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Carbon footprints of hotels: Analysis of three archetypes in Hong Kong

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Abstract:

The need of curbing greenhouse gas (GHG) emissions, especially those arising from operations in existing buildings, has been well-recognized. Incessant hotel operations, in particular, result in significant GHG emissions. Given the limited in-depth findings about the emissions from hotels of different classes, a study was conducted to probe into the carbon footprints of three typical hotels in Hong Kong. Through face-to-face meetings, detailed and reliable data under scopes 1, 2, and 3 of the GHG Protocol were collected for analysis. The emission levels, when normalized by number of guestrooms, were different from those normalized by floor area. Use of purchased electricity was the dominant contributor to the emissions; emissions from use of portable liquefied petroleum gas and emergency operation of power generator were negligible. Reference levels of emissions due to staff daily travels were determined. The hotels' emissions bore a strongly positive correlation with outdoor air temperature rather than occupancy rate. Regression models that can estimate the hotels' emissions with changes in outdoor temperature were developed. Recommendations were made to tackle the problems with recording the necessary data and mitigate the emissions from the hotels. Wider adoption of the methodology of this study can establish carbon emission benchmarks, which are essential for monitoring and optimizing the carbon footprints of hotels.

Keywords:

Building operation; carbon footprint; greenhouse gas; Hong Kong; hotel; sustainable environment.

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1. Introduction

Resources utilization during the long operational stage of buildings gives rise to enormous greenhouse gas (GHG) emissions, which are central to the global warming problem. To tackle this problem for attaining a sustainable built environment, it is essential to assess the environmental performance of buildings (Dakwale et al., 2011), especially the huge volume of existing buildings.

Recognizing the need of monitoring GHG emissions, there has been a growing trend of enforcing mandatory schemes on reporting of GHG emissions (Lai, 2013). Examples around the world include: GHG Emission Reporting Scheme in Canada, Mandatory GHG Accounting and Reporting System in Japan, National Greenhouse and Energy Reporting Scheme in Australia, and Mandatory Reporting GHG Rule in the US (Kauffmann et al., 2012).

In other places such as Hong Kong, however, reporting of GHG emissions remains voluntary. The first set of guidelines on quantification of carbon emissions from buildings was launched in 2008 (Environmental Protection Department & Electrical and Mechanical Services Department, 2008) and implementation of carbon audits has not been common. But according to the latest available statistics (Environmental Protection Department, 2012), the total GHG emissions in Hong Kong amounted to 42,900 kilotonnes CO_2-e in year 2009, or 6.1 tonnes per capita, representing a significant increase of 22% from the level of year 1999 (5.0 tonnes per capita).

Given the round-the-clock operations of hotels, their resources consumptions are intensive and so are their GHG emissions. Studies on this area have grown in recent years. For instance, Taylor et al. (2010) used computer simulations to study the feasibility of reducing the emissions from hotels in the UK. In a benchmarking study in Singapore (Wu et al., 2010), surveyed data of some hotels were analysed to determine their emission levels. Earlier in Hong Kong, a case study was conducted to audit the emissions from a hotel (Lai et al., 2012). But research that analyses and compares the emissions from different classes of hotels is yet to be seen. Therefore, a research project was carried out to probe into the GHG emissions from hotels of three different grades and analyse their carbon footprints in a comparative manner.

In the next section, the scope of the study, the process of data collection, and the types of data collected are described. Then, analyses of the data, which reveal the characteristics of the hotels and the comparative findings about their emission levels, are reported. Based on the data collection experience and the analysed findings, recommendations that can minimize the carbon emissions from the hotels are made. Finally, the conclusions drawn from the study and the further works needed are given.

2. Scope and Data Collection

To start with, it is vital to define the boundary of carbon footprint the study covered (Matthews et al., 2008). With reference to the GHG Protocol (World Resources Institute & World Business Council for Sustainable Development, 2004) and the International Standard on Greenhouse Gases (ISO 14064-1), the Environmental Protection Department and the Electrical and Mechanical Services Department of the

Hong Kong government jointly formulated a guidance document to facilitate accounting for GHG emissions/removals from buildings. Following the latest version of such document (Environmental Protection Department & Electrical and Mechanical Services Department, 2010), the scopes of emissions studied, namely direct emissions/removals (scope 1), energy indirect emissions (scope 2), and other indirect emissions (scope 3), are listed in Table 1.

Prior to data collection, the study team convened a briefing during which the purpose, scope, work plan, and expected outcome of the study were outlined. Afterwards, the study team visited the hotels, walked through their key and typical areas, and met with the hotels' representatives. After the representatives briefed about the operations of their hotels, the study team explained to them the contents of two electronic templates which were tailored for collecting the required data.

The initial part of the first template solicited the physical and operational characteristics of the hotels: grading; age; numbers of floors and guestrooms; occupancy rate; number of employees; total construction floor area; and areas of places including guestrooms and food and beverage outlets. The remaining parts requested for the following types of data of the preceding 12 months: a) diesel oil consumption (e.g. for emergency power generation); b) amount of fuels consumed by mobile combustion sources (e.g. transport service provided for hotel staff); c) inventory levels of refrigerants and amounts of refrigerants added and removed; d) quantity and height of trees planted or removed; e) electricity consumptions and metered readings of electricity used; f) gas consumptions and metered readings of gas used; g) inventory levels of paper and amounts of paper used and collected for recycling; and h) water consumptions and metered readings of fresh water used.

To save their time from entering the voluminous data into the template, the representatives were encouraged to provide the relevant documentations from which the required data can be retrieved. They included: i) operation and maintenance (O&M) logbooks of emergency power generator and boiler; ii) records of types, quantities and mileages of vehicles provided as transport service for hotel staff/guests; iii) O&M logbooks of equipment using refrigerants; records of horticulture and gardening work; iv) electricity bills and logbooks recording metered readings of electricity consumptions; v) gas bills and logbooks recording metered readings of gas consumptions; vi) inventory records of paper for office use; records of orders issued for purchase of paper for office use; vii) records of orders issued for collection of paper for recycling; viii) records of orders issued for providing newspapers, magazines, etc. for hotel staff/guests; and ix) water bills and logbooks recording metered readings of water consumptions.

