Energy-saving Supporting Tourism Sustainability: A Case Study of Hotel Swimming Pool Heat Pump

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Based on energy-related measurements, this article evaluates the thermal performance, energy-saving, indirect emissions and financial feasibility of using heat pumps for hotel out-door swimming pools in subtropical climates. A rooftop pool of a city-centre hotel was investigated. It was found that the average coefficient of performance (COP) was around 2.0. The measured electricity consumption was 24.6 MWh and the total heat output was 49.1 MWh for the heating season studied (mid-December to the late April). Compared with conventional electric boilers and gas-fired condensing/non-condensing boilers, the total energy savings during the heating season ranged from 26.5 to 32.5 MWh. Greenhouse and noxious emissions can also be indirectly reduced by about 12,000 kg. A discounting approach was adopted to compute the net present value of fuel costs over a lifecycle of 10 years. It was found that, over a 10-year lifecycle, the energy cost could be reduced by HK$226,400 when a heat pump with an average COP of 2.0 was used instead of a conventional electric boiler. Derived from the energy cost saving over other conventional type of water heating equipment, the simple pay-back period can be about 2 years and the lowest internal rate of return can be 39%.

Introduction

The Hong Kong economy has been shifting from being manufacturing-based to being service-oriented since the early 1980s. Tourism and hence the hotel industry has become a major energy end-user (Lam & Ng, 1994). There is growing concern about energy consumption and its adverse effects on the environment. The drive to get the hotel industry and other businesses to recognise the importance of environmental management gathered momentum after the action plan for sustainable development Agenda 21 was adopted at the 'Rio's Earth Summit 1992'. After this Summit, the green movement gained more recognition in hotels worldwide through efforts made by various associations. In 1993, the International Hotels Environment Initiative (IHEI) and the Prince of Wales Business Leaders Forum reinforced this green campaign and 11 international hotel chains agreed to work together and initiated the advancement of 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). As a result of these trends, the hotel industry has

0966-9582/03/01 0074-10 $20.00/0

begun to become more energy and environment-conscious. During the Asian financial turmoil in late 1990s, hotel managements became keen to lower operational costs; energy-saving issues and energy-efficient technology have, therefore, received further attention.

The heat pump is one of the energy-saving technologies considered by hotel operators. Working on a refrigeration cycle it extracts heat from a heat source at a low temperature and upgrades it to a high temperature.[1] The amount of heat discharged from the heat pump is generally several times larger than the power consumed in driving its compressor. Heat pumps have been used for water heating in in-door swimming and pleasure pools in Europe since the 1970s (Bobel, 1974; Butson *et al.*, 1985; Kirn & Fluck, 1977). However, most of the studies are confined to the application of heat pumps for indoor swimming pools. Very little work has been done on heat pump applications for outdoor swimming pools, especially in the subtropical region.

Among the over 80 hotels in Hong Kong, there are currently 31 outdoor swimming pools. All but four pools do not have heating during the heating season. There is a growing interest in the installation of heating systems so that these non-heated outdoor pools will be opened during the heating season, usually from mid-October to April. Using air-to-water heat pumps for water heating instead of the conventional electric and condensing /non-condensing boiler systems has been generally regarded as an energy-efficient and environment-friendly technology. There is, however, very little information on the energy performance of heat pumps for pool water heating and its financial implications. Such data are crucial in deciding whether to adopt heat pump technology for pool water heating in new hotel buildings or existing ones during a major refurbishment. Therefore, the objectives of this study were to evaluate the energy efficiency, calculate the amount of energy saved, estimate the reduction in emissions and to appraise the investment in heat pump application for hotel swimming pools. To this end, an outdoor pool in a city hotel with a heat pump installation was selected as a case study. This article presents the work and discusses its findings.

