1	Reduce to use the timbers and replace the timbers with the bamb	Global Warming	Specialist works (F1)	Project ma	0
10	I12R2	Avoid using the insulation materials made with polystyrene produc	Global Warming	Specialist works (F1)	Project ma	1
11	I12R3	Advocate using the cements produced from New-Style-Dry-Metho	Global Warming	Specialist works (F1)	Project ma	1
12	I12R4	Tolba, 1992 (Tolba, 1992).	Global Warming	Specialist works (F1)	Project ma	1
13	I12R5	Avoid to use nylon carpet and advocate using the wool carpet; avo	Global Warming	Specialist works (F1)	Project ma	0
14	I12R6	Advocate using the roofing made of reclaimed tiles/slates certified	Global Warming	Site management (F2)	Project ma	[illegible]
15	I13R1	Either no air conditioning is installed or the refrigerants employed	Ozone Depletion	Site management (F2)	Project ma	0
16	I13R2	A comprehensive automatic refrigerant detection system has beer	Ozone Depletion	Site management (F2)	Project ma	1
17	I13R3	A fixed or portable refrigerant recovery unit is provided permanently	Ozone Depletion	Site management (F2)	Project ma	0
18	I13R4	There are no halon-based fixed or portable fire protection systems	Ozone Depletion	Site management (F2)	Project ma	0

Figure 7.8 Typical data segment for storing benchmarks and contribution factor



Calc(	Indicator	FWeight1	FCredit1	FWeigh	FCredit2	FWeight3	FCredit3	FWeight4	FCredit4	FWeigh	FCredit5	Summary
1	Acid Rain	0.023	3	0.023	1	0.060	5	0.036	4	0.010	1	0.646
2	Global Warming	0.029	3	0.029	1	0.076	4	0.046	4	0.013	0	0.604
3	Ozone Depletion	0.013	0	0.013	1	0.034	1	0.020	1	0.006	0	0.067
4	Toxics	0.050	0	0.050	1	0.132	1	0.079	1	0.023	0	0.261
5	Waste	0.012	2	0.012	1	0.033	2	0.020	1	0.006	1	0.128
6	Air	0.003	2	0.003	9	0.008	5	0.006	2	0.001	4	0.063
7	Land	0.004	0	0.004	0	0.011	1	0.006	1	0.002	0	0.017
8	Water	0.006	1	0.006	8	0.015	9	0.009	5	0.003	3	0.243
9	Noise	0.002	5	0.002	3	0.005	10	0.003	6	0.001	4	0.068
10	PhotoChemical	0.010	3	0.010	0	0.027	3	0.016	2	0.005	1	0.148
11	Extraction of Materials	0.004	0	0.032	0	0.160	4	0.160	4	0.110	4	1.64
12	Manufacture of Components	0.010	0	0.079	3	0.371	6	0.371	6	0.274	5	[illegible]
13	Transport to Site	0.001	0	0.006	2	0.029	4	0.029	4	0.022	2	0.288
14	Construction Practices	0.002	1	0.013	2	0.082	4	0.082	4	0.046	3	0.662
15	Recycling Energy and Resource	0.194	5	0.194	2	0.581	10	0.387	8	0.194	5	1.234
16	Reusing Energy and Resources	0.360	5	0.360	2	1.079	6	0.719	4	0.360	2	2.59
17	Maintenance	0.045	5	0.045	1	0.135	6	0.090	3	0.045	3	1.485
18	Public Safety and Health	0.078	2	0.118	8	0.313	10	0.078	4	0.078	5	4.932
19	Community Communication	0.032	0	0.048	3	0.127	3	0.032	0	0.032	0	0.525
20	Region Development	0.192	2	0.293	1	0.772	5	0.192	2	0.192	4	5.689
21	Environment Engineer	0.043	3	0.043	3	0.066	4	0.017	1	0.017	2	0.569
22	Working Health and Safety	0.011	6	0.011	7	0.017	9	0.004	5	0.004	2	0.324
23	Site Environment Management	0.005	3	0.005	4	0.007	4	0.002	3	0.002	2	0.073

Figure 7.9 Typical data segment for storing weightings and credits

7.4 Application procedures of C-EPAS

The application of C-EPAS will follow a number of procedures. These procedures are flowcharted as shown in Figure 7.10. There are three major procedures, namely, inputting data, calculating and producing reports. In the following discussion, assumed data are used to display the use of these procedures. The platform of Windows 98 by using Borland Delphi 5.0 is adopted to operate the system as this platform has the advantage with good capacity of system programming and database management.

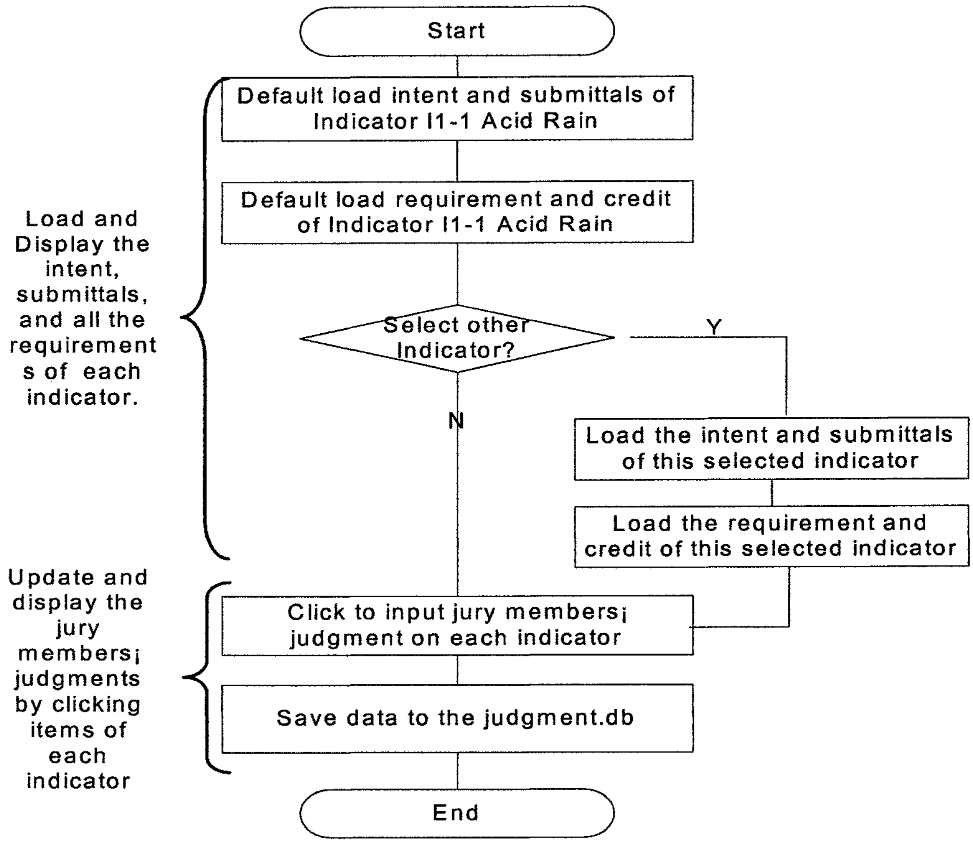


Figure 7.10 Operating process of data input module

7.4.1 Data input

Having built the database structure for C-EPAS, as shown in Figure 7.7, 7.8 and 7.9, the actual operation of data input can be undertaken. In operating the data input module, applicant needs to input his/her judgment on what benchmarks which have been satisfactorily met in contractor's practice. A simple tick will do this. Figure 7.11 presents the sample layout for processing this operation.

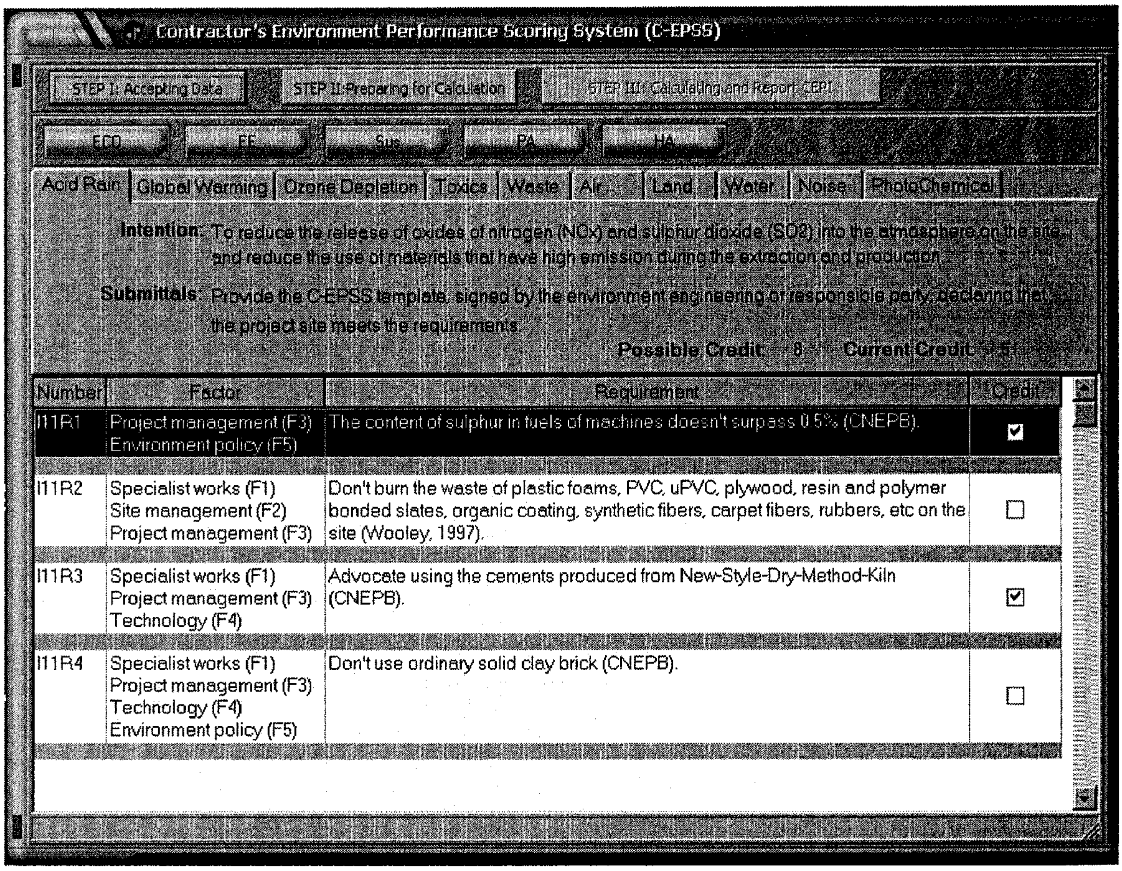
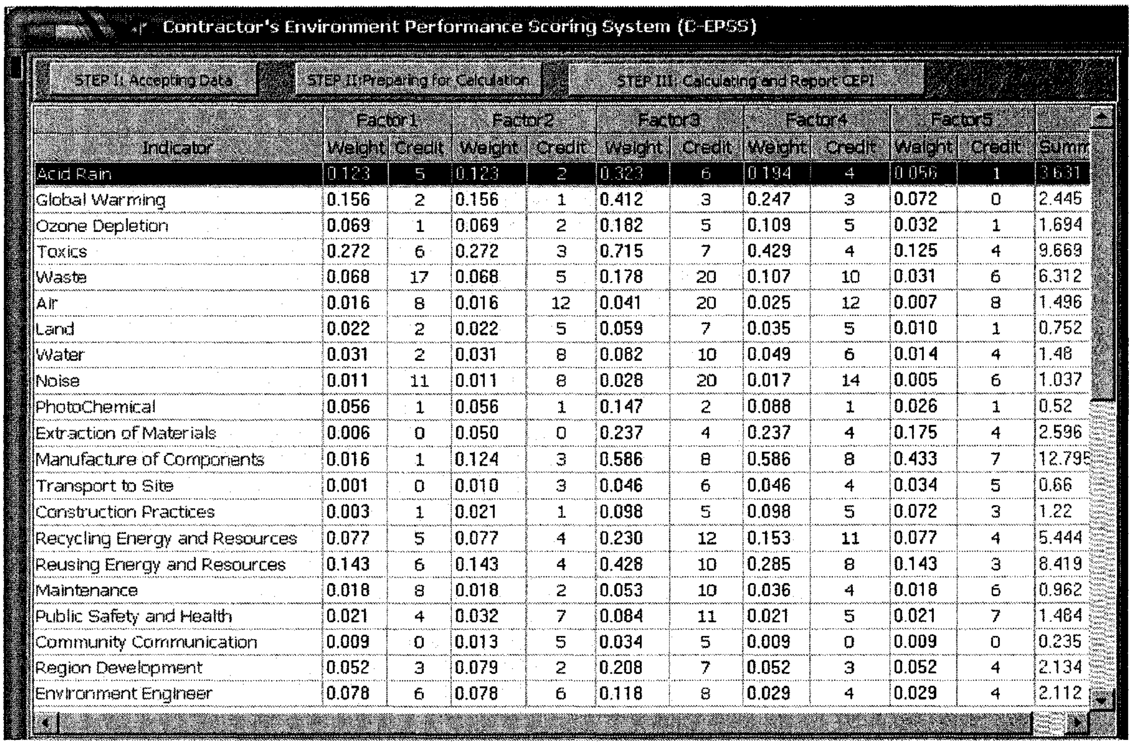


Figure 7.11 Main Interface—Data Input Module

7.4.2 Calculating

After inputting all data, the applicant can modify if necessary any data inputted. The data can be confirmed after modification. The confirmed data will be used for calculation. The number of credits for each indicator will be counted. The indicator credits, together with weightings, will be recorded in a table format. And the sample layout of this calculation process is shown in Figure 7.12.



