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Waterfront Hotels' Chillers: Energy Benchmarking and ESG Reporting

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Abstract: Chillers consumes the largest amount power in subtropical hotels. To monitor chillers' power usage is of critical importance in energy control. This study attempted to establish the benchmark of electricity usage of hotel chillers and elucidate how the benchmarking results can be integrated with the various types reports for monitoring purposes. A survey of 20 waterfront hotels in the city of Greater Bay Area was conducted and 13 complete samples were used in the analysis. Multiple regression with selected 12 parameters—outdoor temperature, solar radiation, wind speed, cooling degree days, room occupancy, number of employees, service types, and unequally sized chillers were employed. The investigation found that the mean electricity usage of a chiller is 118 kWh/m^2 on an annual basis for a deluxe waterfront hotel. The analysis excluded air-conditioned floor area, an exploratory variable, as the valid factor in the chiller's electricity usage. While the overall R^2 of the modeling equation for the whole year was limited to 0.76, the explanatory power of equations for humid spring and deep summer reached 80%. Hoteliers may harness this exercise as a reference to monitor and report the performance of key energy production facility per the Environment, Social, and Governance (ESG) guide.

Keywords: water-cooled chillers; waterfront hotel; ESG reports; Greater Bay Area

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1. Introduction

Energy consumption is a major environmental concern in the lodging industry. Apart from the depletion of fossil energy resources, indirect emissions from power plants attributable to hotel energy use poses another environment problem that cannot be ignored. It was predicted that the hotel sector in Hong Kong indirectly produced sulfur dioxide (1889 tons), nitrogen oxide (3022 tons), particulate (104 tons), and carbon dioxide (605,014 tons) annually in the 2020s [1]. Among the various forms of energy used in hotels, electricity is the principal form.

A heating ventilation air conditioning (HVAC) system is the core facility accounting for approximately 50% of total electricity consumption in subtropical hotels based on the averages of four prior studies [2–5]. Within the system, the chilling subsystem producing and delivering cooled water for airside operations typically accounts for 40% of the entire hotel's electricity consumption [6]. Thus, an effective hotel energy-saving strategy should cover the energy efficiency and energy consumption of chillers. As such, hotel management should comprehensively monitor the electricity consumption of chillers so as to reduce energy usage more effectively. Alternatively, benchmarking on hotel chillers' energy consumption could be one of the other options. The prerequisite for benchmarking is to investigate the relationship between the chiller's electricity consumption and associated parameters and to subsequently identify ways to report the chiller's power consumption for control purposes.

The primary objective of the present study was to simulate and model the relationship between chillers' electricity consumption and associated parameters. Specifically, the current research would establish both simulating and modeling equations to predict chiller electricity usage during all air-conditioning months and two distinctive seasonal intervals, including humid spring and deep summer. These models and simulations may help hotel practitioners in formulating and predicting the benchmark of chillers' energy consumption and may allow them to make comparisons with their own hotels' situations. A secondary yet equally important objective was to elucidate the integration of the modeled and simulated results into hotel reports.

2. Literature Review

The earliest demonstration of the use of the regression technique and weekly data to estimate energy usage of an individual hotel in a temperate region of the United States can be traced back to 1980 [7]. Studies in the early 2000s focused on analyzing the relationship between the electricity usage of the entire hotel and its associated parameters, namely, hotel size and business activity, based on the rationale that the weather-induced differences in electricity usage change significantly from one year to another [8,9]. Their findings also confirmed that gross floor area (GFA) and number of occupied rooms (OCC) had the highest explanatory power for the electricity consumption of hotels.

At approximately the same time, another investigation identified mean outdoor air temperature and total number of guests as the two most significant variables for predicting electricity usage [5]. However, the former does not indicate the temperature that activates air-conditioning systems, and the latter does not include the number of hotel staff and restaurant guests who also consume electricity. In addition, a description of the reliability of the adopted parameters was lacking. Cooling degree days (CDD) is considered as an additional explanatory variable, increasing the predictive power of the modeling equation to 96% [1]. Likewise, the number of staff and their densities are ranked on the top of a list of factors associated with overall hotel energy consumption in Singapore hotels [10]. Table 1 shows a summary of investigated variables and an established equation for estimating electricity usage in subtropical areas. However, these studies only considered the electricity consumption of all electricity-driven facilities in hotels and did not narrow down the focus on the energy consumption of the HVAC system or the chiller, which is a potential area for achieving substantial and effective energy savings. While there have been two studies about chiller energy usage in sub-tropical latitudes, it is scrutinized that Lam's study [9] was confined by the five climatic variables in an office building environment, unlike the multi-functional settings and activities in hotels. Similarly, another study has also been limited to a weather profile (being expressed as a building cooling load in response to the climatic index—the product of temperature and humidity ratio of outdoor air) of a hypothetical hotel, not a real case study [11]. Besides, the prior studied hotels' cooling facilities have not stated if the hotel location included distinctive seaside weather properties or not. Thus, there has been a lack of study about a chiller's electricity usage in subtropical and waterfront settings. In view of this situation, the current research investigated the hotel chiller's electricity usage and its associated parameters—both activity and climatic ones.

