Analysis of Sensory Information for Efficient Operation of Energy Management Systems in Commercial Hotels

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ABSTRACT: Due to fluctuating energy prices and ever-increasing uncertainties in supply, the industrial and commercial sectors are poised to speed up introduction of energy saving mechanisms. Having badly hit by recent economic recession, the hotel industry has ever more reasons to save energy. A typical star-class hotel was chosen to conduct the energy usage optimization study presented in this paper. The hotel's energy consumption pattern data was collected and analysed. Based on sensor information and manage information system data, cooling load requirement is correlated with the number of occupied rooms. It is shown that substantial savings can be achieved by introduction of wing operation to the hotel room allocation system. Moreover, the findings from the present study can be incorporated into a building management system (BMS) when it comes to automating the wing operations.

1 INTRODUCTION

Global economic conditions, state regulations and the customer attitudes nowadays require introduction of energy efficient technologies in commercial and industrial ventures. When it comes to the fiercely competitive hospitality industry, a customer's perception on a particular service provider, a hotel for example, decides the future of business. In this backdrop, portraying themselves as being energy efficient and hence caring for environment brings the added advantage of addressing the customers' minds while saving energy bills simultaneously.

In countries like Maldives the economy almost entirely depends on the tourism industry. When it comes to Sri Lanka, the service sector where the tourism industry belongs to, contributes 58% to the GDP while the industrial and agricultural sectors share 30% and 12% respectively. In terms of energy usage, the domestic and commercial sectors consume approximately 48% Sri Lanka's total. The industrial sector consumes 26% and the balance energy is shared by the transportation (Sri Lanka Sustainable Energy Authority, 2007). Out of this, the Sri Lankan hotel sector consumes approximately 180 GWh from the national electrical grid at present. The government is planning to further expand the service sector with a notable attention to the tourism industry, a project that needs more energy supply and efficient energy saving practices. This further highlights the importance of closely investigating the energy consumption pattern of commercial hotels.

There have been numerous studies conducted worldwide in order to investigate the energy consumption and load profile in commercial hotels. As a result, Energy Use Intensity (EUI) has been introduced, which is the average annual energy consumption per square meter of floor area. Deng & Burnett, (2007) reported the energy performance of sixteen of quality hotels in Hong Kong and EUI measurements. To maintain the green image and possible forth coming European Union eco-labeling scheme, Greece has carried out an energy study on hotel sector dividing the sector into three sections; mount, city and costal (Karagiorgas et al, 2007). Study on energy performance of Singapore's hotel buildings had been conducted (Priyadarsini et al, 2009) where energy consumption data and other pertinent information were collected from 29 quality hotels through a national survey. Building features and operational characteristics contributing to the variations in hotel energy performance in Singapore were also discussed. It was reported that in Singapore the annual average total EUI in these hotels was 427 kWh/m^2. Furthermore, utilization of renewable energy in the hotels and introduction of technology into the hotel sector were carried out in (Karagiorgas et al, 2006), focusing on the applications of the renewable energies in the tourism industry. Deng (2003) presented a case study consisting of electrical load profiles analysis in a Hong Kong hotel examining the potential energy saving opportunities (ESOs) in its building services installations. A study of Jordan's energy consumption in the hotel sector was reported by Ali et al (2008). The results through a survey on environmental performance in the tourist accommodation sector in Jordan were used to evaluate energy conservation in hotels. Ali et al (2008)'s study was covering the period 10–17 August 2006, where they claim "survey was designed and distributed to hotels' managers and departments' supervisors in order to understand the environmental performance in the tourist accommodation sector in Jordan during the period".

In this paper, commercial hotel in a tropical climate (in Sri Lanka) has been selected for investigation. This hotel is a five star grade hotel and was the first five star hotels to be built on the coastline. The proposed approach is illustrated with sensor information and manages information system data in order to optimize the hotel allocation system. Rest of the paper is organized as follows: The problem statement with the background is given in Section 2. Proposed methodology which describes the analysis is presented in Section 3. Mathematical model and the optimization criteria with results are described in Section 4. Finally, concluding remarks are given in Section 5.