Indicator	Factor1		Factor2		Factor3		Factor4		Factor5		
	Weight	Credit	Weight	Credit	Weight	Credit	Weight	Credit	Weight	Credit	Summ
Acid Rain	0.123	5	0.123	2	0.323	6	0.194	4	0.056	1	3.631
Global Warming	0.156	2	0.156	1	0.412	3	0.247	3	0.072	0	2.445
Ozone Depletion	0.069	1	0.069	2	0.182	5	0.109	5	0.032	1	1.694
Toxics	0.272	6	0.272	3	0.715	7	0.429	4	0.125	4	9.669
Waste	0.068	17	0.068	5	0.178	20	0.107	10	0.031	6	6.312
Air	0.016	8	0.016	12	0.041	20	0.025	12	0.007	8	1.496
Land	0.022	2	0.022	5	0.059	7	0.035	5	0.010	1	0.752
Water	0.031	2	0.031	8	0.082	10	0.049	6	0.014	4	1.48
Noise	0.011	11	0.011	8	0.028	20	0.017	14	0.005	6	1.037
PhotoChemical	0.056	1	0.056	1	0.147	2	0.088	1	0.026	1	0.52
Extraction of Materials	0.006	0	0.050	0	0.237	4	0.237	4	0.175	4	2.596
Manufacture of Components	0.016	1	0.124	3	0.586	8	0.586	8	0.433	7	12.79
Transport to Site	0.001	0	0.010	3	0.046	6	0.046	4	0.034	5	0.66
Construction Practices	0.003	1	0.021	1	0.098	5	0.098	5	0.072	3	1.22
Recycling Energy and Resources	0.077	5	0.077	4	0.230	12	0.153	11	0.077	4	5.444
Reusing Energy and Resources	0.143	6	0.143	4	0.428	10	0.285	8	0.143	3	8.419
Maintenance	0.018	8	0.018	2	0.053	10	0.036	4	0.018	6	0.962
Public Safety and Health	0.021	4	0.032	7	0.084	11	0.021	5	0.021	7	1.484
Community Communication	0.009	0	0.013	5	0.034	5	0.009	0	0.009	0	0.235
Region Development	0.052	3	0.079	2	0.208	7	0.052	3	0.052	4	2.134
Environment Engineer	0.078	6	0.078	6	0.118	8	0.029	4	0.029	4	2.112

Figure 7.12 Interface of calculating function

7.4.3 Producing reports

In this procedure, applicant can produce several products by choosing different functions designed in the system C-EPAS. Typical reports include the results of C-EPI and diagnosis report. The results of C-EPI include the value of C-EPI and a distribution of the value among the major indicators. Figure 7.13 displays a sample of C-EPI results. The diagnosis report includes a list of areas or items where the assessed contractor has not achieved the environmental performance requirements specified with relevant benchmarks. Figure 7.14 displays a sample diagnosis report.

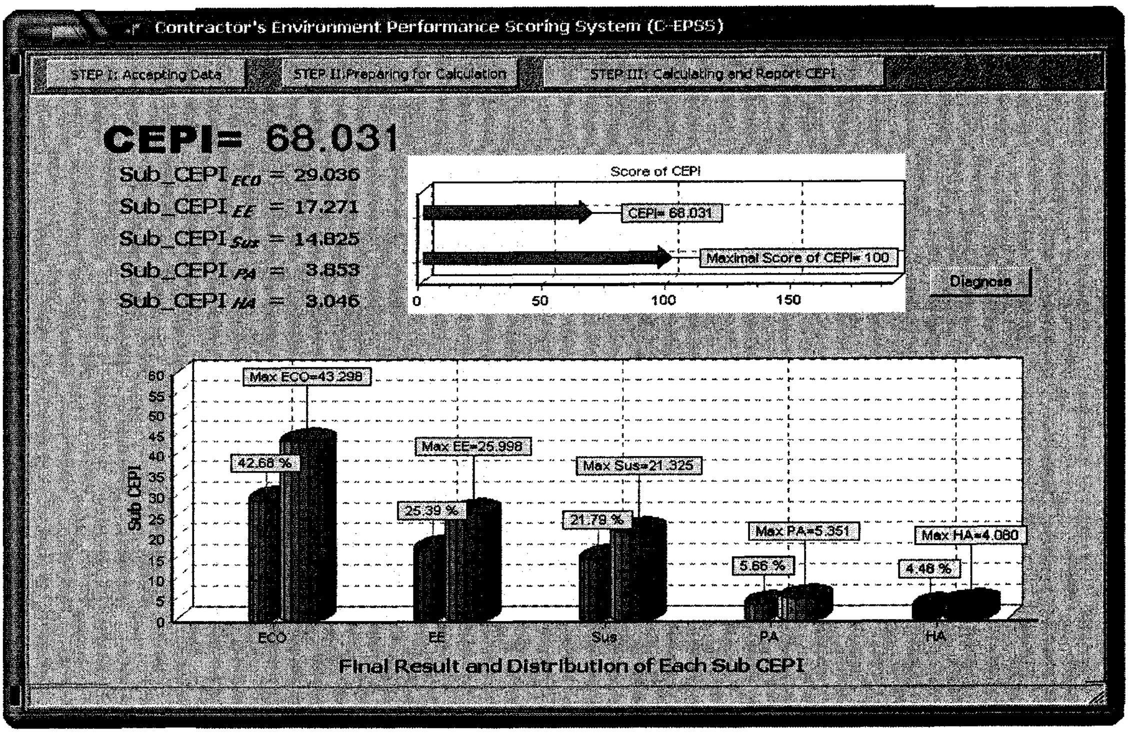


Figure 7.13 Interface of reporting, analyzing CEPI and diagnosing

Dignosing Result

Establish a procedure to ensure that relevant staffs have continuous access to the legal requirements (GGCP).

Establish a procedure to keep track of changes to environmental requirements and to update the environmental requirements accordingly (GGCP).

A flush-out period, beginning as soon as systems are operable and before or during the furniture, fittings, and equipment installation phase. The process involves flushing the building with 100% outside air for a period of not less than 20 days (HPBG).

Non-toxic interventions will be emphasized at all times on sites (HPBGF).

Supply enough containers to hold all wastes generated, and without overflow, between collection days (HPBG).

Wherever possible, construction materials should be stored on racks approximately 18 in/46cm above ground (or floor) in order to prevent creation of rodent (or other) pest harborage, and to enhance inspection procedures (HPBG).

Store potentially harmful materials with roofed, secondary containment to ensure that any spills are contained and to minimize contaminated stormwater run-off (GGCP).

Figure 7.14 Interface of diagnosing result report

7.5 Summary

This chapter has developed a computer-aided system for operating C-EPAS. The major functions of this system are designed to (1) record and sort out data; (2) conduct calculations, which is core function; (3) produce the results of using the system, including i) the calculation result of C-EPI; ii) the distribution charts presenting a contractor's environmental performance between major performance indicators; and iii) diagnosis results on poor performance areas.

The principles and procedures of this computing package have been analyzed and formulated. The application of this system will be demonstrated in next chapter by using a case study.

Chapter 8:

Application of C-EPAS – A Case Study

CHAPTER 8: APPLICATION OF C-EPAS – A CASE STUDY

8.1 Introduction

This chapter is test the applicability of C-EPAS by using a case study. This case study concerns an on-going high rising real estate project undertaken by the China Overseas Construction Company Ltd. The project named 'China Overseas Health City' is located in Tianhe District of Guangzhou City in China, being adjacent to the Guangzhou Olympic Playground. The total construction area of the project is 230,000 M^2, and it schedules to be completed in the end of 2003. The major purpose of this case study is to demonstrate how a contactor's environmental performance in engaging a particular construction project can be evaluated and how useful the diagnosis result from the assessment will be for the contractor to further improve its environmental performance.

In conducting the case study, the author of this study managed to have the support from the project management team engaged in this project. A group of three professionals participated the exercise of the case study. The three professionals include the site manager for the project, a site engineer and the project manager of the project. The whole exercise in conducting this case study took 4 hours. For the first 45 minutes, the three professionals were given an overall briefing about the principles of the C-EPAS system and the procedures of using the system, and queries were also raised by the participants. The preliminary session was to make sure that all participants have a common understanding about the principles of the system, thus data inputted by them would be consistent when the procedures of using the system started. In particular, the participants need to building up a clear understanding about the implications of these performance indicators and the factors affecting environmental performance during construction process. These factors and indicators have been well discussed in Chapter 3 and Chapter 4, as shown in Table 3.1 and table 4.15.

8.2 Results of using C-EPAS in the Case Study

The procedures of applying C-EPAS, discussed in the previous chapter, are used to the case study.

8.2.1 Data input

In the process of inputting necessary data in case study, the data input layout, illustrated before in Figure 7.11 in chapter 7, was presented to the participation panel. The participants were asked to select those benchmarks where they thought that contractor's actual environmental performance was satisfied. For inputting this information, three participants were allowed to discuss when there was different views but asked to input an agreed choice. Figure 8.1 is the part of results from data input. Upon the completion of data input, the database, which records all necessary data, will be formed, as shown in Figure 8.2

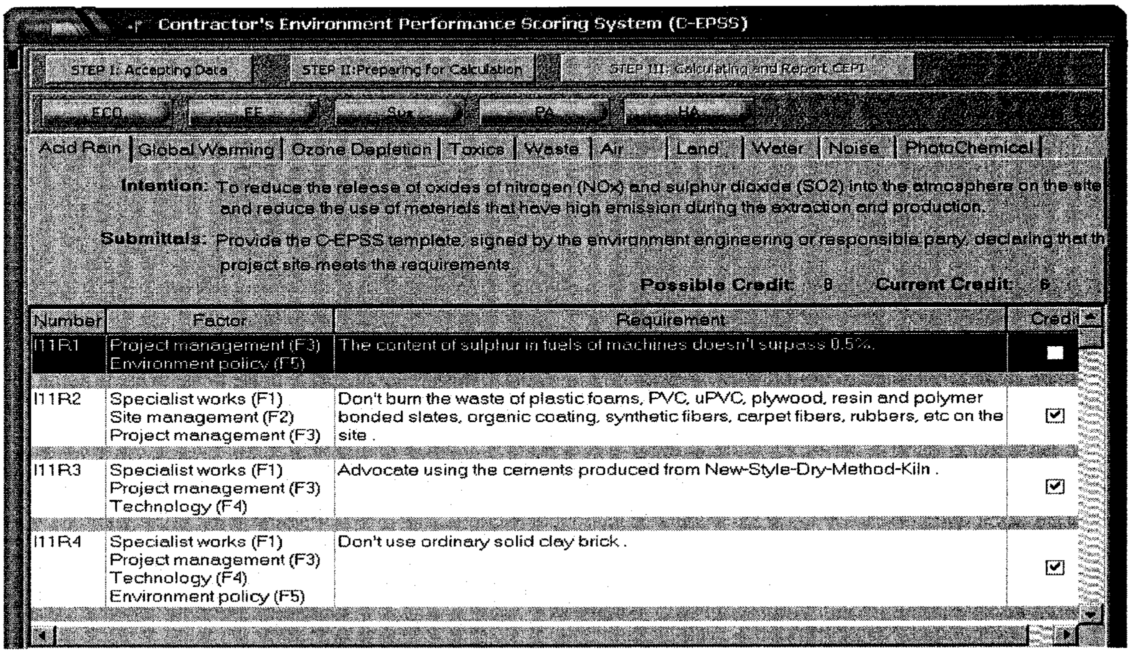
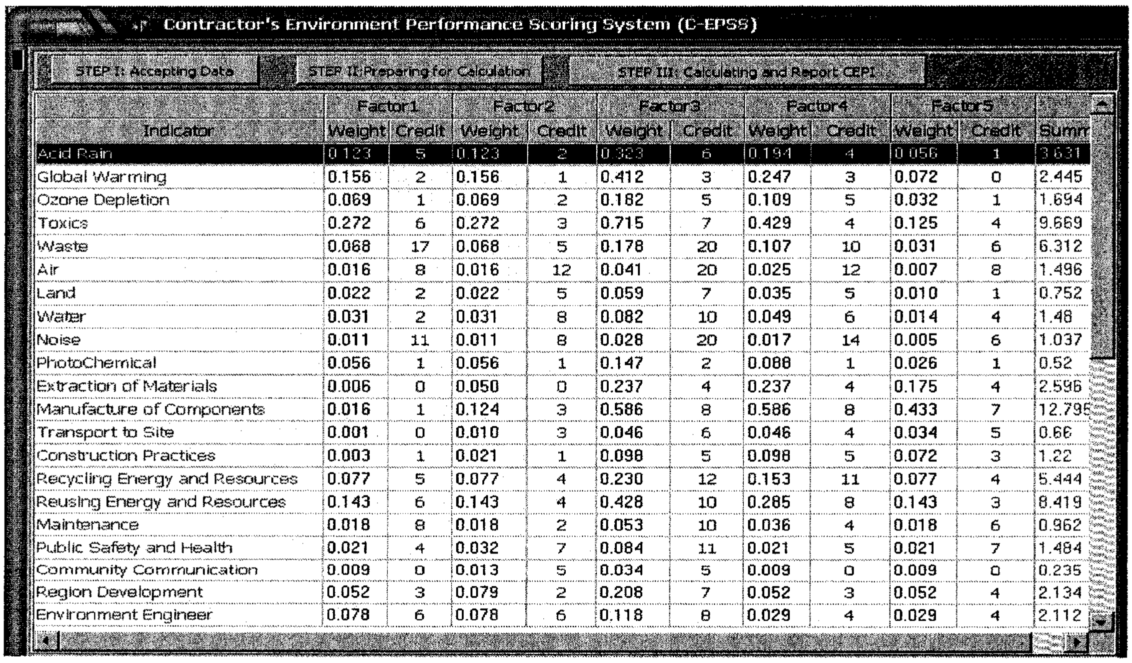