Table 1. Previously studied parameters of whole hotel or hotel chillers.

Investigated Parameters and Established Equations	References
Hotel's overall energy usage in relation with hotel size, OCC, GFA	[8]
Hotel's overall energy usage in relation with GFA, construction year, retrofit, no. of rooms, stars, swimming pool, laundry, number of workers Ee = 326.24 $e^{9E0.05}$ OCC; R^2 = 0.58 Ee = 28.952 × worker × 252.14; R^2 = 0.4	[10]
Hotel's overall energy usage in relation with GFA, room, guest, GFA x room, guest per GFA(m^2)	[12]
Hotel's overall energy usage in relation with GFA, CDD18, OCC Ee = 0.052 × OCC + 151.665 × CDD18 − 163.415; R^2 = 0.96	[13]
Hypothetical hotel's electricity consumption of chiller in relation with the following: Gross floor area, total air-conditioned area, Orientation, aspect ratio, window-to-wall ratio, U-value of wall, U-value of window, U-value of roof, shading coefficient of glass, Floor dimension, area per floor, Air-conditioned area per floor, Number of floors, floor to floor height, Temperature, relative humidity, Ventilation rate, occupancy, Equipment power density, Lighting power density, Occupied periods: Weekdays, Saturdays, Sundays Simulation program	[14]
While the previous research investigated the water-cooled chiller in a hotel and stated the hotel's information (U-value of wall; U-value of window; U-value of roof; shading coefficient of glass; relative humidity; cooling temperature; ventilation rate; occupancy; ventilation rate; occupancy; equipment power density; lighting power density;, air-conditioning system operating hours: weekdays, Saturdays, Sundays; area per floor; air-conditioned area per floor; chilled water flow), this study computed power usage of chillers based on the weather data and the load under which each operating chiller operated. In addition, their investigation was about air-cooled chillers, not water cooled chillers.	[15,16]

Currently, monthly hotel operation statements being prepared by owner-operated hotel management are limited to the revenue and other cost-associated content. These documents usually lack monitoring figures on the performance of their energy-consuming facilities because of resource constraints in an owner-operated hotel. Hospitality scholars have long advocated the incorporation of these kinds of green content into monthly or annual statements [17,18]. In international hotel operations, the monthly report format and structure mostly follow the guide shown in the Uniform System of Account for the Lodging Industry [19]. The indicative content of its energy-related schedule has been confined to various energy consumption figures only. The energy consumption record of chiller systems and other important energy consuming facilities are not yet available. This reflects that the management's awareness of the significance of the chiller system on energy consumption is low. However, there is a lack of a template to demonstrate the ways to compile this kind of report. In addition, most of the existing reports on the energy usage of air-conditioning by hotel management have been based on an averaging approach with bases like number of occupied room, floor area, number of guests [16,20].

Chapter 30 of Agenda 21 encourages business and industry "to report annually on their environmental records as well as on their use of energy and natural resources" [21]. The purpose of this suggested reporting process is to provide a visible yardstick for measuring the improvement of the environment.

The airline industry has recognized and acknowledged the greenhouse effect on the environment, resulting from the fuel consumption of their flights [22,23]. In their standalone environmental or CSR report, airlines have envisaged that the energy efficiency of a flight is an important environmental improvement indicator and have deliberately calculated and shown this fuel efficiency in their reports [24,25]. However, no commonly recognized crucial green indicators in the environmental or CSR reports exist in the hotel sector. Given the significance of chillers in hotel power consumption, chillers' energy-consumption-related indicators should be established in the report at various levels so as to allow comparison and to devise better measures for saving energy.

- Government-driven carbon audit and ESG report

The greenhouse effect results in a gradual increase in global temperatures and accelerates the dissolution of icebergs. Governments across the world have proposed strategies and measures to mitigate this environmental impact. A large amount of carbon emissions and greenhouse gases are the primary factor leading to global warming. Thus, the environmental protection and the electrical and mechanical services departments of local governments have stepped up environmental efforts by creating a portal to enable enterprises to calculate and report the carbon emissions originating from buildings [26].

However, local hotels have been slow in following the steps for estimating their greenhouse gas emissions. As shown in the portal, hotels merely share their environmental practices and some achievements on the web, providing no quantified figures for greenhouse gas reduction. These environmental practices include the application of variable speed drives, LED lighting, T5 light tubes, the use of building management systems, the installment of sensors for switching rooftop signage on or off, participating in used cooking oil recycling programs, diverting bathroom exhaust to cool down the lift machine, and so on. Although the government has uploaded a guide for conducting carbon audit reporting and a number of carbon calculators on the portal, hoteliers have still been lagging behind in reporting the results of carbon audits [27]. This condition is partly due to the difficulty in finding employees who have relevant knowledge or skills in estimating energy consumption, and partly due to inadequacy in resources required to calculate or record the power usage of so many different powered facilities. In addition, the lack of understanding on which energy-consuming equipment should be counted in the first batch of a carbon audit could also be another factor slowing down reporting on related emission.

