AUTOMATED DEMAND RESPONSE FOR A COMMERCIAL BUILDING: A MODEL DESIGN AND PILOT STUDY

C.T.J. Fernando

(159303B)

Degree of Master of Science in Electrical Engineering

Department of Electrical Engineering

University of Moratuwa

Sri Lanka

October 2018

AUTOMATED DEMAND RESPONSE FOR A COMMERCIAL BUILDING: A MODEL DESIGN AND PILOT STUDY

C.T.J. Fernando

(159303B)

Dissertation submitted in partial fulfillment of the requirements for the

Degree Master of Science in Electrical Engineering

Department of Electrical Engineering

University of Moratuwa

Sri Lanka

October 2018

DECLARATION OF THE CANDIDATE & SUPERVISOR

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: Date:

The above candidate has carried out research for the Masters Dissertation under our supervision.

Signature of the supervisor: Date

Dr. P.S.N. De Silva

Signature of the supervisor: Date

Dr. W.D.A.S. Rodrigo

ABSTRACT

The inherent intermittency of non-conventional renewable resources has been the major impediment in admitting renewable resources to the traditional Electricity Grid. The flexibility of loads in the power system are disregarded in such analysis. The traditional Utility and Customer model is now subjected to change with active customer participation from demand side.

With the growing renewable share in the Energy mix, power industry will require more capacity and inertia to have a better control over the power quality. Automated Demand Response is the cutting edge technology which enables the grid to use load flexibility in counteracting the NCRE intermittency.

This project pilots the possibility of mitigating the rooftop solar intermittency of a building with air conditioning loads which has an inherent flexibility as DR resources. A building-wide Home Area Network is implemented together with short term solar prediction and a central controller with dynamic dispatch algorithm.

Results from the pilot project are presented to demonstrate as how the solar transients are mitigated at the Point of Common Coupling (PCC) with an eye on benefits and impacts on the participants.

ACKNOWLEDGEMENT

It is my great pleasures to express gratitude to all those who have helped me in completing my research project.

First I would like to express my sincere gratitude to my supervisor Dr. Narendra De Silva for providing the concept and for his continuous guidance and support throughout the period.

Also, my sincere gratitude goes to Dr. Asanka Rodrigo for his guidance and support from the very beginning to the end.

My sincere thanks goes to my immediate supervisor, LECO system development manager Mr. S.D.C Gunawardana and all my colleagues at Lanka electricity company private limited who helped me in many ways during this period.

Last but not least I would express my heartiest gratitude to my family, for helping to complete this work in difficult circumstances.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 BACKGROUND

The concept of conventional grid is now becoming out of practice due to its own issues such as higher energy loss due to centralized generation and transmission in long distances, limitation of conventional energy sources, environmental hazards, highly increasing demand etc. The requirement of having energy sources using which the grid can have decentralized generation to avoid losses while being able to reduce the environmental hazards are arising as a result of it.

Renewable Energy integration may seem as a good opportunity under the theses circumstances. But then again, Renewable Energy Sources has its own pros and cons when combined with other energy sources, especially when it is coming in a larger scale. High level of RE integration gives some challenging drawbacks to the stability, reliability and quality of supply. Reasons can be listed as the unpredictability due to its own stochastic behavior, uncontrollability in generation, cost on storage etc. These reasons have set a ceiling value to the Renewable Energy Sources added to the Grid. Sri Lanka, by having an islanded grid face these effects more significantly than large interconnected grids.

With the trend of Renewable Energy in the world, so many methods have been proposed in order to minimize these issues and to gain maximum uses from the Renewable Energy Sources. The energy generated through Renewable Energy Sources can be used economically and environmentally feasible manner by using these methods carefully.

1.2 SMART GRIDS

1.2.1 Smart Grid Concept

In the past, the power system used to be observed as a relationship between generation, transmission, and distribution but not extending into customer facilities, whether industrial, commercial, or residential. The traditional power system did not go further than the meter. It did not pay any attention on the possible energy management solutions available from the load side. Even if some customers tried implementing some, it was treated as an attempt to reduce their electricity bill, and the utilities did not pay any attention on possible uses to the grid.

In a smart grid, rather than controlling the grid from utility side, the power system and its control goes beyond the meter.

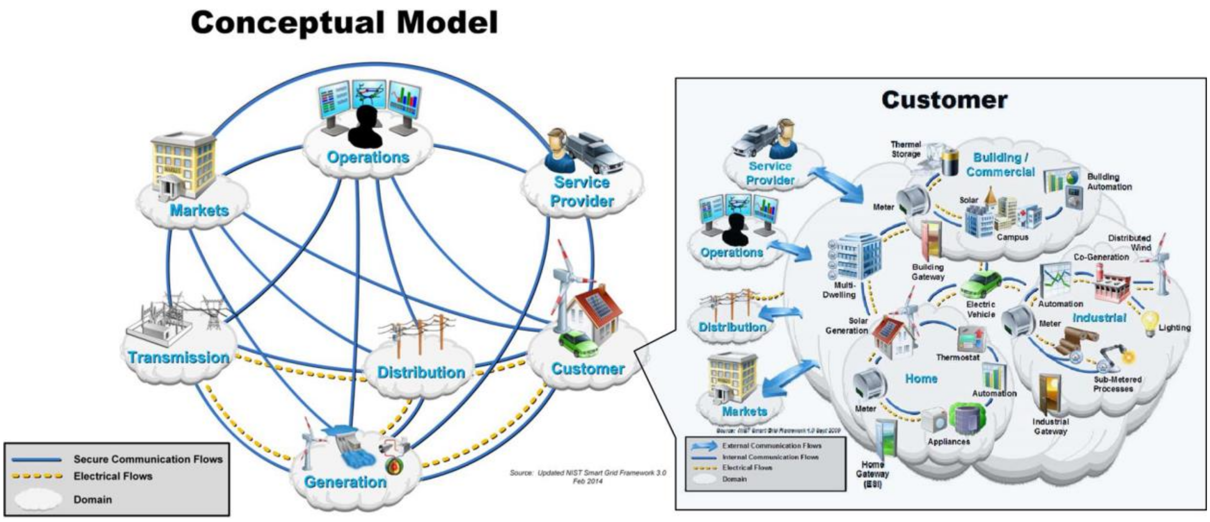

Figure 1.1: Conceptual Model of Smart Grid. From Automated Demand Response for Smart Buildings and Micro grids [1]

1.2.2 Renewable Energy Sources and Demand Response (DR)

Implementation of smart meter was one large step in entering into the world with smart grids, but even using the smart meters, possible stepping beyond the meter is required. Traditional grid was able to control the generation according to the variations of consumption, but when the penetration of Renewable resources increase, there should be something that can be controlled according to the variations of renewable generation. This is where the concept of Demand Response comes into the play. A grid could be viewed as smarter when there is a good use of Demand Response applications coupled with Renewable Energy sources.

There is no cutoff point for a grid to be defined as a smart grid. For a grid to become smarter, communication and controlling of each device shall be performed in such a way to utilize the low cost and environmental friendly energy from renewables in optimal manner without affecting the quality of supply and operate under economical, technical and environmental constraints. Also, when a grid is modernized, there is no requirement of changing the whole electricity grid to be smarter than before at once, which is practically hard to achieve too. Utilities could select small sections of the grid where capacity to modernization is available.

Demand Response offers a number of benefits to energy systems including: increased efficiency of asset utilization; supporting increased participation of renewable on the grid; reduction of capacity issues on distribution networks to facilitate further uptake of distributed generation on congested local networks; reducing required generator margins and costs of calling on traditional spinning reserve, and bringing associated environmental benefits through reduced emissions.

1.2.3 Automated Demand Response (ADR)

ADR is a DR implementation in which the signal is received by control equipment at the customer's facility such that preprogrammed DR strategies are performed in an automated fashion without human intervention. ADR has bring in much interest over the recent past, as advances in communication and control networks have enabled the connectivity of automation systems in premises with utility energy management systems.

1.2.4 Applications of ADR

There are many practical applications in ADR. The following Table lists the program types as used by the Federal Energy Regulatory Commission (FERC) in its 2012 survey [2].

Table 1.1: Demand response program types in the 2012 FERC Survey

Incentive-Based Programs	Time-Based Programs
Demand Bidding and Buyback	Critical Peak Pricing with Control
Direct Load Control	Critical Peak Pricing
Emergency Demand Response	Peak Time Rebate
Interruptible Load	Real-Time Pricing
Load as Capacity Resource	Time-of-Use Pricing
Non-Spinning Reserves	System Peak Response Transmission Tariff
Regulation Service	
Spinning Reserves	

DR is a necessity for reliably and economically operating an electricity infrastructure with a large portion of generation coming from renewable resources. Automating DR will be required to gain the full benefit of this potential; human-in-the-loop operation is inherently limited both by the need for people to be engaged in the process and by the difficulty of satisfying the real-time responsiveness requirements for many applications.

1.3 SRI LANKAN DISTRIBUTION NETWORK

1.3.1 Overview of the Network

The distribution network of Sri Lanka is almost all overhead network operating in the medium voltages of 33kV and 11kV. The low voltage network operates in 400V/ 230V.

As a regulator to the Sri Lankan energy sector PUCSL has provided guidelines and regulations to the utilities on maintaining quality of supply and set goals on reducing energy losses in the network.

The structure of the Sri Lankan distribution network has not faced significant changes from its formation in early 50s until recent past. The power flow was vertically downwards from grid substation to customer premises through primary substation, medium voltage network, distribution transformer and LV network.

1.3.2 Upcoming Challenges

The architecture of the Sri Lanka's grid is now being changed with the rapid addition of distributed energy sources to the medium voltage and low voltage distribution networks. As a tropical country and island surrounded by sea, Sri Lanka has a huge capability and capacity of having solar and wind additions to the distribution network in near future. With the government involvement on increasing renewable energy portion and increasing economic and technical feasibility on renewable energy extraction, renewable distributed energy sources are now adding in to the Sri Lankan distribution network in a remarkable rate.

With these new additions of unpredictable energy sources with stochastic behaviors to the conventional distribution network, now it's time for the utilities to rethink on the arrangement, controlling and operation of the distribution network. The utilities have to reduce the impacts imposed by these renewable additions while maintaining stability of the grid and quality of supply.

Small scale distributed solar is one of the key player in renewable energy sector in the world. The drastic reduction of panel prices and improving technology of appliances related to rooftop solar generation has made solar energy generation affordable to many of the potential customers. The integration of the grid connected rooftop solar to the Sri Lankan national grid was initiated with the introduction of net metering concept to Sri Lanka in 2010. Net metering is one of the world famous methods that enable customers to connect their own on-site generation system to the utility grid and receive credits on their electricity bills for their own renewable energy generation in excess of their electricity consumption.

Due to the net metering, net plus and net accounting schemes, and the government loan facilities to install rooftop solar panels, the addition of solar power to the national grid has reached more than 100 MW in nearly one years' time. This rapid addition has so many advantages to the utility as well as disadvantages.

Advantages to the utility

- Reduction of line losses due to energy generation at the point of usage
- Reduction fossil fuel emissions by energy generation
- Reduction of day peak of the load profile
- Increase the factor of renewable energy generation in the grid

Disadvantages to the utility

- Affect the stability of the network by heavy fluctuations in the solar generation profile
- Uncertainty of generation in planning and forecasting
- Deviation from the regular load flow

1.3.3. Customer Participation

To reduce the impact on the grid while keeping the customers satisfied with their rooftop solar and reduced energy bill, a method of controlling the fluctuations to the grid is required. In achieving this, keeping spinning reserves with high cost will dilute the picture of having clean energy for a low cost, as the cost reduction and the cleanliness would be gone when it comes to maintain a spinning reserve. Therefore, the controlling should be done in the other way; which is from the load side.

Demand Response is not a novel concept to the world energy market. But considering Sri Lanka, the country is still entering into it. Therefore, a good study should be followed in order to find the level of adoption of this to a developing country like Sri Lanka.

On the other way, customers may require a good clean example of how to follow an Automated Demand Response program in line with the energy fluctuation in their premises.

So, basically this proposed ADR application has the following aims to be satisfied:

- Implementing a model for ADR technology - for a commercial building in Sri Lanka

(This includes identifying a suitable technology and architecture)

- Verify the level of adoption through a pilot project

Other than limiting the addition of rooftop solar installations due to technical restrictions, it is worthy to find possible alternatives of controlling and managing the issues arise with additions to the grid.

As one of the alternative solutions on managing and controlling the renewables, an Automated Demand Response solution is formulated and the level of mitigation of transients when having such kind of solution in is presented in this report.

2. PROJECT OVERVIEW

2.1 SCOPE OF THE PROJECT

Considering about Renewable Energy and Demand Response, there are plenty of research works carried out in the world regarding this topic. Some of them were aimed on keeping an ADR portal as a spinning reserve for the day ahead energy market. Some of them were targeting on finding the best energy mix etc.

Renewable Energy sources create many unnecessary transients in the grid, hence the Transmission Network. The focus of this research is to identify the existing methodologies and to model a basic design, with the purpose of managing these transients in the transmission network in Sri Lanka, with an idea of finding the range in which it can operate as an independent demand response portal without the help of other resources such as battery banks.

The degree of adaptation will depend on the design parameters of the selected area. It provides social, technical and economic feasibility study for implementing a model for Automated Demand Response portal using suitable consumer groups.

2.2 RESEARCH OBJECTIVE

Project will achieve the following objectives:

1. Designing and Implementing a model for ADR application suitable for Sri Lankan network.
2. Implement a pilot project in a selected commercial building.
3. Propose and evaluate measures (interfaces, tariffs,) to encourage at least 25% of consumers to participate in the envisaged demand response solution.

The first part of the project is to find out suitable technology, considering the work done in similar capacity. A good literature survey, technological survey, etc. was required in order to achieve this. Then a suitable model should be implemented to the parameters of the selected building. For this, network architecture should be designed and the basic structure of the model to be finalized.

Final implementation will be carried out as a modeled design installed in the selected building with the continuous data recording facility.

2.3 METHODOLOGY

Methodology steps of the study are listed as below.

- Analyze the Integration patterns of Renewable Energy to Smart Grids and associated issues
- Study the similar work done on Renewable Energy integration on Smart grids and Demand Response in other countries
- Analyze the behavior of Renewable sources, such as solar power generation, and the load curve patterns of commercial buildings with solar integration
- Designing a suitable model architecture for the ADR portal
- Integration of suitable communication methods, hardware parts and networking
- Implementing the model and troubleshooting
- Run the pilot project and evaluate the capacity of the ADR portal using the results

2.3 CAPACITY OF THE ADR PORTAL

An ADR portal is introduced in this research, which could be used to track the variations in the transmission network and to provide suitable mitigation. To measure the responsiveness of the ADR application, a pilot project was designed with the idea of tracking the variations of a rooftop solar panel, and a group of Air Conditioners in a selected building as participating loads.

The basic idea of the behavior of solar panels needed to gain a good output in the pilot project. The ability to mitigate depends on the magnitude and duration of solar transients together with the number and sizes of the loads involved. The extent up to where the ADR portal can assure a smooth output could be a key output of the project.

3. LITERATURE REVIEW

3.1 PREVIOUS RESEARCH WORKS

Since renewable resources are acquiring larger proportions of generation, end use facilities should be sensitive and responsive to grid connection in new ways. Automated Demand Response (ADR) is widely acknowledged as a key approach. Since the early implementations, the technology has substantially developed, and many research works have been done in different areas. Publications of some researches have been selected in order to identify the works done, architecture, load selections, models etc.

3.2 ADR ARCHITECTURE

The first part is to find out suitable architecture, considering the work done in similar capacity.

T. Samad, E. Koch, P. Stluka in their research paper [1] has presented a typical system architecture for ADR (shown in figure 3.1). The DR automation server (DRAS) acts as an intermediary between the Service Operator and the facility whose loads are to be adjusted. Based on prior agreements with end-use customers, specific load actions are associated with specific utility signals, and the DRAS can issue commands to facility assets accordingly. In most cases customers will be notified ahead of time and will have the option to not participate in a particular DR event (i.e., to opt-out). Mechanisms for monitoring and communicating load response are required. Using smart meters for this purpose can enhance the implementation of a DR program. Smart meters also enable customers to better track their load profiles in order to optimize their DR strategies and potentially even track their performance in close to real time.

