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Carbon audit and energy audit in a hotel in Hong Kong

Man Chun Sing

MEng in BUILDING SERVICES ENGINEERING
THE HONG KONG POLYTECHNIC UNIVERSITY
2009/10
Abstract

Abstract of dissertation entitled:

**Carbon audit and energy audit in a hotel in Hong Kong**

submitted by **Man Chun Sing**

for the degree of **MEng in Building Services Engineering**

at The Hong Kong Polytechnic University in April 2010

Both carbon audits and energy audits can be used as a tool to combat climate change. By checking the major sources of greenhouse gas (GHG) emissions of a building with a carbon audit and the energy consumptions in various systems in the building with an energy audit, the building owner can set emissions reduction targets and identify opportunities for energy efficiency and reduction of emissions. Previous studies demonstrated the methods to conduct carbon audits and energy audits in different types of buildings. Most of these studies, however, concentrated on presenting the energy or environmental performance of the studied buildings. There was limited discussion on the difficulties in conducting the carbon audits or energy audits. Besides, carbon audits and energy audits were not conducted and studied simultaneously in most of these studies. Thus, this dissertation aims to demonstrate a case study on conducting a carbon audit and an energy audit simultaneously in a hotel in Hong Kong based on the guidelines for carbon audits and energy audits in Hong Kong. The data for the carbon audit was collected by means of a questionnaire survey which was conducted through interviews with the engineers in the hotel, while that for the energy audit was by means of site inspections and measurements, and a collection of energy billing information and documents.
Based on the results of the carbon audit, the normalized GHG emissions of the studied hotel were 31.07 kg CO₂eq per room day, which were similar to those of hotels in the US with reference to the data from the Environment Protection Agency. Purchased electricity and town gas were the major sources of GHG emissions of the hotel studied. Through the energy audit, energy performance of the hotel was analyzed. Energy utilization index (EUI) of the hotel in 2009 was 1492 MJ/m²/year. The total energy consumption in the hotel was dominated by electricity, with the greatest portion for air conditioning because of sub-tropical climate. Detailed regression analyses were undertaken using the electricity consumption, energy consumption and operational data from the hotel. The results indicated that electricity consumption and energy consumption in the hotel are affected by the outdoor temperature and number of guests together, with the former being the stronger affecting factor. For gas consumption, a strong correlation between the town gas consumption and the number of food covers was obtained. With the identification of the areas of inefficiency in energy consumption, corresponding opportunities for improvement on GHG emissions and energy consumption of the hotel were proposed. Difficulties encountered during the implementation of the energy-cum-carbon audit in the hotel were also identified in this study. This study shows that there are still many difficulties in actual implementation of a carbon audit and an energy audit in a hotel in Hong Kong, although guidelines for carbon audits and energy audits were established in Hong Kong. In addition, a GHG emissions calculator for buildings (commercial, residential or institutional purposes) in Hong Kong was established in this study to facilitate the calculation of GHG emissions with computerized calculation.
Acknowledgements

I would like to express my gratitude to Dr H. K. Lai, Joseph, my supervisor, for his support, supervision and patient guidance.

I also wish to thank Mr C. S. Leung and Mr W. K. Fung, Michael, for their assistance in conducting the experiment work.

Special thanks are given to the group of staff in the audited hotel for their sincere help and support.
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Chapter 1

Introduction

This chapter outlines the importance of carbon audits and energy audits for buildings in combat climate change. An overview of the state-of-the-art of standards and guidelines for carbon audits and energy audits is provided.

1.1 Background

Climate change has become a challenge to the international community since the 20th century and it is threatening the lives on earth. The basic causes and mechanism of climate change are well understood by scientists. The world is becoming warm mainly caused by the human emissions of greenhouse gases. Global warming is accelerating and bringing many and varied impacts around the world.

Electricity production is one of the major processes that generate most of the greenhouse gases in the world. In the past few decades, people have focused on energy conservation to solve the problem of global warming. Measures, such as energy audit in buildings, were formulated to reduce energy consumption. In recent years, scientists thought that merely focusing on measures in reducing energy consumption is insufficient to solve the problem of global warming. Scientists have become aware that attention should be paid on reducing greenhouse gas (GHG) emissions. Significant amount of GHG emissions comes from the construction and operation of buildings. Therefore, the carbon audit has been introduced and become a widely discussed topic in addition to energy audit in buildings. Controlling the amount of GHG emissions produced in the buildings is an important action to solve
the global warming problem. There is a trend for the construction industry to move toward net zero energy building – a building with net zero site energy, net zero source energy, net zero energy costs and net zero energy emissions [1].

1.2 Significance of carbon audits and energy audits for buildings

Both carbon audits and energy audits can be used as a tool to combat climate change. By checking the major sources of GHG emissions with a carbon audit and the energy consumptions in various systems in the building with an energy audit, the building owner can set emissions reduction targets and identify opportunities for energy efficiency and reduction of emissions. Means of improvement, such as the use of renewable energy and energy management, could be identified. Significant amount of electricity supplied from the utility grid can be reduced. This can reduce the demand for burning of fossil fuels to generate electricity. Hence, the amount of GHG emissions can also be reduced. A large-scale investigation can be implemented when using both audits together. Carbon audits can allow building owners or operator understand the amount of GHG emissions in different areas of operations, while energy audits can provide a detailed investigation into the energy consumption of different systems in the building.

1.3 State-of-the-art of standards and guidelines for carbon audits and energy audits

The governments and practitioners in the construction industry all over the world started their discussion on how to conduct precise carbon audits and energy audits and how to report the audits’ results systematically as these are important steps in the
programme of reducing GHG emissions and electricity consumption. Therefore, standards and guidelines were established in different countries in order to give guidance to organizations to conduct their carbon audits and energy audits.

In order to assist the users and owners of buildings to improve their awareness of energy conservation and GHG emissions and encourage them to participate in actions to combat climate change actively, the Hong Kong government has prepared guidelines on carbon audits and energy audits. The guidelines provide guidance on measuring the GHG emissions performance and the energy performance of buildings in Hong Kong. They also provide systematic and scientific approaches to account for and report on the GHG emissions and removals from buildings in Hong Kong and the energy consumptions of buildings in Hong Kong respectively.

1.4 Objectives of the study

Hotels are among the most energy intensive of all building categories. As a result, their energy use and environmental impact can be quite large, especially in popular tourist destinations [2]. Therefore, it is worthwhile to conduct a carbon audit and an energy audit in a typical hotel in Hong Kong by using the existing guidelines on carbon audits and energy audits in Hong Kong. Besides, another reason for conducting the audits in a typical hotel is because a relatively well organized data for carbon audit and energy audit can be obtained. In addition, the difficulties in conducting a carbon audit and an energy audit in a building is imperceptible without a thorough study, and a trial on a carbon audit and an energy audit in a building. Thus, a carbon audit and an energy audit are conducted in a hotel as a case study and the objectives of this study are:
to review the literatures, codes, standards and guidelines related to carbon audits and energy audits in Hong Kong and other countries in order to understand the background and methodologies for conducting carbon audits and energy audits.

- to conduct a carbon audit and an energy audit in a hotel in Hong Kong to identify the major sources of GHG emissions and investigate how efficiently energy has been used in the hotel.

- to identify opportunities for improvement on GHG emissions and energy consumption for the hotel.

- to examine the difficulties in conducting a carbon audit and an energy audit in the hotel based on the guidelines for carbon audits and energy audits in Hong Kong.

1.5 Organization of the dissertation

In this dissertation, literature and guidelines from Hong Kong and other countries are reviewed in order to understand the background, statutory requirements and methodologies of carbon audits and energy audits in Hong Kong and other countries. The requirements and criteria of the Building Energy Codes (BECs) and guidelines on the carbon audits and energy audits in Hong Kong are examined in the review. Methods to conduct the carbon audit and the energy audit in this study are also explained in Chapter 3. Results obtained from the study will be analyzed in Chapter 4. The dissertation will conclude with a summary of the study and suggestions for future research.
Chapter 2

Literature Review

This chapter introduces the issues related to carbon audits and energy audits. The first section reviews recent situation of energy consumptions and carbon dioxide emissions in the world and in Hong Kong. The second and third sections introduce the definitions and the guidelines for conducting carbon audits and energy audits in Hong Kong. The Building Energy Codes (BECs) in Hong Kong are introduced in the third section. The fourth and fifth sections explore the guidelines for carbon audits and energy audits in other countries. Comparisons among the guidelines in Hong Kong and in other countries are included in each section.

2.1 Energy consumptions and carbon dioxide emissions in the world and in Hong Kong

During the last two decades (1984-2004) energy consumption and carbon dioxide emissions in the whole world have increased by 49% and 43% respectively, with an average annual increase of 2% and 1.8% respectively [3]. These figures attracted the attention of engineers, scientists and environmentalists. Actions should be taken to relieve the increase in energy consumption and the increase in greenhouse gas emissions.

According to the Hong Kong Greenhouse Gas Inventory released by the Hong Kong Environmental Protection Department (EPD) in 2009, about 46.7 million tonnes CO₂-equivalent (CO₂-e) of total greenhouse gas emissions were released in Hong Kong in 2005 [4]. The CO₂-e per capita emissions in Hong Kong was 6.7 tonnes per
capita per year in 2007 [4]. This figure is lower than those recorded in most of the
developed regions in the world in 2007 such as the USA (19.1 tonnes/capita/year),
Australia (18.75 tonnes/capita/year), the UK (8.6 tonnes/capita/year), Japan (9.68
tones/capita/year) and Singapore (9.8 tonnes/capita/year), according to the statistics
from the International Energy Agency (IEA) [5]. The CO₂-e per capita emissions in
Hong Kong in 2007, however, was still higher than that of the whole world. The
above figures from EPD and IEA were obtained from processing of data with the
same method and emission factors from the Intergovernmental Panel of Climate
Change (IPCC). The CO₂-e per capita emissions in some major developed regions in
the world in 2007 are summarized in Table 1.

<table>
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<th>Region</th>
<th>CO₂-e per capita emissions (tonnes/capita/year)</th>
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<tr>
<td>Hong Kong [4]</td>
<td>6.70</td>
</tr>
<tr>
<td>USA [5]</td>
<td>19.10</td>
</tr>
<tr>
<td>Australia [5]</td>
<td>18.75</td>
</tr>
<tr>
<td>UK [5]</td>
<td>8.60</td>
</tr>
<tr>
<td>Japan [5]</td>
<td>9.68</td>
</tr>
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</table>

In Hong Kong, over 60% of total greenhouse gas emissions are produced from
electricity generation [6]. Buildings account for about 89% of end uses of electricity
in Hong Kong [6]. Therefore, reducing electricity consumption for building
operations is important to reduce greenhouse gas emissions in the territory.
Meanwhile, the local air quality can be improved as the electricity generation process
accounts for the emissions of 89%, 46% and 28% of sulphur dioxide (SO₂), nitrogen
oxides (NOₓ) and respirable suspended particulates (RSP) respectively in the
territory [7]. Furthermore, reducing electricity consumption in buildings can reduce
buildings' operational costs.
2.2 Carbon audit

2.2.1 Definition of carbon audit

Carbon audit is a life cycle assessment with the analysis limited to emissions that have an effect on climate change [8]. It is useful in improving the understanding of GHG emissions of companies. Conducting carbon audits can help identify the most effective reduction opportunities.

2.2.2 Guidelines for carbon audits in Hong Kong

In order to raise the building users’ and owners’ awareness of GHG emissions in buildings, the Environmental Protection Department (EPD) and the Electrical and Mechanical Services Department (EMSD) of the Government of the Hong Kong Special Administrative Region (HKSAR) have published the “Guidelines to Account for and Report on Greenhouse Gas Emissions and Removals for Buildings (Commercial, Residential or Institutional Purposes) in Hong Kong” in 2008. Latest edition was published in 2010. The guidelines were formulated based on the Greenhouse Gas Protocol (GHG Protocol) and ISO 14064 standards.

The GHG Protocol was published by the World Resourced Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). It provides the accounting framework for GHG standards and programmes in the world. It also provides standards and guidance for companies and other organizations to prepare their GHG emissions inventories [9]. The six greenhouse gases which are covered by the Kyoto Protocol have to be accounted for and reported according to the GHG
Protocol. The six greenhouse gases include carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF₆), however, since SF₆ is not commonly found in normal operations of building types covered in the guidelines, no quantification methodology related to SF₆ is provided in the guidelines for carbon audits in Hong Kong.

ISO 14064 was published by the International Organization for Standardization (ISO). It is also a standard for companies and other organizations to account for and report on GHG emissions and removals [10, 11, 12]. It is not a competing standard of the GHG Protocol.

(a) Classification of GHG emissions and removals

In the guidelines for carbon audits in Hong Kong, the greenhouse gas emissions and removals in buildings can be broadly classified into three separate scopes as below [6]:

Scope 1 – direct emissions from sources and removals by sinks
Scope 2 – energy indirect emissions
Scope 3 – other indirect emissions

These three different scopes quantify and report greenhouse gas emissions and removals which are generated or removed by different activities within the physical boundary of the building concerned, as shown in Figure 1. The GHG emissions are basically classified into direct (Scope 1) and indirect emissions (Scopes 2 and 3) by
judging whether the sources of emissions and removals are within the physical boundary of the building concerned. The scope of indirect emissions is further divided into two scopes. Scope 2 defines the indirect emissions that are emitted in the generation of purchased energy outside the physical boundary of the building concerned, while Scope 3 defines the indirect emissions that are a consequence of emission-releasing activities and which are not classified into scope 2.

The GHG emissions and removals for the activities covered in Scopes 1 and 2 have to be reported on a gas-by-gas basis; however, those GHG emissions for the activities covered in Scope 3 are optional. Reports of the GHG emissions for the activities covered in Scope 3 as shown in Figure 1 are encouraged because there are simple quantification methodologies developed in Hong Kong to quantify and report them. Meanwhile, it seems that the guidelines allow certain level of flexibility for the building users or owners to report on certain GHG emissions by including an “others” category. The activities causing GHG emissions are not limited to those shown in Figure 1. Actually, some other emissions caused by activities such as business travels by employees and uses of sold products and services can be included in “others” Scope 3 in the report according to the guidelines. There is, however, usually no simple quantification methodology developed in Hong Kong to quantify these GHG emissions.
Figure 1: Classification of GHG emissions and removals in guidelines for carbon audits in Hong Kong [6]

(b) Emission factors and removal factors

Carbon audits can be conducted by collecting data based on the three scopes described. The data listed in Table 2 are collected.

<table>
<thead>
<tr>
<th>Type and quantity of fuel consumed</th>
<th>Number of trees planted</th>
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<tbody>
<tr>
<td>Quantity of electricity consumed</td>
<td>Quantity of paper purchased</td>
</tr>
<tr>
<td>Quantity of town gas consumed</td>
<td>Quantity of paper recycled</td>
</tr>
<tr>
<td>Type and quantity of refrigerants released</td>
<td>Quantity of water consumed</td>
</tr>
</tbody>
</table>

The collected data are then converted into GHG emissions or removals by the emission factors or removal factors with the equations stated in the guidelines. In this way, the major source of GHG emissions can be clearly identified. The general equations for calculating the GHG emissions and removals are Eq. (1) and Eq. (2) respectively [6].

Estimated Activity Data x Emission Factor = GHG emissions.........................Eq. (1)
Estimated Activity Data x Removal Factor = GHG removals..........................Eq. (2)
There are different sources of emission factors, including government sources (e.g. United States Environmental Protection Agency), credible sources (e.g. university and research institutions). While the GHG Protocol and the IPCC Guidelines for National Greenhouse Gas Inventories published by the Intergovernmental Panel on Climate Change (IPCC) provide internationally agreed methodologies intended for use by countries to estimate greenhouse gas inventories [13]. The emissions factors stated in the guidelines for carbon audits in Hong Kong was making reference to the GHG Protocol, the IPCC Guidelines for National Greenhouse Gas Inventories, the annual report from local power companies, local town gas company and various related government departments, such as the Water Supplies Department and the Drainage Services Department.

There is still no GHG emissions calculator developed in Hong Kong for the calculation of GHG emissions with the assistance of computers. It is known that some countries like Australia and the UK have already developed GHG emissions calculators for their local uses [6, 14, 15].

(c) Ratio indicators

According to the guidelines for carbon audits in Hong Kong [6], quantified GHG emissions and removals can be normalized by floor area or number of occupants to become ratio indicators. These ratio indicators can be used in reporting and compared among different carbon audit reports. As carbon audit is still new in Hong Kong, benchmark database for carbon emissions and removals in hotels is still not available in Hong Kong.
Based on the Environmental Protection Agency (EPA) [16], the GHG emissions of hotels in the US were normalized into emissions associated with a one night stay in a hotel room. The emissions were calculated at 29.53 kg CO$_2$-e per room day for average hotels and 33.38 kg CO$_2$-e per room day for upscale hotels.

(d) Certificates scheme

The Hong Kong Awards for Environmental Excellence (HKAEE) has introduced the Carbon “Less” Certificate scheme which aimed to recognized buildings or organizations that achieved a verified absolute reduction of overall carbon emissions [17]. Buildings are able to obtain a Carbon “Less” Certificate if a minimum of 3% reduction in overall carbon emissions against baseline total emissions is achieved for first time participation [17].

2.2.3 Guidelines for carbon audits in other countries

Guidelines for carbon audits were also established in other countries in order to give guidance to organizations to conduct their carbon audits and energy audits. Australia and the UK are the leading countries of carbon audits where standards and guidelines for carbon audits have been established. This section explores the standards and guidelines published in these two countries. The similarities and differences between the guidelines in these countries and that in Hong Kong are also discussed.

(a) Australia

Australia adopts AS ISO 14064 for conducting carbon audits. The Department of
Climate Change of the Australian Government published the “National Carbon Offset Standard” which will come into effect on 1 July 2010 [18]. The standard specifies the general principles and requirements for calculating and reporting the carbon footprint of an organization. The standard contains provisions which are based on Australian and international standards and Australia legislation, such as AS ISO 14064, ISO 14040 [10, 11, 12], the GHG Protocol, and the National Greenhouse and Energy Reporting Act 2007 (NGER Act) [19].

The National Carbon Offset Standard [18] has no specification on the reporting period for a carbon audit; however, it has taken a 12-month period as an example. All the six greenhouse gases which are covered by the Kyoto Protocol have to be accounted for and reported according to the standard. The standard identifies and categorizes emissions-releasing activities into three scopes as shown in Figure 2. The classification in this standard is slightly different from that in the guidelines for carbon audits in Hong Kong. The National Carbon Offset Standard does not include the GHG removals into any one of the scopes. Meanwhile, waste disposal, either in landfill, as management of wastewater, or from waste incineration is classified in Scope 1 instead of Scope 3. Moreover, Scope 3 is not optional in reporting, which is different from Hong Kong. At least, emissions from business travel, disposal of waste generated by the organization and the use of paper are required to be included and reported in Scope 3.

With the data collected for the three scopes, amount of GHG emissions can be calculated by using emissions factors derived from the National Greenhouse Account Factors [20]. In addition, a calculation tool called National Greenhouse and Energy Reporting calculator (NGER calculator) was developed in Australia to assist the
auditors to calculate the GHG emissions.

Note: According to the “Nation Carbon Offset Standard”, “Facility” means “an activity, or a series of activities (including ancillary activities), that involves the production of greenhouse gas emissions, the production of energy or the consumption of energy and that forms a single undertaking or enterprise and meets the requirements of the National Greenhouse and Energy Reporting (NGER) Regulations”.

**Figure 2: Classification of GHG emissions-releasing activities in the “National Carbon Offset Standard” [18]**

(b) United Kingdom

The Department for Environmental, Food and Rural Affairs (Defra) and the Department for Energy and Climate Change (DECC) in the UK published the “Guidance on how to measure and report your greenhouse gas emissions” which specifies the general principles and requirements for conducting carbon audits for business and organizations [15].

The guidance in the UK clearly recommends a reporting period of 12 months, which ideally corresponds with the organization’s financial year [15]. All the six greenhouse
gases which are covered by the Kyoto Protocol have to be accounted for and reported according to the guidance. The guidance has also identified and categorized emissions-releasing activities into three scopes as shown in Figure 3.

![Diagram of GHG emissions classification](image)

**Figure 3: Classification of GHG emissions-releasing activities in the “Guidance on how to measure and report your greenhouse gas emissions” [15]**

The method of classification is found to be based on the GHG Protocol. The GHG emissions are basically classified into direct (Scope 1) and indirect emissions (Scopes 2 and 3) by judging whether the sources of emissions are owned or controlled by the building owners. The indirect emissions are further divided into two scopes. Scope 2 defines the indirect emissions that are emitted from the generation of purchased energy at the sources that did not owned or controlled by building owners, while Scope 3 defines the indirect emissions that are consequences of emission-releasing activities and which are not classified into scope 2.

The classification of GHG emissions-releasing activities in the guidance in the UK is similar to that in Hong Kong, except the GHG removals did not classified into any
one of the scopes in the UK guidance. Although the emissions that were defined in Scope 1 in the guidance in UK are similar to those in Hong Kong, more detailed classification of the emissions is provided in the guidance in the UK. The size of vehicles is considered in the carbon audit in the UK. Different emission factors are provided for different sizes of vehicles. Similar to Hong Kong, reporting of Scope 3 emissions is optional in the UK and the users may consider including emissions due to activities such as business travel and purchased materials or fuels, as shown in Figure 3.

One major difference between the guidelines in the UK and Hong Kong is that Defra/DECC GHG conversion factors stated in “Guidelines to Defra / DECC’s GHG Conversion Factors for Company Reporting” [21] are used in calculation of GHG emissions in the UK instead of those from the GHG Protocol. According to the guidelines for carbon audits in the UK, Defra/DECC annually updated excel spreadsheets can be used for GHG emissions calculation in the UK [15].

The results of the comparisons among carbon audit guidelines in Hong Kong, Australia and the UK are summarized in Table 3. Generally, the guidelines for carbon audits in these three places followed the framework provided by the GHG protocol and ISO14064 to account for and report on GHG emissions. The guidelines for carbon audits in Hong Kong can only be applied to buildings for commercial, residential or institutional purposes but they cannot be applied to industrial buildings or buildings for other special purposes. There are no simplified qualification methodologies and conversion factors in the guidelines in Hong Kong to be used for activities associated with industrial buildings or buildings for special purposes because of the complexities of greenhouse gas (GHG) emitting processes in these
buildings. As far as the emission factors are concerned, the guidelines for carbon audits in these three places also make reference to the GHG Protocol and the IPCC Guidelines for National Greenhouse Gas Inventories. The three places prepare emission factors applicable in the respective territories. In Australia and the UK, separate guidelines to emission factors are issued for use by auditors to estimate GHG emissions for reporting. The methods for the estimation of GHG emissions from industrial processes, such as chemical industry, metal production and etc., are also defined in Australia and the UK. The process emissions in different countries might be slightly different. Moreover, the guidelines for carbon audits in Hong Kong are based on buildings, but that in Australia and in the UK are based on organizations.

<table>
<thead>
<tr>
<th>Table 3: Comparisons of carbon audit guidelines in HK, Australia and the UK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Guidelines</strong></td>
</tr>
<tr>
<td>Guidelines to Account for and Report on Greenhouse Gas</td>
</tr>
<tr>
<td>Emissions and Removals for Buildings</td>
</tr>
<tr>
<td>(Commercial, Residential or Institutional Purposes) in Hong</td>
</tr>
<tr>
<td>Kong</td>
</tr>
<tr>
<td>Standards that the guidelines are based on</td>
</tr>
<tr>
<td>GHGs quantified</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Emissions classified into Scope 1, 2 and 3</td>
</tr>
<tr>
<td>Optional for reporting Scope 3</td>
</tr>
<tr>
<td>Separate guidelines for emission factors</td>
</tr>
<tr>
<td>Calculation tools</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
2.3 Energy audit

2.3.1 Definition of energy audit

An energy audit is an examination of energy consuming systems to ensure that energy is being used efficiently in many ways. The building manager examines the energy consumption of various building services systems and the way that energy is used in various system components. Hence, areas of inefficiency and suitable means for improvement can be identified [22].

The energy audit is an effective energy management tool. By identifying and implementing the means to achieve energy efficiency and conservation, not only can energy savings be achieved, but lives of equipment/systems can also be extended. All these mean savings in money. Most importantly, less fossil fuel will be burnt in the power plants when less energy is consumed. Therefore, relatively fewer pollutants will be generated [22].

