OPTIMAL ALLOCATION OF AIR CONDITIONING SERVICES:
A CASE STUDY FOR A HOTEL IN SRI LAKA

A dissertation submitted to the
Department of Electrical Engineering, University of Moratuwa
in partial fulfilment of the requirements for the
Degree of Master of Science

By
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Abstract

Tourism industry is one of the key players in Sri Lankan economy. With the long run internal conflict, Sri Lankan tourism industry had a negative growth in the last few decades. Not only that, but also due to global economic meltdown, almost all the industries all over the world are facing an extremely hard time. The increase of global warming, with its effects on North Pole glaziers, which have started to-meltdown, the entire world has started to be concerned on the concept of the "green house effect".

With global economic crisis and the "go green" concept most of the industries have started to practice cost reduction and energy saving methods in order to make their industries profitable. The situation in Sri Lanka's industry has no difference from that and especially the tourism industry has started to implement such methods.

In this thesis a case study has been carried out at one of the five star category resort type hotels in down south, Heritance Ahungalla, to analyze the pattern of energy consumption in that hotel in order to implement a method to reduce their production cost, as energy is one of the heights components in the hotel's expenses.

The chilled water distribution system has been studied and the hotel was divided to five section based on that. Cooling load requirement is correlated with the number of occupied rooms hence the energy could be saved by introducing wing operation to the hotel room allocation system.

A practical evaluation on wing operation was carried out only based on the energy consumption and a theoretical evaluation was also carried out based on both the energy consumption and the profit. Results showed the energy could be saved by introducing "wing operation" to the system of allocation of rooms in the hotel.

With the wing operation, it is required to implement automatic operation of chiller plant as well as isolation of each wing from the hotel main system as the wing

operation is highly cost effective. That could be achieved with introduction of building management system to the hotel.

DECLARATION

The work submitted in this dissertation is the result of my own investigation, except where otherwise stated.

It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

UOM Verified Signature

L. A. A. N. Perera

I endorse the declaration by the candidate.

UOM Verified Signature

Prof. Lanka Udawatta

Contents

Acknowledgement

Thanks are due first to my supervisor, Professor Lanka Udawatta, Co-supervisors Eng. Sanjeeva Witharana and External supervisor Eng. Rohitha Rajaratne, for their great insights, perspectives, guidance and sense of humor. My sincere thanks go to the officers in Post Graduate Office, Faculty of Engineering, University of Moratuwa, Sri Lanka for helping in various ways to clarify the things related to my academic works in time with excellent cooperation and guidance. Sincere gratitude is also extended to the people who serve in the Department of Electrical Engineering office.

I would like to extend my sincere gratitude to, the Aitken Spence Hotel Managements (Pvt) Ltd, Sri Lanka and the Heritance Ahungalla Hotel, for providing me the necessary information, and the opportunity to analyze the system.

I thank many individuals, friends and colleagues who have not been mentioned here personally in making this educational process a success. May be I could not have done it without your support.

L. A. A. N. Perera

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Chapter 1

Introduction

1.1. Hotel Industry

Each country has its own way of producing foreign currency in order to maintain the country's economy. Some countries manufacture vehicles, machinery, plants and export them while some countries export raw materials for production processes. The economy in a country like Maldives totally depends on the tourism industry.

The hotel sector in a country plays a vital role when considering its tourism industry. Situation is more or less same in Sri Lanka as well. With the collapse of tourism industry in Sri Lanka due to security reasons during the last few decades, the hotel industry has faced very hard times.

Sri Lankan economy constitute of three main sectors, Agriculture, Industry and Service sector. Tourism industry in Sri Lanka belongs to the Service sector. The service sector is the major contributor to the national GDP (Gross Domestic Product), with a contribution of 60% of GDP while Industry contributes 28% and Agriculture contributes 12% [8].

In consideration of energy sector, and the total energy consumption of the country, 50% is consumed by the domestic and commercial consumers. The Industrial sector consumed 23.15% and 26.34% in year 2004 and 2005 respectively, and balance by transportation in Sri Lanka [1].

From the total generated electricity, industrial sector consumes almost 36% while domestic sector consumes about 38.9% and commercial sector consumes 22.7% as described in Sri Lanka energy balance publication in year 2008 [2], published by Sri Lanka Sustainable Authority who is responsible for implementing of energy efficiency practices.

1.2. Internal conflict and Global economic crisis

Sir Arthur C Clarke has stated that "Though the Sri Lanka is a small Island, it is just like the universe, as it contains many variations of culture, scenery and climate. A country like Sri Lanka is very hard to find as it has a lot of variations in every sense, where other countries have only few of them when considering a single country". With the establishment of Ceylon Tourist Board in 1966, there was a weakening in tourism industry in Sri Lanka. The main attractive area of the Sri Lanka was the Southwestern coastal area.

Since 1976 to 1982 until the internal conflict came into the action, there was a 24% increase in tourism industry.

Sri Lanka has experienced one of the longest internal conflicts in the world, though it has ended up recently. As an effect of this internal conflict, most of the foreigners were reluctant to visit Sri Lanka for the last decade . Some government made some restrictions to visit Sri Lanka labeling it as one of the most unsafe countries in the world stating the risk due to bomb blasts which took place around the country during the last few decades.

As the terrorists targeted major economic points in Sri Lanka like, the Central Bank, the Airport and etc, the European countries have highly restricted their citizen traveling to Sri Lanka. Without foreign tourists the tourisms industry could not perform well. As a result, the entire hotel industry of the Sri Lanka was collapsed.

With the terrorist attacks to Orugodawatte oil storage and Katunayake Airport, most of the shipping lines and air lines added more levis on each shipment, which resulted in an increase of cost of food and services within the country.

With the terrorism and the war against terrorism, there was a negative perception on Sri Lanka among other nations. To keep the travels and tourism industry alive in Sri Lanka, the country has done quite a lot, according to the annual report of Aitken Spence Hotel Holdings for the last financial year [14].

The tourism industry of Sri Lanka has not yet strengthened up as expected with the end of thirty years dragged internal conflict. This is mainly due to the global economic crisis which has continued for the last few years.

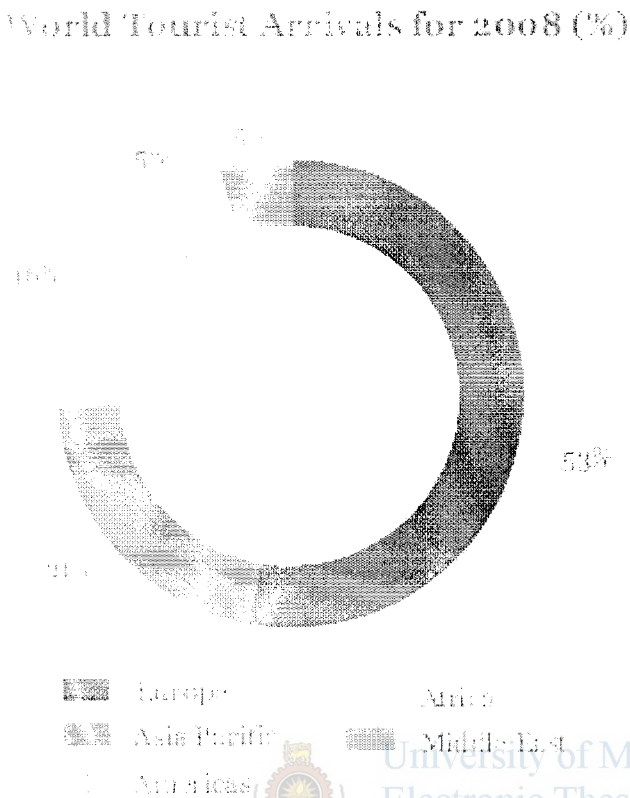


Figure 1.1– World Tourism Arrivals for 2008

There was a significant slowing in demand on tourism during year 2008 under the influence of an extremely volatile world economy. It is clearly shown by the 7% increase during the year 2007 and the 2% increment during year 2008 when considering the world travels and tourism industry [14].

The reason is clearly described by the above figure, as the main portion of the world tourism is Europeans [14]. As the European economy was badly affected by the global economy meltdown, it is obvious that the number of visitors could be lower compared to previous years where economic crisis was not there.

According to thes World Bank South Asia region report, the global economic crisis has badly affected the South Asian region as the fuel price was almost doubled as the existing price. Countries in the region have reacted with the situation by several actions like adjusting domestic fuel price, reducing development expenses and tightening monetary policy [11].

As the price of petroleum has gone high, almost all sectors in all countries faced losses. With the effect of petroleum price increase, price of food has increased, price of energy has increased and many more. It could be clearly shown in the following figure [11].

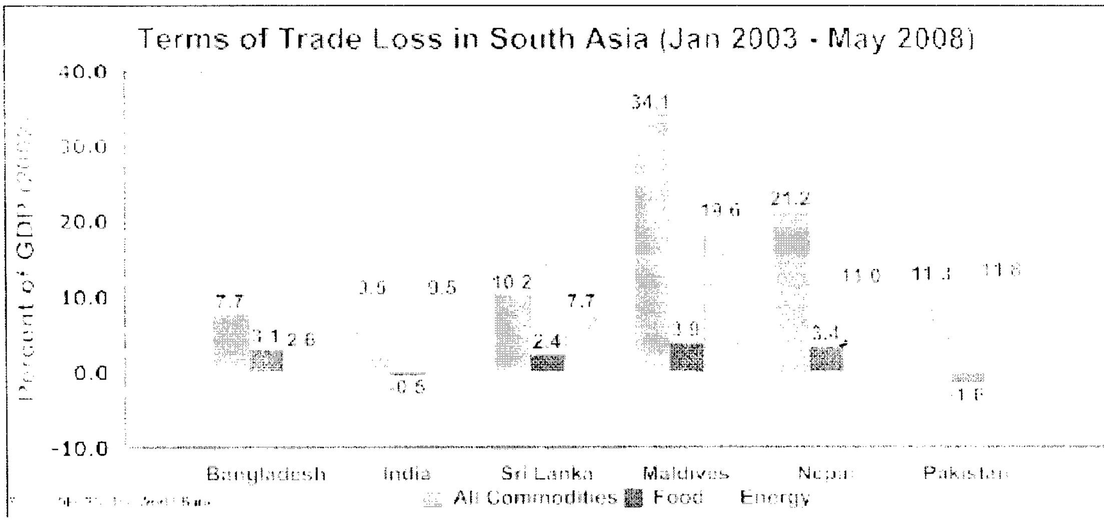


Figure 1.2 – Terms of Trade loss in South Asia (Jan 2003 – May 2008)

The global economic downturn is a huge blow to tourism industry of all over the world. As most country's economies were unstable, willingness of traveling of people has been reduced. Even though the willingness is there the ability of spending money is much lesser, therefore the tourism industry is yet to be developed in the entire world.

The web site of Asia Economic Institute stated regarding the tourism industry of Singapore that the global economic downturn lead to a decrease in Singapore's tourism industry by 12.9% in January 2009 with compared to the total arrivals to the Singapore in January 2008.

According to K. R. Pushparajan, hundreds of establishments in private sector relating to various fields have been closed down due to the global economic crisis. Not only the developing countries, but also developed countries felt the heat of global meltdown. The situation is same in Sri Lanka, and some of the highly affected industries are Tea, Rubber, Coconut, Garment, Gem and Jewelry and Tourism industry. Out of all, the tourism industry in Sri Lanka is operating at grave losses [12].

With comparison to the year 2007, there was a 11% decline of visitor arrivals in year 2008; this downturn is not merely arrivals but also in earning as well. Due to lower arrivals and decline in the foreign exchange receipts per tourist per day, the foreign exchange earnings were declined by 12.8% during the last financial year in Sri Lanka travels and tourism industry. This badly affected the country's economy as its position as sixth largest Foreign exchange earner to the nation [14].

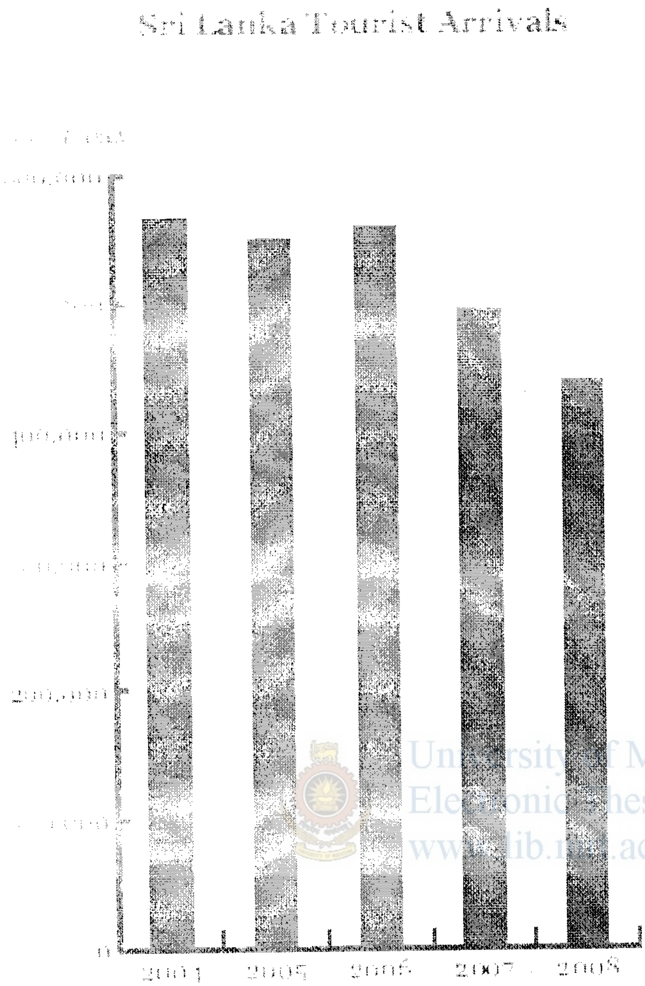


Figure 1.3 – Sri Lanka Tourist Arrivals

1.3. Trend to Greening Projects

After signing Kyoto Protocol in 1997 almost all the countries in the world highly concentrated on reducing ways of environmental pollution. Sri Lanka signed the Kyoto Protocol in September 2002 and also joined with the rest of the world to protect the ozone layer and to reduce the pollution of environment due to human activities. There is a threat on melting of glaziers as well. To address this, various methods are being practiced by each country. Recently the Maldivian government held their cabinet meeting in the deep sea to indicate that still the world's concern on global warming is inadequate. .

Not only country wise, at an individual level most of the companies has started to practice several actions to minimize their contribution to global warming. Similarly the hotel industry worldwide provided their contribution to this. Several studies have been carried out on energy performance related to hotel industry in recent past in countries like Tunisia, Singapore, Jordan, Greece and etc.

Most of the studies were based on total energy consumption of the hotel and the energy use intensity of the hotel (EUI), energy performance study has been carried out in 16 quality hotels in Hong Kong in 1995 and performance was measured in EUI [4]. As mentioned in above paragraph, with the concern of greening image, greening concept is one of the main aspects of the energy study carried out in Greek hotels was to have surplus advantage for hoteliers in forthcoming European Union eco-labeling scheme in hotel sector. The study was based on three categories of hotels in Greece; Mount, City and Coastal [10].

Various organizations in Sri Lanka are handling several programs to promote the concept of Greening Sri Lanka. Responsible Tourism Partnership is handling "Greening Sri Lanka Hotels" program with the collaboration with Ministry of Tourism and Travel Foundation, UK, which targets only the hotel sector of the country. Another program is being handled by Sri Lanka Sustainable Energy Authority with the Consultancy of Gamini Senanayake Association, called "National Energy Efficiency Award" targeting five main sectors with three sub sectors, altogether fifteen sectors covering almost all the industries in public and private sector.

With the publication of Sri Lanka Sustainable Authority for buildings energy efficiency codes, they have defined so many variable for energy saving practices. For examples, maximum allowable power for illumination systems, indoor design conditions for air conditioning systems, standard chilled water inlet and outlet temperatures [15].

Not only in national level, but also in global level there is some certification system to categorize the hotel industry. The one of the most famous certification system is Green Globe certification system. Green Globe evaluation system ensures that the hotels are practicing best energy efficiency methods and reduction of their wastage at the given values or below. Further more, Green Globe evaluation in one of the marketing tools for hospitality industry.

1.4. Achievement in brief

As described above there is a lot of concern on poor performance in Sri Lankan industries. In order to be competitive in the hospitality sector by making their "green image" globally and use it as one of the important marketing tools, most of the hospitality companies are practicing several methods to reduce carbon emission to the environment and at the same time to minimize their losses

As environmental friendly projects some hotels started renewable energy source projects like, Gasifier projects in Heritance Tea Factory, Heritance Kandalama and Sigirya Hotel. Almost all the hotels are continuing to replace inefficient machinery and plants with efficient machinery and plants, conventional incandescent lamps with compact fluorescent lamps and magnetic ballast with electronic ballast wherever possible.