2 PROBLEM STATEMENT

With the global economic downturn some of the industries collapsed irrespective of the country status. In fact the same situation has been experienced in the hospitality industry, in particular, when it comes to operation of commercial hotels. To make the business profitable various optimization techniques have been introduced. However, the cost reduction mechanisms should not compromise the quality of service. One possible way to reduce the operational cost is to introduce energy saving mechanisms. As per most of previous studies carried out in several countries, EUI at hotels in London is 715 kWh/m^2 (Deng & Bunnet, 2007), same reported in Hong Kong hotels as 564 kWh/m^2 while electrical energy intensity has been reported as 257.8 kWh/m^2 and 366 kWh/m^2 in two studies in Hong Kong hotels. Though the research team found very weak correlation between electricity consumption and the room occupancy, yet they recommended the management to make much higher attention on energy management during low occupancy period (Priyadarshihi et al, 2009). From previous studies on hotel energy sector; it has been found that almost 73% from the total hotel energy requirement was electrical energy in a selected set of hotels in Hong Kong, while it was higher at 77% in Singapore hotel sector. When it comes to energy consumption by the air conditioning system, its about 44% of total electrical energy of the hotel in Hong Kong (Deng & Bunnet, 2007) and more than 50% in Singapore. These numbers included included air handler units, fan coil units, from the total electrical energy consumption of the hotel (Kinney & Lee, 2000). In Greece, energy consumption for ventilation and air conditioning found to be over 60% (Karagiorgas et al, 2007).

In the five star hotel selected for this study, the major energy sources are grid electricity, diesel for self electricity generation, furnace oil for steam boiler operation and LP gas for cooking purpose. In comparison to world-average EUI, it was found that the EUI at selected hotel was much lower at 139.9 kWhe/m^2. The electrical energy intensity was at 95.4 kWhe/m^2. Per month energy consumption for this hotel is presented in Table 1:

Table 1: Monthly energy consumption on energy basis

Energy Source	Energy MJ/month	Percentage
Total Electricity	822,369	68.2%
Furnace fuel oil	312,361	25.9%
LP Gas	71,450	5.9%
Total Energy	1,206,179	100.0%

From Table 1, it is evident that 68.2% of the total energy requirement is fulfilled by the electrical energy. In financial terms this accounts to approximately Rs. 2.4 million US$ 24000), or 84.8% of the total energy bill, which in turn is a staggering 21% of the total operational cost of the hotel. Though in energy basis furnace fuel oil shared over 25% from the total energy requirement none of the energy source exceed 10% on cost basis. In Figure 1, it shows the graphical interpretation of above tow.

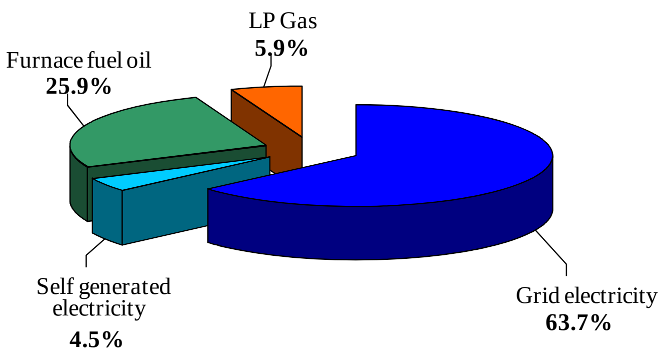

Figure 1. Hotel energy consumption on energy basis including self generated electricity.

This brief analysis shows that energy is one of the possible cost centers to be optimized by careful operation. To achieve this, main point will be to tackle the electrical energy consumption of the hotel. To lay groundwork, daily electrical load profile of the hotel was plotted for a period of three days. This is shown in Figure 2.