Three types of energy are consumed in a hotel, which include electricity, town gas and fuel oil [23, 24]. Therefore the consumptions of these three types of energy are investigated in energy audits. Various building services systems consume electricity. These systems include heating, ventilation and air conditioning (HVAC) system, lighting system, vertical transportation system and plumbing and drainage system. The three types of energy investigated in this current study of the selected hotel will be further explained in Chapter 4.
2.3.2 Guidelines for energy audits in Hong Kong

Similar to the guidelines for carbon audits in Hong Kong, “Guidelines on Energy Audit” was published in Hong Kong in 2007 by the EMSD of the government of the HKSAR in order to raise the building users and owners’ awareness of energy conservation in buildings [22]. The guidelines provide information on conducting energy audits, proposing energy management opportunities and writing up audit reports. The guidelines should be read in conjunction with a set of Building Energy Codes (BECs) which were published to address energy requirements by setting out minimum design requirements on building services installations.

(a) Building Energy Codes in Hong Kong

Building Energy Codes (BECs) are instruments that guide and specify the direction for improving energy efficiency practices [25]. With a growing concern about energy consumption and its implications to the environment, actions were taken by the Hong Kong Government in the 1990s to promote energy conservation and a set of BECs was developed by the EMSD to control the total energy consumption in new commercial and office buildings. As stated in the guidelines for energy audits in Hong Kong, site survey and measurement should be conducted to determine if the energy consuming equipment/systems are operating per design after the information of building and equipment/systems has been obtained. Data obtained is compared against requirements in various BECs in order to identify the areas of inefficiencies.

The current BECs in Hong Kong consist of four prescriptive codes and one performance based code [26, 27, 28, 29, 30]. The four prescriptive codes stipulate
energy efficiency requirements for four key types of building services installations in buildings: lighting, air conditioning, electrical as well as lift and escalator installations, while the performance based code provides details on the total building energy approach. EMSD [31] has summarized the BECs in Hong Kong in a study on enhanced promotion of Building Energy Codes in Hong Kong. Table 4 shows the current BECs in Hong Kong which cover various aspects of building energy efficiency. These five energy codes are implemented on a voluntary basis under the Hong Kong Energy Efficiency Registration Scheme for Buildings (HKEERSB) managed by the EMSD. The codes are applied to all buildings with some exceptions as shown in Table 4. The codes mainly control the design but not the daily operation of the concerned building services installations in principle [32]. It is believed that different approaches are required to apply BECs in different building projects and situations [31]. The prescriptive codes can provide building owners a straightforward compliance path for small and simple buildings, while the performance based code can provide an effective method for investigating innovative and energy-efficient building design features that the prescriptive codes cannot address [31, 32]. The aim of performance based approach is to encourage the use of energy efficient equipment, innovative installations and renewable energy [32].

<table>
<thead>
<tr>
<th>Area of concern</th>
<th>First issued</th>
<th>Current version</th>
<th>Status</th>
<th>Scope of application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>1998</td>
<td>2007</td>
<td>Voluntary (by EMSD)</td>
<td>All buildings except domestic, industrial and medical ones*</td>
</tr>
<tr>
<td>Air-conditioning</td>
<td>1998</td>
<td>2007</td>
<td>Voluntary (by EMSD)</td>
<td>All buildings except domestic, industrial and medical ones*</td>
</tr>
<tr>
<td>Electrical</td>
<td>1999</td>
<td>2007</td>
<td>Voluntary (by EMSD)</td>
<td>All buildings except for special industrial process*</td>
</tr>
<tr>
<td>Lift and escalator</td>
<td>2000</td>
<td>2007</td>
<td>Voluntary (by EMSD)</td>
<td>All buildings except for special industrial process*</td>
</tr>
<tr>
<td>Performance-based</td>
<td>2004</td>
<td>2007</td>
<td>Voluntary (by EMSD)</td>
<td>All buildings except for special industrial process*</td>
</tr>
</tbody>
</table>

Note: *Communal areas of domestic and industrial buildings are included under the present scope.
(b) Energy Utilization Index (EUI)

Energy Utilization Index (EUI) can be used to indicate the energy performance of a building in an energy audit. It is obtained by dividing the annual energy consumption by the Gross Floor Area (GFA) [22]. EUI takes into account the difference in energy consumption due to difference in building floor areas and is used for comparison of energy consumption among buildings of similar nature [22]. From the regression analyses conducted by Priyadarsini et al. [2], GFA has the best correlation with the energy consumption in hotels. In Hong Kong, EUIs vary significantly among different hotels according to a study of energy use in 16 quality hotels in Hong Kong conducted by Deng and Burnett [24]. The maximum and minimum EUIs were 3370 MJ/m²/year and 1070 MJ/m²/year respectively. The average EUI for the 16 hotels was 2030 MJ/m²/year. Meanwhile, the average EUI for the five-star hotels involved in the study was 2039 MJ/m²/year and those for four-star and three-star hotels were 2148 MJ/m²/year and 1823 MJ/m²/year respectively in the same study. These average EUIs indicated that the class of a hotel does not affect the energy consumption in a hotel in Hong Kong.

(c) Benchmarking energy data

It is noticed that the use of EUIs for assessing energy performance does not truly reveal the actual energy use performance in existing commercial buildings like hotels, because their energy consumptions are affected by a number of factors. Direct comparison of energy performance among a number of existing buildings is virtually impossible using EUIs, unless there is a database of EUIs from a statistically meaningful number of buildings having similar functions and operating schedules.
With a database of EUIs for benchmarking, better and more meaningful comparison of energy performance among buildings can be achieved.

The EMSD has established an online benchmarking tool for energy consumption which is called "Energy Consumption Indicators & Benchmarks" [33]. The tool can be used to benchmark energy consumption of the hotel being studied. It can allow users to seek advice in setting targets to improve the energy consumption performance of their buildings. The tool requests data on energy consumptions for different types of fuels in the hotel within the consumption record period and details of the hotel, such as star number awarded for the hotel, age, total number of guests per year and guest room area to gross floor area of the hotel, for benchmarking. Whereas the guest room area is defined as “the area of all enclosed space of all guest rooms measured to the internal face of enclosing external and/or party walls” and the gross floor area is defined as “the area contained within the external walls of the hotel or boarding houses building measured at each floor (including any floor below the level of ground), together with the area of each balcony in the building, which shall be estimated from the overall dimensions of the balcony (including the thickness of the sides thereof), and the thickness of the external walls of the building. Outdoor gardening area and car-park area are excluded in the calculation of the gross floor area of the premises.” [33, 34].

(d) Energy Management Opportunities (EMOs)

According to the "Guidelines or Energy Audit" in Hong Kong [22], Energy Management Opportunities (EMOs) are referred to the means that can achieve energy efficiency and conservation. EMOs are classified into three categories
according to the cost and the complexity for implementation, as shown in Table 5.

<table>
<thead>
<tr>
<th>Categories of EMOs</th>
<th>Capital cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat. I</td>
<td>Involves practically no cost investment and without any disruption to building operation, normally involving general housekeeping measures.</td>
</tr>
<tr>
<td>Cat. II</td>
<td>Involves low cost investment with some minor disruption to building operation.</td>
</tr>
<tr>
<td>Cat. III</td>
<td>Involves relatively high capital cost investment with much disruption to building operation.</td>
</tr>
</tbody>
</table>

2.3.3 Energy audits in other countries

Different building energy codes (BECs) have been established in different countries. Table 6 shows a comparison of general BEC and energy audit legislation in different countries/places [32]. It is found that the implementation of BECs in Hong Kong is still voluntary. Unlike other countries such as Australia, Singapore and England, the implementation of BECs is mandatory. In the USA, the mandatory implementation of BECs is varied between cities or states. It seems Hong Kong is moving behind other countries in terms of mandatory process of implementation of BECs. Energy audits in buildings are still voluntary in most countries or regions, like Hong Kong, Australia and Singapore. It is, however, mandatory in England. In addition, the countries listed in Table 6 have developed their own documents on energy efficiency standards.

A comparison among some of the latest standards adopted in BECs in Hong Kong, overseas countries and the Mainland China has been done by Li and Yeung [32]. Tables 7 to 9 show the results obtained by Li and Yeung. Li and Yeung found that Hong Kong’s standards on air-conditioning systems and electrical installations are broadly comparable to the standards adopted by other countries, whereas Hong
Kong's standards on lighting installations are relatively less stringent to meet the
general local preference for better illuminated interior space.

Table 6: Comparison of general BEC and energy audit legislation in different countries/places [32]

<table>
<thead>
<tr>
<th>Country</th>
<th>Mandatory / Voluntary of BEC</th>
<th>BEC document on energy efficiency standards</th>
<th>Mandatory / Voluntary of energy audit in building</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hong Kong</td>
<td>Voluntary (under proposal for mandatory implementation)</td>
<td>Codes and practice for energy Efficiency in electrical, lighting, air condition, lift &amp; escalator Installations and Performance based Building Energy Code</td>
<td>Voluntary (under proposal)</td>
</tr>
<tr>
<td>Australia</td>
<td>Mandatory</td>
<td>Included in the Building Code of Australia</td>
<td>Voluntary</td>
</tr>
<tr>
<td>Singapore</td>
<td>Mandatory</td>
<td>SS 530 – Energy Efficiency Standard for Building Services and Equipment</td>
<td>Voluntary</td>
</tr>
<tr>
<td>UK</td>
<td>Mandatory</td>
<td>Approved Document L2 – Conservation of fuel and power in buildings other than dwellings</td>
<td>Mandatory</td>
</tr>
<tr>
<td>USA</td>
<td>Mandatory depends on cities or states</td>
<td>Building Energy Standards, California Energy Commission</td>
<td>Not widely adopted but being emerging in various cities or states</td>
</tr>
</tbody>
</table>

Table 7: Comparison of some standards of lighting power density in different countries/places [32]

<table>
<thead>
<tr>
<th>Space</th>
<th>Maximum allowable lighting power density (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hong Kong BEC</td>
</tr>
<tr>
<td>Open plan office / Cellular Office</td>
<td>17</td>
</tr>
<tr>
<td>Retails</td>
<td>20</td>
</tr>
<tr>
<td>Restaurant</td>
<td>23</td>
</tr>
<tr>
<td>Atrium / Foyer</td>
<td>25</td>
</tr>
</tbody>
</table>
Table 8: Comparison of some standards of Coefficient of Performance of typical air-conditioning chillers in different countries/places [32]

<table>
<thead>
<tr>
<th>Type/Rating of air-conditioning chiller</th>
<th>Coefficient of Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hong Kong BEC</td>
</tr>
<tr>
<td>Air cooled, scroll/screw</td>
<td>2.7-2.9</td>
</tr>
<tr>
<td>Water cooled, screw, 500-1000kW</td>
<td>4.6</td>
</tr>
<tr>
<td>Water cooled, screw, &gt;1000kW</td>
<td>5.5</td>
</tr>
<tr>
<td>Water cooled, centrifugal, 500-1000kW</td>
<td>4.5</td>
</tr>
<tr>
<td>Water cooled, centrifugal, &gt;1000kW</td>
<td>5.7</td>
</tr>
</tbody>
</table>

Table 9: Comparison of some standards of electrical motor efficiency in different countries/places [32]

<table>
<thead>
<tr>
<th>Motor (4-pole) Rating, P (kW)</th>
<th>Hong Kong BEC</th>
<th>Australia BCA</th>
<th>Singapore SS 530</th>
<th>US ASHRAE 90.1</th>
<th>Europe (e.g. UK Approved Document L.2)</th>
<th>China GB 50189</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 ≤ P&lt;5.5</td>
<td>76.2-84.2</td>
<td></td>
<td></td>
<td>83.8-88.3</td>
<td>84.0-87.5</td>
<td>76.2-84.2</td>
</tr>
<tr>
<td>5.5 ≤ P&lt;22</td>
<td>85.7-90.0</td>
<td>No specific requirement</td>
<td>89.2-92.2</td>
<td>89.5-92.4</td>
<td>85.7-90.0</td>
<td>No specific requirement</td>
</tr>
<tr>
<td>22 ≤ P&lt;55</td>
<td>90.5-92.5</td>
<td>92.6-93.9</td>
<td>92.4-93.6</td>
<td>90.5-92.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>55 ≤ P&lt;90</td>
<td>93.0-93.6</td>
<td>94.2-94.7</td>
<td>94.1-94.5</td>
<td>93.0-93.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P ≥ 90</td>
<td>93.9</td>
<td>95.0</td>
<td>94.5</td>
<td>93.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.4 Previous studies

As different guidelines and standards for carbon audits and energy audits were established in different countries, investigations in the energy and environment performance of different types of buildings based on the guidelines and standards have attracted the interest of many researchers.
Yik et al. [35] conducted a detailed energy audit for a commercial office building in Hong Kong. The study was conducted based on the energy consumption data obtained from the audited building. Annual energy consumption for the entire building was evaluated. It was found that HVAC system, lighting system and vertical transportation system accounted for 39%, 27% and 7% of the total electricity consumption respectively in the audited building. Energy improvement opportunities for the audited building were identified in the study.

Deng and Burnett [24] conducted an energy use study in 16 hotels in Hong Kong. The study was conducted based on the energy consumption data obtained from 16 hotels. The results showed that HVAC system, lighting system and vertical transportation system accounted for 45%, 17% and 7% of the total electricity consumption respectively in the hotels under investigation [24]. The remaining 31% of the total electricity consumption was contributed by miscellaneous equipment.

Another study on the energy performance of offices in Hong Kong was conducted by Li [36]; however, the offices studied were Government Offices. Li examined the EUIs for all of the selected government office buildings. Factors affecting the EUIs for the Government Offices have been identified. It is found that the energy performance of the Government Offices is affected by the energy management practice.

From the above studies, it is found that different types of buildings behave differently in terms of energy performance. Meanwhile, it is found that most of the previous studies concentrated on presenting the energy or environmental performance of different types of buildings. There has been limited discussion on the difficulties in
conducting the carbon audits or energy audits. In addition, in most cases, carbon audits and energy audits were not conducted and studied simultaneously in the different studies. It is worth conducting a carbon audit and an energy audit in a hotel in Hong Kong simultaneously (energy-cum-carbon audit) as a case study. The energy and environmental performance of the hotel can be examined at the same time. The energy improvement opportunities can be identified. Meanwhile, the difficulties in conducting the carbon audit and the energy audit in the concerned hotel can be analyzed.
Chapter 3
Methodology

This chapter illustrates the characteristics of the hotel being investigated in this study and the methods on conducting a carbon audit and an energy audit in the hotel. The carbon audit and the energy audit were conducted simultaneously. In order to have a deeper and updated understanding about the hotel, it was essential and important to visit the hotel regularly. Detailed information about the hotel, the equipment and the systems inside the hotel required for the two audits was obtained at the beginning of the audits. The data listed in Figure 4 was collected.

![Diagram](image)

**Figure 4: Data collected in the carbon audit and the energy audit**

3.1 Hotel description

The hotel was built in 1975. It is a four-star hotel situated in Kowloon, Hong Kong, with 23 storeys including three basement floors. 13/F is skipped in the hotel. Its total gross floor area (GFA) is about 40678m² and the air conditioning area is about
32870m². There are 626 guest rooms, 4 restaurants in different styles, a bar, a ballroom, three function rooms and a number of retail shops, however, it is noted that the retail shops in the hotel are not under investigation in this study as data from the shops was unavailable. Occupancy details including space usages and floor areas are shown in Table 10. The average daily number of direct-control staff is about 400. This hotel has a regular record in the energy consumptions and it was equipped with a number of electricity sub-meters which greatly facilitated the audit study.

<table>
<thead>
<tr>
<th>Floor number</th>
<th>Usage</th>
<th>Floor area (m²)</th>
<th>Operation hours</th>
<th>Daily hours of operation (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R/F</td>
<td>Chiller plant and tank</td>
<td>1138.02</td>
<td>Depends on demand</td>
<td>Depends on demand</td>
</tr>
<tr>
<td>19/F</td>
<td>Swimming pool</td>
<td>444.98</td>
<td>7:00am - 9:00pm (Summer), 7:00am - 7:00pm (Winter)</td>
<td>14 (Summer), 12 (Winter)</td>
</tr>
<tr>
<td>2/F – 18/F (without 13/F)</td>
<td>Guest rooms</td>
<td>31 for each guest room (bathroom included)</td>
<td>Whole day</td>
<td>24</td>
</tr>
<tr>
<td>1/F</td>
<td>Café</td>
<td>643.60</td>
<td>6:00am - 1:00am</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Pastry</td>
<td>29.93</td>
<td>7:00am - 5:00pm</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Butchery</td>
<td>65.61</td>
<td>7:00am - 5:00pm</td>
<td>10</td>
</tr>
<tr>
<td>M/F</td>
<td>Italian restaurant</td>
<td>286.49</td>
<td>11:30am - 2:00pm, 5:30pm - 10:00pm (Monday - Saturday only)</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Bar</td>
<td>306.95</td>
<td>6:00am - 1:00am</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Reception counter</td>
<td>307.00</td>
<td>Whole day</td>
<td>24</td>
</tr>
<tr>
<td>B1</td>
<td>Chinese restaurant</td>
<td>572.89</td>
<td>11:00am - 3:00pm, 6:00pm - 11:00pm</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Western restaurant</td>
<td>296.49</td>
<td>11:30am - 11:00pm</td>
<td>11.5</td>
</tr>
<tr>
<td>B2</td>
<td>Laundry</td>
<td>76.77</td>
<td>7:00am - 7:00pm</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Staff canteen</td>
<td>88.6</td>
<td>8:00am - 2:00pm, 6:00pm - 9:00pm</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Staff kitchen</td>
<td>28.4</td>
<td>7:00am - 2:00pm, 6:00pm - 9:00pm</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Heat pump room</td>
<td>196.29</td>
<td>Depends on demand</td>
<td>Depends on demand</td>
</tr>
<tr>
<td>B3</td>
<td>Chinese kitchen</td>
<td>201.54</td>
<td>10:00am - 3:00pm, 6:00pm - 11:00pm</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Western kitchen</td>
<td>187.70</td>
<td>10:30am - 11:00pm</td>
<td>12.5</td>
</tr>
<tr>
<td></td>
<td>Ballroom</td>
<td>711.62</td>
<td>Depends on demand</td>
<td>Depends on demand</td>
</tr>
<tr>
<td></td>
<td>Function rooms</td>
<td>288.57</td>
<td>Depends on demand</td>
<td>Depends on demand</td>
</tr>
<tr>
<td>G/F, B2</td>
<td>Offices</td>
<td>146</td>
<td>9:00am - 7:00pm</td>
<td>10</td>
</tr>
</tbody>
</table>

Different types of energy are used in the hotel, including electricity, town gas and fuel oil. Electricity is the form of energy widely used within the hotel. It is used generally for air-conditioning, heating, lighting, lifts, escalators and miscellaneous
items like kitchen equipment. Town gas is used for cooking, while fuel oil is used for the operation of standby generator.

3.2 Carbon audit

3.2.1 Reporting period

The reporting period of the carbon audit of the hotel is from 1 January to 31 December 2009 (1 year). This reporting period was determined based on actual data as well as information monitored and collected during project implementation. A one-year reporting period is also recommended in the guidelines for carbon audits in Hong Kong [6] and in the UK [15]. With the one-year reporting period, an annual overall GHG emission of the hotel could be calculated at the end of the audit. Therefore, the reporting period was started on 1 January 2009 because data on paper consumption was only available starting from that day. The reporting period was finished on 31 December 2009 in order to obtain one year data to calculate annual greenhouse gas emissions.

3.2.2 Process of data collection and analysis

The data for the carbon audit was collected by means of a questionnaire survey which was conducted through interviews with the engineers in the hotel. Face-to-face personal interviews were conducted to facilitate obtaining sensitive, yet essential information. A questionnaire for the carbon audit was designed according to the guidelines for carbon audits in Hong Kong [6]. The questionnaire used is attached in Appendix A. There are ten sections in the questionnaire. Section 1 was used to obtain
general information of the hotel. Sections 2 to 9 asked the hotel engineers for the data for different sources of GHG emissions or removals. Bills for utilities, including electricity, town gas, fuel oil and fresh water, during the reporting period were collected for analysis. Section 10 asked the hotel engineers for other comments.

The required data collected were converted into amount of GHG emissions or removals by the emission factors or removal factors with the equations (see Table 11) stated in the guidelines for carbon audits in Hong Kong. A summary of equations for calculating GHG emissions and removals in tonnes of CO₂ equivalent (CO₂-e) obtained from the “Guidelines to Account for and Report on Greenhouse Gas Emissions and Removals for Buildings (Commercial, Residential or Institutional Purposes) in Hong Kong” [6] with updated emission factors and removal factors is shown in Table 11. Emission factors and removal factors updated in the year of reporting period were used in the calculations. The major source of GHG emissions was clearly identified after the calculations. Measures targeting the major source were recommended to reduce GHG emissions of the hotel. At the same time, annual overall GHG emission of the hotel was calculated and normalized by floor area and number of guest rooms for analysis.
<table>
<thead>
<tr>
<th>Scope of emissions</th>
<th>Equations for calculating tonnes of CO2 Equivalent (CO2-e)</th>
</tr>
</thead>
</table>

### Scope 1 Direct Emissions

#### Stationary Sources Combustion

CO₂ emissions in tonnes of CO₂-e = Σ Amount of Fuel Consumed (litre) x Emission Factor of CO₂ / 1000

\[ \text{Eq(3)} \]

CH₄ or N₂O emissions in tonnes of CO₂-e = Σ Amount of Fuel Consumed (litre) x Emission Factor of CH₄ or N₂O / (1000 x 1000) x GWP

\[ \text{Eq(4)} \]

where emission factor of CO₂ = 2.614 (kg/litre) for diesel oil,
emission factor of CH₄ = 0.0239 (g/litre) for diesel oil,
emission factor of N₂O = 0.0074 (g/litre) for diesel oil,
Global Warming Potential (GWP) of CH₄ is 21 while it is 310 for N₂O [6]

### Mobile Sources Combustion

CO₂ emissions in tonnes of CO₂-e = Σ Amount of Fuel Consumed (litre) x Emission Factor of CO₂ / 1000

\[ \text{Eq(5)} \]

CH₄ or N₂O emissions in tonnes of CO₂-e = Σ Amount of Fuel Consumed (litre) x Emission Factor of CH₄ or N₂O / (1000 x 1000) x GWP

\[ \text{Eq(6)} \]

where emission factor of CO₂ = 2.360 (g/litre) for unleaded petrol (ULP),
emission factor of CH₄ = 0.645 (g/litre) for gas oil for ship
emission factor of N₂O = 0.429 (g/litre) for jet kerosene
emission factor of CH₄ = 0.253 (g/litre) for ULP for passenger car
emission factor of CH₄ = 0.146 (g/litre) for gas oil for ship
emission factor of CH₄ = 0.069 (g/litre) for jet kerosene
emission factor of N₂O = 1.105 (g/litre) for ULP for passenger car,
emission factor of N₂O = 1.095 (g/litre) for gas oil for ship,
emission factor of N₂O = 0.006 (g/litre) for jet kerosene,
Global Warming Potential (GWP) of CH₄ is 21 while it is 310 for N₂O [6]

### Fugitive Emissions

\[ \text{OE} = \sum (C_{i} + G_{i} - C_{n} - C_{0}) \times \text{GWP}_i / 1000 \]

\[ \text{Eq(7)} \]

where \( \text{OE} = \text{SF6 or HFC or PFC emissions from operation of equipment due to release of refrigerant } i \) (in tonnes of CO₂-e),
\( C_{i} = \text{Refrigerant inventory at beginning of the reporting period (in storage, not equipment) } (kg) \),
\( G_{i} = \text{Refrigerant added to the inventory during the reporting period } (kg) \),
\( C_{n} = \text{Refrigerant disposed of through environmentally responsible means (e.g. collected by contractor for recycling) during the reporting period } (kg) \),
\( C_{0} = \text{Refrigerant inventory at end of the reporting period (in storage, not equipment) } (kg) \),
\( \text{GWP}_i = \text{100-year global warming potential of the refrigerant } i, 1300 \text{ for } \text{HFC-134a, 3260 for R-404A and 0 for R22 as not covered in Kyoto protocol} [6] \).

### GHG Removals

Assimilation of CO₂ into biomass through planting of additional trees CO₂ removed by trees in tonnes of CO₂-e = net number of additional trees which are able to reach at least 5m in height planted since the concerned building is constructed x Removal Factor (23kg / tree / year) / 1000 x length of reporting period in years

\[ \text{Eq(8)} \]

### Scope 2 Energy Indirect Emissions

#### Consumption of purchased electricity

Indirect GHG emissions in tonnes of CO₂-e = Quantity of purchased electricity (kWh) x Emission Factor / 1000

\[ \text{Eq(9)} \]

where GHG emission factor for China Light Power (CLP) in Hong Kong in 2009 was 0.560 kg CO₂-e/kWh [17], or emission factor = territory-wide default value = 0.7kg CO₂-e/kWh [6].

