A Study on Pollutant Emission Through Gas Consumption in the Hong Kong Hotel Industry

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A survey of 11 hotels in Hong Kong was carried out to collect three years' energy consumption data. Regression analysis indicated that gross floor area was a major and statistically acceptable factor in explaining the gas consumption in new hotels. Based on past consumption data and some established pollutant emission factors, the amount of sulphur dioxides, nitrogen dioxides, carbon dioxides and particulate created by the Hong Kong hotel industry's gas usage during a 10-year period from 1989–1998 was estimated. The study predicts the increase in these amounts in 1999–2003 accompanying the rise in the number of hotels. The findings indicate that emissions will rise by nearly 40% in the next few years, requiring urgent discussions. The study also finds that a heat pump running on coal-fired electricity and with a coefficient of performance (COP) greater than 3 could produce lower level emissions than a gas-fired boiler. It is further suggested that an effective method to reduce the emissions is to substitute naptha with natural gas as the fuel for generating town gas and electricity. We believe the hotel industry should adopt a more proactive approach to reduce gas usage and propose the inclusion of environmental reporting in trade journals.

Introduction

In recent years, concern about the environment and the world ecosystem has become a major world-wide public issue. In Hong Kong, there is a growing concern about energy consumption and its likely implications for the environment. Within its tourism sector, hotels have been generally regarded as a major energy end-user. Also, the rapid growth in the number of hotels during the past three decades has resulted in a substantial increase in energy consumption. In 1998, there were about 90 hotels in Hong Kong consuming over HK$22 billion worth of energy (HKTA *et al.*, 1999). It is generally believed that a substan-

[illegible] pollutants are produced indirectly by hotels through energy usage. There is, however, very little information on the magnitude of these pollutants.

With the much publicised debate on climate change and global warming, the green movement has gained more recognition in the hotel industry worldwide through efforts made by various associations since the Rio Earth Summit in 1992. In 1993, the green campaign was reinforced by the International Hotels

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Environment Initiative and the Prince of Wales Business Leaders Forum. Eleven international hotel chains agreed to work together and initiated the development of manuals and guidelines to promote better environmental performance in the hotel industry (IHEI, 1993). In the following year, another 16 hotel groups echoed this campaign and formed the Asia Pacific Hotels Environment Initiative (Mackie, 1994).

Since then, environmental guide books for the hotel sector published by trade associations, hotel chains and scholars have become more readily available and drawn more attention from the hotel industries (Burnett *et al.*, 2000a and 2000b; Deng, 1996; Green Globe, 1994; IHIE, 1993; Marriott International, 1998; Reynolds, 1995). Many of these publications highlighted the importance of emissions such as sulphur dioxides and nitrogen oxides and their environmental implications, such as global warming, acid rain, and the depletion of natural resources. These publications also described different approaches taken by the hotel industry to address the environmental problems. There is, however, very little information on how to quantify environmental impacts due to hotel operations, particularly the emission of pollutants as a result of energy use. There appears to be a need for a better understanding of the local emission problem in relation to hotel operations and to find out the hotel industry's share in the total emissions.

In the past, hot water systems in the Hong Kong hotel industry were completely dominated by diesel oil fired boilers. After the enactment of an air pollution ordinance, cleaner gas-fired boilers penetrated the market. In 1996, there were some 20 hotels using gas-fired boilers (Hong Kong and China Gas Co Ltd, 1996). At least 50 hotels still use diesel oil fired boilers plus another four use electric boilers. In the late 1990s, three hotels installed electric heat pumps for water heating. It is envisaged that the application of heat pumps for hot water supply will become more popular in the local hotel industry. This is particularly because heat pumps have been widely recognised to have higher energy efficiency, ranging from 2 to 4, than gas-fired boilers which are limited to a range of 0.86–0.95 (ASHRAE, 1996). This implies a good financial saving potential on energy cost. It is thus worthwhile comparing emissions due to the use of gas boilers and electric heat pumps.

The main objective of this study is therefore to estimate the quantity of pollutants, namely, sulphur dioxides, nitrogen oxides, carbon dioxides and particulate, created indirectly by the Hong Kong hotel industry due to its gas consumption, and to discuss any likely implications for the environment. The scope of this study includes:

- estimating the air pollution attributable to gas consumption in the hotel industry during the 10-year period from 1989–1998;
- testing the validity of variables for estimating gas consumption in the hotel sector;
- estimating the likely rise in air pollution due to growth of the hotel industry envisaged in the years 1999–2003; and
- comparing the emissions attributable to the use of electric heat pumps and gas boilers.

