INVESTIGATION ON THE IMPACT OF SMART BUILDINGS IN THE MODERN SOCIETY

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical and Electronic Engineering

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September 2016

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

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INVESTIGATION ON THE IMPACT OF SMART BUILDINGS IN THE MODERN SOCIETY

ABSTRACT

The idea of smart buildings also known as intelligent buildings, had come out way back in the 1980s. Smart buildings are classified into few categories which are commercial, residential and so forth. There are 3 main components in smart buildings which are hardware, software and network. In fact, smart buildings with technological elements like automation system bring a lot of benefits. Besides that, smart metering provides the pattern of occupants' energy behaviour that can be used to increase the awareness about the impacts of energy consumption. Nowadays, a lot of research and investigation of smart buildings have been conducted to improve the functionality and efficiency of the technological elements used in the smart buildings. However, there are some challenges for smart buildings like high installation cost and providing limited security features. There are still some doubts on the possible impacts smart buildings will bring towards the society. This had been one of the reasons for the low implementation of these smart buildings. To promote smart buildings, some basic investigations must be carried out for the purpose of clearing the doubts of the society. In this Final Year Project, Smart Parking System (SPS) and Energy Storage System (ESS) integrated with renewable energy used in smart building are chosen for the study. The possible impacts of the SPS and ESS of the smart buildings will be investigated in this project. The time and fuel consumption in a smart parking system and the cost benefit of Energy Storage System integrated with renewable energy were investigated. These impacts were compared with that for the conventional parking system and Energy storage system used in a conventional commercial building. Solidworks and Matlab were used in this investigation. The results show that there are some impacts on the society due to smart commercial buildings.

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LIST OF SYMBOLS / ABBREVIATIONS

a	acceleration of vehicle (ms^{-2})
BEMS	Building Energy Management System
BMS	Building Management System
bsfc	brake specific fuel consumption (g⁄kmh)
CO_2	Carbon dioxide
c_x	drag coefficient
d	distance to move a vehicle from platform to parking lot (m)
D	moving distance between parking lot and entrance (m)
DSM	Demand Side Management
EBWESS	Electricity Bill with ESS
EBWESSRE	Electricity Bill with ESS integrated RE
EBWOESS	Electricity Bill without ESS
EBWOESSRE	Electricity Bill without ESS integrated RE
ESS	Energy Storage System
F_{air}	force of air (N)
$F_{inertia}$	force of vehicle inertia (N)
$f_{rolling}$	coefficient of rolling force
$F_{rolling}$	force of tires rolling (N)
F_{slope}	force of slope road (N)
F_{total}	total force (N)
g	gravity acceleration (ms^{-2})
GHG	Greenhouse Gas
H	height between parking lot and platform (m)
HEMS	House Energy Management System
HVAC	Heating, Ventilation and Air-Conditioning
IAQ	Indoor Air Quality
L	horizontal distance between parking lot and platform (m)

m	mass of vehicle (kg)
MIT	Massachusetts Institute of Technology
P_{engine}	engine power (kW)
PID	Proportional Integral Derivative
PLC	Programmable Logic Controller
RWH	Rainwater Harvesting
S	frontal area of vehicle (m^2)
s_1	platform elevating speed (ms^{-1})
s_2	platform horizontally moving speed (ms^{-1})
SPS	Smart Parking System
v	average velocity of vehicle (ms^{-1})
ZEB	Zero Energy Building
α	angle slope road (°)
η_{trans}	efficiency of transmission
ϑ	coefficient of inertia force
ρ_{air}	air density (kg/m^3)
ρ_{fuel}	density of fuel (kg/m^3)

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction to Smart Building

The term "smart building" is used to represent buildings that integrate technological elements to observe the energy performance of smart buildings and automation of energy activities. For example, these buildings are able to switch off the lights automatically 5 minutes after occupants left the office or room and there are a lot of sensors everywhere that track occupants' movements.

There are 3 main components for smart buildings as shown as below:

- Hardware
- Software
- Network

Hardware

Smart buildings are equipped with hardware like sensors and meters. These sensors are able to determine the rooms' occupation, intensity of light, temperature inside and outside the building and so on.

Software

Hardware provides only raw information. Thus, a special software is needed to provide useful information and make the decisions and also predict the future state of people's activities and environment.

Network

Network is needed to allow smart buildings to be buildings with communication network. It can connect all the devices with each other and also with artificial intelligence elements.

We can conclude that the potential benefits provided by smart buildings are actually wider than a remote control. It includes:

- Inhabitants’ comfort: Smart buildings are able to learn and observe occupants' behaviour and maximize occupants' comfort.

- Energy savings: Smart buildings are able to reduce energy consumption. It is profitable and leading to low cost of energy.

- Time saving: Smart buildings equipped with automation system can save a lot of operating time.

- Safety: Smart buildings are able to detect any affair like fire, water leakage and so forth. It is because of having self-diagnostic and self-monitoring system. The system can warn occupants when such incidents happen.

- Health and care: Occupants’ health is the highest priority for the smart building. Therefore, smart buildings will improve the quality of life by providing a safe and comfortable environment.

(Eugeny I. B., 2015)

1.2 Problem Statement

There has always been doubt among the people regarding the impact of smart building on the society. It is important that the investigations to be conducted to study the impact of smart buildings to increase the awareness and to make people more confident on it. Therefore, an investigation on the impacts of smart buildings has been discussed in this research.

1.3 Rationale for the Research

In this research, Smart building is said that it brings a lot of benefits. For instance, smart metering provides the pattern of occupants' energy behaviour so that they can help to increase the awareness about the impacts of energy consumption. From the literature, we can understand that smart buildings also have few disadvantages such as higher installation cost, lacking of knowledge and expertise at smart building technology. In order to promote the smart buildings and also to know the problems and challenges, this study investigates the impacts of smart buildings with a view to increase awareness among people. In this research, Smart Parking System (SPS) and Energy Storage System (ESS) used in smart building are chosen to be studied. The time and fuel consumption of Smart Parking System and the cost benefits of Energy Storage System integrated with renewable energy have been identified in this project.

1.4 Aims and Objectives

In this research project, the aims are:

1. To investigate the impact of smart commercial buildings.
2. To aid in public understanding about smart commercial buildings.

The objectives of this research project are:

1. To identify the possible impacts of the smart commercial buildings.
2. To investigate the time and fuel consumption for a Smart Parking System used in smart commercial buildings
3. To investigate the cost benefits of an Energy Storage System integrated with Renewable Energy source used in smart commercial buildings
4. To analyse and compare the impacts of a smart commercial building with that of a conventional commercial building.

1.5 Report Outline

Chapter One

Chapter one, introduction, describes the aims and objectives of this research study. The main objective is to study the possible impacts of smart buildings. Some of the problems and issues are discussed in this chapter.

Chapter Two

Chapter two, a detailed literature review is included. Most of the ideas and concepts are taken from the journals related to the selected are of study.

Chapter Three

Chapter three, methodology, describes the method to investigate the possible impacts of smart buildings. The equations have been identified to calculate the time and fuel consumption of Smart Parking System used in smart commercial building. Moreover, the equations have been identified to calculate the cost benefits of Energy Storage System integrated with Renewable Energy source used in smart commercial building. The results obtained have been compared with that of a conventional commercial building.

Chapter Four

Chapter four, results and discussion, has covered the results from calculation for all the studied impacts. Calculation process, table of results, graphs and discussion of results were included in this chapter.

Chapter Five

Chapter five, the final chapter of this report would be concluding the studies that had been carried out in this project. From the results obtained, conclusion was able to be deduced. To ensure further investigation could be carried out on the topic, some suggestions were given to improve the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Smart buildings with a set of technologies to improve the energy efficiency and occupant comfort as well as monitoring building. The headquarters of New York Times provides an example of how smart building can reduce energy consumption and increase occupant comfort by operating elevators and heating, ventilation, and air-conditioning (HVAC) system. In overall, smart building is able to consume 30% less energy.

A smart building is designed by Renzo Piano and it opens in November 2007, the building is integrated with lighting control systems. The system is ensuring electrical lighting is only utilised when required. Besides that, according to another journal, Sharples et al. (1999), smart building can be distinguished first-, second- and third-generation. First-generation building are equipped of many stand-alone self-regulating devices which are operating independently. For examples, HVAC system. For second-generation buildings, systems are connected in specialised networks in order to let occupants control remotely For instance, occupants able to switch off the lighting system when offices or rooms are not occupied. Moreover, Third-generation systems able to learn from occupant behaviour and the building and adapting monitoring and controlling systems. (OECD, 2010)

Figure 2.1 shows that the energy performance of the building affected by the following characteristics.

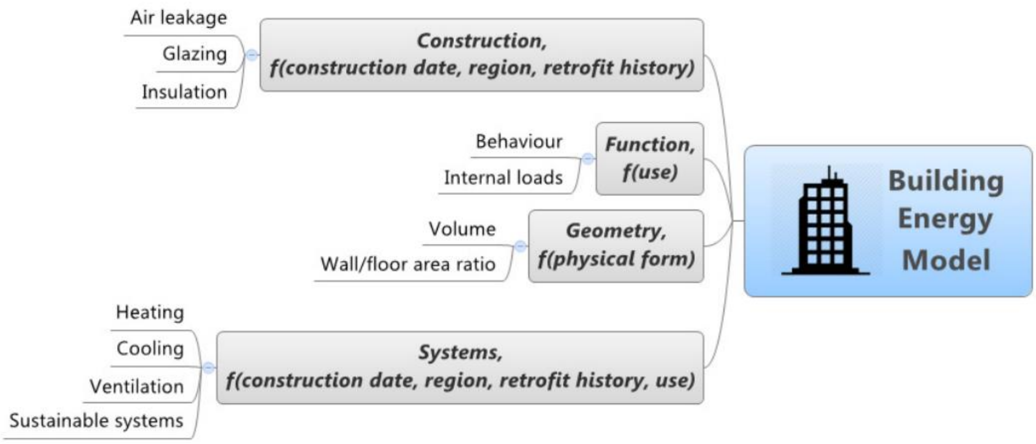

Figure 2.1: Characteristics of a building that can influence energy performance
(William J.N. T., 2014)

Construction

The materials that are used to build the building can affect the impact of the building. For instance, the heavyweight buildings have a great different energy use with the comparison with lightweight building which made from wood. The energy used for the building normally is due to thermal mass effect. (William J.N. T., 2014)

Function

Function determines how the building is working. The facilities or equipment of the building can be affecting the amount of energy consumption. As there is a swimming pool or small shopping complex, the amount of energy consumption would be greater than a normal building without those facilities. (William J.N. T., 2014)

Geometry

Geometry refers to the physical description such as the building size, design and the location of the building.

The building size can be a factor to affect the impact of the building. The volume of building determines the amount of air to be heated, cooled, or replaced by using ventilation system inside the building. The bigger the building size, the greater amount of air needs to be heated or cooled. (William J.N. T., 2014)

System

System, like HVAC systems, provide services to occupants of the building. HVAC systems provide the thermal comfort to occupants with good air quality. Moreover, the other systems include lighting to provide the light to occupants and also the hot water systems to people.

Sustainable systems, include renewable energy sources such as hydroelectricity and solar energy designed to generate electricity for the building at zero cost of energy. Sustainable systems are designed to reduce the amount of energy consumed by building occupants. (William J.N. T., 2014)

Internal load

Internal loads determine the thermal effect or gains from the indoor sources. The sources like lighting, HVAC or some application inside the building are considered internal loads. In fact, there is a big difference between commercial and residential building. The internal loads for commercial building normally are more significant comparing to residential building. (William J.N. T., 2014)

Air-leakage

Air leakage refers to the air change rate of the building. Therefore, ventilation system has played an important role for this purpose. The ventilation rate, the rate for the indoor air exchanged with outside the building, can improve the health of occupants. As the outdoor air temperature is lower than indoor, the indoor air can be exchanged with outside by utilising ventilation system. This will lead to reduction of energy consumption of HVAC system of the building. (Prashant K., 2015)

Occupant behaviour

Occupant behaviour is referring to the energy performance or the pattern of energy consumed by building occupants. This will be greatly and directly affect the amount of energy consumption. For instance, the examples of behaviour of using energy are switching lights on and off, opening and closing HVAC. (William J.N. T., 2014)

2.2 Automation and Control System

In March 2007, European Council planned to reduce the energy consumption by 20% compared with previous year. To monitor the energy performance of the smart building, the building systems need to be integrated with technological elements like HVAC, lighting and some advance device such as sensors and wireless communication. It is leading to reduced energy consumption. Sensor can be used to monitor the energy consumed. Nowadays, sensor networks are playing important role as energy sources change. (Prashant K., 2015)

Building Management Systems (BMS), systems that satisfy building occupants' comfort and also minimise the energy consumption. BMS is used to monitor and control system such as HVAC system, lighting, lifts and so forth. (Yazeed Y. G., 2014)

Building Energy Management System (BEMS), also known as House Energy Management System (HEMS) consists of sensors, computing systems, and a communication network as shown as Figure 2.2. BEMS or HEMS is applied to the control some systems such as HVAC systems, while also can determine the operating times by using advanced control techniques. Some tests which are focusing on the advantages of automation systems in the smart building. Moreover, some researches which have been conducted to study the impact of the system. (Prashant K., 2015)

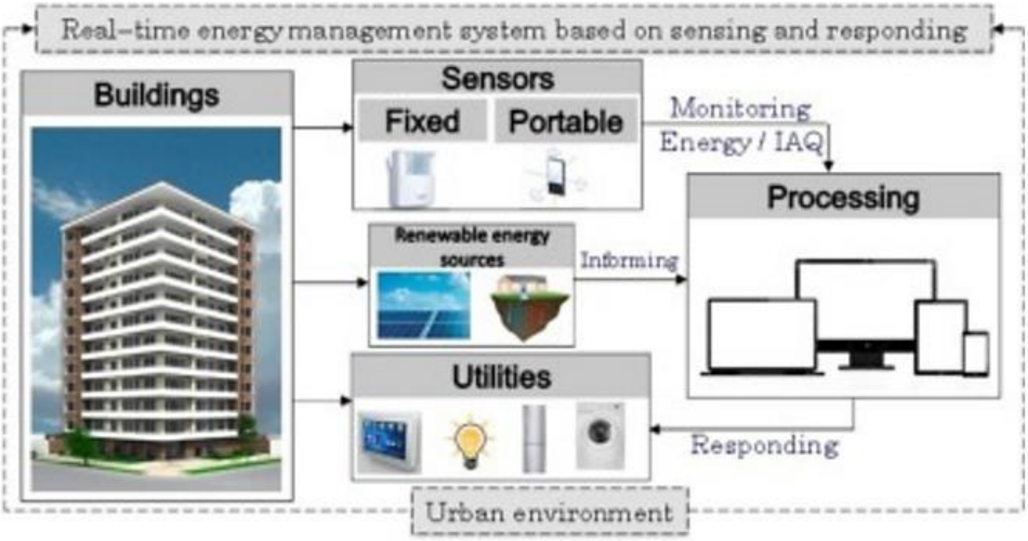

Figure 2 2: Real-time Energy Management System

(Prashant K., 2015)

Demand Side Management (DSM) is a load management technique which provides support for functionalities such as controlling peak demand. The concept of DSM was introduced in 1980's. DSM is designed to observe the patterns of electricity consumption. (Sumedh P., 2014)

For building with smart grid, the micro grid has become "system of systems". However, nowadays, the new building, Nearly Zero Energy Buildings (NearlyZEBs) which are basically Nano grids. (Stefano B., 2015)

2.3 Local Energy Storage System

To increase the energy efficiency, the attention to renewable energy adoption has been increased. Therefore, the renewable energy sources that are available such as solar and wind need to be used for smart building. (Mehmet B. B., 2016) Figure 2.3 shows that the contribution of renewable energy sources can be very small, nevertheless it could be very useful to a demonstration level.