Hong Kong's Climate and the Case Study

Hong Kong, with 22.3°N latitude and 14.2°E longitude, is situated along the southern coast of China within the subtropical region, and experiences distinct changes in weather due to its location on the southern edge of the continent of Asia facing a vast expense of the ocean. The winter months are between December and February. Mean temperatures are around 15–18 °C with monsoon winds blowing from the North and North East. Spring is from March till early May, and is usually cloudy with periods of light rain. The summer season spans May to September. The monsoon blows from the South and South East with an average temperature of 27–29°C. It is hot and humid with occasional showers and thunderstorms. At times, typhoons strike Hong Kong and bring heavy rain and strong winds. Autumn is short and normally runs from October to November. Sunny bright skies dominate with dry conditions and a mean temperature of 25 °C.

A four-star hotel in the city centre of Hong Kong was selected for this study.

The outdoor pool was located on the rooftop with a total water surface area of 35 m^2 and a volume of 52 m^3. The pool water was circulated was by conventional means, i.e. through a sand filter and chlorinator. An electric air-to-water heat pump was installed on the floor underneath the rooftop. Cold air released by the heat pump was extracted through louver-type windows to the building's exterior. The heat pump ran on refrigerant R_{22} and had a peak heating capacity of 30 kW. The pool temperature was maintained at 28 °C by a thermostat in the return water line from the pool.

Energy Efficiency Analysis

The energy efficiency of the electric air-to-water heat pump was investigated in terms of its coefficient of performance (COP), which is the ratio of the total thermal power released from the heat pump to the total electrical power used by the heat pump. In this study, the COP is determined as follows.

$$\mathrm{COP} = \frac{\rho \quad m \quad C_p \quad (T_{out} - T_{in})}{P}$$

where ρ is the density of water (kg m^{-3}); m, the volume flow rate of water (m^3 s^{-1}); C_p, the specific heat of water (kJ kg^{-1} °C^{-1}); T_{out}, the temperature of the water supply to the swimming pool (°C); T_{in}, the temperature of water return from the swimming pool (°C); and P, the electrical power input (kW).

An electrical power meter, two temperature probes and a water flow meter were installed to measure the electrical power input, water temperatures and water flow rate. Data were automatically logged half-hourly during the heating period from mid-December 1999 to April 2000.

To estimate the reduction in emissions to the atmosphere achieved by the use of a heat pump as opposed to an electric boiler, the difference in total electrical energy used by each system was calculated. The saving achieved was multiplied by the two types of emission factors that were taken into account, as follows. First, the lifecycle emission factors for electricity generation established by a local study was adopted for the analysis (Heinke *et al.*, 1995). These factors included the emissions released during the fuel lifecycle of electricity generation including the stages: mining, transportation, production and distribution. The other type of emission factors used is related to the emissions during the electricity production stage – from primary energy to secondary energy. The data were obtained the from Heinke *et al.* (1995) study and were adjusted according to the fuel mix of the electricity generation.

Lifecycle Energy Cost

Discussions with several contractors revealed that the capital cost of a heat pump could vary widely from one project to another, depending on who the client was and how eagerly the contractor wanted the job. It is envisaged that the capital cost of a heat pump system would be close to that of an electrical heating one and lower than a gas-fired boiler system because of the extra flue and pipe work involved in a gas-fired installation. The capital costs of different heating systems were not, therefore, compared in this study. Only the lifecycle energy costs of using different heating systems were investigated.

A lifecycle of ten years was assumed for the machine and its associated installations. Since the vendor was responsible for maintenance, the financial evaluation of the running costs considered only the energy costs. The total heating requirement for the swimming pool during the heating season was obtained from the measurements made in this study. The corresponding electricity consumption of the heat pump was determined from the heating requirement and the measured COP. The likely energy usage of the other heating equipment (i.e. conventional electric boiler and condensing/non-condensing boilers) was estimated from the measured heating requirement and the average operation efficiency given by prospective suppliers. The net present value of the energy cost over the 10-year analysis period was determined from the following equation:

$$NPV = \sum_{n=1}^{10} (EC)_n = (EC)_1 \sum_{n-1}^{10} \left(\frac{1+i}{1+d} \right)^{n-1}$$