Besides, more recently, the stock exchange has also required all listed corporations to submit the ESG reports annually. While the ESG reporting guide specifies the report on direct and indirect energy intensity, the guide also states that energy consumption of key energy facilities is also an example for reporting [28].

3. Methodology

Currently, there are about 400 highly deluxe hotels located in the Greater Bay Area (GBA), which is chiefly influenced by the subtropical climate. Subtropical climates or warm temperate climates are characterized by hot and humid summers, and cold to mild winters. Such climatic zones normally lie on the southeast areas of all continents, generally between latitudes 25° and 40°, plus they are adjacent to the regions with tropical climates. In most cases, this climate is found along coastal area. In China and the US, such climatic characteristics extend inland in some locations.

The studied location of hotels is subject to the effects of a humid subtropical climate with typically long, humid, and hot summers. Monthly average summer temperatures are around 24 °C to 27 °C. Temperatures in winter are often mild, typically ranging 8 °C to 16 °C. The humid and windy conditions of the studied location are more pronounced due to the evaporation of the nearby sea surface and the flat surface over the sea, respectively. Rainfall often displays a summer peak.

A survey was conducted by dispatching data collection forms (Appendix A) to 20 high-tariff hotels, which are located along water front in a city of Greater Bay Area (GBA) and listed in local tourism office publications [29]. Only high tariff hotels with their locations less than 50 m away from the waterfront were counted in this investigation. While all 20 hotels returned the questionnaire, only 13 of the returned questionnaires were duly completed. The content of the data collection form was designed with reference to two previous studies [8,30].

3.1. Analytical Methods

Four types of estimation techniques are generally used for analysis in this area of study, including energy used per occupied room, gas used per food cover, normalized performance indicators, and multiple regression [18]. The first two items are typically used in the managerial analysis. The third technique refers to the annual electricity consumption based on a hotel's gross floor area and has prevailed in the building profession [8]. To gauge the average cooling capacity and electricity consumption of upscale hotel chillers on a per square meter basis, the current investigation adopted the third technique in the present analysis. With the advancement of computing facilities, the present work also used multiple regression to model the relationship between the chillers' power consumption and associated parameters. These parameters included GFA, air-conditioned gross floor area (AGFA), number of occupied room night (OCC), number of staff members (STAFF), cooling degree days (CDD), outdoor average dry bulb temperature (TEMP), wind velocity (Wind_S), solar radiation (Solar_R), relative humidity (RH), service type (SER_TYPE), water front location (WF), and unequally sized chiller design (Chiller). Both the enter (Table 2) and stepwise (Table 3) methods of the Statistical Package for the Social Sciences were employed in the model formulation.

To deliberately estimate the climatic influence on chiller power usage over distinctive seasonal intervals, including the humid spring (February to April), the deep summer (June to August), and less hot months (May and September to December), three separate modeling equations were established (Figure 1).

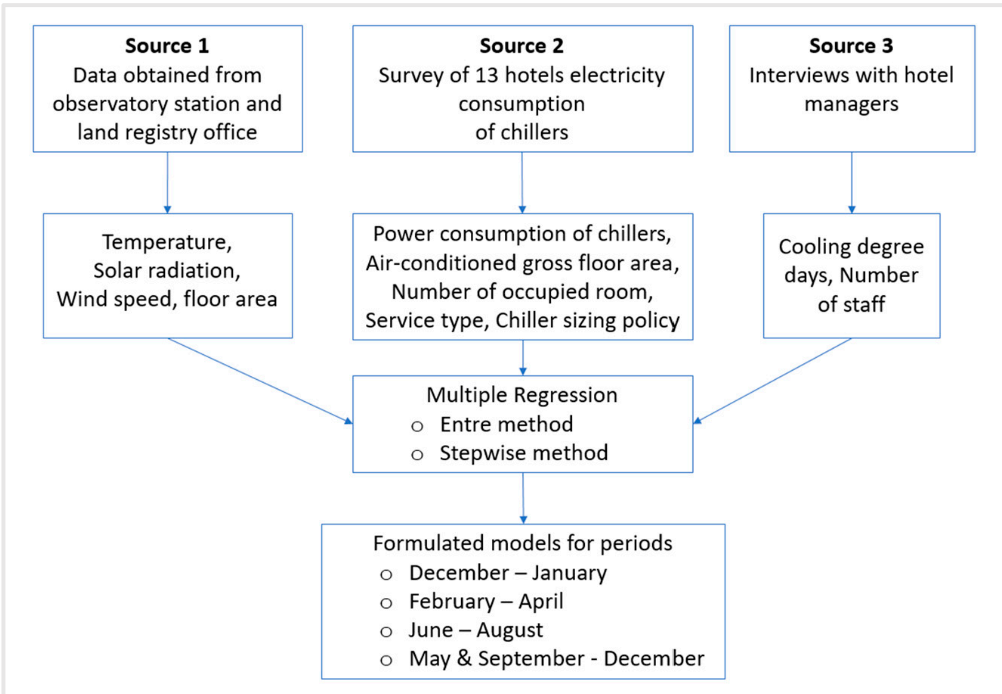

Figure 1. Flow chart of model development.