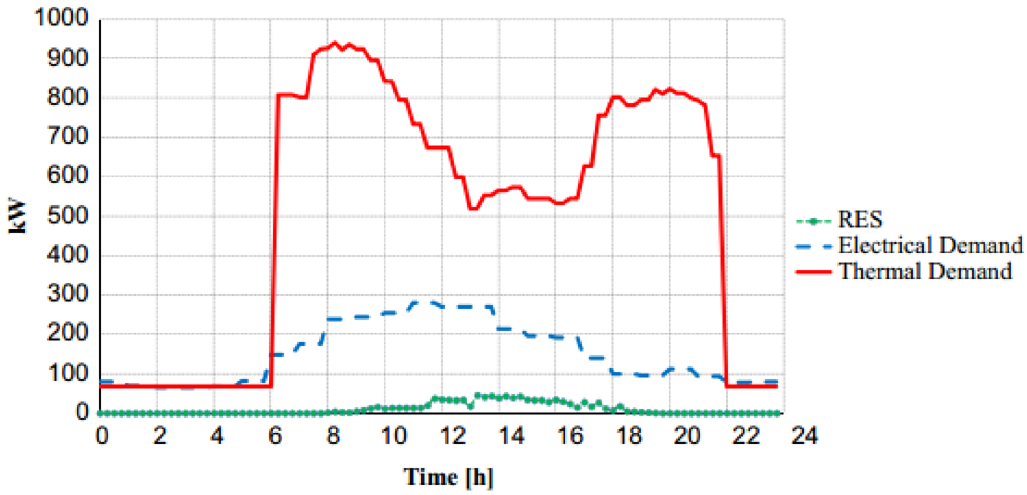

Figure 2.3: Electrical/thermal demand and renewables availability

(Stefano B., 2015)

Excess thermal energy dissipated from HVAC systems can be stored in thermal storage that can be utilised to generate electricity. (Wolters K., 2015) In Sweden, around half of all buildings are heated. The heat can be produced from surplus heat from renewable energy sources. Sometimes the heat is required to smooth out and cover the peak heat demand. If the peaks demand could be covered, the entire system would be more cost efficient and with less carbon dioxide (CO_2) emissions. (Carl-Eric H., 2015)

Zero energy buildings (ZEBs) are the buildings that have almost zero carbon emissions. ZEBs can reduce the energy demand by adopting renewable source. Therefore, the energy efficiency of the building can be increased by reducing its energy demand. Nowadays, new ZEBs can reduce energy consumption by two-thirds on average compared to the current buildings. (Angeliki K., 2015)

2.4 Smart metering

Visualising the use of energy is an effective solution to influence the energy behaviour. Many people suggest that the system integrated with mobile applications and also the website can be more effective. By the way, occupants can login and observe their energy behaviour on the internet every time and everywhere. (Mehmet B. B., 2015)

Figure 2.4 shows, smart meter that enable the users to observe their energy consumption pattern so that they can adopt the appropriate solution for energy saving. Smart meters have increased the awareness about the impacts of energy consumption and also flatten the peak energy demand. In North America and Europe, they use smart meter device to provide the feedback on electricity consumption. It shows that the electricity consumption has been reduced by approximately 6 - 10%. In Italy, this country has the highest rates of penetration of smart meters in the world. By the year of 2011, around 37 million smart meters has been installed in Italy. (Jacopo T., 2014)

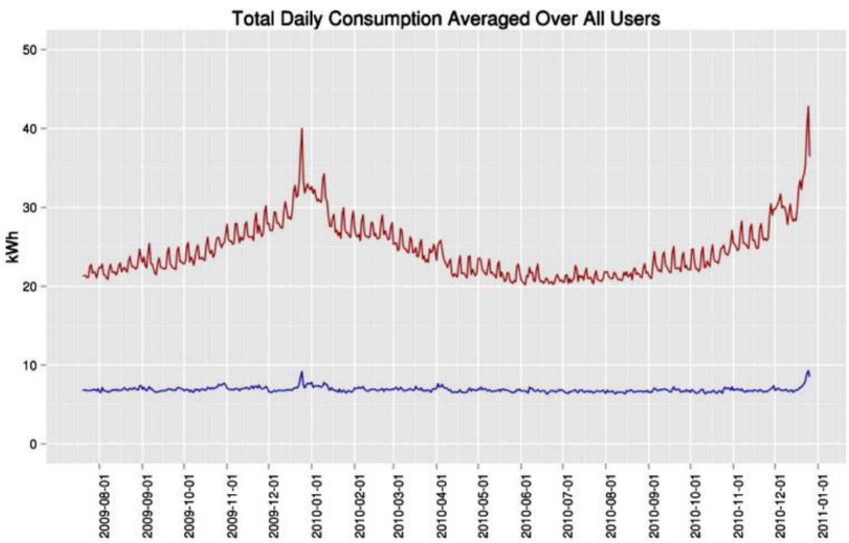

Figure 2.4: Total daily consumption averaged over all users

(Amir K., 2015)

2.5 Rainwater Harvesting System

Rainwater harvesting system (RWH) is the system that involves the storage to collect the rainwater. It is the collection for subsequent use of rainwater. The RWH system usually is built at the rooftop of the building so that the system can easily collect the rainwater. RWH system can use the rainwater collection to substitute the main water for some application such as toilet flushing and vehicle washing. (Wolters K., 2015)

2.6 Air Quality Monitoring System

Many people nowadays concern about the indoor air quality (IAQ) of a building. It is because poor IAQ will cause high health risk such as respiratory illness and fatigue. (Yazeed Y. G., 2015)

Many modern buildings, such as the Massachusetts Institute of Technology (MIT) Media Lab, are embedded with smart sensors and high-tech data management system to monitor the energy consumption patterns with IAQ parameters. (Prashant K., 2015) Moreover, system can measure the gap of air quality between indoor and outdoor to determine the effectiveness of HVAC system in the function of filtering air.

In China, IAQ monitoring system was deployed in four Microsoft campuses. At every floor, they set up a monitor which called Dylos DC1700 is connected to a local server. While the server receives the air quality readings from the monitor. It will submit the reading to the cloud. The cloud will store the data. Users can observe the data through a mobile application and website. Figure 2.5 has identified that employees can use mobile phone or website to monitor IAQ of a building instantly. After that, they can do decision making like turn on their own air filters as the air quality inside the room is bad. (Chen X. X., 2014)

A) Select a location B) Location list C) Trend of air quality

Figure 2.5: Mobile User Interface

(Chen X. X., 2014)

2.7 Fuzzy based control systems

Fuzzy based control system is the system which can adjust the indoor comfort, leads to energy conservation. It is able to shut down the building systems if necessary. (Yazeed Y. G., 2014) Space of a room can detect the user presence in order to personalize the environment such as lighting, indoor air quality, temperature and so on. Besides that, Fuzzy logic control is the heating control system and it is applied in order to maximize energy efficiency and comfort. In most of the applications, proportional–integral–derivative (PID) controllers are still integrated with fuzzy logic as a multivariable supervisory controller. Figure 2.6 shows, the most common supervisory controller's frameworks are used in many control fields.

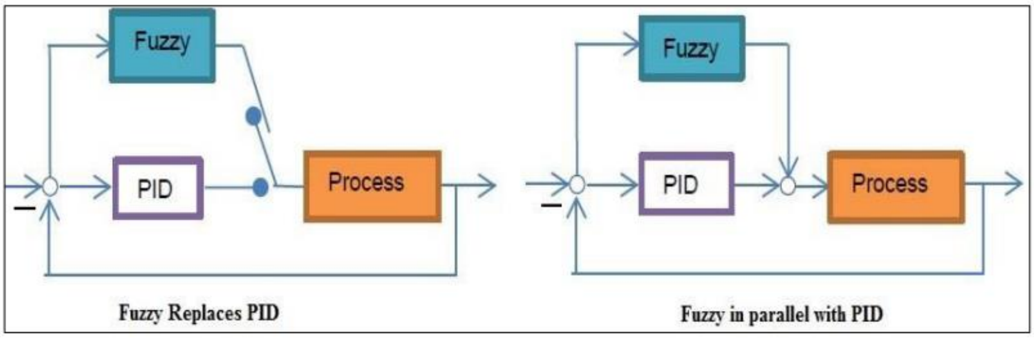

Figure 2.6: Fuzzy set contains fuzzy loops coupled with PID

(Yazeed Y. G., 2014)

Furthermore, Fuzzy P controllers, allowing windows to open in order to reach comfort level by using natural ventilation. In case of indoor lighting, fuzzy system able to switch on the electric lighting when the room or office is too dark especially at night or cloudy days. In contrast, as the indoor illumination increases, then the electrical light is turned off to minimize energy consumption. (Yazeed Y. G., 2015)

2.8 Electric vehicle

Cornwall Partnership NHS Trust provides service in a large area, the company's staffs are needed to find and meet their costumer who stay far away from them. They need to travel long distances to attend. Therefore, the Trust has identified the electrical vehicle as the priority to reduce the cost of energy and greenhouse gas (GHG) emissions. The use of diesel and petrol has been replaced. Smaller electric powered vehicles could be used with locally sourced renewable energy. (Wolters K., 2015)

2.9 Smart Parking System

Smart parking is the vehicles are being parked with computer controlled motorized devices from a place where the vehicles drop off at to a desired parking lot. And there is no human inside the vehicle. In fact, Smart Parking Facilities are not new, the first operational automated garage in the world was found in Paris, France in 1905.

There are a lot of advantages brought by Smart Parking system. For instance, increased parking capacity by reducing parking space. This reduction has implications for land use, creating green space and walkability. Besides that, when the vehicles enter the parking platform, the engine of cars are turned off, the cars will be moved by the platform to desired place, so there is no fuel consumed by the vehicles, it is greatly reducing all emissions and reducing fuel use. Since there is no driver is allowed to enter the parking area, so the energy cost for lighting can be at minimum.

Smart Parking Management Software is used to control and select the desired parking lot where the car would be moved to. Moreover, Smart payment system is implemented in the effort to overcome the limitation of the conventional payment methods by revamping the payment method via parking meter and introduce new technologies. This is because the conventional method causes delay and inconvenience for the patrons as they have to deal with cash.

2.10 Limited security feature

According to the journal of Universal Computer Science, smart buildings, nowadays, equipped with a lot of technological features while providing limited security features. In fact, new buildings are usually compatible to older systems. Nevertheless, the older components do not provide security features. Moreover, it is tough to integrate high technology security feature into old building. It is because of the limited computing power and memory system. (Jörg K., 2016)

2.11 Air quality problem

Ventilation plays an important role for smart building. The increase in ventilation rate can enhance the occupant health. If the outdoor air temperature is lower than indoor, the outdoor air can flow through the ventilation system into the building. However, replacing the air from outdoor to indoor can create problem of IAQ if outdoor air is polluted especially urban environments. The pollutants normally originate from indoors and outdoors, for example from combustion. (Prashant K., 2015) Many countries are trying to solve the problem of air pollution, especially Particulate Matter with diameter of 2.5 micrometers or less (PM2.5). Nowadays, systems still unable to monitor and dealt indoor PM2.5 effectively. For HVAC system, PM2.5 is not considered as a factor when the system circulates fresh air from outdoors. According to some researches, they monitor the concentration of CO_2. But they do not provide suggestions to solve the air quality problems. (Chen X. X., 2014)

2.12 Installation and maintenance cost

One of the bad impact or disadvantage of smart building is the maintenance cost. The maintenance cost usually is caused by the complexity of the system. Some people pointed out that the cost of automation systems is too high although the resulted electricity price is low. The interest for the system thus is too low. According to Mehmet B. B., that high costs of the system remain a barrier to adoption. Beside high costs, people may feel that too much automation will intervene with their privacy. (Mehmet B. B., 2015)

2.13 Conclusion

There are some characteristics that might affect the energy performance of smart building, such as construction, function, geometry, system and so on. Nowadays, smart buildings bring a lot of benefits. For instance, smart metering provides the pattern of occupants' energy behaviour that can be used to increase the awareness about the impacts of energy consumption. Automation system like Building Management System (BMS) is used to monitor and control system such as HVAC system to satisfy building occupants' comfort and also minimise the energy consumption. Moreover, Air Quality Monitoring System can measure the gap of air quality between indoor and outdoor to determine the effectiveness of HVAC system in the function of filtering air. Nevertheless, there are still some possible impacts smart buildings will bring towards the society. For examples, high installation cost to build automation system for smart building. According to some research paper, some people pointed out that the cost of automation systems is too high. In conclusion, in this Final Year Project, Smart Parking System (SPS) and Energy Storage System (ESS) integrated with renewable energy used in smart building are chosen for the study. The possible impacts of the SPS and ESS of the smart buildings will be investigated in this project. The time and fuel consumption in a smart parking system and the cost benefit of Energy Storage System integrated with renewable energy were investigated. These impacts were compared with that for the conventional parking system and Energy storage system used in a conventional commercial building. Solidworks and Matlab were used in this investigation. The results show that there are some impacts on the society due to smart commercial buildings.

CHAPTER 3

METHODOLOGY

3.1 Overview

In this chapter, to achieve the aim and objective, the steps were taken for further planning. After identifying the topic to be studied, reading materials related to the topic were collected. Much reading and analysis on materials collected were done to obtain further understanding on how the smart parking system and energy storage system integrated with renewable energy source would affect the smart commercial buildings.

From the reading materials available in the literature, the relationships between time consumption and smart and conventional parking system were obtained. Apart from that, the equation for the fuel consumption rate affected by the smart parking system had been studied and identified for the investigation. The parameters' value required for the investigation were obtained either from the calculation or from the information in database made based on certain assumptions. The choice of vehicle for the investigation was chosen, Toyota Prius 2004. On the other hand, daily load profile of a commercial building was determined. Moreover, solar energy had been chosen as the renewable energy source which integrated with the Energy Storage System used in smart commercial buildings. The analysis of solar irradiance for sunny and rainy day were obtained based on certain assumptions.