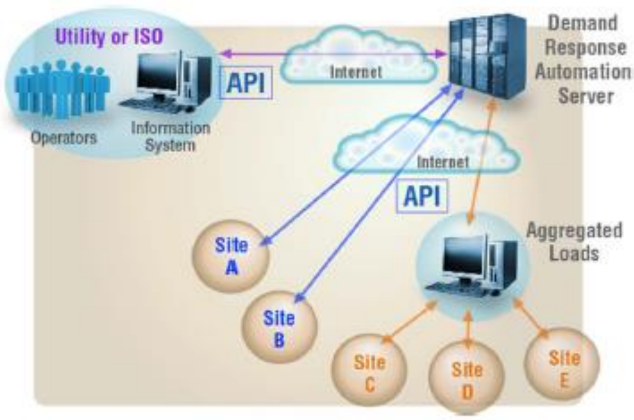

Figure 3.1: System Architecture of typical ADR [1]

S. Kiliccote, M. A. Piette, E. Koch, D. Hennage in their paper [3] has presented utilizing an ADR portal as an ancillary service. They have presented a participating load (PL) architecture with a DR Automation server, utility, facility and an independent system operator (shown in figure 3.2) without a human in the loop.

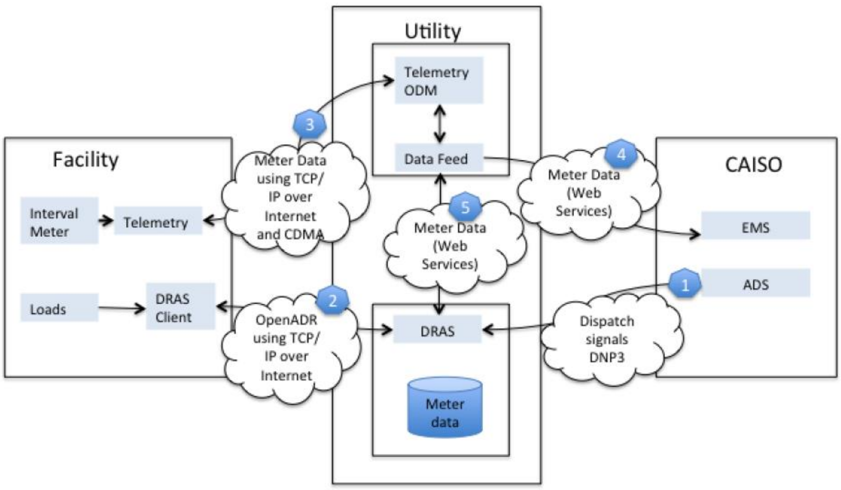

Figure 3.2: PL Architecture [3]

3.3 SELECTION OF PARTICIPATING LOADS

T. Samad, E. Koch, P. Stluka in their research paper [1] has mentioned that many of the fully automated DR actions fall into HVAC and lighting. Here they have suggested to control the global temperature, duct static pressure etc. in a centralized air conditioning system. Also, they have mentioned that with larger buildings and micro grids, the actions need not be limited to loads. For example, such facilities can have onsite diesel generators that are intended primarily as emergency backup electricity supplies.

S. Kiliccote, M. A. Piette, E. Koch, D. Hennage in their paper [3] has mentioned about a selection criteria of the site with participating loads. According to that, the site should be able to deliver the resources within a set time limit, when an ADR event is triggered. Also, the site should be able to shed a sensible amount of load (a minimum limit could be defined).

B. Biegel, P. Andersen, J. Stoustrup, L. H. Hansen, A. Birke has published a paper [4] and in their research they have used heat pumps installed in each house in a selected village as their participating loads.

3.4 BEHAVIOUR OF LOADS AND MODELING THE EVENTS

T. Samad, E. Koch, P. Stluka in their research paper [1] has mentioned that there are some facts when selecting the best suitable consumer type for participating the DR events. Usually it is possible to create average daily estimates for an industrial facility but their accuracy is influenced by the level of understanding of production patterns, which are not publicly available. Forecasting of electricity consumed in commercial buildings is easier in the sense that each building follows a typical daily profile and respective influencing factors, such as weather conditions or type of day, are usually well known. When the load profile is easily forecasted, Prediction of normal and DR affected Load Profiles became easy. After the building is selected, each load to be integrated must be characterized. Depending on the application and the load type, this characterization can include modes of operation, the energy consumption, interrupt ability and criticality of operation, and measurement and control capabilities. Without doing this manually, plug and play devices could be foreseen that their types and properties recognized by automation systems with no operator input.

S. Kiliccote, M. A. Piette, E. Koch, D. Hennage in their paper [3] has mentioned about dispatch rules for the participating loads. In a dispatch rule, the maximum participation time for an ADR event, and the maximum no. of events per one load per day could be set.

B. Biegel, P. Andersen, J. Stoustrup, L. H. Hansen, A. Birke in their research paper [4] has proposed a relay connected in series with the heat pumps participating for ADR events. So they could be switched ON and OFF.

3.5 COMMUNICATION METHODS

B. Biegel, P. Andersen, J. Stoustrup, L. H. Hansen, A. Birke in their research paper [4] has proposed control commands to be transmitted over an internet connection to a server. The sampling time of the communication link between the heat pump and the server was 5 min.

S. Kiliccote, M. A. Piette, E. Koch, D. Hennage in their paper [3] has used 5-minute load forecasts and hourly forecasts using those. The DR signals are sent via a server and loads are required to response within 10-minute ramp time.

3.6 CASE STUDIES

B. Biegel, P. Andersen, J. Stoustrup, L. H. Hansen, A. Birke in their research paper [4] has presented their results in hourly basis. Each night at midnight, an hourly reference was provided for the following 24 h. The overall controller then regulated the consumption during the day to track this reference. The results were shown indicating that the heat pumps were able to roughly follow the given reference (shown in figure 3.3).

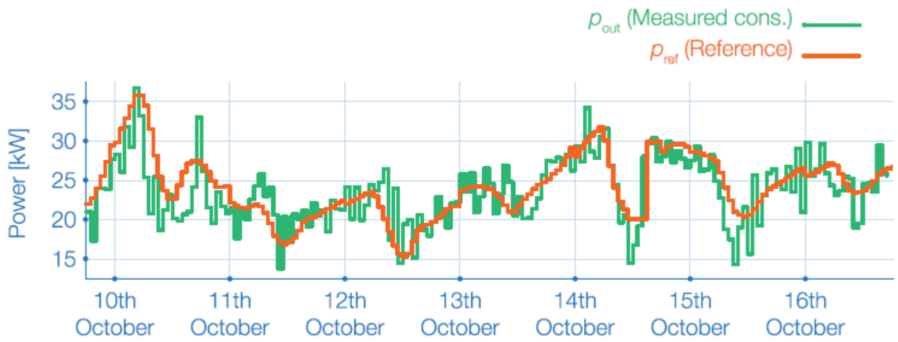

Figure 3.3: Behavior of heat pumps with reference [4]

S. Kiliccote, M. A. Piette, E. Koch, D. Hennage in their paper [3] has presented their results by running ADR events for time periods varying from 10-15 minutes to 1-2 hours using a local government office building.

4. DESIGN OF THE ADR ARCHITECTURE

4.1 ADR ARCHITECTURE

In this case ADR model is proposed for a commercial building with a pilot study with a rooftop solar panel. To study about the building parameters, and to implement the system, LECO head office was selected. It is a 5 story building where LECO head office is situated in 4 stories of that, and the total load is exceeding 50 kW in demand.

In this system, a set of loads that have a considerably larger share in the total demand of the building with a good yield are required to participate to the events. When checked about the loads in a commercial building (e.g. office building), it could be clearly seen that air conditioning loads consume more than 50% of the total demand. Another reason to select the air conditioners was that switching off an air conditioner for a few minutes won't affect the comfort in the people occupying the room. If another type of load such as lighting loads or computers were selected, switching them off during the working hours at least for a single minute would not be practical.

Although centralized air conditioning systems are widely used as ADR participating loads as mentioned in T. Samad, E. Koch, P. Stluka in their research paper [1], Split type air conditioners were selected as participating loads in this research.

Table 4.1: Electricity use of selected buildings

Description	**LECO Head Office**	**LECO Kotte Branch**
Monthly Energy usage (average)	17.5 MWh	7.5 MWh
Total Avg. Power consumption of Air Conditioners	50 kW	26 kW
Energy usage for Air Conditioners as a factor (assuming 9 hours per day)	51%	62%

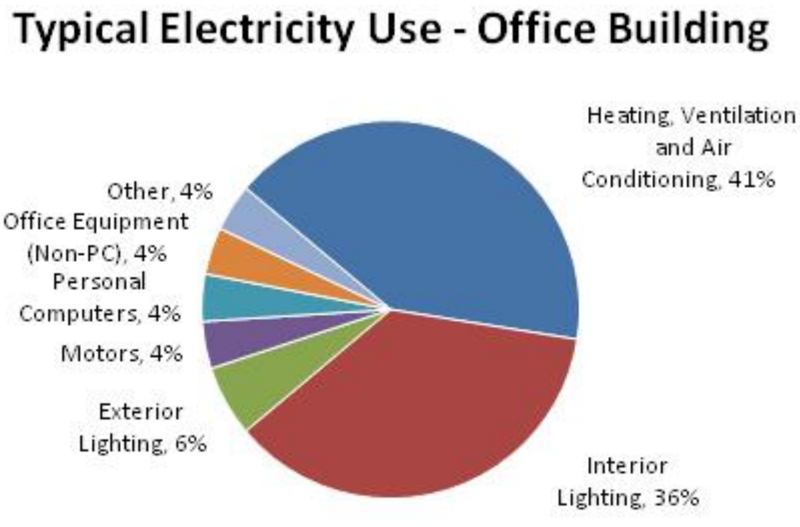

Figure 4.1: Typical Electricity Use of an Office Building

This model provides demand response through dynamic load controlling based on solar energy variations observed.

4.2 ADR MODEL

The ADR modal was designed using the parameters considered in deciding the ADR architecture. The selected building has split type Air Conditioners, which need to be controlled according to the amount to be suppressed according to each ADR event. Therefore, each unit has to be controlled individually. Also there should be a centralized controller to control these units. There should be ways to take required inputs and the outputs. Therefore, the following model was designed.

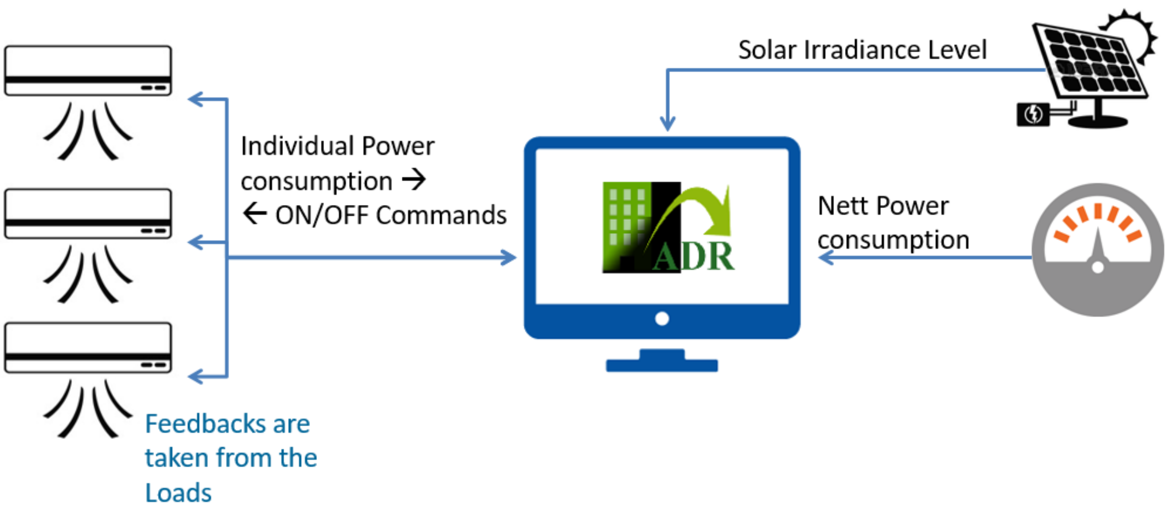

Figure 4.2: ADR model

4.2.1 Participating Loads and their dispatching methods

A local government office building was selected to participate in the designed ADR portal, and Air Conditioner loads inside the building were selected as the Participating Loads for the events. These loads operate in their own duty cycles which remain nearly constant if the room condition does not change rapidly. Analyzing their load profiles therefore gives information in designing the switching patterns. Therefore, each participating load should be connected with a unit capable of reading their load profile as well as giving commands.

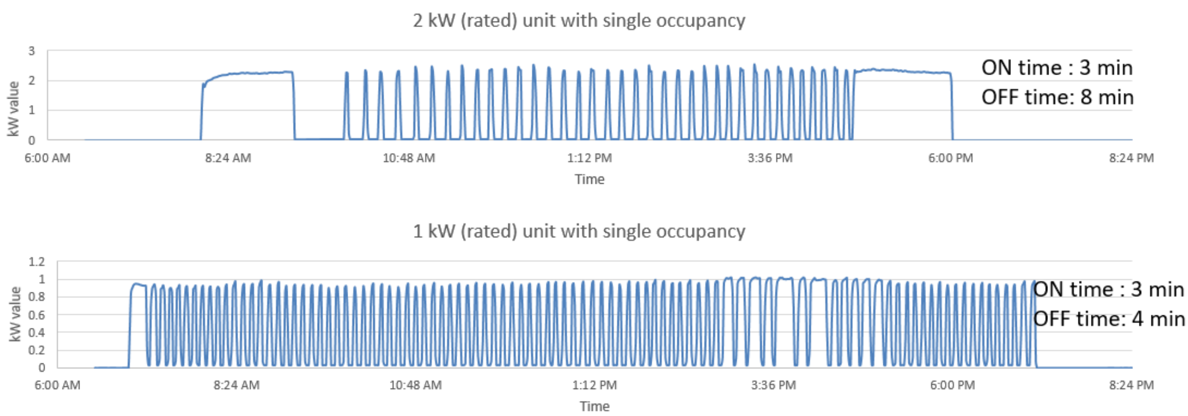

Figure 4.3: Sample Air Conditioner Load Profiles

Air Conditioner loads have different duty cycles. The larger the off time, the stronger the loads in participating for ADR (i.e. those loads have better yield). So these data were considered in deciding the switching patterns.

Some dispatch rules were implemented in order to limit the duration of each ADR event, and the no. of events per device per day. The duration of a single event was limited to one minute, as the solar level may have subjected to change in the next minute, and also it would not be a good practice to keep the air conditioners switched off for long.

As mentioned in section 3.4, relays were kept in series with the air conditioning loads, so that ON and OFF commands could be given, and fast ADR event could be triggered.

4.2.2 Behavior of Solar Transients

Solar panels are having different types of transients throughout time. Those transients vary with their both magnitude and duration. The level of solar transients up to which the ADR portal can mitigate the effect to be identified.

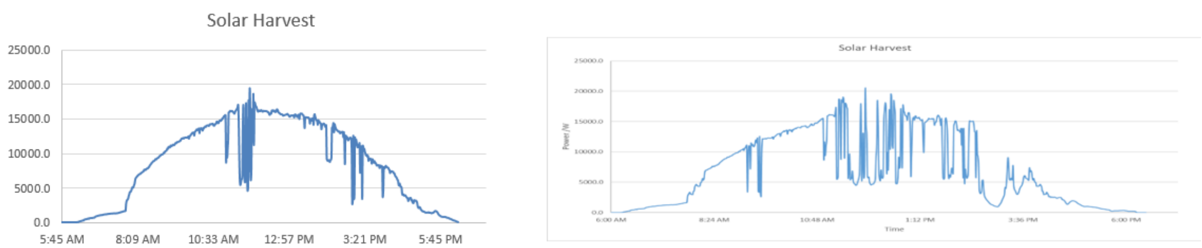

Figure 4.4: Sample solar curves

4.2.3 Net Power Consumption of a building with a Solar panel

One of the important measure for doing ADR in this context is to measure the net power consumption of the building. This could be considered as the simplest point of obtaining feedback on the successive ADR event.

The load profile pattern of building may vary from one to another, but generally, similar kind of load profiles can be identified from buildings serve similar facilities. For example, office buildings operating in normal working hours show load profiles with similar shape, but in different sizes, but a two shift or three shift manufacturing plants may show a totally different load profiles [1].