Table 2. Multiple regression (enter method) summary.

January–December			February–April			June–August			September–December		
Enter Method			Enter Method			Enter Method			Enter Method		
R^2		0.76	R^2		0.82	R^2		0.84	R^2		0.82
SE		85,815.22	SE		67,147.18	SE		92,305.92	SE		85,776.40
a		131,824.19			−100,720.33	a		−5,210,476.34	a		1,746,893.73
independent variables	coefficient (t value)		independent variables	coefficient (t value)		independent variables	Coefficient (t value)		independent variables	coefficient (t value)	
GFA	b1(t1)	−14.50 ** (−2.65)	GFA	b1(t1)	−19.26 (−1.75)	GFA	b1(t1)	−33.36 ** (−2.25)	GFA	b1(t1)	−9.97 (−1.19)
AGFAa	b2(t2)	24.08 ** (2.44)	AGFAa	b2(t2)	23.62 (1.14)	AGFAa	b2(t2)	77.15 ** (2.61)	AGFAa	b2(t2)	17.74 (1.16)
Occ	b3(t3)	1935.04 (0.80)	Occ	b3(t3)	−153.80 (−0.03)	Occ	b3(t3)	18,234.59 ** (2.56)	Occ	b3(t3)	1362.63 (0.30)
Staff	b4(t4)	−135.86 (−0.33)	Staff	b4(t4)	291.65 (0.34)	Staff	b4(t4)	−2927.10 * (−2.15)	CDD	b4(t4)	16,328.80 (1.06)
CDD	b5(t5)	4947.82 * (1.70)	CDD	b5(t5)	4026.10 (0.75)	CDD	b5(t5)	96,079.40 (0.86)	Staff	b5(t5)	−68.85 (−0.10)
Temp	b6(t6)	4090.74 (0.54)	Solar_R	b6(t6)	284.14 (0.97)	Wind_S	b6(t6)	11,976.92 (0.52)	Wind_S	b6(t6)	−13,532.23 (−0.97)
Wind_S	b7(t7)	−4525.46 (−0.99)	RH	b7(t7)	2693.18 (0.33)	RH	b7(t7)	14,071.73 (1.08)	Solar_R	b7(t7)	−1725.36 (−0.58)
Solar_R	b8(t8)	13.03 (0.06)	service_type	b8(t8)	6890.37 (0.05)	service_type	b8(t8)	423,398.75 * (2.12)	RH	b8(t8)	−10,501.72 (−0.64)
RH	b9(t9)	−475.03 (−0.17)	WF	b9(t9)	−64,249.36 (−0.84)	WF	b9(t9)	336,991.05 **(2.54)	service_type	b9(t9)	70,243.54 (0.55)
service_type	b10(t10)	60,738.81 (0.83)	Chiller	b10(t10)	−83,251.08 (−0.37)	Chiller	b10(t10)	−1,014,610.91 r ** (−3.04)	WF	b10(t10)	57,077.77 (0.66)
WF	b11(t11)	31,783.81 (0.70)							Chiller	b11(t11)	−273,055.25 (−1.53)
Chiller	b12(t12)	−259,197.1 ** (−2.39)									

Note: * $p < 0.10$; ** $p < 0.05$.

Table 3. Multiple regression (stepwise) summary.

January–December			February–April			June–August			September–December		
Stepwise Method			**Stepwise Method**			**Stepwise Method**			**Stepwise Method**		
R^2		0.73	R^2		0.58	R^2		0.69	R^2		0.79
SE		87,899.83	SE		81,512.82	SE		101,337.77	SE		79,292.50
a		63,088.72	a		157,164.08	a		264,136.60	a		−309,524.12
independent variables	coefficient (t value)		independent variables	Coefficient (t value)		independent variables	coefficient (t value)		independent variables	coefficient (t value)	
Staff	b1(t1)	603.91 *** (9.65)	Staff	b1(t1)	413.03 *** (4.22)	Staff	b1(t1)	973.93 *** (6.77)	Staff	b1(t1)	586.47 *** (6.77)
Temp	b2(t2)	18,572.36 *** (10.35)	Temp	b2(t2)	11,396.61 ** (2.78)	service_type	b2(t2)	−155,374.94 *** (−3.49)	Temp	b2(t2)	22,967.75 *** (6.70)
service_type	b3(t3)	−83,851.29 *** (−3.14)							Chiller	b3(t3)	−112,846.06 *** (−4.02)
Occ	b4(t4)	−2785.89 ** (−2.24)									
Chiller	b5(t5)	−45,749.69 ** (−2.09)									

Note: ** $p < 0.05$; *** $p < 0.01$.

