Prospects of Internet of Things (IoT) in Energy Sector of Bangladesh

(In fulfillment of the requirement of Doctor of Philosophy Faculty of Business Studies, University of Dhaka)

Md. Khashrul Alam

Department of Management Information Systems
PhD Program
Reg. No: 19/2017-2018
Faculty of Business Studies
University of Dhaka

DEPARTMENT OF MANAGEMENT INFORMATION SYSTEMS
FACULTY OF BUSINESS STUDIES
UNIVERSITY OF DHAKA
DHAKA, BANGLADESH

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DEPARTMENT OF MANAGEMENT INFORMATION SYSTEMS

Faculty of Business Studies

University of Dhaka

Dhaka, Bangladesh

Under the Supervision of

Dr. M. Helal Uddin Ahmed
Professor
DEPARTMENT OF MANAGEMENT INFORMATION SYSTEMS
Faculty of Business Studies
University of Dhaka
Dhaka, Bangladesh

A THESIS SUBMITTED TO THE DEPARTMENT OF MANAGEMENT INFORMATION SYSTEMS OF THE UNIVERSITY OF DHAKA, BANGLADESH FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN MANAGEMENT INFORMATION SYSTEMS.

Certificate from Supervisor

This is to certify that Md. Khashrul Alam has completed the thesis titled "**Prospects of Internet of Things (IoT) in Energy Sector of Bangladesh**" for the award of the degree of Doctor of Philosophy (PhD). I was his supervisor throughout the program. I do also state that he has not submitted the thesis for the award of any degree or diploma in any other university or institution. The thesis is entirely an independent work which has been conducted by Md. Khashrul Alam.

Professor Dr. M. Helal Uddin Ahmed
Thesis Supervisor
Department of Management Information Systems
Faculty of Business Studies
University of Dhaka

Declaration

I do hereby state that the thesis titled "Prospects of Internet of Things (IoT) in Energy Sector of Bangladesh" submitted to the university of Dhaka, for the award of the degree of Doctor of Philosophy (PhD). Professor Dr. M. Helal Uddin Ahmed of the Department of Management Information Systems, University of Dhaka was my honorable supervisor. This work has been completed by the guidance and supervision of my supervisor. I do also declare that I have not submitted the thesis earlier in any other university or institution for the award of any degree, diploma, or award.

………………………

Md. Khashrul Alam

DEDICATED TO

My Parents

&

My Family

ABSTRACT

The intention of this study is to investigate the Prospects of Internet of Things (IoT) in Energy Sector of Bangladesh. An IoT-based Air Condition system has been considered for the study. The study has been conducted to know technical, economic and environmental prospects of IoT in energy sector in Bangladesh. Air Conditioners (ACs) have been selected for this study as it consumes higher amount of electricity than other electronic devices in both offices and residential buildings. IoT enabled ACs have been considered to know the prospects in energy sector. To achieve the stated objectives, different methods such as experiment, observation and in-depth interview have been used in this study.

Experiment is conducted to know the power consumption and impact of IoT in different temperature settings in ACs. The study has been conducted in different offices of both Dhaka and Khulna University for several months in 2019 and 2021.Experiment is carried out in summer season of Bangladesh. The study was conducted in a decentralized cooling environment where energy optimization was constrained by human comfort level. Observations are carried out to understand users preferred set temperature for ACs.

In addition to that the study endeavors to gain insights into the prospects of Internet of things in Energy sector of Bangladesh through qualitative in-depth interview. In-depth interview has been administered among the experts from power development board, Air conditioner manufacturer and University. They were from west zone power distribution, Dhaka and Khulna University and Walton Bangladesh.

The study uses auto-regressive machine learning and other techniques to capture and record data from various sources. The smart system predicts which temperature setting can meet the desired energy saving given the present temperature and humidity of indoor and outdoor, specific day and time of the week. An auto-regressive machine learning model was trained to predict optimal action for the given level of cost saving. Collected data have been carefully organized and analyzed using MS excel and Python programming language.

The result shows, LSTM model could predict the discrete optimal control signal for 3 air-conditioner with 94% accuracy. Although the work was not applied to centralized air-conditioning system, the author believes, with extensive amount of data, the model can learn optimal saving strategies in centralized setting.

The study reveals that IoT enabled ACs save energy, reduce $CO2$ emission significantly without compromising users' comfort level. Major findings of the of the study are: significant level of savings such as 26.1%-30% energy consumption reduction and nearly 129885 tons of $CO2$ emission reduction is possible with the help of IoT enabled ACs in energy sector in Bangladesh. The study is significant as the prediction model showed enormous potential to save energy as well as reduce the carbon emission in a significant way. It also reveals that savings of energy through use of IoT in ACs varies as per the behavior of the users. At the end of this thesis paper policy recommendations, future research direction and limitations of the study are articulated.

[**Key words: Internet of Things, Sensors, Energy, Temperature, Smart Control, Humidity, Air condition, Consumption, Comfort**]

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INTRODUCTION

1.1 Overview

Introduction chapter focuses on the background of the study with a brief description of IoT and energy sector of Bangladesh. It also depicts research objectives, research methodology, research questions, statement of the problem and contribution of the study. A brief description of each chapter is shown in the end of the chapter.

Nowadays, efficient usage of energy is a big concern among the general masses due to the rising concerns about load shedding, limited power generation, environmental and regulatory requirements. Domestic, industry and commercial sectors are the major consumers of energy sectors. Consumption pattern of BPDB's as per fiscal year 2019-20 is in domestic sector was 45.91%, followed by the industry and commercial, which are 37.03% and 12.77%, respectively(BPDB, 2020). Successful energy management depends largely on the promptness to access energy information and energy efficiency can be achieved by effectively analyzing such real-time data.

In 1999 by IoT concepts is primarily attributed to British technology pioneer Kevin Ashton. At first in 1999, he used this new emerging technology, Internet-of-Things (IoT). This is a technology that connects physical objects using electronic sensors. (EMA, 2015). Internet of Things describes a system where objects are connected to the Internet by sensors.

Corporate supply chain uses the term to explain RFID tags link with the Internet. This is done with a view to count and track goods without the need for human involvement. The

Internet of Things (IoT) was primarily proposed to refer to uniquely identifiable interoperable connected objects with radio-frequency identification (RFID) technology (Van Kranenburg, 2008). Afterwards, researchers relate IoT with other technologies such as sensors, actuators, GPS devices, and mobile devices.

