International Journal of Hospitality Management 33 (2013) 1–5

Contents lists available at SciVerse ScienceDirect

International Journal of Hospitality Management

journal homepage: www.elsevier.com/locate/ijhosman

# Power consumption modeling and energy saving practices of hotel chillers

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ARTICLE INFO

*Keywords:*
Chiller
Hotel
Shanghai
Electricity
Energy
Power consumption

ABSTRACT

Hotel buildings consume a significant amount of energy, especially their chiller systems. This study aims to create a model of the power consumption of the hotel chillers, and to identify the practical means to reduce the power usage of chillers. The examined parameters include air-conditioned floor area, guest floor area, gross floor area, number of employees, room occupancy, food cover, outdoor air temperature, window velocity, service type and relative humidity. It is anticipated that the developed modeling equation may provide a reference for hotel engineers to forecast any diagnostic problems and form a benchmarking indicator for comparing chillers' energy efficiency. A survey of hotels in Shanghai was carried out to collect energy consumption data of chillers during air-conditioned cooling months. Regression analysis indicates that number of staff was a major and statistically accepted factor in explaining the electricity consumption of chiller in hotels. In addition, the paper discusses some means and suggestions in reducing chillers' power consumption.



## 1. Introduction

The close link between environmental effect and consumption of energy is an issue that has gained attention in the past decades. Most externalities of this issue are produced during the generation of electricity and its fuel exploitation. The principal air pollutants are emissions of carbon dioxide ($CO_2$) or the principal "greenhouse gas," sulfur dioxide ($SO_2$), nitrogen oxide ($NO_x$), ozone, and particulates (Chan et al., 2008; Chan and Lam, 2002a,b). Shanghai, as a metropolitan city in China, faces these environmental problems as well. The continued economic boom and the growth of tourism activities in the city bring a significant increase in the number of high-rise hotel buildings and subsequent environmental problems. In fact, the hotels are major energy consumers.

The heating ventilation and air-conditioning (HVAC) system in subtropical hotels consumes about 35–50% of electricity, which ranks it as the most energy-consuming facility (Chow and Chan, 1993). In high latitude countries, like the United Kingdom and Greece, their cooling facilities account for only 4–10% of the total energy usage in hotels (Efficiency Office, 1994; Santamouris et al., 1996). In subtropical areas, Yu and Chan (2010) found that the operation of chillers and cooling towers leads to the peak electricity demand, and accounts for about half of the electricity consumption for air conditioning in hotels. However, a paucity of information exists in the relationship among electricity consumption, its associated parameters, and ways to save the power consumption of chillers. The establishment of the relationship between electricity usage and variables of the power consumption of chillers could enable hoteliers to predict electricity consumption. Predicting the amount of energy consumption may help form the benchmark for monitoring the energy usage and efficiency of chillers.

Shanghai is the major gateway to mainland China and acts as the major engine for regional economic developments. The number of international visitors to Shanghai reached 8.5 million in 2010 (Shanghai Statistical Bureau, 2011), and this number is expected to grow in the coming decades. Hence, hotels play a significant role in the tourism and economic development of Shanghai. In 2009, the total number of hotels reached 298, which is twice the number in 1990 (China National Tourism Administration, 2010). While Shanghai is not located in the subtropical region, its six to seven months of summer hotness require the installation of air cooling facilities in hotels. The foreseeable increase of new hotels will bring huge energy consumption and its associated emission problems. In addition, the initial literature review indicated that previous investigations were confined to the study of the overall power usage and the associated parameters of the HVAC system, and did not look into the core energy consumption of the cooling system and its related parameters. This gap necessitates conducting the present study. Thus, the present study aims to create a model of the power consumption of the hotel chillers in Shanghai, and to identify the practical means to reduce the power usage of chillers.

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0278-4319/$ – see front matter 
http://dx.doi.org/10.1016/j.ijhm.2012.12.008

## 2. Literature review

Prior modeling studies analyzed the relationship between the overall electricity or energy consumption and its respective variables of hotels. Redlin and deRoos (1980) pioneered this type of investigation by using regression techniques and weekly data to estimate the energy usage of individual hotels in the temperate region of the United States.

Although there are studies in energy use of the accommodation industry, their investigations were confined to the overall energy consumption of the hotels, and did not focus on chillers, which consumed most of the electricity in the warm and hot regions. The parameters investigated in previous studies were limited to gross floor area, cooling degree days, outdoor temperature, occupancy, and food cover (Deng and Burnett, 2000; Chan and Lam, 2001, 2002a,b; Chan, 2005). Rajagopalan et al. (2009) reported the number of staff and their densities are ranked on top of the list of factors associated with overall hotel energy consumption in Singapore. However, these studies investigated the electricity consumption of all electricity-driven facilities in hotels, and did not narrow down their focus on the energy consumption of the HVAC systems or the chillers, which are potential areas for substantial and effective energy savings. Chillers alone account for 25% of the overall HVAC system energy usage and play a significant part in the power consumption of the cooling process. Thus, these findings necessitate the investigation of the power consumption of chillers in relation to various variables and parameters (Xue, 2007).