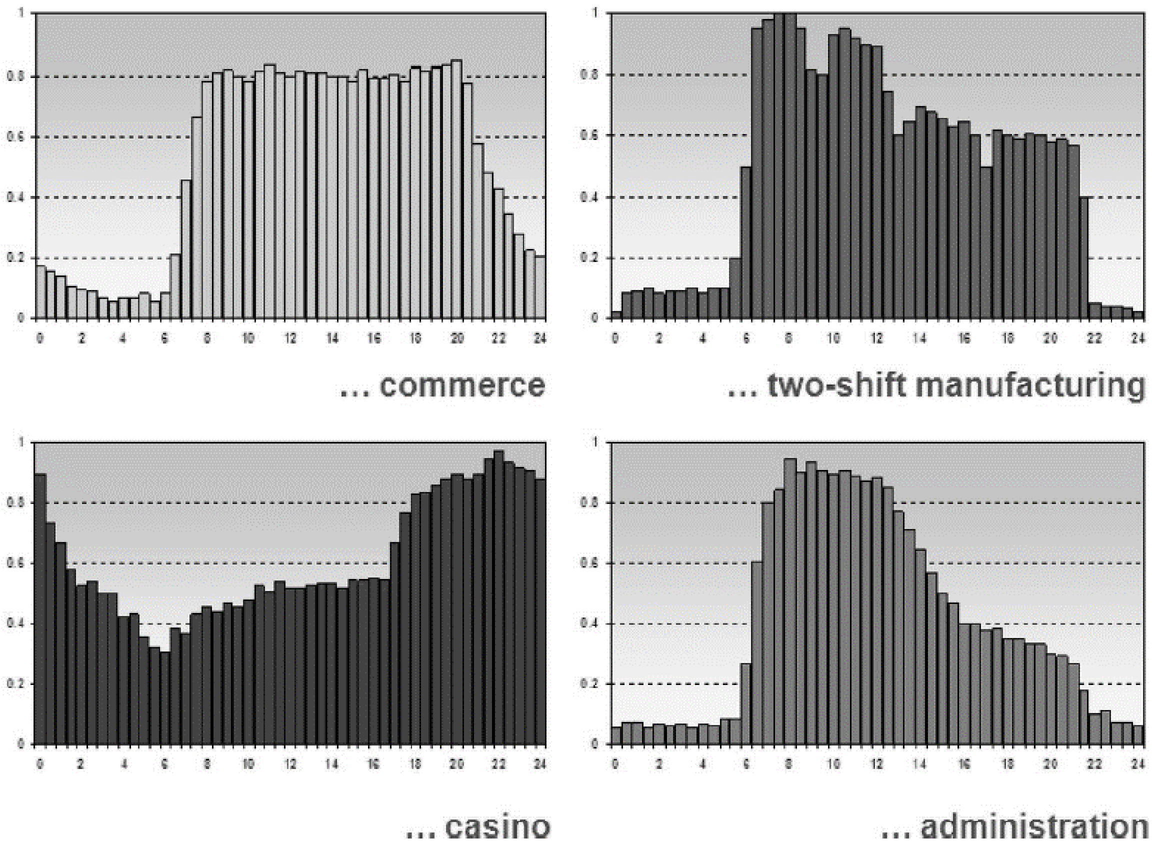

Figure 4.5: Different types of buildings and their load profiles

For the proposed ADR model, a building with considerable number of air conditioner loads are required. Also the loads should be in operational state when the solar energy is present. Therefore, a local government office building was selected. The normal load profile pattern of the selected building would look like in the below figure without being associated with any RE source.

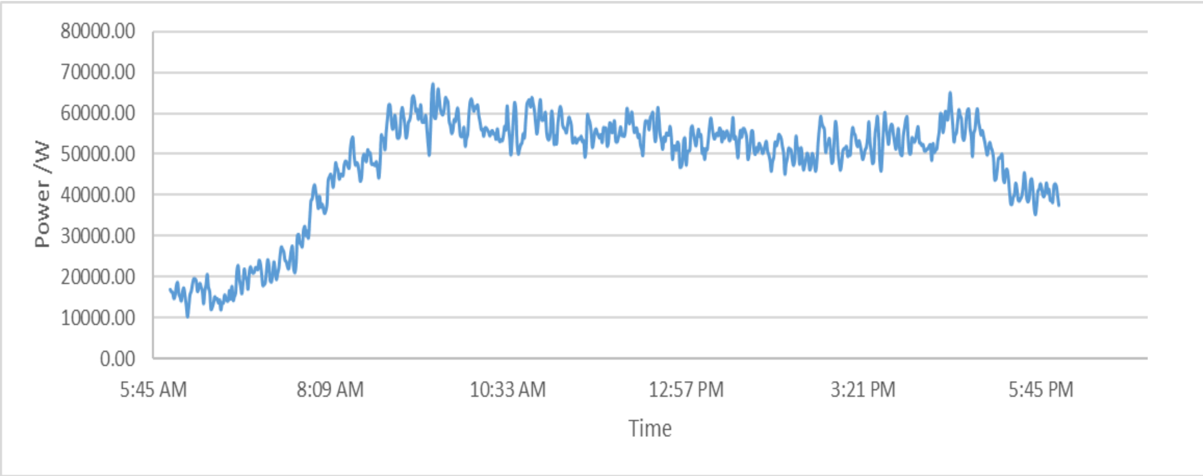

Figure 4.6: Normal Load Profile of the building without Solar integration

Adding a solar panel to this kind of a building would reduce its net consumption in the daytime, but it would suddenly change its net consumption during a solar transient and would require more energy from the grid.

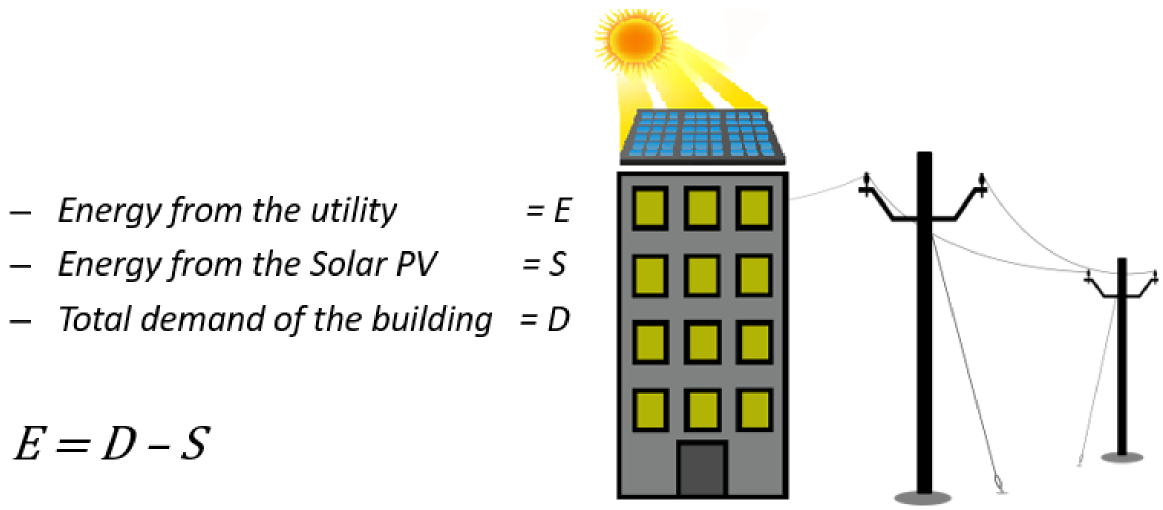

Figure 4.7: Net Power consumption of the building with Solar integration

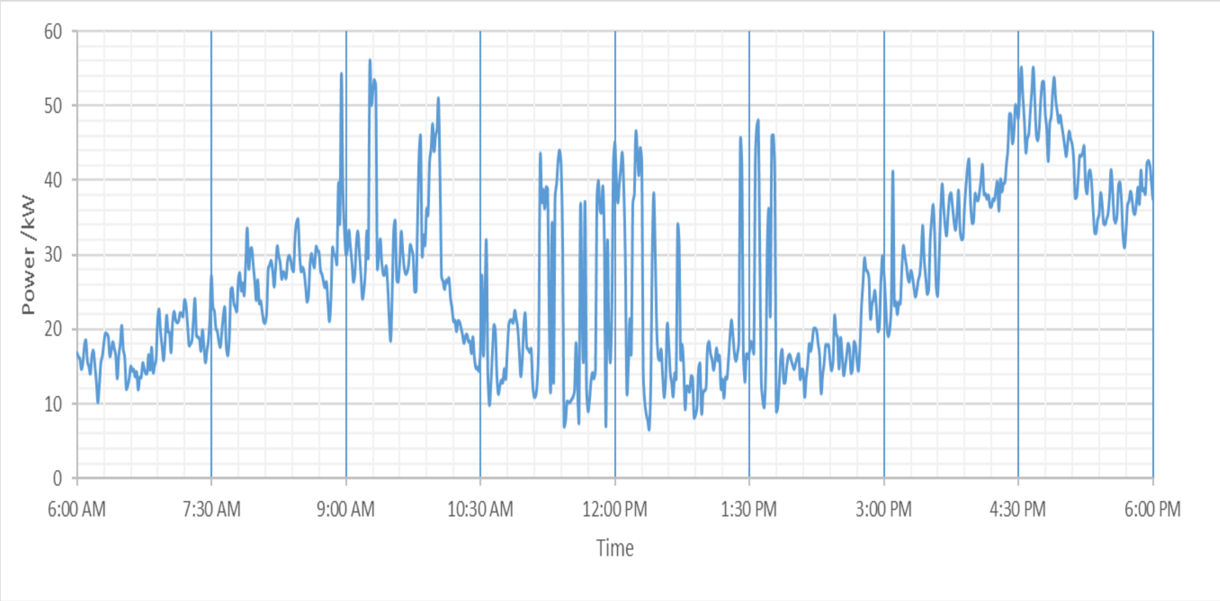

Figure 4.8: Load Profile seen from the Grid for a building with Solar Integration

Having these types of loads in large numbers without any treatment would not be healthy to the grid, as it would require spinning reserves with large capacities and most importantly, with the ability to dispatch in seconds.

4.2.4 Communication Method

As the model is designed to be working in a building, the communication method does not necessarily need to be a long distance one. On the other hand, since the portal is expected to respond within very short time period, the speed of the communication media is important. Rather than having to lay communication cables all over the building, a wireless mode seems to be more attractive in this type of case. A WiFi communication method was selected in this model.

When the central controller is sending On/Off commands to the loads, there should be a way of identification of the receiving load for each command. Hence, each load needs an identity. Therefore, an ip address is given to each of the load, so that the central controller can broadcast their command along with the ip address, knowing that only the required load will read the message.

Each and every load participating are connected to a "Load Controller Module" which consist of a WiFi module and an energy meter with a latching relay in series. The WiFi module is to have the communication with the central controller and to send On/Off commands to the latching relay, and the energy meter is to measure the power consumption of the load.

A separate LAN network was implemented within the building, so that all the individual units and the command giving unit (such as a computer where the software application of the ADR portal is installed) could be connected to that prior to the start of ADR event. The same way, power generation data of the solar panel, and the net power consumption data could be collected.

4.2.5 Central Controller – ADR Algorithm

The ADR algorithm is the one who responsible for all the ADR events and their results. Therefore, designing the ADR algorithm was the most crucial part of the research. In order to analyze the algorithm, analyzing each of its tasks would be easier.

4.2.5.1 Identifying Laps in Solar Power Generation and triggering an ADR event

When a solar curve of a general day was analyzed, slight variations could be visible everywhere. This does not give any sense of triggering an ADR event for all as it would be pretty much disturbing to the loads being participated. On the other hand, for transients with small magnitudes, triggering an ADR event is not required.

For the proposed algorithm, readings from the solar panel was taken in 1 minute intervals, and if there is a reduction of 20% or more from the previous one, it could be identified as the solar value is going down, therefore, an ADR event is triggered.

4.2.5.2 Selection of Loads to Participate

When an ADR event is triggered, the watt amount to be cut off can be calculated. Typically, the value is calculated using the current value and a few of past data of the solar panel. The next Power reading from the solar panel is predicted using the simple moving average method, and it is then compared with the actual reading. Using this method, any deviation from the expected behavior of the panel could be identified. Yet, a margin of 15% from the predicted value is allowed. This margins avoids unnecessary ADR events for each and every small variation, where running an ADR event is not a necessity.

The next step is to find out which loads are to be selected in participating to the ADR event. For this, the following facts are considered.

- kW consumption of each load
- duty off time of each load
- priority level of each load
- Position of the load in its own duty cycle
- event counter of each load (how many ADR events the load has participated for the day)

Using the first two items in the list, the famous knapsack problem could be used to identify the most suitable loads. While the Power consumption of the load could be taken as the weight, and the off time in duty cycle could be taken as the value.

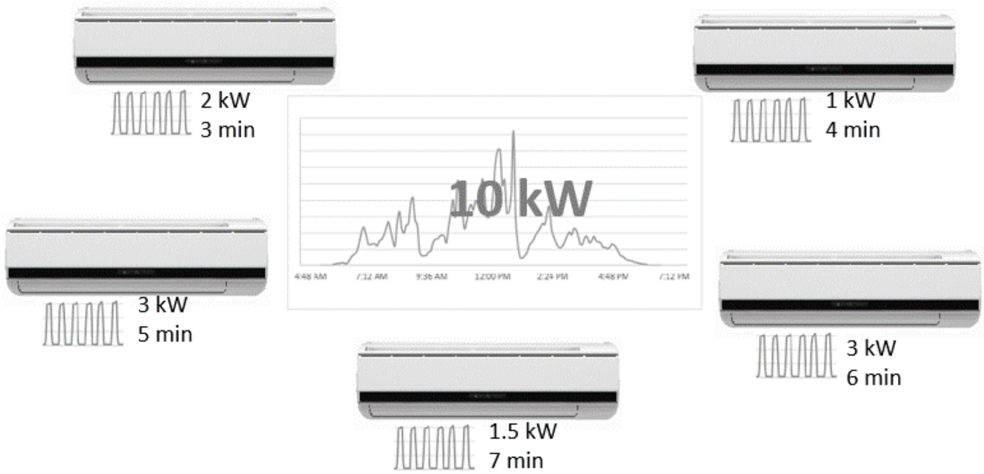

Figure 4.9: Primary Selection of Loads using Knapsack Algorithm

Prior to run the knapsack problem, the other factors could be considered. Air conditioner loads in critical areas could be make facing minimal no. of ADR events by making them top priority.

When an air conditioner is at its duty off time, there would be no much power saving by switching it off. Therefore, the loads in their "On" state should be selected. This was achieved by taking readings on the power consumption of the load in every minute, and by saving those data in a special registry to predict on the next minute. Also, a ceiling value for the no. of ADR events per each load was set by introducing an off counter to avoid same load participating for so many ADR events.

4.2.5.3 Sending ON/OFF commands

When a load is selected to be switched off, the command should be sent to the end point. For this purpose, TCP/IP socket programming method was used. The On/Off command is sent to the load using this architecture along with their ip address. It was selected due to the reliability and connection oriented, bidirectional nature.

4.2.5.4 ADR event log

For the ease of recording and data analyzing purposes, a record of each and every ADR event is saved into an excel workbook. When the software application (described in chapter 4) is run, it imports the details of loads from an excel workbook, and when an ADR event is triggered, it keeps a record of the time of the event with the loads participated as a log in another excel workbook.

5. IMPLEMENTATION OF THE ADR MODEL

5.1 HARDWARE DEVELOPMENT

5.1.1 Individual Load Controllers – Plug and Play

For the proposed ADR model, designing individual Load Controller Modules was required. The module was designed as a "plug and play" unit connected in series with the Air conditioner load. It has an energy meter to take the information about the power consumption of the unit, and a latching relay to perform the On/Off commands, and a WiFi module to communicate with the Software application (controller).

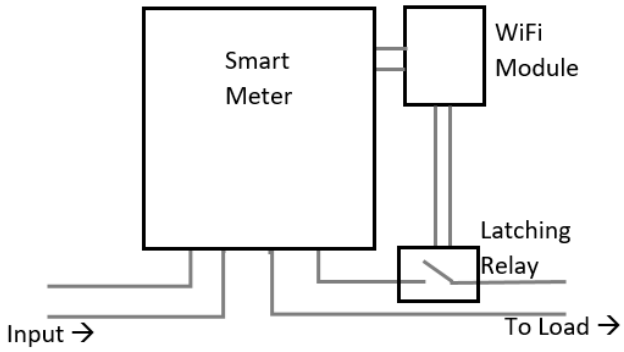

Figure 5.1: Arrangement of the Load Controller Module

Figure 5.2: Load Controller Module

The latching relay inside the smart meter is connected in series with the load. The driver circuit of the relay are given commands from the WiFi module outputs.