Figure 8.1 Inputting data of contractor's environmental performance in the acid rain



Indicator	Factor1 Weight	Factor1 Credit	Factor2 Weight	Factor2 Credit	Factor3 Weight	Factor3 Credit	Factor4 Weight	Factor4 Credit	Factor5 Weight	Factor5 Credit	Summ
Acid Rain	0.123	5	0.123	2	0.323	6	0.194	4	0.056	1	3.631
Global Warming	0.156	2	0.156	1	0.412	3	0.247	3	0.072	0	2.445
Ozone Depletion	0.069	1	0.069	2	0.182	5	0.109	5	0.032	1	1.694
Toxics	0.272	6	0.272	3	0.715	7	0.429	4	0.125	4	9.669
Waste	0.068	17	0.068	5	0.178	20	0.107	10	0.031	6	6.312
Air	0.016	8	0.016	12	0.041	20	0.025	12	0.007	8	1.496
Land	0.022	2	0.022	5	0.059	7	0.035	5	0.010	1	0.752
Water	0.031	2	0.031	8	0.082	10	0.049	6	0.014	4	1.48
Noise	0.011	11	0.011	8	0.028	20	0.017	14	0.005	6	1.037
PhotoChemical	0.056	1	0.056	1	0.147	2	0.088	1	0.026	1	0.52
Extraction of Materials	0.006	0	0.050	0	0.237	4	0.237	4	0.175	4	2.596
Manufacture of Components	0.016	1	0.124	3	0.586	8	0.586	8	0.433	7	12.795
Transport to Site	0.001	0	0.010	3	0.046	6	0.046	4	0.034	5	0.66
Construction Practices	0.003	1	0.021	1	0.098	5	0.098	5	0.072	3	1.22
Recycling Energy and Resources	0.077	5	0.077	4	0.230	12	0.153	11	0.077	4	5.444
Reusing Energy and Resources	0.143	6	0.143	4	0.428	10	0.285	8	0.143	3	8.419
Maintenance	0.018	8	0.018	2	0.053	10	0.036	4	0.018	6	0.962
Public Safety and Health	0.021	4	0.032	7	0.084	11	0.021	5	0.021	7	1.484
Community Communication	0.009	0	0.013	5	0.034	5	0.009	0	0.009	0	0.235
Region Development	0.052	3	0.079	2	0.208	7	0.052	3	0.052	4	2.134
Environment Engineer	0.078	6	0.078	6	0.118	8	0.029	4	0.029	4	2.112

Figure 8.2 Overall data inputted for contractor's environmental performance

8.2.2 Calculation

By using the data in Figure 8.2, calculations can be conducted. The results of the calculations are illustrated in Figure 8.3.

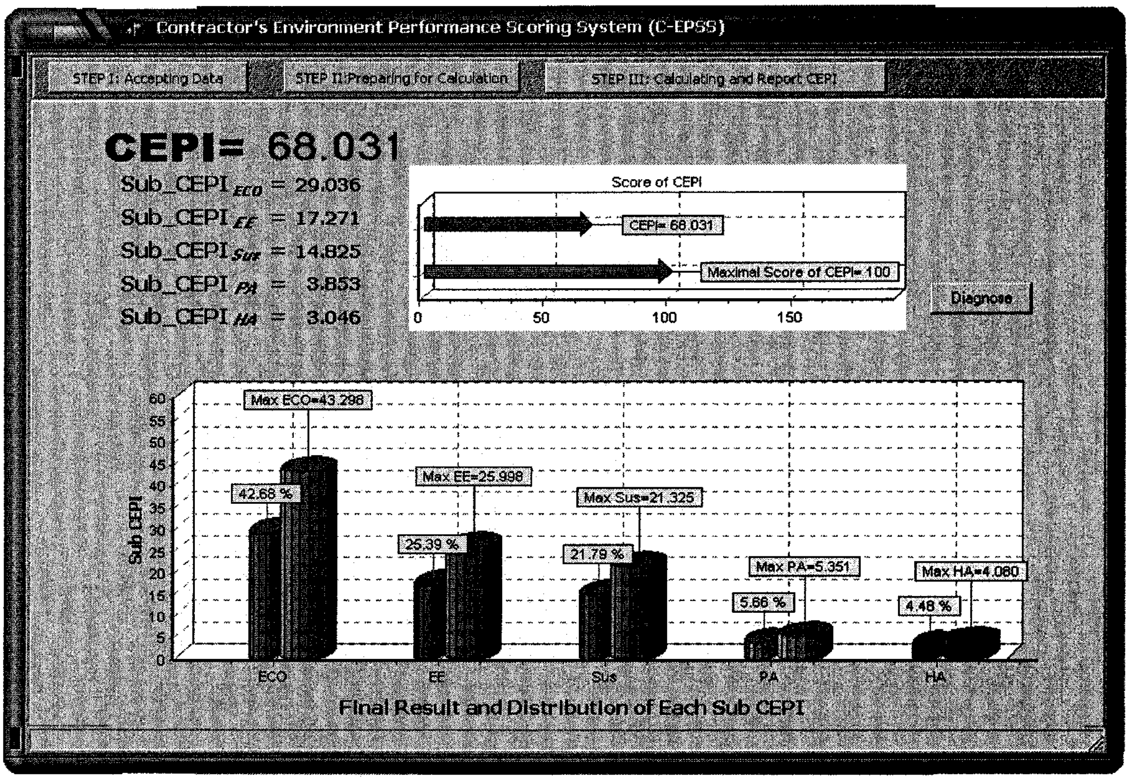


Figure 8.3 The score figure of CEPI of example project

It can be seen that this particular contractor has obtained a score of 68.031 (out of 100) indicating his environmental performance during on-site construction. In fact, the score distributions between the five indicative areas (namely, ecology, embodied energy, sustainability, public aspect, human aspect) are also displayed in Figure 8.3. It can be seen that a score of 29.036 is obtained for the area Ecology, i.e., $CEPI_{ECO}$=29.036; and other results include the score for Embodied Energy $CEPI_{EE}$=17.271; for Sustainability $CEPI_{Sus}$=14.825, for Public Aspect $CEPI_{PA}$=3.853, and for Human Aspect $CEPI_{HA}$=3.046. These values can be converted to the contribution percentages from these five areas to the total performance index, where ecology indicator contributes 42.68%; embodied energy contributes 25.39%; sustainability contributes 21.79%; public aspect contributes 5.66% and human aspect contributes 4.48%. It shows that contractor's environmental performance in protecting ecologic issues is best compared to other areas such as public aspect, human aspect.

8.2.3 Diagnosing

The diagnosing procedure built in the C-EPAS is to assist the contractor to diagnose its poor environmental performance areas. These weak areas will be collected and printed out through operating C-EPAS. The results of the diagnosis report from this case study are included in Table 8.1~8.6. It is suggested that the contractor can take this diagnosis report as useful reference for assisting him in identifying necessary measures for further improving his environmental performance. In fact, by the end of running this system, output results attracted good interests among the participants who helped the exercise of this case study. Whilst they made some comments about the possible improvement of the system, they considered that the results from using the system could help them in further improving their environmental performance.

Table 8.1 Page one of the diagnosis report from this case study

Dignosing Result

The content of sulphur in fuels of machines doesn't surpass 0.5%.

The boilers supplying the main heating load are of the low NOx emitting type with burner emissions of less than 200 mg/kWh of fuel consumed, when running at full-load output .

Reduce to use the timbers and replace the timbers with the bamboo and other materials.

Reduce or avoid using the materials made of synthetic polymer such as fiber reinforced cement roofing and advocate using the alternative roofing materials.

Avoid to use nylon carpet and advocate using the wool carpet; avoid to use synthetic foams underlay and advocate using Hessian/felt under materials; avoid to use vinyl/PVC smooth coverings and advocate using linoleum, cork.

Either no air conditioning is installed or the refrigerants employed in the air conditioning have an ozone depletion potential of less than 0.06 .

There are no halon-based fixed or portable fire protection systems on the sites .

The paints contain no lead .

Reduce the workers absorbing the vapors of components chemicals during in-situ foaming .

Reduce the workers the risks associated with insulation fibres such as glass fibre, which come in much smaller sizes than structural glass fibres .

Eliminate unnecessary finishes and other products on sites where they are not required.

List materials to be salvaged for reuse in the project in the contract documents .

Providing facilities for the sorting of waste and recovery of recyclable materials .

Use durable, reusable hoarding to replace timber hoarding.

Research alternative products and practices, which generate reduced quantities or less dangerous types of chemical waste (GGCP).

CEPI-Contractor's Environmental Performance Index System Page 1

Table 8.2 Page two of the diagnosis report from this case study

Dignosing Result

Use products and materials with reduced packaging and/or encourage manufactures to reuse or recycle their original packaging materials (GGCP).

If asbestos waste is identified during construction works, it should be handled and disposed of in accordance with the Environmental Protection Department's Code of Practice on the Handling, Transportation and Disposal of Asbetos Waste (GGCP).

Install mains-operated smoke alarms with battery back-up at appropriate locations (BREEAM).

There has no visible gaps allowing air to bypass the filter (BREEAM).

Install a permanent carbon dioxide (CO2) monitoring system that provides feedback on space ventilation performance in a form that affords operational adjustments. (LEED).

The site should offer support facilities for bicycling, mass transit, electric vehicles, carpooling, and other less-polluting means of transportation (LEED).

If air handlers must be used during construction, filtration media with a Minimum efficiency Reporting Value (MERV) of 8 must be used at each return air grill, as determined by ASHRAE 52.2-1999 (LEED).

Evaluate sources of contamination from neighboring buildings and soil contamination, Incorporate measures to prevent soil gas from being drawn into the building. Waterproof the slab-on-grade to limit moisture transport (HPBG).

Avoid occupant exposure to airborne pollutants, perform cleaning and pest control activities when the building is largely unoccupied (HPBG).

Ensure that the contractor uses metal ductwork instead of substituting fiberglass (HPBG).

Flush the building with 100% outside air for a period of mot less than 30 days beginning as soon as systems are operable and continuing throughout installation of furniture, fitting, and equipment. (HPBG).

Inspect vehicles regularly to ensure that exhaust emissions are not causing nuisance, such as dark smoke emission (GGCP).

If a power generation is used on-site, maintain it regularly and properly to avoid dark smoke emission (GGCP).

Prevent loss of soil construction by stormwater runoff and prevent sedimentation of storm sever or receiving streams (LEED).

If existing imperviousness is less than or equal to 50%, implement a stormwater management plan that prevents the post-development (LEED)

CEPI-Contractor's Environmental Performance Index System Page 2

Table 8.3 Page three of the diagnosis report from this case study

Dignosing Result

Construct site stormwater treatment systems designed to remove 80% of the average annual post-development total suspended solids (TSS) (LEED).

Use only captured rain or recycled site water to eliminate all potable water use for site irrigation, OR do not install permanent site irrigation systems (LEED).

Undertake measures to reduce water pollution during construction, through adequately designed sediment retention and removal facilities, treatment of wastewater from concrete construction activities (HK-BEAM).

Install an on-site grey water treatment system, to treat grey water for reuse in toilet flushing where seawater is not available (HK-BEAM).

Either with no external warning device OR, where an external audible warning device is fitted, the period of sounding of the device is limited to not more than 20 minutes (BREEAM).

Prevent transmission between rooms by wall, floor, and ceiling assemblies by specifying materials with appropriate sound transmission class ratings. (HPBG).

Erect noise barriers either close to sources or receivers that can achieve a noise reduction of 5-10dB (A) (GGCP).

Locate equipment away from receives (doubling distance will result in a 6dB(A) reduction) (GGCP).

Design exterior lighting such that all exterior luminaries with more than 1000 initial lamp lumens are shielded and all luminaries with more than 3500 initial lamp lumens meet the Full Cutoff IESNA Classification (LEED).

The maximum candela value of all interior lighting shall fall within the building (not out through windows) and the maximum candela value of all exterior lighting shall fall within the property (LEED).

Any luminaire within a distance of 2.5 times its mounting height from the property boundary shall have shielding such that no light from that luminaire crosses the property boundary (LEED).

Of the regionally manufactured materials documented for MR Credit 5.1, use a minimum of 50% of building materials and products that are extracted, harvested or recovered (as well as manufactured) within 500 miles (LEED).

Use materials with recycled content such that post-consumer recycled content constitutes at least 10% of the total value of the materials in the project OR combined post-consumer and 1/2 post-industrial recycled content constitutes at least 20% (LEED).

Of the regionally manufactured materials documented for MR Credit 5.1, use a minimum of 50% of building materials and products that are extracted, harvested or recovered (as well as manufactured) within 500 miles (LEED).

Use materials with recycled content such that post-consumer recycled content constitutes at least 10% of the total value of the materials in the project OR combined post-consumer and 1/2 post-industrial recycled content constitutes at least 20% (LEED).

CEPI-Contractor's Environmental Performance Index System Page 3

Table 8.4 Page four of the diagnosis report from this case study

Dignosing Result

Maintain 100% of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material) AND at least 50% of non-shell areas (interior walls, doors, floor coverings and ceiling systems) (LEED).

Develop and implement a waste management plan, quantifying material diversion goals. Recycle and/or salvage an additional 25% (75% total) of construction, demolition and land clearing waste. (LEED).

Provide alternative fuel vehicles for 3% of building occupants AND provide preferred parking for these vehicles, OR install alternative fuel refueling stations for 3% of the total vehicle parking capacity of the site. (LEED).

No car parking provided (HK-BEAM).