where NPV is the net present value of energy cost over the 10-year period (HK$); $(EC)_1$, the energy cost during the first year (HK$); i is the rate of fuel cost increase; d is the market discount rate; and

$$\sum_{n=1}^{10} \left(\frac{1+i}{1+d} \right)^{n-1}$$

An average bulk electricity tariff of HK$0.8/kWh and a gas tariff of HK$0.21/MJ at the beginning year was assumed. The increase rate in fuel prices was based on the tariff of energy prices during the 10-year period from 1988 to 1998 (Census and Statistics Department, 1988–98). An average rate of 4.3% and 6.2% for the electricity and gas price, respectively, was applied to calculate the net present value. A market discount rate of 7.3% was considered according to the latest information issued by the local monetary authority (Hong Kong Monetary Authority, 1999).

Results and Discussions

Figure 1 shows the results of the field test for the heat pump's daily COP. The average daily COP was 2 and a peak COP of 2.4 was recorded when the mean ambient dry bulb temperature was around 18 °C. In January and February, the heat pump ran with a COP of around 2. After March, the average COP dropped to 1.7 – 1.8 as the ambient air temperature tended to be higher than in January and February. As temperature is generally recognised as a key parameter in the performance of air-source heat pumps, the measured COP data were analysed in relation to the ambient temperature and the result is shown in Table 1. It can be seen that the heat pump attained its highest performance with a COP of 2.13 when the ambient temperature was 18 °C. When the ambient temperature gradually rose from 18 to 22 °C, the COP floated around 2.0. Tests on heat pump water heaters conducted by national laboratories, utilities and manufacturers revealed that the COP usually ranges from 1.5 to 3.0, with averages of 2.0 to 2.2 (Caneta Research Corporation, 1980, 1993; ETI, 1979; Energy Utilization System, 1980). This indicates that the COP found in this field study is in agreement with laboratory measurements.

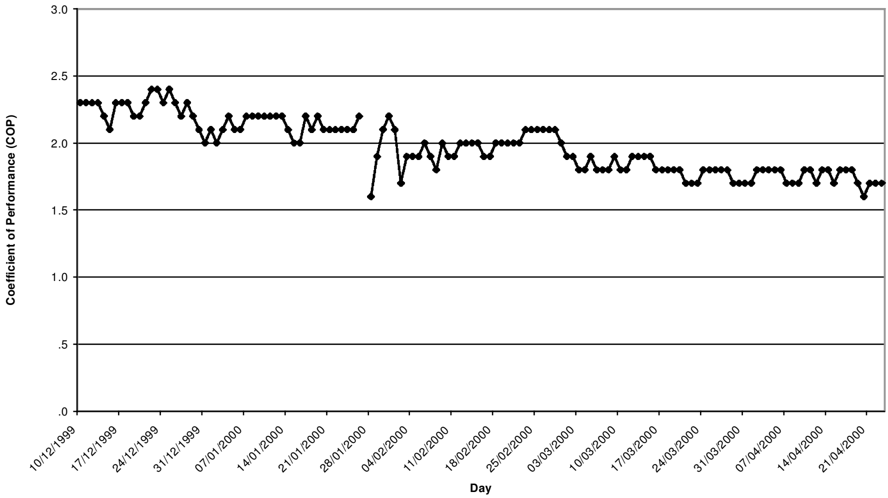

Figure 1 Daily COP of heat pump

Table 1 Coefficient of performance under different ambient temperatures

Proportion of run time	*Average COP*	*Ambient temperature (°C)*
0.1%	1.69	16
1.9%	1.98	17
6.9%	2.13	18
12.4%	2.09	19
16.9%	2.12	20
20.2%	2.12	21
18.2%	2.01	22
12.9%	1.87	23
6.2%	1.77	24
2.9%	1.73	25
0.5%	1.71	26
0.8%	1.80	27
0.1%	1.49	28

It is worthy noting that for 90% of the runtime during the field measurements, the ambient temperature ranged from 18 to 24 ºC. Within this range, the largest proportion – 20% – of runtime the ambient temperature was found to be 21 ºC which would be a valuable indication for future system design tailored for unairconditioned environments in the subtropical area.