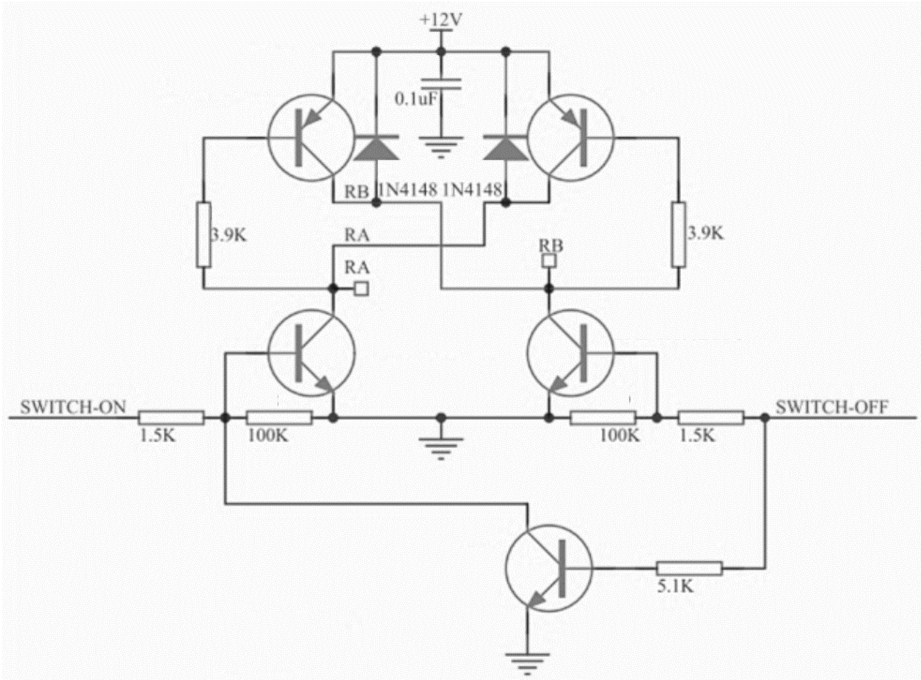

Figure 5.3: The driver circuit of the latching relay

5.1.2 Energy meters

The energy meter in the Load Controller Module is capable of recording the load profile of the Air Conditioner load, and therefore, this could be used to take feedbacks on their duty cycle, power consumption etc.

The total net power consumption from the grid is also taken as an input from the energy meter installed at the incoming power supply.

5.2 WIFI COMMUNICATION NETWORK

To have a smooth run in the system, a WiFi network within the building with a good signal strength is required. To achieve this, a LAN network was implemented using a set of WiFi repeaters, so that all the Load controller modules and the central controller can connect into the same network.

WiFi module ESP8266 is used in the Load controller modules. It has been designed in a way that it can be plugged into the communication port of the smart meter. The power supply requirement of the ESP8266 module is satisfied by the smart meter itself, and the module is sending on/off commands to the latching relay inside the meter.

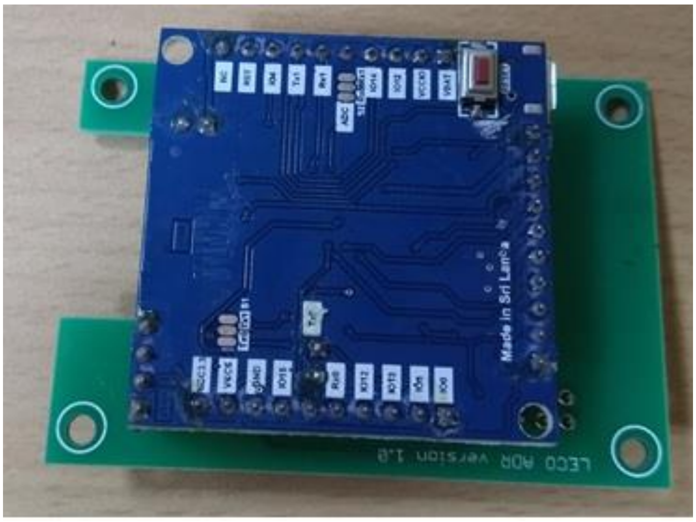

Figure 5.4: ESP8266 WiFi Module

5.3 SOFTWARE APPLICATION DEVELOPMENT

5.3.1 ADR Software application

Software application for the ADR portal was written in C# language with Client-Server program communicates through TCP/IP protocol stack. The function could be basically split into the following categories.

- Start
- Importing load details
- Loop
    - Taking inputs
    - Running the algorithm
    - Sending on/off commands
    - Saving in the log
- Stop

5.3.1.1 Function of the Software application

The first part of the ADR software application is to import the load details. All the load details including their off time, Rated Watt value, location and ip address are saved in an excel workbook. At the very beginning of the run, those details are imported and saved to a list in the cache memory of the application.

The next and most important part is to run the loop. It is designed to run between 6.00 am and 6.00 pm because ADR events would be required only when the solar energy is present.

The application is continuously reading the real time input. ADR events are designed to run in one minute intervals, therefore, the application reads the solar panel input only at the beginning of each minute. Once the solar input value is read, it is compared against the reference value i.e. a value calculated using previous solar inputs. If the reading has gone down to 80% of the reference or more, the application can decide that solar intensity is going down, and hence, trigger an ADR event.

The kW amount required to cut down is decided by the difference between the current reading and the reference, and the loads are selected using the condition of the loads such as priority, duty cycle and off counter followed by knapsack algorithm. There could be some loads in the "Off" position due to an ADR event in the past minute. So the respective loads are then sent On/Off commands using the WiFi network. The loads are then updated in the relevant registries.

After that, the details on the event is logged with time and the loads participated, in a new column of a separate excel workbook. This excel workbook would contain all the ADR event details for the day.

The following flowchart diagram gives an illustration on the function of the software.

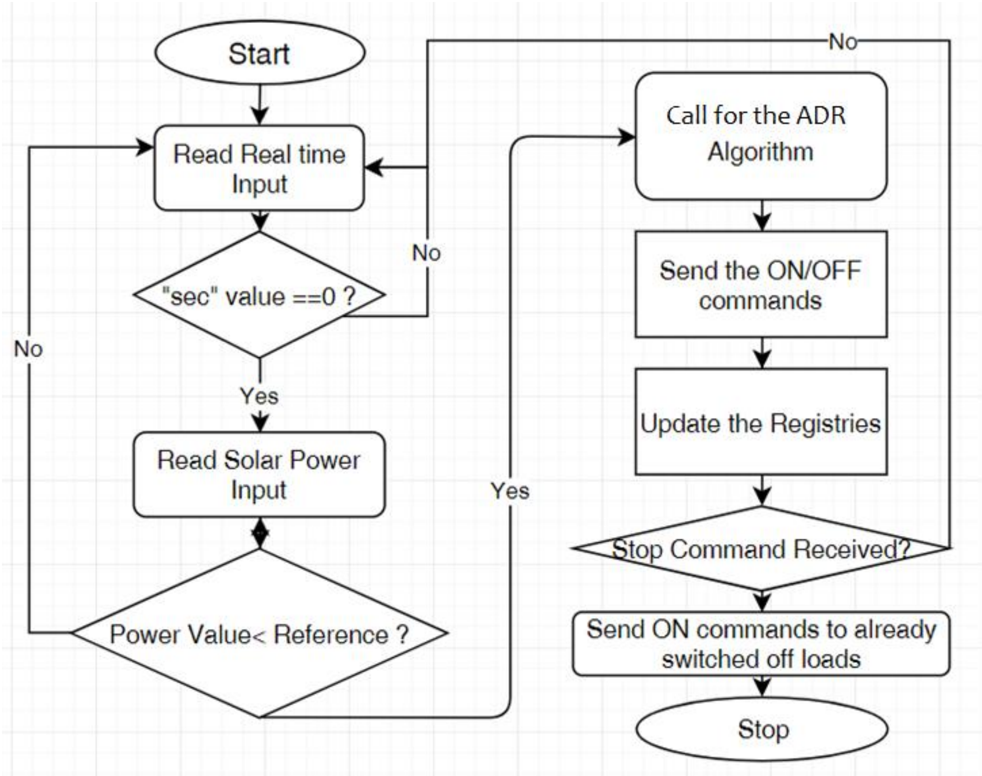

Figure 5.5: Simplified Flowchart for the ADR algorithm

5.3.2 Firmware of the WiFi module

WiFi modules installed in each load controller module has to be given a unique ID, and a set of commands to be followed. Therefore, a firmware was developed to be flashed into each WiFi module. A unique ip address was generated for each module and flashed to the module using the firmware. The most part of the code were the instructions on receiving commands from the WiFi network, and then sending the relevant outputs to the relay. Communication with the meter software and required authentication works before accessing the latching relay was also included.

Chapter 6

6. PILOT PROJECT AND ITS RESULTS

6.1 THE PILOT PROJECT

6.1.1 The participated commercial building and the loads

As mentioned in the previous chapters, a local government office building was selected for the pilot project. The building has 5 floors of 2500 sqft each, and the total power consumption is around 50-60 kW in average. Due to the operation of more than 50 air conditioners in duty cycles, slight variation is visible in the total load curve throughout the day. But this pattern changes when incorporated with a solar panel, since the sudden solar transients tend to request more energy from the grid.

50 no’s of Split type Air Conditioners inside the building were selected as the participating loads for the pilot project. Individual load controller modules were made for each load and ip addresses were given. Then, the behavior patterns (duty cycles) and power consumption details were recorded for each load using these modules. Details of the loads are given in the Appendix 01.

6.1.2 Dispatch rules maintained for the building

A 45 kW rooftop Solar panel was selected for the pilot project. The loads selected are located in different types of places in the building, and are running with different duty cycles. Therefore, the normal duty cycle time of each load was also recorded with the load, for reference.

Since these loads are at places where the office staff working in, switching off these loads for excessive time periods can directly affect their comfort. Therefore, after gathering data about all the loads, a common rule was introduced to keep an individual load switched off for only one minute, and if the time duration of the ADR event exceeds that, another load should be selected to be switched off for the second minute. Also, when a load is selected to participate for an ADR event once, the same load should not be participating in another ADR event for the next 10 minutes.

Therefore, when a load is picked for an event by the ADR application, the ip address of the same is transferred into a separate list called “Off Loads”. The ip address then remain there for the next 10 minutes, making sure that it does not picked again during that time.

Also, the maximum no. of ADR events that an individual load is permitted to participate was limited to 15 events. A point is to be noted here is that this number is selected for the pilot, and it may vary according to the environment of one building to another.

6.2 THE PILOT PROJECT - RESPONSE OF ADR APPLICATION

The pilot project was kept on running for a few weeks, and results for selected days are presented below.

With the integration of solar panel, the load profile of the building transforms into a duck curve. But there are overshoots formed when there is sudden reduction of the solar power generation. Load profiles of the building after running the ADR application for full day were taken into consideration.

Day 1

The selected day was a sunny day with a few amount of clouds. The power generation of the solar curve is shown in the below Figure no. 6.1. Also, Figure no. 6.2 contains the corresponding net power consumption of the building with solar panel after the ADR events.

The net power consumption of the building with solar power input and ADR events is indicated in orange color curve in Figure no. 6.2. The possible net power consumption of the building without any ADR event but with solar power input is calculated using the ADR event log for the day (by adding the loads switched off in each event back to the total load). This load profile is indicated in the blue color curve in Figure no. 6.2. The load curve data and detailed event log are attached in Appendix 2.

Day 2

The selected day was a sunny day with moderate amount of clouds. The power generation of the solar curve is shown in the below Figure no. 6.3. Also, Figure no. 6.4 contains the corresponding net power consumption of the building with solar panel after the ADR events.

The net power consumption of the building with solar power input and ADR events is indicated in orange color curve in Figure no. 6.4. The possible net power consumption of the building without any ADR event but with solar power input is calculated using the ADR event log for the day (by adding the loads switched off in each event back to the total load). This load profile is indicated in the blue color curve in Figure no. 6.4.