Today, Internet connectivity and IT capability to a variety of objects, devices, sensors, and everyday items that are connected with IoT has become a common phenomenon. As a result, popularity of IoT is increasing day by day. The pace of integration of IoT technology is faster than anything else. The solid foundation of IoT depends on the integration of sensors/actuators, RFID tags, and communication technologies and it explains how a variety of objects and devices around us can be linked to the Internet and allow these objects and devices to cooperate and communicate with one another to reach common goals (Jun, 2014). Researchers from academia, industry, and government in recent years are giving much attention on this technology.

There is a great expectation that IoT will easily monitor, control and identify other things automatically. This objects can communicate with each other through Inherent, and can even make decisions by themselves (Uckelmann, 2012).

The IoT technologies incorporate various technologies and devices. As for example, barcodes, smart phones, social networks, and cloud computing which are used to form an extensive network for supporting IoT which are shown in the following diagram (Atzori et al., 2010; Da Xu et al., 2014; Q. Li et al., 2013; S. Li et al., 2012). These technologies often resemble as a vision with technological and social implications.

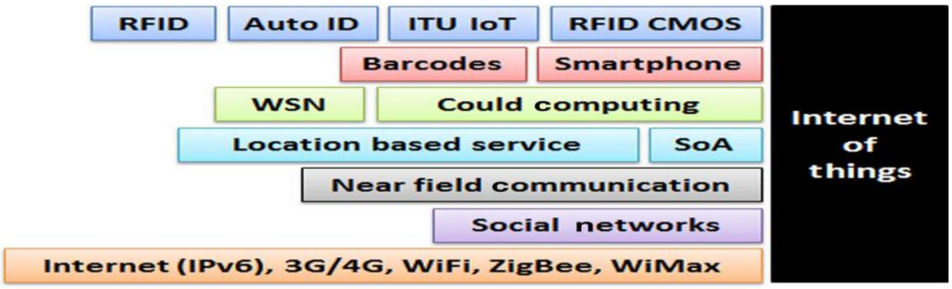

Fig1.1. Technologies associated with IoT.
Source: Atzori et al., 2010

Energy sector includes electricity generation, distribution and consumption. Electricity plays major role in economic growth of a country. United Nations Sustainable Development Goals agenda (New York, 2019), considers energy efficiency is one of the key drivers of sustainable development. In addition to that, economic benefits can be gained in long-term through reducing the cost of fuel imports/supply, energy generation, and reducing emissions from the energy sector. For optimal energy efficiency and an efficient energy management, an effective analysis of the real-time data in the energy supply chain plays a key role (Tan et al., 2017).

The energy supply chain consists of three major parts. Such as: (i) energy supply including upstream refinery processes; (ii) energy transformation processes including transmission and distribution (T&D) of energy carriers; and (iii) energy demand side (Subhes, 2011).

Figure 1.2 shows these three parts with their relevant components.

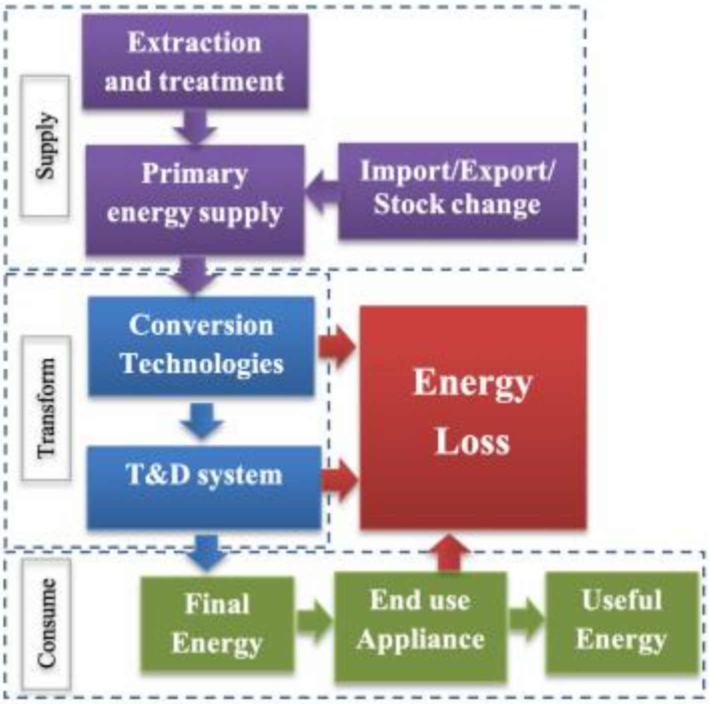

Fig. 1.2. Energy supply chain.

Source: Tamilselvan & Thangaraj, 2020)

IoT employs sensors and communication technologies for sensing and transmitting real-time data, which enables fast computations and optimal decision-making (Tamilselvan & Thangaraj, 2020). Moreover, IoT can help the energy sector to transform from a centralized to a distributed, smart, and integrated energy system. It also helps to collect large volume of data and use of intelligent algorithms. That means real-time data analysis is possible and lets the providers to monitor energy consumption patterns of different users and devices in different time zone. As a result controlling the consumptions become efficient (Motlagh et al., 2018).

For ensuring economic growth, reliable and environmentally friendly electricity supply is a must. But in Bangladesh, power supply is not reliable. Significant amount of system losses, power plant completion delays which is far beyond schedule, unpredictable power supply, pilferage of electricity, blackouts, and shortages of funds for power plant maintenance have made the power sector more vulnerable.

In general, over the last ten years, the nation's electric generation facilities have not been able to fulfill system demand. According to the annual report 2019-20 of Bangladesh power development board, country's total installed electricity generation capacity (including captive power) was 15,351 MW as of January 2017. Average 77.9% population has the access to the electricity in Bangladesh. The figures show the electricity consumption pattern and generation capacity of Bangladesh.