In order to collect data about the transportations used by the hotels' staff, the second template was prepared. It was designed to request the staff to fill in information about the means of transportation they typically used for travelling between their residence and their workplace, the transportation routes, and the corresponding transportation costs. In view of the large number of staff involved and for ensuring the collection of reliable data, the management of each hotel distributed the template to its staff members and asked them to complete and return the templates in person.

3. Data Analysis and Findings

3.1 Characteristics of the hotels

Being representative of their respective class of hotels in Hong Kong, Hotel A was of the highest grade (5-star), Hotel C was a 3-star business hotel, and the quality of Hotel B was between those of Hotels A and C (Table 2). The building accommodating Hotel A was the oldest. Hotel B, in contrast, was newly occupied at the time of the study.

Whereas the differences in the heights of the three hotel buildings were not substantial, Hotel A, which was the biggest in area, was more than six times bigger than Hotel C. When measured by number of guestrooms, the scale of Hotel A was also the largest, exceeding over three times the scale of Hotel C. During the reporting period, the mean occupancy rates of the hotels were relatively high, with that of Hotel C being the highest.

Given the grade and scale of Hotel A, there were five food and beverage (F&B) outlets. Although Hotel B had the same number of such outlets, the aggregate area of those in Hotel A was much bigger and, as compared to that of Hotel C, was near to four-fold. For meeting great demands of guest and F&B services, Hotel A employed more than four times the employees of Hotel C.

3.2 Quantification of GHG emissions

The procedures taken for quantifying the amounts of GHG emissions from the hotels, consolidated based on the guidelines of the Environmental Protection Department & Electrical and Mechanical Services Department (2010) and the University of Hong Kong (2010), are outlined in the following.

3.2.1 Scope 1

To determine the amount of carbon dioxide (CO_2) emission due to stationary and mobile sources of fuel combustions, the relevant data of the amounts of fuel combusted were processed using equation (1). Similarly, the amounts of methane (CH_4) and nitrous oxide (N_2O) emissions from such fuel combustions were calculated using equations (2) and (3). Based on the record data of refrigerants used in the hotels, the amounts of sulphur hexafluoride (SF_6), hydrofluorocarbon (HFC) and perfluorocarbon (PFC) emissions were calculated using equations (4) to (6). Instead of GHG emissions, the amounts of CO_2 removed by planting additional trees were quantified by Equation (7), which entails input of data including number of trees planted at the hotels, estimated carbon removal factor and length of reporting period.

$$E^{C}_{CO_2} = \sum_{f=1}^{f=F} \sum_{t=1}^{t=T} A_{f,t} \times F_{(CO_2)f} \quad (1)$$

$$E^{C}_{CH_4} = \sum_{f=1}^{f=F} \sum_{t=1}^{t=T} A_{f,t} \times F_{(CH_4)f} \times G_{(CH_4)} \quad (2)$$

$$E^{C}_{N_2O} = \sum_{f=1}^{f=F} \sum_{t=1}^{t=T} A_{f,t} \times F_{(N_2O)f} \times G_{(N_2O)} \quad (3)$$

$$E^{R}_{SF_6} = \sum_{r=1}^{r=R} (A_{r[s]} + A_{r[i]} - A_{r[d]} - A_{r[e]}) \times G_r \quad (4)$$

$$E^{R}_{HFC} = \sum_{r=1}^{r=R} (A_{r[s]} + A_{r[i]} - A_{r[d]} - A_{r[e]}) \times G_r \quad (5)$$

$$E_{PFC}^{R} = \sum_{r=1}^{r=R} (A_{r[s]} + A_{r[a]} - A_{r[d]} - A_{r[e]}) \times G_r \tag{6}$$

$$R_{CO_2} = N \times R \times T \tag{7}$$

3.2.2 Scope 2

Referring to the amount of electricity purchased from the relevant power company (i.e. Hong Kong Electric Company or China Light & Power Company) during the reporting period, the corresponding amount of carbon emission was determined by equation (8). Likewise, the amount of emission due to the use of gas (i.e. towngas supplied by Hong Kong and China Gas Company) was calculated using equation (9).

$$E_{CO_2}^{E} = \sum_{t=1}^{t=T} A_{(E)t} \times F_{(E)t} \tag{8}$$

$$E_{CO_2}^{G} = \sum_{t=1}^{t=T} A_{(G)t} \times F_{(G)t} \tag{9}$$

3.2.3 Scope 3

To quantity the generation of CH_4 at landfill due to disposal of paper waste, a range of record data were required, including the inventory of paper at the beginning and the end of the reporting period and the amounts of paper added and collected for recycling. Such data were input to equation (10) to compute the amount of CH_4 generated. Based on the fresh water consumptions, the amounts of CO_2 emitted due to the use of electricity for processing the fresh water consumed were determined by equation (11). Similarly, those emitted due to use of electricity for processing the resultant sewage were calculated by equation (12), where the default emission factor is dependent on whether the water was used by restaurants or for catering services (equation (13)).