Methodology

The present work covers the period 1989–1998 plus a projection for 1999–2003. To calculate the emissions, gas usage was multiplied by pollutant emission factors. Locally established emission factors were used for estimating the amounts of different pollutants in relation to gas consumption (Heinke *et al.*, 1995). These were based on a study and measurements made in 1995 and included emissions released during various stages, such as mining, transportation, and combustion of the fuel – naptha oil – for gas (town gas) generation. The emission factors used are listed in Table 1. The proportion of emissions released during gas combustion in the hotel's boiler was estimated by using an adjustment on the energy efficiencies between domestic water heaters given in Heinke *et al.*, and commercial boilers in general. Gas consumption in the hotel sector during the period from 1989 to 1998 was based on an earlier work on environmental costing (Chan, 2000). Since diesel oil fired boilers have been phased out during the past decade, an on-going structural change of energy mix has occurred. It is therefore not appropriate to use regression analysis on the hotel industry's gas consumption data in the past for the prediction of future gas consumption in the hotel sector. Instead, to reflect the future gas consumption, the study uses a summation of the adjusted old industry's gas consumption level in 1998 which serves as the foundation and the predicted gas consumption of those new hotels in future years. The adjustment factor adopted for the predicted gas consumption in the old hotels is a ratio of the projected occupancy in future years and the occupancy in 1998. For the prediction of gas consumption in new hotels, the data obtained from 11 surveyed hotels that mainly use gas for water heating and cooking was used.

In 1997, a survey was conducted covering energy data for the period 1994–1996 in the hotel industry. Twenty data-collection sheets were returned. Two were incomplete and seven did not have gas-fired boilers. The remaining 11 hotels investigated were located in different parts of the territory, representing around 20% of hotels using gas-fired boilers and gas-cooking equipment in Hong Kong. There were five three-star hotels, four four-star and two five-star. The number of guest rooms ranged from 163 to 736 with a gross floor area (GFA) of 6066 m^2 to 61,500 m^2. The average occupancy during the 1994–1996 period was around 83% for the 11 hotels in the sample. The sample was selected based on personal contacts and the availability of consumption data. Despite

Table 1 Emission factors

	Emission in gm per TJ				
Types	***SO2***	***NOx***	***CO2***	***Particulate***	***Total Weight***
Naptha-town gas	84,697	170,263	107,093,275	773	107,349,008
Natural gas	7,196	107,885	7,649,475	128	7,764,684
Natural gas-fired electricity	16,216	282,264	110,770,435	128	111,069,043
Coal-fired electricity	442,959	452,840	129,786,780	24,628	130,707,207

Source: Heinke *et al.*, 1995: 97, 99 and 100.

its lack of vigorous statistics, it is believed that the sample can give a good indication of the general trend in the local hotel industry. A linear regression method was used to analyze the relationship between gas consumption and three different variables: the hotel size, business activity and macroclimate. The size, activity and climate variables considered were gross floor area (GFA), the number of occupied rooms (OCC) and the heating degree days (HDD), respectively. A best-fit regression equation was then determined and was subsequently used to predict the gas usage of new hotels for the period 1999–2003.

Emissions in 1989–1998

The pollutants emitted during the gas production and its subsequent consumption include sulphur dioxides, nitrogen oxides, carbon oxides and fly ash. The first two pollutants are the main elements causing acid rain, while carbon dioxide is a greenhouse gas affecting global climate. The fly ash could react with the absorbed gases on the surface of the ash or act as a catalyst to chemical reactions.

Table 2 shows the quantities of pollutants emitted attributable to gas consumption in the hotel industry for the period 1989–1998. It can be seen that the annual amount of pollutants has kept growing over these years. During this

Table 2 Estimated emission through gas consumption by the hotel industry 1989-1998

Year	*SO2 (ton)*	*NOx (ton)*	*CO2 (ton)*	*Particulate (ton)*	*Gas consumption estimate by hotel industry (TJ)*
1989	28.37	57.03	35,869.82	0.26	334.94
1990	31.24	62.81	39,503.50	0.29	368.87
1991	33.70	67.74	42,604.92	0.31	397.83
1992	37.78	75.95	47,771.10	0.34	446.07
1993	43.87	88.20	55,474.32	0.40	518.00
1994	43.90	88.24	55,503.23	0.40	518.27
1995	44.89	90.24	56,759.44	0.41	530.00
1996	48.28	97.05	61,043.17	0.44	570.00
1997	48.29	99.68	57,456.48	0.44	569.00
1998	44.99	92.68	53,571.34	0.41	530.00