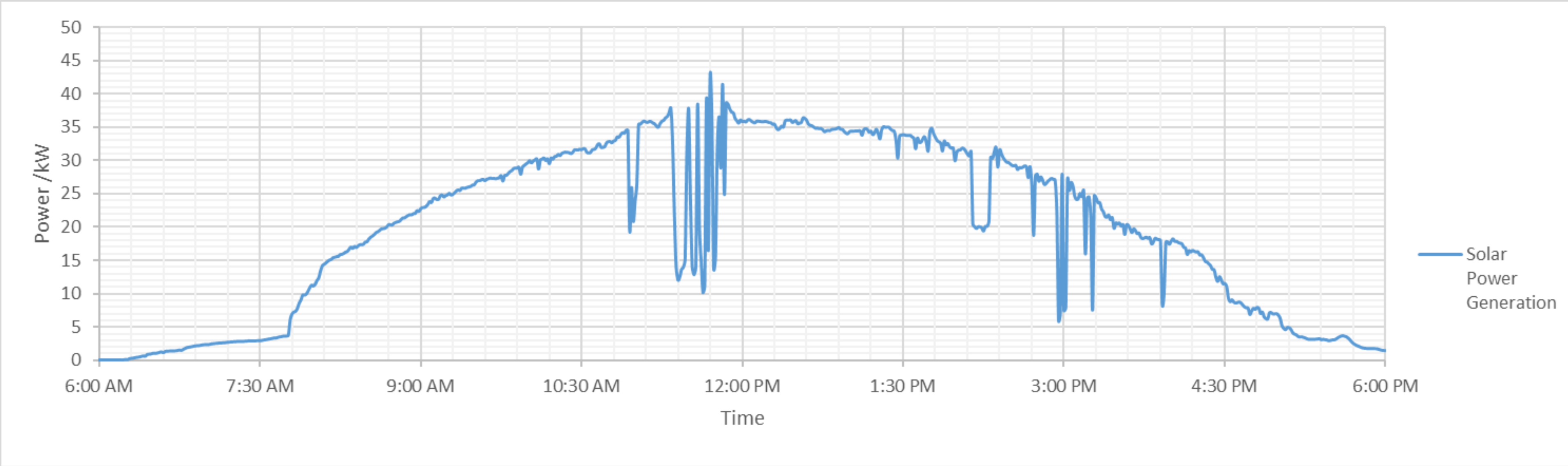

Figure 6.1: Day 1 - Solar Power Generation

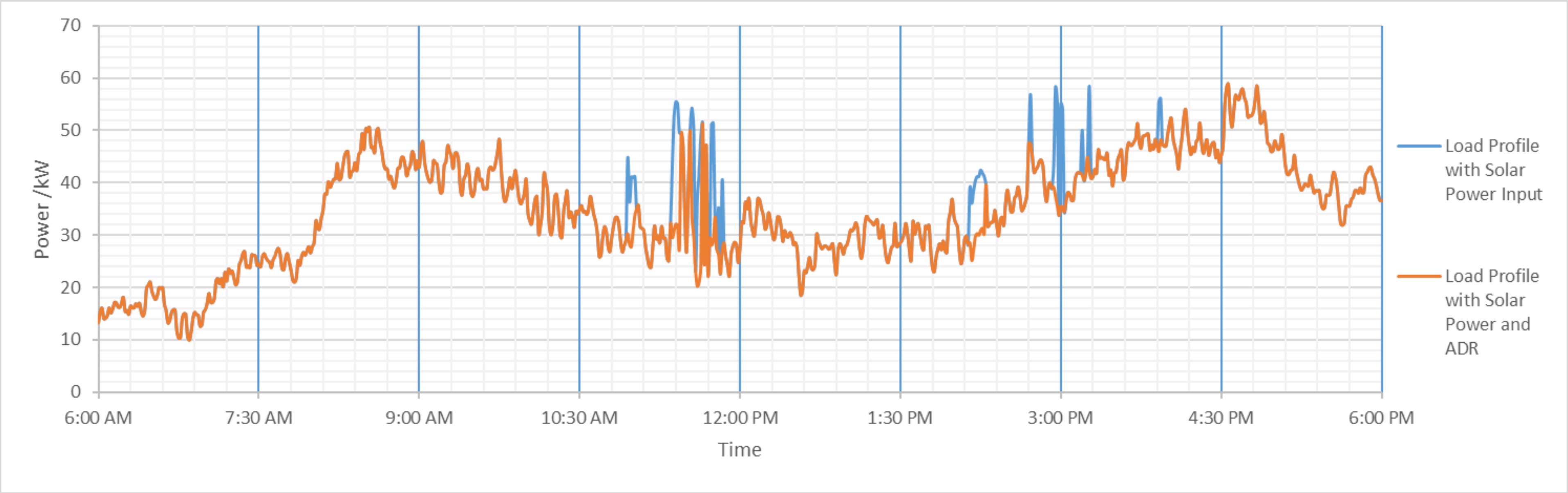

Figure 6.2: Day 1 - Total Consumption of the building

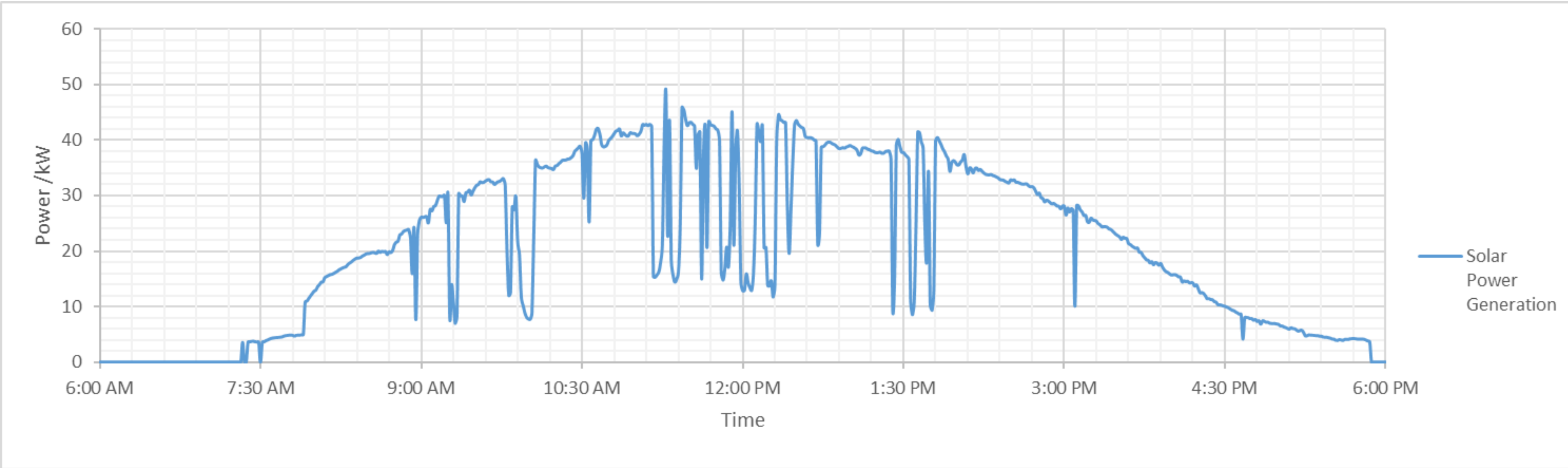

Figure 6.3: Day 2 - Solar Power Generation

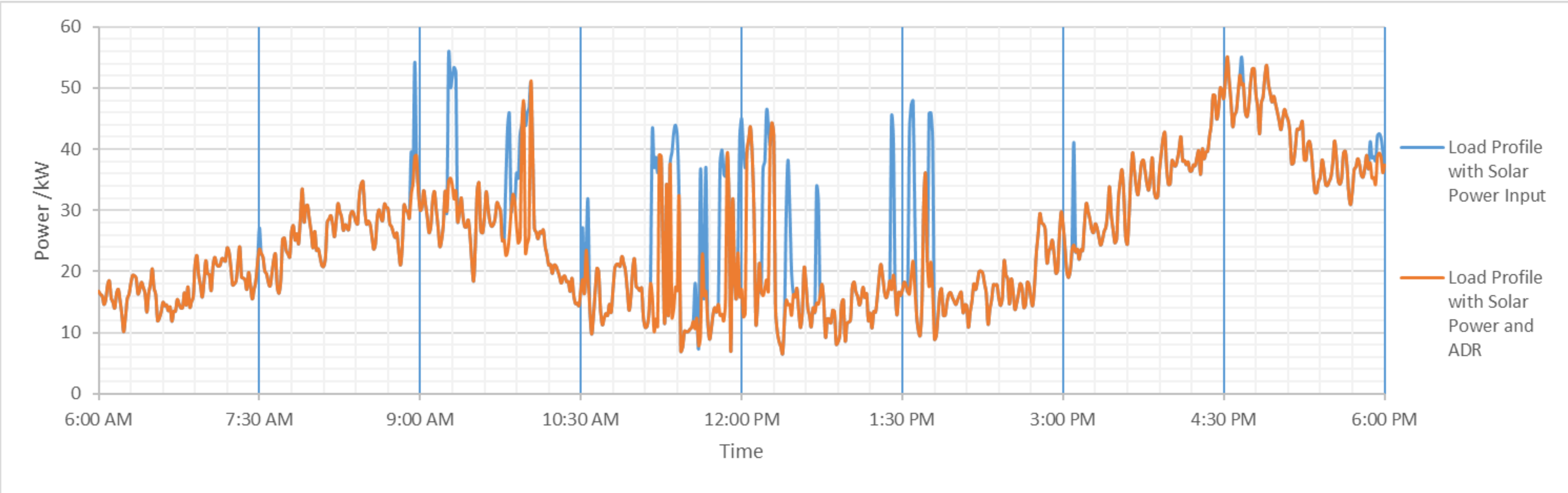

Figure 6.4: Day 2 - Total Consumption of the building

7. DISCUSSION

7.1 RESPONSE OF THE APPLICATION - HIGHLIGHTS

When analyzing the load profiles, it was clearly visible that solar transients have created sudden increases in net power consumption, and some of those were successfully mitigated by ADR events. This verify the results obtained with heat pumps in [4], that the loads participating in an ADR event are capable of following a given reference (section 3.6). the level of smoothing of the output depends on the no. of loads and their behavior.

In the load profiles obtained, time to time there were some leftovers where ADR application had not treated them. Also it was visible that the count of leftovers was larger when there are frequent solar transients within short time periods.

The reason for the leftovers were non availability of loads to shed. Since there is an active dispatch rule of blocking a load from participating another ADR event for next 10 minutes after it has participated for once, the load become non available for ADR portal during that time. When there are frequent ADR events with larger quantities, a possible dead band is created with zero available loads for a short time period. As a result of that, any solar transient during that period would not be treated by the ADR application.

By changing any of the following facts, these dead bands could be avoided.

- Reducing the load non participating time from 10 minutes to a lesser value (but this action may affect the human comfort level)
- Increasing the number of loads participate (total loads size to be at least three times the size of solar panel)
- Adding a battery bank to the ADR portal (adds cost)

This result verifies the suggestion given in [1] to facilitate the sites with diesel generators to be kept as backup electricity supplies (section 3.3). Adding a battery bank coupled with the network would be more environmental friendly and cleaner solution to the same.

8. CONCLUSION

High penetration of rooftop solar adds more trouble to the grid, and when this happens in large scale, the effect become more and more significant. Incorporating an ADR portal with rooftop solar panel was one proposed solution to this situation.

An ADR portal was designed and a pilot project was run with a building which has around 60 kW average maximum consumption, and a solar panel which can give 45kW during peak. In this case, the difference between the total participating load capacity and the capacity of solar panel was small.

8.1 LIMITATIONS OF THE ADR APPLICATION

When analyzing the load profiles after running ADR application, it was clearly visible that the system could completely mitigate some of the solar transients, and some of the transients with a longer duration with high magnitude were not.

The response of an ADR application to a given set of participating loads, and for a given solar panel depends on the following parameters:

- *The sizes and the number of loads*

The smaller the size of a single load and the larger the number of loads, the better the selection of loads to participate.

- *Total capacity of the participating loads*

The larger the total participating load capacity, the larger, and the longer the ADR events it can handle.

- *Load scheduling (e.g. load opt out time from participating the next event)*

The dead time from participating the next ADR event for a given load after participating one event ensures the comfort of the people working in the room with that Air Conditioner load. Reduce this time band will sure let it participate for more ADR events and would strengthen the ADR capacity of the system, but the level of compromising the comfort of people should take into consideration.

- *Size of the solar panel*

The smaller the solar panel, the easier to control.

- *Magnitude and duration of transients*

If we create a virtual volume for a solar transient, it is clearly seen that the smaller the volume, the easier to control.

When considering the size of an ADR event with maximum possible time duration it could be hold, it follows a pattern such as shown below.

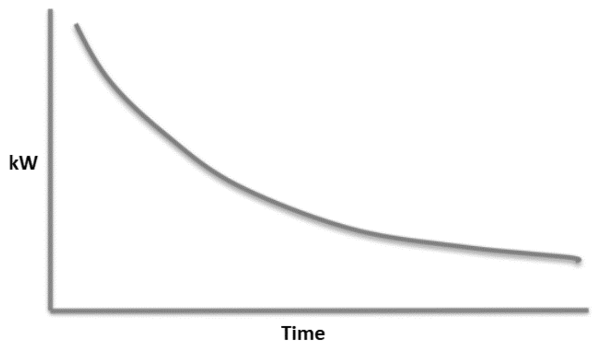

Figure 8.1: Variation of the size of an ADR event with maximum possible time duration

Therefore, the conclusion is, the capacity of an ADR portal could be maximized for a given system using the above mentioned parameters. But if still the capacity is not enough (or when practically increasing or changing the behavior of loads cannot be achieved), coupling a suitable battery bank will solve the rest of the problem.

8.2 CUSTOMER PARTICIPATION

The future consumer points have the potential of operating with rooftop solar (and battery storage if required) and suitable ADR portal will be beneficial to both the grid and the customer. Therefore, the following methods could be followed to encourage the customers.

8.2.1 encourage participation in ADR portals in a financial manner

One of the best ways to encourage the public in doing something new, is to offer a financial benefit. Utilities could introduce a special discount formula for the consumers actively participating in ADR portals. Then the consumers could enjoy their financial benefit as well as reduced electricity bill at the end of the month, while utilities can take the benefit of not requiring costly spinning reserves.

8.2.2 measuring the optimal RE penetration level

The optimum level of RE penetration of a feeder, area or even larger section could be modeled using the data gathered by ADR portals within the limits. Although technically RE integration has no limit, the most cost effective point may be roughly figured out using the available data of RE sources and results of ADR events and associated cost.

8.3 FUTURE WORKS

This pilot project was done in order to evaluate the ability for a commercial building to withstand solar transients with an ADR portal consist of split type air conditioners as participating loads. A good methodology for predicting the solar irradiance level variation by analyzing cloud patterns would be able to help generate more accurate forecast for the future ADR events. It creates another research opportunity to strengthen the performance level of this portal.

On the other hand, a similar kind of ADR applications could be designed for sites with different load types such as central air conditioning systems, lighting loads etc. as their participating loads.

The designed pilot project could be proposed as a working model for an ADR portal which responds to the variations of the Transmission Network. For this kind of large scale ADR application, the same model could be used with all the design parameters including the algorithm, with a suitably larger groups of participating loads of different types, and with a long distance communication network. The dispatch rules for the portal should be finalized according to the nature of the network and the participating loads.

REFERENCES

[1] T. Samad, E. Koch, P. Stluka, "Automated Demand Response for Smart Buildings and Microgrids: The State of the Practice and Research Challenges", Proceedings of the IEEE, Vol: 104, Issue 4, April 2016

[2] Federal Energy Regulatory Commission (FERC), "Assessment of demand response and advanced metering," Dec. 2012. [Online]. Available: http://www.ferc.gov/legal/staff-reports/12-20-12-demandresponse.pdf.

[3] S. Kiliccote, M. A. Piette, E. Koch, D. Hennage, "Utilizing Automated Demand Response in commercial buildings as non-spinning reserve product for ancillary services markets", 50th IEEE Conference on Decision and Control and European Control Conference (CDC-ECC), 2011

[4] B. Biegel, P. Andersen, J. Stoustrup, L. H. Hansen, A. Birke, "Sustainable Reserve Power from Demand Response and Fluctuating Production—Two Danish Demonstrations", Proceedings of the IEEE, Vol. 104, Issue. 4, April 2016

[5] A. Yassine, "Implementation Challenges of Automatic Demand Response for Households in Smart Grids", 3rd International Conference on Renewable Energies for Developing Countries (REDEC), 2016

[6] T. Samad, E. Koch, "Automated demand response for energy efficiency and emissions reduction", Transmission and Distribution Conference and Exposition (T&D), 2012 IEEE PES

[7] M. Behl, N. Shah, L. Vadakedathu, D. Wheeler, R. Mangharam, "Demo Abstract: EnergyLab - Building Energy Testbed for Demand-Response", ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN), 2013

[8] C. Ninagawa, K. Taga, A. Kiyota, T. Yamaguchi, "Emulation System on Smart Grid Fast Automated Demand Response of Widely-distributed Stochastically-operating Building Facilities" 2015 IEEE International Symposium on Systems Engineering (ISSE)

APPENDIX 01

Table 9.1: Participating Loads for the Pilot Project

Rated Watt value	Off time	Location	Priority
2350	7	Chairman	1
1970	5	H. Eng. Room	1
1100	9	Head of HR & Admin	1
1100	9	Chief FO	1
1100	8	GM	1
3670	5	Server room	1
1190	7	Head of Operations	1
1172	4	SDM	2
1910	1	SOM	2
860	9	CSM	2
1900	8	PM	2
1350	3	Conference Room	2
1340	8	RM	2
2367	1	DCC (middle)	2
2300	5	SOD	3
1100	9	Control Engineer	3
2000	8	Finance dept. common	3
6400	7	IT manager	3
5500	1	IT 3rd Floor	3
1550	6	SDD1	3
1150	3	SDD2 (3)	3
2340	1	Common area	3
1800	5	Control room	3
1300	3	Photocopy room	3
2600	6	Finance dept.	3
2700	6	Corporate office	3
6150	3	Reception	3
1970	8	Library	3
6150	3	Admin Office	3
3200	1	Auditorium 1 (right)	3
2840	9	SDD2 (middle)	3
2400	8	Library 2	3
1930	8	Corporate office assistant	3
1600	9	CSD	3
1010	1	Call center	3
825	6	SDD2 (left)	3
2350	7	SDD2 (right)	3
2480	7	Auditorium 1 (left)	3

1100	4	Accountant Treasury	3
1100	4	Financial Accountant	3
2500	6	Operations Division	3
1970	2	IT Development unit	3
3460	4	Supply Department	3
2200	1	Supply Department (right)	3
1700	3	Lunch Room 1	3
1900	1	DCC (corner)	3
1290	1	Chief Internal Auditor - IAD (right)	3
1650	3	Chief Internal Auditor - IAD (left)	3
3100	7	new admin office 1	3
2200	2	new admin office 2	3

APPENDIX 02

Table 9.2: Load Profile data for Day 1

Time	Solar Power Input /kW	Load Profile with solar input and ADR /kW	Load Profile with solar Input /kW
6:00 AM	0.00	13.2	13.2
6:01 AM	0.00	15.3	15.3
6:02 AM	0.00	16.0	16.0
6:03 AM	0.00	14.0	14.0
6:04 AM	0.00	14.1	14.1
6:05 AM	0.00	14.5	14.5
6:06 AM	0.00	16.0	16.0
6:07 AM	0.00	15.0	15.0
6:08 AM	0.00	15.8	15.8
6:09 AM	0.00	17.0	17.0
6:10 AM	0.00	17.0	17.0
6:11 AM	0.00	16.2	16.2
6:12 AM	0.00	16.2	16.2
6:13 AM	0.00	17.0	17.0
6:14 AM	0.04	18.0	18.0
6:15 AM	0.09	15.3	15.3
6:16 AM	0.04	15.6	15.6
6:17 AM	0.20	14.8	14.8
6:18 AM	0.24	16.4	16.4
6:19 AM	0.29	16.0	16.0
6:20 AM	0.35	16.1	16.1
6:21 AM	0.40	16.8	16.8
6:22 AM	0.44	16.3	16.3
6:23 AM	0.48	16.9	16.9
6:24 AM	0.56	15.3	15.3
6:25 AM	0.61	14.5	14.5
6:26 AM	0.56	15.5	15.5
6:27 AM	0.83	19.9	19.9
6:28 AM	0.87	20.4	20.4
6:29 AM	0.91	21.0	21.0
6:30 AM	0.99	19.2	19.2
6:31 AM	0.99	18.2	18.2
6:32 AM	1.01	17.6	17.6
6:33 AM	1.08	18.3	18.3
6:34 AM	1.16	19.9	19.9
6:35 AM	1.23	19.8	19.8
6:36 AM	1.09	19.9	19.9
6:37 AM	1.28	16.8	16.8
6:38 AM	1.32	15.5	15.5
6:39 AM	1.35	13.1	13.1
6:40 AM	1.35	13.7	13.7
6:41 AM	1.36	15.1	15.1
6:42 AM	1.37	15.7	15.7
6:43 AM	1.39	15.6	15.6
6:44 AM	1.44	11.6	11.6
6:45 AM	1.49	10.3	10.3
6:46 AM	1.45	10.3	10.3
6:47 AM	1.57	14.0	14.0
6:48 AM	1.71	14.9	14.9
6:49 AM	1.85	14.8	14.8
6:50 AM	1.92	10.6	10.6
6:51 AM	1.96	9.9	9.9
6:52 AM	2.01	11.4	11.4
6:53 AM	2.07	13.9	13.9
6:54 AM	2.13	15.2	15.2
6:55 AM	2.15	14.7	14.7
6:56 AM	2.18	14.6	14.6
6:57 AM	2.23	12.5	12.5
6:58 AM	2.28	12.8	12.8
6:59 AM	2.30	15.2	15.2
7:00 AM	2.30	15.7	15.7
7:01 AM	2.32	16.9	16.9
7:02 AM	2.35	18.8	18.8
7:03 AM	2.42	17.1	17.1
7:04 AM	2.46	17.1	17.1
7:05 AM	2.49	17.7	17.7
7:06 AM	2.50	21.2	21.2
7:07 AM	2.55	21.6	21.6
7:08 AM	2.56	20.6	20.6
7:09 AM	2.57	21.6	21.6
7:10 AM	2.59	20.0	20.0
7:11 AM	2.63	22.8	22.8
7:12 AM	2.67	21.2	21.2
7:13 AM	2.69	23.4	23.4
7:14 AM	2.71	22.6	22.6
7:15 AM	2.73	23.1	23.1
7:16 AM	2.76	21.8	21.8
7:17 AM	2.77	20.4	20.4
7:18 AM	2.78	20.9	20.9
7:19 AM	2.79	24.2	24.2
7:20 AM	2.80	25.0	25.0