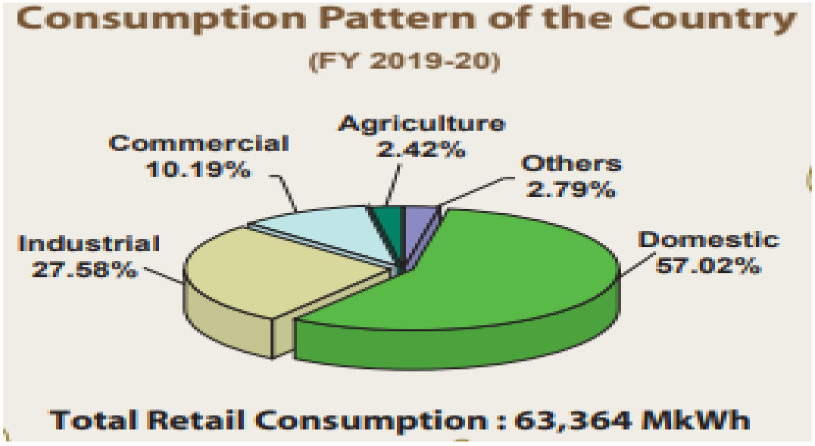

Fig1.3. Retail consumption pattern:
Source: Annual report 2019-20, Bangladesh power development board

Table 1.1. Power generation capacity

Installed Capacity by Plant & Fuel Type			
By type of plant		By type of Fuel	
Hydro	230 MW (1.86%)	Gas	7,628 MW (61.69%)
Steam Turbine	2,578 MW (20.83%)	Furnace Oil	2,629 MW (21.26%)
Gas Turbine	1,193 MW (9.65%)	Diesel	1028 MW (8.31%)
Combined Cycle	3,293 MW (29.63%)	Power Import	600 MW (4.85%)
Power Import	600 MW (4.85%)	Hydro	230 MW (1.86%)
Reciprocating Engine	4,471 MW (36.16%)	Col	250 MW (2.02%)
Total	12,365 MW (100%)	Total	12,365 MW (100%)

Source: Annual Report 2019-2020, Bangladesh power development board

Bangladesh is an increasing power demanding nation and its per capita power consumption is one of the lowest in the world. As of June 2020, Per capita electricity generation is 426.23 kWh and per capita electricity consumption is 378.16 kWh (BPDB, 2020).

Table 1.2. Per Capita generation and consumption

Year	Total Generation	Total Population	Total Sale	Per Capita Generation (kWh)	Per Capita Consumption (kWh)
2015-16	52,193	160	45,299	326.41	283.30
2016-17	52,276	162	50,264	354.10	310.75
2017-18	62,677	164	55,103	383.00	336.71
2018-19	70,533	166	62,037	426.05	374.73
2019-20	71,419	168	63,364	426.23	378.16

Source: Annual Report 2019-2020, Bangladesh power development board

Heightened level of awareness regarding IoT technologies is evolving throughout the world in a rapid and dynamic way. It's revolutionary concept that everyone should monitor and react to those technologies (Aria Systems Inc., 2016). IoT is getting popularity among many applications domains. Applications of IoT in energy sector is just another application domain. Energy management sector is integrated with IoT technology with a view to monitor real time power consumption and energy performance (Bhardwaj, 2015; Karnouskos et al., 2009).

Energy consumption data in real-time at different time and levels, such as machine, production line or facility level can be captured by IoT technology (Tao, Zuo, Da Xu, &

Zhang, 2014). However, collection of these data will be effective only when production or operating data are considered. (Shrouf et al., 2014; Tao, Zuo, Da Xu, Lv, et al., 2014).

In this study, attempts have been made to explore the prospects of IoT in energy sector of Bangladesh. Particularly, the study has been conducted to know the economic impact of IoT in ACs at different offices in various locations of Bangladesh. The research considers ACs, as it consumes most power both in house and office. The study tries to understand the use of IoT in ACs and its impact in reducing level of energy consumption and carbon di -oxide emission in Bangladesh.

1.2 Statement of the Problem

A few numbers of research have been conducted in developed and developing nations including Bangladesh regarding IoT and its applications among various sectors. Literature review shows that research on the application of IoT, in energy sector is limited. In earlier research, the technological views of IoT in various organizations were the primarily focus. In fact, none of the studies regarding IoT & its prospects in energy sector have been conducted in Bangladesh.

1.3 Research Questions

The study's main question for investigation is: What are the prospects of IoT in energy sector of Bangladesh in terms of economic environmental and technical perspectives? Below are some additional research-related queries:

i. What are the major technologies behind IoT?
ii. What are the major applications of IoT in Energy Sectors?

iii. What is the present status of IoT in energy sector?
iv. What are the values users considering while adopting IoT?

1.4 Objectives of the Study

General Objective:

The main objective of the study is to know the prospects of IoT in energy sector of Bangladesh.

Specific Objectives:

With a view to accomplish the objectives, the researcher tries to know economic and environmental prospects of IoT in Air Conditioners of various offices in Bangladesh. Air Conditioners have been selected as it consumes more electricity than any other electronic appliances. Therefore, the study has been initiated with a view to attain the following objectives.

i. To know the preferred set temperatures in centigrade users usually set while turning on the ACs by the users.
ii. To explore and analyze economic and environmental prospects of IoT in energy sector of Bangladesh. Particularly it will try to reveal economic prospects of Internet of things in ACs as it consumes most electricity.
iii. To explore the level of $CO2$ emission reduction through IoT introduction in ACs in Bangladesh.

1.5 Methodology

Multiple research approaches have been followed throughout the study period. Both quantitative and qualitative techniques have been used in this study. The study was conducted during March to October 2019 in Khulna University and April to July, 2021 in Dhaka University. The researcher selected these months of the year as these months are mostly hot and temperature is high i.e., above 30 degrees centigrade in Bangladesh. Several offices of both Dhaka and Khulna University have been selected for the study.

Experiment was conducted in between two variables i.e., level of energy consumption as dependent variables and IoT enabled on/off scheduling, and temperature adjustment as independent variables. Proposed research model (shown in figure below) contains 3 factors consisting of IoT enabled on/off scheduling, users' comforts adjustment and temperature adjustment.

During the study IoT technologies, number of sensors, RFID and other technologies are connected with air conditioners with a view to know the electricity consumption pattern. As for example when there will be no users/person in the room or office IoT will turn off the switches of electronic devices or it will adjust the temperature of air condition devices and thereby saves energy.