Maintain an additional 25% (100% total) of existing building structure and shell (exterior shin and framing, excluding window assemblies) (LEED).

Maintain 100% of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material) AND at least 50% of non-shell areas (interior walls, doors, floor coverings and ceiling systems) (LEED).

For larger boilers, oxygen trim controls to improve combustion efficiency; draft control inducers which reduce off-cycle losses; demand control for larger boilers, based on variations in heating demand; (HPBG)

Generate energy consumption profiles that identify occurrences of peak loads and develop responsive management strategies for reducing utility bills (HPBG)

Use materials with recycled content such that post-consumer recycled content constitutes at least 10% of the total value of the materials in the project OR combined post-consumer and 1/2 post-industrial recycled content constitutes at least 20% (LEED).

Develop and implement a waste management plan, quantifying material diversion goals. Recycle and/or salvage an additional 25% (75% total) of construction, demolition and land clearing waste. (LEED).

The U.S. EPA has identified (and continually updates) a listing of products with recycled content in its Comprehensive Procurement Guidelines (CPGs),(HPBG)

Based on total materials cost, between 20-50% of the materials,shall contain at least 20% post-consumer recycled content OR a minimum of 49% pre-consumer recycled content. Document the materials and corresponding percentages accordingly (HPBG).

Specify the majority (i.e. over 50%) of masonry material (e.g. brick, concrete block and stone) in walls to be recycled or reused (BREEAM).

Maintain 100% of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material) AND at least 50% of non-shell areas (interior walls, doors, floor coverings and ceiling systems) (LEED).

Collect and use rainwater for landscape irrigation, urban gardening, toilet/urinal flushing, roof cooling (for un-insulated roofs), and for other purposes as appropriate (HPBG).

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Table 8.5 Page five of the diagnosis report from this case study

Dignosing Result

Recover excess groundwater from sump pumps for use as a source of recycled water (HPBG).

Collect and use utility district steam system condensate for toilet/urinal flushing cooling tower make-up, and other non-potable uses (HPBG).

Consider a Vacuum-assist' system (in lieu of a standard system) for flushing of water closets and urinals (HPBG).

Consider the use of portion control devices such as mechanical dispensers, which help ensure safe mixing of cleaning solutions, save packaging, and reduce chemical consumption (HPBG).

Coordinate housekeeping and custodial operations with building ventilation schedules to ensure that adequate ventilation is provided, both during and after these activities (HPBG).

The site doesn't have evaporative cooling towers or condensers (BREEAM).

Use of non-static carpets (BREEAM).

No tinted windows (BREEAM).

Smoking ban or smoking allowed only in designated and separately ventilated rooms, which make up less than 5% of the floor space (BREEAM).

No air conditioning (except in computer suites, secure and other special high heat load situations) and building designed to avoid overheating (BREEAM).

Wet cooling towers are not used (HK-BEAM).

The wet cooling towers use seawater (HK-BEAM).

All WCs with a maximum flushing capacity of 6 liters or less (BREEAM).

The sites is previously built up or used for industrial purposes and for reclaimed contaminated land (BREEAM).

Ensure all staffs are aware of the legal liabilities associated with their activities, both to themselves and their employers(GGCP).

CEPI-Contractor's Environmental Performance Index System Page 5

Table 8.6 Page six of the diagnosis report from this case study

Dignosing Result

Establish a procedure to ensure that relevant staffs have continuous access to the legal requirements (GGCP).

Establish a procedure to keep track of changes to environmental requirements and to update the environmental requirements accordingly (GGCP).

A flush-out period, beginning as soon as systems are operable and before or during the furniture, fittings, and equipment installation phase. The process involves flushing the building with 100% outside air for a period of not less than 20 days (HPBG).

Non-toxic interventions will be emphasized at all times on sites (HPBGF).

Supply enough containers to hold all wastes generated, and without overflow, between collection days (HPBG).

Wherever possible, construction materials should be stored on racks approximately 18 in/46cm above ground (or floor) in order to prevent creation of rodent (or other) pest harborage, and to enhance inspection procedures (HPBG).

Store potentially harmful materials with roofed, secondary containment to ensure that any spills are contained and to minimize contaminated stormwater run-off (GGCP).

CEPI-Contractor's Environmental Performance Index System Page 6

8.3 Discussion on the application of the C-EPSS

The discussion was held among the participants after completing the operation of the C-EPSS to the case study. The major comments on the application of the system can be drawn as follows:

The framework of multi-hierarchy system presenting the environmental performance indicators is proper and comprehensive. The establishment of this framework is considered a good contribution in the field for properly assessing contractor's environmental performance.

The framework of multi-hierarchy structure formulating the factors that can affect contractor's environmental performance is also considered proper. It is pointed by the professionals who participated the exercise that these factors can also used as checklist for helping contractors to contribute efforts in those aspects where their environmental performance can be affected.

These proposed benchmarks are useable. It is considered that the majority of the benchmarks can be practiced. However, suggestions are made that the details of these benchmarks could be further improved or modified.

The operation procedures for calculating C-EPI are considered as properly designed. Although the principles of the quantitative model for calculating C-EPI by using the non-structural fuzzy decision system (NSFDS) method are too difficult to be understood by the participants, the basic functions in the system are considered as properly formulated. And it proves that these functions can be achieved through operating a number of user-friendly procedures.

The establishment of the weightings was considered very important. The suggestion was made that further workshops could be conducted for further modifying the formulation of the weightings.

The inclusion of the diagnosis report from running the C-EPAS is considered very valuable. It is convinced that this report can provide useful information to the concerned contractor to further improve his environmental performance with adequate measures. The principle of diagnosis can also motivate contractor to use the system C-EPAS, where a message can be sent that the system does not aim for checking a contractor's weakness but for helping him improving his performance. Therefore, the element of diagnosis is also considered as a good contribution of this study in the area where performance assessment is undertaken.

Other suggestions are given, for example, better output format; a user manual which provides more explanations about the various terms used in the system; better layout in the process of using the package.

Chapter 9:

Conclusion

CHAPTER 9: CONCLUSION

9.1 Introduction

Construction activities have considerable impacts on both the natural and the built environment in various ways. Existing research works suggest that construction activities have adverse environmental effects, such as the loss of soil and agricultural land, the loss of forests, and the consumption on non-renewable energy resources. Construction activity also contributes to the environmental pollution through releasing dust, toxic fumes and noise during the construction process.

In line with the promotion of sustainable development, increasing research efforts have been devoted to investigating methods for mitigating the environmentally adverse effects caused during the process of implementing construction activities. One development is to assess the environmental performance of a construction product at different stages during its life cycle, thus proper action can be taken to mitigate the poor environmental performance if identified. Various assessment systems have been developed for assessing the environmental performance of a construction project. However, it appears that little study has been conducted to find an appropriate way to assess a contractor's environmental performance. In fact, the contractor plays the key role in executing construction activities, and its environmental performance has a strong association with the overall environmental performance in the process of implementing a construction project. Thus the implementation of environmental management across a contractor's operational activities is considered an important contribution towards protecting the environment. To assist contractors understand the level of their environmental performance, a methodology to assess their environmental performance is necessary.

This study finds out an effective method for assessing a contractor's environmental performance according to calculate a contractor's environmental performance index (C-EPI). In order to calculate the C-EPI, a contractor's environmental performance assessment system (C-EPAS) is built up through formulating various parameters and performance assessment benchmarks to a calculation model. Parameters adopted in the system include the environmental performance factors affecting the contractor's environmental performance and the environmental performance indictors used to evaluate the contractor's environmental performance.

A constructive survey was conducted for collecting the data used for determining the weightings of the parameters applied in the assessment system C-EPAS. In applying the system C-EPAS, the value of assessment indicators needs to be allocated. For this, the benchmarks of the indicator values are formulated. In order to calculate the C-EPI, the relative weightings of environmental performance factors to individual performance indicator are determined with applying the NSFDS method.

Based on the establishment of the environmental performance factors, indicators, benchmarks and weightings, a quantitative formula is used in calculating the value of C-EPI. The operation procedures in applying C-EPAS have been programmed, leading to the development of the C-EPAS computing system. The principles and functions of the C-EPAS are defined and the procedures for operating the system are flowcharted. The operation system of the C-EPAS has been developed to user-friendly software.

The adequacy of the principles embodied in the C-EPAS computing system and the applicability of the system operation procedures of the system have been tested and proven through conducting a case study.

9.2 Conclusions

It is considered that this research study has made contributions to the relevant research fields, and the major conclusions from this study can be made as follows:

- There are several methodologies developed for assessing the environmental performance of a building or a construction product, mainly concerning with environmental (green) criteria. However, the limitations exist in these methods. These methods don't provide an effective method for assessing a contractor's environmental performance. In fact, contractors can affect to large extent the impacts from construction activities on the environment. The construction impacts on the environment can be mitigated through employing proper materials, proper construction methods and proper management methods by contractors. Thus a mechanism for measuring a contractor's environmental performance is needed in order to help contractors identify whether there are weak areas in their performance to the environment and take proper corrective measures if necessary. This study has not only found that such mechanism is possible but also established this mechanism.

- This study has properly identified the factors that affecting the environmental performance committed by contractors. There is no existing study examining systematically these factors. Table 9.1 presents these factors, which are classified in three levels. The identification on these factors has involved the practical survey to the construction practice mainly in the Chinese mainland construction industry. The relative significance between these factors has also been established. The study on the environmental performance factors forms part of the basis for building up the calculation model for calculating a contractor's environmental performance index.

Table 9.1 Structure of the factors affecting construction environment performance

1st level factor (F_j)	2nd level factor ($F_{j-j'}$)	3rd level factor ($F_{j-j'-j''}$)
Specialist works (F_1)	Structural works (F_{1-1})	Earthwork and excavation (F_{1-1-1})
		Formwork and formation (F_{1-1-2})
		Reinforcement (F_{1-1-3})
		Concrete (F_{1-1-4})
		Waste treatment (F_{1-1-5})
	External & internal works (F_{1-2})	Wall, roofing and isolation (F_{1-2-1})
		Component instalment (F_{1-2-2})
		Plumbing and drainage (F_{1-2-3})
		Ornament and painting (F_{1-2-4})
		Surrounding landscaping (F_{1-2-5})

		Waste treatment (F_{1-2-6})
Site management (F_2)	Site performance (F_{2-1})	Site security (F_{2-1-1})
		Material storage and security (F_{2-1-2})
		Cleanliness and care (F_{2-1-3})
	Health & block Safety (F_{2-2})	Health & other provision (F_{2-2-1})
		Block related safety (F_{2-2-2})
Project Management (F_3)	Management & organization works (F_{3-1})	Management structure (F_{3-1-1})
		Site planning (F_{3-1-2})
		Environment engineering training (F_{3-1-3})
	Resources (F_{3-2})	Labour (F_{3-2-1})
		Plant (F_{3-2-2})
		Materials (F_{3-2-3})
	Co-ordination & Control (F_{3-3})	Co-ordination (F_{3-3-1})
		Control and supervision (F_{3-3-2})
		Co-operation (F_{3-3-3})
	Documentation (F_{3-4})	Submission (F_{3-4-1})
		Environment report (F_{3-4-2})
	Programming & progress (F_{3-5})	Program (F_{3-5-1})
		Progress (F_{3-5-2})
		Milestone (F_{3-5-3})
Technology (F_4)	Information technology (F_{4-1})	Software package (F_{4-1-1})
		Intranet (F_{4-1-2})
		Internet (F_{4-1-3})
	Construction technology (F_{4-2})	Energy & resource saving technology (F_{4-2-1})
		Pollution reducing technology (F_{4-2-2})
		Waste reducing technology (F_{4-2-3})
	Human skill (F_{4-3})	Environment engineer (F_{4-3-1})
		Environment knowledge (F_{4-3-2})
Environment policy (F_5)	Government policy (F_{5-1})	Environmental law (F_{5-1-1})
		Building regulation (F_{5-1-2})
	Company policy (F_{5-2})	Environment management system (F_{5-2-1})
		ISO14000 (F_{5-2-2})

- The study in this research demonstrates that there exists a set of indicators for assessing a contractor's environmental performance during construction stage. These indicators have been formulated in a two-level structure as shown in Table 9.2. The relative significance between these indicators has been established, based on the survey to the construction practice mainly in the Chinese mainland construction industry. The establishment of these indicators provides the essential basis for calculating a contractor's environmental performance index.

Table 9.2 Structure of environmental performance indicators

1st level indicator (I_i)	2nd level indicator ($I_{i\text{-}i'}$)
Ecology (I_1)	Acid rain ($I_{1\text{-}1}$)
	Global warming ($I_{1\text{-}2}$)
	Ozone depletion ($I_{1\text{-}3}$)
	Toxics ($I_{1\text{-}4}$)
	Waste ($I_{1\text{-}5}$)
	Air pollution ($I_{1\text{-}6}$)
	Land pollution ($I_{1\text{-}7}$)
	Water pollution ($I_{1\text{-}8}$)
	Noise pollution ($I_{1\text{-}9}$)
	Photochemical pollution ($I_{1\text{-}10}$)
Embodied energy (I_2)	Extraction of materials ($I_{2\text{-}1}$)
	Manufacture of components ($I_{2\text{-}2}$)
	Transportation to site ($I_{2\text{-}3}$)
	Construction practices ($I_{2\text{-}4}$)
Sustainability (I_3)	Recycling energy & resources ($I_{3\text{-}1}$)

	Reusing of energy & resources (I_{3-2})
	Maintenance (I_{3-3})
Public Aspect (I_4)	Public health & safety (I_{4-1})
	Community communication (I_{4-2})
	Region development (I_{4-3})
Human Aspect (I_5)	Environment engineer (I_{5-1})
	Working health & safety (I_{5-2})
	Site environmental management (I_{5-3})

- The analysis in the study demonstrates that difficulties exist in formulating a set of proper benchmarks of the indicators measuring a contractor's environmental performance. However, a pilot work has been conducted in this research, leading to the formulation of a set of proposed benchmarks of the assessment indicators, and Table 9.3 gives a sample. In this pilot study, various specific benchmarks are proposed for each indicator, and performance factors contributing to each specific benchmark are also identified.