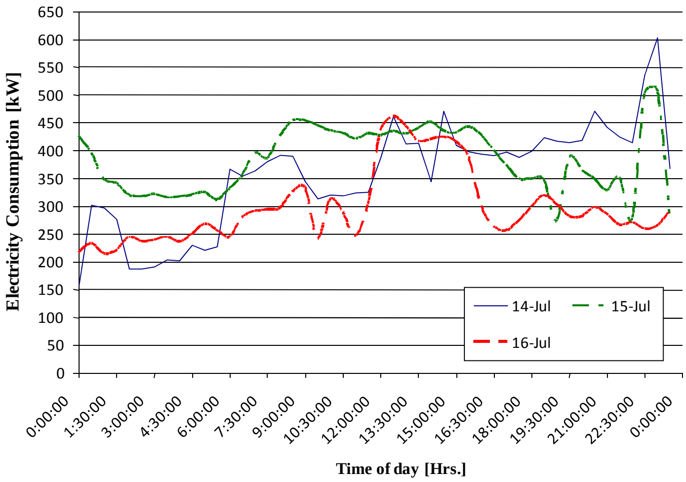

Figure 2. Hotel electrical load profile on three different days

In two days there could be seen sudden peak around 2230 hours. This was an extra ordinary case of operating the 200 kW electrical heat exchanger for a test run. Average per hour consumption is about 300 kWh and the peak is about 236 kWh per 30 minutes time duration, during 1430 hours under normal operation as electric heat exchanger was no longer being used.

3 METHODOLOGY

The major electricity consumption of hotel includes Heating, Ventilating & Air Conditioning (HVAC), outdoor & indoor lighting, lifts, power in guest services, and other various hotel operations including in the kitchen. Electricity consumption of hotel rooms is one of the major cost components which can be optimized. Figure 3 shows the conceptual approach in order to optimize the overall system. In fact, in this study, it is mainly focused on the HVAC system which is the major component of electrical energy.

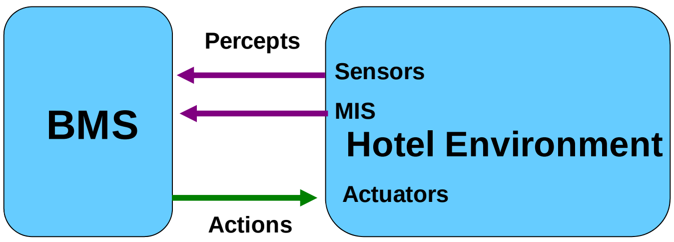

Figure 3. Sensor information and manage information system (MIS) data

Therefore, it is required to investigate the correlation between hotel electricity consumption and other related factor in order to control the consumption. One of the major concerns in hotel sector is number of occupied rooms; hence electricity consumption was analyzed against number of occupied rooms per month as well as per day data sets. However, the correlation is quite low in both cases. Figure 4 shows the analysis on daily basis. In a tropical country, it can be noted that the load pattern variations are similar in different time periods.

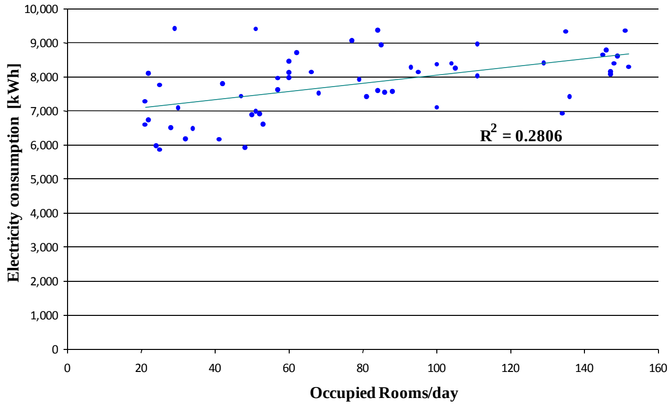

Figure 4. Daily electricity consumption with occupied rooms.

Since the number of functions held and the outdoor temperature impact are not covered by the occupied rooms now consider the number of guest nights versus electricity consumption in Figure 5. The straight-line fit does not sufficiently represent the data, as in Figure 4. This demands the need for a correction methodology.

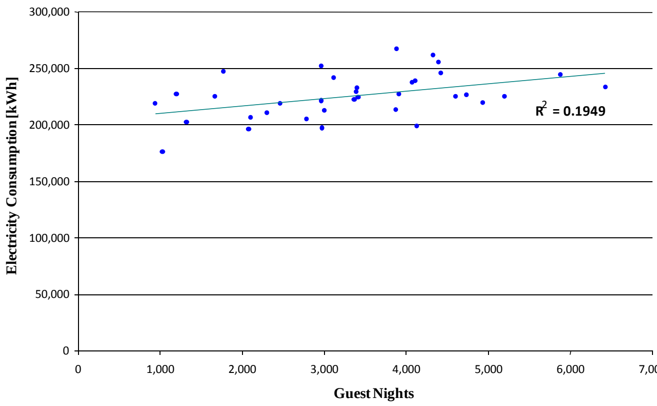

Figure 5. Monthly electricity consumption with guest nights.