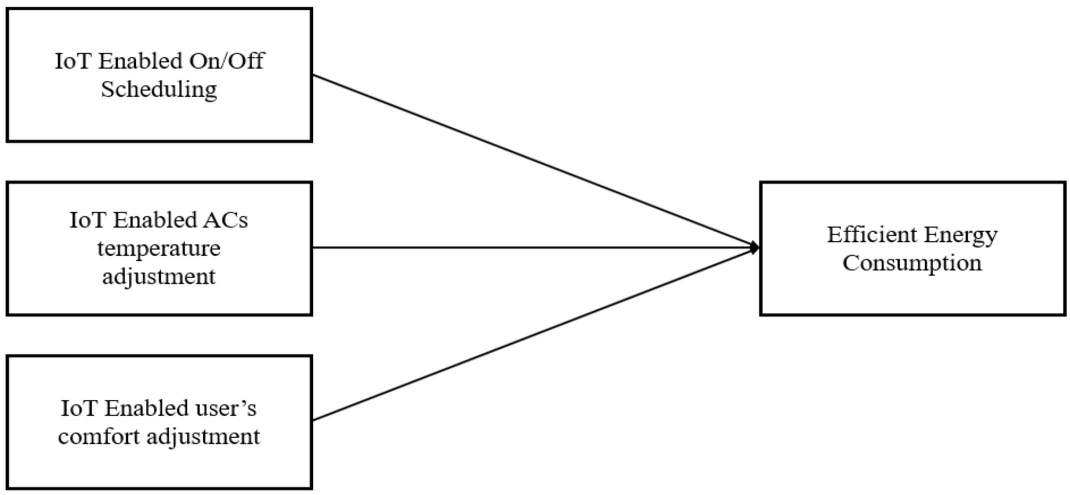

Fig. 1.4. IoT enabled AC's Efficient Energy Consumption Model
Source: Author's own compilation from different sources

So, the factors like IoT enabled on off scheduling, AC's temperature adjustment and users' comfort adjustment work as a catalyst of efficient energy consumption.

The experiment was conducted in a decentralized cooling environment where energy optimization was constrained by human comfort level. Based on that collected data, total savings of electricity will be calculated and subsequently economic analysis will be performed upon the collected data.

In addition to that, optimal energy savings are calculated through the use of Long Short-Term Memory (LSTM) model. Compared to traditional RNNs, Long Short-Term Memory is an enhanced recurrent neural network (RNN) architecture that was created to better accurately simulate chronological sequences and their long-range relationships. The sensors enable IoT predicts which temperature setting can meet the desired energy saving given the present temperature and humidity of indoor and outdoor, specific day and time of the week. An auto-regressive machine learning model was trained to predict optimal action for the given level of cost saving.

Although the work was not applied to centralized air-conditioning system, the author believes, with extensive amount of data, the model can learn optimal saving strategies in centralized setting.

For qualitative study, in-depth interview has been conducted among some experts to know the overall prospects of IoT in energy sector of Bangladesh. Experts have been selected from university, AC manufacturing plant and west zone power distribution company of Bangladesh.

1.6 Contribution of the study

1.6.1 *Contribution to theory and knowledge*

Despite the fact that there is plenty of scope to examine IoT's potential in many Bangladeshi industries, the earlier studies fell short of substantially addressing this problem. Therefore, it is expected that this study will be a successful extension of the present body of knowledge. Besides that, past studies did not cover (i) IoT and its prospects in energy sector (ii) impact of IoT in energy consumption and carbon-di-oxide emission. (iii) clear cut guidelines to deploy IoT in energy sector and its prospects in terms of economic and environmental perspectives in Bangladesh. It is expected that the study will overcome these gaps. So, the researcher thinks that this study will add more with the information and knowledge already in existence.

1.6.2 Contribution to practitioners

Previous studies did not provide economic, technical and environmental prospects of IoT in Energy sector in Bangladesh. Therefore, this research was started in an effort to construct several frameworks in response to the study's developing findings as well as to learn the answers to these issues. These might serve as guidelines for professionals like the authority on electricity generation., energy distribution department, manufacturers and electricity users, Additionally, the researcher thinks that the results will help policymakers comprehend the significance of IoT applications in the energy sectors.

1.7 Structure of the Dissertations

There are eight chapters in the research study. The first chapter of the thesis covers introduction, problem in perspective, objectives of the study, methodology in general orientation, and a brief description on contribution of the study.

Literature review from research related fields, including IoT in various sectors have been shown in chapter two. Here IoT meaning, IoT solution architecture, IoT prospects and application and review of related work are shown. This chapter starts with a review of theoretical literature of the topic under study and discussion of theoretical literature, empirical literature and summary of the literature review in the light of problem statement.

Chapter three delineates the methodology of the study. The appropriate research technique, philosophical aspects and different research design have been elaborated over here. Later choice of methodologies and experimental design with system architecture of IoT enabled ACs in offices are explained. Data collection methods and techniques are spelled out subsequently.

Chapter four explains the energy sector of Bangladesh and digital transformation of its various sub sector. Major digital transformation in energy sector is discussed under this chapter. It also tries to show the level IoT use in energy sector of Bangladesh.

Chapter Five represents collected data and its presentation. Here data are analyzed using quantitative data techniques and presented sequentially to get an insight to the experiment.

Quantitative analysis is performed in chapter six. The major concern of this chapter is to apply Long Short-Term Memory (LSTM) model and find out the energy efficiency in IoT enabled ACs. The chapter begins with the descriptions about the LSTM and prediction through some statistical and machine learning models. Later energy consumption, savings scenarios and other aspects are articulated through using python programming and LSTM techniques.

Chapter seven is designed to analyze the experts' opinion regarding prospects of Internet of things in Air Conditioners in Bangladesh. Experts have been asked to give opinion on various aspects of Internet of Thing and its prospects in ACs.

In chapter eight concluding remarks are made based on previous three chapters (Chapter v, vi, & vii). Here major findings, policy recommendations, limitations and directions of future research are mentioned.

CHAPTER TWO

REVIEW OF LITERATURE

CHAPTER TWO

REVIEW OF LITERATURE

2.0 Introduction

The chapter focuses on existing literatures regarding IoT and its different aspects that are related with the study. The chapter attempts to explore IoT meaning, IoT solution architecture, IoT prospects and application and review of related work. A review of theoretical literature of the topic and empirical literature in the light of problem statement are discussed in this chapter.

2.1 IoT Meaning

"Internet of Things" (IoT) can be defined as a system in which sensor enabled objects are connected to the Internet (R. Liu & Wang, 2017). In another words IoT can be defined as a network that connects uniquely identifiable 'Things' to the Internet. The 'Things' can sense and have programing capabilities. 'Thing' can be changed from anywhere, anytime, by anything.