Table 9.3 The sample benchmark for assessment indicators

Eco	**EE**	**Sus**	**PA**	**HA**
8 optional credits				

Acid Rain

INTENT	**Credit**
To reduce the release of oxides of nitrogen (NO_x) and sulphur dioxide (SO_2) into the	

Contribution Factor	BENCHMARK	
	atmosphere on the site and reduce the use of materials that have high emission during the extraction and production.	
Contribution Factor	**BENCHMARK**	
Project management (F_3) Environment policy (F_5)	The content of sulphur in fuels of machines doesn't surpass 0.5% (CNEPB).	☐
Specialist works (F_1) Site management (F_2) Project management (F_3)	Don't burn the waste of plastic foams, PVC, uPVC, plywood, resin and polymer bonded slates, organic coating, synthetic fibres, carpet fibres, rubbers, etc on the site (Woolley, 1997).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Advocate using the cements produced from New-Style-Dry-Method-Kiln (CNEPB).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4) Environment policy (F_5)	Don't use ordinary solid clay brick (CNEPB).	☐
Specialist works (F_1) Project management (F_3) Technology (F_4)	Advocate using the glass produced in 'Luoyang-Fufa' Method (CNEPB).	☐
Site management (F_2) Project management (F_3)	Don't burn the coals on the site directly (HMSO, 1992).	☐
Site management (F_2) Project management (F_3)	The boilers supplying the main heating load are of the low NO_x emitting type with burner	☐

Technology (F_4)	emissions of less than 200 mg/kWh of fuel consumed, when running at full-load output (BREEAM).	
Specialist works (F_1) Project management (F_3) Technology (F_4)	Advocate using flue-gas desulphurization (FGD) gypsum (HPBD).	☐
	Submittals	Total
	Provide the C-EPSS template, signed by the environment engineering or responsible party, declaring that the project site meets the requirements.	

- The non-structural fuzzy decision system (NSFDS) has been found suitable for assisting in establishing the relative weightings of environmental performance factors in referring to individual performance assessment indicators. The NSFDS has been successfully adopted in establishing these weightings, which is essential for calculating the value of C-EPI.

- The study demonstrates that the level of a contractor's environmental performance can be measured by a quantitative value, and this value is expressed by contractor's environmental performance index (C-EPI). A quantitative model for calculating the value of C-EPI has been formulated, and the process of the calculation has been established. The calculation model has been proven applicable and effective. It is considered that the results from calculating C-EPI provide valuable information not only for judging the level of a contractor's environmental performance, but also for assisting the concerned contractor to effectively allocate necessary resource for improving their environmental management.

- The C-EPAS software is developed as a strong support tool for the applicants who use C-EPAS system to conduct the environmental assessment. The principles of the computing system are established to include (1) providing a proper mechanism to accept the large amount of data; (2) dealing with the complex calculating procedures and achieve the last index; and (3) producing analysis reports. Reports present the calculation result of C-EPI, the distribution charts presenting a contractor's environmental performance between major performance indicators, and a diagnosis result on poor performance areas. The diagnosis report is designed to provide information to the concerned contractor to take corrective action for further improving its environmental performance with adequate measures.

The sample output layout for results including C-EPI score, distribution of C-EPI and diagnosis reports are shown in figure 9.1 and 9.2. The C-EPAS computing system was proven effective and applicable through the test by employing a case study.

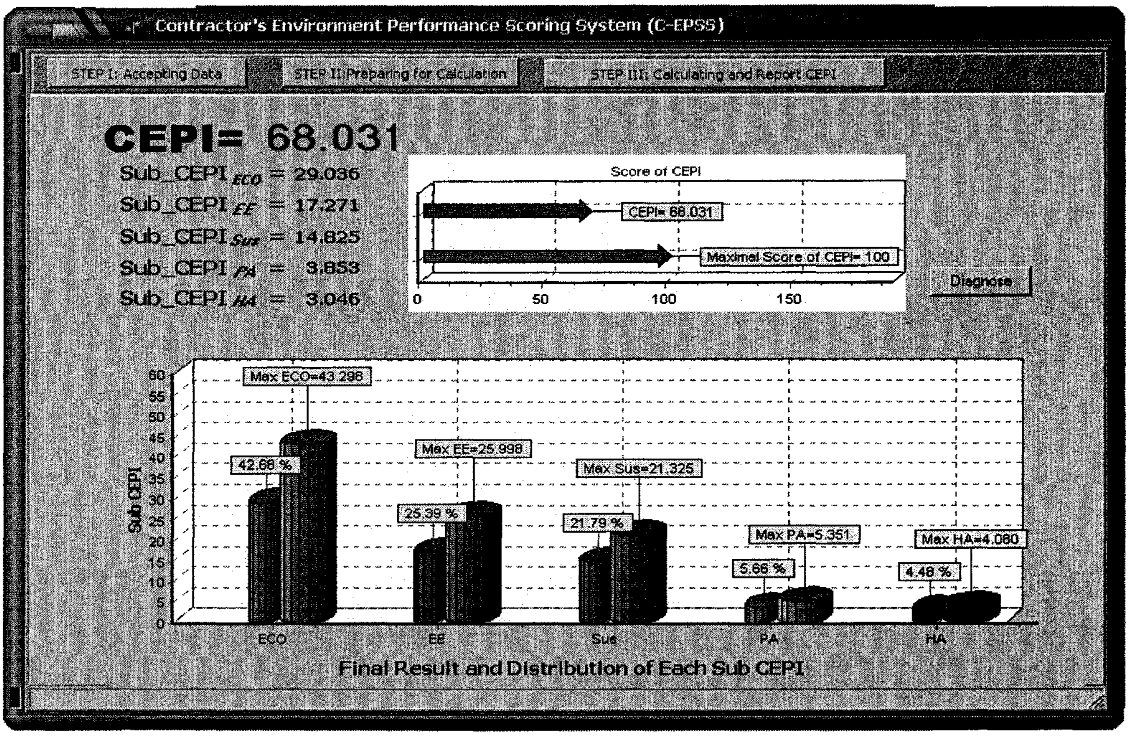

Figure 9.1 Sample layout for CEPI and distribution analysis

Dignosing Result

Establish a procedure to ensure that relevant staffs have continuous access to the legal requirements (GGCP).

Establish a procedure to keep track of changes to environmental requirements and to update the environmental requirements accordingly (GGCP).

A flush-out period, beginning as soon as systems are operable and before or during the furniture, fittings, and equipment installation phase. The process involves flushing the building with 100% outside air for a period of not less than 20 days (HPBG).

Non-toxic interventions will be emphasized at all times on sites (HPBGF).

Supply enough containers to hold all wastes generated, and without overflow, between collection days (HPBG).

Wherever possible, construction materials should be stored on racks approximately 18 in/46cm above ground (or floor) in order to prevent creation of rodent (or other) pest harborage, and to enhance inspection procedures (HPBG).

Store potentially harmful materials with roofed, secondary containment to ensure that any spills are contained and to minimize contaminated stormwater run-off (GGCP).

CEPI-Contractor's Environmental Performance Index System Page 6

Figure 9.2 Sample layout for CEPI diagnosis report

Recommendations

Limitations exist in this study and further research works are recommended particular in the followings:

- The multi-hierarchy structure of environmental performance factors could be established in a format that is easy to understand to contractors and construction professionals, thus they can serve as checklist for helping contractors to identify those major factors relating to specific projects.

- More consideration should be given to economic aspect in the establishment of the indicators for assessing contractors' environmental performance during construction. It is considered that a close relation exists between economic benefits and the environmental benefits. Further study is encouraged to investigate this area.

- The formulation of the benchmarks for evaluating a contractor's environmental performance is considered essential to the implementation of a proper assessment process. This study is only able to propose a framework of the benchmarks with the test within limited scope. It is considered that proper benchmarks can be established through comprehensive practical investigations and tests. This is recommended as a potentially important research area in the future.

- The diagnosis function in applying C-EPAS is considered valuable. However, the establishment of a guidance knowledge basis for improving environmental performance in those weak areas will be very significant. This is also considered a potential research topic that can make fully use of the benefits of the C-EPAS methodology.

Appendix I:

Questionnaires of Indicators and Factors

Questionnaire Survey

Environmental Indicators and Factors during Construction

This research group is undertaking a research project which aims to develop a model for diagnosing construction activities' environmental impacts, thus measures can be formulated for improving construction environmental performance. This questionnaire is designed to obtain professionals' opinions about the environmental indicators/factors and their significance to environmental impact during construction. The results of this survey will provide very valuable information for properly building up the environmental indicators & factors in our study.

We shall greatly appreciate if you could assist us by filling the attached questionnaires. We would like to assure you that your response would be used only for research purpose.

Please provide your correspondence address if you want to receive a copy of the survey result.

Name:____________________

Email:____________________

Address:____

Please return the questionnaire back before April 24, 2001.

Project Researcher (for correspondence):
Mr. WU Dehua (PH.D Candidate)
Department of Building & Real Estate
The Hong Kong Polytechnic University.
Hung Hom, Kowloon, Hong Kong
Telephone: 00852-27665873 Fax: 00852-27645131
Email: 9990
Project Leader:
Dr.SHEN Liyin (Associate Professor, The Hong Kong Polytechnic University, Department of Building & Real Estate)

L.Y.Shen\
2001/4/2

Please indicate the area of your profession:

☐ client ☐ contractor/subcontractor ☐ architect ☐supplier

☐ consultant ☐ governmental department ☐ research/education organization

Part One: Environmental Indicators During Construction

The following indicators are used to evaluate building's environmental performance during construction. Please indicate the level of the significance of each indicator. The level of significance is divided into ten grades and from 10 to 1: 10 for Most Essential (ME), 9 for Most Important (MtI), 8 for Very Important (VI), 7 for More Important (MeI), 6 for Commonly Important (CI), 5 for Slightly Important (SlI), 4 for Less Important (LeI), 3 for Some Impact (SoI), 2 for Little Impact (LiI) and 1 for No Impact (NI). Please tick the proper box in the following tables.

Table 1: General Environmental Indicators' Associated with construction activities

Environmental Indicators	Rate of importance									
	ME	MtI	VI	MeI	CI	SlI	LeI	SoI	LiI	NI
	10	9	8	7	6	5	4	3	2	1
Ecology environment (I_1)										
Energy & resource consumption (I_2)										
Sustainable environment (I_3)										
Social aspect (I_4)										
Human aspect (I_5)										

Table 2: Ecology Environment (I_1) Indicators' Associated with construction activities

Environmental Indicators	Rate of importance									
	ME	MtI	VI	MeI	CI	SlI	LeI	SoI	LiI	NI
	10	9	8	7	6	5	4	3	2	1
Acid rain										
Particulate										
Global warming										
Ozone depletion										
Toxics										
Waste										
Air pollution										
Land pollution										
Water pollution										
Noise pollution										
Photochemical pollution										

Table 3: Energy & Resource Consumption (I_2) Indicators' Associated with construction activities

Environmental Indicators	Rate of importance									
	ME	**MtI**	**VI**	**MeI**	**CI**	**SII**	**LeI**	**SoI**	**LiI**	**NI**
	10	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Energy use										
Thermal performance										
Bio resource depletion										
Non-bio resource depletion										

Table 4: Sustainable Environment (I_3) Indicators' Associated with construction activities

Environmental Indicators	Rate of importance									
	ME	**MtI**	**VI**	**MeI**	**CI**	**SII**	**LeI**	**SoI**	**LiI**	**NI**
	10	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Usage of recycled materials										
Reusing of the materials										
Maintenance of materials										
Usage of renewable materials										
Usage of renewable energy										

Table 5: Social Aspect (I_4) Indicators' Associated with construction activities

Environmental Indicators	Rate of importance									
	ME	**MtI**	**VI**	**MeI**	**CI**	**SII**	**LeI**	**SoI**	**LiI**	**NI**
	10	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Public health										
Public safety										
Site polite construction										
Community communication										
Local economic development										
Public relation										

Table 6: Human Aspect (I_5) Indicators' Associated with construction activities

Environmental Indicators	Rate of importance									
	ME	**MtI**	**VI**	**MeI**	**CI**	**SII**	**LeI**	**SoI**	**LiI**	**NI**
	10	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Employment										
Health										
Safety										
Working condition										

Part Two: Environmental Factor during construction

The following factors are considered the causes which can impact the environment during construction. Please indicate the level of the environmental significance for each factor. The level of significance of each factor. The level of the significance is divided into ten rates from 10 to 1: 10 for Most Essential (ME), 9 for Most Important (MtI), 8 for Very Important (VI), 7 for More Important (MeI), 6 for Commonly Important (CI), 5 for Slightly Important (SlI), 4 for Less Important (LI), 3 for Some Impact (SoI), 2 for Little Impact (LI) and 1 for No Impact (NI). Please tick the proper box in the following tables.