Calculations were done to get the understanding on the effect of time and fuel consumption of smart parking system. Furthermore, for energy storage system, the electricity tariff had been calculated based on the daily load profile of the building. Besides that, the cost benefits of energy storage system and that integrated with solar energy were calculated as well. The installation cost for the systems had been determined based on certain assumptions. The payback period for the installation cost of the systems had been calculated for both cases. The results obtained through the calculations were analysed and compared in order to achieve the objectives of this project.

3.2 Process Flow Chart

Flowchart is used to specify steps and method applied for certain process. Besides, it also shows how to achieve the objectives of research steps by steps. Figure 3.1 shows the flowchart for the progress of the research paper.

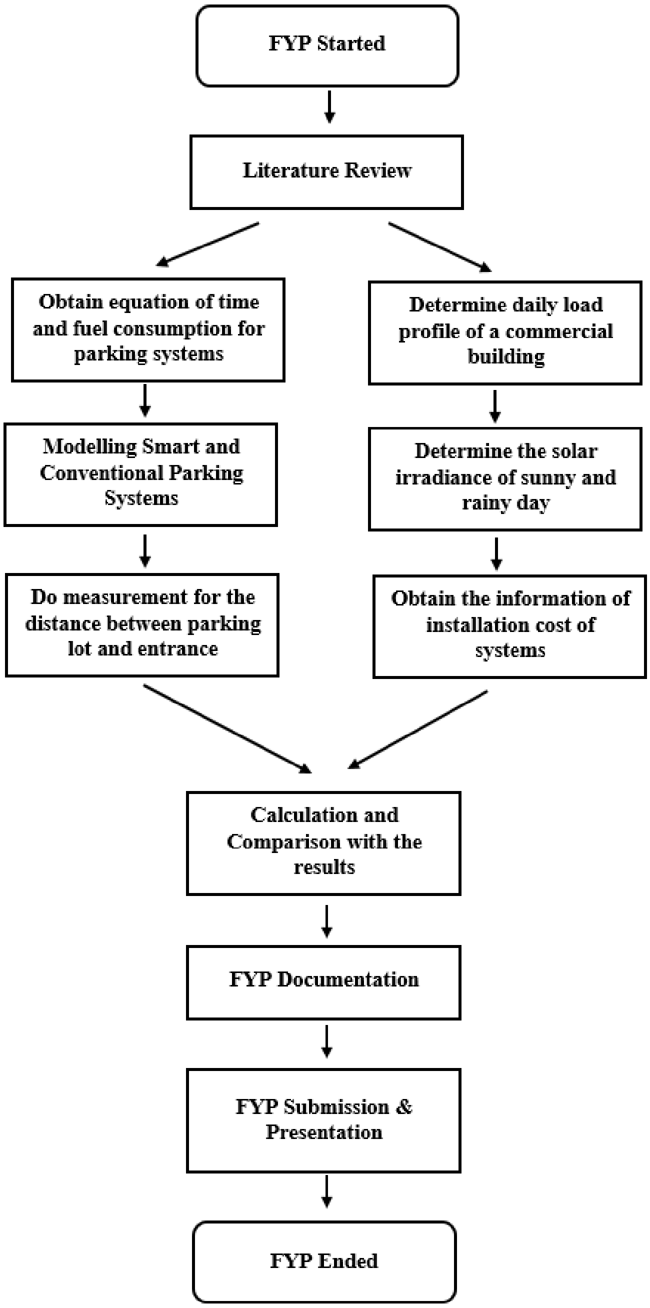

Figure 3.1: Flowchart for the progress of research

3.3 Gantt chart

Gantt chart of phase 1 and 2 are shown on Appendix A and B respectively.

3.4 Time consumption of Parking System

To study the time consumption impact for parking system, some equations were used and identified. The equations of time consumption for Smart Parking System used in Smart Commercial Building and Conventional Parking System used in Conventional Commercial Building were obtained and used to compare with each other to provide a better understanding about the impacts investigated.

3.4.1 Time consumption for Smart Parking System

The equations of time consumption during non-peak and peak periods were obtained separately since they are different in time consuming for parking during non-peak period and peak period.

To complete the calculations, Solidworks was used to design a Smart Parking System used in smart commercial building. Some parameters such as distances between parking lots and platform were measured by using Solidworks. Figure 3.2 showed the Smart Parking Building used in this project. The red colour objects are considered as the vehicles.

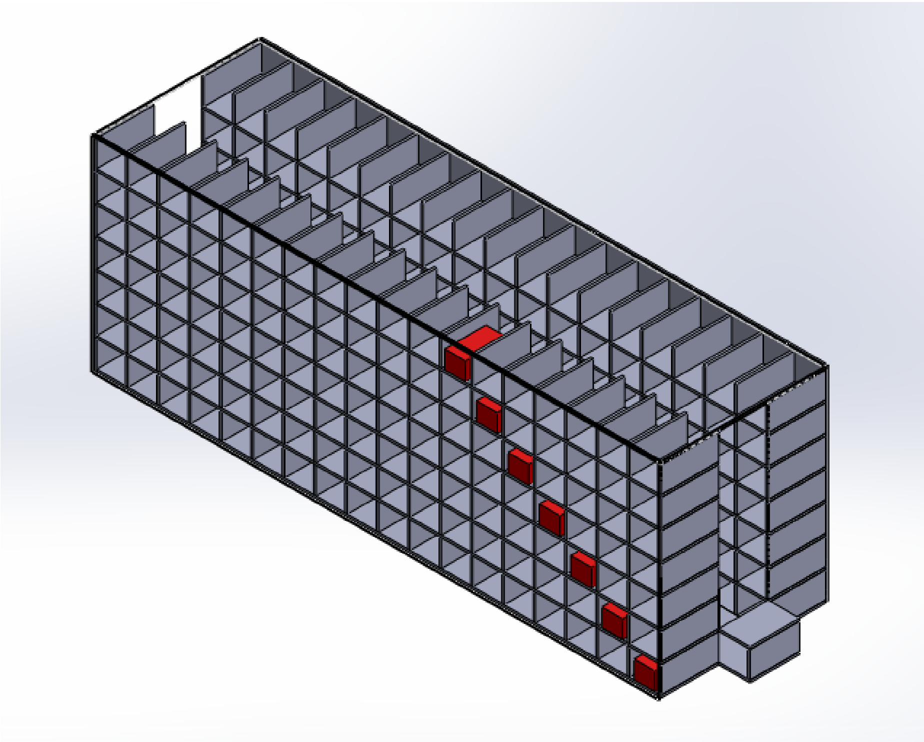

Figure 3.2: Smart Parking Building

3.4.1.1 Non-peak period

During non-peak period, when a vehicle was parked on the platform, the platform would start to move along the vehicle to desired parking lot. The equation of time consumption by platform moving to desired parking lot was determined as shown as equation 3.1 below. From the equation, calculation was done. These values for the parameters needed in the equation were either obtained from assumptions made and information provided in other sources or from taken from further calculations.

$$time\ consumption, t_{(np)} = \frac{H}{s_1} + \frac{L+d}{s_2} \tag{3.1}$$

where

$H = height\ between\ parking\ lot\ and\ platform\ (m)$

$L = horizontal\ distance\ between\ parking\ lot\ and\ platform\ (m)$

$d = distance\ to\ move\ a\ vehicle\ from\ platform\ to\ parking\ lot\ (m)$

$s_1 = platform\ elevating\ speed\ (ms^{-1})$

$s_2 = platform\ horizontally\ moving\ speed\ (ms^{-1})$

3.4.1.2 Peak period

During peak period, assuming that there were a lot of vehicles wanted to park inside the building. Initially, the parking building was empty, many vehicles were queuing to park inside the building. Therefore, the awaiting time for each vehicle was considered. Assuming each vehicle was parking separately during non-peak period, all vehicles wanted to park in the same time during peak period, therefore, the time consumption during non-peak period would be accumulated as awaiting time. The equation 3.2 below was used.

$$time\ consumption, t_{(p)n} = t_{(np)n-1} + t_{(np)n-1} + t_{(np)n} \tag{3.2}$$

where

$time\ consumption\ during\ non-peak\ period, t_{(np)0} = 0s$

$vehicle\ no, n = 1, 2, 3, 4, 5, 6, 7$

3.4.2 Time consumption for Conventional Parking System

Same as Smart Parking System, the equations during non-peak and peak periods were obtained separately.

To complete the calculations, Solidworks was used to design a Conventional Parking System used in conventional commercial building. Some parameters such as distances between parking lots and entrance were measured by using Solidworks. Figure 3.3 showed the Conventional Parking Building used in this project. The red colour objects are considered as the vehicles.

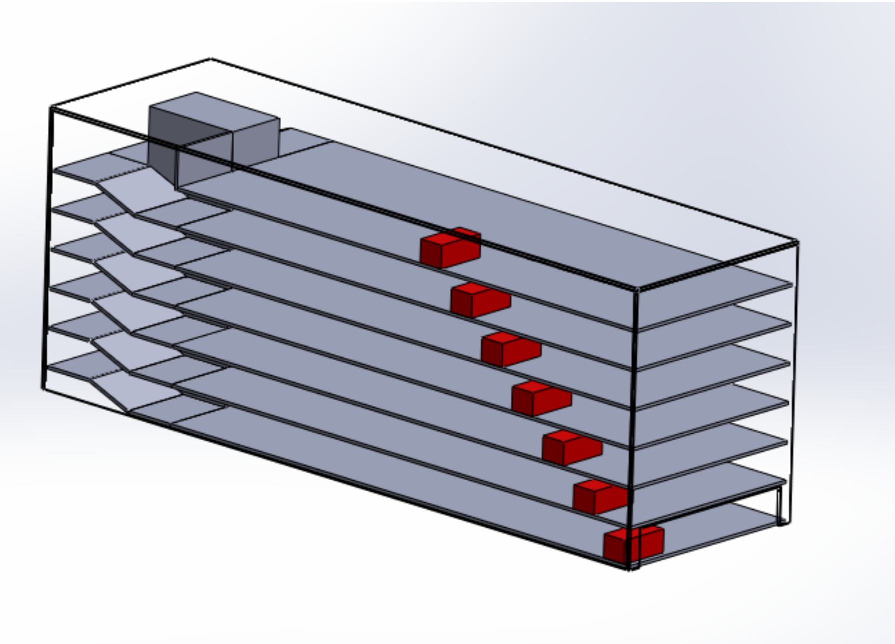

Figure 3.3: Conventional Parking Building

3.4.2.1 Non-peak period

The equation 3.3 was used as shown as below. According to equation 3.3, the longer the distance between parking lot and entrance, the slower the average velocity of vehicle, the longer the time take for parking to desired parking lot. The parameter such as average velocity of vehicle was obtained from assumptions made and information provided in other sources.

$$time\ consumption, t = \frac{D}{v} \quad (3.3)$$

where

$D = moving\ distance\ between\ parking\ lot\ and\ entrance\ (m)$

$v = average\ velocity\ of\ vehicle\ (ms^{-1})$

3.4.2.2 Peak period

During peak period, initially the parking building was empty, considering all vehicles were moving simultaneously inside the parking building. Therefore, the equation used was same as the equation during non-peak period.

$$time\ consumption, t = \frac{D}{v} \quad (3.3)$$

where

$D = moving\ distance\ between\ parking\ lot\ and\ entrance\ (m)$

$v = average\ velocity\ of\ vehicle\ (ms^{-1})$

3.4.3 Comparison

Matlab was used to plot graphs in order to compare the time consumption impacts of Smart and Conventional Parking System. Graph would give a better understanding about the impacts.

3.5 Fuel consumption for Parking System

To study the fuel consumption impact for parking system, some equations were determined. The equations of fuel consumption for Smart Parking System used in Smart Commercial Building and Conventional Parking System used in Conventional Commercial Building were obtained and used to compare with each other.

3.5.1 Equation for fuel consumption

There were a lot of equations related to fuel consumption and they were shown as below.

3.5.1.1 Total force

According to equation 3.4, a driving vehicle must overcome force of air, rolling, inertia and slope. These forces must be overcome by engine torque, the actual value of engine torque will vary depending on driving forces during driving cycle. In order to calculate the total driving force and total driving power of which determined the engine power, these forces must be calculated.

$$Total\ force, F_{total} = F_{air} + F_{rolliing} + F_{inertia} + F_{slope} \tag{3.4}$$

where

$F_{air} = force\ of\ air\ (N)$

$F_{rolling} = force\ of\ tires\ rolling\ (N)$

$F_{inertia} = force\ of\ vehicle\ inertia\ (N)$

$F_{slope} = force\ of\ slope\ road\ (N)$

3.5.1.2 Force of air

$$Force\ of\ air, F_{air} = \frac{s \times c_x \times \rho_{air} \times v^2}{2} \quad (3.5)$$

where

$s = frontal\ area\ of\ vehicle\ (m^2)$

c_x = drag coeficient

ρ_{air} = air density (kg/m^3)

$v =\ vehicle\ speed\ (ms^{-1})$

3.5.1.3 Force of rolling

$$Force\ of\ rolling, F_{rolling} = m \times g \times f_{rolling} \times \cos\alpha \quad (3.6)$$

where

$m = mass\ of\ vehicle\ (kg)$

$g = gravity\ acceleration\ (ms^{-2})$

$f_{rolling} = coefficient\ of\ rolling\ force$

$\alpha = angle\ slope\ road\ (°)$

3.5.1.4 Force of inertia

$$Force\ of\ inertia, F_{inertia} = m \times a \times \vartheta \quad (3.7)$$

where

$m = mass\ of\ vehicle\ (kg)$

$a = acceleration\ of\ vehicle\ (ms^{-2})$

$\vartheta = coefficient\ of\ inertia\ force$

3.5.1.5 Force of slope

$$Force\ of\ slope, F_{slope} = m \times g \times \sin\alpha \tag{3.8}$$

where

$m = mass\ of\ vehicle\ (kg)$

$g = gravity\ acceleration\ (ms^{-2})$

$\alpha = angle\ slope\ road\ (°)$

3.5.1.6 Engine Power

Once all driving forces were calculated, the power required to overcome the driving forces and the required engine power could be determined by using the equation 3.9.

$$Engine\ Power, P_{engine} = \frac{F_{total} \times v}{1000} \times \frac{1}{\eta_{trans}} \tag{3.9}$$

where

$F_{total} = total\ force\ (N)$

$v = average\ velocity\ of\ vehicle\ (ms^{-1})$

$\eta_{trans} = efficiency\ of\ transmission$

3.5.1.7 Fuel consumption

Equation 3.10 was used to calculate the fuel consumption of a vehicle.

$$Fuel\ consumption, FC = \frac{100 \times bsfc \times P_{engine}}{\rho_{fuel} \times v} \quad (3.10)$$

where

$bsfc = brake\ specific\ fuel\ consumption\ (g/kmh)$

$P_{engine} = reguired\ engine\ power\ (kW)$

$\rho_{fuel} = density\ of\ fuel\ (kg/m^3)$

3.5.2 Fuel consumption for Smart Parking System

The calculations were made for non-peak period and peak period.