In the field of building engineering, few studies investigated the links of chiller power usage, its consumption-related components, and building areas of hotels. Moreover, the studies focused mainly on establishing the relationship between the power usage of chillers and the physical activities of the components of the HVAC systems (see Yu and Chan, 2010).

The above-studied variables are correlated with hotel energy consumption to a certain degree. The present investigation incorporates all these variables in the test and development of a model representing the electricity usage of chillers. However, since gross floor area is a loosely defined parameter, this study attempts to use two additional energy-related floor area variables for testing the proposed model. These variables include the air-conditioned floor area and the guest floor area, which are the two types of floor areas that really use cooling service.

## 3. Methodology

As of 2010, 54 four star hotels are operating in Shanghai (Shanghai Statistical Bureau, 2009). A survey of the electricity consumption of chillers in the four-star hotel segment was conducted. Questionnaires were sent to all 54 hotels and 13 questionnaires were rated valid. After eliminating the two extreme cases, information obtained from the 11 hotels were analyzed. The number of guest rooms in the sampled hotels ranged from 200 to 761 with a gross floor area of 24,523–113,287 $m^2$. The average occupancy from April to November was around 75%. The sample was selected based on personal contacts and the availability of consumption data. Despite its less rigorous statistics, the sample provided a good indication of the general electricity usage of chillers in the local four-star hotel segment.

Multiple linear regression method was used to analyze the relationship between the electricity consumption of the chillers and the 11 different variables. The studied parameters followed three dimensions, namely, hotel size, business activity, and climatic influence. For hotel size, the current study examined the gross, air-conditioned, and guest room floor areas. For activities or operations, the tested parameters included number of staff,

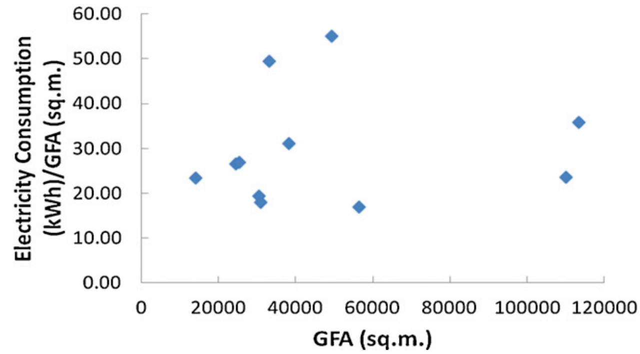


**Fig. 1.** Relationship between electricity consumption and gross floor area.

room occupancy, cooling degree days, types of service, and design strategy of unequally sized chillers. Weather-related parameters investigated were outdoor average temperature, wind velocity, and relative humidity.

To identify the energy saving methods available for chillers, the investigation conducted 15 interviews with HVAC consultants responsible for the hotel projects, a director of engineering of the hotel groups, and lecturers in building energy research. Interviewees were asked to recommend ideas on energy saving for chillers in both operation and design perspectives. Literature research on the energy saving potential of chillers and their aspects was conducted to justify the collected views.

## 4. Results

Electricity consumption data of chillers from the survey were gathered and analyzed. Electricity performance indicators based on gross floor area (GFA) were determined. Fig. 1 shows the annual electricity use of the chillers of the samples against the corresponding GFAs. The survey found the mean electricity usage of chillers is 24 kWh per square meter on annual basis with a standard deviation of 12 kWh during the study period from April to November. At 95% confidence interval, the mean lies within a range of 15–33 kWh.

Both simultaneous and stepwise methods were applied to create the model. The analysis indicated that the explanatory power, $R^2$, of all modeling linear multiple regressions under the above two methods were over 0.8, with a standard error ranging from 174,580 to 218,908 kWh.

Under the stepwise regression method, the following regression with $R^2 = 0.84$ was obtained:

$$\begin{aligned} E_{(\text{Apr-Oct})} = {} & 1091.8 \times \underset{(t=6.65)}{\text{STAFF}} - 283,120.1 \times \underset{(t=5.17)}{\text{CHILLER}} \\ & + 27.1 \times \underset{(\text{t}=14.72)}{\text{GFA}} - 35.9 \times \underset{(t=-14.18)}{\text{A\_GFA}} \\ & + 25,439.1 \times \underset{(t=4.89)}{\text{TEM}} - 494,605.6 \end{aligned} \tag{1}$$

where $E$ is the electricity consumption of the chiller (unit in kWh); STAFF is the number of hotel employees (unit in head); CHILLER is the unequally sized chiller design (a dummy variable in which CHILLER = 1 if an unequally sized chiller is available, and CHILLER = 0, otherwise); GFA is unit in square meter; A_GFA is air-conditioned GFA (unit in square meter); TEM is average temperature (unit in degree Celcius). All these five parameters are statistically accepted and strongly correlated variables in explaining the electricity consumption of chillers. Given that the VIFs of the GFA and A_GFA were less than 10, there was no colinearity between these two variables.

As shown in Eq. (1), the availability of unequally sized chiller designs has the largest magnitude of influence on the electricity consumption of chillers. This statistically accepted parameter