The total heating requirement during the heating season was determined from

Table 2 Comparison of energy consumption per heating season

Equipment	*Energy consumption per heating season (MWh)*
Heat pump (2.0 COP)	24.6
Electric boiler (0.96 OEE)	51.1
Condensing boiler (0.95 OEE)	51.6
Non-condensing boiler (0.86 OEE)	57.1

Table 3 Estimated reduction in annual emissions due to the use of a heat pump

	Emission (kg)				
	SO_2	NO_x	CO_2	*Particulate*	*Total weight*
Types					
Electricity production plant	39	37	11,937	2	12,016
Fuel cycle	42	43	12,382	2	12,469

the measured supply-water flow rate and the difference between the supply- and return-water temperatures. The total heat supplied to the outdoor swimming pool was 49.1 MWh. The corresponding measured total electricity consumption was 24.6 MWh. This gives an average COP of 2.0 as reported earlier in Table 1. The energy performance of four different heating systems, namely a heat pump, an electric boiler, a condensing boiler and a non-condensing boiler were considered. Table 2 shows a comparison of the total energy usage for the heating season. The average overall energy efficiencies (OEE) for the boilers were obtained from the manufacturer and local suppliers. Compared with conventional water heating systems, a heat pump can generate a total energy-saving ranging from 26.5 to 32.5 MWh in a heating season.

If we consider only the use of a heat pump instead of an electric boiler, this study estimated that 26.5 MWh could be saved in the heating season. Table 3 shows the estimated reduction in emissions due to the adoption of a heat pump to replace an electric boiler. It can be seen that, on a fuel-cycle basis, 42 kg of SO_2, 43 kg of NO_x, 12 10^3 kg of CO_2 and 2 kg of particulates can therefore be saved. For the likely reduction in emissions confined to Hong Kong, it is estimated that the reduction in SO_2, NO_x, CO_2 and particulates for this case would be 39 kg, 37 kg, 12 10^3 kg and 2 kg, respectively.

An equation was used to estimate the net present value of the energy cost over a 10-year lifecycle for the four different heating systems. Table 4 shows the net present value of energy costs over the 10-year lifecycle for the four types of heating systems. It can be seen that the annual energy costs for heating the outdoor pool would be about HK$40,000 for conventional heating systems (i.e. electric and gas-fired boilers). If a heat pump system with an average COP of 2.0 was used, the annual energy costs would be about HK$20,000, a financial saving of about 50%. Over a 10-year lifecycle, the energy costs could be reduced by

Table 4 Lifecycle energy cost analysis showing the net present value

Discounting factor			*Net present value of energy cost (000 HK$)*			
Year	*Electricity*	*Gas*	*Heat pump (2.0 COP)*	*Electric boiler (0.96 OEE)*	*Condensing boiler (0.95 OEE)*	*Non-condensing boiler (0.86 OEE)*
2000	1.000	1.000	19.7	40.9	39.2	43.4
2001	0.972	0.990	20.0	41.5	41.3	45.6
2002	0.945	0.980	20.3	42.1	43.4	48.0
2003	0.918	0.970	20.6	42.7	45.6	50.5
2004	0.893	0.960	20.9	43.4	48.0	53.1
2005	0.868	0.950	21.2	44.0	50.4	55.8
2006	0.844	0.940	21.5	44.6	53.0	58.7
2007	0.820	0.930	21.8	45.3	55.8	61.7
2008	0.797	0.921	22.1	45.9	58.7	64.9
2009	0.775	0.911	22.5	46.6	61.7	68.2
Total	–	–	210.6	437.0	497.1	549.9

HK$226,400 when a heat pump with an average COP of 2.0 was used instead of a conventional electric boiler. The lifecycle energy costs for the non-condensing gas boiler was HK$550,000, the highest among all the heating systems considered. The total saving in energy costs over a 10-year lifecycle was of the order of HK$340,000. This is considered attractive financially, because the average hot water system costs range from HK$30–70,000 for the size of the swimming pool investigated in this study.