Another group of activities under scope 3 were staff travels. Equation (14) enables quantification of CO_2 emission if data about travel distances of the transportations taken by the staff of the hotels are available. Since it was not feasible to obtain such data, equation (15), which requires the input of cost data of the relevant transportations, was used to determine the amounts of CO_2 emitted due to daily travels of the staff. Finally, based the record information of overseas travels of the hotel staff, the corresponding CO_2 emissions were calculated using equation (16).

$$E_{CH_4}^{P} = \sum_{p=1}^{p=P} (A_{p[s]} + A_{p[a]} - A_{p[r]} - A_{p[e]}) \times F_p \quad (10)$$

$$E_{CO_2}^{W} = \sum_{t=1}^{t=T} A_{(W)t} \times F_{(W)t} \quad (11)$$

$$E_{CO_2}^{S} = \sum_{t=1}^{t=T} A_{(W)t} \times F_{D|(W)t} \quad (12)$$

$$F_{D|(W)_t} = C_a \times F_{(S)t} \quad (13)$$

$$E_{CO_2}^{tr} = \sum_{s=1}^{s=S} \sum_{tr=1}^{tr=TR} D_{s,tr} \times F_{tr|D} \quad (14)$$

$$E_{CO_2}^{tr} = \sum_{s=1}^{s=S} \sum_{tr=1}^{tr=TR} C_{s,tr} \times F_{tr|C} \quad (15)$$

$$E_{CO_2}^{fl} = \sum_{s=1}^{s=S} D_{s,fl} \times F_{fl} \times F_{B/E} \quad (16)$$

3.3 GHG emissions of the hotels

Covering the three scopes in Table 1, the annual total emissions (in carbon dioxide equivalent; CO_2-e) of the hotels were: 9,619 tonnes (Hotel A), 7,078 tonnes (Hotel B), and 2,219 tonnes (Hotel C). The peaks of their monthly emissions were in the summertime; those of both Hotel A and Hotel C appeared in August and the emission from Hotel B peaked in July (Figure 1).

To allow making fair comparisons between the emissions from the hotels, the amounts of emissions were normalized by their scale, the proxies of which being total floor area and number of guestrooms. The monthly emissions calculated in this way, as graphed in Figure 2, show that the emission levels of Hotel A, when normalized by number of guestrooms, were all above the counterparts of the other two hotels. Yet the peaks of such levels (in tonnes/room), 1.94 for Hotel A and 1.92 for Hotel C, were very close.

An inspection on the emission levels normalized by total floor area (in tonnes/m^2), on the other hand, unveiled that the carbon footprints of Hotel C, which ranged between 0.017 in February and 0.037 in August, were in fact the largest among the hotels. On average, the monthly emission from Hotel C was 0.024 tonne/m^2, which was significantly more than the mean levels of Hotel A (0.015) and Hotel B (0.014). The annual profiles of the latter two, as Figure 2 shows, were highly similar.

Table 3 summarizes the proportions of various sources of carbon emissions from the hotels. Common to all of them, use of purchased electricity was the dominant source (87.34% to 93.38%). In contrast, the emissions produced due to the use of diesel oil for the hotels' power generators were negligible because such generators were not demanded for emergency operation during the reporting period but were only test-run for 30 minutes a month in order to comply with the statutory maintenance requirement. Disregarding the emission from such occasional operations, the proportion of emission due to consumption of portable liquefied petroleum gas (LPG) was the least (0.04%) for Hotel B and even none for Hotel C as no cylinder LPG was used there.

Since Hotel B had been occupied for one year only, the refrigerant in its chiller plant were yet to be replaced. Without the release of refrigerant, there was no GHG emission in this connection. For Hotel C, the emission due to business travels could not be determined because the relevant information was not recorded.

Other than electricity, water and gas are two sources of utilities whose consumptions are typically substantial and thus a key operating cost element of hotels (Lai & Yik, 2008). Since pumping water to the hotels and processing their sewage discharge were handled by the central systems of the Water Supplies Department and the Drainage Services Department of the government, the associated amounts of electricity consumptions were optimized by taking advantage of the large scale of electricity used by the central systems. As a result, the corresponding carbon emissions from the hotels were minimal, lying between 0.60% and 1.19%.

The proportions of carbon emissions arising from consumption of gas, for cooking in the F&B outlets and for hot water heating purposes, ranged from 2.62% to 3.66%. The peaks of such emissions from Hotel A (33.1 tonnes) and Hotel C (8.2 tonnes) were found with the coolest month (January) during which the demand for hot water heating was great. Whereas the emission from Hotel B in the same period was high

(19.8 tonnes), its peak level (20.2 tonnes) occurred in March. On the other hand, the troughs of this kind of emissions occurred in the summer period: June (Hotel B), August (Hotel A), and September (Hotel C). The annual profiles of the emissions, normalized by number of guestrooms and total floor area, are shown in Figure 3.

Although the proportion of emission due to staff daily travel ranked third among the various categories of emissions, the transportation data provided by the large number of hotel staff - 304, 275 and 107 from Hotels A, B and C respectively - warrant further analysis.

In Table 4, a summary of the emissions due to staff daily travels is shown, including the fractions of staff taking different types of transportation for travelling between their home and their workplace, and the corresponding average amounts of carbon emission per staff. Common to the three hotels, most of their staff took the mass transit railway (MTR) or buses for their daily travels. While tram was not a transportation means used by any of the respondents of Hotels A and B, a large proportion of the staff of Hotel C travelled by tram given its close proximity to a main tram station. As for mini-buses, their use by the staff was not popular. Travelling by taxi, ferry, or driving was even rare.

The amounts of carbon emission per staff due to travelling by MTR were 0.239 kg or less, which were generally the lowest among the various transportation means. The emissions associated with travelling by bus were higher and the counterparts of mini-bus were even up to 1.090 kg. Despite the uncommon use of taxi by the staff, its carbon emission levels pertaining to Hotels A and B were much higher than the levels of the preceding means of transportation. While the use of ferry was also uncommon, the associated per-capita emission level far outweighed the levels of the other means.

3.4 Regression analysis of the emissions

The monthly occupancy rates of the hotels, as noted from the data collected, varied from time to time. Whereas the rates of Hotel A in the first two months of the reporting period were not provided for analysis, those in the remaining period ranged from 75.8% (May) to 87.7% (July). The range of the rates of Hotel B was wider, between 63.6% (May) and 94.0% (August); the counterpart of Hotel C lied between 75.3% (September) and 96.7% (July). These observations led to the hypothesis that fluctuation in occupancy rates may cause variations in the volume of resources used for serving the hotel patrons. This, in turn, may affect the amounts of carbon emission from the hotels.