#### Consumption of Town gas

Indirect GHG emissions in tonnes of CO₂-e = Quantity of purchased Town gas x Emission Factor / 1000

\[ \text{Eq(10)} \]

where Town gas is charged in unit (i.e. 1 unit registered by the gas meter = 48 mega joules (MJ) consumed), emission factor for town gas from the Hong Kong and China Gas Company in 2008 was 0.593 kg CO₂-e/unit [28].

### Scope 3 Other Indirect Emissions

#### Methane gas generation at landfill due to disposal of paper waste

Indirect emissions in tonnes of CO₂-e = (Ps + Pi - Pr - Pe) x Emission Factor (4.8 kg CO₂-e / kg)

\[ \text{Eq(11)} \]

where Ps = Paper inventory at the beginning of the reporting period (in storage) (kg),
pi = Paper added to the inventory during the reporting period (kg),
Pr = Paper collected for recycling purpose (kg),
Pe = Paper inventory at the end of the reporting period (in storage) (kg),
emission factor = 4.8 kg CO₂-e/kg of waste [6].

#### Consumption of fresh water

Indirect emissions in tonnes of CO₂-e = Amount of fresh water consumed as listed on the water service bill (m³) x Emission Factor / 1000

\[ \text{Eq(12)} \]

where emission factor = unit electricity consumption of fresh water x territory-wide default value (i.e. 0.7kg CO₂-e/kWh) of purchased electricity = 0.4116kg CO₂-e/m³ [29] in 2009 from Water Supplies Department in HK.

#### Treatment of waste water

Indirect emissions in tonnes of CO₂-e = Amount of fresh water consumed as listed on the water service bill (m³) x Default Emission factor / 1000

\[ \text{Eq(13)} \]

where default emission factor (kg/m³) for restaurants and catering services = (0.7 x Emission Factor), assuming 70% of the fresh water consumed will enter the sewage system,
default emission factor (kg/m³) for other commercial, residential and institutional purposes = (1.0 x Emission Factor), assuming 100% of the fresh water consumed will enter the sewage system,
emission factor = unit electricity consumption of processing sewage x territory-wide default value (i.e. 0.7kg/kWh) of purchased electricity = 0.172kg CO₂-e/m³ [6] in 2008 from Drainage Services Department in HK.
3.3 Energy audit

The general procedures for conducting an energy audit stated in the “Guidelines on Energy Audit” [22] published by the EMSD of the government of the HKSAR were followed; however, there were some modifications to the procedures with the consideration of limitations of this study. This is because the budgeting and costing for conducting the energy audit were not under the control of the researcher. The modified procedures for conducting the energy audit in the hotel concerned are shown in Figure 5.

![Flow chart on conducting the energy audit](image)

Figure 5: Flow chart on conducting the energy audit

The scope of the energy audit was defined at the beginning. This energy audit focused on the investigation of the consumptions of electricity, town gas and fuel oil. The performance of major building services systems was investigated. The systems include heating, ventilation and air conditioning (HVAC) system, lighting system, vertical transportation system as well as plumbing and drainage system.
3.3.1 Audit period

An energy audit team which comprises the researcher, engineers and technicians in the hotel was formed to conduct the energy audit. The audit period of the hotel was from 1 January 2006 to 31 December 2009. It was because minimum three years electricity consumption record is required as stated in the guidelines for energy audits in Hong Kong and a four-year-record was available in the hotel. Bills for utilities, including electricity, town gas and fuel oil, during the audit period were collected for analysis.

3.3.2 Process of data collection, site measurement and analysis

Generally, the methods for obtaining data for an energy audit could be classified into three levels of work as shown in Figure 6. The first level of work involved the collection of energy billing information and various documents for the performance investigation of the equipment and systems. The second level of work involved site inspections and measurements on the electricity consumed equipment and systems. The third level of work involved computer simulations for further analysis on the performance of the equipment and systems.
In this study, data for the energy audit in this study was obtained by the first two levels of work as demonstrated in Figure 6. For the first level of work in this study, bills for utilities and the following types of documents were collected for the performance investigation of the equipment and systems, namely:

- layout drawings of the hotel
- as-fit drawings of equipment, meters and sub-meters
- catalogs and specifications of equipment
- operation and maintenance (O&M) manuals
- testing and commissioning (T&C) reports
- operation records of equipment and systems
For the second level of work in this study, site inspections and measurements on the electricity consumed equipment/systems were conducted in the hotel to determine if the energy consuming equipment/systems were operating per design. Spot checking strategy was used for the site inspections and measurements in order to reduce the interruptions to the operation of the hotel. Spot checks were conducted for major and typical equipment/systems as listed in Appendix C. The performance criteria for the equipment and systems to be investigated as stated in the BECs published by the EMSD are showed in Appendix C. The methods used in performance investigation of the systems were described as follows:

(a) HVAC system

(i) Chillers Performance

Based on the design data as well as testing and commissioning record of the chillers, the initial coefficients of performance (COPs) of the chillers at the time that they were newly installed were calculated and compared with that required in the BECs in Hong Kong. The COPs were calculated with the following equation [41]:

\[
\text{COP} = \frac{m \cdot c \cdot (T_{in} - T_{out})}{\text{Power Input}} \quad \text{Eq. (14)}
\]

where \( m \) is the mass flow rate of the chilled water in kg/s,

\( c \) is the specific heat capacity of water (i.e. 4.2kJ/kg/°C),

\( T_{in} \) is the inlet temperature of chilled water in °C,

\( T_{out} \) is the outlet temperature of chilled water in °C,

Power Input is the power input of the compressor in kW.
(ii) Motor efficiencies

Based on the design data as well as testing and commissioning records, motor efficiencies of chilled water pumps, condenser water pumps, cooling tower fans, AHUs, PAUs and exhaust air fans were investigated and compared with that requirement stated in the BECs in Hong Kong. The motor efficiencies for the chilled water pumps and condenser water pumps were found from their pump curves in catalogs and based on the pump heads and flow rates at their operating points. Meanwhile, the motor efficiencies of cooling tower fans, AHUs, PAUs and exhaust air fans could be determined by the following equation [27] with the rated power output, the supply voltage and a one-off measurement of the full load running current and power factor.

$$\text{Motor efficiency} = \frac{\text{Rated power output of the motor in W}}{\sqrt{3} \times V \times I \times PF} \times 100\% \quad \text{Eq.(15)}$$

where $V$ is the three phase supply voltage to the motor in V,

$I$ is the full load running current of the motor in A,

$PF$ is the power factor.

(iii) Piping system and air ducts

According to the BECs in Hong Kong, piping system used in HVAC applications should ensure a pipe friction loss less than 400Pa/m and air duct leakage should not exceed certain limit with respect to corresponding static pressure. However, the pipe friction test and air duct leakage test could not be conducted as the commencement of these tests might interrupt the operation of the hotel. Instead, spot visual
inspection on the piping systems and air ducts was conducted to identify any leakage of chilled water and condensing water in the piping systems as well as any damage of insulations for the piping system and air ducts.

(b) Lighting system

Spot site investigations and measurements for the lighting systems in twelve typical functional areas of the hotel as shown in Appendix C were conducted. Types, numbers and power inputs of lamps and luminaires used in these functional areas were recorded. Lamps and luminaires for decoration were not counted in inspection based on the BECs in Hong Kong. The dimensions of the functional areas were measured and recorded. Areas of the functional spaces were then calculated. Lighting power densities of the twelve functional areas were calculated separately with the following equation [28]:

\[
\text{Light Power Density} = \left\{ \frac{(N_1 \times CW_1) + (N_2 \times CW_2) + \cdots + (N_n \times CW_n)}{(A)} \right\} \quad \text{Eq.(16)}
\]

where \(N_1, N_2, \ldots, N_n\) refer to quantities of \(n\) different types of luminaires installed in a space,

\(CW_1, CW_2, \ldots, CW_n\) refer to Circuit Wattage of \(n\) different types of luminaires in the space,

\((A)\) refers to area of space.

Average illuminances of the twelve functional areas were measured in the site inspections respectively as a reference for studying how efficient the electricity was being used, although it is not required according to the BECs. Full grid method of
measurement suggested in the Code for interior lighting from the Chartered Institution of Building Services Engineers (CIBSE) [42] was followed. The interior space was divided into a number of equal areas with the shape as square as possible. The illuminance at working plane level (assumed 0.8m above ground) at the centre of each area was measured with a lux meter and the mean value was then calculated. The estimated average illuminance of the interior space was found. The number of measurement points is proportional to accuracy. The minimum number of measurement points for each functional area was determined based on the room index of the space according to Table 5.7 of the Code for interior lighting from CIBSE [42] (see Table 12). The room indices of the functional areas were calculated with the following equation [42]:

\[
K = \frac{L \times W}{(L+W)h_m}
\]

Eq.(17)

where \( K \) refers to room index of a space,

\( L \) refers to the length of the space,

\( W \) refers to the width of the space,

\( h_m \) refers to the luminaire mounting height (height of luminaire above working plane).

Table 12: Minimum number of measurement points required to measure the average illuminance for a space [42]

<table>
<thead>
<tr>
<th>Room index</th>
<th>Number of points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 1</td>
<td>9</td>
</tr>
<tr>
<td>1 and below 2</td>
<td>16</td>
</tr>
<tr>
<td>2 and below 3</td>
<td>25</td>
</tr>
<tr>
<td>3 and above</td>
<td>36</td>
</tr>
</tbody>
</table>
The estimated average illuminance in each functional area was then compared with the recommended value from the Code for interior lighting published by CIBSE.

In addition, luminous efficacies of the lamps and controlgear losses of the luminaires were collected for analysis and they could be found from the manufacturers’ catalogues, from the labels on the packaging boxes, or even on the bodies of the lamps and the luminaires.

(c) Vertical transportation system

According to the BECs, several parameters of the lift motor drive systems at the moment the lift cars is moving up with rated load at its rated speed were investigated, including the running active power, the total harmonic distortion (THD) and power factors. The BECs’ requirements for these parameters were summarized in Appendix C. These parameters could be measured by a power and quality analyzer. However, the measurements for the lifts with rated load were unavailable as the implementation of complete tests may interrupt the normal operation of the lifts. Therefore, the measurements were conducted during the normal operation of the lifts and with variable load.

Similarly, the running active power, the total harmonic distortion (THD) and power factors of the escalators were measured by a power and quality analyzer but under no-load condition based on the BECs in Hong Kong. The BECs’ requirements for these parameters were also summarized in Appendix C.

Based on the design data as well as testing and commissioning records, motor
efficiencies of the motors of lifts and escalators were also examined and compared with the requirement stated in the BECs in Hong Kong (see Appendix C). The motor efficiencies of the lift motors could be determined by using equation Eq.(15).

(d) Plumbing and drainage system

Similar to motors in HVAC system and vertical transportation system, motor efficiencies of the pump motors in plumbing and drainage system were also examined and compared with the requirement stated in the BECs in Hong Kong (see Appendix C). Based on the design data as well as testing and commissioning records, the motor efficiencies of the pump motors could be determined by using equation Eq.(15).

3.3.3 Breakdowns of total electricity consumption and total energy consumption by types of services systems

In addition to the power company’s meters, twenty sub-meters have been installed in June 2009. The areas or usages that served by the sub-meters were showed in Table 13 and Figure 7. These sub-meters allow the total electricity consumption to be broken down into consumption of individual services systems. However, not all the sub-meters were ideally installed based on usages of electricity, most of them were installed based on areas that the electricity was consumed. Therefore, approximate electricity consumption of individual services systems could be determined by manipulating the sub-meters’ readings. Besides, certain assumptions have been made during in the manipulation. Manipulations used in finding the electricity consumptions of major building services systems are shown in Table 14.
Table 13: Electricity sub-meters in the hotel

<table>
<thead>
<tr>
<th>Meter No.</th>
<th>Areas or usages served</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2/F-19/F FCUs</td>
</tr>
<tr>
<td>2</td>
<td>2/F-18/F PAUs and AHUs (west)</td>
</tr>
<tr>
<td>3</td>
<td>2/F-18/F PAUs and AHUs (south)</td>
</tr>
<tr>
<td>4</td>
<td>15/F-19/F guest rooms</td>
</tr>
<tr>
<td>5</td>
<td>1/F-14/F guest rooms</td>
</tr>
<tr>
<td>6</td>
<td>8/F-10/F guest rooms</td>
</tr>
<tr>
<td>7</td>
<td>2/F-7/F guest rooms</td>
</tr>
<tr>
<td>8</td>
<td>1/F Café</td>
</tr>
<tr>
<td>9</td>
<td>1/F Pastry</td>
</tr>
<tr>
<td>10</td>
<td>1/F Butchery</td>
</tr>
<tr>
<td>11</td>
<td>M/F Italian restaurant</td>
</tr>
<tr>
<td>12</td>
<td>M/F Bar</td>
</tr>
<tr>
<td>13</td>
<td>B1 Chinese restaurant</td>
</tr>
<tr>
<td>14</td>
<td>B1 Western restaurant</td>
</tr>
<tr>
<td>15</td>
<td>B2 Laundry</td>
</tr>
<tr>
<td>16</td>
<td>B2 Heat pump system</td>
</tr>
<tr>
<td>17</td>
<td>B2 Heater system</td>
</tr>
<tr>
<td>18</td>
<td>B3 Chinese kitchen</td>
</tr>
<tr>
<td>19</td>
<td>B3 Western kitchen</td>
</tr>
<tr>
<td>20</td>
<td>B3 Ballroom and function rooms</td>
</tr>
</tbody>
</table>

Figure 7: Simplified schematic diagram of the electricity sub-meters in the hotel

As there was no sub-meter monitoring the electricity consumption of the HVAC water side system, the electricity consumption of the HVAC water side system was
found by subtracting the total electricity consumption with the electricity consumptions of all other electrical systems, including the electricity consumptions recorded by the sub-meters and other approximated electricity consumptions which was not measured by the sub-meters. Although it is attempted to estimate the electricity consumption of the HVAC water side system with the operation records of the chillers, chilled water pumps and condensing water pumps, including the hours of operation and the number of compressors or pumps in operation; accurate estimation could not be accomplished as the coefficients of performance (COPs) of the chillers varied with different operating conditions. Thus the electricity input of the chillers was changing under different operating conditions. Generally, the electricity consumption of the chillers could also be estimated with higher accuracy by using computer simulation with the input of information such as the capacities of the chillers, the hours of operations and the operating conditions; however, this is beyond the scope of work in this study.

Electricity consumption of the HVAC air side system was estimated by the summation of the readings from sub-meters 1, 2 and 3 with the approximated electricity consumption of the air side equipment on 1/F to B3. Sub-meters 1, 2 and 3 were used to measure the electricity consumed by the PAUs, AHUs and FCUs on 2/F to 19/F. For the approximated electricity consumption of the air side equipment on 1/F to B3, it is approximated from the total running hours, supply voltage, running current and power factor for each of the equipment, as the electricity consumption of the air side equipment on 1/F to B3 were rather stable as the running hours of them were scheduled according to the operation hours of the offices, restaurants and kitchens. Besides, it is assumed that these air equipment were switched on round the year. This assumption is reasonable as these equipment were serving the areas that
often require cooling, such as the offices, restaurants and kitchens, especially for the equipment serving the basement floors.

The amount of electricity consumed by the lighting system was estimated by the summation of the readings from sub-meters 4, 5, 6 and 7 with the approximated electricity consumptions by the façades lighting installations and by the lighting installations in the areas that were not monitored by the sub-meters, including the lighting installations in the areas inspected and in the areas not inspected. The inspected areas include the staff canteen, staff kitchen, Chinese kitchen, western kitchen, ballroom, function rooms, offices, toilets, lift lobbies, staircases, corridors and circulation areas. The electricity consumptions of the lighting installations in these inspected areas were approximated from the total installed lighting powers and the total operation hours which were assumed to be the same as the opening hours of the spaces. Meanwhile, the non-inspected areas include the café, pastry, butchery, bar, Chinese restaurant and western restaurant. The reason for the unavailable of the inspection was because of the disruption of business that might cause by the inspection. Moreover, there was no as-fit drawing of the lighting installations in the hotel available for investigation. Therefore, the types and number of luminaires used in these non-inspected areas were unknown. This demonstrates a difficulty in conducting an energy audit. In this case, it is assumed the installed lighting power densities in the non-inspected areas were the same as those recommended in the BECs. Hence, the electricity consumption of the lighting installations in each of these non-inspected areas was approximated from the assumed lighting power density, area of the space and the total operation hours of the luminaires which were assumed to be the same as the opening hours of the space. Furthermore, sub-meters 4, 5, 6 and 7 were used to measure the electricity consumption of all the guest rooms. It
is, however, unable to separate the amount of electricity consumption contributed by the lighting system and by the small power within the guest rooms as the operation hours of the luminaires and the demand for small power in the guest rooms were irregular and unpredictable. It is assumed that the electricity consumed inside the guest rooms is only contributed by the lighting system. It is noted that this assumption might cause the overestimation of the electricity consumption of the lighting system of the hotel.

Regarding to the electricity consumed by the heat pump system and the backup hot water heater, it could be determined by the summation of the readings from the sub-meters 16 and 17.

Moreover, there is also no sub-meter installed to measure the electricity consumptions of the lifts and escalators. The amount of electricity consumed by the lifts and escalators could be approximated from the measurements of power consumption of the lifts and escalators in a day, and the number of days in the investigation period. For the lifts, one-day power consumption measurement was conducted on one of the lifts with a power analyzer. Although the lifts were identical, the lifts were grouped to serve for different purposes, 6 of them were passengers lifts and 2 of them were goods lifts. However, in order to avoid any disruption and failure to the lift service provided to the guests, the measurement could only be conducted on one of the goods lifts. It should be noted that the loading of the goods lifts may be different from that of the passengers lifts, perhaps the loading of the goods lifts were higher as all the hotel staff have to use the goods lifts for travelling between floors. It should also be noted that it is difficult to define a typical day for lift power measurement as the occupancy rate of the hotel and the pattern of lift usage are
variable every day. In addition, the error in approximation could be minimized by conducting the power measurement for a longer period, such as a week or a month. However, longer period of measurement was not available in this investigation due to the limited schedule of the lift contractor.

For the escalators, although permission was gained to measure the power consumption of escalators through the distribution board of the escalators, the measurement could not be conducted finally due to safety reasons. It is found that the distribution board was located in an area where easily accessible by most staff. It is risky to expose the distribution board for measurement for a day as this may endanger the people who approach there. Hence, the electricity consumed by the escalators was approximated from the number of daily operation hours, the number of days in the investigation period and the full load power of each escalator.

Regarding to the plumbing and drainage system, the power demand of the constant speed constant flow pumps were rather stable throughout the operating periods. Hence, the power consumption of each pump could be approximated from the total running hours, the supply voltage and a one-off measurement of the running current and power factor for each pump. The daily running hours of the pumps were logged by data logger. It is assumed that the running hours of the pumps were identical in each day. Hence, the total running hours of the pumps in the investigation period was found by multiplying the daily operation hours of the pumps with the number of days in the investigation period. For the electricity consumption of the whole plumbing and drainage system, it was equal to the sum of approximated electricity consumption of the pumps in the system.
Table 14: Manipulations used in finding the breakdown electricity consumptions of various building services systems in the hotel

<table>
<thead>
<tr>
<th>End uses</th>
<th>Manipulations used</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) HVAC (water side)</td>
<td>(Total electricity consumption from June 2009 to December 2009) - (sum of readings from sub-meters 1 to 20) - (Electricity consumption not measured by sub meters) = (Total electricity consumption from June 2009 to December 2009) - (sum of readings from sub-meters 1 to 20) - [(approximated electricity consumption of air side equipment from G1 to B3) + (approximated electricity consumption of lighting for offices, toilets, lift lobbies, staircases, corridors and circulation areas) + (approximated electricity consumption of façade lighting) + (approximated electricity consumption of lifts and escalators) + (approximated electricity consumption of plumbing and drainage system)]</td>
</tr>
<tr>
<td>(B) HVAC (air side)</td>
<td>(Sum of readings from sub-meters 1, 2 and 3) + (approximated electricity consumption of air side equipment from 1/F to B3)</td>
</tr>
<tr>
<td>(C) Lighting</td>
<td>(Sum of readings from sub-meters 4, 5, 6 and 7) + (approximated electricity consumption of lighting installations for areas inspected) + (approximated electricity consumption of lighting installations for areas not inspected) + (approximated electricity consumption of façade lighting from June 2009 to December 2009) = (Sum of readings from sub-meters 4, 5, 6 and 7) + (approximated electricity consumption of lighting installations in staff canteen, staff kitchen, Chinese kitchen, western kitchen, ballroom, function rooms, offices, toilets, lift lobbies, staircases, corridors and circulation areas) + (approximated electricity consumption of lighting installations in café, pastry, butchery, bar, Chinese restaurant, western restaurant) + (approximated electricity consumption of façade lighting from June 2009 to December 2009)</td>
</tr>
<tr>
<td>(D) Hot water (the heat pump system and the heater)</td>
<td>Summation of the readings from sub-meters 16 and 17</td>
</tr>
</tbody>
</table>
| (E) Lifts and escalators                     | (i) For lifts  
  (Measured electricity consumption of a lift in one day) x (number of lifts) x (number of days from June 2009 to December 2009) x (number of lifts)  
  (ii) For escalators  
  (Approximated full load power of an escalator) x (number of daily operation hours) x (number of days from June 2009 to December 2009) x (number of escalators)                                                                 |
| (F) Plumbing and drainage system             | (i) For each duty pump  
  (Approximated full load consumption of the pump) x (measured operation hours on one day) x (number of days from June 2009 to December 2009)  
  (ii) For the whole system  
  = sum of the approximated electricity consumption of the pumps from June 2009 to December 2009                                                                 |
| (G) Other electrical equipment               | (Sum of readings from sub-meters 8 to 15 and 18 to 20) - (approximated electricity consumption of lighting installations in the areas that sub-meters 8 to 15 and 18 to 20 served) |

For the approximated electricity consumption of the other electrical equipment, it was found by the sum of the readings from sub-meters 8 to 15 and 18 to 20 less the
approximated electricity consumption of lighting installations in the areas that sub-meters 8 to 15 and 18 to 20 served.

3.3.4 Energy Utilisation Index (EUI) and benchmarking

The Energy Utilisation Indices (EUIs) of the hotel in the four audited years were calculated and then compared with the averaged EUI of 16 local hotels in a study conducted by Deng and Burnett [24]. Online benchmarking tool for energy consumption established by EMSD as mentioned in Chapter 2 was used to benchmark energy consumption of the hotel. Energy consumptions for different types of fuels in the hotel within the consumption record period and details of the hotel, such as star number awarded for the hotel, age, total number of guests per year and guest room area to gross floor area of the hotel, were inputted as requested by the tool for benchmarking.

3.3.5 Energy Management Opportunities (EMOs)

Having collected the measurements, the data were analyzed and compared with the requirements in the BECs published by the EMSD [26, 27, 28, 29, 30] in order to identify the areas of inefficiencies. Based on Energy Management Opportunities (EMOs) analysis, recommendations for improving the efficiencies of energy consumed equipment/systems were made.
Chapter 4

Results and Discussion

A carbon audit and an energy audit were conducted in the selected hotel based on the methodology presented in Chapter 3. This chapter evaluates the results obtained in the audits. The major sources of greenhouse gas emissions and the energy use pattern of the hotel are examined in this chapter. It is noted that the greenhouse gas emissions and the energy consumptions of the shops in the hotel were not included in the two audits as data from the shops was unavailable, unless the tenants are willing to release their private data. The evaluation of results is followed by a discussion on the opportunities for improvement on greenhouse gas emissions and energy consumption for the hotel. Difficulties in conducting a carbon audit and an energy audit in a hotel are also examined and discussed.