In general, the Internet of Things is known as a computer base network linked with sensors and actuators. The technology can monitor or manage the wellbeing and activities of connected objects and machines. Linked sensors can also track the natural world, people, and animals (Qibo et al., 2010). The IoT consists of physical objects (or "things") which embed electronics, software, sensors, and communication components, enabling them to collect and exchange data. Physical things are no longer separated from the virtual world, but connected to the Internet. They can be accessed remotely, i.e., monitored, controlled and even made to act. Ideas resembling the IoT reach back to the year 1988, starting with the field of ubiquitous computing.

In 1991, Mark Weiser framed his ideas for the computer of the 21st century. Weiser envisioned computers being small enough to vanish from our sight, becoming part of the background, so that they are used without further thinking. Rooms would host more than 100 connected devices, which could sense their environment, exchange data and provide human beings with information similar to physical signs, notes, paper, boards, etc. Devices would need self-knowledge, e.g., of their location.

Many of Weiser's original ideas can still be found in current definitions of the IoT and requirements for according devices. For example, Mattern and Floerke Meier (Mattern & Floerkemeier, 2010) enumerate similar capabilities needed to bridge the gap between the virtual and physical world. Objects must be able to communicate and cooperate with each other, which requires addressability, unique identification, and localization. Objects may collect information about their surroundings and they may contain actuators for manipulating their environment. Objects can embed information processing, featuring a processor or microcontroller, and storage.

In fact, the history of the IoT itself started in 1999, with the work on Radio-frequency identification (RFID) technology by the Auto-ID Center of the Massachusetts Institute of Technology (MIT) (Evans, 2011; Mattern & Floerkemeier, 2010). In a Cisco whitepaper, Dave Evans (2011) estimates that the IoT came into real existence between 2008 and 2009, when the number of devices connected to the Internet began to exceed the number of human beings on earth. Many of such devices were mobile phones, after in 2007, Steve

Jobs had unveiled the first iPhone at Macworld conference. Since then, more and more devices are getting connected.

It is estimated that by 2020, the IoT consists of almost 50 billion objects (Mattern & Floerkemeier, 2010). The World Wide Web (WWW) fundamentally changed in at least four stages (Mattern & Floerkemeier, 2010). First, the web was called the Advanced Research Projects Agency Network (ARPANET) and foremost used by academia. The second stage was characterized by companies acquiring domain names and sharing information about their products and services. The "dot-com" boom may be called the third stage. Web pages moved from static to interactive transactional applications that allowed for selling and buying products online.

The "social" or "experience" web marks the current fourth stage, enabling people to communicate, connect and share information. In comparison, Internet’s underlying technology and protocols have gradually improved, but didn’t change fundamentally. Now, connecting billions of physical things, crossing borders of entirely different types of networks poses new challenges to Internet’s technologies and communication protocols. This is why the IoT was called the first evolution of the Internet (Mattern & Floerkemeier, 2010). As did the Internet, the IoT has the potential to change our lives in fundamental ways.

2.2 **The Internet of Things Solution Architecture**

The IoT solution architecture comprises the following sub components (Vishwanath, Chandan, et al., 2019).

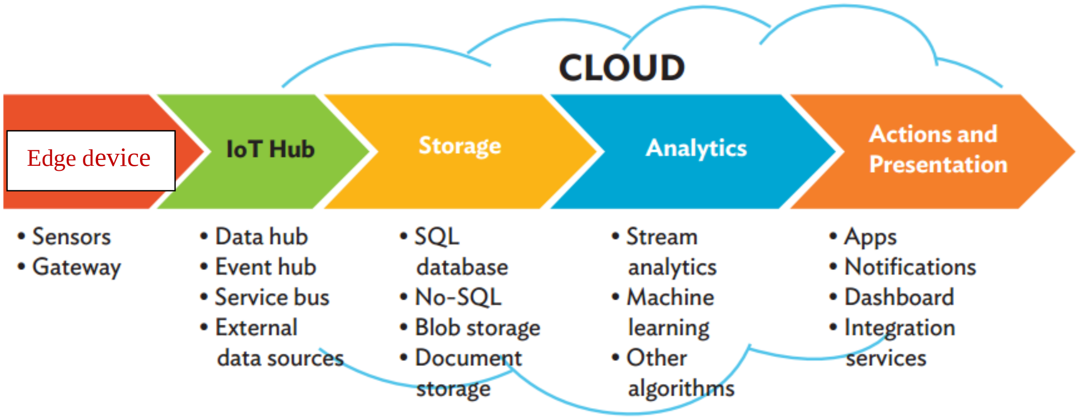

Fig.2.1. IoT Solution Architecture
Source: (Vishwanath, Chandan, et al., 2019)

- Edge devices: It is a collection of dissimilar devices and technologies. It helps to measure the state of assets, gather, aggregate and perform limited data analysis, and send to gateway devices.
- Except edge device, the IoT industry has a standardized and cloud-based Platform as a service (PaaS) for the remaining components. There are several reputed Providers of PaaS. Some them are:
    - Bluemix-IoT of IBM
    - MS Azure-IoT and
    - SAP IoT
    - HANA-IoT

2.3 Applications of IoT and Its prospect

IoT has a wide variety of applications and prospects in different sectors such as agriculture, healthcare, supply chain management in different industries. The prospects and wide variety of applications are possible as IoT is context-aware in nature. The IoT may also create new business opportunities. Various stakeholders like customers, citizens and companies as a whole are enjoying more benefits, better operation of machines and quality control, accelerating growth and business performance, as well as improving safety and a reduction of risk (Chau et al., 2021; Mahbub, 2020; Song et al., 2020; Verizon, 2015).