Energy use of air-conditioning systems is known to be positively correlated with outdoor air temperature (e.g. Yik et al., 1998). As Table 3 shows, carbon emission due to electricity consumption prevailed over the other categories of emissions. Moreover, air-conditioning system is a dominant energy consumer in buildings. Hence, it was hypothesized that there exists a correlation between the amount of carbon emissions from the hotels and outdoor air temperature.

For testing the above hypotheses, a multiple regression model as shown by equation (17) was used, where y denotes monthly total carbon emission (E_T) from the hotels, variables x_1 and x_2 denote monthly occupancy rate (O_R) and monthly mean outdoor air temperature (T_O) respectively, β_0 is the intercept of the regression equation, β_1 and β_2 are the coefficients of the variables, and ε is a random variable. The values of T_O were obtained from the record of the Hong Kong Observatory.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon \quad (17)$$

$$E_{T,A} = 122.25 + 2.77 \times O_{R,A} + 19.74 \times T_O \quad (18)$$

$$E_{T,B} = 103.24 + 2.14 \times O_{R,B} + 13.46 \times T_O \quad (19)$$

$$E_{T,C} = -71.78 + 1.02 \times O_{R,C} + 7.34 \times T_O \quad (20)$$

$$E_{T,A} = 346.20 + 19.81 \times T_O \quad (21)$$

$$E_{T,B} = 249.86 + 14.60 \times T_O \quad (22)$$

$$E_{T,C} = 8.99 + 7.65 \times T_O \quad (23)$$

The regression statistics, including the values of multiple coefficient of determination (R^2), F test, and the coefficients and p-values of the variables, are summarized in Table 5. As evidenced by the large R^2 values, the estimated multiple regression equations can explain most of the variability in the carbon emissions from the hotels: 88.9% (Hotel A), 85.3% (Hotel B), and 81.7% (Hotel C). With a level of significance $\alpha = 0.01$, the significance F values show that a significant relationship existed in the multiple regression equations for the three hotels. Hence, the relationships among total carbon emission, outdoor air temperature and occupancy rate of Hotels A, B and C can be represented by Equations (18), (19) and (20), respectively.

Scrutinizing the p-values found that the hotels' total carbon emissions had significant correlations with the outdoor air temperatures but not with their occupancy rates. In view of this finding, scatter plots of the monthly total carbon emissions against the monthly occupancy rates were prepared, as shown in Figure 4. The small R^2 values (0.028 to 0.233) indicate that there were no significant correlations between the total emissions and the occupancy rates, and neither were there any significant correlations (R^2 = 0.010 to 0.220) between the latter and the carbon emissions resultant from the hotels' electricity consumptions. Suggested reasons for these findings are: i) the relationship between these parameters could not be represented by a simple linear regression; ii) the amounts of resources used for running the hotels, and hence their carbon emissions, were not sensitive to changes in occupancy rate; and iii) the range of occupancy rates the analysis covered was not wide enough to illustrate the sensitivity of the carbon emissions. Verification of such suggestions, which was beyond the scope of the present study, requires further studies to be undertaken in future.

Plotting the monthly carbon emissions of the hotels against the monthly mean outdoor air temperatures, as shown in Figure 5(a), reveals the existence of strongly positive correlations between them. For Hotel A, for instance, its total carbon emissions were strongly and positively correlated with the outdoor air temperatures (R^2 = 0.890). The carbon emissions due to electricity consumption of Hotel C exhibited an even stronger positive correlation with the temperatures (R^2 = 0.917). Based on this group of findings, equations (21) to (23) were constructed, which can be used for estimating the carbon emissions from the hotels based on outdoor air temperatures.

The relationships between the normalized carbon emissions and the mean outdoor temperatures were further examined. The plots in Figure 5(b) show that when normalized by number of guestrooms, the emissions from Hotel B were the highest, followed by those of Hotel A, and Hotel C. But the order of the emissions became different when referring to Figure 5(c), where the emissions normalized by floor area were plotted against the outdoor temperatures. Coincidentally, the fitted line for the normalized emissions due to electricity consumptions of Hotel A is almost congruent with that for the normalized total emissions from Hotel B.

4. Recommendations

Based on the observations during the data collection process and the findings from the above analyses, some limitations of the study were identified. A series of recommendations, which can help overcome these limitations and are conducive to reducing the carbon footprints of the hotels, are described in the following.

For Hotel A, data of transport services provided for the hotel guests from November to March and business travels of the hotel staff in November and December were not available. For Hotel B, similarly, record data of transport services provided for the hotel guests in November were missing. Same for the three hotels, inventory levels of paper at the beginning and the end of the reporting period were not recorded. Although the expected amounts of GHG emissions associated with these outstanding data are negligible as compared to the dominant emissions due to electricity and gas consumptions (Table 3), complete records of such data should be kept in proper order.

It was known from the on-site meeting that some staff of Hotel C had to travel by ship to attend business functions such as meetings, but data of such travels were not available. While the contribution of carbon emission due to such business activities should be minor (Table 3), a proper record of the relevant travel data is needed.

Many of the regular staff (54.3%: Hotel A; 74.7%: Hotel B; 97.3%: Hotel C) were cooperative enough to provide their daily travel information, based on which the total GHG emission due to staff travels was determined in proportion. The amounts of such emissions were comparatively small (Table 3). But for obtaining a more exact quantification of the emissions, the rest of the regular staff and the casual labor should provide their travel information.

Without on-site laundry facilities, the laundry services for the three hotels were outsourced. The emissions from these services, belonging to scope 3 of the GHG Protocol, were not included in the scope of the study as the guidelines (Environmental Protection Department & Electrical and Mechanical Services Department, 2010) provide that reporting of such emissions is optional. Indeed, more specific guidance is needed for quantification of scope 3 emissions (Huang et al., 2009). Record information about the laundry services, if made available, can help reveal more complete carbon footprints of the hotels (Filimonau et al., 2011).

In Hotel B, refrigerants R134A and R404 were used. While understanding that replacement of refrigerants for the new chillers was not yet required at the time of the study, proper inventory records of the refrigerants should be maintained. In Hotel C, refrigerant R22, a kind of HCFC having a global warming potential (GWP) of 1810, was used. Even though only 27.27 kg of such refrigerant was purchased during the reporting period, its high GWP value has resulted in 2.22% of the emissions.