4.1 Carbon audit

This section evaluates the greenhouse gas emissions of the hotel in 2009 and the results are summarized in Table 15. The table shows the overall GHG emissions of the hotel in 2009 in terms of tonnes of CO$_2$-e. The table also shows the breakdown of the amount of GHG emissions in different scopes.
Table 15: Summary table of carbon audit results

<table>
<thead>
<tr>
<th>Scope of emissions</th>
<th>Carbon dioxide</th>
<th>Methane</th>
<th>Nitrous oxide</th>
<th>Hydrofluoro-carbons</th>
<th>Perfluoro-carbons</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tonnes of CO₂-e</td>
<td>Tonnes of CO₂-e</td>
<td>Tonnes of CO₂-e</td>
<td>Tonnes of CO₂-e</td>
<td>Tonnes of CO₂-e</td>
</tr>
<tr>
<td><strong>Scope 1 Direct Emissions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Stationary Sources Combustion</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generator</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Mobile Sources Combustion</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road transportation</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Air transport</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Water transport</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Fugitive Emissions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refrigeration</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Air Conditioning – Building (fixed)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Air Conditioning – Vehicle (mobile)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Sub Total</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Scope 1 GHG Removals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assimilation of CO₂ into biomass through planting of additional trees</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Sub Total</strong></td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Scope 2 Energy Indirect Emissions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumption of purchased electricity</td>
<td>6867.7</td>
<td>(8584.6)²</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Consumption of Town gas</td>
<td>154.0</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Sub Total</strong></td>
<td>7021.7</td>
<td>(8738.6)²</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Scope 3 Other Indirect Emissions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methane gas generation at landfill due to disposal of paper waste</td>
<td>-</td>
<td>-</td>
<td>-20.3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Consumption of fresh water</td>
<td>72.15</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Treatment of waste water</td>
<td>25.84</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Sub Total</strong></td>
<td>97.99</td>
<td>-</td>
<td>-20.3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Other GHG Removals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other GHG reductions and removals project</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Sub Total</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Total Scope 1 Emissions**

| Sub Total | 0 tonnes of CO₂-e (0% of overall emissions) |

**Total Scope 1 GHG Removals**

| Sub Total | 0 tonnes of CO₂-e |

**Total Scope 2 Emissions**

| Sub Total | 7021.7 tonnes of CO₂-e (98.91% of overall emissions) (8738.6 tonnes of CO₂-e (99.12% of overall emissions)) |

**Total Scope 3 Emissions**

| Sub Total | 77.69 tonnes of CO₂-e (1.09% of overall emissions) (0.88% when “GHG emissions from electricity purchased” was quantified with a territory-wide default value) |

**Overall Emission**

| 7099.4 tonnes of CO₂-e |

| (8816.3 tonnes of CO₂-e) |

Note:

1. The values in brackets were calculated when “GHG emissions from electricity purchased” was quantified with a territory-wide default emission factor (i.e. 0.7kg CO₂-e/kWh), while the values without brackets were calculated when “GHG emissions from electricity purchased” was quantified with the specific emission factor from the power company.
4.1.1 Scope 1: Direct emissions from sources and removals by sinks

As shown in Table 15, there was zero GHG emission reported in Scope 1. This indicates that there was no direct emission and removal in the hotel. The reasons contribute to this are discussed as follows.

(a) Combustion of fuels in stationary sources to generate electricity

There is only one type of stationary source which emits greenhouse gases during operation. It is the combustion of diesel oil in the diesel power generator in the hotel. Diesel oil is consumed in each monthly test of the generator. However, the engineers of the hotel reported that there was no record on the diesel oil consumption as the amount of consumption in each month was too small. Originally, there were two boilers which consume diesel oil to produce hot water. However, the boilers were replaced by a heat pump system and a back up hot water heater before the reporting period. Therefore, there is no record on GHG emission due to the combustion of fuels in stationary sources.

(b) Combustion of fuels in mobile sources

There was no GHG emission due to the combustion of fuels in mobile sources as no shuttle bus service was provided by the hotel for the guests and staff. Taxis or vans will be called for the guests as requested. As these transportation services were not provided by the hotel, the fuel consumptions of the taxis or vans were not included in the calculation of GHG emissions of the hotel.
(c) Use of refrigeration and air conditioning equipment from fixed and mobile sources

Fugitive Hydrofluorocarbons (HFCs) and Perfluorocarbons (PFCs) emissions might be emitted during the operation and maintenance of the refrigeration and the air conditioning equipment from fixed and mobile sources. Refrigerant R22 was used in chillers while R134a and R404a were used in refrigerators in the hotel. Based on the maintenance record, there were no refrigerant refill works undertaken for this group of equipment during the reporting period. As confirmed by the engineers of the hotel, the chillers and the refrigerators in the hotel did not have the need for refrigerant refill works in 2009. Therefore, based on the guidelines for carbon audits established by the Hong Kong government, it is assumed that there was no greenhouse gas emitted by this group of equipment during the reporting period and there was no GHG emission impact arising from these fixed sources.

There was also no GHG emission due to the use of refrigeration and air conditioning equipment from mobile sources because there was no vehicle owned by the hotel and no transportation services provided by the hotel. Without the mobile source, there should not be any GHG emission under this category obviously.

(d) Vegetation sinks by planting trees

There was no tree planted in the hotel to assimilate CO₂ into biomass. Therefore, there is no greenhouse gas removal by planting trees.
4.1.2 Scope 2: Energy indirect emissions

As shown in Table 15, there was significant amount of GHG emissions reported in Scope 2. The Scope 2 emissions were reported in two ways according to the guidelines for carbon audits in Hong Kong. There was 7021.7 tonnes of CO₂-e emitted under Scope 2 when the emissions were quantified with the specific emission factor from the power company, while the value was changed into 8738.6 tonnes of CO₂-e when the emissions were quantified with a territory-wide default emission factor. Significant difference in the amount of GHG emissions could be obtained with two different reporting methods. These two methods are applicable for reporting GHG emissions without contradiction; however, it seems that the method using the specific emission factor from the power company is more accurate as this emission factor is derived by the actual emission of greenhouse gases in the production of each unit (kWh) of electricity in the power plant every year.

(a) Electricity consumption

It is found that the amount of electricity consumption of the hotel in 2009 was 12263785kWh which contributed to a substantial amount of GHG emissions. 6867.7 tonnes of CO₂-e emitted from the hotel stemmed from the consumption of electricity when the emissions were quantified with the specific emission factor from the power company. Meanwhile, the amount of emissions rose to 8584.6 tonnes of CO₂-e when the emissions were quantified with a territory-wide default emission factor.
(b) Town gas consumption

Cooking appliances in the kitchens consume town gas. From the town gas bills, it is found that 259645.8 units of town gas were consumed in the hotel in 2009, which led to 154 tonnes of CO₂-e emissions.

4.1.3 Scope 3: Other indirect emissions

(a) Methane gas generation at landfill due to disposal of paper waste

Based on the records on the amount of paper consumed and paper collected for recycle in the hotel, 1125 reams of 50 gram per square meter (gsm) A4 paper were consumed, which was equivalent to 2806.6kg of paper. Meanwhile, 7032 kg of paper was collected for recycle. A negative value of indirect emissions due to disposal of paper waste (-20.3 tonnes of CO₂-e) was obtained in calculation. It seems that the result for this part was slightly strange. This is due to the recorded amount of paper consumed being less than that of paper collected for recycle. The available record on the amount of paper consumption was restricted to A4 paper; however, other sizes of paper such as B3 paper and A3 paper were also used in the hotel. Besides, other kinds of paper such as receipt paper, packaging paper, paper boxes, newspapers and magazines were consumed in the hotel but have not been recorded. In contrast, the paper collected for recycle contained different kinds of paper.

This case demonstrates a difficulty in conducting a carbon audit in a hotel. A clear and complete record of paper consumption data is needed. All kinds of paper used
should be counted and weighed; however, hotels may not carry out these measurements and keep a good record due to the complication of the measurement. It may not be possible for the hotel staff to count the number and measure the weight of certain paper after purchase or before use every time, for instance, paper boxes of products, unlike the measurement of the amount of paper collected for recycle which is relatively easy to weigh by a counter balance when all the paper used is collected together. Therefore, the result in this part greatly depends on the effectiveness of the record keeping process and the effort put in the process.

(b) Electricity consumed for processing fresh water

Electricity is used for processing fresh water by Water Services Department (WSD). According to the water supply bill, 175302m³ fresh water was used in the hotel in 2009, which accounted for 72.15 tonnes of CO₂-e indirect emissions of the hotel in 2009.

(c) Electricity consumed for processing sewage

Electricity is used for processing sewage by Drainage Services Department (DSD). Based on equation (13), the default emission factor has to be found before calculating the indirect emissions due to the electricity consumed for processing sewage. Two assumptions on the percentage of consumed fresh water which entered the sewage system had been made in the guidelines for carbon audits in Hong Kong for the calculation of default emission factor according to the purpose of water used. It is assumed that 70% of the consumed fresh water for restaurant and catering services would enter the sewage system; while 100% is assumed for other
commercial, residential and institutional purposes. In the hotel, water was used for both restaurant and catering services as well as other commercial purposes (such as water for guests and laundry). Therefore, the water consumption of the restaurants in the hotel and that of the guestrooms should be considered separately. The emission factor for the electricity used for sewage processing by DSD (0.172 CO$_2$-e/kWh) was multiplied by 0.7 for the water used for restaurant and catering services in order to obtain the default emission factor, while that for water used by other commercial purposes was multiplied by 1. Hence, the amounts of indirect emissions for water used for different purposes were calculated by multiplying the fresh water consumption for the purpose with the default emission factors.

As mentioned in 4.1.3(b), 175302 m$^3$ fresh water was used in the hotel in 2009, while 83552 m$^3$ fresh water was used for restaurant and catering services, and 91750 m$^3$ fresh water was used for other commercial purposes. Therefore, the sewage from the restaurant and catering services of the hotel accounted for 10.06 tonnes of CO$_2$-e indirect emissions; while that from other commercial purposes in the hotel contributed to 15.78 tonnes of CO$_2$-e indirect emissions. In total, 25.84 tonnes of CO$_2$-e indirect emissions were generated due to the electricity used for sewage processing by DSD.

4.1.4 Overall emissions and discussion

The overall GHG emissions were 7999.4 tonnes of CO$_2$-e when the GHG emissions from electricity purchased were quantified with the specific emission factor from the power company and 8816.3 tonnes of CO$_2$-e when the GHG emissions from electricity purchased were quantified with a territory-wide default value.
As mentioned in Chapter 2, benchmark database for carbon emissions and removals in hotels is still not available in Hong Kong. Although benchmarking of the carbon emissions and removals in this hotel with Hong Kong data was unavailable, the overall GHG emissions of the hotel could be normalized into emissions associated with a one night stay in a hotel room and made reference to the normalized data from the Environment Protection Agency [16]. As mentioned in Chapter 2, the GHG emissions of hotels in the US were calculated by EPA at 29.53 kg CO₂-e per room day for average hotels and 33.38 kg CO₂-e per room day for upscale hotels. As shown in Table 16, 31.07 kg CO₂-e per room day of GHG emissions were emitted in the hotel in this study when GHG emissions from electricity purchased were quantified with the specific emission factor from the power company. The value was between the normalized GHG emissions of average hotels and upscale hotels in the EPA analysis. This shows that the normalized GHG emissions of the hotel in this study were similar to those of hotels in the US. Meanwhile, the normalized GHG emissions of the hotel in this study when GHG emissions from electricity purchased were quantified with a territory-wide default value were 38.59 kg CO₂-e per room day. The value became higher than that of both average and upscale hotels in the EPA analysis. This demonstrates the consequence of using different values of emissions factors for reporting. In addition, it is noted that the US data can only act as a reference as there might be slight differences in the methods and the emission factors used in quantifying the GHG emissions for hotels in the US and in Hong Kong, and the climate in the US might also be different from that in Hong Kong.
Table 16: Normalized GHG emissions of the hotel

<table>
<thead>
<tr>
<th>Average hotels in EPA analysis</th>
<th>Normalized GHG emissions (ratio indicator)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upscale hotels in EPA analysis</td>
<td>29.53 kg CO₂-e per room day [16]</td>
</tr>
<tr>
<td>Hotel in this study</td>
<td>33.38 kg CO₂-e per room day [16]</td>
</tr>
<tr>
<td></td>
<td>31.07 kg CO₂-e per room day [16]</td>
</tr>
<tr>
<td></td>
<td>(38.59 kg CO₂-e per room day)²</td>
</tr>
</tbody>
</table>

Note:
1. The value was calculated with the use of overall GHG emissions when GHG emissions from electricity purchased were quantified with the specific emission factor from the power company.
2. The value was calculated with the use of overall GHG emissions when GHG emissions from electricity purchased were quantified with a territory-wide default value.

Moreover, in order to obtain a Carbon “Less” Certificate from the Hong Kong Awards for Environmental Excellence (HKAEE) as mentioned in Chapter 2, the hotel should achieve a minimum of 3% reduction in overall carbon emissions, which is equivalent to about 213 tonnes of CO₂-e when the GHG emissions from electricity purchased were quantified with the specific emission factor from the power company.

In both reporting methods, it is noticed that majority of the GHG emissions stemmed from the energy indirect emissions categorized in Scope 2, about 99% as shown in Figures 8 and 9. Meanwhile, only about 1% of the total GHG emissions in the hotel was brought about by other indirect emissions categorized in Scope 3. There was no Scope 1 direct emission and removal in the hotel. It is found that there is no measure to remove or offset the GHG emissions in the hotel, such as planting trees in the physical boundary of the hotel and the application of renewable energy.

Concerning the Scope 2 emissions, it is found that the GHG emissions arising from the consumption of purchased electricity dominated the GHG emissions under this Scope (about 98% of Scope 2 emissions). This demonstrates that the use of electricity is crucial to the GHG emissions. Therefore, it is important to monitor the
electricity consumption of the hotel and ensure the equipment or systems inside the building are functioning properly and efficiently. An energy audit is useful to identify the areas of inefficiency for the equipment or systems inside the hotel and to understand how efficient the energy was used in the hotel. In addition, GHG emissions reduction strategies targeting Scope 2 emissions or electricity consumption in particular might be more effective in reducing the GHG emissions of the hotel.

![Diagram showing GHG emissions breakdown]

*Figure 8: Breakdown of GHG emissions from the hotel (with the use of overall GHG emissions when GHG emissions from electricity purchased was quantified with the specific emission factor from the power company)*
Figure 9: Breakdown of GHG emissions from the hotel (with the use of overall GHG emissions when GHG emissions from electricity purchased was quantified with a territory-wide default value)

4.1.5 Greenhouse gas emissions and removals calculator

Based on the “Guidelines to Account for and Report on Greenhouse Gas Emissions and Removals for Buildings (Commercial, Residential or Institutional Purposes) in Hong Kong, 2010 Edition”, a GHG emissions calculator for buildings in Hong Kong was established in this study. This calculator is applicable to commercial, residential or institutional buildings in Hong Kong. The calculator was developed with Microsoft Excel which provides a simple and user friendly interface, as shown in Figures 10, 11 and Appendix B. Users can simply input the collected data into the data cells indicated in the calculator. The calculator will calculate the overall GHG emissions and the GHG emissions under different Scopes (1, 2 and 3) automatically. The results will be summarized in a result spreadsheet. Two pie charts showing the
breakdown of GHG emissions under the three different scopes will be constructed automatically. One of the pie charts shows the results when the GHG emissions from electricity purchased were quantified with the specific emission factor from the power company; while the other pie chart shows the results when the GHG emissions from electricity purchased were quantified with a territory-wide default value. This GHG emissions calculator can act as a tool to facilitate the complicated manual calculation process in carbon audit. Latest emission factors were set in the calculator which allows users to calculate GHG emissions of buildings in 2009. It is easy and feasible for users to update the emission factors for the calculation of GHG emissions of a building in future years provided that there is no change in the calculation methodologies.

![Greenhouse Gas Emissions and Removals Calculator for Buildings (Commercial, Residential or Institutional Purposes) in Hong Kong](image)

*Figure 10: Front page of the GHG emissions calculator*
4.2 Energy audit

This section examines the energy performance of the hotel and the energy performance of main energy consuming building services systems in the hotel in order to ensure that energy was used efficiently in many ways. The energy consumption pattern of the hotel during the audit period was investigated. Areas of inefficiency and suitable means for improvement are identified.

4.2.1 Building services systems investigated in the energy audit

Four key types of building services systems in the hotel were investigated, including HVAC system, lighting system, vertical transportation system as well as Plumbing and drainage system. The energy performance of these systems obtained from energy audit in comparison to the requirements from the building energy codes by EMSD are summarized in Appendix C. Table 17 summarize the audited equipment of the building services systems in the hotel and their compliance with the BECs requirements.
Table 17: Audited equipment of the building services systems in the hotel and their compliance with the BECs requirements

<table>
<thead>
<tr>
<th></th>
<th>Comply</th>
<th>Not comply</th>
<th>Cannot be confirmed</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC system</td>
<td>• 150 Ton reciprocating air cooled chillers (Number 1-4)</td>
<td>• 180 Ton reciprocating water-cooled chillers (Number 1-4)</td>
<td>• Piping system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 11kW chilled water pumps</td>
<td>• Air duct</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 11kW condenser water pumps</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 5.5kW fan motors for cooling towers</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 1.1kW AHUs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 4kW PAUs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 5.5kW exhaust air fans</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 11kW exhaust air fans</td>
<td></td>
</tr>
<tr>
<td>Lighting system</td>
<td>• Guest room (exclude bathroom) lighting installations</td>
<td>• Lighting installations of bathroom inside guest room</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Function room lighting installations</td>
<td>• Ballroom lighting installations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Corridor lighting installations</td>
<td>• Kitchen lighting installations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Switch room lighting installations</td>
<td>• Lift lobby lighting installations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Reception lighting installations</td>
<td>• Guest toilet / washroom lighting installations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Office lighting installations</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Staircase lighting installations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical transportation system</td>
<td>• Maximum allowable running active power of lifts</td>
<td>• Power factors of lifts</td>
<td>• Maximum allowable total harmonic distortion of lifts</td>
</tr>
<tr>
<td></td>
<td>• Maximum allowable total harmonic distortion of lifts</td>
<td>• Maximum allowable running active power of escalators</td>
<td>• Power factors of escalators</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Motor efficiencies of lifts and escalators</td>
<td></td>
</tr>
<tr>
<td>Plumbing and drainage system</td>
<td>• 1.25kW roof fresh water booster pumps</td>
<td>• 15kW fresh water transfer pumps</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 1.5kW roof fresh water booster pumps</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 2.2kW Hot water pressure pumps</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 15kW flush water pumps</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 4.4kW sewage pumps</td>
<td></td>
</tr>
</tbody>
</table>
(a) Heating, Ventilation and Air conditioning (HVAC) system

The hotel was equipped with two central chiller plants. As shown in Table 18, there were four reciprocating air-cooled chillers installed on the roof to provide a total cooling capacity of 2100kW (equivalent to 600 Tons of Refrigeration (TR), from 4 x 150TR chillers). Five chilled water pumps and associated piping system were installed to circulate chilled water between the central chiller plant and the primary air handling units (PAUs) as well as fan coil units (FCUs) on M/F, G/F, B1-B3. There were another four reciprocating water-cooled chillers installed on B1 to provide a total cooling capacity of 2500kW (equivalent to 720TR, from 4 x 180TR chillers). Five chilled water pumps and associated piping system were installed to circulate chilled water between the central chiller plant and the PAUs as well as FCUs on 1/F-12/F, 14/F-19/F (18 storeys, without 13/F). Four cooling towers installed on B1 were used for rejection of the condenser heat from the four water-cooled chillers. Each of them had a cooling capacity of 250 tons. Five condensing water pumps and associated piping system were installed to circulate condensing water between water-cooled chillers and the cooling towers. The chilled water temperatures of the chillers were 12°C in and 6°C out.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Description</th>
<th>Capacity</th>
<th>Year of installation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Each</td>
<td>Total</td>
</tr>
<tr>
<td>4</td>
<td>Air-cooled chiller</td>
<td>150 ton</td>
<td>600 tons</td>
</tr>
<tr>
<td>4</td>
<td>Water-cooled chiller</td>
<td>180 ton</td>
<td>720 tons</td>
</tr>
<tr>
<td>4</td>
<td>Cooling tower (CT)</td>
<td>250 ton</td>
<td>1000 tons</td>
</tr>
</tbody>
</table>

It is noticed that the chillers on the roof were used to serve the lower floors which are far away from the roof chiller plant, however, this is unlikely to be a problem to the pump power requirement as closed loop piping system was used.
PAUs and FCUs were used to treat and supply cooled air to different areas of the hotel, including the reception, ballroom, function rooms, guest rooms, offices, restaurants and kitchens. The temperature set points for FCUs were controlled by the local thermostatic control switches. The temperature set points for FCUs were 22°C and they could be adjusted in the range between 16°C to 32°C. Exhaust air fans were used to extract exhaust air from kitchens. Fresh air in the corridors on guest room floors was treated and supplied by air handling units (AHUs). Toilets, plant rooms and the switch room were provided with mechanical ventilation. Space heating was no longer provided by the central air conditioning system, heaters will be provided to guests for heating as needed instead.

As shown in Table 19, based on spot measurements on the dry bulb temperatures and relative humidity in a typical day in summer and a typical day in winter in different functional areas of the hotel, including a typical guest room, a corridor, a lift lobby and the ballroom, the indoor design conditions of the measured areas conformed to that recommended by EMSD for sizing air conditioning systems and equipment in a hotel.

<table>
<thead>
<tr>
<th>Functional area</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry bulb temperature (°C)</td>
<td>Dry bulb temperature (°C)</td>
</tr>
<tr>
<td>Guest room</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Corridor</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>Lift lobby</td>
<td>25</td>
<td>23</td>
</tr>
<tr>
<td>Ballroom</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>EMSD recommended indoor design</td>
<td>22 (Minimum)</td>
<td>24 (Maximum)</td>
</tr>
</tbody>
</table>

Table 19: Spot measurements on the dry bulb temperatures and relative humidity in a typical day in summer and a typical day in winter in different functional areas of the hotel
As shown in Appendix C, the performance of major HVAC system components were investigated. Based on the design data as well as testing and commissioning record of the chillers, the initial coefficients of performance (COPs) of the eight chillers at the time that they were newly installed were calculated and compared with that required in Building Energy Codes (BECs) in Hong Kong. It is found that only the reciprocating air-cooled chillers could comply with the BECs required COP. They had COPs of 2.96 which were higher than the minimum requirement of 2.8. However, the COPs of the reciprocating water-cooled chillers (COPs = 3.45) were slightly lower than the minimum requirement (COP = 3.9) in the BECs. This might perhaps be due to the limitation of technology that could be accomplished at the time that the chillers were installed. It is expected that higher COPs could be achieved by the reciprocating chillers with higher technology at the time the BECs were established.

Although only the performance of chillers at design and newly installed conditions is concerned in BECs, it might presumably be better to further investigate the performance of chillers at actual operating conditions. There was an attempt to investigate the COPs of chillers at operating conditions, however, the investigation could not be accomplished due to the limitations of the Building Management System (BMS) of the hotel and insufficiency of the data logged in daily operations. Data of cooling capacitities, power inputs and chilled water flow rates of the chillers were unable to be measured and logged by the BMS. Although there were monthly maintenance records for the chillers, limited data were recorded for calculating COPs.

The motor efficiencies of chilled water pumps, condenser water pumps, cooling tower fans, AHUs, PAUs and exhaust air fans were investigated (Appendix C). The
motors inside all the equipment could not satisfy the minimum efficiency requirements stated in the BECs. This again might be due to the limitation of technology that could be achieved at the time that the equipment was installed. Apparently, the motors in the past were not as efficient as those nowadays. It is also found that this group of equipment had not employed any Variable Speed Drive (VSD) which could enable the motors of equipment to be operated over a range of speeds in accordance with the needs.

Regarding the HVAC piping system and the air ducts, the commencement of pipe friction test and air duct leakage test might interrupt the operation of the hotel as mentioned in Chapter 3. This demonstrates one of the difficulties in conducting an energy audit. This kind of tests could only be conducted when the equipment was just installed and commissioned normally. Meanwhile, spot visual inspections on the piping systems and air ducts were conducted. It is observed that there was no leakage of chilled water and condensing water in the HVAC piping systems, and there was no damage of insulations for the piping systems and air ducts.

(b) Lighting system

As mentioned in Chapter 3, spot site investigations and measurements were conducted in twelve functional areas in the hotel. Different types of lamps and luminaires were used in different functional areas, as shown in Appendix D. It is found that the luminous efficacy of 14W T5 fluorescent lamps used in the inspected kitchen and staircase was lower than the minimum allowable value stated in BECs. It is also found that the circuit wattages of certain types of luminaires had exceeded the maximum allowable values stated in BECs, as indicated in Appendix D. Through the
investigation, it is also noticed that the T8 linear fluorescent luminaire used in the hotel had rated lamp power value out of the range that was given for finding the maximum allowable ballast-lamp circuit power in the BECs. Therefore, extrapolation was used to find out the allowable values for the luminaire. The chart and equation generated for extrapolation are shown in Appendix E.