This study has two aspects, direct and indirect. Direct aspect is the reduction of operational cost and the indirect aspect is the reduction of energy consumption, but this is not by way of replacing any machine with an efficient machine but by just practicing a better way of allocating rooms and thereby save energy as much as possible.

Heritance Ahungalla, is one of the five star grade prime properties of Aitken Spence group and which is the first ever five star hotels on beach side. This study has been carried out as a case study in Heritance Ahungalla.

Chapter 2

Problem Statement

As discussed in Chapter 1, Sri Lankan hotel sector had a really hard time due to the internal conflict, global economic crisis and so on. Not only the Sri Lankan hotel sector, but also the entire hospitality sector and almost all the industries all over the world have been collapsed as a result of global economic downturn. To overcome the situation almost all the industries have tried several methods.

In trade we could make profit in several ways. If we keep a lower margin of profit and we could sell a higher number of products we could gain more revenue, same as with higher margin of profit even with lesser number of product selling, same revenue could be earned. As the first option is not valid as the number of products which could be sold is lesser, second option is to be considered. In second option, profit margin per product can be increased in two ways. One is keeping a constant production cost but increase the selling price. Other way is keeping the selling price as it is, and reducing cost of production

As visitors' willingness of spending money is less, it is very difficult to increase the selling price and gain the desired profit level as increase of selling price would cause for a future reduction of sales. Therefore it is time to think on a second option. In that case the factor to be considered is maintenance of product quality without compromising with the reduction of production, where the hospitality industry is concerned the "product" is the "service" which is provided to the guest. To maintain the quality of service, certain things cannot be compromised which are relevant to the star category and the hotel prestige.

The most efficient way of reducing production cost is minimization of wastages. Theoretically it should be zero wastage. For that it is highly important to identify the cost centers, because without knowing the exact location to be treated, if we apply any solution it would be a waste of time and lower the product quality unnecessarily. In hospitality industry there are two components of cost, cost of sales and operational costs. Cost of sales is basically food and beverage cost and cannot be controlled as it directly affects the hotel income. From the total expenses, operational cost is the highest component, but the percentage is highly variable as the cost of sales is a highly variable factor, based on the monthly Profit and Loss account report at Heritance Ahungalla.

When concerning the operational cost there are two major components, payroll related expenses and energy expenses. These two shares over 50% from the operational cost and other expenses are administrational costs, sales and marketing costs and so on. At Heritance Ahungalla, payroll related expense is about 28% from the total operational cost while energy expense is more than 25% based on monthly Profit and Loss account report at

Heritance Ahungalla. To maintain the sense of five star level and to maintain luxurious architecture of the hotel, it is very difficult to reduce the number of staff and hence the payroll related expenses. The energy sector of the hotel is the sector which is the most effective and possible in reducing the cost, after considering the above.

Not only the reduction of expenses, but alos to improve the green image and thereby save the planet earth to future generations most of the hotels world wide mentioned in Chapter 1 are practicing energy efficiency methods and introduce new renewable energy projects They have also carried out several studies in order to identify the potential of energy saving with existing systems as new introduction or replacement would not be feasible all the time with cost factor, as lack of investment capabilities.

Almost all those studies were based on the total energy consumption. They were highly concerned on average annual energy consumption per square meter which is called Energy Use Intensity (EUI). It was 715kWh/m^2 for hotels in London in 1988 [4]. In Hong Kong hotels' electrical energy use intensity has being reported as 257.8kWh/m^2 and 366kWh/m^2 in two studies [4]. It was found out that EUI is 564kWh/ m^2 in 16 numbers of Hong hotels, by a study on energy performance of hotel building in Singapore, carried out with the collected data on 29 quality hotels. Performances were discussed in EUI of the hotel and also investigated the relationship between electricity consumption and the occupied rooms of the hotel and found that the correlation is very poor. In that report the analysis team recommended to the hotel management to give a higher concern to management of energy during low occupancies [5].

Previous studies on analysis of energy consumption in hotel sector, carried out in various countries, clearly say that the major energy source is electricity, which is more than 70% from the total energy consumption. It was found that electrical energy is 73% from the total energy consumption in the 16 Hong Kong hotels [4], and it was higher as 77% in Singapore hotel sector [5]. In these two cases Hong Kong as well as Singapore, energy mix is electricity, diesel and gas. This figure slightly differs in Greek hotel sector, as the purpose of energy source usage is slightly different and the considered hotels belonged to different categories, but still for all, electricity was the major contributor to the total energy requirement of the hotels in Greece and the contribution varied from 38% to over 60% from the total energy [10].

When considering the electrical energy consumers in hotel sector, the major consumer is the air conditioning system. The study carried out in the 16 Hong Kong hotels, air conditioning system's energy consumption is 32% from the total energy and that is about 44% from the electrical energy [4]. According to the study in the three Singapore hotels, air conditioning system component (including main plant, Air handler units (AHU) and Fan coil units (FCU)) was found to consume more than 50% of the electrical energy [6]. When the rooms were occupied 60% of energy was consumed by the ventilation and air conditioning system in Greek hotels [10].

The Heritance Ahungalla, hotel uses three major energy sources, Electricity for most of the areas, Furnace fuel oil for steam generation boiler where steam is used for laundry operation and hot water circulation system and LP gas for cooking purposes. In addition the hotel uses diesel for operation of generators, and is considered under electricity as diesel is not going to be considered as the fourth energy source in this study.

In parallel with the previous audit target, it has been shown that EUI at Heritance Ahungalla is very much lower as $139.9kWh_e/m^2$ with compared to the hotels in Hong Kong, Singapore and Greece as the values mentioned earlier, though the Heritance Ahungalla is a five star category hotel. Along with that, the calculated electrical energy intensity is about $95.4kWh_e/m^2$.

Analysis of last three years energy consumption at Heritance Ahungalla can be tabulated as follows.

Energy Source	Energy Consumption MJ/month	As a percentage
Grid Electricity	768,254	63.7%
Self generated electricity	54,115	4.5%
Boiler operation (Furnace Fuel Oil)	312,361	25.9%
LP Gas	71,450	5.9%
Total Energy	1,206,179	100.0%

Table 2.1 - Monthly Energy Consumption on Energy Basis

Energy Source	Energy Consumption MJ/month	As a 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%

Table 2.2- Monthly Energy Consumption on Energy Basis (Electricity together)

Total energy consumption at Heritance Ahungalla is about 1,206,179 MJ/month as per last three years energy data. Major energy source of the hotel is Electricity as it contributes 68.2% from the total energy consumption of the hotel, which included both grid electricity consumption and the self generated electrical energy. In this case generator efficiency has been taken as 40%.

The boiler energy consumption has taken the second place with 25.9% from the total energy consumption of the hotel, as amount 312, 361 MJ/month. Boiler is operated with Furnace fuel oil. With compared to the electrical energy and the boiler energy consumption, cooking purpose energy consumption is negligent, which is LP gas with 5.9% from the total energy. Graphical representations of above tabulated data are as follows.

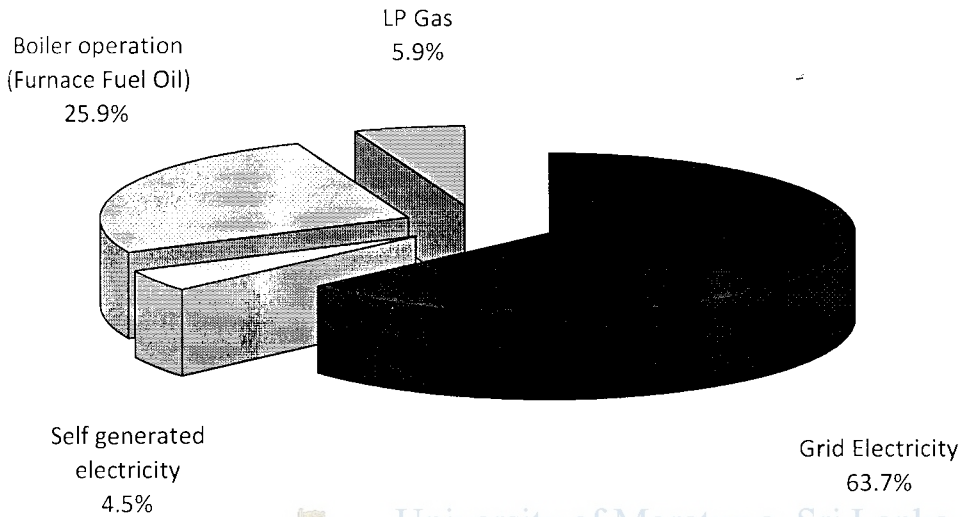


Chart 2.1 – Hotel Energy Consumption on Energy Basis

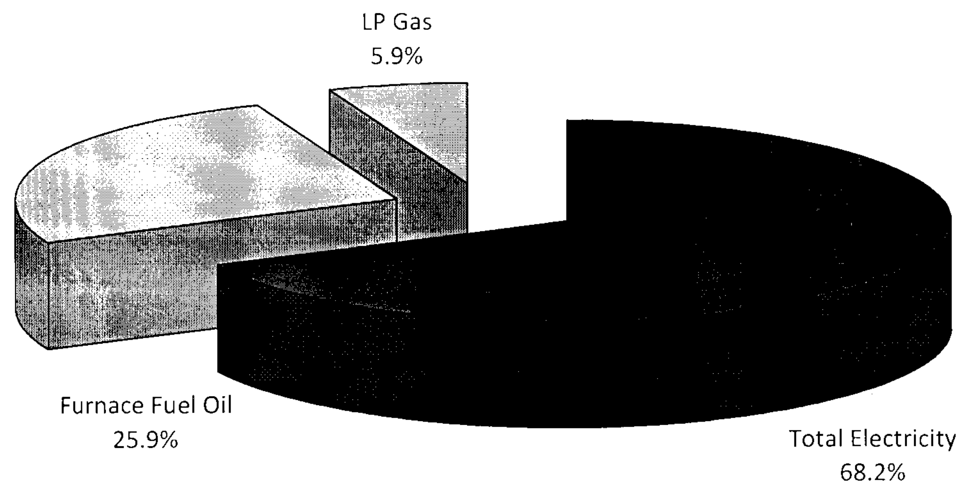


Chart 2.2- Hotel Energy Consumption on Energy Basis (Electricity together)

When considering the cost factor, cost for energy at Heritance Ahungalla can be tabulated as below.

Energy Source	Cost Rs./month	As a percentage
Grid Electricity	2,411,463	76.3%
Self generated electricity	269,650	8.5%
Boiler operation (Furnace Fuel Oil)	262,483	8.3%
LP Gas	217,497	6.9%
Total Energy	3,161,093	100.0%

Table 2.3 - Hotel Energy Consumption on Cost Basis

Energy Source	Cost Rs./month	As a percentage
Total Electricity	2,681,113	84.8%
Furnace Fuel Oil	262,483	8.3%
LP Gas	217,497	6.9%
Total Energy	3,161,093	100.0%

Table 2.4 - Hotel Energy Consumption on Cost Basis (Electricity together)

Table 2.3 and Table 2.4 show the cost analysis of energy consumption at Heritance Ahungalla. Average annual cost of energy at Heritance Ahungalla is about Rs. 3.16 million and from that 84.8% is for either grid electricity or self generated electricity. To calculate above cost the following facts and figures have been considered.

Electricity tariff – based on Ceylon Electricity Board tariff structure, Hotel Industrial (II)

Electricity Energy cost	=	Rs. 9.30/kWh
Maximum demand	=	Rs. 675/ kVA
Fixed Charge	=	Rs. 3,000/month

With considering last three years average electricity consumption and the average maximum demand, it has been found out that overall unit cost is Rs. 11.30/ kWh as there is no fuel adjustment cost in current tariff structure. At the same time diesel price is Rs. 75/litre, furnace fuel oil is at Rs. 33.90/litre and LP Gas is at Rs. 140.2/kg.

Graphical interpretation of above cost analysis can be given as following charts.

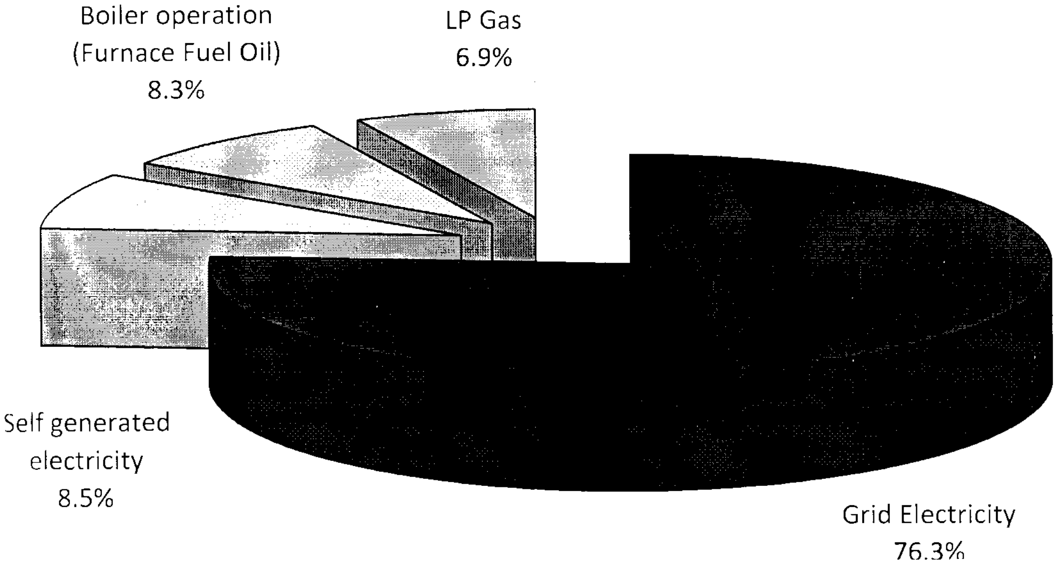


Chart 2.3 – Hotel Energy Consumption on Cost Basis

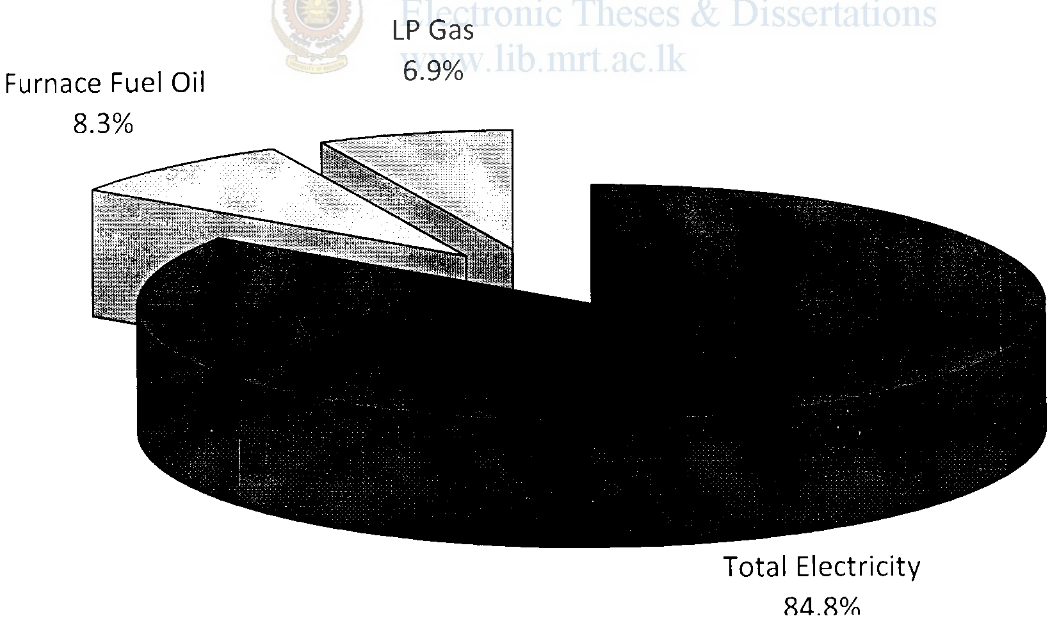


Chart 2.4 – Hotel Energy Consumption on Cost Basis (Electricity together)

As the Heritance Ahungalla, electricity is used for various requirements such as air conditioning, lighting, to operate kitchen, and laundry equipments, pump and motors related to water treatment plant, sewerage treatment plant and swimming pool etc.

As discussed in Chapter 1 and this chapter, the causes for falling of travels and tourism industry rand hotel sector in Sri Lanka are mainly internal conflict and the global economic downturn. Above two factors are affected in two ways, major factor is lack of foreign tourists arrival and the second is due to higher inflation, and increasing of consumables and services prices.