According to the Environmental Protection Department (EPD), the government commits to compliance with the developed parties' requirements on protection of the ozone layer (under the Montreal Protocol). The EPD has implemented a licensing quota system for HCFCs and would reduce their consumption in a step-wise fashion over time beginning 1 January 2004 to a complete phase-out in 2030. Given the use of HCFCs is only an interim solution, it is recommended to develop a long-term management plan for the HCFC air-conditioning and refrigeration system in Hotel C. This plan may include, for example, retrofitting the existing HCFC system for use with non-ozone-depleting substitutes, or providing proper servicing to the system to avoid refrigerant leakage.

There were sub-metered readings of water consumptions for different floors of Hotel C, but the water consumptions of its F&B outlets were not monitored. Without such data, the GHG emission due to sewage processing (activity-dependent factor C_a being 0.7 instead of 1.0) could not be computed in an accurate manner. Dedicated sub-meters monitoring the water consumptions of the outlets are needed in order to provide the respective consumption data, which are essential for pursuing a more detailed carbon footprint analysis.

Collection of paper for recycling was not practiced in Hotels A and C. It is recommended to implement this environmental-friendly practice so as to help minimize the GHG emission due to use of paper in the hotel. Common to the three hotels, no trees were planted over the reporting period and so there was no removal of GHG emission. Planting of trees at places such as roofs and podiums of the hotels can help reduce their carbon footprints.

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5. Conclusions

The GHG emissions from three representative hotels in Hong Kong, quantified in carbon dioxide equivalent, were analyzed in detail. The comparisons made between the carbon footprints of the hotels unveiled that normalization of the emission levels by different parameters, namely number of guestrooms and floor area, led to different comparison results. This is an important point that should be considered in interpreting comparison results of carbon emissions from hotels.

Electricity consumption was the dominant source of carbon emission. Efforts on reducing the carbon footprints of the hotels, therefore, should be focused on minimizing the use of electricity. In order to find out whether, and to what extent the use of electricity was efficient, it is necessary to carry out detailed energy audits for the hotels.

Despite the relatively small proportion of carbon emission due to daily travels of the hotel staff, the per-capita emission levels of the various transportation means, which were derived from a large sample of the staff, can serve as references in estimating the same kinds of emissions from other similar hotels.

Under the current guidelines (Environmental Protection Department & Electrical and Mechanical Services Department, 2010), it is optional to report carbon emissions belonging to scope 3. An example of this category is the laundry services in the hotels, which were provided by outsourced contractors beyond the physical boundary of the hotel buildings. In order to identify the amount and significance of carbon emissions from this kind of services and others such as outsourced operation and maintenance works (Lai et al., 2008), the relevant data should be recorded.

As revealed by the regression analyses, the carbon emissions of the hotels bore a strongly positive correlation with the outdoor air temperatures but not with their occupancy rates. Since the levels of the latter were on the high side and their ranges were rather narrow, further investigations are needed to study the relationship between carbon emissions and a wider range of occupancy rates. The regression models developed from this study, nevertheless, can be used to estimate the hotels' carbon emissions with respect to variations in outdoor temperatures.

The experience gained from the data collection process underscored the effort needed in gathering a broad range of detailed data for quantification of the carbon emissions. Besides keeping proper record of the required data, measures that can mitigate the emissions, including use of environmentally friendly refrigerants, installation of sub-meters for monitoring utilities consumptions, collection of paper for recycling and planting of trees, need to be implemented.

Drawn on the result of this research project, its methodology can be taken to further investigate the carbon footprints of more existing hotels, including not only those locally but also the others elsewhere. When more study findings of this kind are available, representative emission benchmarks can be established, which will help monitor and optimize the carbon footprints of hotels for attaining a sustainable built environment.

Notation

$A_{(E)t}$ = amount (kWh) of electricity used in the t^{th} period
$A_{f,t}$ = amount (litre) of the f^{th} type of fuel used in the t^{th} period
$A_{(G)t}$ = amount (unit; 1 unit = 48 MJ) of gas used in the t^{th} period
$A_{p[a]}$ = amount (kg) of the p^{th} type of paper added to the inventory during the reporting period
$A_{p[e]}$ = inventory (kg) of the p^{th} type of paper at the end of the reporting period (in storage)
$A_{p[r]}$ = amount (kg) of the p^{th} type of paper collected for recycling during the reporting period
$A_{p[s]}$ = inventory (kg) of the p^{th} type of paper at the beginning of the reporting period (in storage)
$A_{r[a]}$ = amount (kg) of the r^{th} type of refrigerant added to the inventory during the reporting period
$A_{r[d]}$ = amount (kg) of the r^{th} type of refrigerant disposed of through environmentally responsible means during the reporting period
$A_{r[e]}$ = inventory (kg) of the r^{th} type of refrigerant at the end of the reporting period (in storage, not equipment)
$A_{r[s]}$ = inventory (kg) of the r^{th} type of refrigerant at the beginning of the reporting period (in storage, not equipment)
$A_{(W)t}$ = amount (m^3) of fresh water used in the t^{th} period
C_a = activity-dependent factor (0.7 for restaurants and catering services; 1.0 for other commercial, residential and institutional purposes)
$C_{s,tr}$ = cost paid by the s^{th} staff for taking the tr^{th} type of transportation
$D_{s,fl}$ = flight travel distance of the s^{th} staff
$D_{s,tr}$ = travel distance of the s^{th} staff taking the tr^{th} type of transportation
$E^{C}_{CH_4}$ = CH_4 emission (kg) due to stationary or mobile sources of fuel combustions
$E^{P}_{CH_4}$ = CH_4 emission (kg) due to use of paper
$E^{C}_{CO_2}$ = CO_2 emission (kg) due to stationary or mobile sources of fuel combustions
$E^{E}_{CO_2}$ = CO_2 emission (kg) due to use of purchased electricity
$E^{fl}_{CO_2}$ = CO_2 emission (kg) due to flights taken by staff
$E^{G}_{CO_2}$ = CO_2 emission (kg) due to use of purchased gas
$E^{S}_{CO_2}$ = CO_2 emission (kg) due to processing of sewage
$E^{tr}_{CO_2}$ = CO_2 emission (kg) due to transportation taken by staff
$E^{W}_{CO_2}$ = CO_2 emission (kg) due to use of fresh water
E^{R}_{HFC} = HFC emission (kg) due to uncontrolled release of refrigerants
$E^{C}_{N_2O}$ = N_2O emission (kg) due to stationary or mobile sources of fuel combustions
E^{R}_{PFC} = PFC emission (kg) due to uncontrolled release of refrigerants
$E^{R}_{SF_6}$ = SF_6 emission (kg) due to uncontrolled release of refrigerants
$F_{B/E}$ = business-economic factor of flight class (economy: 0.9; business: 1.4)
$F_{(CH_4)f}$ = emission factor of CH_4 for the f^{th} type of fuel