3.2. Parameter Selection

Prior research has indicated that parameters affecting hotel energy consumption can be classified into two dimensions: climatic influence and in-house activities [18].

To apply the associated climatic variables, the current investigation purchased the climatic data from the local weather station [31]. Relevant parameters encompassing outdoor temperature, Solar_R, and Wind_S were selected as testing variables for the first round.

Discussions with hotel practitioners also indicated that other than temperature, RH is also an important criterion for determining the ON/OFF operation of the chiller because foreign tourists may not easily adapt to the humid weather in the territory. The cooling provided by the chiller may help dehumidify the indoor air. Particularly during spring in March and April, when the moist ocean air is frequently present in the coastal area, the chiller is switched on even when the temperature does not reach the required level. Given such a background, RH was also employed as a variable in the testing. Thus, a specific regression was run with the data in the misty period of February to April to detect whether there will be a difference with the regression result using the data throughout the air-conditioning months (February to December).

The variable testing also extended to the number of CDD in hotels. In subtropical hotels, the cooling function is activated to maintain a comfortable temperature and dryness for guests for approximately 11 months, except for January, which has a daily temperature of approximately 10°C. Moreover, a large number of deluxe hotels are located at the waterfront, which is subjected to the effect of stronger wind and relatively higher humidity. Thus, a new dummy variable, WF, was also adopted in the testing.

To analyze how in-house consumption activities affect the chillers' electricity consumption, the study collected OCC data from hotels. In addition, the current research specifically added the number of employees (STAFF) as an additional testing variable following recent findings [10]. Another dummy variable, the service types (SER_TYPE), has also been employed [32].

Aside from the two dimensions, climatic influence and in-house activities, building professionals have found that the building materials and structure also significantly affect the energy consumption of a building. An aggregate variable gross floor area, labeled as GFA, has been frequently adopted in building energy analysis. However, not all GFAs are provided with air conditioning—staircases, storage, and duct spaces are a few exceptions. Precisely speaking, only the AFGA is cooled. Thus, this investigation used both GFA and AFGA as testing variables in the regression.

The energy efficiency of a chiller may be reduced by 50% under part-load conditions, so hotel project planners usually maximize the full-load operation of chillers using a design strategy that employs unequally sized chillers. Thus, this study also included the availability of the unequally sized chiller (CHILLER), as a dummy variable in testing.

4. Findings and Discussion

The survey found that the mean electricity usage of a chiller is 118 kWh/m^2 on an annual basis, with a standard deviation of 53 kWh. At a 95% confidence interval, the mean lies within the range of 82 kWh to 154 kWh.

Figure 2 shows the average electricity usage of chiller in relation to the size of the hotels. It was observed that two hotels with more or less the same total floor area and equally sized chiller design consumed more than average electricity, about 200 kWh/m^2. Conversely, hotels with unequally sized chillers installed are capable of attaining electricity usage the below mean. These two contrasting observations further confirmed that the planning strategy using unequally sized chillers may provide more opportunities for saving energy.

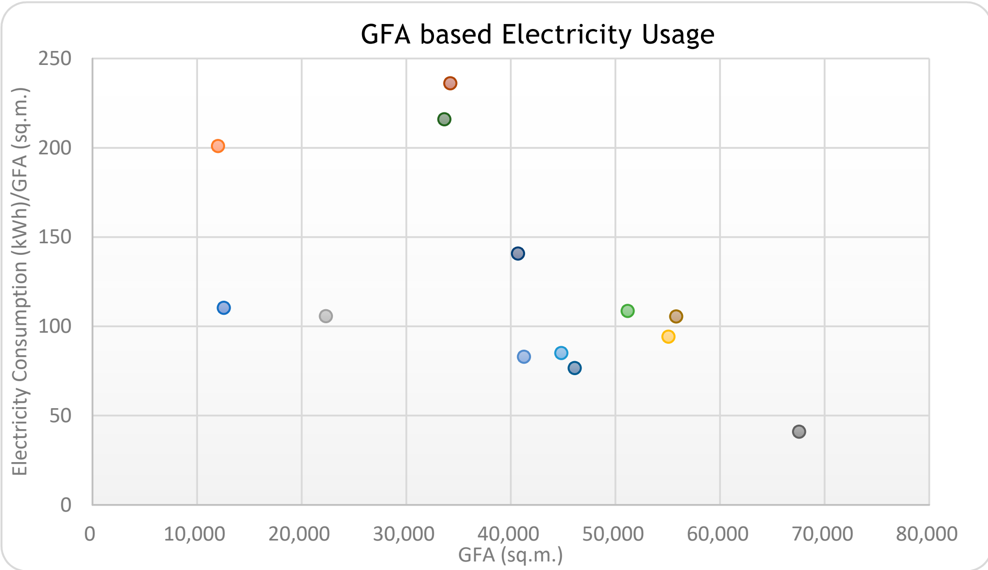

Figure 2. Average electricity consumption of a chiller.