Some of the previous studies carried out in other countries proved that correlation between electricity consumption and the hotel occupancy is weak (Deng & Bunnet, 2007). However, in Cyprus, it was found that better correlation on hotel electricity consumption and the occupancy in exponential regression model (Papamarcou & Kalogirou, 2001). It was also found poor correlation between hotel electricity consumption and the hotel gross floor area (Lam & Chan, 1994). As a practice most of the quality hotels maintain room temperatures around 26°C although unoccupied, in order to prevent from odors or discomfort. As a consequence, unoccupied rooms instead be considered as partially loaded. With this correction, a better correlation was found (Refer Figure 6 and Figure 7).

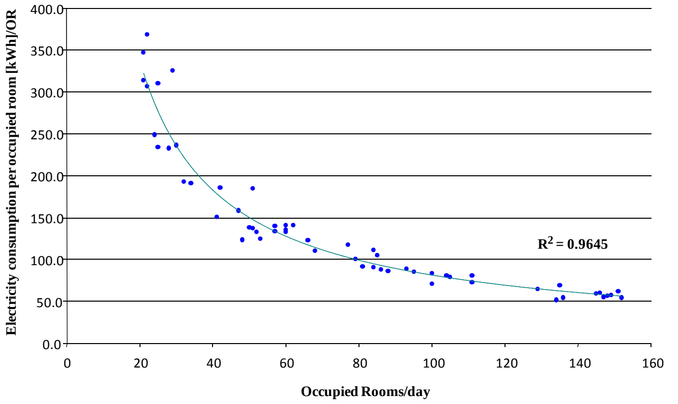

Figure 6. Per occupied room electricity consumption of the hotel.

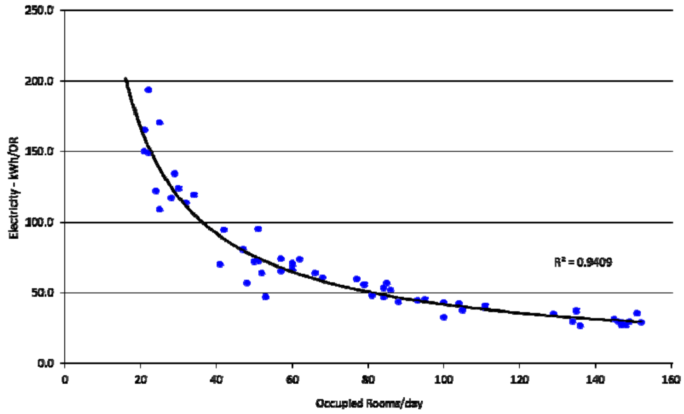

Figure 7. Per occupied room electricity consumption; chiller plant along.

Based on daily data of two consecutive months, it was found that 53% from the total electrical energy is consumed by the chiller plant operation including condenser pumps, chilled water pumps and cooling tower fan motors.

Energy audit carried out at this particular hotel confirmed that the highest electrical energy consumer of the hotel is air conditioning system of the hotel. Electrical data loggers were placed at Main incoming breaker of the electricity to the hotel, chiller plant, water treatment plant, sewerage treatment plant, main restaurant, kitchen and laundry.

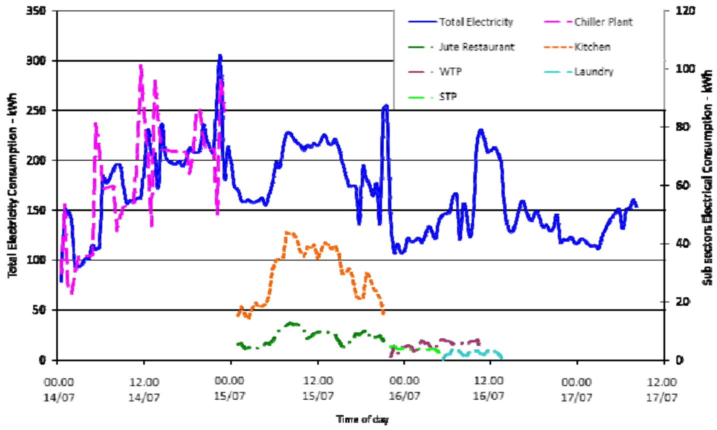

Figure 8. Hotel electrical load profile with individual loads.