As described in above two chapters, to overcome above mentioned two matters and make hotel sector profitable, hotel sector has to reduce their expenses. The most effective way for Heritance Ahungalla is the reduction of energy cost of the hotel and thereby the reduction of operational cost.

Clearly it should be the reduction of electrical energy consumption of the hotel as it constitute 85% of the total energy cost at Heritance Ahungalla, hence over 21% from total hotel operational cost is electrical energy cost. In Heritance Ahungalla, to make some profit by reducing operational cost, it is highly recommended to consider on the electrical energy consumption of the hotel.

It necessitates the identification of electrical energy consuming pattern of the hotel.

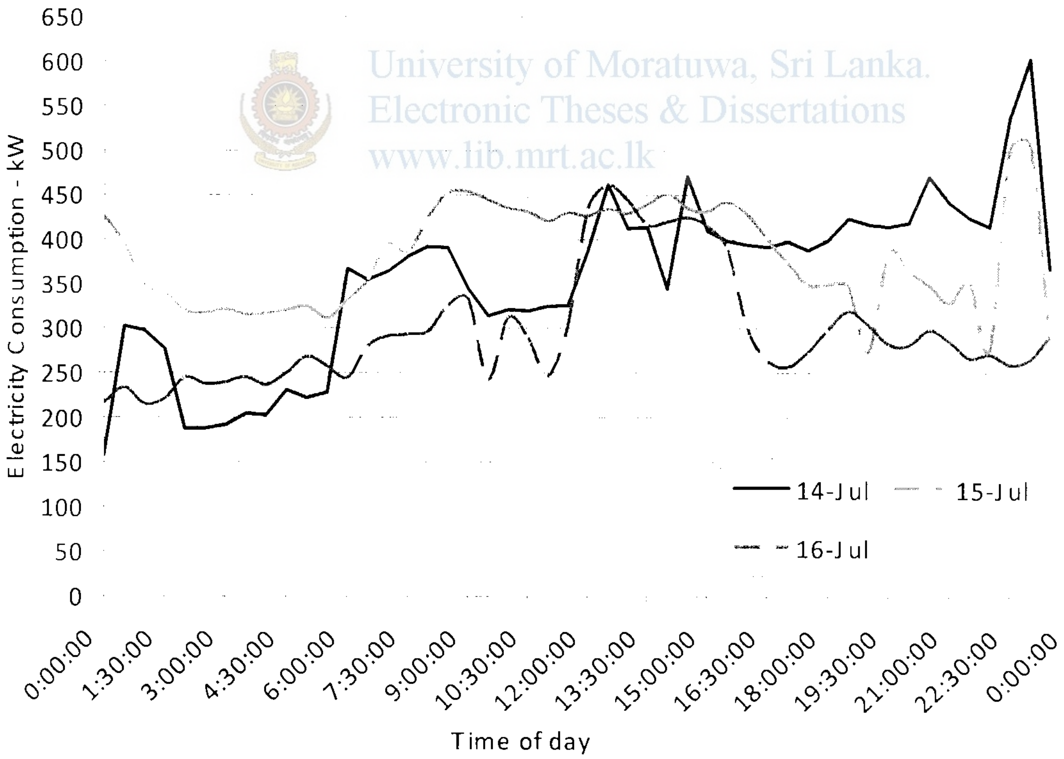


Figure 2.1 - Electrical Load Profile

Above figure shows the hotel load profile in three different days. Graph is plotted with 30 minutes power consumption, and according to the graph data average consumption per 30 minutes is about 150 kWh, and per hour consumption is about 300 kWh. It shows that from 11 30 hours to 16 30 hours there is a slight peak. There is an unexpected peak in the latter part of the day on 14th July and 15th July since, at that time electric hot water calarifier was operated to analyze its performance though not used anymore at the hotel. The electric hot water calarifier has been used to maintain the temperature of the hot water during night time as the steam boiler was not operating at that time. The maximum electricity consumption under normal conditions is about 236 kWh per 30 minutes and the peak is at around 14 30 hours.

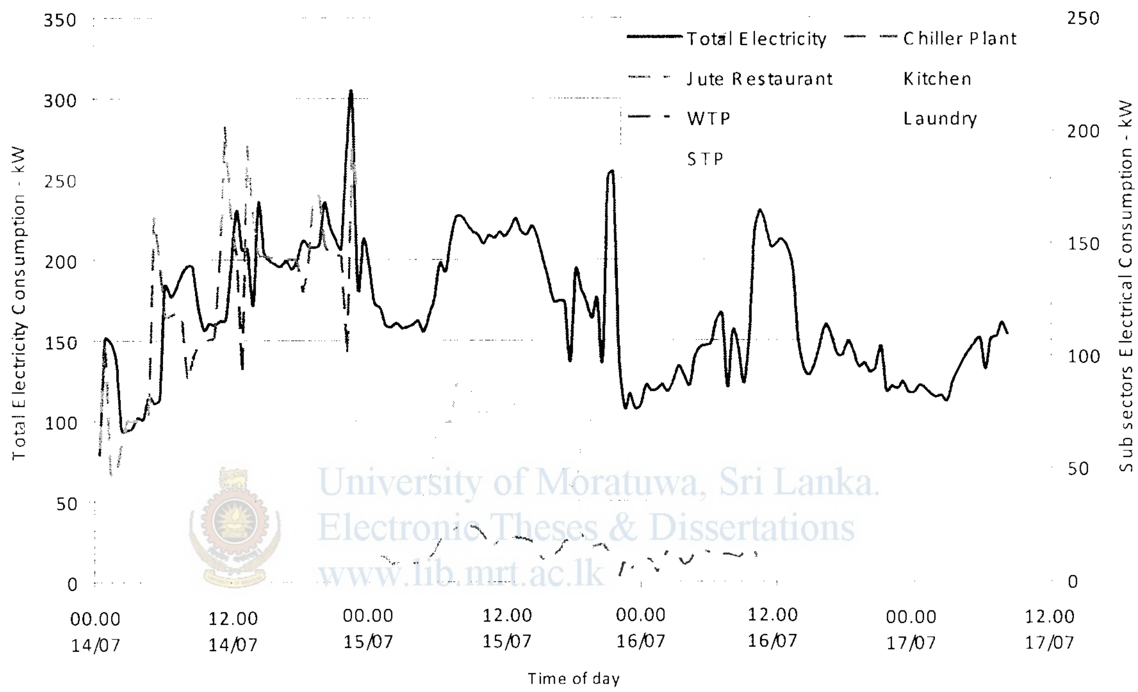


Figure 2.2 - Electrical Load Profile with Individual Loads

Figure 2.2 shows the electrical load consumption profile of the hotel along with the individual load profiles of Chiller plant, Jute Restaurant, Kitchen, Water Treatment Plant (WTP), Laundry and Sewerage Treatment Plant (STP). The graph shows that the total electricity load profile is mainly defined by the chiller plant, followed by the kitchen.

2.1. Energy balance in area wise

With the analysis of daily records of the last two months it was found out that about 53% from the total electricity requirement of the hotel is for air conditioning plant operation, which includes chiller plants, cooling towers, cooling tower fans and primary and secondary chilled water pumps.

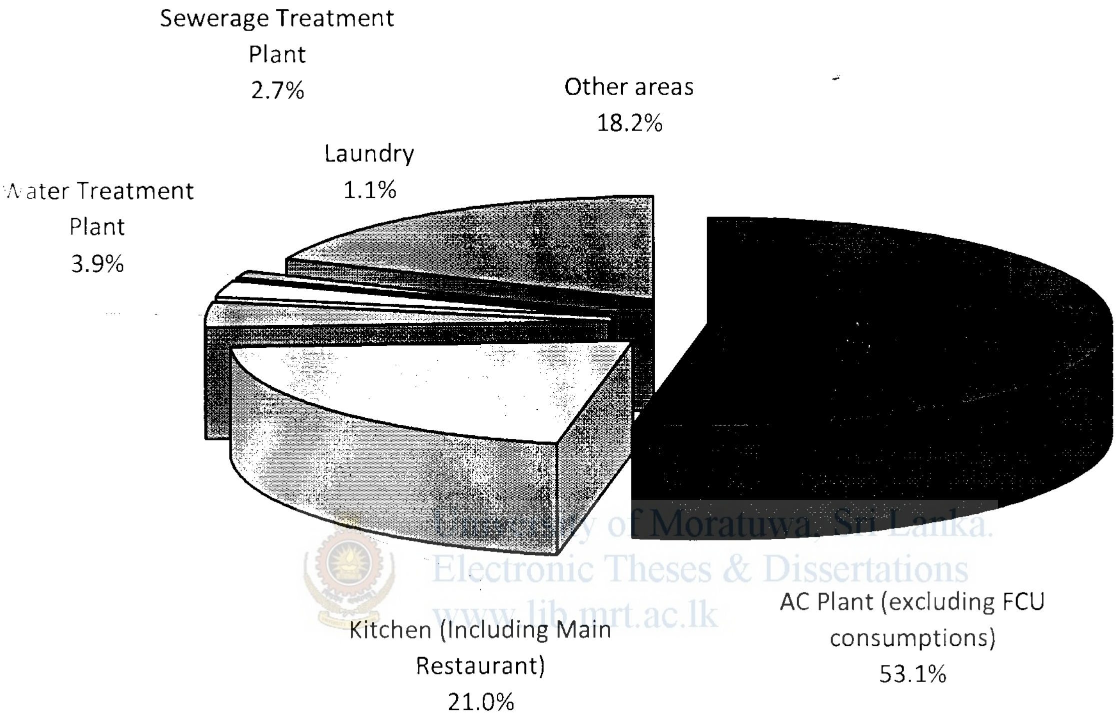


Chart 2.5 – Electrical Energy Balance

As in the above chart, though the kitchen electrical consumption contributes to the defining of shape of the Heritance Ahungalla electrical daily load profile, it's just a 21% from the total load, that includes main restaurant consumption and the elevator consumption. As per last energy audit results it was found out that about 5% from the total electricity is consumed by the main restaurant (alias Jute Restaurant), hence the effectiveness of kitchen is about 16% from the total electricity consumption of the hotel [13].

As described in above two chapters, the hotel energy consumption has to play the major role in the cost saving factor, as it is the most possible and effective cost centre of the hotel, considering operational cost. In addtion, from the energy expenses, electricity plays a dominant character and its contribution is over 80% in cost basis. Further analyzing, it has been proved that the air conditioning system of the Heritance Ahungalla consumes more than 50% from the total electricity requirement of the hotel. Above percentage is excluding the FCU consumption, the individual spilt type and window type air conditioners consumption.

Heritance Ahungalla air conditioning system consists of four 120 refrigerant tones (RT) screw type water cooled chillers. Chiller plant is designed in such a way that it could cater 154 numbers of guest rooms and few numbers of land side rooms, restaurant, bars, gymnasium, all the office areas and conference hall, with the operation of three chillers and the 4th chiller is operational only under special circumstances.

At present, the air conditioning system at Heritance Ahungalla is operating without having a variable speed driver installation, continuous monitoring of the chilled water inlet and outlet temperatures, the number of chillers to be operated is defined.

During the designed stage of the Heritance Ahungalla refurbishment in year 2005, it was calculated that the guest room requirement would be 235 refrigerant tonnage and 175 refrigerant tons for public area requirement.

Chapter 3

Methodology

3.1. Identification of areas to be addressed

When considering saving of electricity of the hotel by means of altering electricity consumption of air conditioning plant, the first step was to identify the relationship between electricity consumption of the hotel with various factors such as number of occupied rooms, number of guest nights, number of covers and so on.

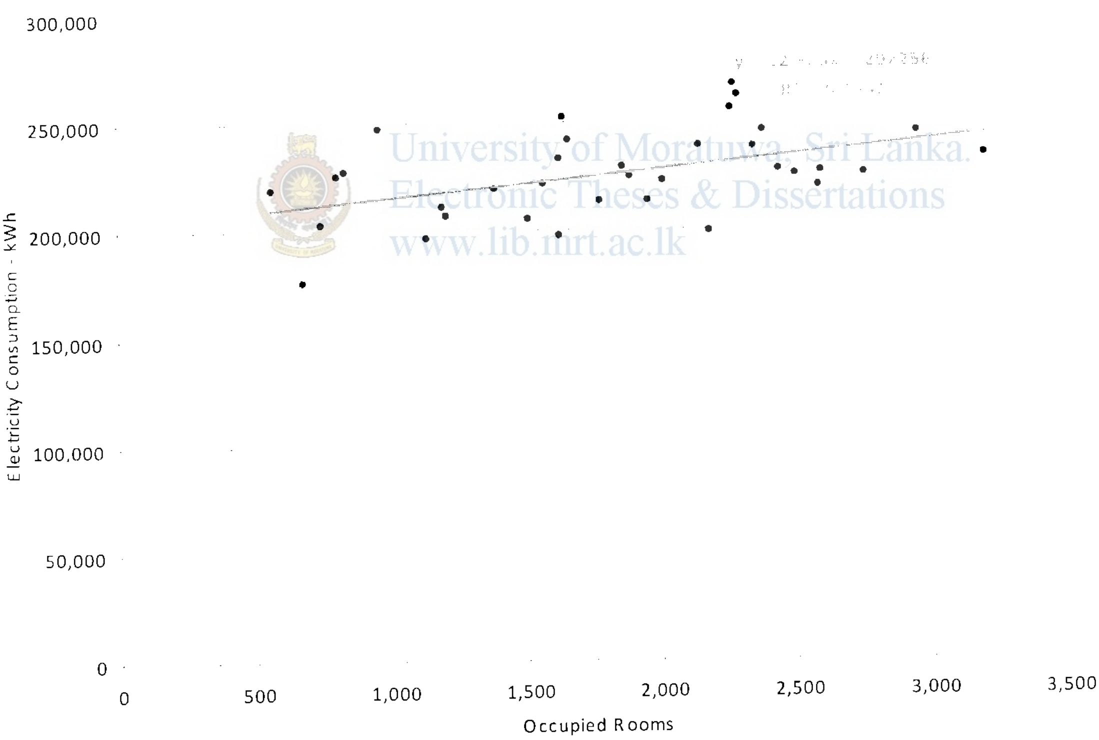


Figure 3.1 - Monthly Electricity Consumption with Occupied Rooms

Above graph shows the monthly electricity consumption in kWh against the number of occupied rooms of the hotel. The linear relationship between number of occupied rooms and the consumed electrical energy is very poor (R^2 = 0.1981). The graph clearly shows that the electricity consumption has slight variations though the occupied rooms are same, that is because though the rooms are not occupied, the room temperature is maintained at

26°C, hence some months the energy consumption is much higher than the others as the outdoor temperature is high. In some months the number of functions held in the hotel is high and is not reflected in the number of occupied rooms.

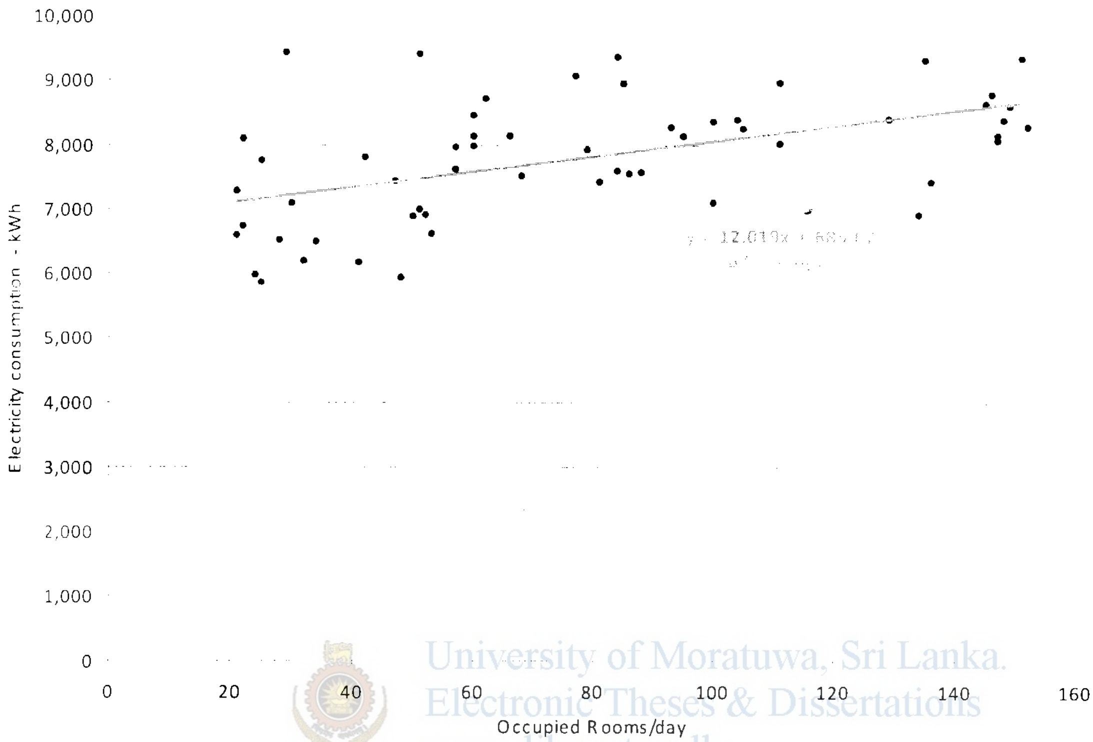


Figure 3.2 - Daily Electricity Consumption with Occupied Rooms

A better relationship could be shown when occupied rooms were taken in daily basis. This is because on daily basis, variation of function is from zero to two, but on monthly basis it could be 0 to 50. But still the outdoor temperature variation, variation of occupied rooms from "full board" to "bed and breakfast mode" cause the poor relationship between occupied rooms and the electrical energy consumption at Heritance Ahungalla.