Lighting power densities for the twelve investigated functional areas were calculated as shown in Appendix F. These areas were typical and could be used to represent other areas of the same functions. It is found that the light power densities for certain functional areas had exceeded the limits stated in the BECs. These areas include bathrooms in guest rooms, guest toilets, kitchens, lift lobbies and the ballroom. Simultaneously, illuminance levels of the twelve functional areas were measured. Although the illuminance levels in all these areas were designed according to the recommended values, deviations were observed in actual measurement. The results show that the illuminance level in the typical bathroom exceeded the recommended value from CIBSE greatly (166.7% exceeded). Besides, the light power density in the typical bathroom also exceeded the BECs requirement greatly (+392.3%). This implies that there is opportunity for improvement by providing fewer lamps and using lamps with lower wattage in order to reduce the light power density but maintain a suitable illuminance level. Regarding the lighting installations in lift lobbies and guest toilets, although suitable illuminance level was provided, the light power density has exceeded the BECs requirement. Especially for the lift lobbies, the light power density exceeded the BECs requirement by 473.3%. It is, however, unavoidable to install a large number of incandescent lamps (or called candle lamps) in there as it is important to provide a luxurious environment in the lift lobbies, which led to a high light power density in there. Regarding to the lighting
installations in the guest toilets, there is still opportunity to reduce the light power intensities in these areas by removing some lamps or by changing some of the existing lamps with lamps with lower power input, but further verification are needed in order to avoid influence on the illuminance levels. Meanwhile, although the light power densities in the reception and the function room were much lower than the maximum allowable values stated in the BECs, the illuminance levels of these areas were lower than the recommended values from CIBSE. There is still opportunity to increase illuminance levels in these two areas by increasing the number of lamps in these two areas. Regarding the lighting installations in the ballroom and the kitchens, not only the light power densities in these two areas were unacceptable, but also the illuminance level. Although light power densities in these two areas were very high already, the illuminance levels in these two areas were still insufficient. However, as it is important to provide a grand and luxurious environment in the ballroom, it is unavoidable to install a large number of incandescent lamps (or called candle lamps) in there, which led to a high light power density in there.

In contrast, lighting systems in other functional areas, including corridors, offices, staircases and the switch room, could achieve both the light power density and averaged illuminance requirements. Meanwhile, during the site inspection, it was observed that incandescent lamps were still being used in the guest rooms and in the corridors. Incandescent lamps are considered to be energy inefficient and the production of this type of lamps was banned in Hong Kong. Besides, it is noticed that although timer for automatic on/off control of lighting installations in the corridors was installed, it was overridden by manual on/off control as the demand for lighting in the corridors was fluctuant. Therefore, energy conservation relied much more on housekeeping.
The inspection reveals that a number of tungsten halogen lamps in the reception were replaced with LEDs. This has led to significant reduction in the light power density in the reception. Hence, significant amount of electricity consumption could be saved. However, this may be the cause of insufficient illuminance level in the reception as the light output from the LEDs used there may not be sufficient. The inspection also reveals that the hotel had replaced the T8 fluorescent lamps in the staircases with T5 fluorescent lamps which are more energy efficient.

(c) Vertical transportation system

There are eight lifts in the hotel, including six passengers lifts (L1-L6) and two goods lifts (A1-A2) with one of them serving as a fireman’s lift. No zoning is provided by the lifts. The characteristics of the passengers lifts in the hotel are summarized in Table 20. The rated load and rated speed of the lifts are identical. They serve B3 to 18/F, therefore, 22 stops in total. Each of the lifts has a DC motor of 24kW with a full load current of 175A. The lifts operate for 24 hours throughout a day.

Six escalators were also installed in the hotel. The characteristics of escalators in the hotel are summarized in Table 21, including rises, speeds, steps widths, angle of inclinations, floors served, machine motor ratings and full load currents of the escalators. The daily hours of operation of the escalators were 15 hours (9am-12am).

From the design data, the motor efficiencies of the lifts were calculated. As shown in Appendix C, the motor efficiencies of the lifts were lower than the required value stated in the BECs. This again might be due to the limitation of technology that could
be achieved at the time that the lifts were installed. The lifts were installed in 1975. Apparently, the lift motors at that time were not as efficient as nowadays. Based on the site measurements, it is found that the running active powers and the total harmonic distortions of the lift motor drive systems have satisfied the requirements in the BECs, however, it is noted that the measurements were conducted during the normal operation of the lifts and with variable load as mentioned in Chapter 3. Regarding the power factors of the lift motor drive systems, the measured values were found to be 0.6, which could not satisfy the required value of 0.85 as shown in Appendix C.

As mentioned in Chapter 3, site measurements on the escalators could not be conducted. Thus, the total harmonic distortions and power factors of the motor drive systems of the escalators were unknown. Based on the design specification and O&M records of the escalators, it is found that the running active power and the motor efficiencies of the escalators could not satisfy the requirements stated in BECs (see Appendix C).

<table>
<thead>
<tr>
<th>Description</th>
<th>Lift No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L1-L6</td>
</tr>
<tr>
<td>Rated load (kg)</td>
<td>1360</td>
</tr>
<tr>
<td>Rated speed (m/s)</td>
<td>2.5</td>
</tr>
<tr>
<td>No. of stops</td>
<td>22</td>
</tr>
<tr>
<td>Floors served</td>
<td>B3-18/F</td>
</tr>
<tr>
<td>Motor</td>
<td>DC motor</td>
</tr>
<tr>
<td>Motor power (kW)</td>
<td>24</td>
</tr>
<tr>
<td>Full load current (A)</td>
<td>175</td>
</tr>
<tr>
<td>Daily hours of operation (hrs)</td>
<td>24</td>
</tr>
</tbody>
</table>
(d) Plumbing and drainage system

Both cold water and hot water were provided in the hotel for catering, bathing and hand washing. It is also noted that cold water was used in the swimming pool of the hotel. Pumps are required to circulate the cold and hot water to different areas in the hotel.

Regarding the cold water supply system, there were two 15kW fresh water transfer pumps (one standby, one duty), two 1.25kW roof fresh water booster pumps (one standby, one duty), two 1.5kW roof fresh water pumps (one standby, one duty) and a pneumatic tank. Fresh water in the transfer tank supplied by the water main will be delivered to the roof tank with the fresh water transfer pumps. Fresh water was then supplied to 18/F and floors below by gravity. A pneumatic tank was used to maintain the water pressure. The two 1.25kW roof fresh water booster pumps used to pressurize the fresh water when the pressure inside the pneumatic tank was insufficient. Due to insufficient head developed by gravity for water supplied to the water outlets on 19/F, the 1.5kW roof fresh water booster pumps were used to pressurize cold water supplied to the water outlets on 19/F, including the swimming pool.
Regarding the hot water supply system, hot water was produced by two diesel oil boilers; however, the boilers were replaced by a heat pump system together with a backup hot water heater in 2008. A hot water tank was located on the roof. The hot water was pressurized by two 2.2kW hot water pressure pumps (one standby, one duty) and supplied to water outlets on 19/F and floors below.

Two 15kW flush water pumps (one standby, one duty) on ground floor were used to pump flush water up to a flush water tank on the roof. Flush water was then supplied to the water closets inside the hotel by gravity. All the waste water collected will be delivered to the government sewer with 3 sets of 4.4kW sewage pumps on B3.

The motor efficiencies of the pumps used in the plumbing and drainage system were analyzed. As shown in Appendix C, only the 1.25kW roof fresh water booster pumps could achieve motor efficiencies that could comply with the minimum requirements stated in BECs. This might be because the 1.25kW roof fresh water booster pumps were newly installed for just one year with newer technology which could achieve higher motor efficiency. However, it was not the case for other pumps in the plumbing and drainage system.

Similar to the pumps used in the HVAC system, it is also found that all the pumps in the plumbing and drainage system had not employed any Variable Speed Drive (VSD) which could enable the motors of pumps to be operated over a range of speeds in accordance with the needs to achieve energy saving.

The inspection also reveals that the pneumatic tank in the cold water supply system could not provide sufficient pressure for the cold water due to its failure. Therefore,
the booster pumps had to operate continuously throughout the day in order to maintain the pressure of fresh water at the water outlets.

4.2.2 Energy consumption

(a) Electricity consumption

Electricity supply to the hotel was provided by the power company from three 2500kVA transformers on B1. Main low voltage switchboard was located in the adjacent main switch room to receive the incoming supply and to distribute electricity to different areas of the hotel. The monthly total electricity consumption of the hotel for the audit period was obtained from the electricity bills and it is demonstrated in Figure 12. It is revealed that the year round electricity consumption patterns have been rather consistent. However, there was a sudden increase in electricity consumption from November 2008 to February 2009. This may probably be because of the extra energy use for commissioning and optimization of the heat pump system and the backup hot water heater after the completion of the replacement of the boilers with a heat pump system and a backup hot water heater during the period.

The monthly variations of electricity consumption with mean outdoor temperature for the four years audited (2006-2009) are shown in Figures 13 to 16 and the monthly variation of electricity consumption with number of guests for the four years audited (2006-2009) are shown in Figures 17 to 20. It is found that the electricity consumption was strongly affected by the weather conditions, but not clearly by the number of guests. Electricity consumption reached peak in summer, which was conceivably caused by the summer air conditioning. Regression analyses were
conducted to find out the correlations of monthly electricity consumption with monthly mean outdoor temperature, monthly number of guests and monthly room occupancy rate respectively as shown in Figures 21 to 23. Two sets of data were used in the regression analysis in order to observe the effects that may be caused by the replacement of the boilers with a heat pump system and a backup hot water heater. The first set involved data from January 2006 to October 2008 when the boilers were still in operation. Another set involved data from November 2008 to December 2009 when the boilers was replaced with the heat pump system and the backup hot water heater. A reasonably strong correlation between the monthly electricity consumption and the monthly mean outdoor temperature was obtained. With the data from January 2006 to October 2008, the resulting coefficient of determination (R²) for the regression was found to be 0.8864. With the data from November 2008 to December 2009, the R² for the correlation was 0.6498 and the regression line shifted upward as more electricity was consumed after the replacement of the boilers with the heat pump system and the backup hot water heater.

Regarding the correlation between the monthly electricity consumption and the monthly number of guests, the R² is only 0.1586 with the data from January 2006 to October 2008 and only 0.0959 with the data from November 2008 to December 2009. This indicates a weak correlation between the monthly electricity consumption and the monthly number of guests. Another weak correlation between the monthly electricity consumption and the monthly room occupancy rate was also obtained. The R² is only 0.0284 with the data from January 2006 to October 2008 and the R² is only 0.0315 with the data from November 2008 to December 2009. These two weak correlations might probably be because there was a portion of electricity consumption contributed by areas where electricity was consumed regularly and not
much dependent on the number of guests or room occupancy rate normally, such as offices and restaurants which were open to the public apart from the hotel guests.

The regression lines in the correlation between the monthly electricity consumption and the monthly number of guests as well as the correlation between the monthly electricity consumption and the monthly room occupancy rate have also shifted upward after the replacement of the boilers with the heat pump system and the backup hot water heater as more electricity was consumed by the heat pump system and the backup water heater.

A further multiple regression analysis was performed based on the data in 2009 to examine the combined influence of the monthly mean outdoor temperature and the monthly number of guests on the electricity consumption in the hotel. The correlation derived from the multiple regression analysis is as follows:

\[ E = 147353 + 28127.3\, T_o + 11.6\, G \] \text{Eq.}(18)

where \( E \) is the monthly total electricity consumption (kWh), \( T_o \) is the monthly mean outdoor temperature (°C) and \( G \) is the monthly total number of guests.

The \( R^2 \) for the regression is 0.86, indicating a strong correlation between the total electricity consumption and the two influencing factors. This correlation is stronger than the correlations that just correlate the total electricity consumption with individual influencing factors. Meanwhile, the p-values for the two influencing factors are 5.74×10^{-5} and 0.03 respectively, indicating that \( T_o \) is more significant than \( G \) in affecting electricity consumption in the hotel.

In addition to the power company’s meters, twenty sub-meters were installed in June
2009 as mentioned in Chapter 3. These sub-meters allow the total electricity consumption to be broken down into consumption of individual services systems and this will be discussed in Section 4.2.3.

Figure 12: Monthly electricity consumption of the hotel from January 2006 to December 2009

Figure 13: Monthly electricity consumption and monthly mean outdoor temperature in 2006

Figure 14: Monthly electricity consumption and monthly mean outdoor temperature in 2007
Figure 15: Monthly electricity consumption and monthly mean outdoor temperature in 2008

Figure 16: Monthly electricity consumption and monthly mean outdoor temperature in 2009

Figure 17: Monthly electricity consumption and monthly number of guests in 2006

Figure 18: Monthly electricity consumption and monthly number of guests in 2007
Figure 19: Monthly electricity consumption and monthly number of guests in 2008

Figure 20: Monthly electricity consumption and monthly number of guests in 2009

Figure 21: Monthly electricity consumption against monthly mean outdoor temperature

\[ y = 25.047x + 544.8 \]
\[ R^2 = 0.6498 \]

\[ y = 35.82x + 174.9 \]
\[ R^2 = 0.8864 \]
(b) Town gas consumption

Town gas was consumed by cooking appliances in the kitchens. From the town gas bills, the monthly total town gas consumption of the hotel in giga joule (GJ) in the
audit period was obtained. As shown in Figure 24, the year round town gas consumption patterns have been rather consistent in the four years. The amount of consumption in terms of energy was stable throughout a year.

Since the consumption of town gas was solely for cooking in kitchens in the hotel, a regression analysis was conducted and only the number of food covers was included in the analysis (see Figure 25). It is noted that only the monthly total number of food covers in 2009 was available for this regression analysis. The correlation derived is as follows:

\[ y = 0.0166x + 358.54 \] \hspace{1cm} \text{Eq.(19)}

where \( y \) is the monthly town gas consumption (GJ), and \( x \) is the monthly total number of food covers made.

The coefficient of determination \( (R^2) \) for the regression is 0.7752, indicating a reasonably strong correlation between the monthly town gas consumption and the monthly total number of food covers.
(c) Fuel oil consumption

Diesel oil was used not only for the operation of the emergency generator in emergency and in monthly tests, but also used for the combustion in boilers to produce hot water at the time before the boilers were replaced by a heat pump system and a backup hot water heater. Figure 26 shows the monthly total fuel oil
consumption of the hotel in giga joule (GJ) in the audit period. It is found that the year-round fuel oil consumption patterns were rather consistent in 2006 and 2007. The fuel oil consumption in winter was relatively higher than that in summer. However, zero consumption had been recorded since November 2008. This actually stemmed from the replacement of boilers by a heat pump system and a backup hot water heater. The replacement work was divided into several stages, which had led to the gradual decrease in fuel oil consumption from July 2008. The boilers completely retired in November 2008. Moreover, as discussed in 4.1.1(a), there was a diesel power generator in the hotel. However, there is no record on the diesel oil consumption of the generator as the amount of consumption in each month was too small. Therefore, zero fuel oil consumption was found from November 2008 to December of 2009.

![Image: Monthly fuel oil consumption of the hotel from January 2006 to December 2009](image)

**(d) Total energy consumption**

Electricity, town gas and diesel consumptions recorded are summarized and
converted into energy unit of giga joule (GJ) for analysis. The monthly variations of total energy consumption with mean outdoor temperature for the four audited years (2006-2009) are shown in Figures 27 to 30. These figures demonstrates that the total energy consumption follows the fluctuations of outdoor temperature. It is observed that the hotel exhibited seasonally varied energy use profiles similar to the seasonal variation pattern of outdoor temperature. Similar phenomenon could be observed in other hotels in Hong Kong [23]. Figure 31 demonstrates the correlation between the monthly mean outdoor temperature and the total energy consumption by using simple linear regression model. $R^2$ is 0.6127 with the data from January 2006 to October 2008 and $R^2$ is 0.5106 with the data from November 2008 to December 2009. These indicate a reasonably strong correlation between the monthly total energy consumption and the monthly mean outdoor temperature. The regression line in the correlation shifted downward after the replacement of the boilers with the heat pump system and the backup hot water heater as overall less amount of energy was consumed after the replacement work.

![Figure 27: Monthly total energy consumption and monthly mean outdoor temperature in 2006](image1)

![Figure 28: Monthly total energy consumption and monthly mean outdoor temperature in 2007](image2)
The monthly variation of total energy consumption with number of guests for the four years audited (2006-2009) are shown in Figures 32 to 35. It appears that the effect on the total electricity consumption by the variation in the number of room guests was not clear. Similar to monthly electricity consumption, regression analyses were conducted to find out the correlations of monthly total energy consumption with monthly number of guests and monthly room occupancy rate respectively as
shown in Figures 36 to 37. However, no clear linear relationships could be perceived. \( R^2 \) for the correlation between the monthly total energy consumption and the monthly number of guest is only 0.1617 with the data from January 2006 to October 2008 and only 0.2351 with the data from November 2008 to December 2009. This indicates a weak correlation between the monthly total energy consumption and the monthly number of guest. Another weak correlation between the monthly total energy consumption and the monthly room occupancy rate was also obtained. \( R^2 \) is only 0.0661 with the data from January 2006 to October 2008 and only 0.0531 with the data from November 2008 to December 2009. These two week correlations might probably be because there was a portion of energy consumption contributed by areas where energy was consumed regularly or not much dependent on the number of guests or room occupancy rate normally, such as offices and restaurants which were open for the public apart from the hotel guests.

The regression lines showing the correlation between the monthly total energy consumption and the monthly number of guests as well as the correlation between the monthly total energy consumption and the monthly room occupancy rate also shift downward after the replacement of the boilers with the heat pump system and the backup hot water heater as overall less amount of energy was consumed after the replacement work.

A further multiple regression analysis was performed based on the data in 2009 to examine the combined influence of the monthly mean outdoor temperature and the monthly number of guests on the energy consumption in the hotel. The correlation derived from the multiple regression analysis is as follows:
\[ E_n = 1643.9 + 89.3 \, T_o + 0.05 \, G \]  \hspace{1cm} \text{Eq.(20)}

where \( E_n \) is the monthly total energy consumption (kWh), \( T_o \) is the monthly mean outdoor temperature (\(^\circ\)C) and \( G \) is the monthly total number of guests.

\( R^2 \) for the regression is 0.82, indicating a strong correlation between the total energy consumption and the two influencing factors. This correlation is stronger than the correlations that just correlate the total energy consumption with individual influencing factors. Meanwhile, the p-values for the two influencing factors are 0.0003 and 0.022 respectively, indicating that \( T_o \) is more significant than \( G \) in affecting energy consumption in the hotel.
Figure 34: Monthly total energy consumption and monthly number of guests in 2008

Figure 35: Monthly total energy consumption and monthly number of guests in 2009

Figure 36: Monthly total energy consumption against monthly number of guests
As shown in Figure 38, the year round total energy consumption patterns of the hotel have been rather consistent from 2006 to 2009. It is, however, observed that the curve in 2009 shifts downward, indicating a reduction in the total energy consumption throughout the year. The total energy consumptions of the hotel in 2006, 2007, 2008 and 2009 are shown in Figure 39. It is found that the total energy consumption was decreasing over the four years. Apparently, a significant reduction in the total energy consumption is observed in 2009. When the total energy consumption in each of the year is broken down by types of energy as shown in Figure 40, it is observed that the energy consumption due to electricity was actually increasing and that due to town gas was stable over the four years. Meanwhile, the energy consumption due to fuel oil was decreasing from 2006 to 2008 and the consumption level was zero in 2009 as the boilers that consumed fuel oil were replaced by a heat pump system and a backup hot water heater. It is noted that the fuel oil used for monthly test of diesel generator was neglected as there was no record on this relatively small amount of fuel oil consumption. Conceivably, the
gradual decrease of the total energy consumption from 2006 to 2008 was brought about by the decreasing energy consumption due to fuel oil over the three years, while the significant reduction in fuel oil consumption in 2009 stemmed from the removal of the boilers that consumed fuel oil. It is, however, indicated that electricity consumption has become increasingly predominant over the total energy consumption in the hotel. It reached 79% of the total energy consumption in 2009.

Figure 38: Monthly total energy consumption of the hotel from January 2006 to December 2009

Figure 39: Total energy consumptions of the hotel in 2006, 2007, 2008 and 2009
4.2.3 Breakdowns of total electricity consumption and total energy consumption by types of services systems

Twenty electricity sub-meters were installed in June 2009. These sub-meters allow the total electricity consumption to be broken down into the consumptions of individual services systems. However, it is noted that only ten-month data were available, from 1 June 2009 to 31 March 2010, which was the period of time that the sub-meters started to be operated and until the end of the audit. Although there was no one-year-data for the calculation of energy utilization indices (EUIs) for the major services systems in the hotel, it is still possible to have an overview on the breakdown of total electricity consumption by types of services system with the ten-month data obtained as the data covered both the months in summer and the months in winter. However, not all the sub-meters were ideally installed based on usages of electricity. Most of them were installed based on areas where the electricity
was consumed. Therefore, approximate electricity consumptions of individual services systems could be determined by manipulating the sub-meters' readings and making some assumptions as mentioned in Chapter 3.

The breakdown of total electricity consumption of the hotel are shown in Table 22 and a pie chart showing the percentage breakdown of total electricity consumption of the hotel is shown in Figure 41. It can be observed that the air conditioning dominated (approximately 49%) the total electricity consumption because of the sub-tropic climate in Hong Kong. The water side equipment, including chillers, chilled water pumps, condenser water pumps and cooling towers, were responsible for approximately 38% of the total electricity consumption. The air side equipment, including AHUs, PAUs, FCUs and exhaust air fans, were responsible for approximately 11% of the total electricity consumption. Lighting system was the second most significant electrical load of the hotel, responsible for approximately 19% of the total electricity consumption. HVAC system and lighting system together has already accounted for about two-thirds of the total electricity consumption of the hotel. Other loads include hot water heating system (heat pump system and the backup heater) (5%), lifts and escalators (4%), and plumbing and drainage system (2%). The remaining 21% electricity consumption stemmed from other electrical equipment. It seems that the percentage breakdown of total electricity consumption of the hotel was similar to the averaged percentage breakdown of the total electricity energy use in 16 hotels in Hong Kong from a study conducted by Deng and Burnett [24].
Table 22: Breakdown of total electricity consumption by types of services systems

<table>
<thead>
<tr>
<th>End uses</th>
<th>Electricity consumption (kWh)</th>
<th>Percentage of total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC system (water side)</td>
<td>4093900</td>
<td>38</td>
</tr>
<tr>
<td>HVAC system (air side)</td>
<td>1187200</td>
<td>11</td>
</tr>
<tr>
<td>Lighting system</td>
<td>2080487</td>
<td>19</td>
</tr>
<tr>
<td>Hot water production (Heat pump system and back up heater)</td>
<td>527320</td>
<td>5</td>
</tr>
<tr>
<td>Lifts and escalators</td>
<td>443426</td>
<td>4</td>
</tr>
<tr>
<td>Plumbing and drainage system</td>
<td>218975</td>
<td>2</td>
</tr>
<tr>
<td>Other electrical equipment</td>
<td>2336542</td>
<td>21</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>10887850</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Figure 41: Breakdown of total electricity consumption by types of services systems

As far as the breakdown of total energy consumption was concerned, town gas consumption was further included in the analysis. The results are summarized in Table 23 and a pie chart demonstrating the percentage breakdown of the total energy consumption is shown in Figure 42. It is found that air conditioning was also the dominant load in the hotel, responsible for approximately 38% of the total energy consumption. Town gas was the second significant load in the hotel, responsible for approximately 17% of the total energy consumption; while lighting system was the third significant load in the hotel, responsible for approximately 15% of the total energy consumption. This implies that town gas was one of the most important
sources of energy consumption of the hotel that should not be overlooked. This is because a large amount of town gas was used for cooking meals that were served the room guests and the public.

<table>
<thead>
<tr>
<th>End uses</th>
<th>Energy consumption (GJ)</th>
<th>Percentage of total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC system (water side)</td>
<td>14738</td>
<td>29</td>
</tr>
<tr>
<td>HVAC system (air side)</td>
<td>4274</td>
<td>9</td>
</tr>
<tr>
<td>Lighting system</td>
<td>7490</td>
<td>15</td>
</tr>
<tr>
<td>Hot water production (Heat pump system and back up heater)</td>
<td>1898</td>
<td>4</td>
</tr>
<tr>
<td>Lifts and escalators</td>
<td>1596</td>
<td>3</td>
</tr>
<tr>
<td>Plumbing and drainage system</td>
<td>788</td>
<td>2</td>
</tr>
<tr>
<td>Other electrical equipment</td>
<td>8412</td>
<td>17</td>
</tr>
<tr>
<td>Town gas</td>
<td>10574</td>
<td>21</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>49770</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

![Figure 42: Breakdown of total energy consumption by types of services systems](image)

**4.2.4 Energy Utilisation Index (EUI) and benchmarking**

The overall electricity consumptions of the hotel in the four audited years have been normalized by the total gross floor area (GFA) of the hotel to yield energy utilization indices (EUIs) for the four audited years respectively and the calculated EUIs are
shown in Table 24. The EUI of the hotel was decreasing over the four audited years, from 1737MJ/m²/year in 2006 to 1492MJ/m²/year in 2009. It is found that the EUI of the hotel was lower than the average EUI of hotels in Hong Kong in a previous study (2030 MJ/m²/year) by Deng and Burnett [24]. The EUI of the hotel was also lower than the averaged EUI for four-star hotels in Hong Kong and even lower than the averaged EUI for five-star hotels in Hong Kong (2039 MJ/m²/year) [24]. This implies less amount of energy was consumed annually in each square meter of the hotel in this study when compared with the average values for hotels in Hong Kong from previous study by Deng and Burnett.