Section by section has been removed from the system by keep attention on system temperature and the pressure. When firstly removed the Section D and then the Section C, there was no any noticeable impact to the system. When Section E removed from the system, by pass line on chilled water secondary pump header was opened, because the cooling load demand was much lower than the generated cooling capacity, hence the one of the secondary pump was switched off in order to balance the pressure. Then the Section B was removed and as the system temperature levels went down one of the chiller plant was switched off. Then the guest rooms of Section A were removed from the system. Figure 9 shows the reduction of power consumption as explained here.

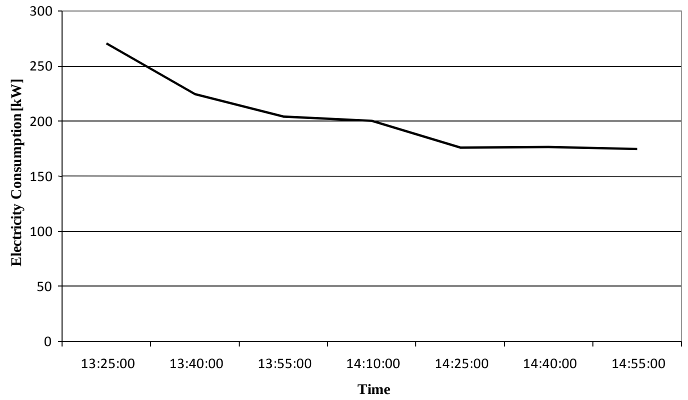

Figure 9. Cooling power requirement when unloading.

Theoretically, removal of one chiller plant equivalent removal of 122.7kW from the system, with the study we carried out it was noticed that reduction about 100kW. But to the final result, there were some obstacle as the transfer which supply the electricity to chiller plant is also feeding to laundry of the hotel including electric hot water heat exchanger and to the cooling tower of generator.

After removig all the sections from the operation while public areas on operation section by section were added to the operation. When added each section inlet and outlet temperatures of chilled water lines and pressures were monitored. First addition was Section A, when only one chiller plant was on operation. After addition of Section A, there was temperure increments on both temperature inlet and outlet of chilled water line, hence the second chiller was switched on for operation. After that Section B, Section C, Section D and Section E were added to the system for operation consequently. Inbetween the addition of two sections there was a time gap in order to settle the chiller water line temperature and pressure. With the addition of each setion, cooling load requirement and power consumption increment can be shown as Figure 10.

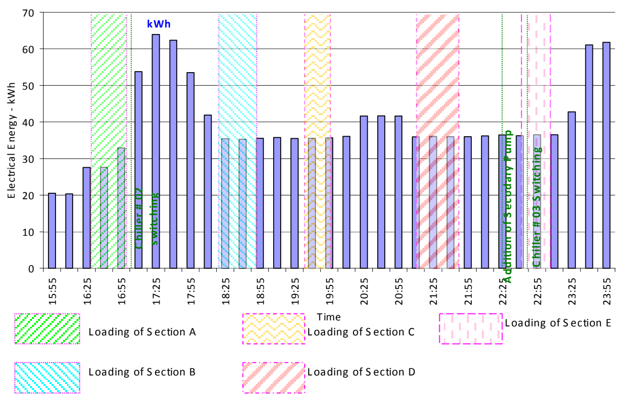

Figure 10. Cooling power requirement increment with loading each section.

Though the second highest electricity consuming center of the particular hotel is kitchen, yet it been consumed comparatively low electrical energy. Therefore study was fully focused on only the air conditioning system of the hotel.