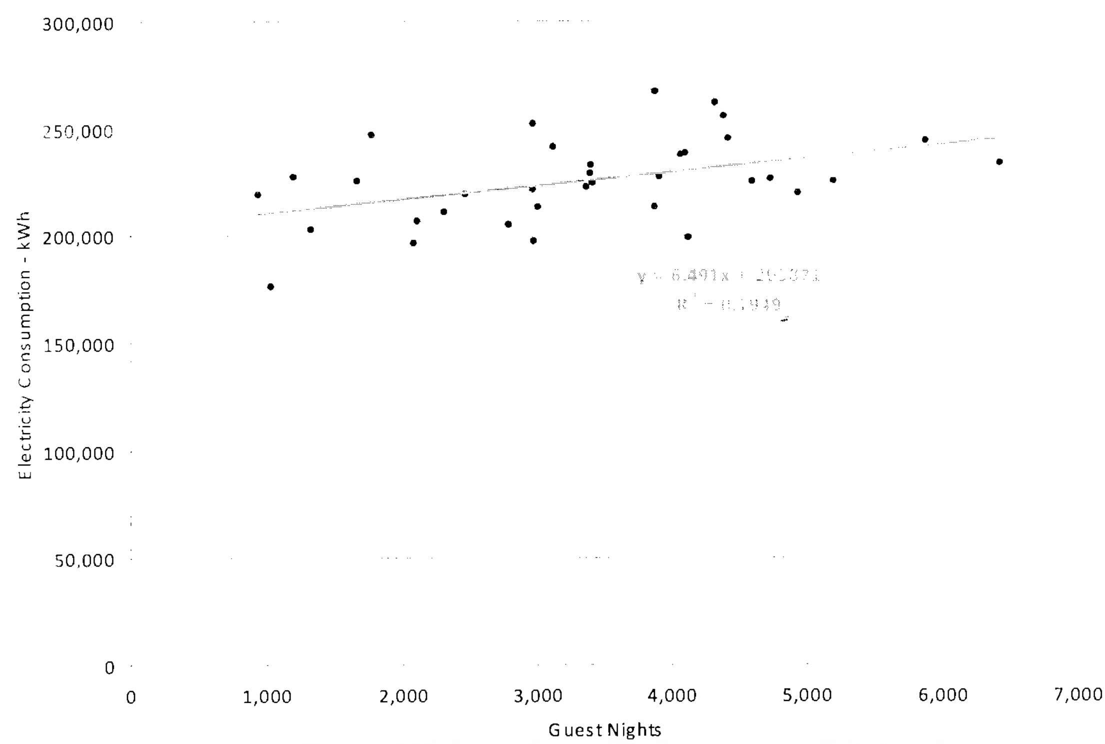


Figure 3.3 - Monthly Electricity Consumption with Guest Nights

The linearity for the relationship of electricity consumption against the number of guest nights is also poor. This is because, there is a considerable amount of electricity consumed by the general area regardless of the rooms is occupied or not. In addition, there may be some functions which are not counted into the occupied rooms as well as there is no direct method to add number of guest in a function to the guest nights.

According to previous studies carried out by various parties, it has been given the result that hotel monthly energy consumption correlates weakly with the monthly occupancy of that particular hotel [4], [5]. But in Cyprus it was found out that the hotel electricity consumption highly correlated with the number of occupied rooms in exponential regression model [9].

In many quality hotels in Hong Kong, even when a guestroom is not occupied, the air conditioning will still be provided to prevent odors or discomfort [4]. Heritance Ahungalla is also maintaining the room temperature at 26 ^{o}C though the room is unoccupied, through out the year without considering outdoor temperature. In one of the studies, attempts were made to correlate energy performance with total gross floor area, but the correlation is rather poor [3].

Though it is difficult to formulate a better correlation with hotel electricity consumption and the occupied rooms due to various reasons, it is obvious that there is a correlation as we have to increase the number of chillers to be operated with the number of occupied rooms. It has also been found out that the hotel energy consumption is very high whenever the occupied rooms are less. Electricity consumption per occupied room is highly correlated with the number of occupied rooms.

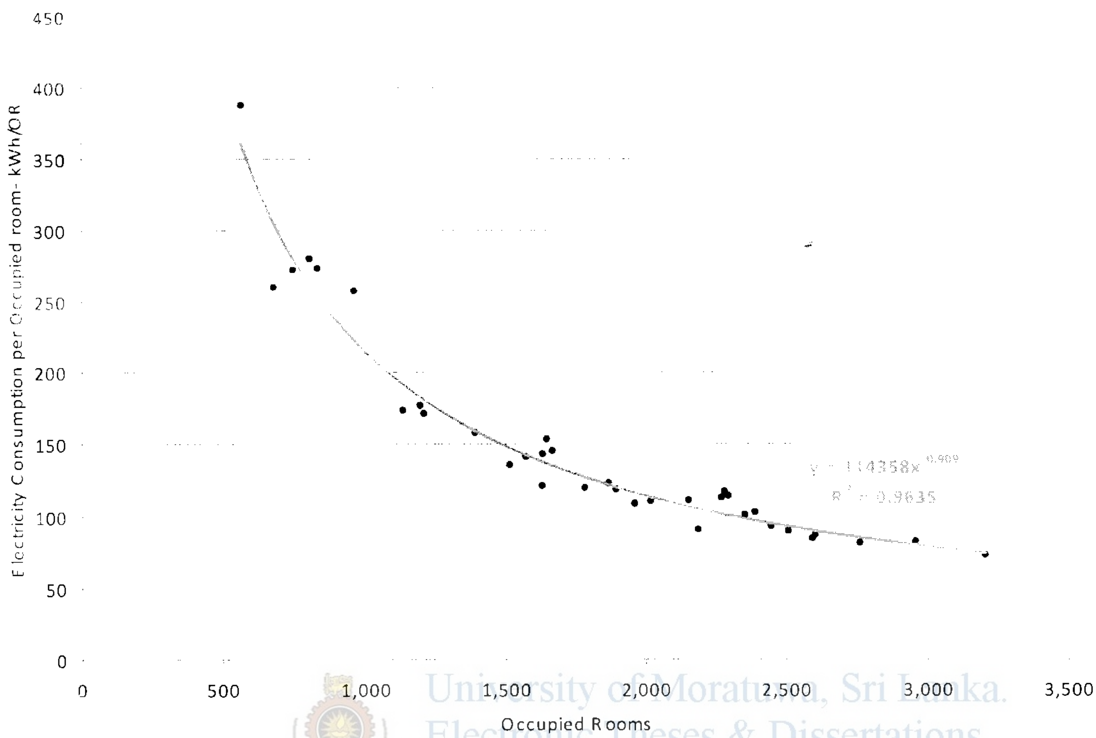


Figure 3.4 - Electricity Consumption per Occupied room for a month period

With analysis of figure 3.4, it is clear that the electricity consumption of the hotel is high as almost 400 kWh per occupied room when the monthly hotel occupied rooms are lesser as 600 and the per occupied room electricity consumption is low as just 75 kWh per occupied room when the monthly occupied rooms exceed 3000.

Therefore it is time to consider energy saving during low occupancies in order to maintain the lesser production cost. One of the recommendation on the study carried out on energy performance of hotel building in Singapore is Hotel management should consider the ways of reduction of energy consumption reduction during low occupancy seasons [5].

The figure 3.5 explains the above variation on daily basis and clearly. With the higher base electrical load, per occupied room consumption is varying from 335 kWh to 55 kWh at the occupied rooms from 20 to 150 per day. The main component on electrical base load is the operation of chiller plant as described as above.

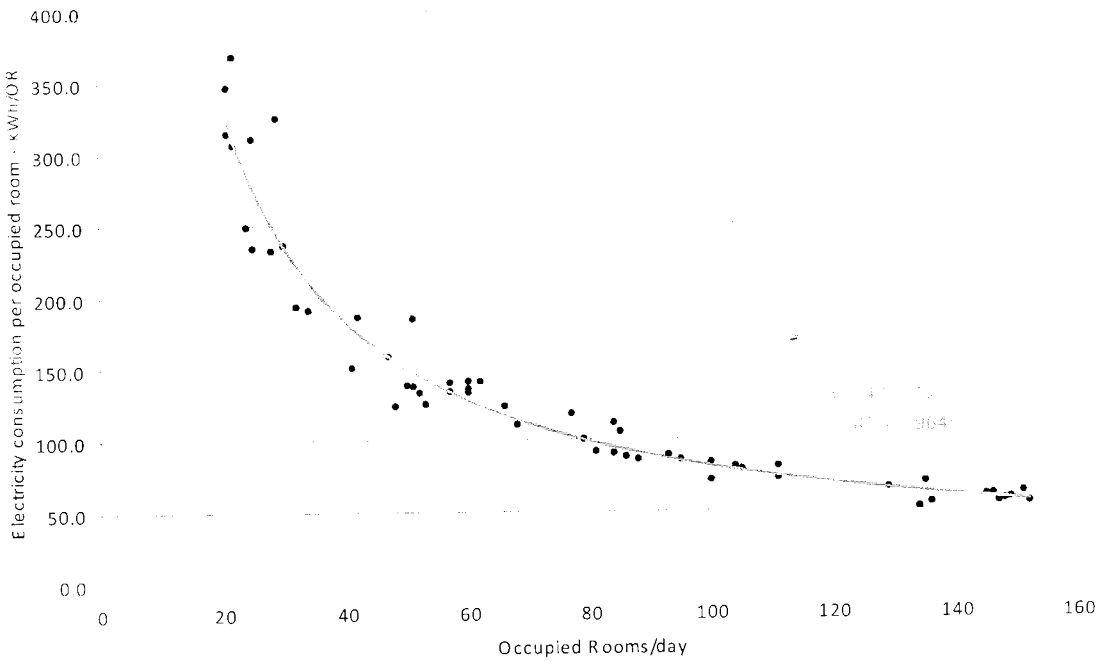


Figure 3.5 - Electricity Consumption per Occupied room for a day

As described in previous two chapters, air conditioning system is selected as the controlling point of electricity consumption of the hotel. Therefore the relationship between electricity consumption by the chiller plant and the hotel occupied rooms is analyzed.

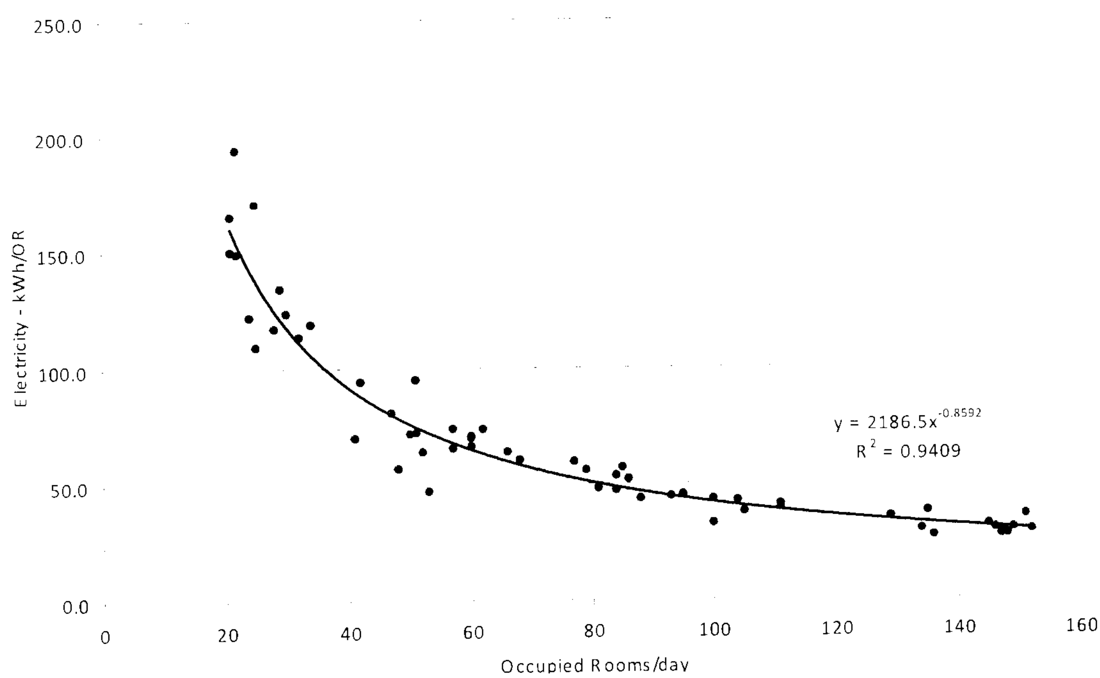


Figure 3.6 - Electricity Consumption per Occupied room for a day (AC Plant)

This shows that the air conditioning plant electricity consumption per occupied room is varying from almost 170 kWh to 30 kWh per day when the occupied rooms vary from 20 to 150 per day.

This is because as mentioned earlier, the hotel is maintaining 26°C of the guest room temperature though the rooms are occupied or not. One reason is to avoid the possible odor and the other reason is with the system of occupied rooms are allocated, even though it is required or not chilled water to be traveled through entire chilled water circuit of the hotel.

As the first step, since the study was based on controlling the hotel electricity consumption by means of air conditioning plant electricity consumption, have to check whether there is a controlling mechanism in relation with guest rooms. In this case, hotel chilled water distribution system was studied. The hotel chilled water distribution system can be divided into five main sections covering all guest rooms, restaurant, bars, conference hall, offices and other areas.

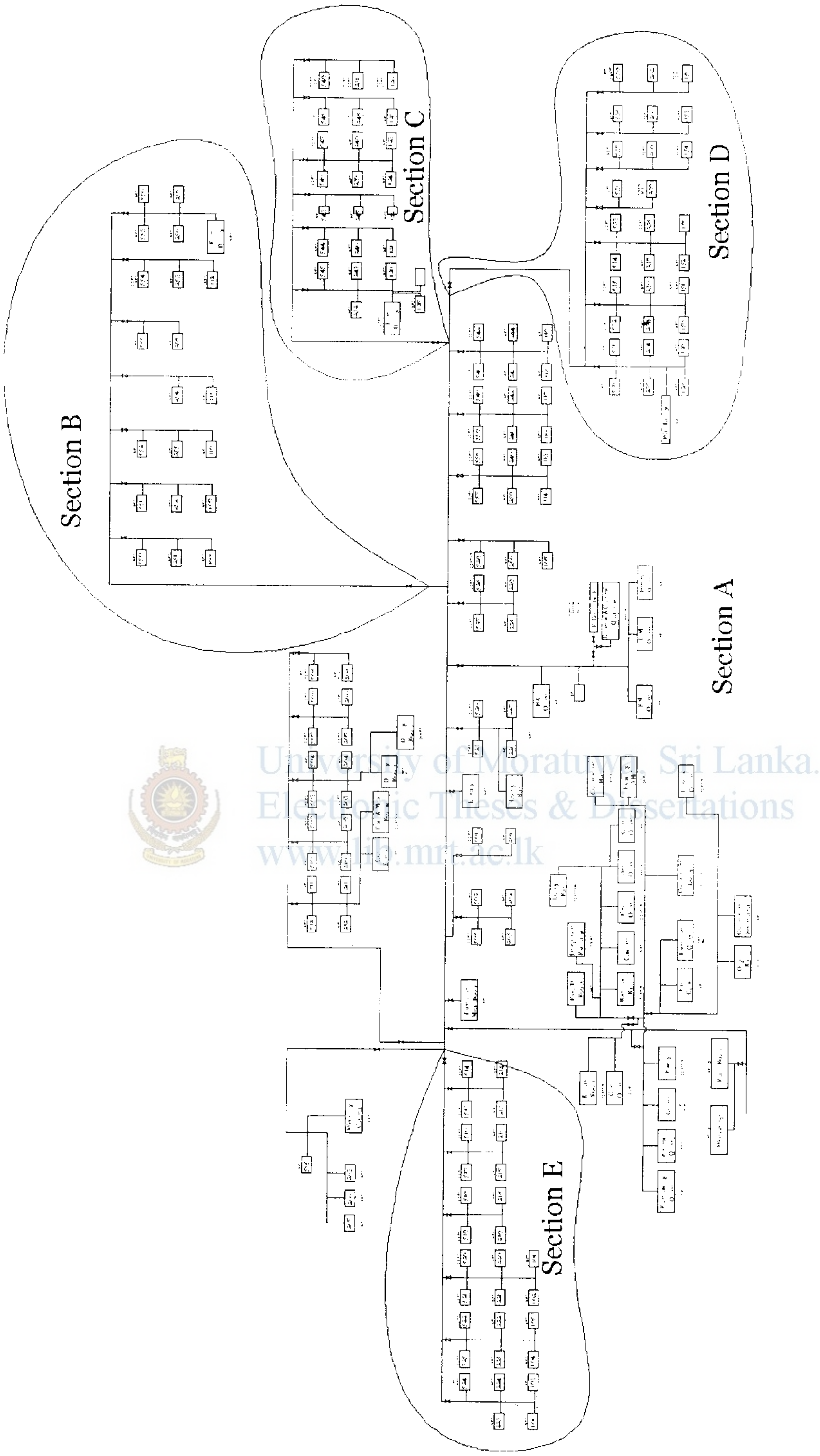


Figure 3.7 - Layout (Hotel Chilled water distribution line)

These sections have been selected mainly because there is a possibility to isolate each section by means of a valve from the main chilled water distribution and feasibility of reaching mentioned valves to operate as those are not motorized operated valves. Then the numbers of rooms allocated in each section with these categories were analyzed.