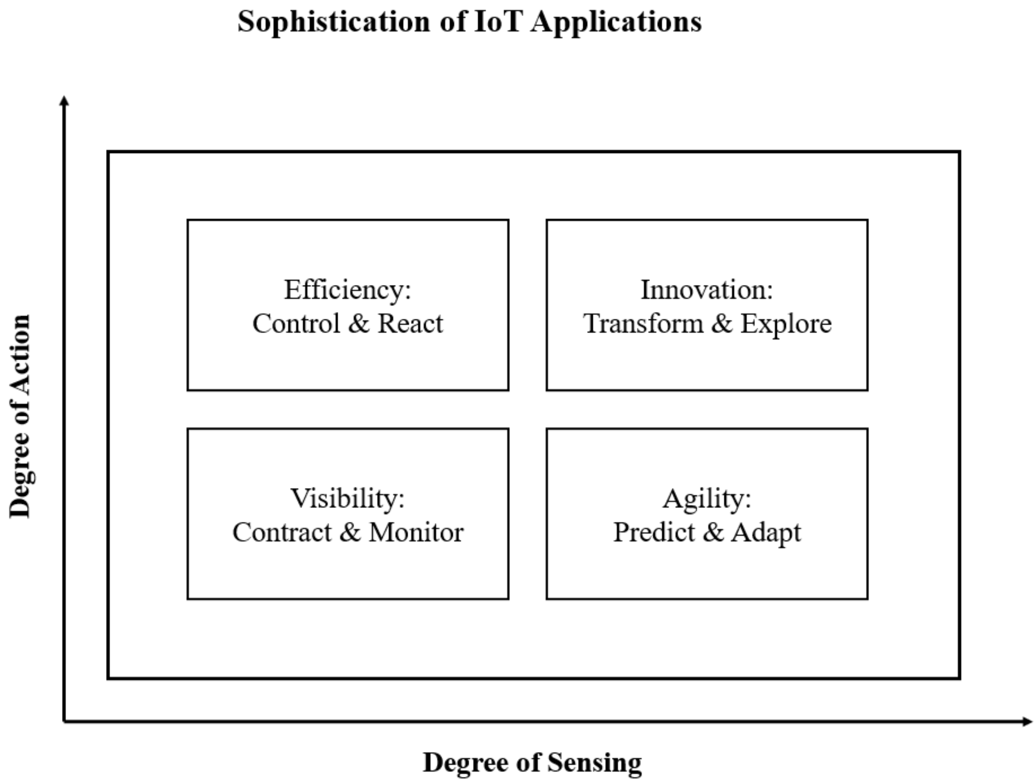

Figure 2.2: Sophistication levels of IoT applications
Source: (Cao et al., 2015)

IoT applications can be divided into three major domains. They are: industrial, smart city and health domain. Each are is interrelated with another domain. For example, product tracking, normally in the manufacturing and health sector area, but it can be used to monitor goods or food, or to monitor the distribution of medicines (Y. Li et al., 2020).

Table 2.1 Application domains of Internet of things.

Main Application Areas	Domain Segmentation	Examples
Industry	Logistics and Product Lifecycle Management	Inventory management, cargo transport
		Food preservation
	Agriculture and animal husbandry	Agricultural Production and Breeding
		Animal Disease Infection Control
	Industrial processes	Real - time vehicle diagnosis
		Baggage Management
Smart city	Smart Home / Building	Home Area Network (HAN)
		Multimedia management, power management
	Public Safety and Environmental Monitoring	Environmental monitoring
		Smart mobile devices
Health Care	Disease diagnosis and treatment	Real-time chiri-cal consmlfation
		Vital signs monitoring
	Independent live	Assisted persons with disabilities
		emergency rescue

Source: Y. Li et al., 2020.

Table 2.1 shows the three major application domains of the IoT. At present it would be unwise to think that IoT applications domains' maturity levels are same. Some applications are in the experimental stage while other applications domains are in its infancy level. The following segment provides a brief discussion to the major application domains.

2.3.1 Industry

Several industries like manufacturing, bank and financial services, and others are embracing IoT for their daily activities, including inter-firm commercial or financial transaction.

2. 3.1.1 Management of Logistics and product lifecycle

Today, logistics and supply chain management embraces IoT widely. As for example, an electronic tag embedded to particular objects that can be used to locate and track the type goods. The goods can be anything like clothing, furniture, equipment, food or liquids (Villanueva et al., 2012). The use of this technology yields huge benefits. For example, the technology can reduce inventory level and minimizes uncertainties in warehouse management in a dramatic way. The whole product life cycle can be managed effectively(Cai et al., 2014).

The benefits of an advanced IoT system are too many. As for example, it helps to minimize level of material waste, reduce operating cost and improve margins for retailers and manufacturers. (Corsten & Gruen, 2005).

Moreover, the technology helps to avoid the shortfall and overproduction through drawing inference by capturing data from the smart shelf. In addition to that IoT can determine the deterioration of the product by performing real-time analysis of the sensors data.

2.3.1.2 Management of Agriculture and animal husbandry

Application of IoT in agriculture sector is increasing day by day. Any events related with agriculture or animal husbandry, as for example, disease, abnormalities can be tracked and monitored with the help of IoT. As for example, isolates infected animals with the help of this technology. (Voulodimos et al., 2010). Another potential use can be the application of advanced sensor enabled IoT for monitoring and controlling of agricultural related production (such as additives, pigments).

2. 3.1.3 Various Industrial processes management

Cutting-edge solutions for different industrial processes are possible with IoT. For example, the technology can help real-time vehicle monitoring i.e. tire pressure, motor data, fuel consumption, position, speed, distance from other vehicles, etc., and then report the captured data to the central system (Hank et al., 2013).

The IoT application makes more convenient and comfortable for the people and goods and services transportation. One scenario can be an airlines industry can manage ticket pricing and ensure more secure baggage handling through IoT enabled automatic tracking and sorting effectively. The industrial IoT technology can be used to reduce the incidence of accidents, especially in high-risk manufacturing entities (e.g., oil and gas plants). In any emergency situations, the sensors connected to Internet can automatically send an alarm to the authority which certainly helps to avoid disaster.

2.3.2 The smart city domain

Sustainable environment and quality of life for a community can be enhanced with the help of IoT. Smart city concepts help to use energy and resources effectively and efficiently. Actually, IoT enabled smart city seeks to find out intelligent solution for an enjoyable personal as well as family life.

2.3.2.1 Smart home / building

Different types of sensors and smart devices (e.g., broadband gateway, mobile phone, computer, TV, surveillance camera and electric bulb) will help integrate ICT into building and house known as the future smart city. Some example of IoT enabled applications in smart city are video surveillance and intrusion detection, factory safety and security management and maintenance, fault detection in machine and equipment, automatic service delivery, optimum service from HVAC and lighting and entertainment system at home and optimization of the domestic consumptions (Lu et al., 2010).