3.5.2.1 Non-peak period

During non-peak period, there was no fuel consuming when a vehicle was moved by the platform to desired parking lot. Therefore, the fuel consumption would be equal to zero.

3.5.2.2 Peak period

During peak period, all the vehicles were needed to queuing to park inside the building. When queuing, the vehicle engine was running and the fuel was consuming. Therefore, the fuel consumption during awaiting must be considered.

3.5.3 Fuel consumption for Conventional Parking System

The calculations were made for non-peak period and peak period.

3.5.3.1 Non-peak period

During non-peak period, vehicle was moving and parking inside the building. Since the vehicle kept moving inside the parking building, the engine was running, fuel was consuming. The fuel consumption was considered and calculated based on certain assumptions and information provided.

3.5.3.2 Peak period

During peak period, initially the parking building was empty, considering all vehicles were moving simultaneously inside the parking building. Therefore, the equation used was same as the equation during non-peak period.

3.5.4 Comparison

Matlab was used to plot graphs in order to compare the fuel consumption impacts of Smart and Conventional Parking System. Graph would give a better understanding about the impacts

3.6 Cost benefit of Energy Storage System

To study the cost benefit of Energy Storage System, a daily electricity demand of a commercial building was determined and recorded on Table 3.1 below. A load profile for the daily electricity demand was shown as Figure 3.4 below.

Table 3.1: Daily electricity demand

Time	Electricity Demand (kW)	Time	Electricity Demand (kW)	Time	Electricity Demand (kW)
00:00	38	08:00	83	16:00	76
00:30	38	08:30	82	16:30	64
01:00	38	09:00	82	17:00	62
01:30	39	09:30	83	17:30	61
02:00	38	10:00	82	18:00	59
02:30	38	10:30	82	18:30	58
03:00	40	11:00	81	19:00	55
03:30	40	11:30	82	19:30	48
04:00	43	12:00	81	20:00	46
04:30	47	12:30	82	20:30	45
05:00	49	13:00	81	21:00	42
05:30	50	13:30	80	21:30	40
06:00	65	14:00	78	22:00	40
06:30	78	14:30	77	22:30	40
07:00	78	15:00	78	23:00	39
07:30	81	15:30	78	23:30	38

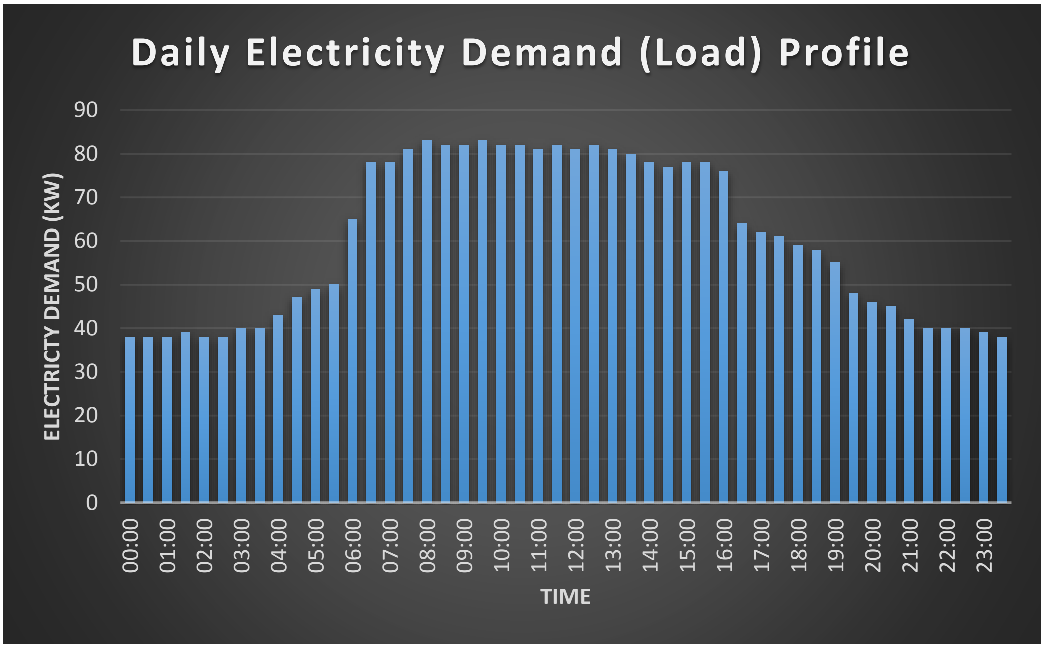

Figure 3.4: Load Profile for Daily Electricity Demand

3.6.1 Energy Storage System integrated with Renewable Energy

For Smart Commercial Building, Energy Storage System (ESS) integrated with Renewable Energy (RE) was used. Solar Energy was used as the renewable energy source to supply electricity. To find the cost saving, electricity bill for the building without ESS integrated with RE and with ESS integrated with RE were needed to be calculated. Furthermore, the payback period would be determined.

3.6.1.1 Without ESS integrated with RE

Peak and off peak tariff were determined as shown as Table 3.2 below. Without ESS integrated with RE, the electricity bill was calculated based on the load profile above and based on the information provided below.

Tariff during peak period = 36.50sen (8am until 10pm)

Tariff during off-peak period = 22.40sen (10pm until 8am)

Table 3.2: Peak and off peak Commercial Tariff

Tariff Category	Existing Rates (1 June 2011)	New Rates (1 January 2014)
	Sen / US cent	Sen / US cent
Tariff C2 - Medium Voltage Peak/Off-Peak Commercial Tariff		
For each kilowatt of maximum demand per month during the peak period	38.60 / 12.06	45.10 / 14.09
For all kWh during the peak period	31.20 / 9.75	36.50 / 11.41
For all kWh during the off-peak period	19.20 / 6.00	22.40 / 7.00
The Minimum Monthly Charge is	*600.00 / 187.50*	*600.00 / 187.50*

3.6.1.2 With ESS integrated with RE

With ESS integrated with RE, solar energy was used as this renewable energy source. Solar panel would generate and supply the demand to the building, the excess energy would be stored in ESS to flatten the peak demand. Since the cost of solar energy is free, the cost of power supplied by solar energy was not considered. After the peak demand was flattened, the electricity bill would be calculated based on the information provided and certain assumptions.

3.6.1.3 Cost Benefit

Equation 3.11 was used to calculate the cost benefit. It determined the how much the cost saved by ESS integrated with RE in a month.

$$\text{Cost benefit} = \text{EBWOESSRE} - \text{EBWESSRE} \tag{3.11}$$

where

$EBWOESSRE = Electricity\ Bill\ without\ ESS\ integrated\ RE$

$EBWESSRE = Electricity\ Bill\ with\ ESS\ integrated\ RE$

3.6.1.4 Payback period

Payback period determined the period to finish paying the installation cost by using the cost saved. Equation 3.12 was shown as below.

$$Payback\ period = \frac{Installation\ cost}{cost\ saved} \tag{3.12}$$

3.6.2 Energy Storage System

Energy Storage System (ESS) only was used in Conventional Commercial Building. ESS would do charging during off peak period due to lower electricity tariff. ESS would discharge and supply the demand to flatten the peak demand during peak period. To find the cost saving, electricity bill for the building without ESS and with ESS were needed to be calculated. Furthermore, the payback period would be determined.

3.6.2.1 Without Energy Storage System

Peak and off peak tariff were determined on Table 3.2. The electricity bill without ESS was calculated based on the load profile above and based on the information provided below.

Tariff during peak period = 36.50sen (8am until 10pm)

Tariff during off-peak period = 22.40sen (10pm until 8am)

3.6.2.2 With Energy Storage System

With Energy Storage System (ESS), ESS would charge during off-peak period due to lower electricity tariff. It would discharge and flatten peak demand. After the peak demand was flattened, the electricity bill would be calculated based on the information provided and certain assumptions.

3.6.2.3 Cost Benefit

Equation 3.13 was used to calculate the cost benefit. It determined the how much the cost saved by ESS in a month.

$$Cost\ benefit = EBWOESS - EBWESS \tag{3.13}$$

where

$EBWOESS = Electricity\ Bill\ without\ ESS$

$EBWESS = Electricity\ Bill\ with\ ESS$

3.6.2.4 Payback period

Payback period determined the period to finish paying the installation cost by using the cost saved. Equation 3.12 was used to calculate the payback period.

3.6.3 Comparison

The payback period for ESS integrated with RE used in Smart Commercial Building and for ESS only used in Conventional Commercial Building were calculated and used to compare with each other. A bar chart was used to compare the results in order to provide a better understanding about the cost benefit impact.

3.7 Conclusion

With correct choice of equations, the impacts were studied. Through calculation, certain assumptions must be made.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

After proper planning of the methods to be carried out for the investigation of the possible impacts, parameters needed in the equations were sought and collected. For Parking System, Toyota Prius 2004 was selected as chosen vehicle. The specifications of the chosen vehicle were referred for some parameters' values. For Energy Storage System, the specifications of the storage system were referred from some information provided.

With the values of parameters needed, calculation results were obtained. By comparison, the time and fuel consumption impacts for SPS and the cost benefit for ESS integrated with RE were deduced. The comparison would be done by using software MATLAB.

4.2 Time consumption of Parking System

As aforementioned, comparison of time consumption for Smart Parking System and Conventional Parking System was done.

4.2.1 Time consumption for Smart Parking System

Time consumption for Smart Parking System was done based on certain assumptions and information provided.

4.2.1.1 Non-peak period

From Equation 3.1 mentioned before,

$$time\ consumption, t_{(np)} = \frac{H}{s_1} + \frac{L+d}{s_2} \tag{3.1}$$

Based on certain assumptions and information provided, there are some constants as below:

$Distance\ to\ move\ a\ vehicle\ from\ platform\ to\ parking\ lot, d = 6m$

$Platform\ elevating\ speed, s_1 = 1\text{m}s^{-1}$

$Platform\ horizontally\ moving\ speed, s_2 = 0.5ms^{-1}$

Seven vehicles were parked at seven different places, the height between parking lot and platform, H and the horizontal distance between parking lot and platform, L were measured by using Solidworks. Moreover, time consumption was calculated and shown as Table 4.1 below.

Table 4.1: Table of result for time consumption during non-peak period

Car	Height between parking lot and platform, H (m)	Horizontal distance between parking lot and platform, L (m)	Time consumption, $t_{(np)}$ (s)
1	0.00	3.80	19.60
2	3.50	7.60	30.70
3	7.00	11.40	41.80
4	10.50	15.20	52.90
5	14.00	19.00	64.00
6	17.50	22.80	75.10
7	21.00	26.60	86.20

Matlab was used to plot the graph of time consumption against car. The graph was plotted as shown as Figure 4.1.

Figure 4.1: Graph of time consumption during non-peak period against car

4.2.1.2 Peak period

During peak period, assuming those 7 cars were queuing for parking, the awaiting time was needed to be considered. Table 3.2 showed that the result for time consumption during peak hour. Figure 4.2 showed the graph

Table 4.2: Table of result for time consumption during peak period

Car	Time consumption, $t_{(p)}$ (s)
1	19.60
2	69.90
3	142.40
4	237.10
5	354.00
6	493.10
7	654.40

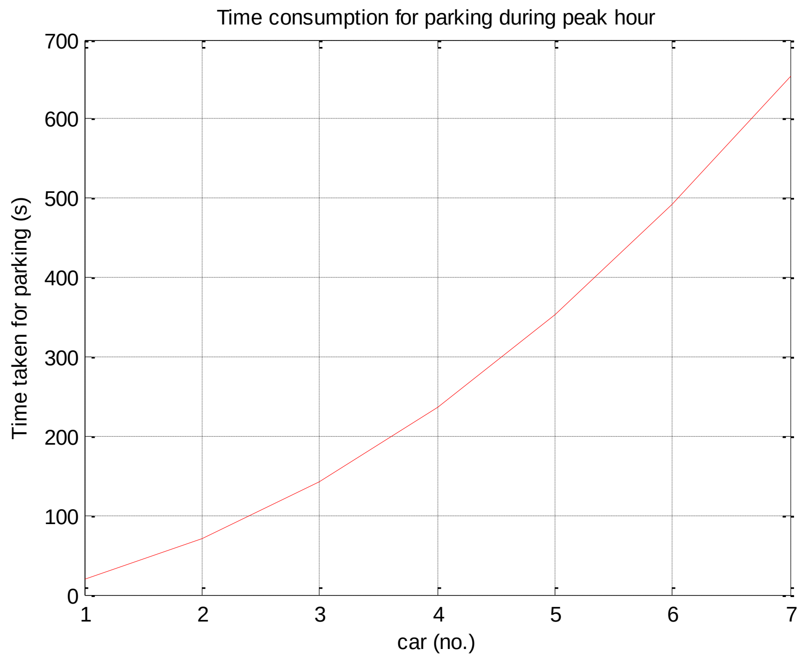

Figure 4.2: Graph of time consumption during peak period against car

4.2.2 Time consumption for Conventional Parking System

Time consumption for Conventional Parking System was done based on certain assumptions and information provided.

4.2.2.1 Non-peak period

From Equation 3.3 mentioned above, the average velocity of vehicle, *v* is constant.

$$time\ consumption, t = \frac{D}{v} \tag{3.3}$$

$Average\ velocity\ of\ vehicle, v = 15kmh^{-1} = 4ms^{-1}$

Assuming the seven vehicles were parked at the same places compared with Smart Parking System, Table 4.3 showed the result for time consumption during non-peak period with different parameters. Figure 4.3 had showed the graph of time consumption against the car.