Notes:
1. Adjustment was made on Heinke's emission factors for SO_2, NO_X and CO_2 emissions according to the environmental performance data contained in the year book of the Hong Kong and China Gas Company Limited 1996–1997.
2. The hotel industry's gas consumption data for the years 1993-1998 was provided by the local gas company. The gas usage data for 1992–1989 was estimated by using the average gas consumption per occupied room multiplied by the number of occupied rooms in the industry.

period, the pollutants produced indirectly by the hotel industry have increased by 58%, due mainly to the growth in gas consumption. In 1998, the total weight of pollutants was estimated to be 53,710 tons including 45 tons SO_2, 93 tons NO_x, 53,571 tons CO_2, 0.41 tons particulate. It is also estimated that 1% of SO_2, 32% of NO_x and 67% of CO_2 are produced during combustion in the boiler. Among these, CO_2's amount is 290 times the total weight of the rest and its annual amount keeps on growing. Since the industrial revolution and particularly after 1950, the yearly emission of CO_2 has risen sharply. If the trend persists, it is estimated that by the end of the 21st century, there will appear an increase in average global temperature of about 4°C and a rise of approximately 88 cm in sea levels (IPCC, 2001). It is important for the local gas industry to consider the use of natural gas and the enhancement of efficiency in energy conversion by installing cogeneration systems.

Validity of Testing Variables

To have some idea about the relationship between annual gas usage and the size of the hotel buildings, annual consumption is plotted against the corresponding gross floor area (GFA) for 11 hotel buildings and the results are shown in Figure.1. It can be seen that annual gas consumption increases with the floor area. This indicates that more space demands more energy for hot water and cooking. Regression analysis of the data has resulted in a linear equation as follows:

$$y = 1{,}173{,}628 + 179x$$

where x = gross floor area (in m^2) and y = annual electricity consumption (in MJ). The correlation coefficient R is 0.919 and the proportion of predictable variance

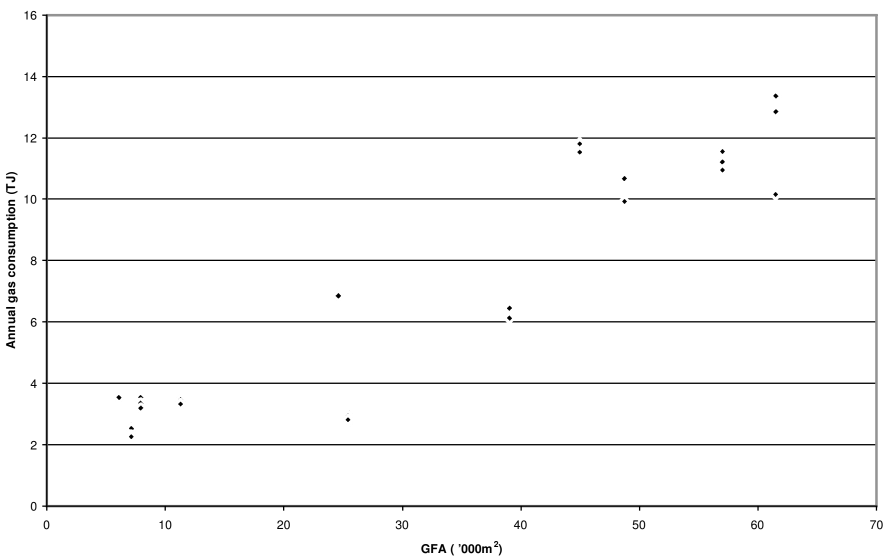

Figure 1 Annual gas consumption against gross floor area

R^2 is 0.845. Since R is above 0.8, the annual gas consumption can be considered well correlated with GFA.

A similar analysis was carried out to detect any relationship between the annual consumption and the other two variables. A weaker correlation, $R = 0.516$ and $R = 0.033$, was observed for the gas usage and the two testing variables, OCC and HDD, respectively. The selection criteria in the stepwise multiple regression further excluded, at the 0.05 level of significance, the entry of these two variables into the regression equation. This might be due to the nature of the proxy variable OCC itself, which has a lower degree of representation, and the insignificant influence of heating degree days in subtropical climates. Unlike most places in Europe and North America where gas is usually used for heating, the short and mild winter in Hong Kong reduces the chance of gas heating being used in the hotels.