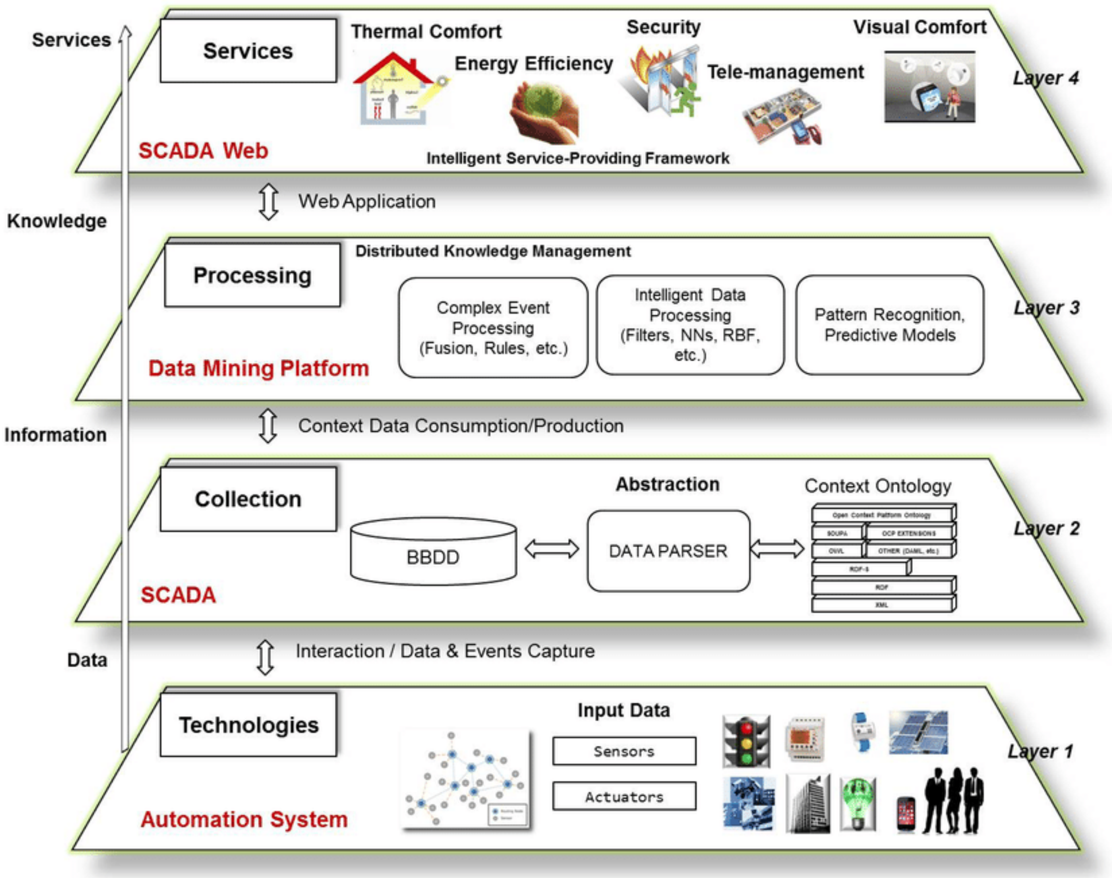

Figure 2.3. Architecture layers of smart building management system
Source: Moreno et al., 2014.

In the figure above the smart building management system are shown. Home area network (HAN) connected with IoT lets electrical devices to communicate and ensure optimum performance by slashing cost significantly. One can manage this home are network connected with IoT by mobile phone from anywhere and anytime.

Here user can manage system smartly and, and monitor and control home electronic devices at a specified time to open, close or set running parameters to make the home atmosphere more comfortable and pleasant for the residents. Data captured from Internet connected sensors are analyzed for information flow.

2. 3.2.2 Environment monitoring and public safety domain

The prevention and protection of public life, private property are more important than before. In addition to that emergency situations like natural or man-made disasters, such as chemical leakage, water flood, conflagration, epidemic disease and power interruption are also a major concern for the community. The IoT aims to manage all these situations smartly (Sun et al., 2012).

2.3.3 Management of Health Industry

Internet of Things technology plays an important role to improve people and social activities through the development intelligent services. Figure 2.4 shows a simple WSN application scenario for healthcare. The system consists of four different categories of actors. It also includes power users of the systems such as administrators and developers in the following sensor enabled health care system.

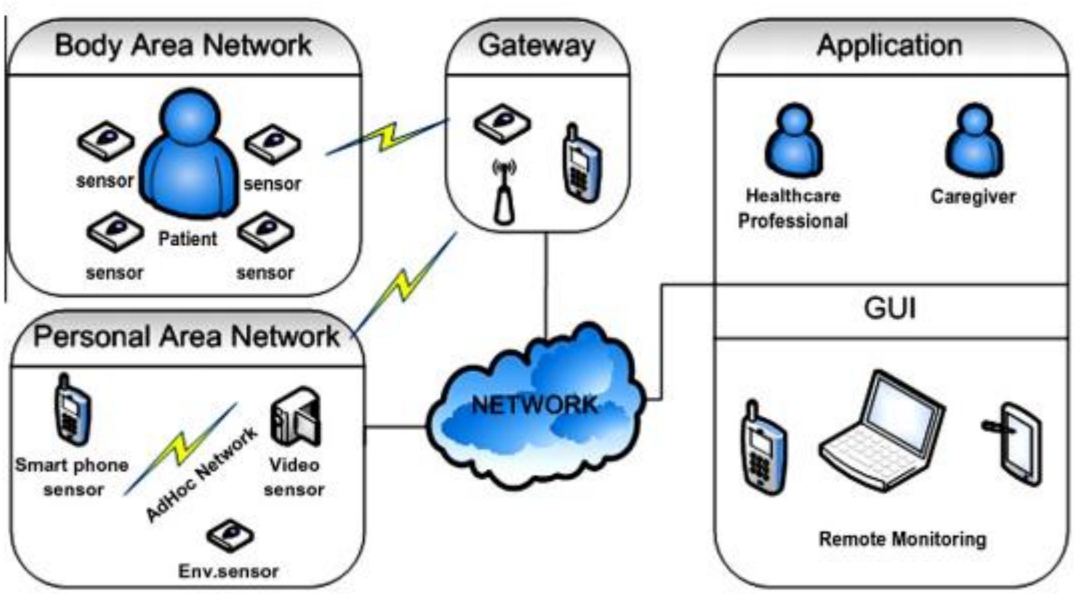

Fig. 2.4. WSN enabled healthcare system
Source: (Mazinga & Mukonyezi, 2017)

A simple IoT enabled healthcare application scenario consists of five subsystems. They are: (i) Body Area Network Subsystem, (ii) Personal Area Network Subsystem, (iii) Gateway to the Wide Area Networks, (iv) Wide Area Networks, and (v) End-user healthcare monitoring application (Alemdar & Ersoy, 2010).