Table 4.3: Table of result for time consumption during non-peak period

Car	Distance between parking lot and entrance, D (m)	Time consumption, $t_{(p)}$ (s)
1	3.80	0.95
2	154.80	38.70
3	297.80	74.40
4	432.80	108.20
5	559.80	139.95
6	678.80	169.70
7	790.80	197.70

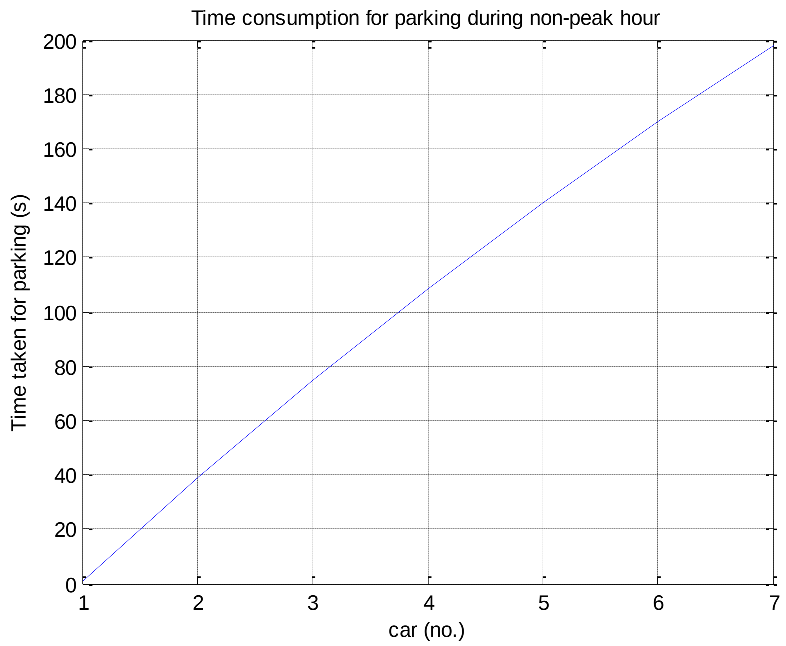

Figure 4.3: Graph of time consumption during non-peak period against car

4.2.2.2 Peak period

During peak period, initially the parking building was empty, considering all vehicles were moving simultaneously inside the parking building. Therefore, the equation used and the parameters were same as non-peak period. The results were same as non-peak period.

4.2.3 Comparison

During non-peak period, the comparison between time consumption for Smart Commercial Building and Conventional Commercial Building was done and the graph was plotted as shown as Figure 4.4.

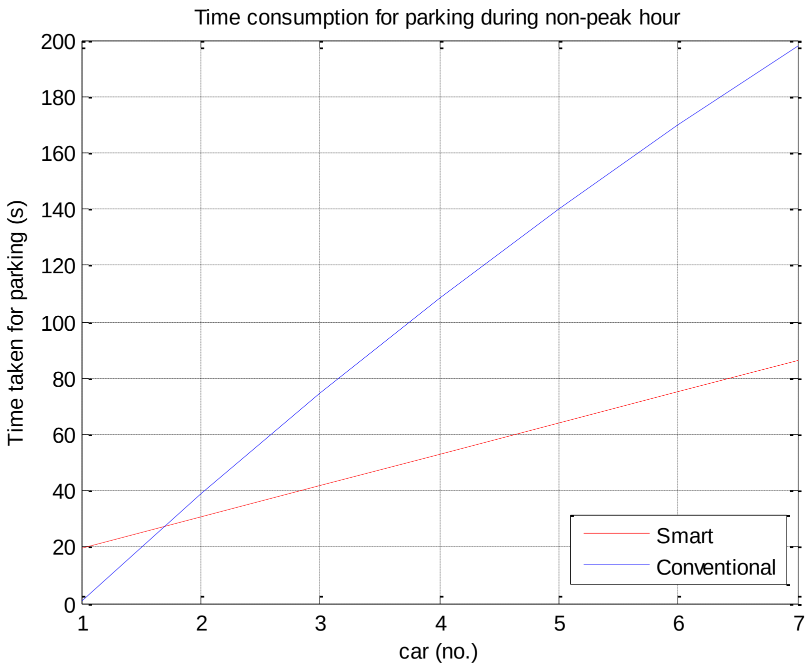

Figure 4.4: Graph of time consumption of Smart and Conventional Commercial Building during non-peak period

From the graph above, it showed that the time consumption for Smart Parking System used in Smart Commercial Building is lesser compared to Conventional Parking System used in Conventional Commercial Building. It is faster when using Smart Parking System.

During peak period, the comparison between time consumption for Smart Commercial Building and Conventional Commercial Building was done and the graph was plotted as shown as Figure 4.5.

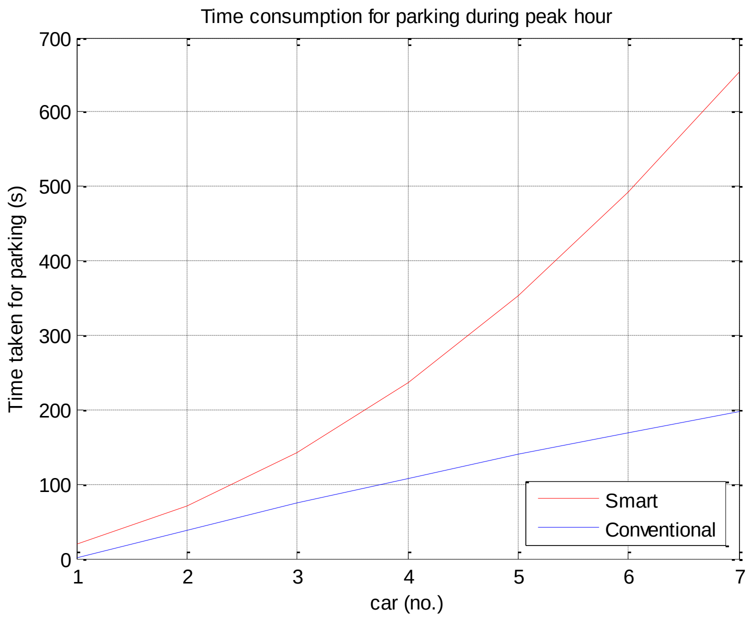

Figure 4.5: Graph of time consumption of Smart and Conventional Commercial Building during peak period

From the graph above, it showed that the time consumption for Smart Parking System used in Smart Commercial Building is more than Conventional Parking System used in Conventional Commercial Building. It is because of the waiting time, the vehicles were queuing for parking. As the platform was occupied, the vehicles were needed to wait for other vehicle to park. Thus, the waiting time was considered.

4.3 Fuel consumption for Parking System

As aforementioned, comparison of fuel consumption for Smart Parking System and Conventional Parking System was done.

4.3.1 Fuel consumption for Smart Parking System

Fuel consumption for Smart Parking System was done based on certain assumptions and information provided.

4.3.1.1 Non-peak period

During non-peak period, there was no fuel consuming when a vehicle was moved by the platform to desired parking lot. Therefore, the fuel consumption would be equal to zero.

4.3.1.2 Peak period

Fuel consumption for Smart Parking System during peak period was calculated to be as followed.

4.3.1.2.1 Force of air

To calculate force of air, there are some constants for the equation as shown as below:

$Frontal\ area\ of\ vehicle, s = 2m^2$

$Drag\ coeficient, c_x = 0.33$

$Air\ density, \rho_{air} = 1.22kgm^{-3}$

During peak period, the vehicles were needed to queue for parking, the average velocity of vehicle will be lower. Thus, the average speed of vehicle was assumed as 0.14ms^{-1}.

$Vehicle\ speed = 0.14ms^{-1}$

Therefore, the force of air was calculated.

$$Force\ of\ air, F_{air} = \frac{2 \times 0.33 \times 1.22 \times 0.14^2}{2}$$
$$= 7.89 \times 10^{-3}\ N$$

4.3.1.2.2 Force of rolling

To calculate force of rolling, there are some constants for the equation as shown as below:

$Gravity\ acceleration, g = 9.81ms^{-2}$

$Coefficient\ of\ rolling\ force = 0.014$

$Angle\ slope\ road, \alpha = 1°$

Toyota Prius 2004 was selected as chosen vehicle. The mass of Toyota Prius 2004 is 3042 pounds which equals to 1400kg.

$Mass\ of\ vehicle, m = 1400kg$

Therefore, force of rolling was calculated.

$$Force\ of\ rolling, F_{rolling} = 1400 \times 9.81 \times 0.014 \times \cos 1$$
$$= 192.25\ N$$

4.3.1.2.3 Force of inertia

To calculate force of inertia, there are some constants for the equation as shown as below:

$Coefficient\ of\ inertia\ force, \vartheta = 0.95$

Assuming the acceleration of vehicle as 2.8ms^{-2}.

$Acceleraction\ of\ vehicle, a = 2.8ms^{-2}$

The force of inertia was calculated.

$$Force\ of\ inertia, F_{inertia} = 1400 \times 2.8 \times 0.95$$
$$= 3724\ N$$

4.3.1.2.4 Force of slope

Force of slope was calculated based on some assumptions and constants.

$$Force\ of\ slope, F_{slope} = m \times g \times \sin \alpha$$
$$= 1400 \times 9.81 \times \sin 1°$$
$$= 239.70\ N$$

4.3.1.2.5 Total of force

The total of force was calculated as to be followed.

$$Total\ force, F_{total} = F_{air} + F_{rolliing} + F_{inertia} + F_{slope}$$
$$= 7.89 \times 10^{-3} + 192.25 + 3724 + 239.70$$
$$= 4155.96\ N$$

4.3.1.2.6 Engine Power

Engine Power was calculated based on Equation 3.9 and there is a constant below.
$Efficiency\ of\ transmission, \eta_{trans} = 0.93$

$$Engine\ Power, P_{engine} = \frac{4155.96 \times 0.14}{1000} \times \frac{1}{0.93}$$
$$= 0.6257\ kW$$

4.3.1.2.7 Fuel Consumption

Since Toyota Prius 2004 was selected, the brake specific fuel consumption of Toyota Prius 2004 is 0.370 lb/hph which equals to 225 g/kmh. Moreover, there is a constant for density of fuel.
$Brake\ specific\ fuel\ consumption, bsfc = 225\ g/kmh$
$Density\ of\ fuel, \rho_{fuel} = 840kgm^{-3}$

The fuel consumption for Smart Parking System during non-peak period was calculated.

$$Fuel\ consumption, FC = \frac{100 \times 225 \times 0.6257}{840 \times 0.14}$$
$$= 119.7\ l/100km$$

The result calculated showed that 119.7 litre was consumed when moving 100km. The graph fuel consumption against distance was plotted as figure below.

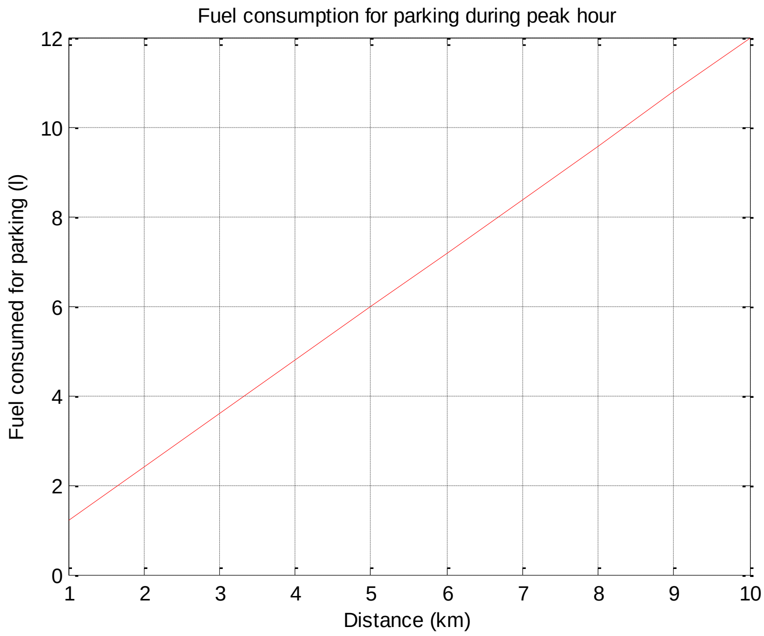

Figure 4.6: Graph of fuel consumption during peak period against distance

4.3.2 Fuel consumption for Conventional Parking System

Fuel consumption for Conventional Parking System was done based on certain assumptions and information provided.

4.3.2.1 Non-peak period

Fuel consumption for Conventional Parking System during non-peak period was calculated to be as followed.

4.3.2.1.1 Force of air

To calculate force of air, there are some constants for the equation as shown as below:

$Frontal\ area\ of\ vehicle, s = 2m^2$

$Drag\ coeficient, c_x = 0.33$

$Air\ density, \rho_{air} = 1.22kgm^{-3}$

The average speed of vehicle was assumed as 4ms^{-1}.

$Vehicle\ speed = 4ms^{-1}$

Therefore, the force of air was calculated.

$$Force\ of\ air, F_{air} = \frac{2 \times 0.33 \times 1.22 \times 4^2}{2}$$
$$= 6.44\ N$$

4.3.2.1.2 Force of rolling

To calculate force of rolling, there are some constants for the equation as shown as below:

$Gravity\ acceleration, g = 9.81ms^{-2}$

$Coefficient\ of\ rolling\ force = 0.014$

$Angle\ slope\ road, \alpha = 1°$

Toyota Prius 2004 was selected as chosen vehicle. The mass of Toyota Prius 2004 is 3042 pounds which equals to 1400kg.

$Mass\ of\ vehicle, m = 1400kg$

Therefore, force of rolling was calculated.

$$Force\ of\ rolling, F_{rolling} = 1400 \times 9.81 \times 0.014 \times \cos 1$$
$$= 192.25\ N$$

4.3.2.1.3 Force of inertia

To calculate force of inertia, there are some constants for the equation as shown as below:

$Coefficient\ of\ inertia\ force, \vartheta = 0.95$

Assuming the vehicle was moving at constant velocity, the acceleration of vehicle would equal to zero.

$Acceleraction\ of\ vehicle, a = 0ms^{-2}$

The force of inertia was calculated.

$$Force\ of\ inertia, F_{inertia} = 1400 \times 0 \times 0.95$$
$$= 0\ N$$

4.3.2.1.4 Force of slope

Force of slope was calculated based on some assumptions and constants.

$$Force\ of\ slope, F_{slope} = m \times g \times \sin\alpha$$
$$= 1400 \times 9.81 \times \sin 1°$$
$$= 239.70\ N$$

4.3.2.1.5 Total of force

The total of force was calculated as to be followed.

$$Total\ force, F_{total} = F_{air} + F_{rolliing} + F_{inertia} + F_{slope}$$
$$= 6.44 + 192.25 + 0 + 239.70$$
$$= 438.39\ N$$

4.3.2.1.6 Engine Power

Engine Power was calculated based on Equation 3.9 and there is a constant below.

$Efficiency\ of\ transmission, \eta_{trans} = 0.93$

$$Engine\ Power, P_{engine} = \frac{438.39 \times 4}{1000} \times \frac{1}{0.93}$$
$$= 1.89\ kW$$

4.3.2.1.7 Fuel Consumption

Since Toyota Prius 2004 was selected, the brake specific fuel consumption of Toyota Prius 2004 is 0.370 lb/hph which equals to 225 g/kmh. Moreover, there is a constant for density of fuel.