Normalised Performance Indicator

Annual gas consumption per unit GFA, called the normalised performance indicator (NPI), was calculated. To get some idea about the relationship between gas consumption per unit floor and the size of hotel buildings, NPI was plotted against the corresponding GFA and is shown in Figure 2. It can be seen that the normalised performance indicators of most hotels with GFA below 12,000 m^2. fall between 300 and 500 MJ/m^2 per year. Hotels with a relatively large area tend to have lower NPIs, especially when GFA exceeds 20,000 m^2. The inverse relationship between NPI and GFA has a generalised correlation coefficient of –0.637. This suggests that larger hot water systems achieve higher energy efficiency. Statistics for NPI are summarised in Table 3. It is observed that the mathematical average and median are 259 and 256 MJ/m^2 per year, respectively. These two values indicate that both means are very close. The standard deviation is about 42% of the average. However, it should be noted that NPI in 1996 is

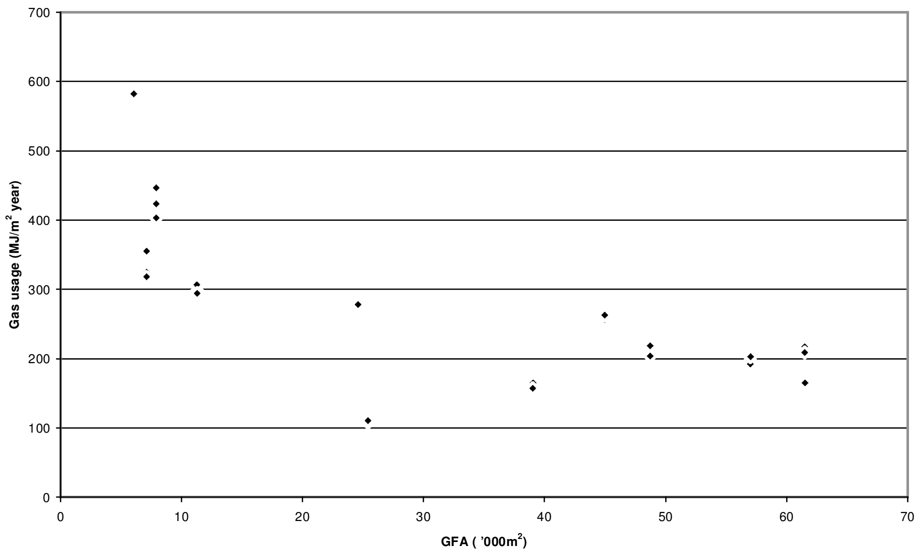

Figure 2 Normalised performance indicator

Table 3 Normalised performance indicators (NPI)

	1994	*1995*	*1996*	*1994–1996*
	(MJ/ m^2 year)	*(MJ/ m^2 year)*	*(MJ/ m^2 year)*	*(MJ/ m^2 year)*
Minimum	110.78	108.06	115.53	108.06
Maximum	403.21	423.34	582.27	582.21
Average	239.21	246.77	285.22	259.27
Median	232.67	232.69	263.03	256.39
Standard deviation	97.66	90.74	134.20	109.08
Occupancy	0.83	0.85	0.85	N.A.

around 15% higher than the other two years. This is mainly due to the higher occupancy, 0.9% more than that recorded in 1995, and a slightly better performance in food business in 1996. The gas consumption of hotel buildings in different parts of the world during the mid-1990s was documented and ranged from 850 MJ/m^2 per year in the US to 1135 MJ/m^2 per year in Canada (Energy Efficiency Office 1993; Energy Information Administration, 1995; Zmeureanu *et al.*, 1994). But none of the studies was conducted in subtropical climates. It is hoped that this finding will add to the literature on energy use in hotel buildings in this region and help contribute to any future work on the development of energy codes or standards for the local hotel building professions.

Emissions in 1999–2003

Since the Disneyland deal was finalised in 1999, the local tourism office has forecast that the number of hotel rooms will reach 45,000 in 2004, an addition of

Table 4 Projected emissions produced by gas usage in the hotel industry in 1999-2003

Year	*SO_2 (ton)*	*NO_x (ton)*	*CO_2 (ton)*	*Particulate (ton)*	*Gas consumption by hotel industry (TJ)*
1999	49.23	101.42	58,625.24	0.45	580.00
2000	53.73	110.69	63,982.37	0.49	633.00
2001	59.16	121.88	70,451.36	0.54	697.00
2002	60.86	125.38	72,472.92	0.55	717.00
2003	62.64	129.05	74,595.56	0.57	738.00

Notes:
1. The projected number of new rooms was derived from the *Hotel Supply Situation No.3* (2000).
2. The number of GFA per room was based on averages used in *Tender Price Indices and Costs Trends*.
3. A 95% market share factor is used to adjust the GFA of new hotels for the purpose of estimating gas consumption. This adjustment factor is based on the assumption that town gas will continue to replace diesel-fired boilers in the next decade and electric water heating systems will maintain a 5% share of the hot water systems as in 1998.