To have some indication of the financial viability of installing a heat pumps, the simple pay-back period, internal rate of return and accounting rate of return were computed. Discussions with hotel operators revealed that the local utilities (power and gas companies) tended to pay for the capital cost of installing conventional heating systems. This was due mainly to the desire to have a bigger market share in the energy supply sector. Consequently, many hotel operators are faced with a choice between zero capital costs with higher electrical or gas bills and paying for a heat pump with lower energy costs. The capital cost of the heat pump installation considered in this study was HK$45,000. This was used in the financial implication analysis and the result is shown in Table 5. The relative saving in energy costs derived from the use of a heat pump for the first two years was in the region of HK$40,000, resulting in a simple payback period of just about two years. Over a 10-year lifecycle, the internal rate of return based on the energy cost savings of a heat pump *versus* other conventional water-heating systems ranged from 47% to 60% and the annualised accounting rates of return were over 50%. Even for a shorter 5-year lifecycle, a heat pump can still produce an economical energy cost saving. The minimum saving was equivalent to an internal rate of return of 39% and an accounting rate of return of 48%. These indicate that the

Table 5 Relative energy cost saving and financial implications

	Net present value of energy cost saving (000 HK$)		
Year	***Heat pump versus electric boiler***	***Heat pump versus condensing boiler***	***Heat pump versus non-condensing boiler***
Initial capital outlay	-45.0	-45.0	-45.0
2000	21.2	19.5	23.7
2001	21.5	21.3	25.6
2002	21.8	23.1	27.7
2003	22.1	25.0	29.9
2004	22.5	27.1	32.2
2005	22.8	29.2	34.6
2006	23.1	31.5	37.2
2007	23.5	34.0	39.9
2008	23.8	36.6	42.8
2009	24.1	39.2	45.7
Total	226.4	286.5	339.3
Payback period in years	2.1	2.2	1.8
Internal rate of return			
in 5-year-period	39%	40%	51%
in 10-year-period	47%	50%	60%
Annualised accounting rate of return			
in 5-year-period	48%	52%	62%
in 10-year-period	50%	64%	75%

heat pump is not only economically viable but also financially attractive from an investment point of view.

Conclusions

Energy conservation with different energy-saving technologies has become a principal element in sustainable development in many developed nations. It is closely related to both environmental issues and monetary considerations. An outdoor heated swimming pool can be a major energy end-user as well as a key value-added service in the hotel business in subtropical regions. The thermal performance and energy costs of applying a heat pump in a 35 m^2 outdoor swimming pool in a city-centre hotel were investigated. The actual electricity consumption and thermal energy output during the heating season (i.e. mid-December to April) was measured and analysed. It was found that the average COP was 2.0 and the electricity consumption was 24.6 MWh during the heating season. The saving in energy use for heating water was substantial, in the region of 50% when compared with other conventional heating systems. The saving in energy can also indirectly reduce some 12,000 kg of greenhouse gas and noxious emissions in a year. The annual energy cost saving was just over HK$340,000 compared with conventional electric and gas-fired boilers. Over a 10-year life cycle, the total financial saving in energy cost would be about HK$340,000. Given a price range of HK$30,000–70,000 for a hot water system for the size of the swimming pool studied, the result indicates that using heat pumps for outdoor swimming pools are beneficial both financially and environmentally.

While the study was carried out in Hong Kong, it is envisaged that the approach would be appropriate to other locations with similar climates and commercial activities. Given the rapid growth in tourism and water parks in southern China, this study can have wider implications for energy efficiency and sustainable development in the region.

Acknowledgements

The authors are grateful to the hotel management and engineering staff for their help with the field measurement. The authors would also like to thank the hotel operators and heating equipment suppliers for their views and information on operation and cost. Financial support for W.W. Chan from the Hong Kong Polytechnic University is gratefully acknowledged.

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