<table>
<thead>
<tr>
<th>Year</th>
<th>EUI</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>1737 MJ/m²/year</td>
</tr>
<tr>
<td>2007</td>
<td>1727 MJ/m²/year</td>
</tr>
<tr>
<td>2008</td>
<td>1662 MJ/m²/year</td>
</tr>
<tr>
<td>2009</td>
<td>1492 MJ/m²/year</td>
</tr>
</tbody>
</table>

Online benchmarking tool for energy consumption established by EMSD was used to benchmark energy consumption of the hotel. Owing to the restriction on the input of the consumption record period in the tool, the consumption record period from August 2008 to July 2009 was used for benchmarking. The results of benchmarking verified that the annual energy consumption per area of the hotel was at least lower than that of 90% of the hotels in Hong Kong.

4.2.5 Energy Management Opportunities (EMOs)

Although the annual energy consumption per area of the hotel was lower than most of the hotels in Hong Kong, there were still some areas of inefficiency identified in the investigation and as discussed in previous sections. Therefore, suitable means for
improvement in terms of energy management opportunities (EMOs) were identified in order to achieve energy efficiency and energy conservation of the hotel, and hence reduce the carbon emissions simultaneously. The following EMOs in different categories are proposed:

(a) EMOs - Cat. 1

(i) Removing excessive amount of lamps in the bathrooms

As the measured light power intensities in the bathrooms exceeded the limit stated in the BECs and excessive illuminance level was provided in the bathrooms, it is recommended that some lamps inside the bathrooms should be removed to lower the light power densities with suitable illuminance level being maintained.

(ii) Reducing number of lift in operation in mid nights

As it is found that all of the lifts in the hotel were readily in use throughout the day, even in the mid nights when the traffic demand was very low, it is possible to reduce the number of lifts in operations in mid nights. Suitable signs are recommended to display the purpose of switching off the lifts as well as to gain the understanding and support from the customers. Otherwise, it seems that it is not effective to maintain eight numbers of lifts in operation to serve a low demand.

(iii) Displaying labels of the recommended temperature set point at each fan coil unit thermostat controller
It is suggested that the recommended temperature set point for fan coil units should be displayed near to each thermostat controller to promote the users’ or guests’ awareness of setting the temperature to a suitable value to avoid overcooling or overheating of the space. A recommended room temperature of 25.5°C based on EMSD is recommended to be employed [22].

(b) EMO - Cat. II

(i) Using energy efficient lamps

As it is noticed that incandescent lamps were still used in the guest rooms and in the corridors, it is recommended that the incandescent lamps should be replaced with other lamps which are more energy efficient. For instance, integral type compact fluorescent lamps can replace the incandescent lamps directly. In addition, it is recommended that the existing 14W T5 fluorescent lamps used in kitchens and staircases should be replaced with same types of lamps but having a higher luminous efficacy in order to satisfy the BECs requirement. It is also suggested to retrofit the lighting design for the areas where the light power densities and illuminance levels were unsatisfactory as discussed in 4.2.1(b). In addition, conventional exit signs illuminated by T8 fluorescent lamps were used in the hotel. The hotel may consider replacing them with LED exit signs which are more energy efficient and have longer life spans.

(ii) Repairing the cold water pneumatic tank

It is suggested that the pneumatic tank in the cold water supply system should be
repaired in order to eliminate the extra energy used by the continuous operation of the booster pumps.

(iii) Using induction heaters in kitchens

As discussed in 4.2.3, town gas was the second significant source of the energy consumption in the hotel. Induction heaters can be employed in the kitchens to reduce the town gas consumption as induction heaters use electricity for cooking and hence energy loss due to convective heat transfer in the cooking process can be reduced.

(iv) Upgrading means to monitor the energy performance of chillers as well as lifts and escalators

It is found that there was no sub-meters to monitor the amount of electricity used by the chiller plants, and the BMS was not able to measure and log the data about cooling capacities, power inputs as well as chilled water flow rates of the chillers for investigating the chiller performance. It is suggested that sub-meters should be added to measure the electricity consumption of the chiller plants and to upgrade the BMS. Similarly, there was no electricity sub-meter for the lifts and escalators. Sub-meters are suggested to be installed to monitor the electricity consumptions of the lifts and escalators in order to achieve a more comprehensive electricity consumption record of different building services systems in the hotel.
(c) EMO Cat. III

(i) Replacing the reciprocating water-cooled chillers

As it is found that the COPs of the existing reciprocating water-cooled chillers could not satisfy the BECs requirement, the hotel may consider replacing these chillers with those with higher COPs. Besides, the hotel may consider using centrifugal chillers which can achieve a much higher COP than reciprocating chillers.

(ii) Using occupancy sensors

As it is noticed that the timer for automatic on/off control of lighting installations in the corridors was overrode by manual on/off control as the demand for lighting in the corridors was fluctuant, it is suggested to replace the timer with occupancies sensors so that energy conservation became less rely on housekeeping. At the same time, quality of services would not be affected as the lamps will switch on automatically as needed.

(iii) Replacing old pumps with pumps with higher motor efficiency

Due to the advancement of technology, much higher motor efficiency can be achieved by the pumps in the market nowadays. Regarding the HVAC system as well as the plumbing and drainage system in the hotel, it is suggested that the existing pumps that could not meet the current BECs requirements should be replaced with pumps with higher motor efficiencies. Besides, VSDs can be employed for the pumps to enable the pumps to be operated over a range of speeds in accordance with
the needs to achieve energy saving.

(d) EMOs which can be adopted

After discussion with the hotel engineers, the above EMOs that can be adopted easily with relatively low cost but significant and predictable electricity savings are:

(i) Removing one 36W fluorescent tube in each bathroom

As shown in Table 25, the measured existing illuminance level and light power density in one of the typical bathrooms greatly exceeded the recommended value from CIBSE and EMSD respectively. There is opportunity to lower the illuminance levels and the light power densities inside the bathrooms in the hotel by removing one of the 36W fluorescent tubes in the twin fluorescent luminaires in the bathrooms. It is assumed that the bathroom lighting installations inside the guest rooms would be switched on for 4 hours daily. It is noted that the daily number of operation hours for each of the bathroom lighting installations is variable and depends on the guests. There are 626 guest rooms in the hotel. Assuming the hotel has an occupancy rate of 85% based on the averaged occupancy rate in the past four years, the annual electricity saving is estimated as follows:

Estimated annual electricity saving

\[ = 0.036 \text{ kW} \times 4 \text{ hours} \times 365 \text{ days} \times 626 \text{ guest rooms} \times 0.85 \]

\[ = 27967 \text{ kWh} \]
Estimated amount of GHG emissions can be avoided annually

\[= 27967 \text{ kWh} \times 0.56 \text{ kg CO}_2\text{-e/kWh} \div 1000\]

\[= 15.7 \text{ tonnes of CO}_2\text{-e}\]

It is estimated that 27967kWh of electricity consumption could be saved. This is equivalent to 0.21% of the annual total electricity consumption of the hotel in 2009 (13399515kWh) or 15.7 tonnes of CO\textsubscript{2}-e that can be avoided when the GHG emissions are quantified with the specific emission factor from the power company. According to the information from the engineering department of the hotel, bulk tariff was applied to charge the electricity consumption of the hotel. The cost for each unit (kWh) of electricity consumption was HK$0.8 on average. Hence, the annual electricity cost saving can be estimated as follows:

Estimated annual electricity saving

\[= \text{HK$0.8/kWh} \times 27967 \text{ kWh}\]

\[= \text{HK$22374}\]

| Table 25: Estimation of annual electricity saving by removing one 36W fluorescent tube in each bathroom |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| **Recommended value** | **Existing installation** | **Proposed Scheme** | **Assumed daily number of hours that the bathroom lighting installations are switched on** | **Estimated annual electricity saving** |
| Illuminance level | Light power density | Illuminance level | Light power density | Illuminance level | Light power density | 4 hours | 27967kWh |
| 150lux | 13W/m\textsuperscript{2} | 400lux | 64W/m\textsuperscript{2} | 298lux | 49.6W/m\textsuperscript{2} | | |
(ii) Closing 3 passengers lifts at 1am to 6am

After the discussion with the hotel engineers and trials, it is found that there is opportunity to close three passengers lifts at 1am to 6am every day when the traffic demand of passengers lifts is very low. This can at least save the standby power of the lifts. The standby power of each of the passengers lifts is 2kW. If three passengers lifts are closed at 1am to 6am every day, the annual electricity saving, the annual electricity cost saving and the annual amount of GHG emissions which can be avoided are estimated as follows:

Estimated annual electricity saving
= 2 kW x 5 hours x 365 days x 3 passengers lifts
= 10950 kWh

Estimated annual electricity cost saving
= HK$0.8/kWh x 10950 kWh
= HK$8760

Estimated amount of GHG emissions which can be avoid annually
= 10950 kWh x 0.56 kg CO2-e/kWh ÷ 1000
= 6.132 tonnes of CO2-e

Hence, it is estimated that 10950kWh of electricity consumption and HK$8760 of electricity cost could be saved annually. This amount of annual electricity saving is equivalent to 0.08% of the annual total electricity consumption of the hotel in 2009 (13399515kWh) or 6.132 tonnes of CO2-e that can be avoided when the GHG
emissions are quantified with the specific emission factor from the power company.

(iii) Replacing the 40W incandescent lamps in corridors with 10W integral type compact fluorescent lamps, and the 60W incandescent lamps in guest rooms with 15W integral type compact fluorescent lamps

According to EMSD, compact fluorescent lamps use about a quarter of the power of incandescent lamps. The light output of a 10W compact fluorescent lamp is equivalent to that of a 40W incandescent lamp and the light output of a 15W compact fluorescent lamp is equivalent to that of a 60W incandescent lamp [43]. There is opportunity to reduce the electricity consumption of the hotel by replacing the 40W incandescent lamps in corridors with 10W integral type compact fluorescent lamps, and the 60W incandescent lamps in guest rooms with 15W integral type compact fluorescent lamps.

There were 440 numbers of 40W incandescent lamps installed in the corridors of the hotel and 1252 numbers of 60W incandescent lamps installed in the guest rooms (two 60W incandescent lamps in each guest room). According to a study on energy saving and safety performance of compact fluorescent lamps conducted by the Consumer Council in Hong Kong, the prices of majority of the sampled compact fluorescent lamps in different brands with rated wattage ranging from 7W to 25W in Hong Kong were between HK$25 and HK$45 [44]. Assuming the prices of the proposed 10W and 15W compact fluorescent lamps are identical and equal to HK$35 (mean between HK$25 and HK$45). The lamps replacement and cleaning would be conducted by hotel staff; therefore the costs for lamps replacement and cleaning are included in the salary of hotel staff already. It is assumed that the lamps in the
corridors would be operated 24 hours daily and the proposed 15W compact fluorescent lamps in the guest rooms would be operated 4 hours daily. It is also noted that the daily number of operation hours of the lamps in the guest rooms are variable and depends on the guests. Assuming the hotel has an occupancy rate of 85% based on the averaged occupancy rate in the past four years and the cost for each unit (kWh) of electricity consumption is HK$0.8. The replacements of incandescent lamps in the corridors and in the guest rooms can be conducted separately or simultaneously. Hence, three cases are considered. Case 1 considers the lamp replacement work to be conducted in the corridor only. Case 2 considers the lamp replacement work to be conducted in the guest rooms only. Case 3 considers the lamp replacement work to be conducted in both the corridors and guest rooms. In each case, the annual electricity saving, the annual electricity cost saving, the payback period and the annual amount of GHG emissions that can be avoided when the GHG emissions are quantified with the specific emission factor from the power company are estimated as follows:

Case 1: Considering the corridors only

Estimated annual electricity saving

\[ = (0.04 \text{ kW} - 0.01 \text{ kW}) \times 24 \text{ hours} \times 365 \text{ days} \times 440 \text{ lamps} \]

\[ = 115632 \text{ kWh} \]

This is equivalent to 0.86% of the annual total electricity consumption of the hotel in 2009 (13399515kWh).
Estimated annual electricity cost saving

\[= \text{HK}\$0.8/\text{kWh} \times 115632 \text{ kWh} \]

\[= \text{HK}\$92506\]

Cost of replacement of the incandescent lamps with the compact fluorescent lamps

\[= \text{HK}\$35/\text{lamp} \times 440 \text{ lamps} \]

\[= \text{HK}\$15400\]

Payback period

\[= \frac{\text{HK}\$15400}{\text{HK}\$92506} \]

\[= 0.17 \text{ year} \]

\[\approx 2 \text{ months} \]

Estimated amount of GHG emissions can be avoid annually

\[= 115632 \text{ kWh} \times 0.56 \text{ kg CO}_2\text{-e/kWh} \div 1000 \]

\[= 64.8 \text{ tonnes of CO}_2\text{-e} \]

Case 2: Considering the guest rooms only

Estimated annual electricity saving

\[= (0.06 \text{ kW} - 0.015 \text{ kW}) \times 4 \text{ hours} \times 365 \text{ days} \times 1252 \text{ lamps} \times 0.85 \]

\[= 69918 \text{ kWh} \]

This is equivalent to 0.52% of the annual total electricity consumption of the hotel in 2009 (13399515 kWh).
Estimated annual electricity cost saving

\[
= \text{HK}\$0.8/\text{kWh} \times 69918 \text{ kWh}
\]

\[
= \text{HK}\$55934
\]

Cost of replacement of the incandescent lamps with the compact fluorescent lamps

\[
= \text{HK}\$35/\text{lamp} \times 1252 \text{ lamps}
\]

\[
= \text{HK}\$43820
\]

Payback period

\[
= \frac{\text{HK}\$43820}{\text{HK}\$55934}
\]

\[
= 0.78 \text{ year}
\]

\[
\approx 9.5 \text{ months}
\]

Estimated amount of GHG emissions can be avoid annually

\[
= 69918 \text{ kWh} \times 0.56 \text{ kg CO}_2\text{-e/kWh} \div 1000
\]

\[
= 39.2 \text{ tonnes of CO}_2\text{-e}
\]

**Case 3: Considering both corridors and guest rooms**

Estimated annual electricity saving

\[
= 115632 \text{ kWh} + 69918 \text{ kWh}
\]

\[
= 185550 \text{ kWh}
\]

This is equivalent to 1.38% of the annual total electricity consumption of the hotel in 2009 (13399515 kWh).

Estimated annual electricity cost saving
\[ = HK\$0.8/\text{kWh} \times 185550 \text{kWh} \]
\[ = HK\$148440 \]

Cost of replacement of the incandescent lamps with the compact fluorescent lamps
\[ = HK\$15400 + HK\$43820 \]
\[ = HK\$59220 \]

Payback period
\[ = \frac{HK\$59220}{HK\$148440} \]
\[ = 0.4 \text{ year} \]
\[ \sim 5 \text{ months} \]

Estimated amount of GHG emissions can be avoided annually
\[ = 185550 \text{kWh} \times 0.56 \text{ kg CO}_2\text{-e/kWh} \div 1000 \]
\[ = 103.9 \text{ tonnes of CO}_2\text{-e} \]

The estimated annual electricity saving, the estimated annual electricity cost saving, the payback period and the estimated annual amount of GHG emissions that can be avoided in each case are summarized in Table 26. It is found that the payback periods for the three cases of lamp replacement are less than one year. Hence, it is financially viable to conduct the lamp replacement work. If the lamp replacement is conducted in the corridors only, the payback period will be as short as two months. If the lamp replacement is conducted in the guest rooms only, the payback period will be 9.5 months. If the lamp replacement is conducted in both the corridors and guest rooms, the payback period will be 5 months.
Table 26: Summary of the estimated annual electricity saving, the estimated annual electricity cost saving, the payback period and the estimated annual amount of GHG emissions that can be avoided by lamp replacement.

<table>
<thead>
<tr>
<th>Case</th>
<th>Area</th>
<th>Estimated annual electricity saving (kWh)</th>
<th>Estimated annual electricity cost saving (HKS)</th>
<th>Cost of lamp replacement (HKS)</th>
<th>Payback period (months)</th>
<th>Estimated annual amount of GHG emissions can be avoided (tonnes of CO₂-e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Corridors only</td>
<td>115632</td>
<td>92506</td>
<td>15400</td>
<td>2</td>
<td>64.8</td>
</tr>
<tr>
<td>2</td>
<td>Guest rooms only</td>
<td>69918</td>
<td>55934</td>
<td>43820</td>
<td>9.5</td>
<td>39.2</td>
</tr>
<tr>
<td>3</td>
<td>Corridors and guest rooms together</td>
<td>185550</td>
<td>148440</td>
<td>59220</td>
<td>5</td>
<td>103.9</td>
</tr>
</tbody>
</table>

The estimated annual electricity savings, the estimated annual electricity cost savings, payback periods and the estimated annual amount of GHG emissions that can be avoided by the above three EMOs are summarized in Table 27. The first two EMOs, (i) and (ii), are Category I EMOs which could achieve electricity saving with practically no cost investment. The third EMO, (iii), is a Category II EMO which involves a low capital cost investment with minor disruption to building operation. If all these three EMOs are adopted, it is estimated that 224467kWh of electricity consumption can be saved annually and it is equivalent to 1.68% of the annual total electricity consumption of the hotel in 2009 (13399515kWh) or 125,732 tonnes of CO₂-e that can be avoided when the GHG emissions are quantified with the specific emission factor from the power company. Besides, annual electricity cost of HKS179574 can be saved.
Table 27: Summary of the estimated annual electricity saving, the estimated annual electricity cost saving, the payback period and the estimated annual amount of GHG emissions that can be avoided if the three selected EMOs are undertaken

<table>
<thead>
<tr>
<th>EMO</th>
<th>Category</th>
<th>Estimated annual electricity saving (kWh)</th>
<th>Estimated annual electricity cost saving (HK$)</th>
<th>Cost (HK$)</th>
<th>Payback period (months)</th>
<th>Estimated annual amount of GHG emissions can be avoided (tones of CO$_2$-e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) Removing one 36W fluorescent tube in each bathroom</td>
<td>I</td>
<td>27967</td>
<td>22374</td>
<td>0</td>
<td>-</td>
<td>15.7</td>
</tr>
<tr>
<td>(ii) Closing 3 passengers lifts at 1am to 6am</td>
<td>I</td>
<td>10950</td>
<td>8760</td>
<td>0</td>
<td>-</td>
<td>6.132</td>
</tr>
<tr>
<td>(iii) Replacing the 40W incandescent lamps in corridors with 10W integral type compact fluorescent lamps, and the 60W incandescent lamps in guest rooms with 15W integral type compact fluorescent lamps</td>
<td>II</td>
<td>185550</td>
<td>148440</td>
<td>59220</td>
<td>5</td>
<td>103.9</td>
</tr>
</tbody>
</table>

| Total | - | 224467 | 179574 | 59220 | - | 125.732 |

It is also noted that the annual energy savings for the EMOs could be estimated by computer simulations in further study if more details on the existing as well as the proposed systems and equipment were obtained, including their operating schedules, operating conditions, and their efficiencies in different operating conditions.
Chapter 5

Conclusion

This dissertation aimed to present a case study which demonstrates a method of conducting a carbon audit and an energy audit in a hotel in Hong Kong based on the relevant guidelines published in Hong Kong. With a detailed analysis on the greenhouse gas (GHG) emissions and energy performance of the hotel, major sources of GHG emissions and areas of inefficiency in energy consumption were identified. Relevant opportunities for improvement were then suggested. Simultaneously, difficulties in conducting a carbon audit and an energy audit in the hotel were examined. This chapter summarizes the major findings and the possible applications of the outcome of the analysis in the field of carbon audits and energy audits study. Recommendations for future research are also proposed.

5.1 Major findings

With regard to the guidelines for carbon and energy audits, the study revealed that there were both similarities and differences among the guidelines for carbon audits used in Hong Kong, Australia and the UK. GHG Protocol and ISO 14064 are the common standards that the guidelines in these three regions or countries based on. The guidelines in these three places classify GHG emissions into three Scopes (Scope 1, 2 and 3), however, the classification of GHG emissions-releasing activities into the three Scopes in the guidelines for the three places have slight differences. Moreover, the reporting of Scope 3 emissions is optional in the guidelines for carbon audits in Hong Kong and in the UK, but not in Australia. Meanwhile, the three places prepare their emission factors and GHG inventories so as to make the guidelines
more applicable in the respective territories.

Building energy codes (BECs) were established in Hong Kong to stipulate energy efficiency requirements for four key types of building services installations in buildings, namely: lighting, air-conditioning, electrical as well as lift and escalator installations. The review of the codes in this study shows that the Hong Kong's standards on air-conditioning and electrical installations are broadly comparable to standards adopted by other countries like Australia, Singapore, the UK and the USA; whereas Hong Kong standards on lighting installations are relatively less stringent than those in Australia, Singapore, the UK and the USA.

Based on the guidelines for carbon audits and energy audits in Hong Kong, a carbon audit and an energy audit were conducted simultaneously in a hotel in Hong Kong as a case study. The carbon audit results showed that majority of the GHG emissions stemmed from the energy indirect emissions categorized in Scope 2. Only small portion of the GHG emissions was caused by the other indirect emissions categorized in Scope 3. Meanwhile, there was no Scope 1 direct emission and removal in the hotel. Concerning the Scope 2 emissions, it is found that the GHG emissions arising from the consumption of purchased electricity have dominated the GHG emissions in Scope 2. This indicated that the use of electricity was crucial to the GHG emissions of the hotel. With reference to a study conducted by the Environment Protection Agency (EPA) in the US, it is found that the normalized GHG emissions of the hotel in this study were similar to those of the hotels in the US.

As the energy indirect emissions were crucial to the GHG emissions of the hotel, it is important to investigate the energy performance of the hotel and the main energy
consuming building services systems in the hotel as well as the energy consumption pattern of the hotel through the energy audit. It is found that the annual total energy consumption was decreasing over the audit period (2006-2009). There was a significant reduction in the annual total energy consumption in 2009 as a result of the replacement of the boilers with a heat pump system and a backup heater. Detailed regression analyses undertook using the records on the electricity consumption and energy consumption as well as the operational data from the hotel. The results indicated that electricity consumption and energy consumption in the hotel were strongly affected by the outdoor temperature and the number of guests together, with the former being the stronger affecting factor. For gas consumption, a strong correlation between the town gas consumption and the number of food covers was obtained. Based on the breakdown of the total electricity consumption by types of services systems, it is demonstrated that the HVAC system and the lighting system were the first and second most significant electrical loads of the hotel respectively. Likewise, another breakdown of the total energy consumption of the hotel by types of services systems was conducted. It is shown that the energy consumption of the hotel was dominated by the HVAC system; while town gas and lighting system were the second and third most important sources of energy consumption of the hotel.

Although it is found that the annual energy consumption per gross floor area (or EUI) of the hotel was lower than that of the average of hotels in Hong Kong in a previous study by Deng and Burnett [24] as well as that of 90% of the hotels in Hong Kong in benchmarking, there were still some areas of inefficiency identified based on the results in the energy audit. For instance, in the investigation on the energy performance of the major electricity consumption systems and equipment, it is found that the COPs of the reciprocating water-cooled chillers in the hotel were slightly
lower than the required value stated in the BECs. The investigation shows that some of the functional areas were over-lit with excessive amount of luminaires installed, such as bathrooms and lift lobbies. Some functional areas, such as kitchens and the ballroom, had installed excessive amount of luminaires but the illuminance levels of these areas were still insufficient. Besides, incandescent lamps were still being used in some areas in the hotel. It is, however, unavoidable to install excessive amount luminaires and use incandescent lamps in some areas, like the ballroom, where providing a grand and luxurious environment for the guests is a prime need. It is also found that the lifts and most of the water pumps in the hotel, including the pumps in the HVAC system, and the pumps in the plumbing and drainage system, had motor efficiencies lower than that required in the BECs in Hong Kong. This might probably be due to the limitation of technology that could be achieved at the time that these motors and pumps were installed. Besides, it is found that the booster pumps in the cold water supply system had to operate continuously because the pneumatic tank was failed to provide sufficient pressure for the cold water. Based on the areas of inefficiency identified, suitable energy management opportunities (EMOs) were proposed in Chapter 4. These proposed EMOs have covered both technical and managerial issues.