Table 7: General factors' affecting the environment during construction

Environmental Factors	Rate of importance									
	ME	MtI	VI	MeI	CI	SlI	LeI	SoI	LiI	NI
	10	9	8	7	6	5	4	3	2	1
Specialist works (F_1)										
Site management (F_2)										
Project management (F_3)										
Technology (F_4)										

Table 8: Specialist works (F_1) associated factors affecting the environment

Environmental Factors	Rate of importance									
	ME	MtI	VI	MeI	CI	SlI	LeI	SoI	LiI	NI
	10	9	8	7	6	5	4	3	2	1
Structural works (F_{11})										
External & internal works (F_{12})										

Table 9: Site management (F_2) associated factors affecting the environment

Environmental Factors	Rate of importance									
	ME	MtI	VI	MeI	CI	SlI	LeI	SoI	LiI	NI
	10	9	8	7	6	5	4	3	2	1
Site performance (F_{21})										
Health & block safety (F_{22})										

Table 10: Project management (F_3) associated factors affecting the environment

Environmental Factors	Rate of importance									
	ME	MtI	VI	MeI	CI	SlI	LeI	SoI	LiI	NI
	10	9	8	7	6	5	4	3	2	1
Management &organization works (F_{31})										
Resources (F_{32})										
Co-ordination & control (F_{33})										
Documentation (F_{34})										
Programming & progress (F_{35})										

Table 11: Technology (F_4) associated factors affecting the environment

Environmental Factors	Rate of importance									
	ME	MtI	VI	MeI	CI	SlI	LeI	SoI	LiI	NI
	10	9	8	7	6	5	4	3	2	1
Information technology										
Construction technology										
Human skill										

Table 12: Structural Works (F_{11}) associated factors affecting the environment

Environmental Factors	Rate of importance									
	ME	MtI	VI	MeI	CI	SlI	LeI	SoI	LiI	NI
	10	9	8	7	6	5	4	3	2	1
Earthwork and excavation										
Formwork and formation										
Reinforcement										
Concrete										
Waste treatment										

Table 13: External & internal works (F_{12}) associated factors affecting the environment

Environmental Factors	Rate of importance									
	ME	MtI	VI	MeI	CI	SlI	LeI	SoI	LiI	NI
	10	9	8	7	6	5	4	3	2	1
Wall, roofing and isolation										
Component installment										
Plumbing and drainage										
Ornament and painting										
Surrounding landscaping										
Waste treatment										

Table 14: Site performance (F_{21}) associated factors affecting the environment

Environmental Factors	Rate of importance									
	ME	MtI	VI	MeI	CI	SlI	LeI	SoI	LiI	NI
	10	9	8	7	6	5	4	3	2	1
Site security										
Material storage and security										
Cleanliness and care										

Table 15: Health & block safety (F_{22}) associated factors affecting the environment

Environmental Factors	Rate of importance									
	ME	MtI	VI	MeI	CI	SlI	LeI	SoI	LiI	NI
	10	9	8	7	6	5	4	3	2	1
Health & other provision										
Block related safety										

Table 16: Management & organization works (F_{31}) associated factors affecting the environment

Environmental Factors	Rate of importance									
	ME	MtI	VI	MeI	CI	SlI	LeI	SoI	LiI	NI
	10	9	8	7	6	5	4	3	2	1
Management structure										
Site planning										

Table 17: Resources (F_{32}) associated factors affecting the environment

Environmental Factors	Rate of importance									
	ME	MtI	VI	MeI	CI	SlI	LeI	SoI	LiI	NI
	10	9	8	7	6	5	4	3	2	1
Labor										
Plant										
Materials										

Table 18: Co-ordination & control (F_{33}) associated factors affecting the environment

Environmental Factors	Rate of importance									
	ME	MtI	VI	MeI	CI	SlI	LeI	SoI	LiI	NI
	10	9	8	7	6	5	4	3	2	1
Co-ordination										
Control and supervision										
Co-operation										

Table 19: Documentation (F_{34}) associated factors affecting the environment

Environmental Factors	Rate of importance									
	ME	MtI	VI	MeI	CI	SlI	LeI	SoI	LiI	NI
	10	9	8	7	6	5	4	3	2	1
Submission										
Environment report										

Table 20: Programming & progress (F_{35}) associated factors affecting the environment

Environmental Factors	Rate of importance									
	ME	MtI	VI	MeI	CI	SlI	LeI	SoI	LiI	NI
	10	9	8	7	6	5	4	3	2	1
Program										
Progress										
Milestone										

Suggestion Board:

If you have some suggestions about these indicators and factors, please write them down in the Suggestion Board. Thanks for your suggestions! (If the board is not enough, please write them in the back of this paper.)

--END--

Appendix II:

Part Source Code of C-EPAS

Part Source Code of C-EPAS

```
unit Unit1;

interface

uses
  Windows, Messages, SysUtils, Classes, Graphics, Controls, Forms, Dialogs,
  TFlatButtonUnit, KsTabs, KsSkinTabs, KsControls, KsMenus, KsSkinMenus,
  KsHooks, KsForms, KsSkinForms, KsSkinEngine, KsPanels, KsSkinPanels,
  KsButtons, KsSkinButtons, ComCtrls, StdCtrls, TFlatTabControlUnit,
  dxCntner, dxTL, dxDBCtrl, dxDBGrid, Db, DBTables, dxDBTLCl, dxGrClms,
  ExtCtrls, FR_DSet, FR_DBSet, FR_Class;

type
  TForm1 = class(TForm)
    SeSkinEngine1: TSeSkinEngine;
    SeSkinForm1: TSeSkinForm;
    StatusBar1: TStatusBar;
    DataSource1: TDataSource;
    Table1: TTable;
    Query1: TQuery;
    SeSkinPanel2: TSeSkinPanel;
    SeSkinButton6: TSeSkinButton;
    SeSkinButton7: TSeSkinButton;
    SeSkinButton8: TSeSkinButton;
    Panel1: TPanel;
    TabControl1: TTabControl;
    Label1: TLabel;
    Label2: TLabel;
    Label3: TLabel;
    Label9: TLabel;
    Label8: TLabel;
    Label10: TLabel;
    Label11: TLabel;
    Label12: TLabel;
    Label4: TLabel;
    Label5: TLabel;
    Label6: TLabel;
    Label7: TLabel;
    dxDBGrid1: TdxDBGrid;
    dxDBGrid1Number: TdxDBGridMaskColumn;
    dxDBGrid1Factor: TdxDBGridMaskColumn;
    dxDBGrid1Requirement: TdxDBGridMaskColumn;
    dxDBGrid1Credit: TdxDBGridCheckColumn;
    Panel2: TPanel;
    dxDBGrid2: TdxDBGrid;
    DataSource2: TDataSource;
    Table2: TTable;
    Query2: TQuery;
    dxDBGrid2Indicator: TdxDBGridMaskColumn;
    dxDBGrid2F1Weight: TdxDBGridMaskColumn;
    dxDBGrid2F1Credit: TdxDBGridMaskColumn;
```

```
    dxDBGrid2F2Weight: TdxDBGridMaskColumn;
    dxDBGrid2F2Credit: TdxDBGridMaskColumn;
    dxDBGrid2F3Weight: TdxDBGridMaskColumn;
    dxDBGrid2F3Credit: TdxDBGridMaskColumn;
    dxDBGrid2F4Weight: TdxDBGridMaskColumn;
    dxDBGrid2F4Credit: TdxDBGridMaskColumn;
    dxDBGrid2F5Weight: TdxDBGridMaskColumn;
    dxDBGrid2F5Credit: TdxDBGridMaskColumn;
    dxDBGrid2Summary: TdxDBGridMaskColumn;
    Panel3: TPanel;
    Label13: TLabel;
    Label14: TLabel;
    SeSkinPanel1: TSeSkinPanel;
    SeSkinButton1: TSeSkinButton;
    SeSkinButton2: TSeSkinButton;
    SeSkinButton3: TSeSkinButton;
    SeSkinButton4: TSeSkinButton;
    SeSkinButton5: TSeSkinButton;
    frReport1: TfrReport;
    frDBDataSet1: TfrDBDataSet;
    DataSource3: TDataSource;
    Table3: TTable;
    Button1: TButton;
    procedure SeSkinButton1Click(Sender: TObject);
    procedure SeSkinButton2Click(Sender: TObject);
    procedure SeSkinButton3Click(Sender: TObject);
    procedure SeSkinButton4Click(Sender: TObject);
    procedure SeSkinButton5Click(Sender: TObject);
    procedure FormCreate(Sender: TObject);
    procedure TabControl1Change(Sender: TObject);
    procedure dxDBGrid1Click(Sender: TObject);
    procedure SeSkinButton6Click(Sender: TObject);
    procedure SeSkinButton7Click(Sender: TObject);
    procedure SeSkinButton8Click(Sender: TObject);
    procedure FormClose(Sender: TObject; var Action: TCloseAction);
    procedure Button1Click(Sender: TObject);
  private
    { Private declarations }
  public
    { Public declarations }
  end;

var
  Form1: TForm1;
  CurrentCredit:Integer;
Const
  Indicator1:array[1..10] of String =('Acid Rain','Global Warming','Ozone Depletion','Toxics',
'Waste','Air','Land','Water','Noise','PhotoChemical');
  Indicator2:array[1..4] of String =('Extraction of Materials',
                        'Manufacture of Components','Transport to Site','Construction Practices');
  Indicator3:array[1..3] of String =('Recycling Energy and Resources',
                        'Reusing Energy and Resources','Maintenance');
  Indicator4:array[1..3] of String =('Public Safety and Health',
                        'Community Communication','Region Development');
  Indicator5:array[1..3] of String =('Environment Engineer','Working Health and Safety',
                        'Site Environment Management');
```

```
implementation

{$R *.DFM}

procedure TForm1.SeSkinButton1Click(Sender: TObject);
Var I:Integer;
begin
   ///////////////////////////////////////////////////////////////
   ////Read the Indicators then arrange them to the TabControl////
   ///////////////////////////////////////////////////////////////
   TabControl1.Tabs.Clear;
   for I:=1 to 10 do
      TabControl1.Tabs.Add(Indicator1[i]);
   Table1.Filtered := False;
   Table1.Filter := 'Indicator="Acid Rain"';
   Table1.Filtered := True;
   Form1.TabControl1Change(Sender);
end;

procedure TForm1.SeSkinButton2Click(Sender: TObject);
Var I:Integer;
begin
   ///////////////////////////////////////////////////////////////
   ////Read the Indicators then arrange them to the TabControl////
   ///////////////////////////////////////////////////////////////
   TabControl1.Tabs.Clear;
   For I:=1 to 4 do
     TabControl1.Tabs.Add(Indicator2[i]);
   Table1.Filtered := False;
   Table1.Filter := 'Indicator="Extraction of Materials"';
   Table1.Filtered := True;
   Form1.TabControl1Change(Sender);
end;


procedure TForm1.SeSkinButton3Click(Sender: TObject);
Var I:Integer;
begin
   ///////////////////////////////////////////////////////////////
   ////Read the Indicators then arrange them to the TabControl////
   ///////////////////////////////////////////////////////////////
   TabControl1.Tabs.Clear;
   For I:=1 to 3 do
     TabControl1.Tabs.Add(Indicator3[i]);
   Table1.Filtered := False;
   Table1.Filter := 'Indicator="Recycling Energy and Resources"';
   Table1.Filtered := True;
   Form1.TabControl1Change(Sender);
end;

procedure TForm1.SeSkinButton4Click(Sender: TObject);
Var I:Integer;
begin
   ///////////////////////////////////////////////////////////////
   ////Read the Indicators then arrange them to the TabControl////
```

```
    /////////////////////////////////////////////////////////
    TabControl1.Tabs.Clear;
    For I:=1 to 3 do
      TabControl1.Tabs.Add(Indicator4[i]);
    Table1.Filtered := False;
    Table1.Filter := 'Indicator="Public Safety and Health"';
    Table1.Filtered := True;
    Form1.TabControl1Change(Sender);
end;

procedure TForm1.SeSkinButton5Click(Sender: TObject);
Var I:Integer;
begin
    /////////////////////////////////////////////////////////
    ////Read the Indicators then arrange them to the TabControl////
    /////////////////////////////////////////////////////////
    TabControl1.Tabs.Clear;
    For I:=1 to 3 do
      TabControl1.Tabs.Add(Indicator5[i]);
    Table1.Filtered := False;
    Table1.Filter := 'Indicator="Environment Engineer"';
    Table1.Filtered := True;
    Form1.TabControl1Change(Sender);
end;

procedure TForm1.FormCreate(Sender: TObject);
Var I:Integer;
begin

    CurrentCredit := 0;
    Panel2.Visible := False;
    Panel3.Visible := False;
    Panel1.Visible := True;
    /////////////////////////////////////////////////////////
    ////Initial the DataBase Setting                      ////
    /////////////////////////////////////////////////////////
    Query1.DatabaseName := ExtractFileDir(Application.ExeName);
    Query2.DatabaseName := ExtractFileDir(Application.ExeName);
    Table1.DatabaseName := Query1.DatabaseName;
    Table1.TableName := 'Judgment.db';
    Table1.Active := True;
    Table2.DatabaseName := Query1.DatabaseName;
    Table2.TableName := 'CalculateForm.db';
    Table2.Active := True;
    Table3.DatabaseName := Query1.DatabaseName;
    Table3.TableName := 'Judgment.db';
    Table3.Active := True;
    ///////////////
    for I:=1 to 10 do
       TabControl1.Tabs.Add(Indicator1[i]);
    Table1.Filtered := False;
    Table1.Filter := 'Indicator="Acid Rain"';
    Table1.Filtered := True;
     With Query1 do
      begin
      Close;
```

```
      SQL.Clear;
      SQL.Add('Select Number from Judgment.db where Credit="1" and Indicator=:Ind');
      ParamByName('Ind').AsString := TabControl1.Tabs[TabControl1.TabIndex];
      Open;
      while not eof do
      begin
      CurrentCredit := CurrentCredit+1;
      Next;
      end;
    end;
    Label7.Caption := IntToStr(CurrentCredit);
end;

procedure TForm1.TabControl1Change(Sender: TObject);
begin
  CurrentCredit := 0;
  with Query1 do
  begin
    Close;
    SQL.Clear;
    SQL.Add('Select Intent,Submittals from IntAndSub.db where Indicator=:InD');
    ParamByName('InD').AsString := TabControl1.Tabs[TabControl1.TabIndex];
    Open;
    while not eof do
    begin
      if Length(Query1.Fields[0].AsString)<=108 then
      begin
      Label2.Caption := Query1.Fields[0].AsString;
      Label3.Caption :='';
      label9.Caption :='';
      end
      else
      if Length(Query1.Fields[0].AsString)<=216 then
      begin
      Label2.Caption := Copy(Query1.Fields[0].AsString,1,107);
      Label3.Caption := Copy(Query1.Fields[0].AsString,108,108);
      Label9.Caption := '';
      end
      else
      if Length(Query1.Fields[0].AsString)<=324 then
      begin
      Label2.Caption := Copy(Query1.Fields[0].AsString,1,107);
      Label3.Caption := Copy(Query1.Fields[0].AsString,108,108);
      Label9.Caption := Copy(Query1.Fields[0].AsString,216,108);
      end;
      //////////
      if Length(Query1.Fields[1].AsString)<=108 then
      begin
      Label10.Caption := Query1.Fields[1].AsString;
      Label11.Caption := '';
      Label12.Caption := '';
      end
      else if   Length(Query1.Fields[1].AsString)<=216 then
      begin
      Label10.Caption := Copy(Query1.Fields[1].AsString,1,107);
      Label11.Caption := Copy(Query1.Fields[1].AsString,108,108);
```

```
      Label12.Caption := '';
      end
      else if Length(Query1.Fields[1].AsString)<=324 then
      begin
      Label10.Caption := Copy(Query1.Fields[1].AsString,1,107);
      Label11.Caption := Copy(Query1.Fields[1].AsString,108,108);
      Label12.Caption := Copy(Query1.Fields[1].AsString,216,108);
      end;
      next;
    end;
  end;
      Table1.Filtered := False;
      Table1.Filter := 'Indicator='+QuotedStr(TabControl1.Tabs[TabControl1.TabIndex]);
      Table1.Filtered := True;
      Label5.Caption := IntToStr(Table1.RecordCount);
      With Query1 do
      begin
      Close;
      SQL.Clear;
      SQL.Add('Select Number from Judgment.db where Credit="1" and Indicator=:Ind');
      ParamByName('Ind').AsString := TabControl1.Tabs[TabControl1.TabIndex];
      Open;
      while not eof do
      begin
      CurrentCredit := CurrentCredit+1;
      Next;
      end;
    end;
    Label7.Caption := IntToStr(CurrentCredit);
end;

procedure TForm1.dxDBGrid1Click(Sender: TObject);
begin
    CurrentCredit := 0;
    with Query1 do
    begin
      Close;
      SQL.Clear;
      if dxDBGrid1.FocusedNode.Strings[3]='0' then
      SQL.Add('Update Judgment.db set Credit="1" where Number=:Num')
      else
      SQL.Add('Update Judgment.db set Credit="0" where Number=:Num');
      ParamByName('Num').AsString:= dxDBGrid1.FocusedNode.Strings[0];
      ExecSQL;
    end;
    Table1.Refresh;

    With Query1 do
    begin
      Close;
      SQL.Clear;
      SQL.Add('Select Factor from Judgment.db where Credit="1" and Indicator=:Ind');
      ParamByName('Ind').AsString := TabControl1.Tabs[TabControl1.TabIndex];
      Open;
      while not eof do
      begin
```

```
      CurrentCredit := CurrentCredit+1;
      Next;
      end;
    end;
    Label7.Caption := IntToStr(CurrentCredit);
end;

procedure TForm1.SeSkinButton6Click(Sender: TObject);
begin
  Panel2.Visible := False;
  Panel3.Visible := False;
  Panel1.Visible := True;
end;

procedure TForm1.SeSkinButton7Click(Sender: TObject);
var I,F1Credit,F2Credit,F3Credit,F4Credit,F5Credit:integer;
    RowSummary:Real;
begin
  Panel1.Visible := False;
  Panel3.Visible := False;
  Panel2.Visible := True;
  F1Credit := 0;
  F2Credit := 0;
  F3Credit := 0;
  F4Credit := 0;
  F5Credit := 0;
  RowSummary :=0;
  For I:=1 to 10 do
  begin
    With Query1 do
     begin
     Close;
     SQL.Clear;
     SQL.Add('Select Factor from Judgment.db where Credit="1" and Indicator=:Ind');
     ParamByName('Ind').AsString := Indicator1[i];
     Open;
     while not eof do
     begin
     if Pos('F1',Fields[0].AsString)>0 then
     F1Credit := F1Credit+1;
     if Pos('F2',Fields[0].AsString)>0 then
     F2Credit := F2Credit+1;
     if Pos('F3',Fields[0].AsString)>0 then
     F3Credit := F3Credit+1;
     if Pos('F4',Fields[0].AsString)>0 then
     F4Credit := F4Credit+1;
     if Pos('F5',Fields[0].AsString)>0 then
     F5Credit := F5Credit+1;
     Next;
     end;
     end;
    ////Write the credits to the calculating form
    with Query2 do
    begin
     Close;
     SQL.Clear;
```

```
      SQL.Add('Update CalculateForm.db set FCredit1=:FC1,FCredit2=:FC2,FCredit3=:FC3,
             FCredit4=:FC4,FCredit5=:FC5 where Indicator=:InD');
     ParamByName('FC1').AsInteger := F1Credit;
     ParamByName('FC2').AsInteger := F2Credit;
     ParamByName('FC3').AsInteger := F3Credit;
     ParamByName('FC4').AsInteger := F4Credit;
     ParamByName('FC5').AsInteger := F5Credit;
     ParamByName('Ind').AsString   := Indicator1[i];
     ExecSQL;
   end;
   F1Credit :=0;
   F2Credit :=0;
   F3Credit :=0;
   F4Credit :=0;
   F5Credit :=0;
 end;
//////////
   For I:=1 to 4 do
 begin
   With Query1 do
    begin
    Close;
    SQL.Clear;
    SQL.Add('Select Factor from Judgment.db where Credit="1" and Indicator=:Ind');
    ParamByName('Ind').AsString := Indicator2[i];
    Open;
    while not eof do
    begin
    if Pos('F1',Fields[0].AsString)>0 then
    F1Credit := F1Credit+1;
    if Pos('F2',Fields[0].AsString)>0 then
    F2Credit := F2Credit+1;
    if Pos('F3',Fields[0].AsString)>0 then
    F3Credit := F3Credit+1;
    if Pos('F4',Fields[0].AsString)>0 then
    F4Credit := F4Credit+1;
    if Pos('F5',Fields[0].AsString)>0 then
    F5Credit := F5Credit+1;
    Next;
    end;
    end;
   ////Write the credits to the calculating form
   with Query2 do
   begin
    Close;
    SQL.Clear;
     SQL.Add('Update CalculateForm.db set FCredit1=:FC1,FCredit2=:FC2,FCredit3=:FC3,
            FCredit4=:FC4,FCredit5=:FC5 where Indicator=:InD');
    ParamByName('FC1').AsInteger := F1Credit;
    ParamByName('FC2').AsInteger := F2Credit;
    ParamByName('FC3').AsInteger := F3Credit;
    ParamByName('FC4').AsInteger := F4Credit;
    ParamByName('FC5').AsInteger := F5Credit;
    ParamByName('Ind').AsString   := Indicator2[i];
    ExecSQL;
   end;
```

```
    F1Credit :=0;
    F2Credit :=0;
    F3Credit :=0;
    F4Credit :=0;
    F5Credit :=0;
  end;
  ////////
    For I:=1 to 3 do
  begin
    With Query1 do
     begin
     Close;
     SQL.Clear;
     SQL.Add('Select Factor from Judgment.db where Credit="1" and Indicator=:Ind');
     ParamByName('Ind').AsString := Indicator3[i];
     Open;
     while not eof do
     begin
     if Pos('F1',Fields[0].AsString)>0 then
     F1Credit := F1Credit+1;
     if Pos('F2',Fields[0].AsString)>0 then
     F2Credit := F2Credit+1;
     if Pos('F3',Fields[0].AsString)>0 then
     F3Credit := F3Credit+1;
     if Pos('F4',Fields[0].AsString)>0 then
     F4Credit := F4Credit+1;
     if Pos('F5',Fields[0].AsString)>0 then
     F5Credit := F5Credit+1;
     Next;
     end;
     end;
     ////Write the credits to the calculating form
    with Query2 do
    begin
     Close;
     SQL.Clear;
      SQL.Add('Update CalculateForm.db set FCredit1=:FC1,FCredit2=:FC2,FCredit3=:FC3,
               FCredit4=:FC4,FCredit5=:FC5 where Indicator=:InD');
     ParamByName('FC1').AsInteger := F1Credit;
     ParamByName('FC2').AsInteger := F2Credit;
     ParamByName('FC3').AsInteger := F3Credit;
     ParamByName('FC4').AsInteger := F4Credit;
     ParamByName('FC5').AsInteger := F5Credit;
     ParamByName('Ind').AsString    := Indicator3[i];
     ExecSQL;
    end;
    F1Credit :=0;
    F2Credit :=0;
    F3Credit :=0;
    F4Credit :=0;
    F5Credit :=0;
  end;
  //////
    For I:=1 to 3 do
  begin
    With Query1 do
```

```
      begin
      Close;
      SQL.Clear;
      SQL.Add('Select Factor from Judgment.db where Credit="1" and Indicator=:Ind');
      ParamByName('Ind').AsString := Indicator4[i];
      Open;
      while not eof do
      begin
      if Pos('F1',Fields[0].AsString)>0 then
      F1Credit := F1Credit+1;
      if Pos('F2',Fields[0].AsString)>0 then
      F2Credit := F2Credit+1;
      if Pos('F3',Fields[0].AsString)>0 then
      F3Credit := F3Credit+1;
      if Pos('F4',Fields[0].AsString)>0 then
      F4Credit := F4Credit+1;
      if Pos('F5',Fields[0].AsString)>0 then
      F5Credit := F5Credit+1;
      Next;
      end;
      end;
      ////Write the credits to the calculating form
    with Query2 do
    begin
      Close;
      SQL.Clear;
       SQL.Add('Update CalculateForm.db set FCredit1=:FC1,FCredit2=:FC2,FCredit3=:FC3,
                 FCredit4=:FC4,FCredit5=:FC5 where Indicator=:InD');
      ParamByName('FC1').AsInteger := F1Credit;
      ParamByName('FC2').AsInteger := F2Credit;
      ParamByName('FC3').AsInteger := F3Credit;
      ParamByName('FC4').AsInteger := F4Credit;
      ParamByName('FC5').AsInteger := F5Credit;
      ParamByName('Ind').AsString    := Indicator4[i];
      ExecSQL;
    end;
    F1Credit :=0;
    F2Credit :=0;
    F3Credit :=0;
    F4Credit :=0;
    F5Credit :=0;
end;
   For I:=1 to 3 do
begin
   With Query1 do
     begin
     Close;
     SQL.Clear;
     SQL.Add('Select Factor from Judgment.db where Credit="1" and Indicator=:Ind');
     ParamByName('Ind').AsString := Indicator5[i];
     Open;
     while not eof do
     begin
     if Pos('F1',Fields[0].AsString)>0 then
     F1Credit := F1Credit+1;
     if Pos('F2',Fields[0].AsString)>0 then
```

```
      F2Credit := F2Credit+1;
      if Pos('F3',Fields[0].AsString)>0 then
      F3Credit := F3Credit+1;
      if Pos('F4',Fields[0].AsString)>0 then
      F4Credit := F4Credit+1;
      if Pos('F5',Fields[0].AsString)>0 then
      F5Credit := F5Credit+1;
      Next;
      end;
      end;
      ////Write the credits to the calculating form
     with Query2 do
     begin
      Close;
      SQL.Clear;
       SQL.Add('Update CalculateForm.db set FCredit1=:FC1,FCredit2=:FC2,FCredit3=:FC3,
               FCredit4=:FC4,FCredit5=:FC5 where Indicator=:InD');
      ParamByName('FC1').AsInteger := F1Credit;
      ParamByName('FC2').AsInteger := F2Credit;
      ParamByName('FC3').AsInteger := F3Credit;
      ParamByName('FC4').AsInteger := F4Credit;
      ParamByName('FC5').AsInteger := F5Credit;
      ParamByName('Ind').AsString   := Indicator5[i];
      ExecSQL;
     end;
     F1Credit :=0;
     F2Credit :=0;
     F3Credit :=0;
     F4Credit :=0;
     F5Credit :=0;
  end;
  //////////Calculating the summary of each row
  For I:=1 to 10 do
  begin
  With Query2 do
  begin
     Close;
     SQL.Clear;
     SQL.Add('Select
Fweight1,FCredit1,Fweight2,FCredit2,Fweight3,FCredit3,Fweight4,FCredit4,Fweight5,FCredit5 from
CalculateForm.db where Indicator=:InD');
     ParamByName('Ind').AsString := Indicator1[i];
     Open;
     while not eof do
     begin
         RowSummary :=
          (Fields[0].AsFloat)*(Fields[1].AsInteger)+(Fields[2].AsFloat)*(Fields[3].AsInteger)

                    +(Fields[4].AsFloat)*(Fields[5].AsInteger)+(Fields[6].AsFloat)*(Fields[7].AsInteger)
                    +(Fields[8].AsFloat)*(Fields[9].AsInteger);
       next;
     end;
  end;
  /////////
  with Query2 do
  begin
```

```
        Close;
        SQL.Clear;
        SQL.Add('Update CalculateForm.db set Summary=:Suma where Indicator=:InD');
        ParamByName('Suma').AsString := FloatToStr(RowSummary);
        ParamByName('InD').AsString := Indicator1[i];
        ExecSQL;
    end;
    end;
    RowSummary :=0;
    ////////
    For I:=1 to 4 do
    begin
    With Query2 do
    begin
      Close;
      SQL.Clear;
      SQL.Add('Select
Fweight1,FCredit1,Fweight2,FCredit2,Fweight3,FCredit3,Fweight4,FCredit4,Fweight5,FCredit5 from
CalculateForm.db where Indicator=:InD');
      ParamByName('Ind').AsString := Indicator2[i];
      Open;
      while not eof do
      begin
          RowSummary :=
           (Fields[0].AsFloat)*(Fields[1].AsInteger)+(Fields[2].AsFloat)*(Fields[3].AsInteger)
            +(Fields[4].AsFloat)*(Fields[5].AsInteger)+(Fields[6].AsFloat)*(Fields[7].AsInteger)
                        +(Fields[8].AsFloat)*(Fields[9].AsInteger);
        next;
      end;
    end;
    /////////
    with Query2 do
    begin
        Close;
        SQL.Clear;
        SQL.Add('Update CalculateForm.db set Summary=:Suma where Indicator=:InD');
        ParamByName('Suma').AsString := FloatToStr(RowSummary);
        ParamByName('InD').AsString := Indicator2[i];
        ExecSQL;
    end;
    end;
    RowSummary :=0;
    /////////
    For I:=1 to 3 do
    begin
    With Query2 do
    begin
      Close;
      SQL.Clear;
      SQL.Add('Select
Fweight1,FCredit1,Fweight2,FCredit2,Fweight3,FCredit3,Fweight4,FCredit4,Fweight5,FCredit5 from
CalculateForm.db where Indicator=:InD');
      ParamByName('Ind').AsString := Indicator3[i];
      Open;
      while not eof do
      begin
```

```
        RowSummary := (Fields[0].AsFloat)*(Fields[1].AsInteger)+(Fields[2].AsFloat)*(Fields[3].AsInteger)
            +(Fields[4].AsFloat)*(Fields[5].AsInteger)+(Fields[6].AsFloat)*(Fields[7].AsInteger)
                        +(Fields[8].AsFloat)*(Fields[9].AsInteger);
        next;
      end;
   end;
   ////////
   with Query2 do
   begin
       Close;
       SQL.Clear;
       SQL.Add('Update CalculateForm.db set Summary=:Suma where Indicator=:InD');
       ParamByName('Suma').AsString := FloatToStr(RowSummary);
       ParamByName('InD').AsString := Indicator3[i];
       ExecSQL;
   end;
   end;
   RowSummary :=0;
   ////////
     For I:=1 to 3 do
   begin
   With Query2 do
   begin
     Close;
     SQL.Clear;
     SQL.Add('Select
Fweight1,FCredit1,Fweight2,FCredit2,Fweight3,FCredit3,Fweight4,FCredit4,Fweight5,FCredit5 from
CalculateForm.db where Indicator=:InD');
     ParamByName('Ind').AsString := Indicator4[i];
     Open;
     while not eof do
     begin
       RowSummary := (Fields[0].AsFloat)*(Fields[1].AsInteger)+(Fields[2].AsFloat)*(Fields[3].AsInteger)
            +(Fields[4].AsFloat)*(Fields[5].AsInteger)+(Fields[6].AsFloat)*(Fields[7].AsInteger)
                        +(Fields[8].AsFloat)*(Fields[9].AsInteger);
       next;
     end;
   end;
   ////////
   with Query2 do
   begin
       Close;
       SQL.Clear;
       SQL.Add('Update CalculateForm.db set Summary=:Suma where Indicator=:InD');
       ParamByName('Suma').AsString := FloatToStr(RowSummary);
       ParamByName('InD').AsString := Indicator4[i];
       ExecSQL;
   end;
   end;
   RowSummary :=0;
   //////
     For I:=1 to 3 do
   begin
   With Query2 do
   begin
     Close;
```

```
      SQL.Clear;
      SQL.Add('Select
Fweight1,FCredit1,Fweight2,FCredit2,Fweight3,FCredit3,Fweight4,FCredit4,Fweight5,FCredit5 from
CalculateForm.db where Indicator=:InD');
      ParamByName('Ind').AsString := Indicator5[i];
      Open;
      while not eof do
      begin
        RowSummary := (Fields[0].AsFloat)*(Fields[1].AsInteger)+(Fields[2].AsFloat)*(Fields[3].AsInteger)
                      +(Fields[4].AsFloat)*(Fields[5].AsInteger)+(Fields[6].AsFloat)*(Fields[7].AsInteger)
                      +(Fields[8].AsFloat)*(Fields[9].AsInteger);
        next;
      end;
    end;
    ////////
    with Query2 do
    begin
       Close;
       SQL.Clear;
       SQL.Add('Update CalculateForm.db set Summary=:Suma where Indicator=:InD');
       ParamByName('Suma').AsString := FloatToStr(RowSummary);
       ParamByName('InD').AsString := Indicator5[i];
       ExecSQL;
    end;
    end;
    Table2.Refresh;
    SeSkinButton8.Enabled := True;
end;

procedure TForm1.SeSkinButton8Click(Sender: TObject);
Var cepi:Real;
begin
   Panel1.Visible := False;
   Panel2.Visible := False;
   Panel3.Visible := True;
   Cepi := 0;
   with Query1 do
   begin
   Close;
   SQL.Clear;
   SQL.Add('Select Summary from CalculateForm.db');
   Open;
   while not eof do
     begin
       cepi := cepi+Fields[0].AsFloat;
       next;
     end;
   end;
   Label14.Caption := FloatToStr(Cepi);
end;

procedure TForm1.FormClose(Sender: TObject; var Action: TCloseAction);
begin
   Table1.Close;
   Table2.Close;
end;
```

```
procedure TForm1.Button1Click(Sender: TObject);
var Report:TfrReport;
begin
  Table3.Filtered := False;
  Table3.Filter := 'Credit<>''1''';
  Table3.Filtered := True;
  Report := frReport1;
  Report.LoadFromFile('Diagnose.frf');
  Report.ShowReport;
end;

end.
```