Section A contains 52 guest rooms including 47 deluxe rooms, 03 luxury rooms, one suite and one luxury suite room with almost all the public and office areas including Plant Room, Work Shop, Purchasing office, Stores office, Cellar, Pastry, Chef office, Billiard Room, Orpheus Bar, Conference Secretarial, Information Centre, Executive Cyber, Executive Office, Conference Lobby, Conference Hall, Bacchus Bar, Cashier, Front Office, Accounts Office, Chief Office, Lobby Bar, Executive Television Room and Telephone Exchange, Wedding Gallery and Cold Kitchen, Fish and Meat Room, Dining Room (Restaurant), Land side rooms and Wedding gallery

Section B consists of 21 guest rooms including only one upper category room. Section C consists of 23 guest rooms including 3 upper category rooms (2 suites and one luxury suite room).

Section D consists with 23 guest rooms including 14 upper class rooms, categorically 12 luxury rooms and two luxury suites while Section E contains only one upper category room out of 29 guest rooms.

With the identification of each section, the change of electricity consumption change in the hotel with each section is practically measured.

3.2. Procedure

Initially 2 air conditioning chiller plants were in operation with 2 secondary pumps.2 primary pumps and 2 cooling towers. At this time all the offices were working and all the guest room sections were in operation though those has been unoccupied, room temperature was maintaining at 26°C.

3.2.1. Isolation of Identified Sections

As the first step of the study, since all sections were in operation, section by section has been removed from the system to identify the impact to the system, in this case firstly section D was isolated by closing the valve number (V - 351) at about 13 25 hours and checked the impact to the secondary pumps. There was no noticeable impact to the drawing current of the secondary pump and the chilled water line pressure. Then the section C was closed by means of valve number (V-343). There was no noticeable impact to the drawing current of the secondary pumps and to the chilled water line pressures.

Next the section E was closed and it was noticed that the by-pass line at the chilled water secondary pump header was opened, that is because demand is much lesser than the supply load, as a result of that, pressure has been increasing in the supplier header. In order to balance the pressure of chilled water line, one of the secondary pumps was switched off and managed with one secondary pump.

Finally the section B was closed by valve number (V-329). After some time it was observed that one plant was running with unload condition hence that plant was switched off along with cooling tower and primary pump at about 15 25 hours. The figure 3.8 shows how the total power requirement of the chiller plant was reduced with the reduction of number of rooms are occupied. With reduction of demand total reduction of power requirement was about 100 kW (from 275 kW to 175 kW).

As per name plate data, chiller plant power consumption is 85 kW at full load and plant is operated at four steps. Further more, secondary pump power consumption is 22.5 kW, primary pump power consumption is 4.0 kW and cooling tower fan motor and condenser water pump power consumption are 3.7 kW and 7.5 kW respectively.

Theoretically, removal of one chiller plant including primary, secondary pumps and the cooling tower with related condenser water pump from the system, reduction of total power requirement of the hotel is 122.7 kW and hence 122.7 kWh per hour.

Figure 3.8 shows the total electricity consumption reduction when cooling load is unloading in panel number 02, which supplies electrical power to mainly Air Conditioning plant. In addition to the air conditioning plant, panel number 02 supplies electrical power to Laundry including electrical heat exchanger (calorifier), generator room lights and generator cooling tower.

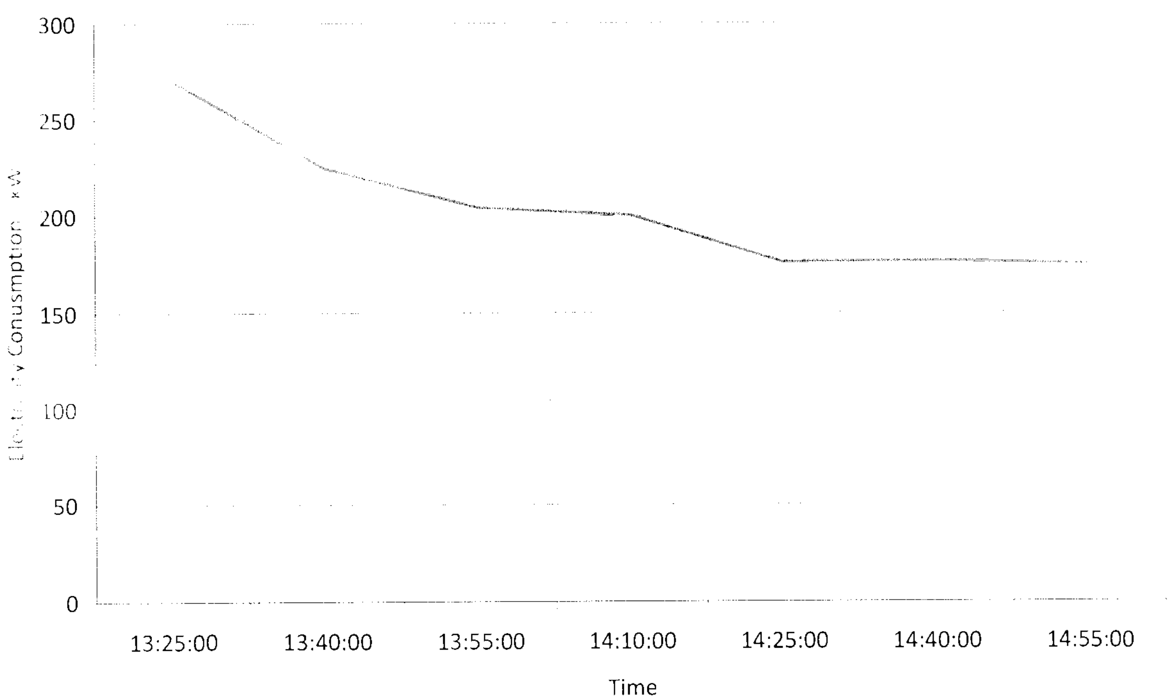


Figure 3.8 - Cooling Requirement unloading

3.2.2. Loading

During the time of the study was carried out, as the hotel occupancy is pretty low, though we were able to switch off the chiller plants and do the study, during loading procedure it was not highly reflecting the actual situation as there were no guests in most of the rooms, just lighting load was making the room heated up.

As the out side temperature was 28 °C and most of the rooms were un–occupied inside lights of rooms were switched on in addition to the FCU to compensate the load.

About 30 minutes has been left to raise the chilled water line temperature to normal delivery temperature in order to get more accurate loading figure. Then started the loading of rooms to the system from Section A as what ever the condition Section A to be operated as it contains almost all the public areas and offices.

As the rooms in Section A loading was started at 16 00 hours and entire section were manually loaded at about 16 50 hours. With the addition of 52 guest rooms in addition to the public areas and office areas. After loading section A, after some time it was observed that temperature of supply header was 12 °C and 14 °C of the return header.

Chiller number 2 was switched on along with respective cooling tower & condenser pump and primary pump. After one and half hours temperature of both supply and return header were reduced up to 8 °C and 10 °C respectively. Then about one hour was let to maintain the set values.

As the second step, loading of Section B was started at about 18 25 hours and completed at 18 50 hours and the behavior of the plant was studied. Chilled water temperature was not increased and hence it was decided to open Section C by means the valve V -343. It was started from 19 45 hours and completed at 20 10 hours. It was observed that supply header temperature was 8 °C and return header temperature was 11 °C at 20 25 hours.

Loading of Section D was started at 21 45 hours and completed at 22 25 hours and managed with two chillers and one secondary pump. After sometimes it was observed that temperature in both supply and return header were increased up to 10.5 °C and 13.5 °C respectively and hence another secondary pump was started at 23 10 hours .

Loading of Section E was started at 23 25 hours and completed at 23 50 hours. 111 rooms were purposely loaded apart from the occupied rooms at 23 50 hours and temperature of supply and return headers were 9 °C and 11.5 °C respectively.

The third chiller was switched on at 23 45 hours and after one hour chilled water temperatures was 7.5 °C and 10.5 °C at supply and return headers respectively.

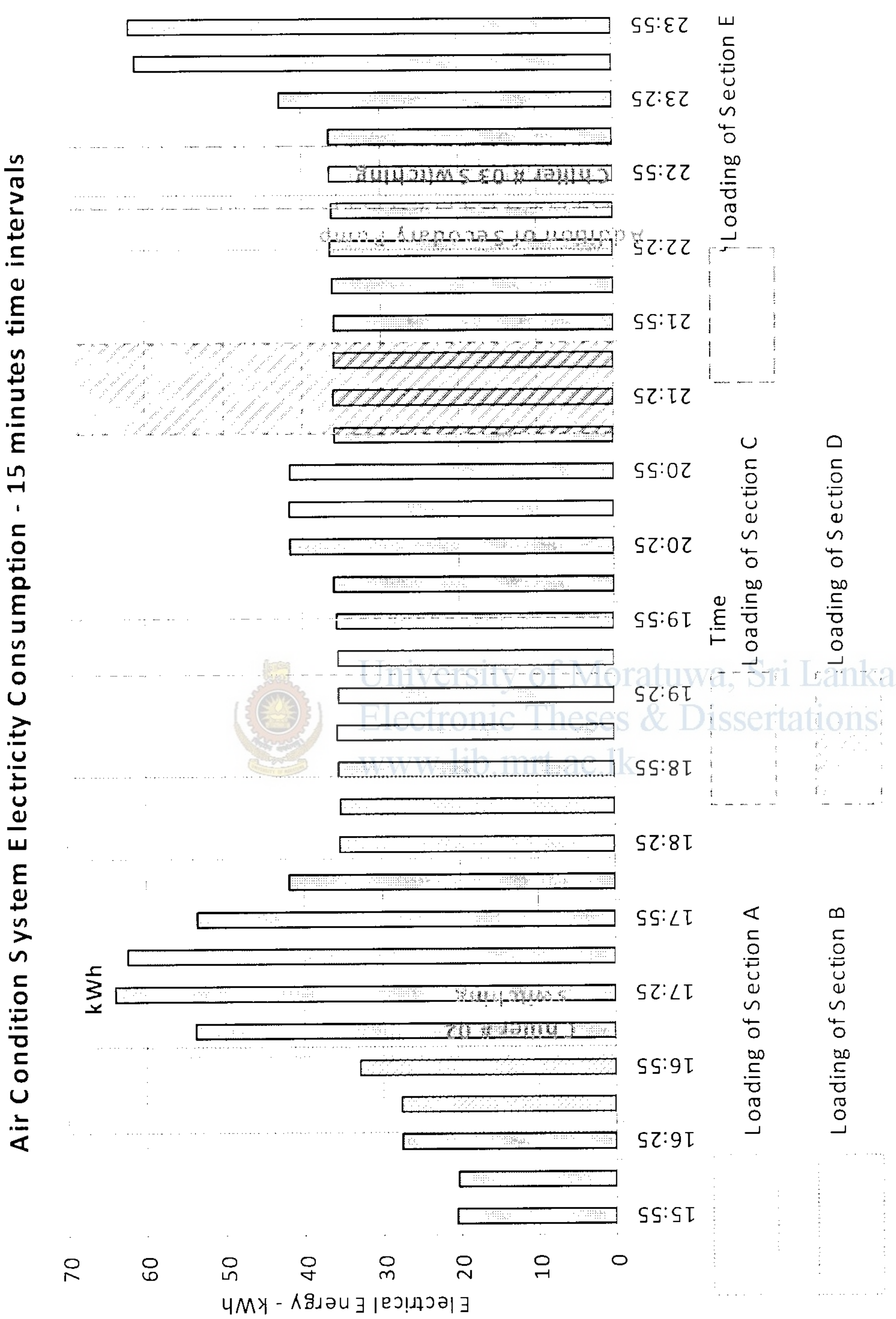


Figure 3.9 - Chiller plant loading (Energy)

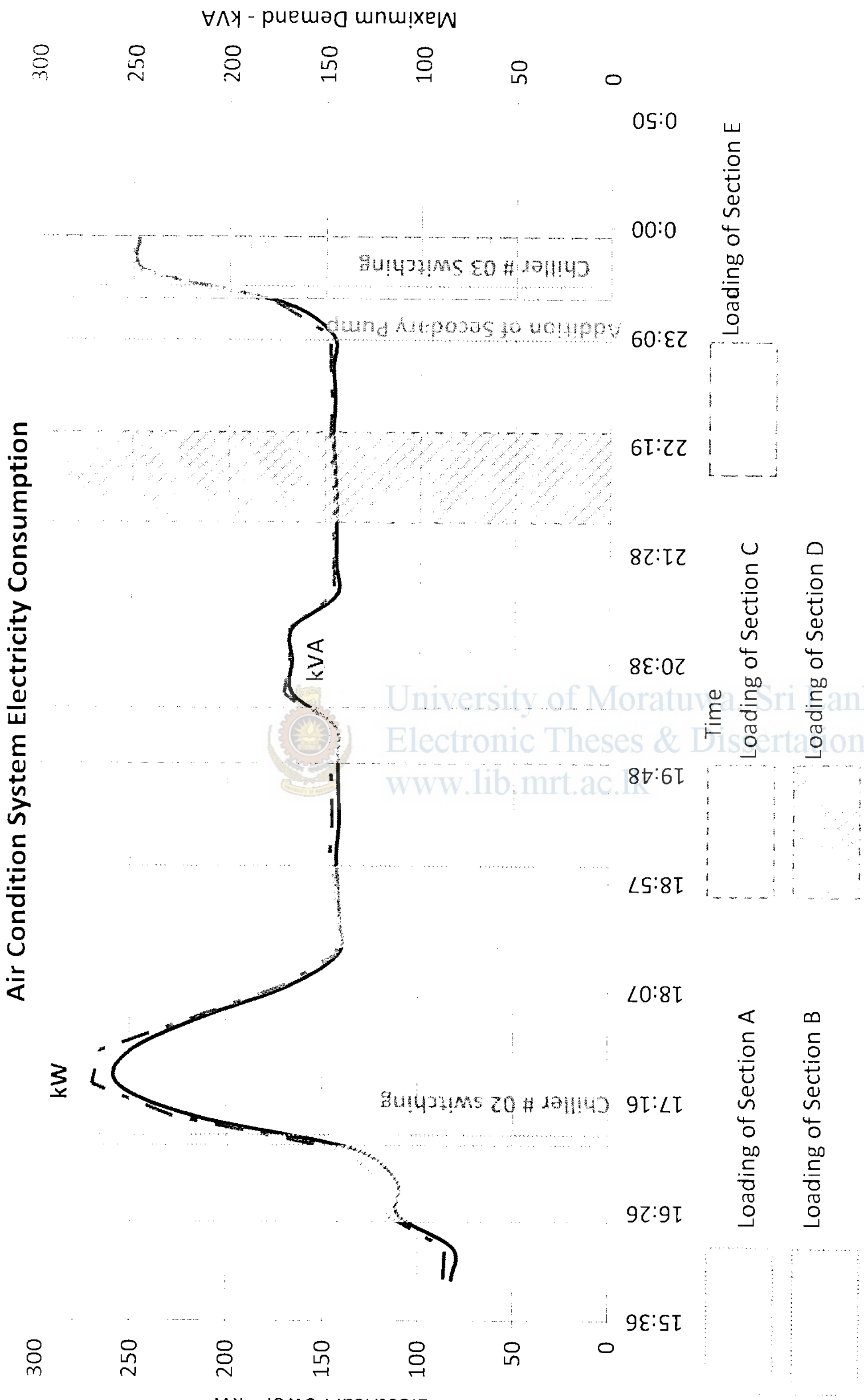


Figure 3.10 - Chiller plant loading (Power)

It was noticed that once a chiller plant has added up to the system, as the chilled water IN temperature to the plant and chilled water OUT from the chiller plant is much higher than the set values, the newly added chiller plant was loading in its full scale and once the temperature is dropped to set values then only the chiller plant started to unload till the generating load is equivalent to the demand.