5.2 Difficulties and problems

Through the implementation of the carbon audit and the energy audit in the hotel under investigation, some difficulties and problems were aroused in the process.

Regarding the carbon audit, it is found that a clear and comprehensive record of required data is essential for the audit. For instance, it is essential to keep a precise
record of the amount of paper consumed and paper collected for recycle as mentioned in Chapter 4. It may not be possible for the hotel staff to count the number and measure the weight of different kinds of paper after purchase or before use every time. Besides, as the required data spread over a variety of trades or different departments, there were difficulties in collecting a comprehensive set of data. Good coordination among different departments was required.

It is stated in the guidelines for carbon audits in Hong Kong that it is optional to report GHG emissions covered in Scope 3 and there are no obvious requirements on the report on GHG emissions due to certain activities. The GHG emissions to be reported in Scope 3 are generally determined by the building users or owners. This may cause several problems. Firstly, the building users or owners may underestimate the total GHG emissions of the building if the carbon audits do not report on GHG emissions covered in Scope 3. Secondly, the building users or owner may try to mask the GHG emissions from activities covered in Scope 3 by simply not reporting the GHG emissions covered in Scope 3. Thirdly, carbon audits in different buildings may or may not report the GHG emissions from the activities covered in Scope 3 or different activities are taken into account to quantify the GHG emissions in Scope 3 although Scope 3 emissions are reported in the carbon audits even for the same type of buildings with the same usage. There is difference in the scope of data to be reported. This might cause problem during the comparisons of GHG emissions among buildings, even for the same building with different activities covered and reported. It is difficult to provide consistency among different reports.

Regarding the difficulties related to the energy audit, as mentioned in Chapter 3, it is found that the number of sub-meters was inadequate to investigate the breakdowns of
the total electricity consumption and the total energy consumption by types of services systems. Besides, most of the sub-meters were installed based on areas where the electricity was served instead of installed ideally based on the usages of electricity. Therefore, certain assumptions had to be made to determine the electricity consumption and the energy consumption of some of the building services systems. Thus, sufficient sub-metering and good quality instrumentation are important and helpful in monitoring as well as studying the energy performance of a building.

Site measurements were required in the approximation of electricity consumption and in the energy performance investigation of various building services systems. However, some of the measurements could not be conducted because of the possible interruption of the normal operation of the hotel or the possible dangers to the occupants. Besides, the requirements in the building energy codes (BECs) in Hong Kong are criteria applicable for new designs and installations of building services systems. Therefore, it is difficult to conduct certain site measurements or tests, such as air duct leakage test, on existing systems in order to examine the energy performance of various building services systems based on the requirements stated in the BECs without interrupting the normal operation of the systems, especially in a hotel. In addition, the BECs specified the energy efficiency requirements of systems or equipment in full load operation, such as COPs of chillers, however, the systems in the hotel are usually running in part load situation.

5.3 Limitations and suggestions

In the energy audit, as the breakdowns of the total electricity consumption and the total energy consumption by types of building services systems were based on the
manipulation of electricity sub-meters' readings and many assumptions, the breakdown results were approximated values. Besides, as mentioned in Chapter 4, EUIs for the major building services systems in the hotel could not be found as the electricity sub-meters have operated for ten months only and there was no one-year-data recorded. Hence, these EUIs remain to be further analyzed when one-year-data was obtained. In further analysis, computer simulations can also be undertaken to analyze and predict the improvements on the electricity and energy consumptions after taking the improvement measures.

In addition, it is important to note that the GHG emissions and the energy consumptions of the shops in the studied hotel were not included in the two audits as the data from the shops was unavailable, unless the tenants are willing to release their private data. It is also important to note that this dissertation is a case study conducted based on one hotel only. It would be useful to repeat the study in other hotels with different star ranking in order to build up a database for further analysis.

5.4 Contribution of the study

This dissertation presented a case study on conducting a carbon audit and an energy audit simultaneously in a hotel in Hong Kong based on the guidelines for carbon audits and energy audits in Hong Kong. Based on the results of the carbon audit, purchased electricity and town gas were the major sources of GHG emissions of the hotel studied. In addition to the implementation of the carbon audit, a GHG emissions calculator for buildings (commercial, residential or institutional purposes) in Hong Kong was established in this study in order to facilitate the calculation of GHG emissions of commercial, residential or institutional buildings in Hong Kong.
with computers as an existing GHG emissions calculator was not available in Hong Kong. Through the energy audit, the energy performance of the hotel was analyzed. With the identification of the areas of inefficiency in energy consumption, corresponding opportunities for improvement on GHG emissions and energy consumption of the hotel were proposed. Difficulties encountered during the implementation of the energy-cum-carbon audit in the hotel were also demonstrated in this study.
References


Appendix A

Questionnaire for the carbon audit

Carbon Audit Questionnaire

The questionnaire is concerned with the period: 1 January, 2009 to 31 December, 2009

Section 1: General Information

Q1.1 Please fill in the following building characteristics of the hotel:

A. Gross floor area: __________m²

B. Number of floors: __________

C. Number of guest rooms: __________

D. Average daily number of direct-control staff: __________

E. Please provide occupancy details in Table 1.

<table>
<thead>
<tr>
<th>Floor number (e.g. 1/F)</th>
<th>Usage (office, communal area, etc.)</th>
<th>Floor area (m²)</th>
<th>Hours of operation per day (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(office)</td>
<td>(50)</td>
<td>(9)</td>
<td></td>
</tr>
</tbody>
</table>

Please provide details in a separate sheet as necessary
Section 2: Greenhouse gas (GHG) emissions from stationary combustion sources

Q2.1 Any combustion equipment installed: YES / NO (please circle one)

Go to: (Q2.2 / Section 3)

Q2.2 Please provide details in Table 2 (NO NEED to input this section if the fuel is supplied from Central town gas).

<table>
<thead>
<tr>
<th>Source description</th>
<th>Fuel used</th>
<th>Amount of fuel used during reporting period</th>
<th>Type of fuel used</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fuel type</td>
<td>Fuel unit Note 1</td>
<td>Type of fuel used</td>
</tr>
<tr>
<td>Boilers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burners</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heaters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Furnaces</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ovens</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dryers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Combustion engines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Generator</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any other equipment or machinery that</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>combuts carbon bearing fuels or waste</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>streams</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please provide details in a separate sheet as necessary

Note 1: Please choose the unit for the corresponding fuel type from the table below.

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Oil</td>
<td>Litre</td>
</tr>
<tr>
<td>LPG</td>
<td>Kg</td>
</tr>
<tr>
<td>Kerosene</td>
<td>Litre</td>
</tr>
<tr>
<td>Charcoal</td>
<td>Kg</td>
</tr>
<tr>
<td>Town gas</td>
<td>Unit</td>
</tr>
<tr>
<td>Non-Industrial Gas Oil</td>
<td></td>
</tr>
<tr>
<td>(fuel used for portable electricity generator)</td>
<td>Litre</td>
</tr>
</tbody>
</table>
Section 3: GHG emissions from mobile combustion sources, and hydrofluorocarbons (HFC) and perfluorocarbons (PFC) emissions for refrigerant used on mobile combustion sources

Fuel consumption data related to all mobile sources between the building and specified destinations (owned by the hotel and serving the hotel only).

**Q3.1** Any mobile sources provision: YES / NO (please circle one)

*Go to: (Q3.2/ Section 4)*

**Q3.2** Please provide details in Table 3.

<table>
<thead>
<tr>
<th>Source description</th>
<th>Fuel used</th>
<th>Fuel type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amount of fuel used during reporting period</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fuel unit</td>
<td></td>
</tr>
<tr>
<td><strong>Road Transport</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motorcycle</td>
<td>litres</td>
<td>Unleaded Petrol</td>
</tr>
<tr>
<td>Passenger Car</td>
<td>litres</td>
<td>Unleaded Petrol</td>
</tr>
<tr>
<td></td>
<td>litres</td>
<td>Diesel Oil</td>
</tr>
<tr>
<td>Public Van</td>
<td>litres</td>
<td>Unleaded Petrol</td>
</tr>
<tr>
<td></td>
<td>litres</td>
<td>Diesel Oil</td>
</tr>
<tr>
<td>Public Light Bus</td>
<td>litres</td>
<td>Diesel Oil</td>
</tr>
<tr>
<td></td>
<td>litres</td>
<td>LPG</td>
</tr>
<tr>
<td>Light Goods Vehicle</td>
<td>litres</td>
<td>Unleaded Petrol</td>
</tr>
<tr>
<td></td>
<td>litres</td>
<td>Diesel Oil</td>
</tr>
<tr>
<td>Heavy Goods Vehicle</td>
<td>litres</td>
<td>Diesel Oil</td>
</tr>
<tr>
<td>Medium Goods Vehicle</td>
<td>litres</td>
<td>Diesel Oil</td>
</tr>
<tr>
<td><strong>Navigation</strong></td>
<td>litres</td>
<td>Gas Oil</td>
</tr>
<tr>
<td><strong>Aviation</strong></td>
<td>litres</td>
<td>Jet Kerosene</td>
</tr>
</tbody>
</table>

*Please provide details in a separate sheet as necessary*
Q3.3 Any refrigerant used on mobile sources: YES / NO (please circle one)

Go to: (Q3.4 / Section 4)

Q3.4 Please provide the details of refrigerant used in Table 4.

<table>
<thead>
<tr>
<th>Table 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source description</td>
</tr>
<tr>
<td><strong>Road Transport</strong></td>
</tr>
<tr>
<td>Motorcycle</td>
</tr>
<tr>
<td>Passenger Car</td>
</tr>
<tr>
<td>Public Van</td>
</tr>
<tr>
<td>Public Light Bus</td>
</tr>
<tr>
<td>Light Goods Vehicle</td>
</tr>
<tr>
<td>Heavy Goods Vehicle</td>
</tr>
<tr>
<td>Medium Goods Vehicle</td>
</tr>
<tr>
<td><strong>Navigation</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Aviation</strong></td>
</tr>
</tbody>
</table>

Please provide details in a separate sheet as necessary

Section 4: HFC and PFC emissions for refrigeration / air-conditioning (AC) equipment

Q4.1 Any refrigeration / AC equipment installed: YES / NO (please circle one)

Go to: (Q4.2 / Section 5)

Q4.2 Please provide details in Table 5.

<table>
<thead>
<tr>
<th>Table 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of refrigerant</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>(e.g. HFC-134a)</td>
</tr>
</tbody>
</table>

Please provide details in a separate sheet as necessary
Section 5: Direct GHG removals from newly planted trees

Q5.1 Any newly planted tree since the building erected: YES / NO (please circle one)

Go to: (Q5.2 / Section 6)

Q5.2 Please provide details in Table 6.

<table>
<thead>
<tr>
<th>Source location (i.e. Area / floor number) (e.g. G/F)</th>
<th>No. of trees newly planted (at least 5 meters height) (10)</th>
<th>No. of planted trees removed (at least 5 meters height) (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please provide details in a separate sheet as necessary

Section 6: Energy indirect GHG emissions due to electricity purchased

Q6.1 Any meter installed by power company: YES / NO (please circle one)

Go to: (Q6.2 / Section 7)

Q6.2 Power Company: CLP / HEC (please circle one)

Q6.3 Amount of electricity purchased during the reporting period (from electricity bill):

__________ kWh

Section 7: Energy indirect GHG emissions due to town gas purchased

Q7.1 Any meter installed by the town gas company: Yes / No (please circle one)

Go to: (Q7.2 / Section 8)

Q7.2 Amount of town gas purchased during the reporting period (from town gas bill):

__________ unit
Section 8: Methane generation at landfill in Hong Kong due to disposal of paper waste

Q8.1 Any record on paper consumption: Yes / No (please circle one)

Go to: (Q8.2 / Step 9)

Q8.2 Will paper be collected for recycling: Yes / No (please circle one)

Q8.3 Paper recycling method: Own Disposal / via PMA

Q8.4 Please provide details in Table 7.

<table>
<thead>
<tr>
<th>Types and sizes of paper</th>
<th>Amount of paper in storage at the beginning of the reporting period (kg)</th>
<th>Amount of paper purchased during the reporting period (kg)</th>
<th>Amount of paper collected for recycling during the reporting period (kg)</th>
<th>Amount of paper in storage at the end of the reporting period (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(e.g. A4 paper, 80GSM)</td>
<td>100</td>
<td>1000</td>
<td>500</td>
<td>100</td>
</tr>
</tbody>
</table>
Section 9: GHG emissions due to electricity used for fresh water processing by Water Supplies Department and GHG emissions due to electricity used for processing by Drainage Services Department

Q9.1 Any meter installed by Water Services Department: Yes / No (please circle one)

Go to: (Q9.2 / Section 10)

Q9.2 Amount of fresh water purchased during the reporting period (from water service bill):

_______ m³

Q9.3 Please provide details in Table 8.

<table>
<thead>
<tr>
<th>Table 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area of water used</td>
</tr>
<tr>
<td>(e.g. Chinese kitchen)</td>
</tr>
</tbody>
</table>

Section 10: Other Comments

--- End of questionnaire ---
Appendix B

Greenhouse gas emissions and removals calculator

![Greenhouse Gas Emissions and Removals Calculator for Buildings (Commercial, Residential or Institutional Purposes) in Hong Kong](image)

*Figure B-1: Front page of greenhouse gas emissions and removals calculators*
<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Amount used per year</th>
<th>Unit</th>
<th>Emission Factor</th>
<th>CO₂ x 1000</th>
<th>Total tonnes of CO₂eq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel Oil</td>
<td>litre</td>
<td>x</td>
<td>2.614 kg/litre</td>
<td>2.039</td>
<td>0</td>
</tr>
<tr>
<td>LPG</td>
<td>kg</td>
<td>x</td>
<td>3.077 g/kg</td>
<td>0.032</td>
<td>0</td>
</tr>
<tr>
<td>Kerosene</td>
<td>litre</td>
<td>x</td>
<td>2.429 kg/litre</td>
<td>0.025</td>
<td>0</td>
</tr>
<tr>
<td>Charcoal</td>
<td>kg</td>
<td>x</td>
<td>2.97 g/kg</td>
<td>0.055</td>
<td>0</td>
</tr>
<tr>
<td>Biomass</td>
<td>Unit</td>
<td>x</td>
<td>2.549 g/Unit</td>
<td>0.046</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Amount used per year</th>
<th>Unit</th>
<th>Emission Factor</th>
<th>CH₄ x 1000</th>
<th>Total tonnes of CH₄eq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel Oil</td>
<td>litre</td>
<td>x</td>
<td>2.039 g/litre</td>
<td>0.004</td>
<td>0</td>
</tr>
<tr>
<td>LPG</td>
<td>kg</td>
<td>x</td>
<td>0.032 g/kg</td>
<td>0.007</td>
<td>0</td>
</tr>
<tr>
<td>Kerosene</td>
<td>litre</td>
<td>x</td>
<td>0.025 g/litre</td>
<td>0.006</td>
<td>0</td>
</tr>
<tr>
<td>Charcoal</td>
<td>kg</td>
<td>x</td>
<td>0.055 g/kg</td>
<td>0.005</td>
<td>0</td>
</tr>
<tr>
<td>Biomass</td>
<td>Unit</td>
<td>x</td>
<td>0.046 g/Unit</td>
<td>0.001</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Amount used per year</th>
<th>Unit</th>
<th>Emission Factor</th>
<th>N₂O x 1000</th>
<th>Total tonnes of N₂Oeq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel Oil</td>
<td>litre</td>
<td>x</td>
<td>2.039 g/litre</td>
<td>0.012</td>
<td>0.310</td>
</tr>
<tr>
<td>LPG</td>
<td>kg</td>
<td>x</td>
<td>0.032 g/kg</td>
<td>0.0006</td>
<td>0.0006</td>
</tr>
<tr>
<td>Kerosene</td>
<td>litre</td>
<td>x</td>
<td>0.025 g/litre</td>
<td>0.0004</td>
<td>0.0004</td>
</tr>
<tr>
<td>Charcoal</td>
<td>kg</td>
<td>x</td>
<td>0.055 g/kg</td>
<td>0.00004</td>
<td>0.00004</td>
</tr>
<tr>
<td>Biomass</td>
<td>Unit</td>
<td>x</td>
<td>0.046 g/Unit</td>
<td>0.00001</td>
<td>0.00001</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.310</td>
</tr>
</tbody>
</table>

**Figure B-2:** Page for the calculation for GHG emissions from stationary sources
### GHG Emissions from the Mobile Sources

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Fuel Type</th>
<th>Amount used per year</th>
<th>Unit</th>
<th>Emission Factor</th>
<th>CO₂</th>
<th>Total tonnes of CO₂ eq</th>
<th>( \text{CH}_4 )</th>
<th>Total tonnes of ( \text{CH}_4 \text{eq} )</th>
<th>( \text{N}_2\text{O} )</th>
<th>Total tonnes of ( \text{N}_2\text{O}\text{eq} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorcycle</td>
<td>Unleaded Petrol (ULP)</td>
<td>litre</td>
<td>x</td>
<td>2.35 kg/litre</td>
<td>x</td>
<td>1.42 (1000x1000) x 21</td>
<td>x</td>
<td>0.066 (1000x1000) x 310</td>
<td>0</td>
<td>0.22 (1000x1000) x 310</td>
</tr>
<tr>
<td>Passenger Car</td>
<td>Unleaded Petrol (ULP)</td>
<td>litre</td>
<td>x</td>
<td>2.35 kg/litre</td>
<td>x</td>
<td>1.30 (1000x1000) x 21</td>
<td>x</td>
<td>0.15 (1000x1000) x 310</td>
<td>0</td>
<td>0.04 (1000x1000) x 310</td>
</tr>
<tr>
<td>Private Van</td>
<td>Diesel Oil (DO)</td>
<td>litre</td>
<td>x</td>
<td>2.614 kg/litre</td>
<td>x</td>
<td>1.23 (1000x1000) x 21</td>
<td>x</td>
<td>0.11 (1000x1000) x 310</td>
<td>0</td>
<td>0.03 (1000x1000) x 310</td>
</tr>
<tr>
<td>Public Light Bus</td>
<td>Diesel Oil (DO)</td>
<td>litre</td>
<td>x</td>
<td>2.614 kg/litre</td>
<td>x</td>
<td>1.14 (1000x1000) x 21</td>
<td>x</td>
<td>0.05 (1000x1000) x 310</td>
<td>0</td>
<td>0.01 (1000x1000) x 310</td>
</tr>
<tr>
<td>Light Goods Vehicle</td>
<td>Unleaded Petrol (ULP)</td>
<td>litre</td>
<td>x</td>
<td>2.35 kg/litre</td>
<td>x</td>
<td>1.07 (1000x1000) x 21</td>
<td>x</td>
<td>0.05 (1000x1000) x 310</td>
<td>0</td>
<td>0.01 (1000x1000) x 310</td>
</tr>
<tr>
<td>Medium Goods Vehicle</td>
<td>Diesel Oil (DO)</td>
<td>litre</td>
<td>x</td>
<td>2.614 kg/litre</td>
<td>x</td>
<td>1.07 (1000x1000) x 21</td>
<td>x</td>
<td>0.05 (1000x1000) x 310</td>
<td>0</td>
<td>0.01 (1000x1000) x 310</td>
</tr>
<tr>
<td>Ships</td>
<td>Gas Oil</td>
<td>litre</td>
<td>x</td>
<td>2.645 kg/litre</td>
<td>x</td>
<td>1.07 (1000x1000) x 21</td>
<td>x</td>
<td>0.05 (1000x1000) x 310</td>
<td>0</td>
<td>0.01 (1000x1000) x 310</td>
</tr>
<tr>
<td>Aviation</td>
<td>Jet Kerosene</td>
<td>litre</td>
<td>x</td>
<td>2.929 kg/litre</td>
<td>x</td>
<td>1.07 (1000x1000) x 21</td>
<td>x</td>
<td>0.05 (1000x1000) x 310</td>
<td>0</td>
<td>0.01 (1000x1000) x 310</td>
</tr>
<tr>
<td>Other Mobile Machinery</td>
<td>Diesel Oil (DO)</td>
<td>litre</td>
<td>x</td>
<td>2.614 kg/litre</td>
<td>x</td>
<td>1.07 (1000x1000) x 21</td>
<td>x</td>
<td>0.05 (1000x1000) x 310</td>
<td>0</td>
<td>0.01 (1000x1000) x 310</td>
</tr>
<tr>
<td></td>
<td>Liquefied Petroleum Gas (LPNG)</td>
<td>litre</td>
<td>x</td>
<td>1.679 kg/litre</td>
<td>x</td>
<td>0.0036 (1000x1000) x 21</td>
<td>x</td>
<td>0 (1000x1000) x 310</td>
<td>0</td>
<td>0.0036 (1000x1000) x 310</td>
</tr>
<tr>
<td></td>
<td>Kerosene</td>
<td>litre</td>
<td>x</td>
<td>2.429 kg/litre</td>
<td>x</td>
<td>0.0241 (1000x1000) x 21</td>
<td>x</td>
<td>0 (1000x1000) x 310</td>
<td>0</td>
<td>0.0241 (1000x1000) x 310</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure B-3:** Page for the calculation for GHG emissions from mobile sources
<table>
<thead>
<tr>
<th>No. of trees planted (unit)</th>
<th>No. of trees removed (unit)</th>
<th>CO₂ removal factor</th>
<th>CO₂ removals in tonnes of CO₂ eq</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>23</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

Figure B-5: Page for the calculation for direct GHG removals from newly planted trees
<table>
<thead>
<tr>
<th>Amount of electricity purchased (in kWh)</th>
<th>Power company (Please select)</th>
<th>Emission factor (kg/kWh)</th>
<th>CO2 removals in tonnes of CO2eq</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>China Light Power (CLP)</td>
<td>0.56</td>
<td>6667.7196</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.7</td>
<td>8584.6495</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note

<table>
<thead>
<tr>
<th>Power company</th>
<th>Power company specific emission factor (kg/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China Light Power (CLP)</td>
<td>0.56 (in 2009)</td>
</tr>
<tr>
<td>Hong Kong Electric (HEC)</td>
<td>0.64 (in 2008)</td>
</tr>
</tbody>
</table>

Figure B-6: Page for the calculation for GHG emissions from electricity purchased from power companies
Table 6

<table>
<thead>
<tr>
<th>Amount of Towngas purchased (Unit$	extsuperscript{3}$)</th>
<th>Emission factor (kg/Unit)</th>
<th>( \div 1000 )</th>
<th>Total tonnes of CO$_2$eq</th>
</tr>
</thead>
<tbody>
<tr>
<td>259645.8333</td>
<td>0.593</td>
<td>( \div 1000 )</td>
<td>163.9699791</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>163.9699791</strong></td>
</tr>
</tbody>
</table>

Note:

1. Each unit registered by gas meter represents that the town gas with a heat value of 48 MJ.
2. Latest GHG emission factor from Towngas company in 2008 = 0.593kg CO$_2$eq/Unit)

Figure B-7: Page for the calculation for GHG emissions from town gas purchased from the town gas company
### Table 7

<table>
<thead>
<tr>
<th></th>
<th>Amount of paper in storage at the beginning of the reporting period (kg)</th>
<th>Amount of paper purchased during the reporting period (kg)</th>
<th>Amount of paper collected for recycling during the reporting period (kg)</th>
<th>Amount of paper in storage at the end of the reporting period (kg)</th>
<th>Emission factor (kg CO₂eq/kg of waste)</th>
<th>/1000</th>
<th>Total tonnes of CO₂eq</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>2608.65</td>
<td>7032</td>
<td>0</td>
<td>3.2</td>
<td>/1000</td>
<td>20.28168</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20.28168</td>
</tr>
</tbody>
</table>

Figure B-8: Page for the calculation for methane generation at landfill in Hong Kong due to disposal of paper waste
<table>
<thead>
<tr>
<th>Amount of water consumed as listed on the water service bill (m²)</th>
<th>Emission factor (kg/km²)</th>
<th>Territory-wide default value (0.7 kg/kWh)</th>
<th>Total tonnes of CO₂eq</th>
</tr>
</thead>
<tbody>
<tr>
<td>175302</td>
<td>x</td>
<td>x</td>
<td>72.1543032</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>72.1543032</td>
</tr>
</tbody>
</table>

Figure B-9: Page for the calculation for GHG emissions due to electricity used for fresh water processing by Water Supplies
Table 9: GHG Emissions due to Electricity Used for Sewage Processing by Drainage Services Department

<table>
<thead>
<tr>
<th>Fresh water consumption (m³)</th>
<th>Source description</th>
<th>Default emission factor (kg/m³)</th>
<th>Emission factor (kg CO₂eq/kWh)</th>
<th>Total tonnes of CO₂eq</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.552</td>
<td>Restaurant and catering services</td>
<td>0.7</td>
<td>0.172</td>
<td>0.009608</td>
</tr>
<tr>
<td>9.1750</td>
<td>Other commercial, residential and institutional purposes</td>
<td>0.7</td>
<td>0.172</td>
<td>15.831</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>15.840608</td>
</tr>
</tbody>
</table>

Table 9: GHG Emissions due to Electricity Used for Sewage Processing by Drainage Services Department

<table>
<thead>
<tr>
<th>Source description</th>
<th>Default emission factor (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restaurant and catering services</td>
<td>(0.7 x Emission Factor) assuming 70% of the fresh water consumed will enter the sewage system</td>
</tr>
<tr>
<td>Other commercial, residential and institutional purposes</td>
<td>(1.0 x Emission Factor) assuming 100% of the fresh water consumed will enter the sewage system</td>
</tr>
</tbody>
</table>

In which: Emission Factor = the emission factor for GHG emissions due to electricity used for processing fresh water derived from the following equation:

Emission Factor = Unit electricity consumption of processing sewage (from DSD) x Territory-wide default value (i.e. 0.7kg/kWh) of purchased electricity.