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Glossary

GLOSSARY

AHP: Analytical hierarchy process. AHP is a decision-aiding method developed by Saaty in 1979. It aims at quantifying relative priorities for a given set of alternatives on a ration scale, based on the judgment of decision-maker, and stresses the importance of the intuitive judgment of a decision-maker as well as the consistency of the comparison of alternatives in decision-making process.

APCO: Air pollution control ordinance.

AW: Absolute weighting

AW: Architectural works.

BREEAM: Building Research Establishment Environmental Assessment Method. This assessment method, which is carried out at the design stage, is based on readily available and generally accepted information. The method identifies and credits designs where specific targets are met.

BSRIA: Building Services Research and Information Association.

CD: Committee drafts.

C-EPAS: Contractor's Environmental Performance Assessment System.

C-EPI: Contractor's Environmental Performance Index.

CFC: Chlorofluorocarbon. Used in refrigerants, foam insulation material, and many other consumer products. CFCs have been linked to the destruction of the ozone layer.

CI: Commonly important

CR: Consistency ration

DIS: Draft international standards.

Eco: Ecology. In biology, it is the study of the relationship between living organisms and their environment. In sociology, it is the study of the relationship between the distribution of human groups with reference to material resources and the consequent social and cultural pattern.

EE: Embodied energy

EIA: Environmental impact assessment.

EIAO: Environmental impact assessment ordinance.

Embodied energy: The total energy that a product may be said to 'contain', including all energy used in growing, extracting, and manufacturing it, and energy used to transport it to the point of use. The embodied energy of a structure or system includes the embodied energy of a structure or system includes the embodied energy of its components, plus the energy used in construction.

EMS: Environment management system

Environmental assessment: An environmental analysis prepared pursuant to the National Policy Act (NEPA) which assesses the potential environmental and cumulative impacts of a project and possible ways to minimize effects of a project on the environment.

Environmental indicator: A measurement, statistic, or value that provides a proximate gauge or evidence of the effects of environmental management programs or of the state or condition of the environment.

Environmental management system (EMS): One tool which organizations are using to facilitate implementation of environmental policy is environmental management system (EMS) which meets the need of organizations identified of 'planned and programmed change to support environmental management'.

Environmental management system is defined by the British Standards Institute as: the organizational structure, responsibilities, practices, procedures, processes and resources for determining and implementing environmental policy.

EPD: Environmental performance department.

FRP: Fabrics-reinforced polymer.

GBTool: Green Building Tool. GBTool is a product of Green Building Challenge (GBC), which is an international initiative that set up an agenda for environmental assessment of buildings. It is a very comprehensive assessment tool that focuses on the biophysical aspects of a building development. GBTool is a market-orientated tool for awarding eco-labels, as well as a design guideline tool. It was developed to assess such building types as commercial, multi-residential and schools.

GGCP: Guide to Green Construction Practice. This guidebook presents practicable measures on how to develop a green culture in the management and operation of construction sites. Its preparation involved an examination of existing practices within Hong Kong and around the world to ensure its comprehensiveness.

GHG: Greenhouse gas. Any number of gases traps heat in the atmosphere, including carbon dioxide, methane, and chlorofluorocarbons.

Global warming: A long-term gradual increase in the average temperature in climate systems throughout the world as a result of the greenhouse effect.

Green building: It is not simply about protecting the biosphere and natural resources from over-exploitation or over-consumption, nor is it simply about saving energy to reduce our heating bills. It is about reducing energy use, minimizing external pollution and environmental damage, reducing embodied energy and resource depletion, and minimizing internal pollution and damage to health.

HA: Human aspect

HCFCs: Hydrogen-Chlorofluorocarbon.

HK-BEAM: Hong Kong Building Environmental Assessment Method. It provides authoritative guidance to developers (and their consultants), owners, operators and users on practices which minimize the adverse effects of buildings on the global and local environments, whilst promoting a healthy indoor environment.

HK-PASS: Hong Kong Performance Assessment Scoring System.

HKPC: Hong Kong Productivity Council.

HPBG: High performance building guidelines. It is designed as a guideline for public sector capital designer and planners to increase their knowledge on energy and environmentally efficient construction technologies and practices, was developed by the Department of Design and Construction (DDC) of New York.

HVAC: Heating, ventilation, and air-conditioning.

IAQ: Indoor air quality. The cleanliness or health effects of air in a building are affected by the amount of compounds released into the space by various materials, carbon dioxide levels, and microbial contaminants. IAQ is heavily influenced by both choice of building materials (and cleaning procedures) and ventilation rates.

ISO: International Organization for Standardization.

LCA: Life-cycle analysis. An objective assessment of the cost of a design feature that allows for production, sales, operation, maintenance, and demolition or recycling costs. The cost also encompasses all the environmental burdens of a product or process through its entire service life.

LEED: Leadership in Energy and Environmental Design. LEED is a design supporting tool and product marketing tool launched by the US Green Building Council to rate commercial office buildings.

LeI: Less important

LiI: Little impact

MALAYSIA MHLG: Malaysia Ministry of Housing and Local Government.

ME: Most essential

MeI: More important

MtI: Most important

NI: No impact

Non-renewable resources: Natural resources that are consumed faster than can be produced. Thus, they are limited resources that could eventually be depleted.

NP: New proposals.

NSFDS: Non-structural fuzzy decision system. In using NSFDS method, there are three procedures: (a) decomposition, (b) comparative judgment, and (c) synthesis of priorities. In the decomposition stage in using NSFDS, an objective variable will be decomposed into a number of a number of detail variables forming a hierarchy. Comparative judgment will be made to the relative significance or importance through pair-wise comparisons between the variables, which are in the same group and at the same level in the variable hierarchy. The function of synthesis of priorities in using DSFDS is to establish relative weightings between variables, which are in different groups under the decomposition hierarchy.

OO: Other obligations.

Ozone depletion: Destruction of the stratospheric ozone layer, which shields the

Earth from ultraviolet radiation harmful to life. This destruction of ozone is caused by the breakdown of certain chlorine and/or bromine containing compounds (chlorofluorocarbons or halons), which break down when they reach the stratosphere and then catalytically destroy ozone molecules.

PA: Public aspect

P-CEPI: Perfect contractor's environmental performance index

RI: Random index

RW: Relative weighting

SBAT: Sustainable Building Assessment Tool. SBAT is a tool that targets sustainability of construction development. In order to address social, economic and environmental aspects of a development, SBAT compromises in terms of comprehensiveness of covering biophysical issues.

SBS: Sick building syndrome. This sickness is characterized by the symptoms of an unhealthy building's occupants – dizziness, headaches, irritated eyes, nausea, throat irritation, and coughing. These reactions typically cease when the occupants leave the building.

SII: Slightly important

SoI: Some impact

Sus: Sustainability

Sustainable development: It is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs. According to this definition from the World Commission on Environment and Development, it is clear that the various activities of the construction sector have to be regarded and analyzed when considering sustainable development.

Sustainable: Sustainable practices and sustainable communities meet the needs of present generations without compromising those needs for future generations. To be truly sustainable, a human community must not decrease biodiversity, must not consume resource faster than these are renewed, must recycle and reuse virtually all materials, and must rely primarily on resources of its own region. Ecological/environmental sustainability is defined by the EPA as the maintenance of ecosystem components and functions for future generations.

SW: Structural works.

TSP: Air-suspended particulates.

UNEP: United Nations Environmental Programme.

VI: Very important.

VOC: Volatile organic compound. A class of chemical compounds that can cause nausea, tremors, headaches, and, some doctors believe longer-lasting harm. VOCs can be emitted by oil-based paints, solvent-based finishes, and other products on/in construction materials.

WCS: World Conservation Strategy.

WD: Working Drafts.

WWF: World Conservation Strategy.