The analysis under the simultaneous method indicated that the strongest explanatory power, R^2, of the modeling Equation (1) with all twelve parameters for the entire year reached up to 0.76, with a standard error of 85,815.22.

$$cE_{(\text{Jan-Dec})} = -14.5_{(t=-2\cdot65)} \times \text{GFA}^{**} + 24.08_{(t=2\cdot44)} \times \text{AGFA}^{*} + 1935.04_{(t=0\cdot8)} \times \text{Occ} - 135.86_{(t=-0\cdot33)} \times \text{Staff} + 4947.82_{(t=1\cdot7)} \times \text{CDD} + 4090.74(_{t=0\cdot54)} \times \text{Temp} - 4525.46_{(t=-0\cdot99)} \times \text{Winds\_S} + 13.03_{(t=0\cdot06)} \times \text{Solar\_R} - 475.03_{(t=-0\cdot17)} \times \text{RH} + 60{,}738.81_{(t=0\cdot83)} \times \text{service\_type} + 31{,}783.81_{(t=0\cdot7)} \times \text{WF} - 259{,}197.1_{(t=-2\cdot39)} \times \text{Chiller}^{*} + 131{,}824.19 \tag{1}$$

Note: * $p \leq 0.05$; ** $p \leq 0.01$

where E stands for the chiller's electricity consumption; GFA stands for gross floor area; AGFA stands for air-conditioned gross floor area; Occ stands for occupancy; Staff stands for the number of staff members; CDD stands for cooling degree days; Temp stands for average temperature; Wind_S stands for wind velocity; Solar_R stands for solar radiation; RH stands for relative humidity; service_type stands for service type; WF stands for water front location; and CHILLER stands for unequally sized chiller design.

As for each season, the R2 of Equation (2) for humid spring was 0.82, while it was 0.84 for Equation (3) in deep summer. For less hot months, the R2 of Equation (4) was 0.82. Their standard errors were 67,147.18, 92,305.92, and 85,776.40, respectively. Evidently, the explanatory power of the simulated equations improved with the use of segregated seasonal data for input.

$$E\ (\text{Feb-Apr}) = -19.26(t = -1.75) \times \text{GFA} + 23.62(t = 1.14) \times \text{AGFA} - 153.8(t = -0.03) \times \text{Occ} + 291.65(0.34) \times \text{Staff} + 4026.1(t = 0.75) \times \text{CDD} + 284.14(t = 0.97) \times \text{Solar\_R} + 2693.18(t = 0.33) \times \text{RH} + 6890.37(t = 0.05) \times \text{SER\_TYPE} + 64{,}249.36(t = -0.84) \times \text{WF} + 83{,}251.08(t = -0.37) \times \text{CHILLER} - 100{,}720.33 \tag{2}$$

$$E\ (\text{Jun-Aug}) = -33.36(t = -2.25) \times \text{GFA} + 77.15(t = 2.61) \times \text{AGFA} + 18{,}234.59(t = 2.56) \times \text{Occ} - 2927.1(t = -2.15) \times \text{Staff} + 96{,}079.4(t = 0.86) \times \text{CDD} + 11{,}976.92(t = 0.52) \times \text{Winds\_S} + 14{,}071.73(t = 1.08) \times \text{RH} + 423{,}398.75(t = 2.12) \times \text{SER\_TYPE} + 336{,}991.05(t = 2.54) \times \text{WF} + 1{,}014{,}610.91(t = -3.04) \times \text{CHILLER} - 5{,}210{,}476.34 \tag{3}$$

$$cE\ (\text{May \& Sep-Dec}) = -9.97(t = -1.19) \times \text{GFA} + 17.74(t = 1.16) \times \text{AGFA} + 1362.63(t = 0.3) \times \text{Occ} + 16{,}328.8(t = 1.06) \times \text{CDD} - 68.85(t = -0.1) \times \text{Staff} - 13{,}532.23(t = -0.97) \times \text{Wind\_S} - 1725.36(t = -0.58) \times \text{Solar\_R} - 10{,}501.72(t = -0.64) \times \text{RH} + 70{,}243.54(t = 0.55) \times \text{SER\_TYPE} + 507{,}077.77(t = 0.66) \times \text{WF} - 273{,}055.25(t = -1.53) \times \text{CHILLER} + 1{,}746{,}893.73 \tag{4}$$

Stepwise linear regressions were further performed to exclude parameters that were not strongly correlated. The Staff, Temp, Occ, service_type, and Chiller were found to be the key factors for the electricity consumption remaining in the model. The first three identified and valid variables confirmed earlier findings. Testing showed that the number of staff members appears to be a significant parameter affecting electricity consumption because the chiller is powered to remove the hot air being released from the bodies of hundreds of hotel employees. This finding is in agreement with a study in Singapore [10].