7:21 AM	2.80	26.4	26.4
7:22 AM	2.83	26.8	26.8
7:23 AM	2.85	23.8	23.8
7:24 AM	2.89	24.1	24.1
7:25 AM	2.86	23.7	23.7
7:26 AM	2.85	26.2	26.2
7:27 AM	2.87	26.0	26.0
7:28 AM	2.89	26.0	26.0
7:29 AM	2.90	24.1	24.1
7:30 AM	2.92	24.4	24.4
7:31 AM	2.93	23.9	23.9
7:32 AM	2.99	25.8	25.8
7:33 AM	3.04	26.4	26.4
7:34 AM	3.08	25.6	25.6
7:35 AM	3.15	25.1	25.1
7:36 AM	3.18	24.7	24.7
7:37 AM	3.24	23.7	23.7
7:38 AM	3.31	25.2	25.2
7:39 AM	3.32	25.8	25.8
7:40 AM	3.38	26.9	26.9
7:41 AM	3.47	27.4	27.4
7:42 AM	3.51	26.1	26.1
7:43 AM	3.57	23.5	23.5
7:44 AM	3.58	23.3	23.3
7:45 AM	3.61	25.5	25.5
7:46 AM	3.71	26.4	26.4
7:47 AM	5.99	24.8	24.8
7:48 AM	6.90	23.3	23.3
7:49 AM	7.20	21.4	21.4
7:50 AM	7.31	20.9	20.9
7:51 AM	7.73	21.6	21.6
7:52 AM	8.52	25.1	25.1
7:53 AM	9.01	24.1	24.1
7:54 AM	9.74	25.8	25.8
7:55 AM	9.75	26.6	26.6
7:56 AM	9.89	26.1	26.1
7:57 AM	10.34	26.9	26.9
7:58 AM	10.89	27.7	27.7
7:59 AM	11.24	26.5	26.5
8:00 AM	11.11	27.7	27.7
8:01 AM	11.38	28.4	28.4
8:02 AM	11.94	32.6	32.6
8:03 AM	12.35	31.5	31.5
8:04 AM	13.37	31.0	31.0
8:05 AM	14.14	33.2	33.2
8:06 AM	14.36	34.6	34.6
8:07 AM	14.58	37.7	37.7
8:08 AM	14.82	37.7	37.7
8:09 AM	15.01	40.1	40.1
8:10 AM	15.10	39.0	39.0
8:11 AM	15.36	39.8	39.8
8:12 AM	15.43	40.6	40.6
8:13 AM	15.53	40.7	40.7
8:14 AM	15.55	43.6	43.6
8:15 AM	15.83	40.5	40.5
8:16 AM	15.88	40.7	40.7
8:17 AM	16.01	42.7	42.7
8:18 AM	16.21	44.9	44.9
8:19 AM	16.31	45.8	45.8
8:20 AM	16.64	45.9	45.9
8:21 AM	16.96	41.0	41.0
8:22 AM	16.76	42.0	42.0
8:23 AM	17.05	42.3	42.3
8:24 AM	16.89	43.8	43.8
8:25 AM	17.13	42.2	42.2
8:26 AM	17.32	45.2	45.2
8:27 AM	17.33	45.9	45.9
8:28 AM	17.39	49.3	49.3
8:29 AM	17.71	46.3	46.3
8:30 AM	17.75	50.2	50.2
8:31 AM	18.16	49.7	49.7
8:32 AM	18.42	50.5	50.5
8:33 AM	18.61	46.7	46.7
8:34 AM	18.83	46.8	46.8
8:35 AM	19.12	45.7	45.7
8:36 AM	19.25	49.7	49.7
8:37 AM	19.44	50.3	50.3
8:38 AM	19.68	47.7	47.7
8:39 AM	19.72	46.0	46.0
8:40 AM	19.79	43.6	43.6
8:41 AM	19.95	42.5	42.5
8:42 AM	20.31	42.6	42.6
8:43 AM	20.33	40.6	40.6
8:44 AM	20.26	41.2	41.2
8:45 AM	20.53	39.7	39.7
8:46 AM	20.65	38.9	38.9
8:47 AM	20.75	40.2	40.2
8:48 AM	20.81	42.7	42.7
8:49 AM	21.06	42.8	42.8
8:50 AM	21.31	44.7	44.7
8:51 AM	21.35	44.8	44.8
8:52 AM	21.53	43.4	43.4

8:53 AM	21.71	41.2	41.2
8:54 AM	21.82	42.5	42.5
8:55 AM	21.79	43.3	43.3
8:56 AM	21.98	45.9	45.9
8:57 AM	22.01	45.2	45.2
8:58 AM	22.43	42.4	42.4
8:59 AM	22.30	44.1	44.1
9:00 AM	22.70	42.9	42.9
9:01 AM	22.89	46.8	46.8
9:02 AM	22.91	47.8	47.8
9:03 AM	23.05	43.9	43.9
9:04 AM	23.35	42.0	42.0
9:05 AM	23.79	40.8	40.8
9:06 AM	23.64	40.0	40.0
9:07 AM	24.22	40.4	40.4
9:08 AM	24.31	44.1	44.1
9:09 AM	24.10	43.7	43.7
9:10 AM	24.14	43.5	43.5
9:11 AM	24.65	40.1	40.1
9:12 AM	24.77	37.9	37.9
9:13 AM	24.49	38.3	38.3
9:14 AM	24.69	43.2	43.2
9:15 AM	24.78	43.9	43.9
9:16 AM	25.02	47.0	47.0
9:17 AM	24.78	46.0	46.0
9:18 AM	24.86	44.9	44.9
9:19 AM	25.11	42.7	42.7
9:20 AM	25.39	45.5	45.5
9:21 AM	25.55	45.6	45.6
9:22 AM	25.44	44.2	44.2
9:23 AM	25.82	38.9	38.9
9:24 AM	25.80	37.5	37.5
9:25 AM	25.80	40.6	40.6
9:26 AM	25.92	41.4	41.4
9:27 AM	25.98	43.5	43.5
9:28 AM	26.07	41.8	41.8
9:29 AM	26.26	38.0	38.0
9:30 AM	26.31	37.3	37.3
9:31 AM	26.72	38.5	38.5
9:32 AM	26.93	41.7	41.7
9:33 AM	26.93	42.7	42.7
9:34 AM	27.05	40.3	40.3
9:35 AM	27.13	40.6	40.6
9:36 AM	26.93	38.8	38.7
9:37 AM	27.14	38.9	38.9
9:38 AM	27.23	38.8	38.8

9:39 AM	27.33	42.2	42.2
9:40 AM	27.25	43.0	43.0
9:41 AM	27.28	42.4	42.4
9:42 AM	27.21	42.6	42.6
9:43 AM	27.30	44.0	44.0
9:44 AM	27.36	46.0	46.0
9:45 AM	27.69	48.1	48.1
9:46 AM	26.88	42.4	42.4
9:47 AM	27.69	38.2	38.2
9:48 AM	27.73	36.3	36.3
9:49 AM	28.01	37.0	37.0
9:50 AM	28.28	38.9	38.9
9:51 AM	28.45	40.9	40.9
9:52 AM	28.73	38.8	38.8
9:53 AM	28.83	40.4	40.4
9:54 AM	28.82	42.3	42.3
9:55 AM	28.94	39.5	39.5
9:56 AM	27.89	36.9	36.9
9:57 AM	28.97	35.9	35.9
9:58 AM	29.22	36.7	36.7
9:59 AM	29.44	37.9	37.9
10:00 AM	29.62	40.6	40.6
10:01 AM	29.93	34.1	34.1
10:02 AM	29.60	32.7	32.7
10:03 AM	29.88	32.0	32.0
10:04 AM	30.03	34.4	34.4
10:05 AM	30.19	36.8	36.8
10:06 AM	28.68	37.3	37.3
10:07 AM	30.04	30.2	30.2
10:08 AM	30.16	31.8	31.8
10:09 AM	30.35	34.4	34.4
10:10 AM	29.95	41.7	41.7
10:11 AM	30.22	40.1	40.1
10:12 AM	29.49	38.3	38.3
10:13 AM	30.33	31.6	31.6
10:14 AM	30.15	30.0	30.0
10:15 AM	30.56	31.9	31.9

10:16 AM	30.59	37.2	37.2
10:17 AM	30.87	37.7	37.7
10:18 AM	30.69	34.7	34.7
10:19 AM	31.02	30.0	30.0
10:20 AM	31.14	29.4	29.4
10:21 AM	31.22	34.4	34.4
10:22 AM	31.16	36.6	36.6
10:23 AM	31.15	38.3	38.3
10:24 AM	31.00	33.3	33.3
10:25 AM	31.14	34.4	34.4
10:26 AM	31.53	33.3	33.3
10:27 AM	31.57	31.4	31.4
10:28 AM	31.52	34.4	34.4
10:29 AM	31.65	33.9	33.9
10:30 AM	31.58	34.8	34.8
10:31 AM	31.73	35.6	35.6
10:32 AM	31.69	34.3	34.3
10:33 AM	31.18	34.5	34.5
10:34 AM	31.09	33.8	33.8
10:35 AM	31.15	34.8	34.8
10:36 AM	31.56	37.3	37.3
10:37 AM	31.63	35.6	35.6
10:38 AM	31.80	33.8	33.8
10:39 AM	32.30	32.4	32.4
10:40 AM	32.46	30.0	30.0
10:41 AM	31.92	25.8	25.8
10:42 AM	31.94	26.2	26.2
10:43 AM	32.03	29.7	29.7
10:44 AM	32.58	31.5	31.5
10:45 AM	32.79	30.5	30.5

10:46 AM	32.81	27.8	27.8
10:47 AM	32.62	26.8	26.8
10:48 AM	32.89	29.5	29.5
10:49 AM	32.98	31.7	31.7
10:50 AM	33.50	33.2	33.2
10:51 AM	33.45	33.3	33.3
10:52 AM	33.85	32.1	32.1
10:53 AM	34.13	28.6	28.6
10:54 AM	34.05	26.7	26.7
10:55 AM	34.50	27.9	27.9
10:56 AM	34.49	29.0	29.0
10:57 AM	19.35	30.2	44.7
10:58 AM	25.90	28.2	36.3
10:59 AM	20.83	27.7	41.0
11:00 AM	23.83	30.8	40.9
11:01 AM	26.46	33.7	41.1
11:02 AM	35.38	34.9	34.9
11:03 AM	35.40	35.6	35.6
11:04 AM	35.70	31.5	31.5
11:05 AM	35.88	31.2	31.2
11:06 AM	35.74	30.8	30.8
11:07 AM	35.67	27.8	27.8
11:08 AM	35.83	25.6	25.6
11:09 AM	35.77	24.0	24.0
11:10 AM	35.57	23.7	23.7
11:11 AM	35.45	27.5	27.5
11:12 AM	35.10	31.7	31.7
11:13 AM	34.95	29.2	29.2
11:14 AM	35.50	29.8	29.8
11:15 AM	35.85	28.4	28.4

11:16 AM	35.99	31.6	31.6
11:17 AM	36.38	29.4	29.4
11:18 AM	36.55	29.4	29.4
11:19 AM	37.09	25.6	25.6
11:20 AM	37.82	25.0	25.0
11:21 AM	32.76	32.1	32.1
11:22 AM	22.14	29.4	43.3
11:23 AM	14.04	30.8	52.7
11:24 AM	12.03	32.0	55.4
11:25 AM	12.50	31.7	54.9
11:26 AM	13.60	27.4	49.5
11:27 AM	13.94	49.3	49.3
11:28 AM	15.15	47.0	47.0
11:29 AM	31.39	34.5	34.5
11:30 AM	37.66	26.7	26.7
11:31 AM	24.13	39.0	39.0
11:32 AM	14.04	49.8	49.8
11:33 AM	12.81	33.5	54.2
11:34 AM	14.01	29.7	50.3
11:35 AM	38.37	23.3	23.3
11:36 AM	20.07	20.2	36.2
11:37 AM	14.72	20.9	41.8
11:38 AM	10.09	23.8	48.7
11:39 AM	11.23	51.2	51.2
11:40 AM	39.36	24.2	24.2
11:41 AM	16.42	47.2	47.2
11:42 AM	42.68	22.6	22.6
11:43 AM	35.77	29.3	29.3
11:44 AM	13.70	28.0	51.0
11:45 AM	15.49	28.8	51.3

11:46 AM	31.43	33.3	33.3
11:47 AM	36.48	27.3	27.2
11:48 AM	28.89	26.1	35.1
11:49 AM	41.37	22.5	22.5
11:50 AM	24.86	27.0	40.5
11:51 AM	38.63	28.4	28.4
11:52 AM	38.42	25.8	25.8
11:53 AM	37.70	24.0	24.0
11:54 AM	37.22	22.1	22.1
11:55 AM	37.10	26.3	26.3
11:56 AM	36.27	27.8	27.8
11:57 AM	35.91	28.6	28.6
11:58 AM	35.58	28.1	28.1
11:59 AM	36.05	24.7	24.7
12:00 PM	35.79	27.6	27.6
12:01 PM	35.87	32.5	32.5
12:02 PM	35.75	32.2	32.2
12:03 PM	36.04	36.2	36.2
12:04 PM	36.11	34.9	34.9
12:05 PM	35.88	37.0	37.0
12:06 PM	35.71	32.7	32.7
12:07 PM	35.60	30.8	30.8
12:08 PM	35.85	29.8	29.8
12:09 PM	35.86	32.9	32.9
12:10 PM	35.82	36.9	36.9
12:11 PM	35.78	36.6	36.6
12:12 PM	35.79	35.0	35.0
12:13 PM	35.83	33.8	33.8
12:14 PM	35.77	31.1	31.1
12:15 PM	35.65	31.6	31.6