$Brake\ specific\ fuel\ consumption, bsfc = 225\ g/kmh$

$Density\ of\ fuel, \rho_{fuel} = 840kgm^{-3}$

The fuel consumption for Smart Parking System during non-peak period was calculated.

$$Fuel\ consumption, FC = \frac{100 \times 225 \times 1.89}{840 \times 4}$$
$$= 12.66\ l/100km$$

The result calculated showed that 12.66 litre was consumed when moving 100km. The graph fuel consumption against distance was plotted as figure below.

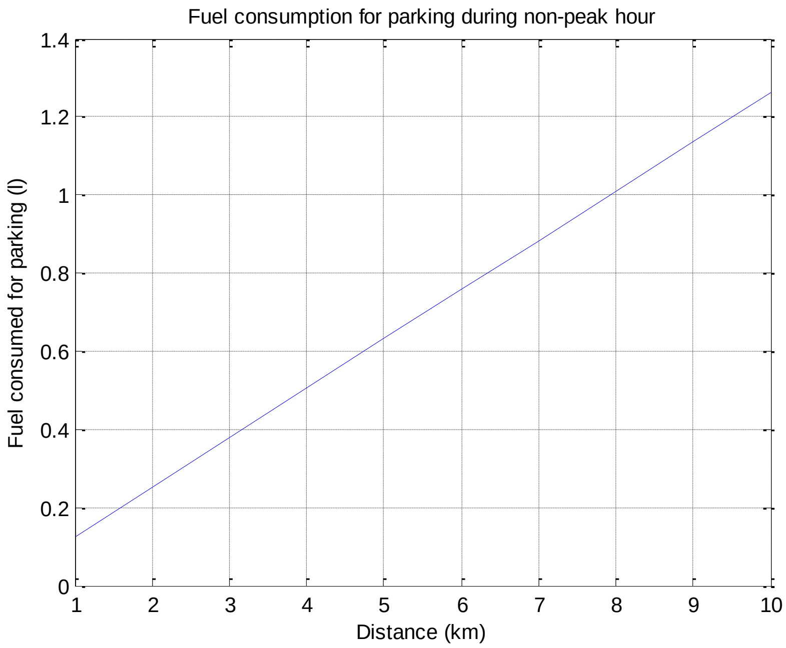

Figure 4.7: Graph of fuel consumption during non-peak period against distance

4.3.2.2 Peak period

During peak period, initially the parking building was empty, considering all vehicles were moving simultaneously inside the parking building. Therefore, the equation used and the parameters were same as non-peak period. The results were same as non-peak period.

4.3.3 Comparison

During non-peak period, the comparison between fuel consumption for Smart Commercial Building and Conventional Commercial Building was done and the graph was plotted as shown as Figure 4.8.

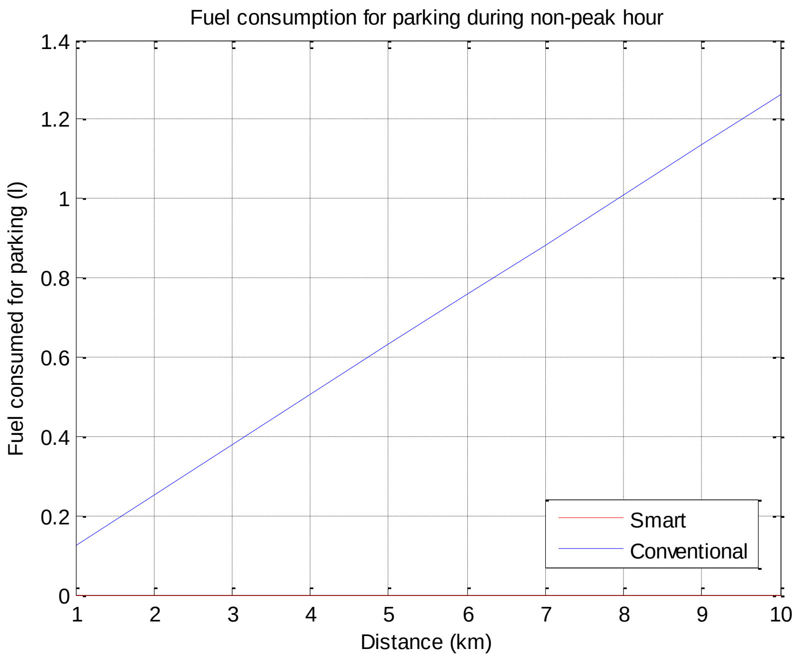

Figure 4.8: Graph of fuel consumption of Smart and Conventional Commercial Building during non-peak period

From the graph above, it showed that the fuel consumption for Smart Parking System used in Smart Commercial Building is zero because there is no fuel consumed by the vehicle which was moved by platform to the parking lot. Therefore, it is better when using Smart Parking System.

During peak period, the comparison between fuel consumption for Smart Commercial Building and Conventional Commercial Building was done and the graph was plotted as shown as Figure 4.9.

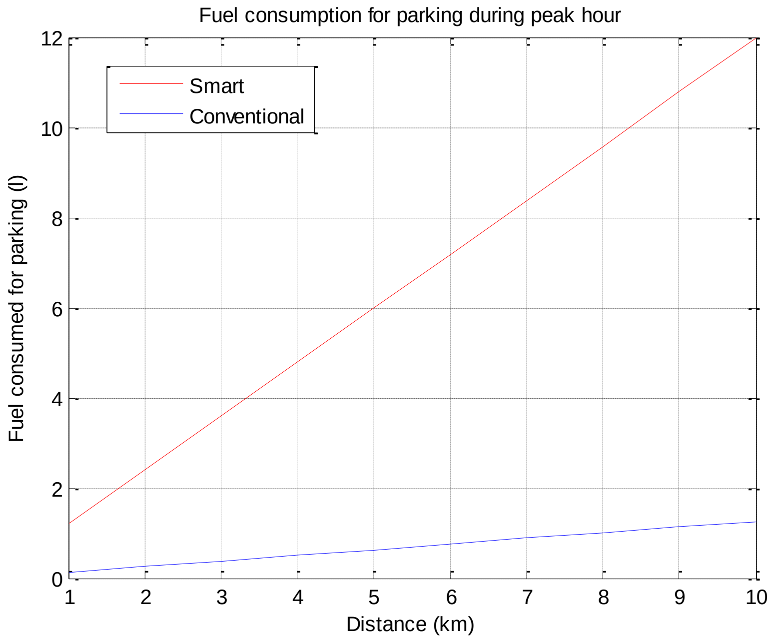

Figure 4.9: Graph of fuel consumption of Smart and Conventional Commercial Building during peak period

From the graph above, it showed that the fuel consumption for Smart Parking System used in Smart Commercial Building is more than Conventional Parking System used in Conventional Commercial Building. It is more fuel consumed for Smart Parking System because of the waiting time, the vehicles were queuing for parking. As the platform was occupied, the vehicles were needed to wait for other vehicle to park. Thus, the vehicle engine was running when waiting for other vehicle, the fuel was consuming.

4.4 Cost benefit of Energy Storage System

As aforementioned, comparison of cost benefit for Smart Parking System and Conventional Parking System was done.

4.4.1 Energy Storage System integrated with Renewable Energy

For Smart Commercial Building, Energy Storage System (ESS) integrated with Renewable Energy (RE) was used. Solar Energy was used as the renewable energy source to supply electricity. The cost benefit and payback period of Energy Storage System integrated with Renewable Energy used in Smart Commercial Building was calculated.

4.4.1.1 Without ESS integrated with RE

Without ESS integrated with RE, the electricity bill was calculated based on the load profile shown as Figure 3.4 and based on the information provided below.

Tariff during peak period = 36.50sen (8am until 10pm)
Tariff during off-peak period = 22.40sen (10pm until 8am)

The monthly electricity bill was calculated as to be followed.

<u>Daily Load Demand</u>
For off-peak period, daily load demand = 458.5 kWh
For peak period, daily load demand = 994 kWh

<u>Monthly Electricity Bill</u>

For off-peak period, daily electricity bill = 458.5 x 22.40 sen

= RM 102.70

For peak period, daily electricity bill = 994 x 36.50 sen

= RM 362.81

Maximum demand charge = 2 x 83 x RM 45.10

= RM 7,486.60

Total monthly electricity bill = (RM 102.70 + RM 362.81) x 30 days + RM7,486.60

= RM 21,451.90

4.4.1.2 With ESS integrated with RE

With ESS integrated with RE, solar energy was used as this renewable energy source. For solar energy, the daily solar irradiance was shown as Figure 4.10 below.

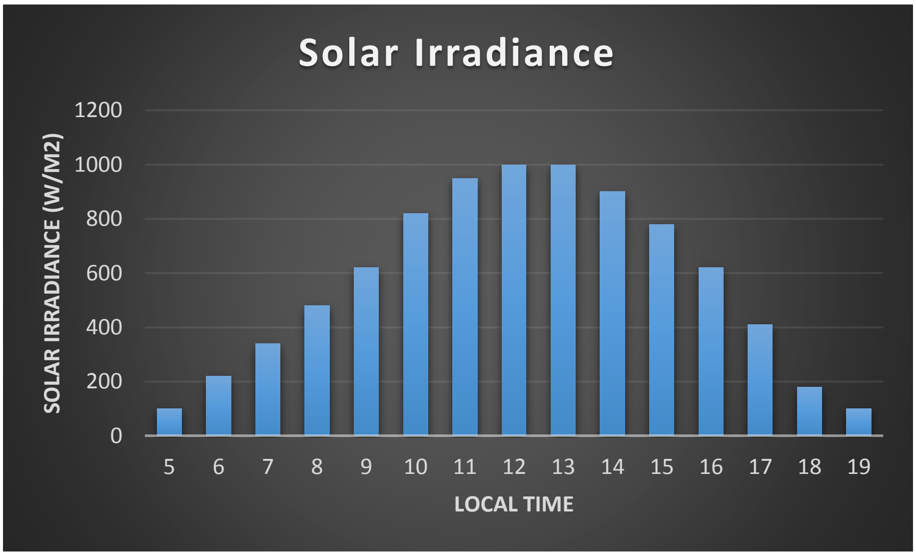

Figure 4.10: Daily Solar Irradiance

<u>Daily Solar Irradiance</u>

Daily solar irradiance = 8,520 Wh/m^2

Assuming the surface area of solar panel installed was 25m^2.

Power Supplied = 8,520 x 25

= 213 kWh

Based on Figure 4.10, Solar panel would generate and supply the demand to the building, the excess energy would be stored in ESS to flatten the peak demand as shown as table below. Moreover, the load profile also was shown as Figure 4.11.

Table 4.4: Daily electricity demand after flattened by ESS integrated with RE

Time	Electricity Demand (kW)	Time	Electricity Demand (kW)	Time	Electricity Demand (kW)
00:00	38	08:00	63	16:00	56
00:30	38	08:30	62	16:30	57
01:00	38	09:00	62	17:00	55
01:30	39	09:30	63	17:30	53
02:00	38	10:00	62	18:00	52
02:30	38	10:30	62	18:30	52
03:00	40	11:00	63	19:00	52
03:30	40	11:30	62	19:30	48
04:00	43	12:00	63	20:00	46
04:30	47	12:30	62	20:30	45
05:00	49	13:00	62	21:00	42
05:30	50	13:30	63	21:30	40
06:00	55	14:00	59	22:00	40
06:30	62	14:30	58	22:30	40
07:00	63	15:00	60	23:00	39
07:30	63	15:30	57	23:30	38

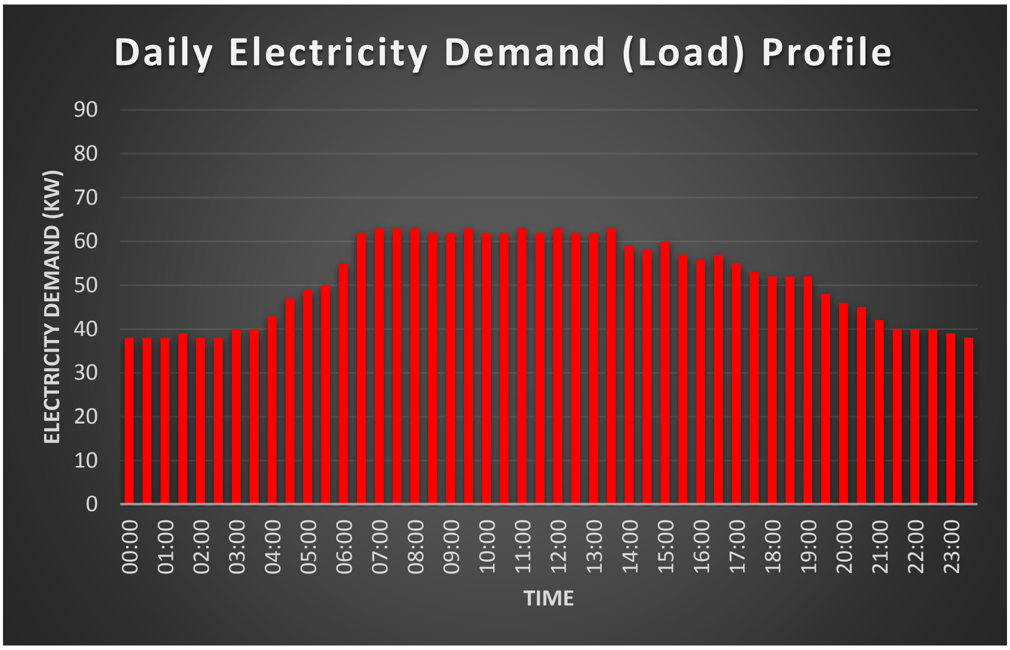

Figure 4.11: Load Profile for Daily Electricity Demand after flattened by ESS integrated with RE

Since the cost of solar energy is free, the cost of power supplied by solar energy was not considered. After the peak demand was flattened, the electricity bill would be calculated based on the information provided and certain assumptions.

<u>Daily Load Demand</u>

For off-peak period, daily load demand = 429 kWh

For peak period, daily load demand = 810.5 kWh

<u>Monthly Electricity Bill</u>

For off-peak period, daily electricity bill = 429 x 22.40 sen

= RM 96.10

For peak period, daily electricity bill = 810.5 x 36.50 sen

= RM 295.83

Maximum demand charge = 2 x 63 x RM 45.10

= RM 5,682.60

Total monthly electricity bill = (RM 96.10 + RM 295.83) x 30 days + RM 5,682.60

= RM 17,440.50

4.4.1.3 Cost Benefit

Cost benefit was calculated as to be followed.

$$\text{Cost benefit} = \text{RM } 21{,}451.90 - \text{RM } 17{,}440.50$$
$$= \text{RM } 4{,}011.40$$

There was an amount of RM 4,011.40 cost saved in a month, around 18.7% cost saved in a month.

4.4.1.4 Payback period

The installation cost was calculated based on certain assumptions and information provided as shown as Table 4.5 below.