The exclusion of AGFA is probably attributable to the presence of leakage and loosening seals in the partition between air-conditioned and non-air-conditioned floors. The infiltrated air flowing through cracks and openings enters an air-conditioned floor through a pressure difference across the building envelope. The introduction of outdoor ventilation must be considered in combination with the infiltrated air. In addition, the parameter AGFA seems to be more valid in the uniform floor and functional space of office and residential buildings. Whereas the existence of many non-uniform floor spaces in deluxe hotels (larger lobby and grand ball room), plus their facilities releasing sensible heat inside hotels, has limited the explanatory power of AFGA. As a result, GFA operates as a better explanatory parameter compared with other floor-related parameters. A number of prior studies have already confirmed GFA as a significant factor in explaining hotels' overall energy usage [32,33].

5. Implications on Reporting

The present study highlighted that air-conditioning systems, especially the chiller systems, consume a very significant portion of energy in sub-tropical and tropical hotels. To formulate an effective energy strategy or to be a genuinely responsible lodging enterprise, measures to raise the chillers' energy efficiency or power consumption should be placed on top of a priority action list. Predicting, monitoring, and benchmarking chillers' power consumption for hotels in these latitudes are necessary steps and should also be reported on a daily, monthly, and yearly basis.

In the late 2000s, there were 80 hotels in Hong Kong [29]. One-third of the built up hotels were classified as owner-operated hotels, another one-third of them were managed by international hotel chains, and the remaining 40% were operated by local hotel chains backed by the real estate giants [34]. These three hotel types have some differences in their reports about operations.

5.1. Owner-Operated Hotel Report

This research demonstrates a way to establish a benchmarking basis for assessing the chiller's energy performance. Thus, owner-operated hotels may follow this demonstration to produce such kinds of indicators, that is, predicted and actual energy consumption, in their reports to remind guests and staff of the environmental problems attributable to chillers.

5.2. International Hotel Chains' Reports

International hotels have developed and compiled their environmental action manuals and corporate social responsibility (CSR) reporting guides over the past decade [35]. The group office management of these hotels can consider echoing these recommendations and incorporating similar types of energy data, even estimated pollutant data, into their monthly reports in the future. These types of modeling equations are particularly appropriate for a hotel group with a number of hotels in the subtropical regions like the Greater Bay Area.

5.3. Local-Real-Estate-Giant-Operated Hotel Report

Hotel chains owned by local real estate companies have preferred using analysis based on a "per square meter basis" rather than the traditional "per room basis" advocated by a large number of international hotel chains. Hong Kong's property prices, including those of hotels, have increased significantly in the past decades. The cost of the construction of a five-star hotel rose from HK$15,000 in 2005 to HK$25,000 in 2010 [36]. Such a large increase in development costs forces hotel owners to try their best to maximize the revenue potential of every aspect in the hotel. For instance, the basement level of the back office is converted into a function room and the accounts office is relocated to other nearby buildings. In addition, in-house laundry for uniform and linen cleaning is outsourced. Thus, in their annual or monthly reports, a number of profitability and cost indicators on a per square meter basis have been added in recent years [37]. The benchmarking indicators, such as electricity costs, consumption, and cooling yield capacity per square meter, developed in the present study, raise the issue of the compatibility of these indicators in the reports of real-estate-owned hotels. The calculating procedures and modeling practices in the current investigation demonstrated the steps for addressing these indicators, thus making the integration of such indicators into the analysis done by property-company-held hotels easier.

5.4. CSR and ESG Reporting

Large hotel chains are, however, slow in the pace of environmental reporting compared with other sectors [8,38]. Large hotel chains began to publish standalone CSR reports in the early 2000s. A study on the content analysis of CSR reports of the top ten hotel chains revealed that 80% of the hotel companies reported socially responsible activities relating to some form of charitable donations [35]. Their work further observed that a diversity policy was reported by 60% of the hotel companies, whereas 40% included some mention of social responsibility in their vision or mission statements. A number of companies were highly focused on providing a balanced approach to social responsibility, whereas other hotel companies were less focused in their efforts.

The low coverage of environment and energy are also probably attributable to the difficulty in quantifying energy consumption and greenhouse gases. However, the modeling practice of the present work may help individual hotel properties in estimating the power consumption of their machines and in establishing several new energy consumption-based indicators for benchmarking. However, recent ESG report guides clearly indicate that the chief energy-consuming facility in a corporation is recommended content for reporting [39].

Presently, the production of a CSR report in a large business usually follows the guidelines and indicators laid down in the Global Reporting Initiatives [40]. The content of the CSR reports being adopted by most listed hotels also follow these guidelines. Although a study [41] suggested that tourism firms should adopt the broader approaches recommended in the GRI in their CSR reporting to embrace more indicators for comparison purposes, this practice does not mean that the CSR report should neglect the significant environmental indicators. The commonly agreed-upon importance of the energy usage of cooling or heating systems and the availability of models for benchmarking derived from the present study imply that hoteliers should rethink the content of the environmental sections of their CSR reports. A new section that contains the energy efficiencies and predicted benchmarks for hotel energy systems should be considered.