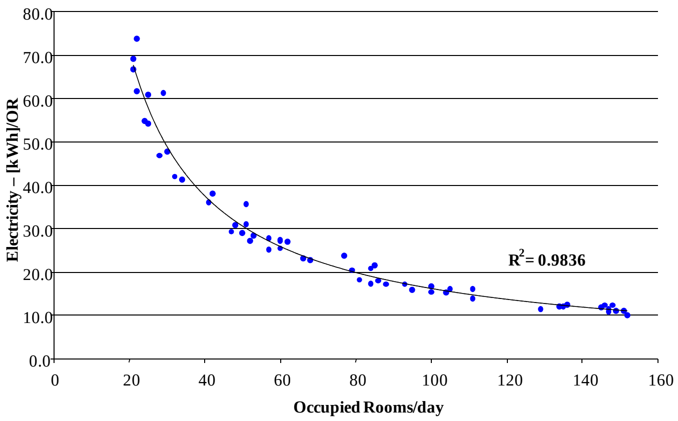

Figure 11. Per occupied room electricity consumption of the hotel; kitchen along with main restaurant

Figure 11 and Figure 12 show the per occupied room electricity consumption for kitchen along with restaurant and water treatment plant along.

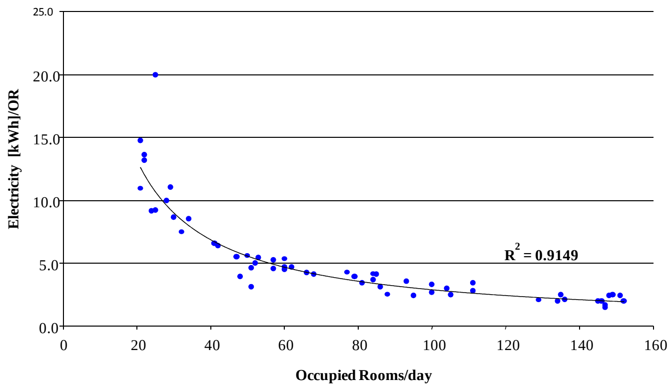

Figure 12. Per occupied room electricity consumption of the hotel; water treatment plant along.

4 MATHEMATICAL MODEL AND RESULTS

Sections, from A to E, have different number of guest rooms and each section has different room combinations as well. For an example, Section A contains 52 numbers of guest room including 47 de-luxe rooms, 3 luxuries, one suite and one luxury suite, where Section B has only one upper category room from its 21 numbers of total guest rooms. Not only have that as the room type varies their cooling capacity also varied. Room cooling capacity vary from 4 $kW_{thermal}$ to 18.5 $kW_{thermal}$,that is 1.1 refriger-ant tones (RT) to 5.3 RT, hence the power consump-tion is different in each types of guest rooms, not on-ly that as the type varies the expected profit levels are also varied. For convenient reference average air conditioning load and average profit levels has been considered for each section can be tabulated as in Table 2.

Table 2: Sectional AC load and profit

Section	Number of rooms	Cooling capacity	Average Profit in Rs.
A	52	1.41	2,060
B	21	1.22	2,025
C	23	1.46	2,090
D	29	1.88	2,260
E	29	1.40	2,060

In addition to that, public areas have cooling load requirement and which has been considered as con-stant cooling load, 90.4 RT. Not only that whenever one section has been open for operation, as hotel maintain guest room temperature at 26°C irrespective of outdoor temperature, from the time the section is opened entire wing has been partially loaded. That could be justified as this, average outdoor temperature at the selected site is about 30°C, if the room is unoccupied set temperature is 26°C and expected room temperature when the room is occupied is 22°C.

Therefore considering linear relationship between electricity consumption and the temperature reduction, unoccupied room consumes 50% from its fully load, but since there are no heat sources in the event of rooms are unoccupied and mainly at the beginning only needed the air conditioning load to cool the room and once the room reaches the temperature then the power requirement is rather low, hence effective consumption is taken as 35% for unoccupied rooms. With the correction factor total constant air conditioning load is 108.8 RT. Based on that following equation can be formulated.