Table 4.5: Installation cost for Energy Storage System

ES Technology	Maturity	Installation Cost		Specific Energy, kWh/kg	Specific Power, kW/kg	Roundtrip Efficiency	½ Storage Time	Lifetime	DOD (depth of discharge)	Minimum Size, kW	Maximum Size, kW
		$US/kWh	$US/kW								
Pumped Hydro	Mature	100	1000-1600	0.00028 Per 100 m height	NA	70% - 85%	To years	10 – 50 years	100%	5,000	2,700,000
CAES (stationary)	Mature	50	425	0.075 (20 bar)	NA	70% - 80%	4 – 10 hours (for underground caverns)	> 10 years	Up to 100%	100,000	300,000
CAES (vehicle)	Available			0.142 (300 bar)			Low self-discharge (for tanks)		98.5%	1	100 (150 in future)
Flywheel	Available	4000	400 - 300	0.01 – 0.1	1 – 10	92% - 97%	From day to month	$10^5 – 10^7$ cycles or 20 years	99%	2	2,000
Battery Technology:											
Lead Acid	Mature	175	125	0.035	0.3	70% - 92%	4 – 25 months	1000 cycles	40%	1	10,000
Lithium-Ion	Available	200 - 360	1000	0.16	0.18	93% - 97%	7 – 14 months	10,000 cycles	40%	1	100
Zink-Air	Emerging	400 - 900	3000	0.375	0.175	40% - 50%	Years (when sealed)	300 cycles	-	1	10
EC Capacitor	Available	9000	300	0.001 – 0.012	0.01 – 15	90% - 98%	1.3 months	10^6 cycles or 10-15 years	98%	2	250
SMES	Available		630	0.05	0.3 – 1	95%	Less than 3 hours	< 20 years	100%	1,000	100,000
H2CAR biofuel	Emerging		-	12.7	NA	13%	Up to year	NA	100%	NA	NA
Molten Salt	Available		-	98 kWh/m³	NA	-	Up to a week	> 4 years	100%	10,000	354,000 (553,000 in 2011)

Since the power supplied by solar energy was 213 kWh,
Minimum energy stored capacity = 213 kWh
If the efficiency of ESS = 70%, the size for ESS = 305 kWh
If it is needed with 20% for reserved capacity, size = 365 kWh

Based on the table above, lead acid battery was chosen as Energy Storage System used in Smart Commercial Building. The installation cost for lead acid battery and solar panel were calculated based on some information provided.

The installation cost for lead acid battery,
365 x $US 175 = $US 63,875
= RM 255,500

The installation cost for solar panel = RM 130,000

Therefore, the total installation cost = RM 255,500 + RM 130,000
= RM 385,500

Payback period was determined as shown as below.

$$Payback\ period = \frac{Installation\ cost}{cost\ saved}$$
$$= \frac{RM\ 385{,}500}{RM\ 4{,}011.40}$$
$$= 96\ months$$

It needed 96 months to finish paying the installation cost by using the cost saved by ESS integrated with RE.

4.4.2 Energy Storage System

Energy Storage System (ESS) only was used in Conventional Commercial Building. The cost benefit and payback period of Energy Storage System used in Conventional Commercial Building was calculated.

4.4.2.1 Without Energy Storage System

Without ESS, the electricity bill was calculated based on the load profile shown as Figure 3.4 and based on the information provided below.

Tariff during peak period = 36.50sen (8am until 10pm)
Tariff during off-peak period = 22.40sen (10pm until 8am)

The monthly electricity bill was calculated as to be followed.

Daily Load Demand
For off-peak period, daily load demand = 458.5 kWh
For peak period, daily load demand = 994 kWh

Monthly Electricity Bill
For off-peak period, daily electricity bill = 458.5 x 22.40 sen
= RM 102.70
For peak period, daily electricity bill = 994 x 36.50 sen
= RM 362.81
Maximum demand charge = 2 x 83 x RM 45.10
= RM 7,486.60
Total monthly electricity bill = (RM 102.70 + RM 362.81) x 30 days + RM7,486.60
= RM 21,451.90

4.4.2.2 With Energy Storage System

With Energy Storage System (ESS), ESS would charge during off-peak period due to lower electricity tariff. It would discharge and flatten peak demand and the electricity demand would be shown as table and figure below.

Table 4.6: Daily electricity demand after flattened by ESS

Time	Electricity Demand (kW)	Time	Electricity Demand (kW)	Time	Electricity Demand (kW)
00:00	58	08:00	63	16:00	65
00:30	57	08:30	62	16:30	64
01:00	59	09:00	63	17:00	62
01:30	60	09:30	62	17:30	61
02:00	58	10:00	64	18:00	59
02:30	60	10:30	65	18:30	58
03:00	59	11:00	65	19:00	57
03:30	57	11:30	63	19:30	56
04:00	58	12:00	63	20:00	57
04:30	58	12:30	64	20:30	55
05:00	58	13:00	64	21:00	56
05:30	61	13:30	65	21:30	56
06:00	65	14:00	63	22:00	57
06:30	65	14:30	63	22:30	55
07:00	65	15:00	64	23:00	55
07:30	64	15:30	62	23:30	55

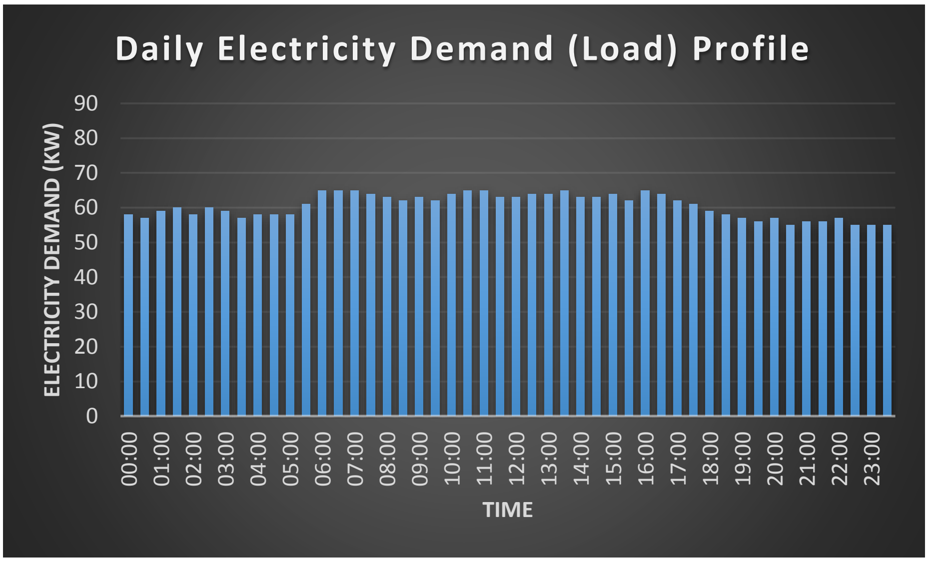

Figure 4.12: Load Profile for Daily Electricity Demand after flattened by ESS

After the peak demand was flattened, the electricity bill would be calculated based on the information provided and certain assumptions.

Monthly Electricity Bill

For off-peak period, daily electricity bill = 563.5 x 22.40 sen

= RM 126.22

For peak period, daily electricity bill = 889 x 36.50 sen

= RM 324.49

Maximum demand charge = 2 x 65 x RM 45.10

= RM 5,863

Total monthly electricity bill = (RM 126.22 + RM 324.49) x 30 days + RM 5,863

= RM 19,384.30

4.4.2.3 Cost Benefit

Cost benefit was calculated as to be followed.

$$\text{Cost benefit} = \text{RM } 21{,}451.90 - \text{RM } 19384.30$$
$$= \text{RM } 2{,}067.60$$

There was an amount of RM 2,067.60 cost saved in a month, around 9.64% cost saved in a month.

4.4.2.4 Payback period

The installation cost was calculated based on certain assumptions and information provided.

Based on the table above, lead acid battery was chosen as Energy Storage System used in Smart Commercial Building. The installation cost for lead acid battery was calculated based on some information provided.

Since the power supplied by solar energy was 105 kWh,
Minimum energy stored capacity = 105 kWh
If the efficiency of ESS = 70%, the size for ESS = 150 kWh
If it is needed with 20% for reserved capacity, size = 180 kWh

The installation cost for lead acid battery,
180 x $US 175 = $US 31,500
= RM 126,000

Payback period was determined as shown as below.

$$Payback\ period = \frac{Installation\ cost}{cost\ saved}$$

$$= \frac{RM\ 126{,}000}{RM\ 2{,}067.60}$$

$$= 61\ months$$

It needed 61 months to finish paying the installation cost by using the cost saved by ESS used in Conventional Commercial Building.

4.4.3 Comparison

The cost benefit for ESS integrated with RE used in Smart Commercial Building and for ESS only used in Conventional Commercial Building were calculated and used to compare with each other as shown as Figure 4.13 below.

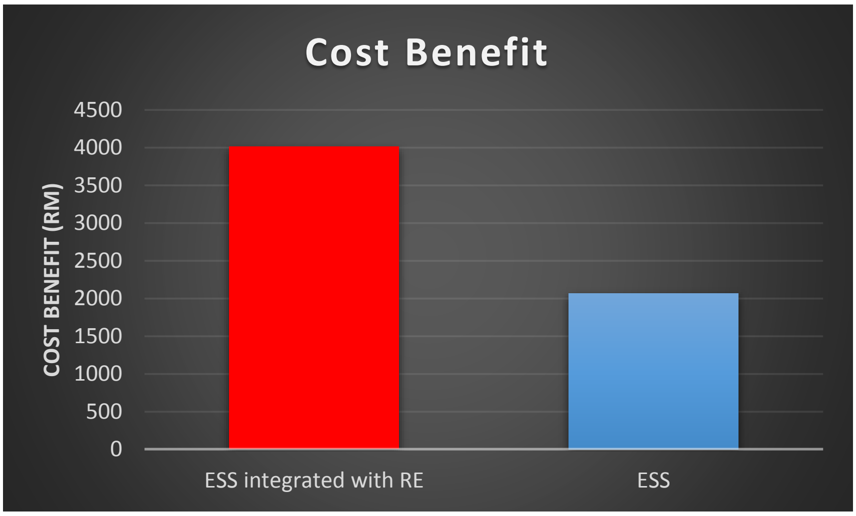

Figure 4.13: Comparison of cost benefit

Figure 4.13 above showed that the cost saved by ESS integrated with RE used in Smart Commercial Building is more than ESS only used in Conventional Commercial Building. It is because the cost for renewable energy, solar energy was not considered since solar energy is free of charge.

The installation cost for ESS integrated with RE used in Smart Commercial Building and for ESS only used in Conventional Commercial Building were calculated and used to compare with each other as shown as Figure 4.14 below.

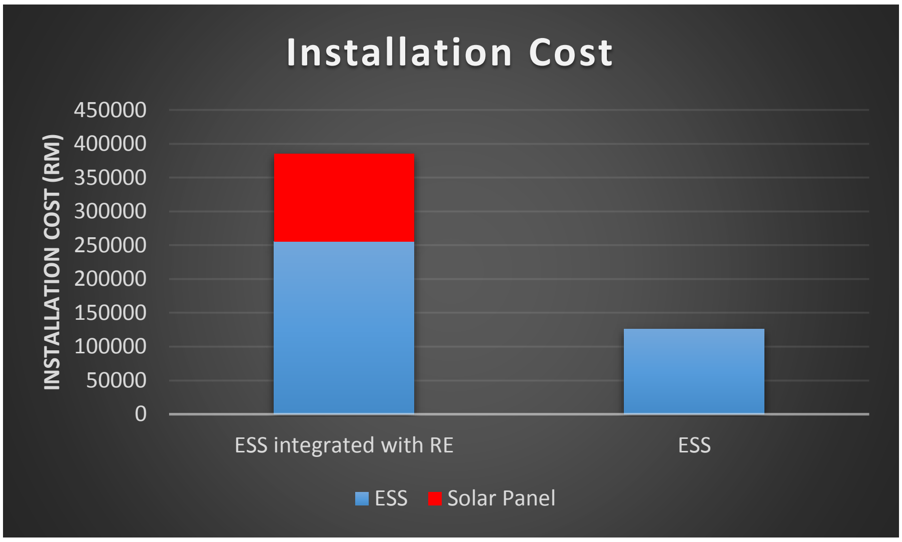

Figure 4.14: Comparison of installation cost

Figure 4.14 above showed that the installation cost of ESS integrated with RE used in Smart Commercial Building is more than ESS only used in Conventional Commercial Building. It is because the installation cost of ESS integrated with RE considered the installation cost of ESS and the solar panel.

The payback period for ESS integrated with RE used in Smart Commercial Building and for ESS only used in Conventional Commercial Building were calculated and used to compare with each other as shown as Figure 4.15 below.

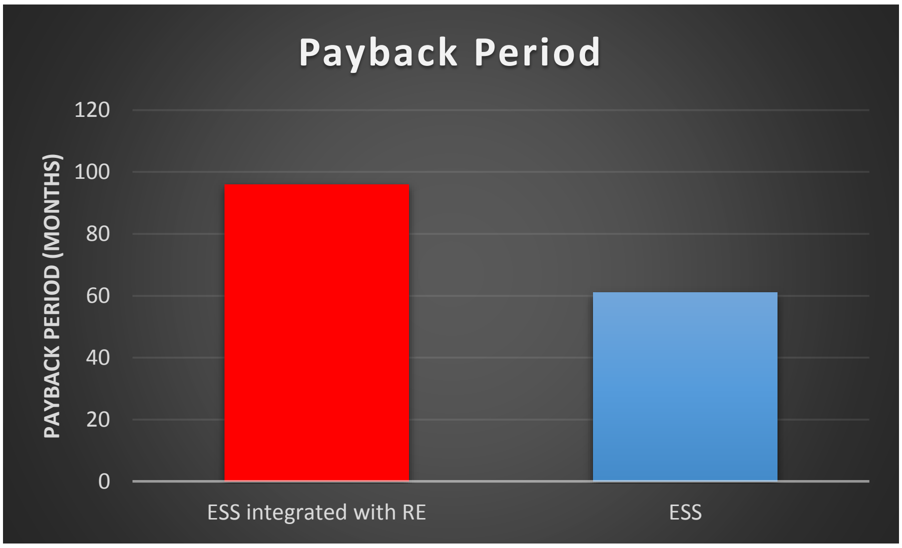

Figure 4.15: Comparison of payback period

Figure 4.15 above showed that the payback period of ESS integrated with RE used in Smart Commercial Building is more than ESS only used in Conventional Commercial Building. Although the amount of cost saved for ESS integrated with RE used in Smart Commercial Building is more than ESS only used in Conventional Commercial Building, but the installation cost for ESS integrated with RE used in Smart Commercial Building is too high compared to ESS only used in Conventional Commercial Building. Therefore, the payback period of ESS integrated with RE used in Smart Commercial Building is more than ESS only used in Conventional Commercial Building.