The gradual unloading was started at 01 45 hours and finished at 02 30 hours. Below figure 3.11 shows the variation of power requirement with the unloading of cooling requirement. Though within 45 minutes unloading has completed, chiller plant unloading has took place till 03 10 hours and during that period total reduction of power requirement was about 162 kW.

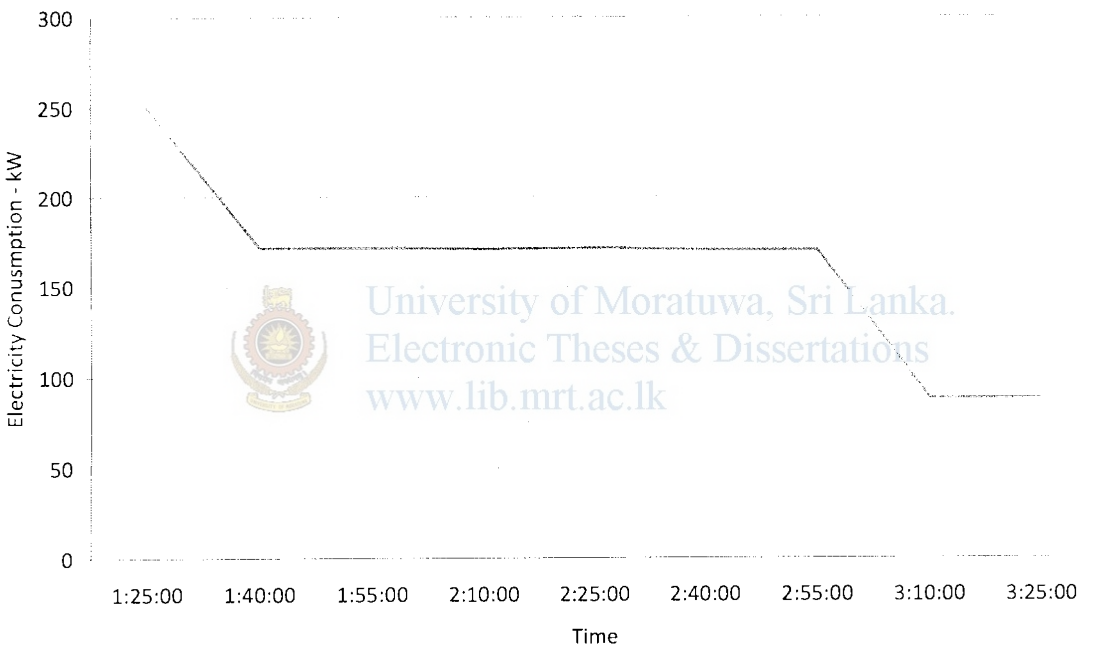


Figure 3.11 - Chiller plant unloading

3.3. Analyzing of Data

It is clearly shown that the total electrical power consumption of the hotel is reduced by almost 100 kW with the removal of one chiller plant from operation. The practical value is almost same as the theoretical value. The energy saving during that period was about 40kWh.

Then the behavior was studied during the loading period. With the existing load of offices, room by room was added to the system from Section A. Study was started with one chiller in operation to cater the operating offices and public areas. In addition to that since the hotel is maintaining guest room temperature at 26°C even though the room is non occupied, it could be realized that the rooms area partially loaded in Section A considering linear relationship between room temperature and the Air Conditioning requirement hence the electricity consumption, as the average outdoor temperature is 30°C in Ahungalla area and the average room set temperature is 22°C when the room is occupied by the guest.

Each chiller has the capacity of 120 RT, and each consistent with four steps. With referring the above graph we could clearly see that gradual increment of electrical power consumption of the hotel. With the chiller plant 01, all the steps were taken in to the operation and it was noted that the one chiller cannot cater the required air conditioning load. As the chilled water IN and OUT temperatures have gone beyond the set values, second chiller was added and a sudden peak is noticed in the hotel power consumption increment in above said graph.

As the temperature variation was too high, second chiller was fully loaded for sometime and once the temperatures achieved the set values, it came back to the normal operation. It was noted that with one chiller the average power consumption was about 110 kW. After loading Section A, the air conditioning main plant power consumption has been increased to 140 kW. From that point onwards it is difficult to identify any variation considering the above graph as there is not much variation in power consumption with the addition of Section B, Section C and Section D to the system.

It was pre assumed that the air conditioning requirement for public areas and the office areas, back of the house is constant other than the guest room requirement. But in practice it is not the actual situation. That is why we cannot distinguish additional power requirements with the additions of Section B to Section D. Some public areas operate during particular time period such as Gymnasium, Gem Shop and some public areas operate through out the day but there are special time durations where the air conditioning requirement is high and rest of the time requirement is the base load, like restaurant and bars.

Some offices were operating through out the day such as the front office managers office, General managers office and some of the offices were operating for a particular time period, like accounts office which operates during 08 00 hours to 17 00 hours. Therefore the air conditioning requirement of the areas other than Guest rooms, is not a constant value through out the day, hence it is very difficult to carry out the study on air conditioning power requirement for guest rooms unless it is measured by the AC consumption by means of measuring air flow measurement of the other areas.

From the above two graphs there is a noticeable hike around 20 00 hours to 21 00 hours as there was a higher utilization in kitchen area (butchery, pastry are air conditioned areas) and the there is peak operation hours in restaurant area.

Chapter 4

Electricity consuming pattern: Other areas of the hotel

As shown in figure 2.2 – Electrical load profile with individual loads in Chapter 2, hotel electricity consumption load profile is highly defined by the air conditioning system, as the air conditioning plant power consumption is more than 53% from the total electricity consumption of the hotel.

Main kitchen and the restaurant combined to give the smoothing factor to the hotel electricity load profile as the contribution is about 21% from the total electricity consumption. Major consumer of the kitchen is cold rooms and the freezer rooms, which did not come under air conditioning system of the hotel.

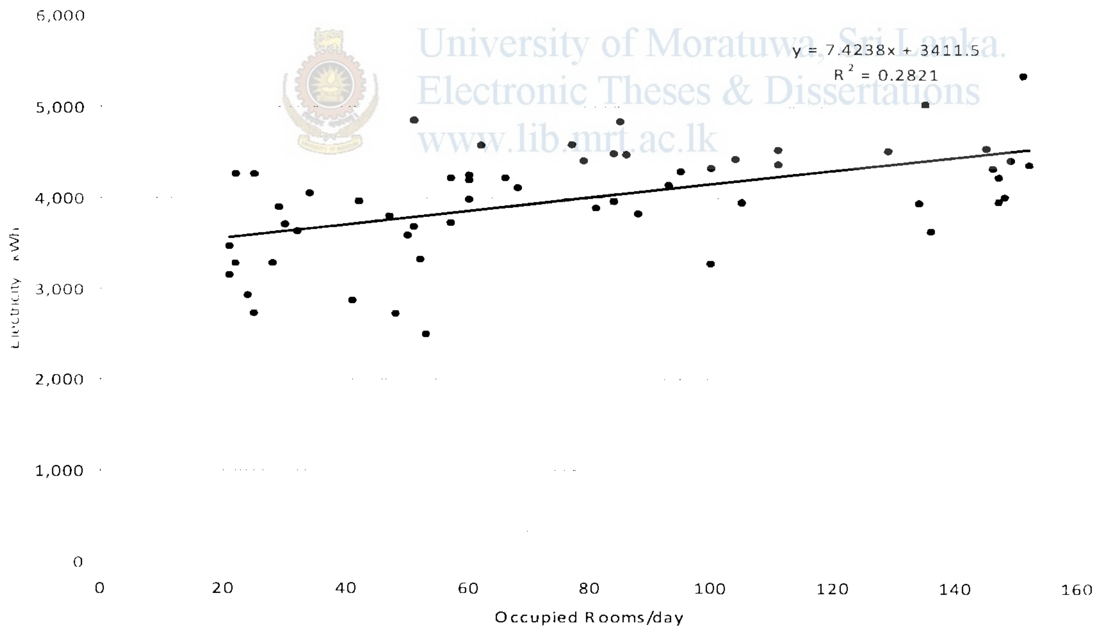


Figure 4.1 - AC Plant Electricity Consumption (Day)

Though the highest percentage of electrical energy is consumed by the air conditioning plant, still a poor relationship is seen between the number of occupied rooms and the electrical energy consumed (only air conditioning plant). As described above, this kind of variation occurred since the number of functions and outdoor temperature has not been taken into account.

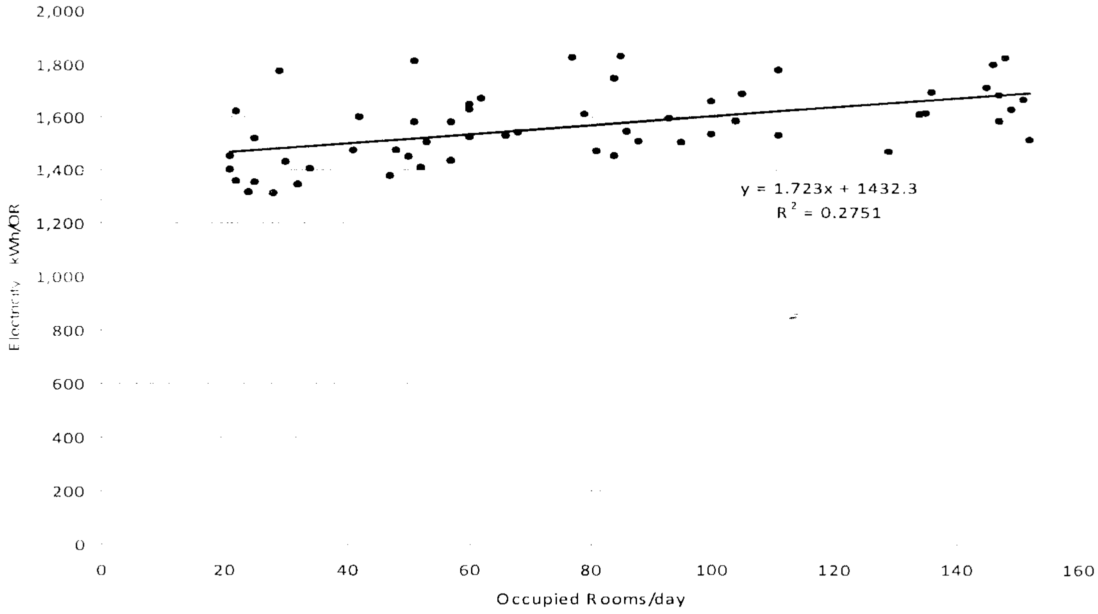


Figure 4.2 - Kitchen Electricity Consumption (Day)

The second major electricity consumer is the kitchen; here the situation is same, no proper correlation. That is because kitchen energy consumption is varying with the number of guest food plates (guest covers), as functions are held there which has to be taken into account. In addition sometimes hotel provides ala'cate, which are also not reflected in occupied rooms.

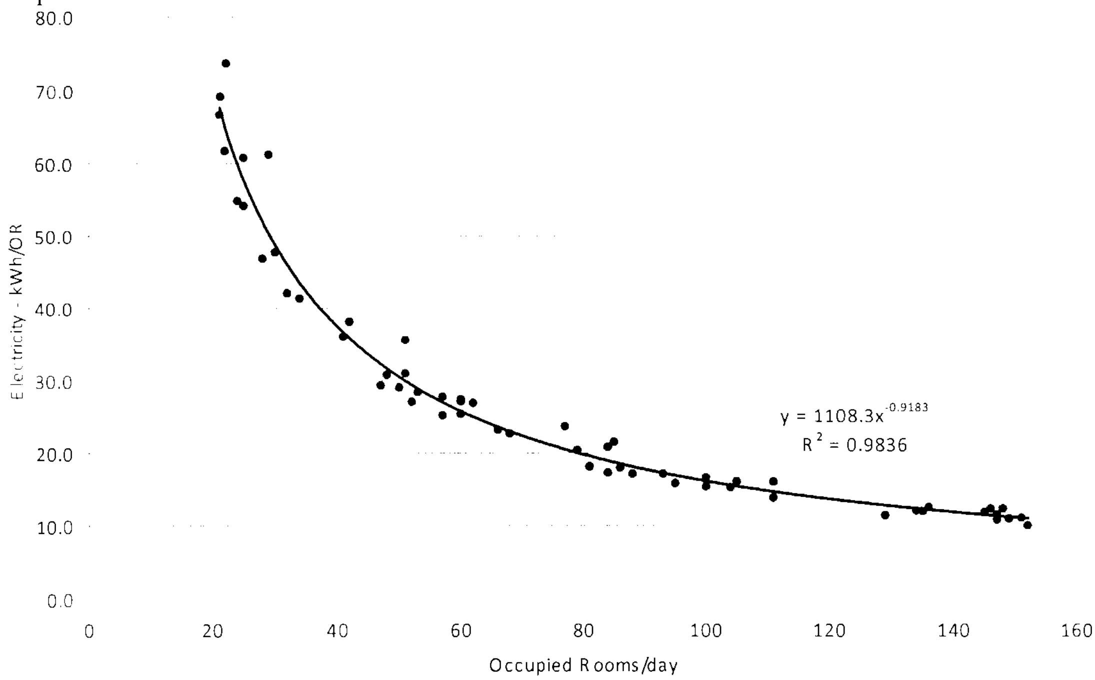


Figure 4.3- Kitchen Electricity Consumption based on per occupied room (Day)

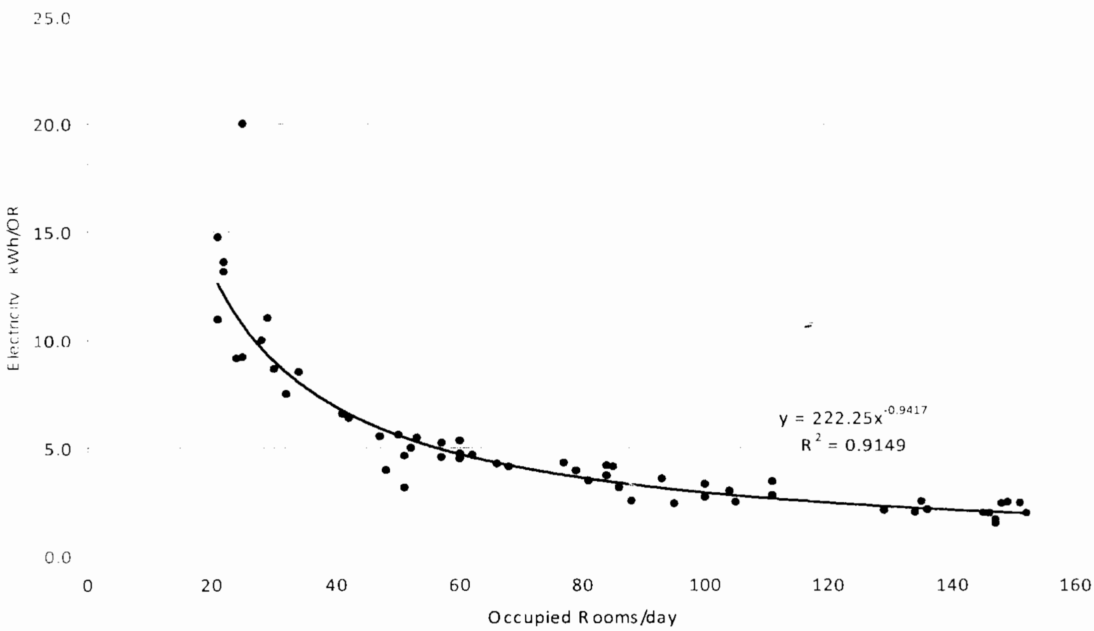


Figure 4.4 - Water treatment Electricity Consumption on per Occupied room (Day)

There is much better correlation between electricity consumption per occupied room against occupied rooms of the hotel (per day). Which has been proved by above two graphs as proved in Chapter 3 as well.

By analyzing the per occupied room electricity consumption against occupied rooms following data could be tabulated.