12:16 PM	35.62	34.2	34.2
12:17 PM	35.38	32.8	32.8
12:18 PM	35.41	30.5	30.5
12:19 PM	34.87	29.0	29.0
12:20 PM	34.57	30.3	30.3
12:21 PM	34.78	33.4	33.4
12:22 PM	35.11	33.3	33.3
12:23 PM	34.97	31.6	31.6
12:24 PM	35.92	28.7	28.7
12:25 PM	36.03	30.8	30.8
12:26 PM	35.99	29.8	29.8
12:27 PM	36.04	29.5	29.5
12:28 PM	35.67	30.4	30.4
12:29 PM	35.83	29.9	29.9
12:30 PM	35.95	28.1	28.1
12:31 PM	35.47	28.5	28.5
12:32 PM	35.58	27.3	27.3
12:33 PM	35.67	22.5	22.5
12:34 PM	36.35	18.5	18.5
12:35 PM	36.27	19.3	19.3
12:36 PM	36.00	23.1	23.1
12:37 PM	35.43	22.7	22.7
12:38 PM	35.24	24.1	24.1
12:39 PM	35.17	25.6	25.6
12:40 PM	34.98	23.6	23.6
12:41 PM	34.78	23.3	23.3
12:42 PM	34.83	24.2	24.2
12:43 PM	34.74	30.1	30.1
12:44 PM	34.76	28.9	28.9
12:45 PM	34.59	27.9	27.9
12:46 PM	34.27	27.3	27.3
12:47 PM	34.43	27.8	27.8
12:48 PM	34.47	27.9	27.9
12:49 PM	34.44	27.6	27.6
12:50 PM	34.61	27.2	27.2
12:51 PM	34.65	27.8	27.8
12:52 PM	34.67	28.2	28.2
12:53 PM	34.75	24.8	24.8
12:54 PM	34.91	22.4	22.4
12:55 PM	34.63	27.0	27.0
12:56 PM	34.64	28.3	28.3
12:57 PM	34.31	27.6	27.6
12:58 PM	34.06	26.3	26.3
12:59 PM	33.97	27.7	27.7
1:00 PM	34.27	28.1	28.1
1:01 PM	34.37	29.3	29.3
1:02 PM	34.37	30.9	30.9
1:03 PM	34.39	30.7	30.7
1:04 PM	34.38	31.4	31.4
1:05 PM	34.41	32.3	32.3
1:06 PM	34.37	31.1	31.1
1:07 PM	33.74	27.6	27.6
1:08 PM	34.61	25.5	25.5
1:09 PM	34.73	27.3	27.3
1:10 PM	34.60	31.9	31.9
1:11 PM	34.20	33.5	33.5
1:12 PM	34.37	33.0	33.0
1:13 PM	33.83	32.6	32.6
1:14 PM	34.14	32.3	32.3
1:15 PM	34.65	31.8	31.8
1:16 PM	34.04	32.4	32.4
1:17 PM	33.21	32.8	32.8
1:18 PM	34.61	29.4	29.4
1:19 PM	35.03	29.6	29.6
1:20 PM	34.95	31.8	31.8
1:21 PM	34.96	28.3	28.3
1:22 PM	34.96	25.6	25.6
1:23 PM	34.65	24.6	24.6
1:24 PM	34.44	26.1	26.1

1:25 PM	34.34	27.6	27.6
1:26 PM	32.99	28.0	28.0
1:27 PM	30.30	32.2	32.2
1:28 PM	33.60	27.7	27.7
1:29 PM	33.78	28.0	28.0
1:30 PM	33.84	28.5	28.5
1:31 PM	33.78	29.0	29.0
1:32 PM	33.70	30.3	30.3
1:33 PM	33.71	32.2	32.2
1:34 PM	33.75	30.0	30.0
1:35 PM	33.49	27.2	27.2
1:36 PM	33.29	25.1	25.1
1:37 PM	31.73	32.5	32.5
1:38 PM	33.31	30.1	30.1
1:39 PM	32.71	31.6	31.6
1:40 PM	32.72	32.1	32.1
1:41 PM	33.21	30.1	30.1
1:42 PM	33.51	27.8	27.8
1:43 PM	32.63	27.1	27.1
1:44 PM	31.39	31.6	31.6
1:45 PM	34.42	31.2	31.2
1:46 PM	34.80	31.8	31.8
1:47 PM	34.02	26.8	26.8
1:48 PM	33.48	23.6	23.6
1:49 PM	32.96	22.9	22.9
1:50 PM	32.76	25.7	25.7
1:51 PM	32.57	27.2	27.2
1:52 PM	31.39	28.3	28.3
1:53 PM	32.88	27.1	27.1
1:54 PM	32.31	28.8	28.8
1:55 PM	32.50	26.9	26.9
1:56 PM	32.02	26.5	26.5
1:57 PM	31.82	32.5	32.5
1:58 PM	31.83	34.3	34.3
1:59 PM	29.92	36.8	36.8
2:00 PM	31.21	33.5	33.5
2:01 PM	31.51	32.2	32.2
2:02 PM	31.53	31.5	31.5
2:03 PM	31.82	27.1	27.1
2:04 PM	31.72	24.4	24.4
2:05 PM	31.36	26.0	26.0
2:06 PM	30.91	29.1	29.1
2:07 PM	30.64	29.7	29.7
2:08 PM	31.29	28.1	28.1
2:09 PM	20.40	28.4	39.0
2:10 PM	20.01	25.1	36.0

2:11 PM	19.75	27.0	38.3
2:12 PM	20.01	29.6	40.2
2:13 PM	19.99	30.2	41.1
2:14 PM	19.84	29.9	41.1
2:15 PM	19.37	30.8	42.3
2:16 PM	20.06	31.2	41.8
2:17 PM	20.07	30.2	41.1
2:18 PM	20.81	39.5	39.5
2:19 PM	30.45	31.6	31.6
2:20 PM	30.27	32.0	32.0
2:21 PM	31.24	32.4	32.4
2:22 PM	31.91	32.5	32.5
2:23 PM	28.96	34.7	34.7
2:24 PM	31.54	32.0	32.0
2:25 PM	30.96	29.7	29.7
2:26 PM	30.37	32.7	32.7
2:27 PM	29.97	33.3	33.3
2:28 PM	29.70	31.8	31.8
2:29 PM	29.65	36.1	36.1
2:30 PM	29.42	38.5	38.5
2:31 PM	29.21	36.6	36.6
2:32 PM	29.14	34.4	34.4
2:33 PM	29.22	34.4	34.4
2:34 PM	28.60	36.9	36.9
2:35 PM	28.90	37.5	37.5
2:36 PM	28.85	39.1	39.1
2:37 PM	28.95	37.5	37.5
2:38 PM	29.16	34.6	34.6
2:39 PM	29.01	35.0	35.0
2:40 PM	27.39	36.1	36.1
2:41 PM	29.05	37.9	37.9
2:42 PM	26.18	47.5	47.5
2:43 PM	18.72	47.4	56.8
2:44 PM	27.65	45.0	45.0
2:45 PM	27.91	41.9	41.9
2:46 PM	26.82	42.5	42.5
2:47 PM	27.49	43.0	43.0
2:48 PM	27.04	44.0	44.0
2:49 PM	26.37	44.3	44.3
2:50 PM	26.49	43.0	43.0
2:51 PM	26.84	38.4	38.4
2:52 PM	27.06	36.3	36.3
2:53 PM	27.29	39.1	39.1
2:54 PM	27.12	40.0	40.0
2:55 PM	27.03	38.9	38.9
2:56 PM	22.51	39.1	43.3

2:57 PM	5.87	37.4	58.2
2:58 PM	7.18	35.5	55.4
2:59 PM	27.90	33.7	33.7
3:00 PM	7.46	35.4	55.0
3:01 PM	7.90	35.2	53.9
3:02 PM	27.19	34.4	34.4
3:03 PM	25.43	36.5	36.5
3:04 PM	26.66	38.1	38.1
3:05 PM	26.12	37.8	37.8
3:06 PM	24.61	36.5	36.5
3:07 PM	24.09	36.6	36.6
3:08 PM	24.23	40.5	40.5
3:09 PM	25.01	41.7	41.7
3:10 PM	24.51	41.9	41.9
3:11 PM	25.44	41.7	41.7
3:12 PM	15.93	41.4	50.0
3:13 PM	24.27	40.4	40.4
3:14 PM	24.49	41.9	41.9
3:15 PM	21.40	44.8	44.8
3:16 PM	7.51	41.9	58.4
3:17 PM	24.68	40.7	40.7
3:18 PM	24.33	41.0	41.0
3:19 PM	23.61	42.5	42.5
3:20 PM	23.64	41.7	41.7
3:21 PM	22.69	46.2	46.2
3:22 PM	22.27	44.7	44.7
3:23 PM	21.57	44.8	44.8
3:24 PM	21.44	44.5	44.5
3:25 PM	21.78	44.4	44.4
3:26 PM	21.07	45.5	45.5
3:27 PM	21.38	41.4	41.4
3:28 PM	19.76	42.4	42.4
3:29 PM	20.58	39.3	39.3
3:30 PM	20.43	41.8	41.8
3:31 PM	20.58	42.0	42.0
3:32 PM	20.10	44.4	44.4
3:33 PM	20.34	45.2	45.2
3:34 PM	18.86	46.2	46.2
3:35 PM	20.31	40.5	40.5
3:36 PM	20.22	41.4	41.4
3:37 PM	19.68	45.9	45.9
3:38 PM	19.13	47.5	47.5
3:39 PM	19.70	47.0	47.0
3:40 PM	19.43	47.1	47.1
3:41 PM	18.98	47.7	47.7
3:42 PM	19.06	48.4	48.4

3:43 PM	18.43	51.2	51.2
3:44 PM	18.23	47.7	47.7
3:45 PM	18.33	46.5	46.5
3:46 PM	18.44	48.8	48.8
3:47 PM	18.27	48.9	48.9
3:48 PM	18.38	49.1	49.1
3:49 PM	17.44	49.3	49.3
3:50 PM	17.69	46.1	46.1
3:51 PM	18.28	47.1	47.1
3:52 PM	18.15	46.4	46.4
3:53 PM	18.07	48.2	48.2
3:54 PM	17.96	47.0	47.0
3:55 PM	8.25	45.9	55.3
3:56 PM	9.99	48.1	56.0
3:57 PM	17.72	47.4	47.4
3:58 PM	17.74	46.9	46.9
3:59 PM	17.39	46.9	46.9
4:00 PM	17.84	49.3	49.3
4:01 PM	18.19	51.2	51.2
4:02 PM	17.82	52.2	52.2
4:03 PM	17.83	48.4	48.4
4:04 PM	17.63	46.8	46.8
4:05 PM	17.53	45.3	45.3
4:06 PM	17.45	42.5	42.5
4:07 PM	16.93	46.0	46.0
4:08 PM	16.80	48.7	48.7
4:09 PM	15.84	52.4	52.4
4:10 PM	16.42	53.9	53.9
4:11 PM	16.22	50.2	50.2
4:12 PM	16.46	47.1	47.1
4:13 PM	16.31	45.3	45.3
4:14 PM	16.21	46.7	46.7
4:15 PM	16.25	45.8	45.8
4:16 PM	15.77	47.8	47.8
4:17 PM	15.81	48.4	48.4
4:18 PM	15.38	51.4	51.4
4:19 PM	14.83	47.3	47.3
4:20 PM	14.71	45.5	45.5
4:21 PM	14.45	46.9	46.9
4:22 PM	14.18	48.1	48.1
4:23 PM	13.62	45.2	45.2
4:24 PM	13.55	46.4	46.4
4:25 PM	12.42	47.5	47.5
4:26 PM	11.81	47.6	47.6
4:27 PM	12.51	44.7	44.7
4:28 PM	12.04	46.2	46.2

4:29 PM	11.44	43.8	43.8
4:30 PM	11.50	45.1	45.1
4:31 PM	11.06	46.9	46.9
4:32 PM	9.29	54.8	54.8
4:33 PM	8.76	58.1	58.1
4:34 PM	9.04	58.8	58.8
4:35 PM	8.71	53.2	53.2
4:36 PM	8.55	50.6	50.6
4:37 PM	8.61	53.5	53.5
4:38 PM	8.72	56.6	56.6
4:39 PM	8.58	56.1	56.1
4:40 PM	8.26	55.8	55.8
4:41 PM	7.98	57.2	57.2
4:42 PM	7.83	57.8	57.8
4:43 PM	7.80	56.1	56.1
4:44 PM	6.84	55.2	55.2
4:45 PM	7.34	52.5	52.5
4:46 PM	7.77	52.7	52.7
4:47 PM	7.60	52.7	52.7
4:48 PM	7.90	53.5	53.5
4:49 PM	7.78	55.7	55.7
4:50 PM	6.97	58.4	58.4
4:51 PM	7.20	55.5	55.5
4:52 PM	6.48	51.3	51.3
4:53 PM	6.21	51.7	51.7
4:54 PM	6.17	53.5	53.5
4:55 PM	7.07	51.0	51.0
4:56 PM	7.11	47.5	47.5
4:57 PM	6.90	47.2	47.2
4:58 PM	6.94	45.9	45.9
4:59 PM	6.96	46.0	46.0
5:00 PM	6.72	47.9	47.9
5:01 PM	6.21	47.0	47.0
5:02 PM	5.13	46.3	46.3
5:03 PM	4.76	46.7	46.7
5:04 PM	4.56	49.2	49.2
5:05 PM	4.88	46.5	46.5
5:06 PM	4.86	43.2	43.2
5:07 PM	4.59	41.6	41.6
5:08 PM	4.10	41.5	41.5
5:09 PM	3.89	42.3	42.3
5:10 PM	3.78	42.5	42.5
5:11 PM	3.53	45.2	45.2
5:12 PM	3.47	42.4	42.4
5:13 PM	3.49	40.8	40.8
5:14 PM	3.41	39.3	39.3

5:15 PM	3.31	38.5	38.5
5:16 PM	3.18	39.0	39.0
5:17 PM	3.09	39.7	39.7
5:18 PM	3.11	39.5	39.5
5:19 PM	3.09	39.3	39.3
5:20 PM	3.10	41.4	41.4
5:21 PM	3.14	39.6	39.6
5:22 PM	3.17	38.0	38.0
5:23 PM	3.21	38.4	38.4
5:24 PM	3.04	38.3	38.3
5:25 PM	3.11	38.4	38.4
5:26 PM	3.06	36.0	36.0
5:27 PM	3.02	35.0	35.0
5:28 PM	2.91	35.1	35.1
5:29 PM	2.93	37.5	37.5
5:30 PM	3.01	37.5	37.5
5:31 PM	3.01	37.7	37.7
5:32 PM	3.11	39.9	39.9
5:33 PM	3.30	41.9	41.9
5:34 PM	3.47	41.1	41.1
5:35 PM	3.60	39.0	39.0
5:36 PM	3.65	35.4	35.4
5:37 PM	3.58	32.1	32.1
5:38 PM	3.49	31.8	31.8
5:39 PM	3.29	32.2	32.2
5:40 PM	3.05	35.4	35.4
5:41 PM	2.72	35.5	35.5
5:42 PM	2.48	35.5	35.5
5:43 PM	2.30	36.7	36.7
5:44 PM	2.16	37.2	37.2
5:45 PM	2.04	38.4	38.4
5:46 PM	1.92	38.4	38.4
5:47 PM	1.83	38.0	38.0
5:48 PM	1.78	38.9	38.9
5:49 PM	1.75	38.0	38.0
5:50 PM	1.72	38.1	38.1
5:51 PM	1.71	41.4	41.4
5:52 PM	1.73	42.0	42.0
5:53 PM	1.74	42.7	42.7
5:54 PM	1.72	42.9	42.9
5:55 PM	1.69	41.4	41.4
5:56 PM	1.62	40.7	40.7
5:57 PM	1.53	39.4	39.4
5:58 PM	1.46	37.8	37.8
5:59 PM	1.43	36.6	36.6
6:00 PM	1.42	36.5	36.5

Table 9.3: Event log for Day 1

ip Address	Rated Watt value	Off time	Location	Priority	Off count	event at: 6/15/2018 10:57 AM	event at: 6/15/2018 10:58 AM	event at: 6/15/2018 10:59 AM	event at: 6/15/2018 11:00 AM	event at: 6/15/2018 11:01 AM	event at: 6/15/2018 11:22 AM	event at: 6/15/2018 11:23 AM	event at: 6/15/2018 11:24 AM
192.168.8.168	2350	7	Chairman	1	4								
192.168.8.175	1970	5	H. Eng. Room	1	3								
192.168.8.176	1100	9	Head of HR & Admin	1	9								
192.168.8.179	1100	9	Chief FO	1	8								
192.168.8.180	1100	8	GM	1	7								
192.168.8.181	3670	5	Server room	1	1								
192.168.8.182	1190	7	Head of Operations	1	6								
192.168.8.154	1172	4	SDM	2	9								
192.168.8.157	1910	1	SOM	2	7								
192.168.8.167	860	9	CSM	2	11								
192.168.8.177	1900	8	PM	2	8								
192.168.8.188	1350	3	Conference Room	2	8								
192.168.8.189	1340	8	RM	2	8								
192.168.8.190	2367	1	DCC (middle)	2	5								
192.168.8.146	2300	5	SOD	3	14				1				1
192.168.8.147	1100	9	Control Engineer	3	15	1					1		
192.168.8.148	2000	8	Finance dept. common	3	15	1					1		
192.168.8.149	6400	7	IT manager	3	10					1			1
192.168.8.150	5500	1	IT 3rd Floor	3	7								
192.168.8.151	1550	6	SDD1	3	15	1					1		
192.168.8.152	1150	3	SDD2 (3)	3	14			1				1	
192.168.8.153	2340	1	Common area	3	9								
192.168.8.155	1800	5	Control room	3	15		1					1	
12.168.8.156	1300	3	Photocopy room	3	14			1				1	
192.168.8.158	2600	6	Finance dept.	3	13			1				1	