9579 rooms on the 1999 level (HKTA, 2000). Thus, it is predicted that the gas usage in the industry and its related emissions will increase. Table 4 shows the estimated annual gas consumption and the corresponding emissions in 1999–2003. The study projected that the gas consumption would reach 738 TJ in 2003. This represents an increase of 39% in gas consumption and hence emissions over the year 1998. Though the increase may be considered moderate, it will add to the burden of the present level of air pollution. It is likely that tourists will experience a deterioration in air quality after the inclusion of additional emissions released by the use of other fossil fuels. In 1999, a local survey of just over 1000 visitors revealed that air quality was acceptable to more than 75% of the tourists. But if the air quality deteriorates further, this could affect the local tourist industry (Cheung & Law, 2000). Another study also acknowledged that in the near future air pollution might deter overseas visitors, and the report encouraged the use of cleaner technologies within the hotel industry and other sectors (HKTA *et al.*, 1999). Thus, hotel industry-related associations and local tourism authorities should discuss with the gas company about this foreseeable increase in emission and consider measures to mitigate the problem. Before the introduction of the new measures, it is recommended that audits of existing hotels should include measures of boiler efficiency in order to determine any potential savings. At the

Table 5 Comparison of emissions between the use of gas boilers and heat pumps

	Energy Required (MJ)	*Emissions produced indirectly via water heating for one occupied room*				
		SO_2 (gm/MJ)	*NO_x (gm/MJ)*	*CO_2 (gm/MJ)*	*Particulate (gm/MJ)*	*Total (gm/MJ)*
Naptha gas						
Town gas boiler (0.86 OEE)	28.63	2.48	5.27	3,133.17	0.03	3,140.95
Coal-fired electricity						
Electric heat pump (2.0 COP)	14.32	6.30	6.44	1,857.94	0.29	1,870.97
Electric heat pump (3.0 COP)	9.54	4.20	4.29	1,238.63	0.19	1,247.31
Electric heat pump (4.0 COP)	7.16	3.15	3.22	928.97	0.14	935.49
Natural-gas fired electricity						
Electric heat pump (2.0 COP)	14.32	0.23	4.04	1,586.23	0.00	1, 590.50
Electric heat pump (3.0 COP)	9.54	0.15	2.69	1,056.75	0.00	1,059.59
Electric heat pump (4.0 COP)	7.16	0.12	2.02	793.11	0.00	795.25

Note: A norm of 24.62 MJ gas consumption for hot water supply per occupied room originated from Towngas Manual for Hotel Hot Water Systems (1996). and this was used as a basis for the above comparison.

same time, hotels should also investigate the feasibility of applying condensing boilers in subtropical areas as this technology has been proven to raise the boiler efficiency from 80% to 90% in cold regions. At a more localised control level, hotels could consider the installation of pressure regulators on shower heads and flow restrictors on water taps and sinks in order to curtail hot water consumption. For the reduction of gas for cooking, hotel management could consider installing energy meters in kitchens in order to monitor the consumption and to identify benefits from any changes made.

Emission from Electric Heat Pumps and Gas Boilers

Table 5 shows a comparison between emissions from the use of an electric heat pump and a gas boiler. The energy consumption of supplying hot water for an assumed 1.5 in-house guests is used as the basis for comparison. When a heat pump runs on coal-fired electricity and operates at a coefficient of performance (COP) of 3 or higher, there will be a significant drop in NO_x and CO_2 emissions. Nevertheless, the amount of SO_2 emitted is still two times that which is released due to gas consumption. If more effective SO_2 reduction technology can be incorporated into the coal-fired plant, an electric heat pump with a COP of not less than 3 would still be a good choice to reduce emissions.