$$\alpha + \beta + \gamma + \delta + \phi = x_1 \qquad (1)$$

Here, x_1 is the number of occupied rooms in the hotel. $\alpha, \beta, \gamma, \delta,$ and ϕ are number of occupied rooms in each section from A to E respectively. Cost function can be defined as

$$\begin{aligned} 4{,}999 + f_A(\alpha) + f_B(\beta) + f_C(\gamma) \\ + f_D(\delta) + f_E(\phi) &= x_2 \end{aligned} \qquad (2)$$

where $f_A(\alpha) \ldots f_E(\phi)$ are cost functions incurred due to switching on of AC in each Section from A to E respectively. These functions can be defined as bellow:

$$f_A(\alpha) = 147.3\alpha$$

$$f_B(\beta) = \begin{cases} 0 & if \beta = 0 \\ 1{,}437 + 127.1\beta & if \beta > 0 \end{cases}$$

$$f_C(\gamma) = \begin{cases} 0 & if \gamma = 0 \\ 1{,}886 + 152.3\gamma & if \gamma > 0 \end{cases} \qquad (3)$$

$$f_D(\delta) = \begin{cases} 0 & if \delta = 0 \\ 3{,}068 + 196.4\delta & if \delta > 0 \end{cases}$$

$$f_E(\phi) = \begin{cases} 0 & if \phi = 0 \\ 2{,}279 + 146.0\phi & if \phi > 0 \end{cases}$$

Constrains on each sections can be expressed as

$$\begin{aligned} &0 \le \alpha \le 52; \quad 0 \le \beta \le 21; \quad 0 \le \gamma \le 23 \\ &0 \le \delta \le 23; \quad 0 \le \phi \le 29 \end{aligned} \qquad (5)$$

Functions from f_B to f_E are discrete since power consumption for air conditioning in each section is zero till the section is not in operation and once the section is on operation section is partially loaded as rooms are maintaining at 26°C. Expected profit function could be formulated as follows:

$$2{,}060\alpha + 2{,}025\beta + 2{,}090\gamma + 2{,}260\delta + 2{,}060\phi = x_3 \qquad (6)$$

These profit margins including the cost to incurred for room air conditioning. To obtain the maximum profit for a given number of occupied rooms $x_3 - x_2$ to be minimized.

All possible combinations store in an array for the solution can be written as

$$\begin{bmatrix} s_1 \\ s_2 \\ . \\ s_i \\ . \\ s_n \end{bmatrix} = \begin{bmatrix} \alpha_1 & \beta_1 & \gamma_1 & \delta_1 & \phi_1 \\ \alpha_2 & \beta_2 & \gamma_2 & \delta_2 & \phi_2 \\ . \\ \alpha_i & \beta_i & \gamma_i & \delta_i & \phi_i \\ . \\ \alpha_n & \beta_n & \gamma_n & \delta_n & \phi_n \end{bmatrix}$$

Reject all S_is which are not satisfying any of the above constraints and calculate following cost function and profit function for accepted S_i. Define

$$C_i = 4{,}999 + f(\alpha_i) + f(\beta_i) + f(\gamma_i) + f(\delta_i) + f(\phi_i)$$

$$P_i = 2{,}060\alpha_i + 2{,}025\beta_i + 2{,}090\gamma_i + 2{,}260\delta_i + 2{,}060\phi_i$$

where

$$f(\alpha_i) = 147.3\alpha_i$$

$$f(\beta_i) = \begin{cases} 0 & if \beta_i = 0 \\ 1{,}437 + 127.1\beta_i & if \beta_i > 0 \end{cases}$$

$$f(\gamma_i) = \begin{cases} 0 & if \gamma_i = 0 \\ 1{,}886 + 152.3\gamma_i & if \gamma_i > 0 \end{cases}$$

$$f(\delta_i) = \begin{cases} 0 & if \delta_i = 0 \\ 3{,}068 + 196.4\delta_i & if \delta_i > 0 \end{cases}$$

$$f(\phi_i) = \begin{cases} 0 & if \phi_i = 0 \\ 2{,}279 + 146.0\phi_i & if \phi_i > 0 \end{cases}$$

Prepare an array of cost and profit values for each set of combinations

$$\begin{bmatrix} s_1 \\ s_2 \\ . \\ s_i \\ . \\ s_n \end{bmatrix} = \begin{bmatrix} C_1 & P_1 \\ C_2 & P_2 \\ . \\ C_i & P_i \\ . \\ C_n & P_n \end{bmatrix}$$