6. Conclusions

The literature review revealed that hospitality-related journal publications on energy management in sub-tropical hotels have lingered around the periphery of energy-saving problems. Few reports have been conducted on the modeling of the energy consumption of chillers, which consume a significant portion of energy in hotels, and their associated parameters. However, the present study highlights the chiller as the most energy-consuming equipment, accounting for a significant portion of electricity consumption in hotels at low latitudes. Given the envisaged growth of hotels along waterfronts in GBA and Hainan Island, the findings and work of this study would be particularly useful to these prospective hotels.

A survey of 13 upscale and full-service hotels, representing 22% of 58 high-tariff hotels in the territory, was conducted to investigate the relationship between chillers' electricity usage and associated parameters [29]. Among the 12 investigated parameters, the current research found that the number of employees and the outdoor temperature are the correlated significant variables affecting the chiller's energy consumption. For the three newly tested variables, chiller sizing design and service type were determined as statistically validated parameters in the present study. A generic modeling equation was established to create a benchmark for comparing the electricity consumption of hotel chillers. The findings in this area could serve as a reference for developing predictions on how chillers affect the electricity consumption of upscale hotels located in the tropical and subtropical regions, especially in South China. The established regression model could be further developed as a benchmark indicator for hotels in the GBA area in China by adding the overall thermal transfer value and associated heat transfer coefficients, which have been employed in modelling the energy usage of chillers in non-hotel buildings [23].

Hoteliers may harness this exercise as a reference to benchmark the use of segregated seasonal data and employment of unequal chiller size to create modeling equations or benchmark for evaluating the performance of chillers among hotels in the area with subtropical climate. Besides, the study elucidates the integration of the chillers' benchmarked results with various sorts of reports being initiated by various parties—hotel owners, hotel management chains, real estate giants, listed companies, and government offices.

While investigations of power consumption using linear regression (which has its explanatory power) are relatively more objective and scientific than the averaging approach, the linear approach, especially in the early stage of their learning process, may make it easier for hotel operators to start their attempt to build up predicting model for their own hotels before hotels embark on the advanced type of analysis based on non-linear approach which is desirable in the later stage of the learning process.

Besides, the investigated data were confined to deluxe hotels along waterfront locations in subtropical areas. Future research may extend to modeling of the chillers' power usage and its associated parameters in other climatic zones and inland locations.

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Nomenclature

HVAC	Heating ventilation air conditioning
R^2	Coefficient of determination
OCC	Total number of occupied rooms
CDD	Cooling degree days
Ee	Predicted electricity consumption
DBI	Dry bulb temperature
WBT	Wet bulb temperature
°C	Degree Celsius

U-value	The rate of heat transfer through a structure or materials
LED	Light-emitting diode
T5	Fluorescent tubes −16 mm in diameter
GFA	Gross floor area
AGFA	Air gross floor area
TEMP	Outdoor air temperature
Wind_S	Wind speed
Solar_R	Solar radiation
RH	Relative humidity
SER_TYPE	Type of service
WF	Waterfront location
STAFF	Total number of staff
CHILLER	Unequally sized chiller strategy
kWh	Kilowatt hour
SE	Standard error
GBA	Greater Bay Area
CSR	Corporate social responsibility
ESG	Environment social governance

Appendix A. Partial Content of Data Collection Sheet—Chiller

Kindly input the following data that are known to you. It would be very helpful if you can approach the architect/E&M consultant or database system of your property developer for those data that you do not know or you cannot find from the catalog of the chiller system. Please return your data to the referrer.

Note: the data collection sheets were dispatched twice (2010) and (2013) for data.

Table A1. Data collection form for cooling facilities.

Chiller Plant Details			
201. Year of existing chiller system installation	☐ Pre-1990	☐ 1991–1999	☐ Post-2000
202. Chillers' refrigerant type			
203. Chiller manufacturer name			
204. Estimated area of air-conditioned floor area	_______m^2		
205. Total cooling capacity installed	_______Ton _______kW		
206. Type of chillers	☐ Centrifugal	☐ Absorption	☐ Screw
207. Total number of chillers	☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐Other _______		
208. Nominal cooling capacity each chiller (kW)			
209. Number of chiller for each of the above capacity			
210. Number of pump for each chiller capacity on the above			
212. Rated power of each pump (kW)			
213. Designed flow rate of each pump (L/s)			
214. Estimated floor area accommodating chilling plant	_______m^2		
215. Contractual maintenance cost (annual)of chilling plant	_______USD/HKD		
216. Heat rejection method of the cooling tower	☐ Water cooling	☐ Air cooling	
217. Average Supply Water Temperature (make up water to the cooling tower)	☐ Normal water supply ______(°C) ☐ Ocean water ______(°C)		

Table A2. Data collection form for electricity consumption.

	Chiller Power Usage (Total) and Occupancy						
	2008 (kWh)	**2008 (Occ)**	**2009 (kWh)**	**2009 (Occ)**	**2010 (kWh)**	**2010 (Occ)**	
January							January
February							February
March							March
April							April
May							May
June							June
July							July
August							August
September							September
October							October
November							November
December							December

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