On the other hand, when the heat pump is driven by natural gas fired electricity, pollutants produced will be remarkably less than those emitted by gas. Even if the heat pump operates with a COP of 2, the reduction on total emission is still significant. This is due to the fact that emissions from natural gas fired power plants are significantly lower than those from coal-fired power as indicated in Table 1. These include an over 99% reduction in SO_2 emissions and 96% reduction on the production of particulate. In addition, the NO_x and CO_2 emissions can also be decreased by 37% and 15%, respectively. Thus, this suggests that hotel operators, as customers of the electricity companies, should urge the electricity suppliers to speed up the change to natural gas in their fuel mix. Alternatively, hotel operators may also encourage gas companies to develop cost-effective and energy-efficient gas-driven heat pumps.

Natural Gas as Fuel for Power Generation

Since natural gas is generally recognised as a cleaner energy source, the energy and power industry in many cities have changed from coal and oil to natural gas for gas and power generation. Particularly in Japan, this gradual shift has been happening since the early 1980s (Osaka Gas Co Ltd, 1998; Tokyo Gas Co Ltd, 1998). As indicated earlier in Table 1, the emissions based on natural gas are also significantly less than emissions from town gas. Both SO_2 and CO_2 emissions drop by over 90%. The reduction also includes 37% less NO_x and 83% less particulate. However, the present gas supply in Hong Kong is extracted mainly from the petroleum product, naptha. Thus, the government and gas company should consider the possibilities of changing from the present naptha fuel to natural gas. The hotel industry, as one of the major town gas users, should also encourage this green motive and investigate the implications of this likely fuel change on the energy cost.

Environmental Reporting

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' (United Nations Environmental Program Industry and Environment Office, 1994). The purpose is to provide a visible yardstick on measuring the improvement of the environment. Currently, energy consumption in the hotel industry published in the trade literature such as the *Hong Kong Hotel Industry, Trends in the Hotel Industry* and *Worldwide Hotel Industry* tends to be in monetary terms. It is hoped that in the future trade publications and reports will incorporate energy use and estimated pollutant data similar to those presented in this study.

Conclusions

Energy data from the survey of 11 hotels have been analyzed in terms of annual gas consumption. It has been found that the average gas usage has a strong correlation with the corresponding gross floor area (GFA). This can help the estimation of gas usage in new hotel projects and the prediction of emissions.

Furthermore, this research has estimated the amounts of the pollutants formed by gas consumption in the hotel sector in Hong Kong. A general picture of emissions related to gas consumption in the local hotel industry has been observed. Also, the prediction of the rise of these pollutants due to the increase in the number of hotels in the next few years indicates there is a case for concern for the government, the energy sector and the hotel industry. It is suggested that additional energy saving measures should be implemented by hotels and more incentives for the purchase of cleaner air technology should be considered by the government. Meanwhile, the schedule for conversion to natural gas for power generation and the feasibility studies of using natural gas as town gas should be speeded up by the local power companies.

The findings in this study are based on a sample with some common characteristics, such as annual occupancies around 80%, high-rise city centre hotels, and number of room between 200–700. These may pose limitations on applying the norms established in this study to hotels with higher and lower occupancies, resort hotels and hotels with over 1000 rooms. Thus, it is suggested that future research and energy audits should look into hotels in these catagories in order to ascertain representative norms for hotels with these properties.

It has been observed that occupancy or occupied room nights has a low correlation with gas consumption. The number of guests plus staff, food cover and weight of linen might be a better choice as an explanatory variable for regression analysis in future since gas in hotels is mainly used for water heating and cooking. For the climate variable, it is suggested that future energy audits and gas consumption analysis should consider the fresh water supply temperature at hotel inlets. It has also been found that electric heat pumps with a coefficient of performance (COP) of 3 or higher would be more environmentally friendly in terms of pollutant emissions. Previous simulation studies indicated that solar-assisted heat pumps may achieve a COP of up to 6 (Çomakli *et al*., 1996; Huang *et al*., 1999). This theoretical COP suggests that solar-assisted heat pumps would probably be a useful alternative in reducing the depletion of power resources and lowering air pollution by end-users in places like Hong Kong where sunlight availability is high. Further investigation and development in this technology is worth considering.

Since the recent announcement of the green focus in the government's business plan, public concern for the environment now runs deeper than at any time in Hong Kong's history. The prospect that the tourism industry will be receptive to a campaign on energy conservation and environmental protection looks promising. Considering the rapid hotel development in Asia, an energy-conscious and environmentally friendly Hong Kong hotel industry would have far-reaching implications for the environment in the region.

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Note

1. Energy efficiency = (Heat added to water ÷ Heat in the fuel or electricity supplied) × 100%.

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