Calculate net profit function for given number of occupied rooms

$$N_i = P_i - C_i$$

Prepare an array of net profit for the set of combination of each section rooms

$$\begin{bmatrix} s_1 \\ s_2 \\ . \\ s_i \\ . \\ s_n \end{bmatrix} = \begin{bmatrix} N_1 \\ N_2 \\ . \\ N_i \\ . \\ N_n \end{bmatrix}$$

Select the maximum net profit value Ni for a given number of occupied rooms, r. Give the output S_i, $[s_i]=[\alpha_i \ \beta_i \ \gamma_i \ \delta_i \ \phi_i]$

This would be the optimum room configuration for a given number of occupied rooms in the hotel. For an example, this has been applied to a case when the occupied room is 60. That means room allocation can be done as follows:

Section A: 31 rooms

Section D: 29 rooms

Using the above mathematical model, computer software program was developed in order to identify the possible way of room allocation for a given number of occupancy and the best solution. Figure 12 shows only a selected set of output data when consider the occupied room is 60 from the above mentioned developed software program. It has been pre-assumed that Section A to be fully occupied if the total rooms to be occupied is less than or equal to 52 number of rooms since almost all the public areas belong to Section A. However, with the consideration of revenue, the pre-situation is not much accurate. No doubt that it is always feasible to have 52 guest rooms from Section A and balance from some other, yet above combination is the best.

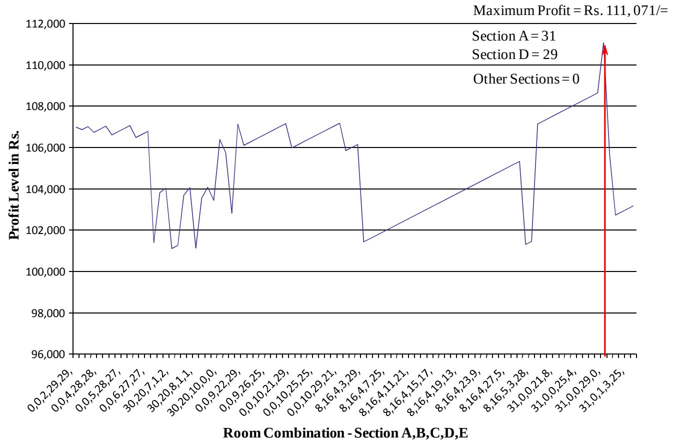

Figure 12. Per occupied room electricity consumption of the hotel.

5 DISCUSSION

The analysis considered here is to optimize the energy consumption which can be implemented in a building management system. To identify the ways of reducing energy consumption major cost components enters have been identified. From energy components, electrical energy share which costs the most has been identified. When it considers the cost, per occupied room consumption was determined. Then the analysis based on air conditioning system and the chilled water distribution system, all guest rooms divided into five sections. Each section has different number of guest rooms as well as within a section there are several types of guest rooms. With the study on sectional operation based on air conditioning system, it was found that there is a potential of saving energy by implementing sectional operation or the wing operation. As the performance tested in sectional wise, the exact point of next chiller plant to be switched on was not identified and if room by room addition performance tested much better result could be obtained, however it is much time consuming and not practicable with in a hotel operation. Even though it is possible to spend some more time, as the test period is high it is difficult to maintain the environmental conditions at the same level though out the day. Furthermore, the areas like kitchen, restaurant having the time to time operation which also leads to change the final result. Also, during the study chiller plant chilled water inlet and outlet temperatures were not maintained at constant values hence, exact increment of cooling load was not properly reflected by the final results.

6 CONCLUSIONS

On energy consumption basis, Section A seemed to be the most economical block to operate. However when energy consumption together with profit margins were considered, using the mathematical model developed in Section 4 of this paper, the case was otherwise. It showed that for 60 guest rooms best room allocation is 31 rooms from Section A and balance from Section D. At the same time other sections are recommended to be isolated from the main system. This suggests that it is worthwhile to go for sectional operation rather than allocating guest rooms randomly. In order for the sectional operation to be feasible it is required to implement BMS for section isolation, temperature measurements etc. Finally it can be concluded that the wing operation implementation and implementation of BMS is much beneficial to the hotel if it percepts the desired senor and MIS data.

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