$F_{(CO_2)f}$ = emission factor of CO_2 for the f^{th} type of fuel
$F_{D|(W)t}$ = default emission factor (kg/m^3) of electricity consumed associated with the amount of sewage processed in the t^{th} period
$F_{(E)t}$ = emission factor of electricity used in the t^{th} period (specific for individual power companies)
F_{fl} = emission factor of flight (short haul: 0.15; medium haul: 0.12; long haul: 0.11)
$F_{(G)t}$ = emission factor (kg/unit) of gas used in the t^{th} period
$F_{(N_2O)f}$ = emission factor of N_2O for the f^{th} type of fuel
F_p = emission factor of the p^{th} type of paper
$F_{(S)t}$ = emission factor (kgCO_2-e/kWh) of electricity consumed associated with the amount of sewage processed in the t^{th} period
$F_{tr|C}$ = emission factor (based on cost) of the tr^{th} type of transportation
$F_{tr|D}$ = emission factor (based on travel distance) of the tr^{th} type of transportation
$F_{(W)t}$ = emission factor (kg CO_2-e/m^3) of electricity consumed associated with the amount of water used in the t^{th} period
f = 1, 2, …, F (assigned to the f^{th} type of fuel; F = total number of fuel types)
$G_{(CH_4)}$ = global warming potential of CH_4
$G_{(N_2O)}$ = global warming potential of N_2O
G_r = global warming potential of the r^{th} type of refrigerant
N = net number of additional trees (at 5m in height)
R = removal factor of tree (23 kg/tree/per year)
R_{CO_2} = removal of carbon emission (kg)
r = 1, 2, …, R (assigned to the r^{th} type of refrigerant; R = total number of refrigerant types)
s = 1, 2, …, S (assigned to the s^{th} staff; S = total number of staff)
T = length of reporting period (years)
t = 1, 2, …, T (assigned to the t^{th} period; T = total number of time periods)

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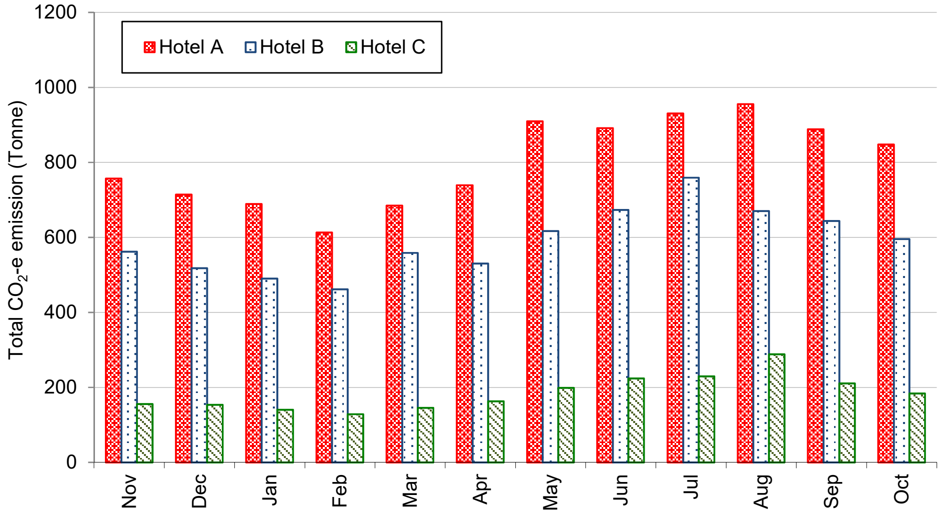

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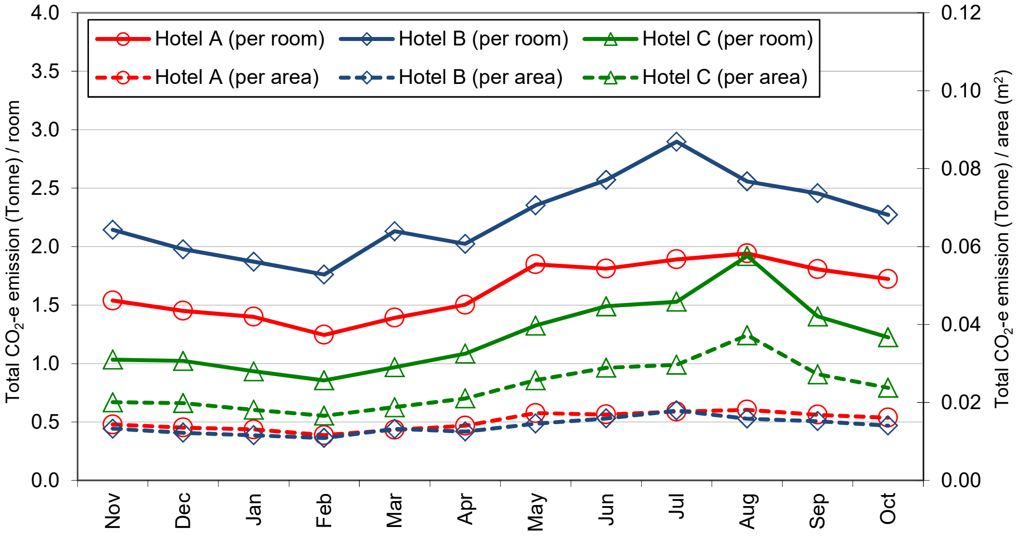