Occupied Rooms	Percentage occupancy	Total Electricity consumption kWh/ OR	Chiller plant kWh/OR		Kitchen & Restaurant kWh/OR		Water Treatment Plant kWh/OR	
20	13.0%	335	**170**	50.7%	**72**	21.5%	**13.2**	3.9%
40	26.0%	182	**93**	51.1%	**37**	20.3%	**6.8**	3.7%
60	39.0%	125	**64**	51.2%	**26**	20.8%	**4.7**	3.8%
80	51.9%	98	**50**	51.0%	**20**	20.4%	**3.5**	3.6%
100	64.9%	80	**42**	52.5%	**16**	20.0%	**2.9**	3.6%
120	77.9%	70	**36**	51.4%	**14**	20.0%	**2.4**	3.4%
140	90.9%	60	**31**	51.7%	**12**	20.0%	**2.1**	3.5%
154	100.0%	55	**29**	52.7%	**11**	20.0%	**1.9**	3.5%

Table 4.1 - Electricity consumption per Occupied room with Occupancy

Above table clearly shows the variation of electricity consumption per occupied room from low occupancy to high occupancy range of the hotel.

Total electricity consumption is varying from 55 kWh per occupied room to 335 kWh per occupied room for high occupancy to low occupancy that is totally from 8, 470 kWh per day to 6, 700 kWh per day. Total difference is 1, 770 kWh per day.

The chiller plant electricity consumption varies from 29 kWh/occupied room to 170 kWh/occupied room from high occupancy to low occupancy. That is as a total energy 4, 466 kWh per day to 3, 400 kWh per day, hence the difference is 1, 066 kWh per day. That difference is almost 60% from the total energy variation.

Kitchen and Restaurant area electrical energy consumption per day variation is about 254 kWh per day while it is about 29 kWh per day in water treatment plant. Percentage wise impact to the total is 14.35% and 1.62% respectively.

That results shows that not only the impact to total electrical energy consumption but also to the difference between electrical energy consumption during low occupancies and high occupancies are mainly depended on air conditioning plant electrical energy consumption, and at the same time the impact from kitchen and restaurant, water treatment plant, laundry and so on, were much lesser.

Chapter 5

Mathematical Model and Results

Chapter 3 discussed the practical situation and the analysis was done based on practical values. In order to implement a generalized model for selecting optimum room combination from each section (wing) of the hotel for a given number of rooms to be occupied, practical behavior as well as theoretical values have to be analyzed.

To implement the generalized model, below procedure has been followed.

Hotel could be divided into two sections; mainly as the guest rooms and the public and office areas. As described in Chapter 3, guest room area could be divided further into five sections considering the chilled water line distribution system and the possibility of valve operation.

Each section has different number of guest rooms and each section room composition is completely different to the other. For an example, Section A contains altogether 52 numbers of guest rooms including 47 deluxe rooms, 3 luxuries, one suite and one luxury suite while Section B contains only 21 guest rooms including only one upper category room.

As there is a variation in room types inside a section, air conditioning load requirement is varying inside a section as well. Therefore the room air conditioning capacity is varying from 4 $kW_{thermal}$ to 18.5 $kW_{thermal}$, in other words 1.1 refrigerant tones to 5.3 refrigerant tones. For easy reference average cooling capacity has been taken for each section.

As the room types are different, hence the expected profit margins also difference from one type of room to other. Therefore average profit level for each section has been taken for easy reference.

Following table shows the average cooling capacity of each section and the expected profit margin.

Section	Number of Guest rooms	Average Cooling capacity TR	Average Profit Level 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

Table 5.1 - Section wise AC consumption and profit level

In addition there is a cooling load requirement in public areas and at the back of the house areas, which is 108.8 RT and this is mainly the base load as this areas should be operated what ever the occupancy level in the hotel. An average operational hour of public areas and the back of the house is about 14 hours per day.

Further more some portion of Section A to be added as the correction factor as once any section has been open for operation, definitely there will be some air conditioning requirement for that particular section though the rooms are unoccupied as the hotel room temperature is maintaining at 26^{o}C when the room is non-occupied.

Average outdoor temperate is 30^{o}C at Heritance Ahungalla and the temperature to be maintained at 26^{o}C when the rooms are un occupied as mentioned earlier, also the average room temperature is 22^{o}C when the rooms are occupied. Therefore considering linear relationship between temperature and the cooling load requirement considered 50% of Section A total AC requirement is needed when the rooms are unoccupied.

But when the room is unoccupied and once the room temperature reaches the set value, then the requirement is much lesser than the original requirement as the losses are low. Therefore instead of taking 50% from the total requirement, it is better to get a smaller percentage, about 35% during the unoccupied period.

Then the correction factor to the base AC load is 18.4 RT, as the Section A is always open for regardless of the occupancy level at the hotel. As the average operational hours of a guest rooms is about 20 hours per day, the corrected base AC load cab be given as, 1,455kWh$_{electrical}$ per day. Therefore the hotel electricity consumption for AC operation can be formulated as following equation (2) if the total occupied room of the hotel is given by equation (1). Sample AC energy cost calculation for a guest room per day as follows,

Average cooling capacity per room (Section B)	=	1.22 RT
Average operational hours	=	20 hours
Thermal power required	=	1.22 x 3.5 kW$_{thermal}$
	=	4.27 kW$_{thermal}$
Electrical energy consumption for AC	=	4.27x20x65%/ 4.9 kWh$_{electrical}$
	=	11.348 kWh$_{electrical}$

Variable AC energy cost per room in Section B = Rs. 11.348 x 11.2
= Rs. 127.1

(AC plant coefficient of performance – COP: 5; 65% of total is the variable load and overall unit cost of electrical energy is Rs. 11.2/kWh)

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

Where,

x_1 - number of occupied rooms of the hotel
α – number of occupied rooms in Section A
β – Number of occupied rooms in Section B
γ – Number of occupied rooms in Section C
δ – Number of occupied rooms in Section D
ϕ – Number of occupied rooms in Section E

$$16.296 + f_A(\alpha) + f_B(\beta) + f_C(\gamma) + f_D(\delta) + f_E(\phi) = x_2 \qquad (2)$$

Where,

16.296 is the cost on base AC load
$f_A(\alpha) - Cost\ incurred\ due\ to\ AC\ on\ Section A$
$f_B(\beta) - Cost\ incurred\ due\ to\ AC\ on\ Section B$
$f_C(\gamma) - Cost\ incurred\ due\ to\ AC\ on\ Section C$
$f_D(\delta) - Cost\ incurred\ due\ to\ AC\ on\ Section D$
$f_E(\phi) - Cost\ incurred\ due\ to\ AC\ on\ Section E$

Function $f_A(\alpha)$ is a linear function as the Section A AC consumption when the occupancy is zero ($\alpha = 0$) is already included in the base AC load, where as all the other functions are discrete functions.

$$f_A(\alpha)=147.3\alpha \quad (3)$$

$$f_B(\beta)=\begin{cases}0 & if\beta=0\\ 1{,}437+127.1\beta & if\beta>0\end{cases} \quad (4)$$

$$f_C(\gamma)=\begin{cases}0 & if\gamma=0\\ 1{,}886+152.3\gamma & if\gamma>0\end{cases} \quad (5)$$

$$f_D(\delta)=\begin{cases}0 & if\delta=0\\ 3{,}068+196.4\delta & if\delta>0\end{cases} \quad (6)$$

$$f_E(\phi)=\begin{cases}0 & if\phi=0\\ 2{,}279+146.0\phi & if\phi>0\end{cases} \quad (7)$$

There are constraints for each section occupied rooms as there is maximum number of rooms per section, which can be given as,

$0 \le \alpha \le 52$

$0 \le \beta \le 21$

$0 \le \gamma \le 23$

$0 \le \delta \le 29$

$0 \le \phi \le 29$

Function from f_B to f_E are discrete because whenever whichever the section has been opened for operation, there will be a base load since hotel rooms have to maintain 26^{0}C though the room is unoccupied as mentioned earlier. As the different section has different room combination, base load as well as the per room incremental cost for AC requirement also varies.

As described earlier, since the room types are different, the expected profit per room is also different. As each section has different combination of each type of rooms, each section has different profit function per selling guest room, which can be given as follows.

$$2{,}060\alpha + 2{,}025\beta + 2{,}090\gamma + 2{,}260\delta + 2{,}060\phi \quad = x_3 \quad (8)$$

From the profit margin, possible electricity cost for AC consumption has not been removed as it is varying with room occupancy.

To obtain the maximum profit for a given number of occupied rooms following equation (9) to minimized,

$$x_3 - x_2 \qquad (9)$$

There can be one or more combination of *α, β, γ, δ* and *Ø* for minimum x_3-x_2 for a given number of occupied rooms x_1. Suitable room combination with *α, β, γ, δ* and *Ø* shall be selected considering the above mentioned constraints on *α, β, γ, δ* and *Ø*.

To achieve this requirement simple program has been created and the followed algorithm is as follows.

5.1. Algorithm

Variable defining

Number of rooms occupied in Section A - α
Number of rooms occupied in Section B - β
Number of rooms occupied in Section C - γ
Number of rooms occupied in Section D - δ
Number of rooms occupied in Section E – Ø

And the total number of occupied rooms – r

Checking of all possible permutation and combination for α, β, γ, δ, and Ø which satisfy the

r = α + β + γ + δ + Ø

All possible combinations store in an array

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

Check the validity of each S_i for following constraints

Constraints

$0 \le \alpha \le 52$

$0 \le \beta \le 21$

$0 \le \gamma \le 23$

$0 \le \delta \le 29$

$0 \le \phi \le 29$

Reject all S_i which not satisfy any of above constraints and calculate following cost function and profit function for accepted S_i.

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

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

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

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

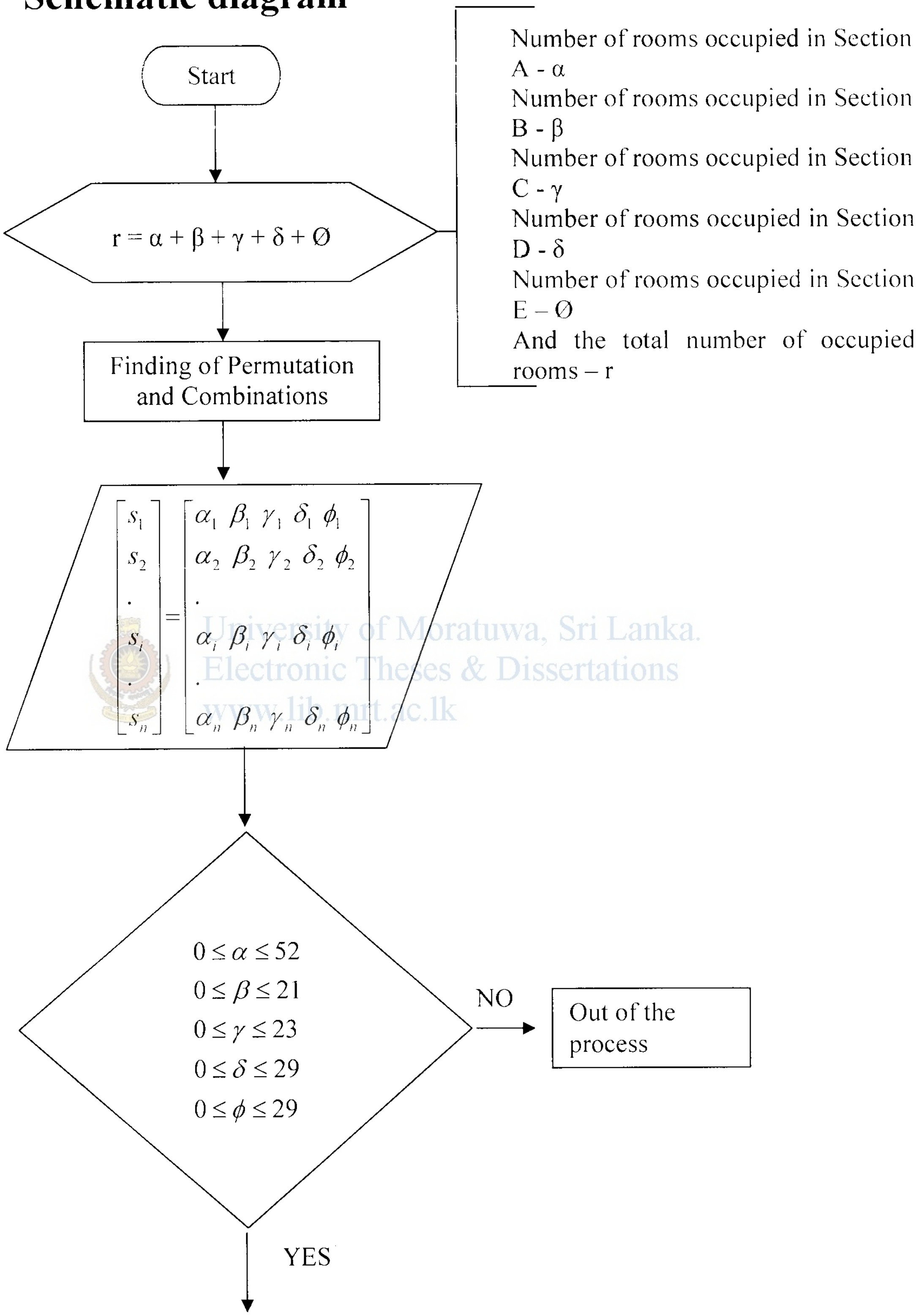
Select the maximum net profit value N_i for a given number of occupied rooms, r.

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 at Heritance Ahungalla.

5.2. Schematic diagram



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

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

where

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

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

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

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

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

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

$$N_i = P_i - C_i$$

Calculating net profit

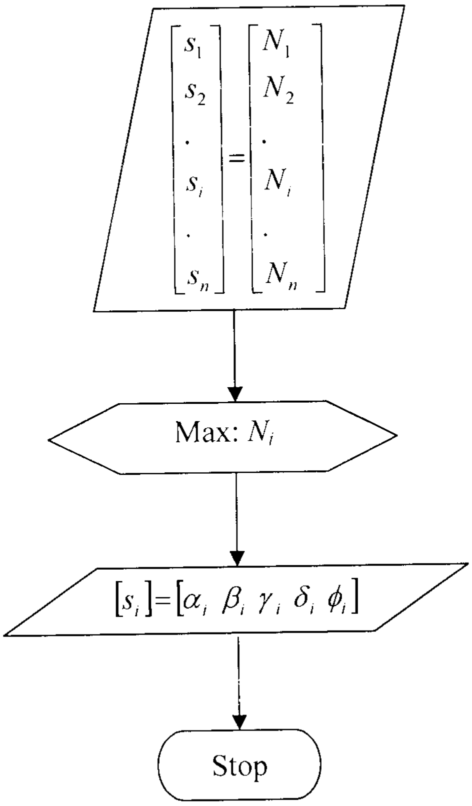


Figure 5.1 – Algorithm flow chart

5.3. Results

Section A, Section B, Section C, Section D, Section E, Profit		
0,0,2,29,29,106994	0,0,8,24,28,106388	0,0,10,29,21,107183
0,0,3,28,29,106868	0,0,8,25,27,106538	0,0,11,20,29,105861
0,0,3,29,28,107018	0,0,8,26,26,106687	0,0,11,21,28,106010
0,0,4,27,29,106742	0,0,8,27,25,106837	0,0,11,22,27,106160
0,0,4,28,28,106892	0,0,8,28,24,106986	0,0,11,23,26,106310
0,0,4,29,27,107041	0,0,8,29,23,107136	0,0,11,24,25,106459
0,0,5,26,29,106616	0,0,9,22,29,106113	0,0,11,25,24,106609
0,0,5,27,28,106766	0,0,9,23,28,106262	0,0,11,26,23,106758
0,0,5,28,27,106915	0,0,9,24,27,106412	0,0,11,27,22,106908
0,0,5,29,26,107065	0,0,9,25,26,106561	0,0,11,28,21,107058
0,0,6,25,29,106490	0,0,9,26,25,106711	0,0,11,29,20,107207
0,0,6,26,28,106640	0,0,9,27,24,106861	0,0,12,19,29,105735
0,0,6,27,27,106789	0,0,9,28,23,107010	0,0,12,20,28,105884
0,0,6,28,26,106939	0,0,9,29,22,107160	0,0,12,21,27,106034
0,0,6,29,25,107089	0,0,10,21,29,105987	0,0,12,22,26,106184
0,0,7,24,29,106364	0,0,10,22,28,106136	0,0,12,23,25,106333
0,0,7,25,28,106514	0,0,10,23,27,106286	0,0,12,24,24,106483
0,0,7,26,27,106664	0,0,10,24,26,106435	0,0,12,25,23,106632