192.168.8.159	2700	6	Corporate office	3	13			1					1
192.168.8.160	6150	3	Reception	3	6								
192.168.8.161	1970	8	Library	3	15	1					1		
192.168.8.162	6150	3	Admin Office	3	6								
192.168.8.163	3200	1	Auditorium 1 (right)	3	9								
192.168.8.164	2840	9	SDD2 (middle)	3	15		1				1		
192.168.8.165	2400	8	Library 2	3	15	1						1	
192.168.8.166	1930	8	Corporate office assistant	3	15	1					1		
192.168.8.169	1600	9	CSD	3	15	1					1		
192.168.8.170	1010	1	Call center	3	13					1			1
192.168.8.171	825	6	SDD2 (left)	3	15	1					1		
192.168.8.172	2350	7	SDD2 (right)	3	15		1					1	
192.168.8.173	2480	7	Auditorium 1 (left)	3	14			1				1	
192.168.8.174	1100	4	Accountant Treasury	3	15	1						1	
192.168.8.178	1100	4	Financial Accountant	3	15		1					1	
192.168.8.183	2500	6	Operations Division	3	13				1			1	
192.168.8.184	1970	2	IT Development unit	3	12				1				1
192.168.8.185	3460	4	Supply Department	3	10								1
192.168.8.186	2200	1	Supply Department (right)	3	9								
192.168.8.187	1700	3	Lunch Room 1	3	13				1				1
192.168.8.191	1900	1	DCC (corner)	3	10								
192.168.8.192	1290	1	Chief Internal Auditor - IAD (right)	3	11								
192.168.8.193	1650	3	Chief Internal Auditor - IAD (left)	3	13				1				1
192.168.8.194	3100	7	new admin office 1	3	12			1				1	
192.168.8.195	2200	2	new admin office 2	3	10								1

ip Address	Rated Watt value	Off time	Location	Priority	Off count	event at: 6/15/2018 11:25 AM	event at: 6/15/2018 11:26 AM	event at: 6/15/2018 11:33 AM	event at: 6/15/2018 11:34 AM	event at: 6/15/2018 11:36 AM	event at: 6/15/2018 11:37 AM	event at: 6/15/2018 11:38 AM	event at: 6/15/2018 11:44 AM
192.168.8.168	2350	7	Chairman	1	4		1						1
192.168.8.175	1970	5	H. Eng. Room	1	3			1					
192.168.8.176	1100	9	Head of HR & Admin	1	9		1						1
192.168.8.179	1100	9	Chief FO	1	8		1						1
192.168.8.180	1100	8	GM	1	7		1						1
192.168.8.181	3670	5	Server room	1	1			1					
192.168.8.182	1190	7	Head of Operations	1	6			1					1
192.168.8.154	1172	4	SDM	2	9		1					1	
192.168.8.157	1910	1	SOM	2	7		1					1	
192.168.8.167	860	9	CSM	2	11		1					1	
192.168.8.177	1900	8	PM	2	8		1					1	
192.168.8.188	1350	3	Conference Room	2	8		1					1	
192.168.8.189	1340	8	RM	2	8		1					1	
192.168.8.190	2367	1	DCC (middle)	2	5		1						1
192.168.8.146	2300	5	SOD	3	14					1			
192.168.8.147	1100	9	Control Engineer	3	15			1					1
192.168.8.148	2000	8	Finance dept. common	3	15			1					1
192.168.8.149	6400	7	IT manager	3	10					1			
192.168.8.150	5500	1	IT 3rd Floor	3	7		1					1	
192.168.8.151	1550	6	SDD1	3	15			1					1
192.168.8.152	1150	3	SDD2 (3)	3	14				1				
192.168.8.153	2340	1	Common area	3	9	1						1	
192.168.8.155	1800	5	Control room	3	15				1				
192.168.8.156	1300	3	Photocopy room	3	14					1			
192.168.8.158	2600	6	Finance dept.	3	13				1				
192.168.8.159	2700	6	Corporate office	3	13					1			
192.168.8.160	6150	3	Reception	3	6	1					1		

192.168.8.161	1970	8	Library	3	15			1					1
192.168.8.162	6150	3	Admin Office	3	6	1					1		
192.168.8.163	3200	1	Auditorium 1 (right)	3	9	1						1	
192.168.8.164	2840	9	SDD2 (middle)	3	15			1					1
192.168.8.165	2400	8	Library 2	3	15				1				
192.168.8.166	1930	8	Corporate office assistant	3	15			1					1
192.168.8.169	1600	9	CSD	3	15			1					1
192.168.8.170	1010	1	Call center	3	13						1		
192.168.8.171	825	6	SDD2 (left)	3	15			1					1
192.168.8.172	2350	7	SDD2 (right)	3	15				1				
192.168.8.173	2480	7	Auditorium 1 (left)	3	14				1				
192.168.8.174	1100	4	Accountant Treasury	3	15				1				
192.168.8.178	1100	4	Financial Accountant	3	15				1				
192.168.8.183	2500	6	Operations Division	3	13				1				
192.168.8.184	1970	2	IT Development unit	3	12						1		
192.168.8.185	3460	4	Supply Department	3	10						1		
192.168.8.186	2200	1	Supply Department (right)	3	9	1						1	
192.168.8.187	1700	3	Lunch Room 1	3	13					1			
192.168.8.191	1900	1	DCC (corner)	3	10	1						1	
192.168.8.192	1290	1	Chief Internal Auditor - IAD (right)	3	11	1						1	
192.168.8.193	1650	3	Chief Internal Auditor - IAD (left)	3	13					1			
192.168.8.194	3100	7	new admin office 1	3	12				1				
192.168.8.195	2200	2	new admin office 2	3	10						1		

ip Address	Rated Watt value	Off time	Location	Priority	Off count	event at: 6/15/2018 11:45 AM	event at: 6/15/2018 11:48 AM	event at: 6/15/2018 11:50 AM	event at: 6/15/2018 2:09 PM	event at: 6/15/2018 2:10 PM	event at: 6/15/2018 2:11 PM	event at: 6/15/2018 2:12 PM	event at: 6/15/2018 2:13 PM
192.168.8.168	2350	7	Chairman	1	4								
192.168.8.175	1970	5	H. Eng. Room	1	3	1							
192.168.8.176	1100	9	Head of HR & Admin	1	9								
192.168.8.179	1100	9	Chief FO	1	8								
192.168.8.180	1100	8	GM	1	7								
192.168.8.181	3670	5	Server room	1	1								
192.168.8.182	1190	7	Head of Operations	1	6								
192.168.8.154	1172	4	SDM	2	9								
192.168.8.157	1910	1	SOM	2	7								
192.168.8.167	860	9	CSM	2	11								1
192.168.8.177	1900	8	PM	2	8								
192.168.8.188	1350	3	Conference Room	2	8								
192.168.8.189	1340	8	RM	2	8								
192.168.8.190	2367	1	DCC (middle)	2	5								
192.168.8.146	2300	5	SOD	3	14		1					1	
192.168.8.147	1100	9	Control Engineer	3	15				1				
192.168.8.148	2000	8	Finance dept. common	3	15				1				
192.168.8.149	6400	7	IT manager	3	10			1					1
192.168.8.150	5500	1	IT 3rd Floor	3	7								
192.168.8.151	1550	6	SDD1	3	15					1			
192.168.8.152	1150	3	SDD2 (3)	3	14	1					1		
192.168.8.153	2340	1	Common area	3	9								
192.168.8.155	1800	5	Control room	3	15	1				1			
192.168.8.156	1300	3	Photocopy room	3	14		1				1		
192.168.8.158	2600	6	Finance dept.	3	13	1					1		
192.168.8.159	2700	6	Corporate office	3	13		1				1		
192.168.8.160	6150	3	Reception	3	6								

192.168.8.161	1970	8	Library	3	15				1				
192.168.8.162	6150	3	Admin Office	3	6								
192.168.8.163	3200	1	Auditorium 1 (right)	3	9								
192.168.8.164	2840	9	SDD2 (middle)	3	15					1			
192.168.8.165	2400	8	Library 2	3	15	1				1			
192.168.8.166	1930	8	Corporate office assistant	3	15				1				
192.168.8.169	1600	9	CSD	3	15				1				
192.168.8.170	1010	1	Call center	3	13		1					1	
192.168.8.171	825	6	SDD2 (left)	3	15				1				
192.168.8.172	2350	7	SDD2 (right)	3	15	1				1			
192.168.8.173	2480	7	Auditorium 1 (left)	3	14	1					1		
192.168.8.174	1100	4	Accountant Treasury	3	15	1			1				
192.168.8.178	1100	4	Financial Accountant	3	15	1					1		
192.168.8.183	2500	6	Operations Division	3	13	1						1	
192.168.8.184	1970	2	IT Development unit	3	12			1					1
192.168.8.185	3460	4	Supply Department	3	10			1					
192.168.8.186	2200	1	Supply Department (right)	3	9								
192.168.8.187	1700	3	Lunch Room 1	3	13		1					1	
192.168.8.191	1900	1	DCC (corner)	3	10								
192.168.8.192	1290	1	Chief Internal Auditor - IAD (right)	3	11								
192.168.8.193	1650	3	Chief Internal Auditor - IAD (left)	3	13			1					1
192.168.8.194	3100	7	new admin office 1	3	12	1						1	
192.168.8.195	2200	2	new admin office 2	3	10								

ip Address	Rated Watt value	Off time	Location	Priority	Off count	event at: 6/15/2018 2:14 PM	event at: 6/15/2018 2:15 PM	event at: 6/15/2018 2:16 PM	event at: 6/15/2018 2:17 PM	event at: 6/15/2018 2:43 PM	event at: 6/15/2018 2:56 PM	event at: 6/15/2018 2:57 PM	event at: 6/15/2018 2:58 PM
192.168.8.168	2350	7	Chairman	1	4								
192.168.8.175	1970	5	H. Eng. Room	1	3								
192.168.8.176	1100	9	Head of HR & Admin	1	9				1				
192.168.8.179	1100	9	Chief FO	1	8				1				
192.168.8.180	1100	8	GM	1	7								
192.168.8.181	3670	5	Server room	1	1								
192.168.8.182	1190	7	Head of Operations	1	6								
192.168.8.154	1172	4	SDM	2	9			1					
192.168.8.157	1910	1	SOM	2	7				1				
192.168.8.167	860	9	CSM	2	11								1
192.168.8.177	1900	8	PM	2	8			1					
192.168.8.188	1350	3	Conference Room	2	8				1				
192.168.8.189	1340	8	RM	2	8			1					
192.168.8.190	2367	1	DCC (middle)	2	5								
192.168.8.146	2300	5	SOD	3	14								1
192.168.8.147	1100	9	Control Engineer	3	15					1	1		
192.168.8.148	2000	8	Finance dept. common	3	15					1		1	
192.168.8.149	6400	7	IT manager	3	10								
192.168.8.150	5500	1	IT 3rd Floor	3	7				1				
192.168.8.151	1550	6	SDD1	3	15						1		
192.168.8.152	1150	3	SDD2 (3)	3	14								1
192.168.8.153	2340	1	Common area	3	9	1							
192.168.8.155	1800	5	Control room	3	15							1	
192.168.8.156	1300	3	Photocopy room	3	14								1

192.168.8.158	2600	6	Finance dept.	3	13								1
192.168.8.159	2700	6	Corporate office	3	13								1
192.168.8.160	6150	3	Reception	3	6		1						
192.168.8.161	1970	8	Library	3	15					1		1	
192.168.8.162	6150	3	Admin Office	3	6			1					
192.168.8.163	3200	1	Auditorium 1 (right)	3	9		1						
192.168.8.164	2840	9	SDD2 (middle)	3	15							1	
192.168.8.165	2400	8	Library 2	3	15							1	
192.168.8.166	1930	8	Corporate office assistant	3	15					1		1	
192.168.8.169	1600	9	CSD	3	15					1	1		
192.168.8.170	1010	1	Call center	3	13								
192.168.8.171	825	6	SDD2 (left)	3	15					1		1	
192.168.8.172	2350	7	SDD2 (right)	3	15							1	
192.168.8.173	2480	7	Auditorium 1 (left)	3	14							1	
192.168.8.174	1100	4	Accountant Treasury	3	15							1	
192.168.8.178	1100	4	Financial Accountant	3	15							1	
192.168.8.183	2500	6	Operations Division	3	13								1
192.168.8.184	1970	2	IT Development unit	3	12								
192.168.8.185	3460	4	Supply Department	3	10	1							
192.168.8.186	2200	1	Supply Department (right)	3	9		1						
192.168.8.187	1700	3	Lunch Room 1	3	13								1
192.168.8.191	1900	1	DCC (corner)	3	10	1							
192.168.8.192	1290	1	Chief Internal Auditor - IAD (right)	3	11	1							
192.168.8.193	1650	3	Chief Internal Auditor - IAD (left)	3	13								1
192.168.8.194	3100	7	new admin office 1	3	12								1
192.168.8.195	2200	2	new admin office 2	3	10	1							

ip Address	Rated Watt value	Off time	Location	Priority	Off count	event at: 6/15/2018 3:00 PM	event at: 6/15/2018 3:01 PM	event at: 6/15/2018 3:12 PM	event at: 6/15/2018 3:16 PM	event at: 6/15/2018 3:55 PM	event at: 6/15/2018 3:56 PM
192.168.8.168	2350	7	Chairman	1	4						
192.168.8.175	1970	5	H. Eng. Room	1	3						
192.168.8.176	1100	9	Head of HR & Admin	1	9						
192.168.8.179	1100	9	Chief FO	1	8						
192.168.8.180	1100	8	GM	1	7						
192.168.8.181	3670	5	Server room	1	1						
192.168.8.182	1190	7	Head of Operations	1	6						
192.168.8.154	1172	4	SDM	2	9						
192.168.8.157	1910	1	SOM	2	7						
192.168.8.167	860	9	CSM	2	11						
192.168.8.177	1900	8	PM	2	8						
192.168.8.188	1350	3	Conference Room	2	8						
192.168.8.189	1340	8	RM	2	8						
192.168.8.190	2367	1	DCC (middle)	2	5						
192.168.8.146	2300	5	SOD	3	14						
192.168.8.147	1100	9	Control Engineer	3	15			1		1	
192.168.8.148	2000	8	Finance dept. common	3	15			1		1	
192.168.8.149	6400	7	IT manager	3	10	1					
192.168.8.150	5500	1	IT 3rd Floor	3	7						
192.168.8.151	1550	6	SDD1	3	15				1		1
192.168.8.152	1150	3	SDD2 (3)	3	14						
192.168.8.153	2340	1	Common area	3	9	1					
192.168.8.155	1800	5	Control room	3	15				1		
192.168.8.156	1300	3	Photocopy room	3	14						
192.168.8.158	2600	6	Finance dept.	3	13						

192.168.8.159	2700	6	Corporate office	3	13						
192.168.8.160	6150	3	Reception	3	6		1				
192.168.8.161	1970	8	Library	3	15			1		1	
192.168.8.162	6150	3	Admin Office	3	6		1				
192.168.8.163	3200	1	Auditorium 1 (right)	3	9		1				
192.168.8.164	2840	9	SDD2 (middle)	3	15				1		1
192.168.8.165	2400	8	Library 2	3	15				1		1
192.168.8.166	1930	8	Corporate office assistant	3	15				1	1	
192.168.8.169	1600	9	CSD	3	15			1		1	
192.168.8.170	1010	1	Call center	3	13	1					
192.168.8.171	825	6	SDD2 (left)	3	15			1		1	
192.168.8.172	2350	7	SDD2 (right)	3	15				1		
192.168.8.173	2480	7	Auditorium 1 (left)	3	14				1		
192.168.8.174	1100	4	Accountant Treasury	3	15			1			1
192.168.8.178	1100	4	Financial Accountant	3	15				1		
192.168.8.183	2500	6	Operations Division	3	13						
192.168.8.184	1970	2	IT Development unit	3	12	1					
192.168.8.185	3460	4	Supply Department	3	10	1					
192.168.8.186	2200	1	Supply Department (right)	3	9	1					
192.168.8.187	1700	3	Lunch Room 1	3	13						
192.168.8.191	1900	1	DCC (corner)	3	10		1				
192.168.8.192	1290	1	Chief Internal Auditor - IAD (right)	3	11		1				
192.168.8.193	1650	3	Chief Internal Auditor - IAD (left)	3	13						
192.168.8.194	3100	7	new admin office 1	3	12						
192.168.8.195	2200	2	new admin office 2	3	10	1					