Figure 2 Normalized monthly emissions from the hotels

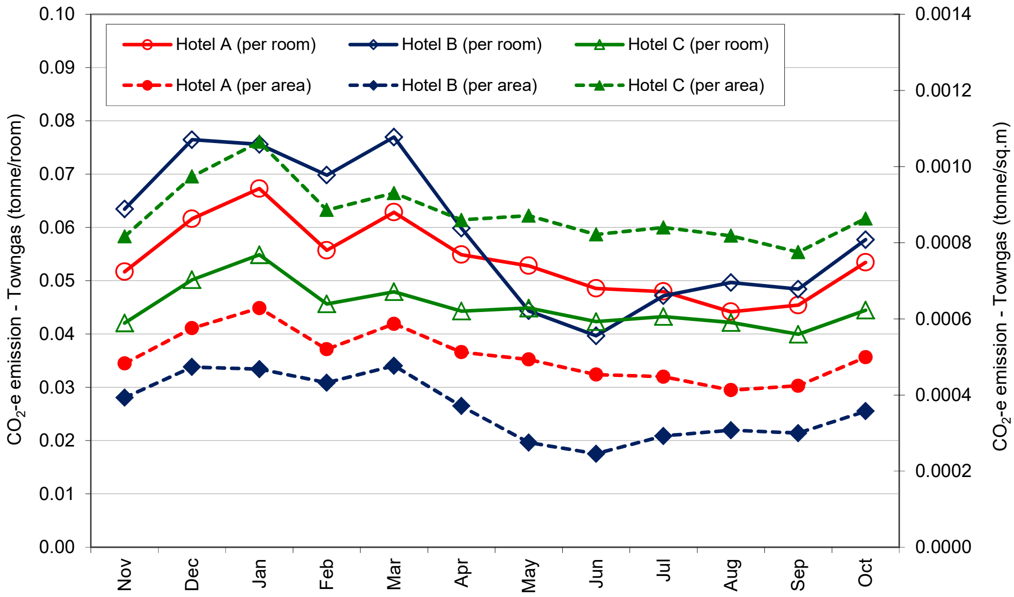

Figure 3 Annual profiles of normalized emissions due to use of towngas

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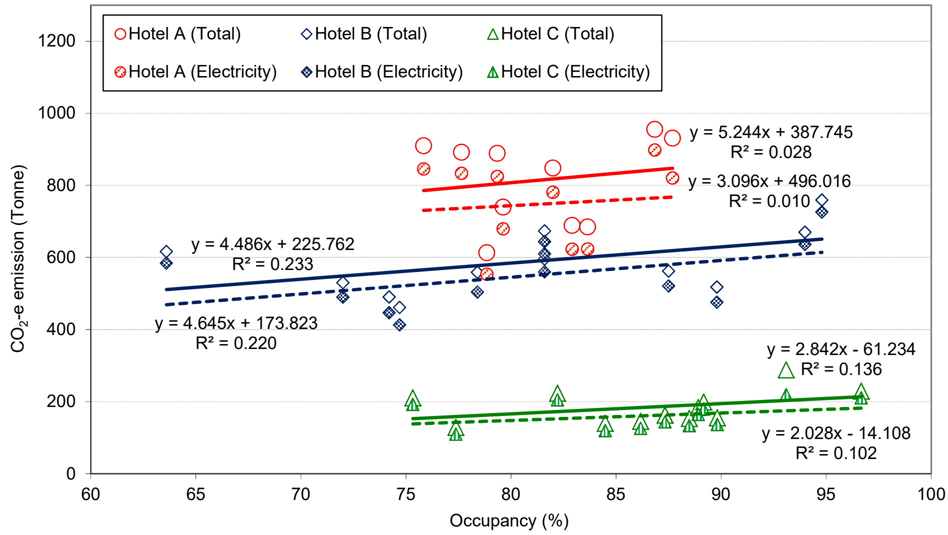
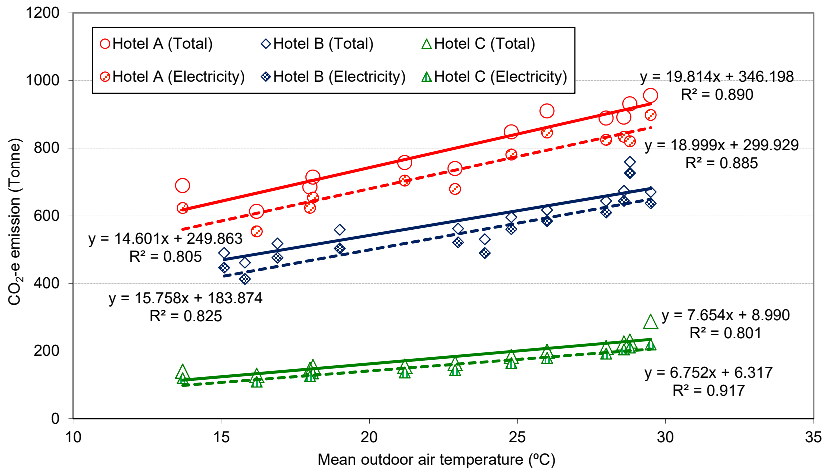
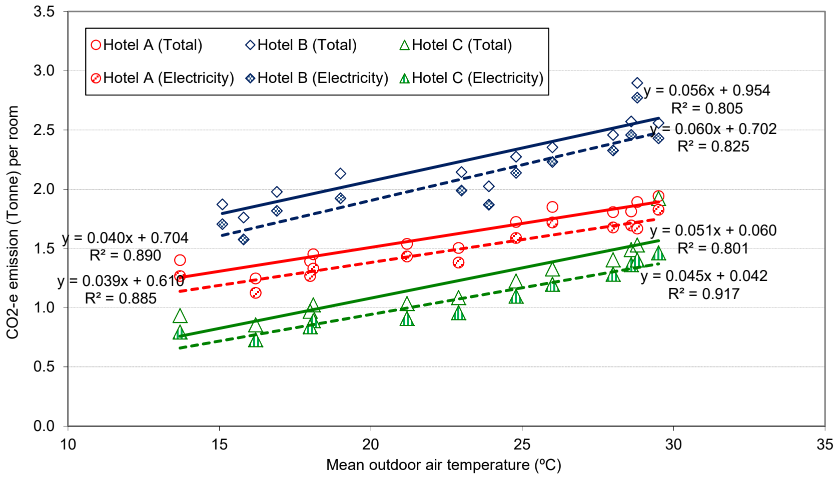