Figure B-10: Page for the calculation for GHG emissions due to electricity used for sewage processing by Drainage Services Department
<table>
<thead>
<tr>
<th></th>
<th>Percentage (When &quot;GHG Emissions from electricity purchased&quot; was quantified with specific emission factor from the power company)</th>
<th>Percentage (When &quot;GHG Emissions from electricity purchased&quot; was quantified with a territory wide default value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Scope 1 Emissions</td>
<td>0 Tonnes of CO₂ equivalent 0.00% 0.00%</td>
<td>0 Tonnes of CO₂ equivalent 0.00% 0.00%</td>
</tr>
<tr>
<td>Total Scope 1 GHG Removals</td>
<td>0 Tonnes of CO₂ equivalent 0.00% 0.00%</td>
<td>0 Tonnes of CO₂ equivalent 0.00% 0.00%</td>
</tr>
<tr>
<td>Total Scope 2 Emissions</td>
<td>When &quot;GHG Emissions from electricity purchased&quot; was quantified with specific emission factor from the power company 7621 669 Tonnes of CO₂ equivalent 0.00% 0.00%</td>
<td>When &quot;GHG Emissions from electricity purchased&quot; was quantified with a territory wide default value 16:48 8 Tonnes of CO₂ equivalent 0.00% 0.00%</td>
</tr>
<tr>
<td>Total Scope 3 Emissions</td>
<td>When &quot;GHG Emissions from electricity purchased&quot; was quantified with specific emission factor from the power company 37 771 952 Tonnes of CO₂ equivalent 0.00% 0.00%</td>
<td>When &quot;GHG Emissions from electricity purchased&quot; was quantified with a territory wide default value 1915 512 Tonnes of CO₂ equivalent 0.00% 0.00%</td>
</tr>
<tr>
<td>Overall emissions</td>
<td>When &quot;GHG Emissions from electricity purchased&quot; was quantified with specific emission factor from the power company 7099 4625 Tonnes of CO₂ equivalent 0.00% 0.00%</td>
<td>When &quot;GHG Emissions from electricity purchased&quot; was quantified with a territory wide default value 8916 1720 Tonnes of CO₂ equivalent 0.00% 0.00%</td>
</tr>
</tbody>
</table>

Figure B-11: Page for the summary of results for GHG emissions
Table C-1: Summary of equipment requirements from BECs and related codes of practice [18. 33], and audited results

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Criteria</th>
<th>Requirement</th>
<th>Design data</th>
<th>Initial design</th>
<th>Measured results</th>
<th>Audited data</th>
<th>Compliance</th>
<th>Difference from requirement</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC system</td>
<td>1. Chillers</td>
<td>COP&lt;sup&gt;1&lt;/sup&gt;</td>
<td>2.8</td>
<td>2.96</td>
<td>+0.16 (+5.7%)</td>
<td>Yes</td>
<td>N/A&lt;sup&gt;6&lt;/sup&gt;</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>150 Ton Reciprocating air-cooled chillers 1-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>180 Ton Reciprocating water-cooled chillers 1-4</td>
<td>COP</td>
<td>3.9</td>
<td>3.45</td>
<td>-0.45 (-11.5%)</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>2. Pumps</td>
<td>11kW Chilled water pumps</td>
<td>Motor efficiency</td>
<td>≥88.4%</td>
<td>70.2%</td>
<td>-18.2%</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>VSDs&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Employed</td>
<td>No</td>
<td>-</td>
<td>-</td>
<td>No</td>
<td>No</td>
<td>-</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>11kW Condenser water pumps</td>
<td>Motor efficiency</td>
<td>≥88.4%</td>
<td>70%</td>
<td>-18.4%</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>VSDs</td>
<td>Employed</td>
<td>No</td>
<td>-</td>
<td>-</td>
<td>No</td>
<td>No</td>
<td>-</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>3. Cooling towers</td>
<td>5.5kW fan motors</td>
<td>Motor efficiency</td>
<td>≥85.7%</td>
<td>88%</td>
<td>+2.3%</td>
<td>Yes</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>VSDs</td>
<td>Employed</td>
<td>No</td>
<td>-</td>
<td>-</td>
<td>No</td>
<td>No</td>
<td>-</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>4. AHU</td>
<td>1.1kW AHUs</td>
<td>Motor efficiency</td>
<td>≥76.2%</td>
<td>58.6%</td>
<td>-17.6%</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>VSDs</td>
<td>Employed</td>
<td>No</td>
<td>-</td>
<td>-</td>
<td>No</td>
<td>No</td>
<td>-</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>5. PAU</td>
<td>4kW PAUs</td>
<td>Motor efficiency</td>
<td>≥84.2%</td>
<td>69.5%</td>
<td>-14.7%</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>VSDs</td>
<td>Employed</td>
<td>No</td>
<td>-</td>
<td>-</td>
<td>No</td>
<td>No</td>
<td>-</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>6. Exhaust air fans</td>
<td>5.5kW Exhaust air fans</td>
<td>Motor efficiency</td>
<td>≥85.7%</td>
<td>83.8%</td>
<td>-1.9%</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>VSDs</td>
<td>Employed</td>
<td>No</td>
<td>-</td>
<td>-</td>
<td>No</td>
<td>No</td>
<td>-</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>11kW Exhaust air fans</td>
<td>Motor efficiency</td>
<td>≥88.4%</td>
<td>77.8%</td>
<td>-20.6%</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>VSDs</td>
<td>Employed</td>
<td>No</td>
<td>-</td>
<td>-</td>
<td>No</td>
<td>No</td>
<td>-</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>7. Piping system</td>
<td>Friction loss</td>
<td>&lt;400Pa/m</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>8. Air duct</td>
<td>Air duct leakage&lt;sup&gt;3&lt;/sup&gt;</td>
<td>0.009 x p&lt;sup&gt;0.65&lt;/sup&gt;</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Equipment</td>
<td>Criteria</td>
<td>Requirement</td>
<td>Design data</td>
<td>Difference from requirement</td>
<td>Compliance</td>
<td>Audited data</td>
<td>Difference from requirement</td>
<td>Compliance</td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>----------</td>
<td>-------------</td>
<td>-------------</td>
<td>-----------------------------</td>
<td>------------</td>
<td>-------------</td>
<td>-----------------------------</td>
<td>------------</td>
<td></td>
</tr>
<tr>
<td>Lighting system</td>
<td>Max. allowable LPD</td>
<td>17 W/m²</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7.27 W/m²</td>
<td>-9.73 W/m² (-57.2%)</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Averaged illuminance</td>
<td>100 lux</td>
<td>0 lux (0%)</td>
<td>Yes</td>
<td>158 lux (25 pts)</td>
<td>+58 lux (+58%)</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Max. allowable LPD</td>
<td>13 W/m²</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>64 W/m²</td>
<td>+51 W/m² (+392.3%)</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Averaged illuminance</td>
<td>150 lux</td>
<td>0 lux (0%)</td>
<td>Yes</td>
<td>400 lux (9 pts)</td>
<td>+250 lux (+166.7%)</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Ballroom lighting</td>
<td>Max. allowable LPD</td>
<td>23 W/m²</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>39.7 W/m²</td>
<td>+16.7 W/m² (+72.6%)</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Averaged illuminance</td>
<td>300 lux</td>
<td>0 lux (0%)</td>
<td>Yes</td>
<td>225 lux (60 pts)</td>
<td>-75 lux (-25%)</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Function room lighting</td>
<td>Max. allowable LPD</td>
<td>23 W/m²</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>17.9 W/m²</td>
<td>-5.1 W/m² (-22.2%)</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Averaged illuminance</td>
<td>300 lux (for conference)</td>
<td>0 lux (0%)</td>
<td>Yes</td>
<td>136 lux (36 pts)</td>
<td>-164 lux (-54.7%)</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Corridor lighting</td>
<td>Max. allowable LPD</td>
<td>12 W/m²</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5.52 W/m²</td>
<td>-6.48 W/m² (-54%)</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Averaged illuminance</td>
<td>100 lux</td>
<td>0 lux (0%)</td>
<td>Yes</td>
<td>162 lux (16 pts)</td>
<td>+62 lux (+62%)</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Kitchen lighting</td>
<td>Max. allowable LPD</td>
<td>13 W/m²</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>24.9 W/m²</td>
<td>+11.9 W/m² (+91%)</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Averaged illuminance</td>
<td>300 lux</td>
<td>0 lux (0%)</td>
<td>Yes</td>
<td>210 lux (36 pts)</td>
<td>-90 lux (-30%)</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Lift lobby lighting</td>
<td>Max. allowable LPD</td>
<td>15 W/m²</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>86 W/m²</td>
<td>+71 W/m² (+473.3%)</td>
<td>No</td>
<td></td>
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<tr>
<td></td>
<td>Averaged illuminance</td>
<td>200 lux</td>
<td>0 lux (0%)</td>
<td>Yes</td>
<td>330 lux (16 pts)</td>
<td>+130 lux (+65%)</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Switch room lighting</td>
<td>Max. allowable LPD</td>
<td>13 W/m²</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.6 W/m²</td>
<td>-8.4 W/m² (-64.6%)</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Averaged illuminance</td>
<td>200 lux</td>
<td>0 lux (0%)</td>
<td>Yes</td>
<td>260 lux (36 pts)</td>
<td>+60 lux (+30%)</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Reception lighting</td>
<td>Max. allowable LPD</td>
<td>14 W/m²</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.82 W/m²</td>
<td>-9.18 W/m² (-65.6%)</td>
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<td></td>
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<tr>
<td></td>
<td>Averaged illuminance</td>
<td>300 lux</td>
<td>0 lux (0%)</td>
<td>Yes</td>
<td>115 lux (36 pts)</td>
<td>-185 lux (-61.7%)</td>
<td>No</td>
<td></td>
<td></td>
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<tr>
<td>10. Office lighting</td>
<td>Max. allowable LPD</td>
<td>17 W/m²</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>16.31 W/m²</td>
<td>-0.69 W/m² (-4%)</td>
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<tr>
<td></td>
<td>Averaged illuminance</td>
<td>500 lux</td>
<td>0 lux (0%)</td>
<td>Yes</td>
<td>530 lux (36 pts)</td>
<td>+30 lux (+6%)</td>
<td>Yes</td>
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<td></td>
</tr>
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<td>Equipment</td>
<td>Criteria</td>
<td>Requirement</td>
<td>Initial design</td>
<td>Measured results</td>
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<td></td>
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<td>Design data</td>
<td>Difference from requirement</td>
<td>Compliance</td>
<td>Audited data</td>
<td>Difference from requirement</td>
<td>Compliance</td>
<td></td>
</tr>
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<td>11. Staircase lighting</td>
<td>Max. allowable LPD</td>
<td>8 W/m²</td>
<td>-</td>
<td>-</td>
<td>5.5 W/m²</td>
<td>-2.5 W/m² (-31.3%)</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Averaged illuminance</td>
<td>100 lux</td>
<td>100 lux</td>
<td>0 lux (0%)</td>
<td>Yes</td>
<td>105 lux (9 pts)</td>
<td>+5 lux (+5%)</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>12. Guest toilet/washroom lighting</td>
<td>Max. allowable LPD</td>
<td>13 W/m²</td>
<td>-</td>
<td>-</td>
<td>25 W/m²</td>
<td>+12 W/m² (+92.3%)</td>
<td>No</td>
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<td></td>
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<tr>
<td></td>
<td>Averaged illuminance</td>
<td>150 lux</td>
<td>150 lux</td>
<td>0 lux (0%)</td>
<td>Yes</td>
<td>152 lux (25 pts)</td>
<td>+2 lux (+1.3%)</td>
<td>Yes</td>
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</tr>
</tbody>
</table>

**Vertical transportation system**

1. Lifts

<table>
<thead>
<tr>
<th>Lift L1-L6 and A1-A2</th>
<th>Max. allowable running active power</th>
<th>36.1kW</th>
<th>N/A</th>
<th>N/A</th>
<th>N/A</th>
<th>24kW</th>
<th>-12.1kW (-33.5%)</th>
<th>Yes</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Max. THD⁵</td>
<td>22.5%</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>6.8%</td>
<td>-15.7%</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Power factor</td>
<td>0.85</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.6</td>
<td>-0.25</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Motor efficiency</td>
<td>90.5%</td>
<td>55.6%</td>
<td>-34.9%</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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</table>

2. Escalators

<table>
<thead>
<tr>
<th>Escalator E1-E4</th>
<th>Max. allowable running active power</th>
<th>1.615kW</th>
<th>4.5kW</th>
<th>+2.885kW (+178.6%)</th>
<th>No</th>
<th>N/A</th>
<th>N/A</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max. THD</td>
<td>35%</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
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<tr>
<td></td>
<td>Power factor</td>
<td>0.85</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td></td>
<td>Motor efficiency</td>
<td>≥78.5%</td>
<td>75.6%</td>
<td>-2.9%</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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</table>

<table>
<thead>
<tr>
<th>Escalator E5-E6</th>
<th>Max. allowable running active power</th>
<th>1.995kW</th>
<th>5.8kW</th>
<th>+3.805kW (+190.7%)</th>
<th>No</th>
<th>N/A</th>
<th>N/A</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max. THD</td>
<td>35%</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td></td>
<td>Power factor</td>
<td>0.85</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td></td>
<td>Motor efficiency</td>
<td>≥78.5%</td>
<td>77.3%</td>
<td>-1.2%</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
### Table C-1 con’t

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Criteria</th>
<th>Requirement</th>
<th>Initial design</th>
<th>Measured results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td>Design data</td>
<td>Difference from requirement</td>
</tr>
<tr>
<td>Plumbing and drainage system</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Pumps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15kW Fresh water transfer pumps</td>
<td>Motor efficiency</td>
<td>≥ 89.4%</td>
<td>82.7%</td>
<td>-6.7%</td>
</tr>
<tr>
<td></td>
<td>VSDs</td>
<td>Employed</td>
<td>No</td>
<td>-</td>
</tr>
<tr>
<td>1.25kW Roof fresh water booster pumps</td>
<td>Motor efficiency</td>
<td>≥ 76.2%</td>
<td>80%</td>
<td>+3.8%</td>
</tr>
<tr>
<td></td>
<td>VSDs</td>
<td>Employed</td>
<td>No</td>
<td>-</td>
</tr>
<tr>
<td>1.5kW Roof fresh water booster pumps</td>
<td>Motor efficiency</td>
<td>≥ 78.5%</td>
<td>70.6%</td>
<td>-7.9%</td>
</tr>
<tr>
<td></td>
<td>VSDs</td>
<td>Employed</td>
<td>No</td>
<td>-</td>
</tr>
<tr>
<td>2.2kW Hot water pressure pumps</td>
<td>Motor efficiency</td>
<td>≥ 81%</td>
<td>40.9%</td>
<td>-40.1%</td>
</tr>
<tr>
<td></td>
<td>VSDs</td>
<td>Employed</td>
<td>No</td>
<td>-</td>
</tr>
<tr>
<td>15kW Flush water pumps</td>
<td>Motor efficiency</td>
<td>≥ 89.4%</td>
<td>82.7%</td>
<td>-6.7%</td>
</tr>
<tr>
<td></td>
<td>VSDs</td>
<td>Employed</td>
<td>No</td>
<td>-</td>
</tr>
<tr>
<td>4.4kW Sewage pumps</td>
<td>Motor efficiency</td>
<td>≥ 84.2%</td>
<td>78.2%</td>
<td>-6%</td>
</tr>
<tr>
<td></td>
<td>VSDs</td>
<td>Employed</td>
<td>No</td>
<td>-</td>
</tr>
</tbody>
</table>

**Note:**
1. COP refers to “coefficient of performance”.
2. VSD refers to “variable speed drive”.
3. For a static pressure p above 750 to 1000.
4. LPD refers to “light power density”.
5. THD refers to “total harmonic distortion”.
6. N/A refers to “not applicable”.
7. Number of points measured, ps refers to “points”.
Appendix D

Table D-1: Lamps and luminaires used in the functional areas investigated

<table>
<thead>
<tr>
<th>Luminaire designation (Designation assigned to each luminaire used in each functional area)</th>
<th>Lamp code</th>
<th>Nominal lamp wattage ( [L_w] ) (lamp only)</th>
<th>Luminous efficacy ( [L_e] ) (manufacturer data)</th>
<th>Luminous efficacy ( [L_e] ) ( \text{Minimum allowable value} )</th>
<th>No. of lamps per luminaire</th>
<th>No. of ballasts per luminaire</th>
<th>Power consumption per luminaire (lamp + ballast) ( [\text{CW}] )</th>
<th>Circuit wattage ( [\text{W}] )</th>
<th>Maximum allowable value ( [\text{W}] )</th>
</tr>
</thead>
<tbody>
<tr>
<td>GR1</td>
<td>TH</td>
<td>20</td>
<td>20</td>
<td>15</td>
<td>1</td>
<td>1</td>
<td>24</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>GR2</td>
<td>CFG</td>
<td>11</td>
<td>67</td>
<td>50</td>
<td>1</td>
<td>1</td>
<td>13</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>GR3</td>
<td>GLS</td>
<td>60</td>
<td>10.5</td>
<td>2</td>
<td>N/A²</td>
<td>2</td>
<td>120</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>GR4</td>
<td>CFG</td>
<td>20</td>
<td>67</td>
<td>50</td>
<td>1</td>
<td>1</td>
<td>(22)³</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>GBR1</td>
<td>MCF T8</td>
<td>36</td>
<td>93</td>
<td>75</td>
<td>2</td>
<td>1</td>
<td>(80)</td>
<td>69.1*¹</td>
<td></td>
</tr>
<tr>
<td>GBR2</td>
<td>GLS</td>
<td>80</td>
<td>15</td>
<td>15</td>
<td>1</td>
<td>1</td>
<td>N/A</td>
<td>80</td>
<td>N/A</td>
</tr>
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<td>BR1</td>
<td>TH</td>
<td>20</td>
<td>20</td>
<td>15</td>
<td>1</td>
<td>1</td>
<td>24</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>BR2</td>
<td>GLS</td>
<td>40</td>
<td>10.25</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>40</td>
<td>N/A</td>
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</tr>
<tr>
<td>FR1</td>
<td>MCF T8</td>
<td>28</td>
<td>91</td>
<td>75</td>
<td>2</td>
<td>1</td>
<td>(64)</td>
<td>53.3</td>
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<td>FR2</td>
<td>TH</td>
<td>20</td>
<td>20</td>
<td>15</td>
<td>1</td>
<td>1</td>
<td>24</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>GLS</td>
<td>40</td>
<td>10.25</td>
<td>40</td>
<td>1</td>
<td>1</td>
<td>40</td>
<td>N/A</td>
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<tr>
<td>K1</td>
<td>MCF T5</td>
<td>14</td>
<td>(83)</td>
<td>97</td>
<td>3</td>
<td>1</td>
<td>(47)</td>
<td>46.6</td>
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<td>MCF T5</td>
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<td>104</td>
<td>97</td>
<td>2</td>
<td>1</td>
<td>(64)</td>
<td>62.1</td>
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<tr>
<td>K3</td>
<td>MCF T8</td>
<td>36</td>
<td>93</td>
<td>75</td>
<td>2</td>
<td>1</td>
<td>(80)</td>
<td>69.1*¹</td>
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<td>K4</td>
<td>GLS</td>
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<td>N/A</td>
<td>100</td>
<td>N/A</td>
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<td>LL1</td>
<td>TH</td>
<td>26</td>
<td>20</td>
<td>15</td>
<td>1</td>
<td>1</td>
<td>24</td>
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<tr>
<td>LL2</td>
<td>GLS</td>
<td>40</td>
<td>10.25</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>40</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>SR1</td>
<td>MCF T5</td>
<td>28</td>
<td>104</td>
<td>97</td>
<td>1</td>
<td>1</td>
<td>32</td>
<td>32</td>
<td></td>
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<td>LED</td>
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<td>32.5</td>
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<td>1</td>
<td>8</td>
<td>N/A</td>
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<td>TH</td>
<td>20</td>
<td>20</td>
<td>15</td>
<td>1</td>
<td>1</td>
<td>24</td>
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<tr>
<td>O1</td>
<td>MCF T5</td>
<td>28</td>
<td>104</td>
<td>97</td>
<td>2</td>
<td>1</td>
<td>(64)</td>
<td>62.1</td>
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<tr>
<td>ST1</td>
<td>MCF T5</td>
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<td>(83)</td>
<td>97</td>
<td>1</td>
<td>1</td>
<td>(17.5)</td>
<td>17</td>
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<td>20</td>
<td>15</td>
<td>1</td>
<td>1</td>
<td>24</td>
<td>N/A</td>
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</tbody>
</table>

Note: 1. Lamp codes are defined in Table D-2.
2. N/A refers not applicable.
3. Values in brackets could not satisfy the allowable value stated in the Code of Practice for Energy Efficiency of Lighting Installations.
4. * By extrapolation of the requirement stated in the Code of Practice for Energy Efficiency of Lighting Installations, the charts and equations generated for extrapolation is shown in Appendix E.
Table D-2: Lamp codes used in Appendix D

<table>
<thead>
<tr>
<th>Lamp code</th>
<th>Lamp type</th>
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<tbody>
<tr>
<td>MCF T5</td>
<td>T5 Tubular fluorescent lamp</td>
</tr>
<tr>
<td>MCF T8</td>
<td>T8 Tubular fluorescent lamp</td>
</tr>
<tr>
<td>CFG</td>
<td>Compact fluorescent lamp (type complete with built-in controlgear)</td>
</tr>
<tr>
<td>TH</td>
<td>Tungsten halogen lamp</td>
</tr>
<tr>
<td>GLS</td>
<td>Tungsten filament lamp</td>
</tr>
<tr>
<td>LED</td>
<td>Light Emitting Diode (LED)</td>
</tr>
</tbody>
</table>
Appendix E

Charts and equations generated for extrapolation the maximum allowable ballast-lamp circuit power stated in the Code of Practice for Energy Efficiency of Lighting Installations.

(a) T8 linear fluorescent lamps

(i) Chart and equation for extrapolation

![Graph showing maximum allowable power consumption vs rated lamp power at 50Hz. The equation is y = 0.9226x + 2.7188.](image)

Figure E-1: Maximum allowable power consumption for T8 linear fluorescent lamps

(ii) Maximum allowable ballast-lamp circuit power stated in the Code of Practice for Energy Efficiency of Lighting Installations (Points shown in the chart for extrapolation)

<table>
<thead>
<tr>
<th>Rated lamp power at 50Hz (W)</th>
<th>Maximum allowable power consumption (maximum input power of ballast-lamp circuit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>11</td>
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<td>13</td>
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<td>38</td>
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<tr>
<td>58</td>
<td>55</td>
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Appendix F

Table F-1: Lighting power densities in inspected functional areas

<table>
<thead>
<tr>
<th>Floor</th>
<th>Name of space</th>
<th>Area [A]</th>
<th>Calculated illuminance (m²)</th>
<th>Designation</th>
<th>Quantity [N]</th>
<th>Circuit wattage [CW] (from Form Appendix C) [W]</th>
<th>Calculated LPD (W/m²)</th>
<th>Maximum allowable LPD (W/m²)</th>
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<tbody>
<tr>
<td>10/F</td>
<td>Guest room (exclude bathroom)</td>
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Note: 1. Values in brackets could not satisfy the maximum allowable value stated in the Code of Practice for Energy Efficiency of Lighting Installations.