Section A ,Section B, Section C, Section D, Section E, Profit		
0,0,7,28,25,106963	0,0,10,26,24,106735	0,0,12,27,21,106932
0,0,7,29,24,107112	0,0,10,27,23,106884	0,0,12,28,20,107081
0,0,8,23,29,106238	0,0,10,28,22,107034	0,0,12,29,19,107231
0,0,13,18,29,105609	0,0,13,29,18,107255	0,0,14,27,19,106979
0,0,13,19,28,105759	0,0,14,17,29,105483	0,0,14,28,18,107129
0,0,13,20,27,105908	0,0,14,18,28,105633	0,0,14,29,17,107278
0,0,13,21,26,106058	0,0,14,19,27,105782	0,0,15,16,29,105357
0,0,13,22,25,106207	0,0,14,20,26,105932	0,0,15,17,28,105507
0,0,13,23,24,106357	0,0,14,21,25,106081	0,0,15,18,27,105656
0,0,13,24,23,106507	0,0,14,22,24,106231	0,0,15,19,26,105806
0,0,13,25,22,106656	0,0,14,23,23,106381	0,0,15,20,25,105956
0,0,13,26,21,106806	0,0,14,24,22,106530	0,0,15,21,24,106105
0,0,13,27,20,106955	0,0,14,25,21,106680	0,0,15,22,23,106255
0,0,13,28,19,107105	0,0,14,26,20,106829	0,0,15,23,22,106404

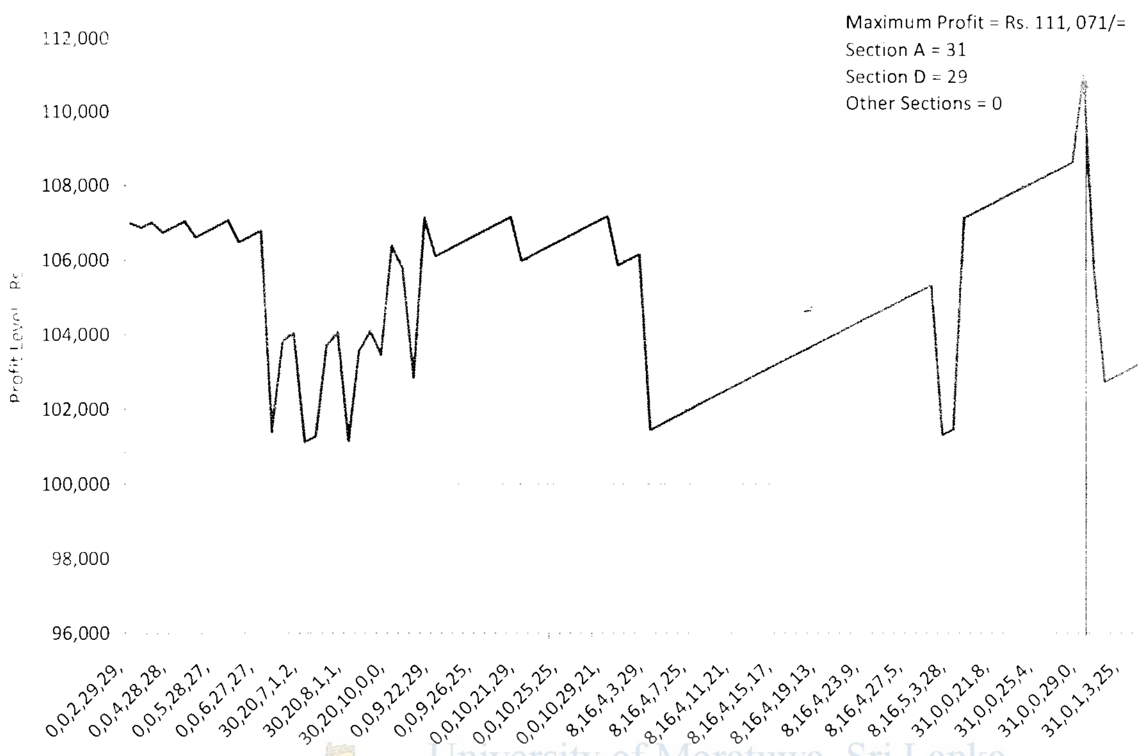


Figure 5.2 – Profit Level with Different Room Combination

Above shows only a fraction of output data when consider the occupied room is 60.

Best Solution: 31, 0, 0,29,0,111071

That means room allocation can be done as follows.

Section A: 31 rooms
Section D: 29 rooms

Other sections: 0

Expected profit level: Rs. 111, 071/=

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. But 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, but above combination is the best.

Above calculation has been done with following assumptions; all costs are constant except expense for AC for all kind of rooms. Further expected profit level has been calculated based on last few months data.

Chapter 6

Conclusion

6.1. Background

As described in early chapters, due to the long run internal conflict and followed by the global economic crisis, Sri Lankan hospitality industry has been highly affected. The situation at Heritance Ahungalla was more or less the same. Therefore they have tried several methods to overcome this issue. As the hotel is not in a position to increase their room rates and other selling prices, they tried to reduce their expenses. This study was based on that requirement.

Based on the profit and loss accounts of Heritance Ahungalla, major cost centre is cost of sales (expenses related to food and beverages), and followed by payroll related expenses and energy expenses. It was found out that there is a potential reduction of cost in the energy sector. When considering the energy sector at Heritance Ahungalla, major cost component is electricity, which is 84.8% from the total energy expense. From the total electricity cost, 53.1% is consumed by the air conditioning system of the hotel.

6.2. Conclusion

By analyzing the cost centers of the hotel, it was found out that the most possible cost saving potential is with the electricity consumption of the air conditioning system in the hotel. Also it was found out that the hotel guest rooms could be divided into five sections including all public areas and office areas with the consideration of chilled water distribution system.

During the low occupancy period, according to the present system even though the particular section is totally unoccupied, still the chilled water is flowing unnecessarily. This leads to waste of energy, hence it is better to go for wing wise (section basis) operation for room allocation.

As each section has different numbers and types of guest rooms, energy consumption and the expected profit levels are different. In the system of wing operation, for room allocation energy consumption is not the only factor to be considered. The expected profit level has to be considered as well.

The results of the practical study showed that a single chiller plant cannot cater the cooling load for section A including public areas and the offices. As the study was done section wise but not room wise, the exact point where the next chiller should be added was unable to locate. Further more, as the chilled water line inlet temperature and outlet temperature were not maintained at a constant value, there were not clear indications of the impact on the air conditioning system when the section B and section C were added to the operation.

In addition, certain areas of the hotel where energy consumption varied according to their functions, for an example restaurant during breakfast, lunch and dinner, made higher impact on the air conditioning system. Therefore the result of the practical study has an error factor which should be corrected.

The theoretical analysis gives the impression that when allocating the rooms for guests, both the energy consumption of the air conditioning system and the expected profit level should be considered. When the profit level is not considered, 52 out of 60 rooms from section A should be occupied along with 8 rooms from sections B, C or D. According to the theoretical analysis, to obtain the maximum profit, the same 60 rooms should be allocated as 31 and 29 from section A and D respectively.

Therefore proper application of wing operation will improve the hotel "green image" as the hotel is able to reduce the energy consumption by minimizing the energy wastage. Further more, the hotel is able to increase their profile level with proper allocation of guest rooms by optimum operation of the air conditioning system.

6.3. Implementation of building management system

In order to practice the wing operation, automatic operation of the chiller plant is required, as at present chiller plant is operated manually by continuous monitoring of the chilled water inlet and outlet temperatures, chilled water line pressures etc. in addition, more frequent operation of chilled water distribution line valves is required. With the implementation of wing operation system it would not be possible to operate those valves manually hence they should be replaced with motorized valves in order to automate the system.

As described in early chapters, guest room temperature is maintained at 26°C even when the room is unoccupied irrespective of outdoor temperature. But with the implementation of building management system it is possible to set the room temperature according to the outdoor temperature levels, according the Adaptive Comfort Standard (ACS) for ASHRAE std. 55.

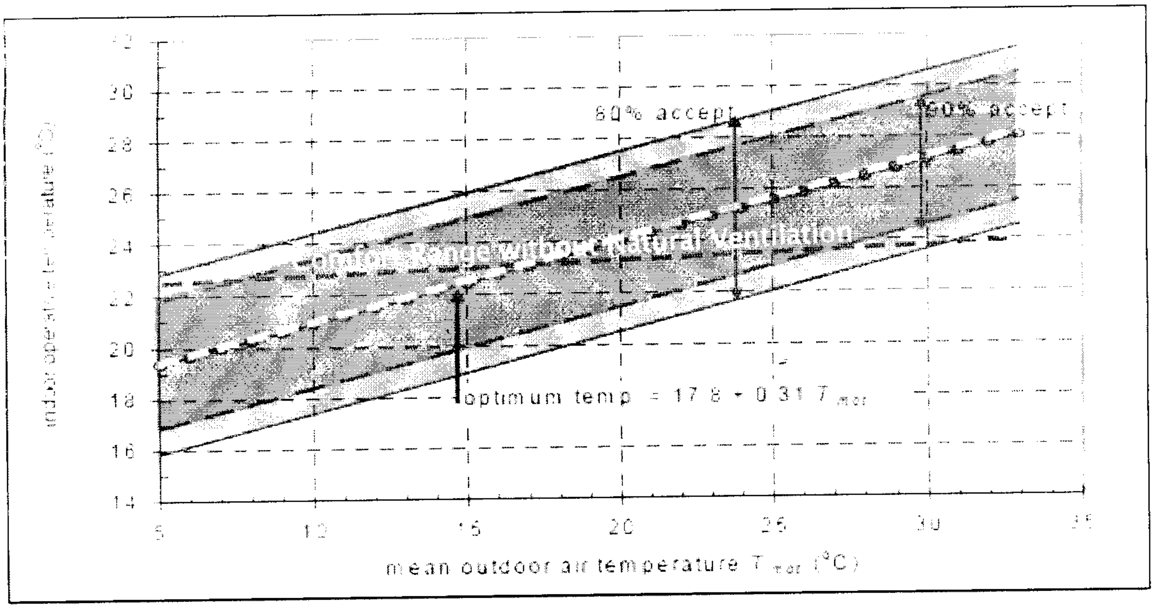


Figure 6.1 - Adaptive Comfort Zone

The building management system will also make way to control the lighting system and the curtains of the guest rooms in addition to the controlling of chiller plant, which would lead to enhance the prestige of the hotel.

6.4. Future work to be carried out

The chiller plant behavior was observed once the full section has been loaded during the practical study as mentioned earlier. With this it was unable to locate exact location where the next chiller to be switched on in order to cater the cooling load requirement of the hotel. Therefore to obtain better results further study should be done based on individual room rather than on section.

During the theoretical analysis, average room electricity consumption for the air conditioning system and the average profit level has been considered. But as mentioned earlier there are several types of rooms within the section, for an example section A has 52 guest rooms including 47 deluxe, 3 luxuries, 1 suite and 1 luxury suite hence the energy consumption for the air conditioning system and the expected profit differ according to the type of room.

This result of the study shows the allocation of the rooms in section by the number rather than the type of room. In future studies it would be possible to obtain both the number and the types of rooms per section to be allocated. .

During the practical study some of the cooling loads were added and some removed from the air conditioning system but none of those have been taken into account as they were not measured. It was assumed that the rest of the cooling load were at a constant other than the cooling load of the rooms through out the period. A better reflection of the behavior of the chiller plant with the addition of guest rooms could be obtained by considering the variations in the cooling load of the other areas.

Also during the practical study, chilled water inlet temperature and outlet temperature varied time to time, which misled the actual results. The maintenance of chilled water inlet and outlet temperatures at constant values is highly recommended in order to observe exact variations in power consumption with increasing of the number of rooms occupied.

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Appendix A - Program Codes

```
[illegible]
[illegible]

#define          SECTION_COUNT          5

int aiRoomCount[] = {52, 21, 23, 29, 29};
double adRoomCharge[] = {2060.0, 2025.0, 2090.0, 2260.0, 2060.0};
double adExtraCost[] = {0.0, 1437.0, 1886.0, 3068.0, 2279.0};
double adUnitCost[] = {147.3, 127.1, 152.3, 196.4, 146.0};

MathOperations::MathOperations(void)
{
}

MathOperations::~MathOperations(void)
{
}

void MathOperations::nHr(int iTotal, int iVarCount,
std::vector<std::vector<int> >& vecResults)
{
	// vector containing positions of markers
	std::vector<int> vecMarkerPos;
	int iIndex = 0;
	for( ; iIndex < iVarCount - 1; iIndex++)
	{
		vecMarkerPos.push_back(0);
	}
	vecMarkerPos.push_back(iTotal);  // final marker stationary
at the end
	int iActiveMarker = iVarCount - 2;     // one before final
	while(true)
	{
		// add the current solution
		std::vector<int> vecSolution;
		int iCurrPos = 0;
		std::vector<int>::iterator ite1 = vecMarkerPos.begin();
		std::vector<int>::iterator iteEnd1 =
vecMarkerPos.end();
		for( ; ite1 != iteEnd1; ite1++)
		{
			vecSolution.push_back(*ite1 - iCurrPos);
			iCurrPos = *ite1;
		}
		vecResults.push_back(vecSolution);

		// do the next move
```

```
            if(vecMarkerPos[iActiveMarker] == iTotal)
            {
                  // traverse and find the next marker to move
                  int iNextMarker = -1;
                  int iTemp = iActiveMarker - 1;
                  while(true)
                  {
                        if(iTemp < 0)
                              break;
                        if(vecMarkerPos[iTemp] < iTotal)
                        {
                              iNextMarker = iTemp;
                              break;
                        }
                        iTemp--;
                  }
                  if(iNextMarker < 0)
                        break;
                  int iNewPos = vecMarkerPos[iNextMarker] + 1;
                  for(iIndex = iNextMarker; iIndex < iVarCount - 1;
iIndex++)
                  {
                        vecMarkerPos[iIndex] = iNewPos;
                  }
                  iActiveMarker = iVarCount - 2;
            }
            else
            {
                  (vecMarkerPos[iActiveMarker])++;
            }
      }
}

void MathOperations::ProcessRequest(int iRoomCount)
{
      std::vector<std::vector<int> > vecResult;
      nHr(iRoomCount, SECTION_COUNT, vecResult);
      PrintResult(vecResult);
}

void MathOperations::PrintResult(std::vector<std::vector<int> >&
vecResults)
{
      double dBest = 0.0;
      std::vector<std::vector<int> >::iterator iteBest;
      bool bBestFound = false;
      std::wfstream oFile(L"Result.txt");
      oFile<<L"Section A,SectionB,Section C,Section D,Section
E,Profit\r\n";
      std::vector<std::vector<int> >::iterator ite1 =
vecResults.begin();
```

```
	std::vector<std::vector<int> >::iterator iteEnd1 =
vecResults.end();
	for( ; ite1 != iteEnd1; ite1++)
	{
		if(IsSolutionViable(*ite1))
		{
			double dProfit = GetProfit(*ite1);
			if(dProfit > dBest)
			{
				dBest = dProfit;
				iteBest = ite1;
				bBestFound = true;
			}
			//oFile<<L"Rooms: ";
			std::vector<int>::iterator ite2 = (*ite1).begin();
			std::vector<int>::iterator iteEnd2 =
(*ite1).end();
			for( ; ite2 != iteEnd2; ite2++)
			{
				oFile<<*ite2<<L",";
			}
			//oFile<<L"\tProfit = "<<dProfit<<L"\r\n";
			oFile<<dProfit<<L"\r\n";
		}
	}
	if(bBestFound)
	{
		oFile<<L"\r\n\r\n";	//Best combination : ";
		std::vector<int>::iterator ite3 = (*iteBest).begin();
		std::vector<int>::iterator iteEnd3 = (*iteBest).end();
		for( ; ite3 != iteEnd3; ite3++)
		{
			oFile<<*ite3<<L",";
		}
		[illegible]
		oFile<<dBest;
	}
	oFile.close();
}

bool MathOperations::IsSolutionViable(std::vector<int>&
vecSolution)
{
	if(vecSolution.size() != SECTION_COUNT)
		return false;
	for(int iIndex = 0; iIndex < SECTION_COUNT; iIndex++)
	{
		if(vecSolution[iIndex] > aiRoomCount[iIndex])
			return false;
	}
	return true;
}
```

```
double MathOperations::GetProfit(std::vector<int>& vecSolution)
{
	return (GetIncome(vecSolution) - GetExpense(vecSolution));
}

double MathOperations::GetIncome(std::vector<int>& vecSolution)
{
	int iIndex = 0;
	double dIncome = 0.0;
	for( ; iIndex < SECTION_COUNT; iIndex++)
	{
		dIncome += (adRoomCharge[iIndex] *
vecSolution[iIndex]);
	}
	return dIncome;
}

double MathOperations::GetExpense(std::vector<int>& vecSolution)
{
	int iIndex = 0;
	double dExpense = 16296.0;
	for( ; iIndex < SECTION_COUNT; iIndex++)
	{
		dExpense += (adUnitCost[iIndex] * vecSolution[iIndex]);
		if(vecSolution[iIndex] > 0)
			dExpense += adExtraCost[iIndex];
	}
	return dExpense;
}
```