4.5 Conclusion

The result output of the calculation has shown to be consistent. The results have been determined that there actually are some impacts for Smart Commercial Building.

CHAPTER 5

CONCLUSION AND FURTHER IMPROVEMENT

5.1 Summary

In this section, all the results from simulation and calculation for this study would be discussed and summarized.

For time consumption of Parking System, during non-peak period, the time consumption for Smart Parking System used in Smart Commercial Building is lesser compared to Conventional Parking System used in Conventional Commercial Building. It is faster when using Smart Parking System. During peak period, the time consumption for Smart Parking System used in Smart Commercial Building is more than Conventional Parking System used in Conventional Commercial Building. It is because of the waiting time, the vehicles were queuing for parking. As the platform was occupied, the vehicles were needed to wait for other vehicle to park. Thus, the waiting time was considered.

For fuel consumption of Parking System, during non-peak period, the fuel consumption for Smart Parking System used in Smart Commercial Building is zero because there is no fuel consumed by the vehicle which was moved by platform to the parking lot. Therefore, it is better when using Smart Parking System. Nevertheless, during peak period, the fuel consumption for Smart Parking System used in Smart Commercial Building is more than Conventional Parking System used in Conventional Commercial Building. It is more fuel consumed for Smart Parking System because of the waiting time, the vehicles were queuing for parking. As the platform was occupied, the vehicles were needed to wait for other vehicle to park. Thus, the vehicle engine was running when waiting for other vehicle, the fuel was consuming.

For cost benefit of Energy Storage System, the amount of cost saved for ESS integrated with RE used in Smart Commercial Building is more than ESS only used in Conventional Commercial Building, but the installation cost for ESS integrated with RE used in Smart Commercial Building is too high compared to ESS only used in Conventional Commercial Building. Therefore, the payback period of ESS integrated with RE used in Smart Commercial Building is more than ESS only used in Conventional Commercial Building.

In a nutshell, it was confirmed that there were some impacts have been studied and discovered. Future work such as real-life simulation must be done to make the results of these impact to be more consistent.

5.2 Challenges Encountered

Being an Electrical and Electronic Engineering student, I’ve found ordeals in understanding structure of building. Lack of knowledge on the structure of Smart Building made it a challenge. Nevertheless, enquiry process to seniors had brought fruitful results.

Smart Building has been around for years yet it wasn’t promoted widely because doubts about the impacts of Smart Building could bring to the modern society. Without previous studies on the possible impacts of Smart Building, information collection process has proved challenging. The challenge was solved with brainstorming sessions with friends and seniors.

In the process of data collection, there had been contradiction and absurdity in the values of the parameters. Due to uncertainty in the standard values of result for reference, the parameters were tested with trial and error method to eliminate the most improbable values. Modification had been made during second phase of the project due to the inappropriateness for the application of the chosen equations.

The most serious problem met was choice of software to be used for project simulation. With limited knowledge on the Architectural software, survey did not help much on the process of choosing software. At first, the Autodesk Revit was chosen in analyzing process. However, it was deemed unsuitable upon learning how it. Upon much discussion with supervisor, it was opted that MATLAB and Solidworks were employed.

Regardless of the challenges laid upon the project, the process has proved to be productive as it had enhanced my problem solving skills. While the repetitive process of failure was discouraging, it had provided a valuable experience on exploring an interesting topic from different major.

5.3 Further Improvement

This project has been focusing on simulation and calculation instead of real experiments due to time and space issue. To provide an accurate result in the real world, the experiment should be carried out with hardware. The experiment might even propose different insights on the possible impacts and a more accurate reading in a real life situation. This would provide a more convincing proof for people.

With more understanding on the possible impacts, more suitable software should be used to study the impacts. It is important to have more knowledge on the software used because it would take up long time for one to understand it fully, not to say operating it for desired purpose.

Last but not least, a more complete set of data could be obtained with more knowledge on the study. Default values and assumptions would not be as accurate as the parameters in real life situation as different places have different standards of regulation and environment readings.

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APPENDICES

APPENDIX A: Gantt chart (Phase 1)

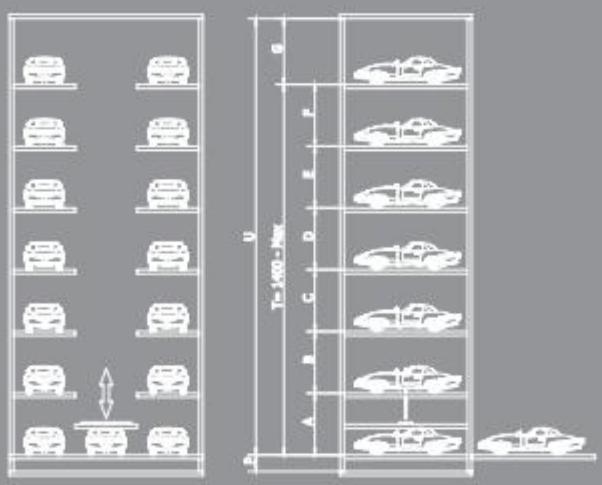
Activity	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
Project Title Selection			■												
1. Literature Review															
1.1 Automation and Control System				■											
1.2 Local Energy Storage System				■											
1.3 Smart metering					■										
1.4 Rainwater Harvesting System					■										
1.5 Air Quality Monitoring System					■										
1.6 Fuzzy based control systems						■	■								
1.7 Electric vehicle							■								
1.8 Smart Parking system								■	■						
1.8 Limited security feature										■					
1.9 Air quality problem										■					
1.10 Installation and maintenance cost											■				
2. Impacts to be Studied															
2.1 Time consumption						■	■	■							
2.2 Fuel consumption							■	■	■						
2.3 Cost benefit									■	■					
3. Determining Equations and Software															
3.1 Equations							■	■	■	■	■				
3.2 Software						■	■	■	■	■					
6 Documentation							■	■	■	■	■	■	■	■	
7 Presentation															■

APPENDIX B: Gantt chart (Phase 2)

Activity	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
3. Determining Equations and Software															
3.1 Equations	■	■	■	■	■										
3.2 Software	■	■													
4. Modelling															
4.1 Smart Parking Building					■	■									
4.2 Conventional Parking Building					■	■									
5. Calculation and Comparison															
5.1 Time consumption						■	■	■							
5.2 Fuel consumption								■	■	■					
5.3 Cost benefit											■	■			
6 Documentation							■	■	■	■	■	■	■	■	
7 Presentation														■	

APPENDIX C: Specification of Automatic Parking System

STANDARD DETAILS	
Capacity	10 - 100 cars
Car available dimensions	5200 (L) x 2100 (W) x 2000 (H)
Car weight	2500 kgs
Elevating motor power	15 - 45 kW
Elevating speed	0,15 - 100 cm/sec
Horizontal moving motor power	0,75 - 1 kW
Horizontal speed	25 cm/sec
TT rotation (optional)	1,5 kW 2rpm
Operating system	magentic key, touch screen or remote control
Safety devices	front indicator for entrance self detect diagnosis inner indicator for entry floor emergency brake, emergency stops
Power	400V triphase



APPENDIX D: Brake Specific Fuel Consumption for vehicles

Power (kW)	Year	Engine type	Application	SFC (lb/hp·h)	SFC (g/kW·h)	Energy efficiency
2,050	1996	Pratt & Whitney Canada PW127 turboprop	ATR 72 regional airliner	0.477	290[1]	29.1%
95	1970	Lycoming O-320 piston, gasoline	General aviation	0.460	280[2]	29.3%
63	1991	GM Saturn I4 engine, gasoline	Saturn S-Series cars	0.411	250[2]	32.5%
150	2011	Ford EcoBoost gasoline, turbo	Ford cars	0.403	245[3]	33.5%
2,000	1945	Wright R-3350 Duplex-Cyclone gasoline, turbo-compound	Bombers, airliners	0.380	231[4]	35.5%
57	2003	Toyota 1NZ-FXE, gasoline	Toyota Prius car	0.370	225[5]	36.4%
550	1931	Junkers Jumo 204 two-stroke diesel, turbo	Bombers, airliners	0.347	211[6]	40%
36,000	2002	Rolls-Royce Marine Trent turboshaft	Combat ships	0.340	207[7]	40.7%
2,340	1949	Napier Nomad Diesel-compound	planned (aircraft intended)	0.340	207[8]	40.7%
165	2000	Volkswagen 3.3 V8 TDI	Audi A8 car	0.337	205[9]	41.1%
2,013	1940	Klöckner-Humboldt-Deutz DZ 710 Diesel two stroke	none (aircraft intended)	0.330	201[10]	41.9%
42,428	1993	General Electric LM6000 turboshaft	Ship, electricity	0.329	200.1[11]	42.1%
130	2007	BMW N47 2L turbodiesel	BMW cars	0.326	198[12]	42.6%
88	1990	Audi 2.5L TDI	Audi 100 car	0.326	198[13]	42.6%
3,600		MAN Diesel 6L32/44CR four-stroke	Ship, electricity	0.283	172[14]	49%
34,320	1998	Wärtsilä-Sulzer RTA96-C two-stroke	Ship, electricity	0.263	160[15]	52.7%
27,060		MAN Diesel S80ME-C9.4-TII two-stroke	Ship, electricity	0.254	154.5[16]	54.6%

APPENDIX E: List of Car Weights

Model	Curb Weight
2012 Toyota Camry	3,190 pounds
2012 Toyota Prius	3,042 pounds
2012 Toyota Avalon	3,572 pounds
2013 Toyota Matrix	2,888 pounds
2013 Chevrolet Equinox LS	3,777 pounds
2013 Chevrolet Corvette	3,208 pounds
2013 Chevrolet Malibu	3,393 pounds
2012 Chrysler Town and Country	4,652 pounds
2012 Subaru Outback	3,495 pounds
2014 Subaru Impreza	3,208 pounds
2013 BMW 740i Sedan	4,344 pounds
2012 Honda Civic LX Coupe	2,617 pounds
2012 Cadillac Escalade EXT	5,949 pounds
2012 MINI Cooper Hatchback	2.535 pounds
2013 Dodge Durango	4,756 pounds
2013 Hyundai Accent	2,396 pounds
2013 Hyundai Elantra	2,701 pounds
2012 Scion xB	3,084 pounds
2012 Scion TC	3,102 pounds
2013 Buick Regal	3,600 pounds
2014 Buick LaCrosse	3,756 pounds
2014 Buick Verano	3,300 pounds
2013 Kia Optima Hybrid	3,496 pounds
2014 Kia Cadenza	3,668 pounds
2012 Lexus IS-F	3,780 pounds
2013 Audi A6	3,682 pounds
2014 BMW 5-Series	3,814 pounds
2012 Nissan Cube	2,768 pounds
2012 Nissan Maxima	3,540 pounds
2014 Nissan Versa	2,354 pounds
2013 Ford Focus	2,935 pounds
2013 Ford Taurus	4,037 pounds
2012 Smart Fortwo	1,808 pounds
2013 Mazda MAZDA6	3,323 pounds
2014 Porsche Panamera	3,968 pounds

APPENDIX F: Electricity Rates

Tariff Category	Existing Rates (1 June 2011)	New Rates (1 January 2014)
	Sen / US cent	Sen / US cent
Tariff B - Low Voltage Commercial Tariff		
For overall monthly consumption between 0-200 kWh per month:		
For all kWh	39.30 / 12.28	
The Minimum Monthly Charge is	*7.20 / 2.25*	
For overall monthly consumption more than 200 kWh per month:		
For all kWh (from 1kWh and above)	43.00 / 13.44	
The Minimum Monthly Charge is	*7.20 / 2.25*	
New Structure		
For the first 200 kWh (1 -200 kWh) per month		43.50 / 13.59
For the next kWh (201 kWh onwards) per month		50.90 / 15.91
The Minimum Monthly Charge is		*7.20 / 2.25*
Tariff C1 - Medium Voltage General Commercial Tariff		
For each kilowatt of maximum demand per month	25.90 / 8.09	30.30 / 9.47
For all kWh	31.20 / 9.75	36.50 / 11.41
The Minimum Monthly Charge is	*600.00 / 187.50*	*600.00 / 187.50*
Tariff C2 - Medium Voltage Peak/Off-Peak Commercial Tariff		
For each kilowatt of maximum demand per month during the peak period	38.60 / 12.06	45.10 / 14.09
For all kWh during the peak period	31.20 / 9.75	36.50 / 11.41
For all kWh during the off-peak period	19.20 / 6.00	22.40 / 7.00
The Minimum Monthly Charge is	*600.00 / 187.50*	*600.00 / 187.50*

APPENDIX G: Installation cost of Energy Storage System

ES Technology	Maturity	Installation Cost		Specific Energy, kWh/kg	Specific Power, kW/kg	Roundtrip Efficiency	½ Storage Time	Lifetime	DOD (depth of discharge)	Minimum Size, kW	Maximum Size, kW
		$US/kWh	$US/kW								
Pumped Hydro	**Mature**	100	1000-1600	0.00028 Per 100 m height	NA	70% - 85%	To years	10 – 50 years	100%	5,000	2,700,000
CAES (stationary)	**Mature**	50	425	0.075 (20 bar)	NA	70% - 80%	4 – 10 hours (for underground caverns)	> 10 years	Up to 100%	100,000	300,000
CAES (vehicle)	**Available**			0.142 (300 bar)			Low self-discharge (for tanks)		98.5%	1	100 (150 in future)
Flywheel	**Available**	4000	400 - 300	0.01 – 0.1	1 – 10	92% - 97%	From day to month	$10^5 – 10^7$ cycles or 20 years	99%	2	2,000
Battery Technology:											
Lead Acid	**Mature**	175	125	0.035	0.3	70% - 92%	4 – 25 months	1000 cycles	40%	1	10,000
Lithium-Ion	**Available**	200 - 360	1000	0.16	0.18	93% - 97%	7 – 14 months	10,000 cycles	40%	1	100
Zink-Air	**Emerging**	400 - 900	3000	0.375	0.175	40% - 50%	Years (when sealed)	300 cycles	-	1	10
EC Capacitor	**Available**	9000	300	0.001 – 0.012	0.01 – 15	90% - 98%	1.3 months	10^6 cycles or 10-15 years	98%	2	250
SMES	**Available**		630	0.05	0.3 – 1	95%	Less than 3 hours	< 20 years	100%	1,000	100,000
H2CAR biofuel	**Emerging**		-	12.7	NA	13%	Up to year	NA	100%	NA	NA
Molten Salt	**Available**		-	98 kWh/m³	NA	-	Up to a week	> 4 years	100%	10,000	354,000 (553,000 in 2011)