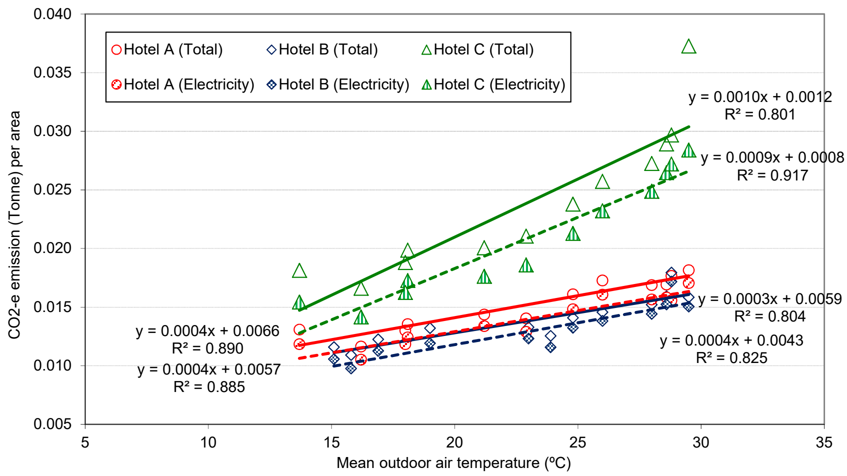
Figure 4 Relationships between occupancy rates and carbon emissions



(a)



(b)



(c)

Figure 5 Relationships between outdoor air temperatures and carbon emissions: (a) without normalization; (b) normalized by room number; (c) normalized by area

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Table 1 Scopes of emissions under the study

Classification	Emission activities	Examples
Scope 1	• Stationary sources combustion	• Electricity generation, boilers, gas cooking stoves
	• Mobile sources combustion	• Commuter shuttle bus services operated for the building
	• Fugitive emissions	• Refrigerants emissions during the use of refrigeration and air conditioning equipment
	• Assimilation of carbon dioxide into biomass	• Planting of trees
Scope 2	• Consumption of purchased electricity	• Electricity used by electrical equipment
	• Consumption of gas	• Gas used by gas appliances
Scope 3	• Methane gas generation at landfill due to disposal of paper waste	• Paper used for office work, newspaper disposed by occupants in the building
	• Consumption of fresh water	• Electricity used for fresh water processing by the Water Supplies Department
	• Treatment of waste water	• Electricity used for sewage processing by the Drainage Services Department
	• Overseas business travels	• Flights taken by staff for attending business activities
	• Daily travels	• Local transportation taken by staff for travelling between residence and workplace

Table 2 Characteristics of the hotels

	Hotel A	Hotel B	Hotel C
Hotel grade	5-star	4-star	3-star
Building age (years)	40	1	25
No. of floors (including basement floors)	20	29	25
Construction floor area (m^2)	52685	42313	7729
No. of guestrooms	492	262	150
Occupancy rate (%)	81.4	81.2	86.6
Food & beverage outlets (No.; m^2)	5; 3087	5; 1866	2; 801
No. of regular employees	560	368	110

Table 3 Proportions (%) of various sources of carbon emissions

Sources	Hotel A	Hotel B	Hotel C
Electricity consumption	91.89	93.38	87.34
Gas consumption	3.31	2.62	3.66
Staff daily travel	1.87	1.44	2.75
Water supply and sewage processing	1.19	0.60	0.86
Refrigerant	0.55	0.00	2.22
Paper waste	0.55	0.95	2.67
Transportation for hotel guests	0.32	0.64	0.49
Business travels of hotel staff	0.25	0.30	n.a.
Cylinder LPG consumption	0.08	0.04	0.00
Emergency power generator	0.002	0.029	0.002

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Table 4 Summary of emissions due to staff daily travels

	Hotel A		Hotel B		Hotel C	
	Fraction (%)	CO_2-e/staff (kg)	Fraction (%)	CO_2-e/staff (kg)	Fraction (%)	CO_2-e/staff (kg)
MTR	56.9	0.207	63.3	0.187	45.8	0.239
Bus	40.8	0.669	45.5	0.744	68.2	0.899
Mini-bus	13.8	1.090	22.2	0.901	19.6	0.842
Tram	0.0	-	0.0	-	61.7	0.280
Taxi	5.6	1.540	8.7	1.635	4.7	0.728
Ferry	0.7	68.284	0.0	-	1.9	43.971
Driving	0.7	5.500	1.5	10.750	0.0	-

*Note: The sum of each column of fractions exceeds unity as some staff used more than one type of transportation.

Table 5 Summary of Regression Statistics

	Hotel A		Hotel B		Hotel C	
	Value	Significance	Value	Significance	Value	Significance
R^2	0.889	-	0.853	-	0.817	-
F	28.076	0.0005**	26.056	0.0002**	20.079	0.0005**
	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value
β_0	122.25	0.7173	103.24	0.3246	-71.78	0.4710
O_R	2.77	0.5073	2.14	0.1211	1.02	0.3976
T_O	19.74	0.0002**	13.46	0.0002**	7.34	0.0003**

**Correlation is significant at the 0.01 level.