Patients' vital signs (e.g., body temperature, blood pressure, heart rate, and cholesterol levels) can be monitored and controlled by IoT enabled health care electric devices in real time and then transmit the acquired data to a doctor via a smart phone or other intelligent technology (e.g., Bluetooth, Wireless HART, ISA100) for diagnosis and monitoring of the patient's signs. Remote monitoring of patient can be done even from outside of the hospital premises (Delmastro, 2012).

2.4 IoT Applications in Energy Sector

A study done by Motlagh et al.(2020) identifies major application of IoT in energy sector. The following table shows the three major application of IoT in energy sector:

Table.2.2. Major Applications of IoT in energy sector

	Application	Section	Description	Benefits
Regulation & market	Energy democratization	Regulatory body	Many small end users are connected to the grid.	Energy supply chain hierarchy reduction, market power, and centralized supply.
	Small prosumers accumulation (virtual power plants)	Power sector	Accumulation and creation of a group of end users to offer to electricity	Reducing Load in peak times and mobilize small loads to stakeholders in competitive market.
Energy supply	Preemptive maintenance	Energy industry (Upstream)	Monitor after analyzing big data derived through sensors	Reduction in risk of failure, loss of production and maintenance downtime.
	Fault maintenance	Upstream oil and gas industry companies	Identifying failures and problems in energy networks	Improvement of service reliability, speed in fixing leakage
	Energy storage and analytics	Industrial supply chain partners	Analyze market data	Supply and demand imbalance reduction
	Power generation through digitalization	System operators & utility company	Controlling many generations units through big data analysis at various time	Enhance security of supply; assets usage and management quality;
Transmission and distribution (T&D) grid	Smart grids	Electric grid management	Big data enabled grid operation	Energy efficiency improvement and integration of distributed generation and load;
	Management of Network	Management & operation of power grid.	Big data use at different points of the grid.	Reinforcing the grid & avoiding blackout through weak points identifications.
	Electric vehicle fleet (EV) control	Power grid management & operation	Charging stations and charge / discharge cycles of EVs via data analysis.	Charging demand at peak times improvement; analyzing and forecasting the load impact of EVs.
	Vehicle to grid (V2G) management & control	Power grid management & operation	Analysis of Load and charge / discharge pattern of EVs .	Flexibility enhancement of the system by activating EVs .
	Microgrids	Electricity grid	Platforms for managing a grid independent from the central grid.	Improving security of supply; creating interoperability
	District heating (DH) network management	DH network	Big data analysis related to temperature and load in the network	Grid efficiency improvement in meeting demand.
	Demand response	Residential /	Essential control	Reduces the grid congestion

		commercial &industry	(i.e., by shedding, shifting, or leveling;	through reducing peak time demand.
	Advanced metering infrastructure	End users	Load and temperature data collection through sensors	Detailed load variations access at various time frame.
	Energy management of battery	End users	Activating battery at suitable time with the help of Data analytics.	Charge of battery at different time.
	Smart buildings	End users	Centralized and remote control of appliances.	HVAC systems comfort improvement through optimum control.

**Abridged
Source: Motlagh et al.2020

2.4.1 **Smart Home**

The energy consumption in cities can be divided into different parts; residential buildings (domestic); and commercial (services), including shops, offices, and schools, and transport. The domestic energy consumption in the residential sector includes lighting, equipment (appliances), domestic hot water, cooking, refrigerating, heating, ventilation, and air conditioning (HVAC) (Figure 2.5). HVAC energy consumption typically accounts for half of energy consumption in buildings (Motlagh et al., 2018).

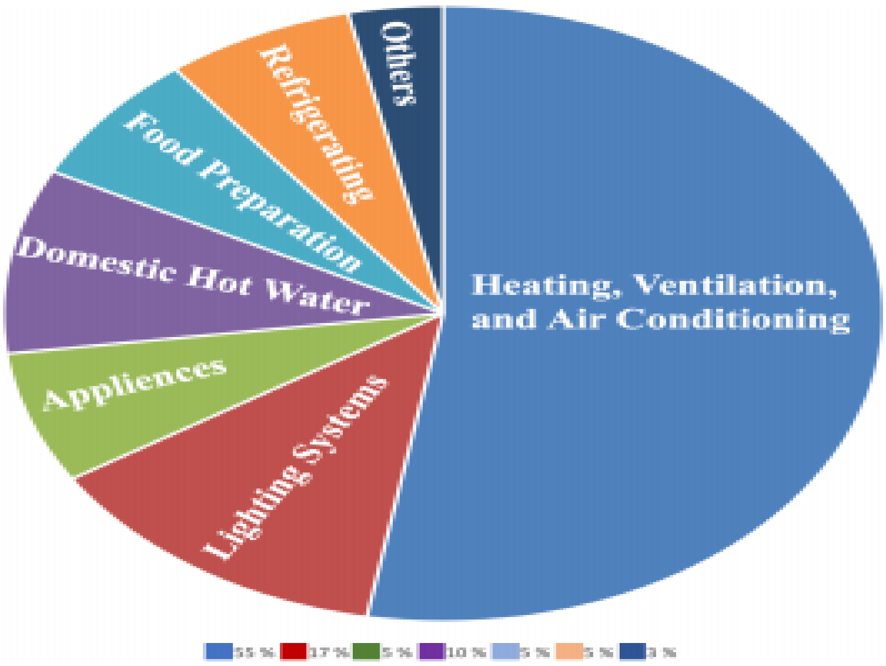

Fig.2.5. Domestic Energy consumption
Source: (Motlagh et al., 2018)

2.4.2 **IoT Enabled ACs/Smart Thermostat Topology**

Wi-Fi thermostats are also known as smart thermostats. The technology can be used with home automation. Home's heating, ventilation, and air conditioning can be enabled through this technology(Huppi et al., 2014).

Fig.2.6. IoT enabled AC/thermostat topology
Source: The Author

The maximum number of smart thermostats are connected to mobile phone through Wi-Fi. An app in mobile lets user schedule heat or cooling turns on, adjust the temperature of the room/home. It does not matter no matter where the users are, and even user can set up automations with other smart devices (Bradford, 2021).

2.4.3 **Smart grid**

Smart grid is a perfect example of the Internet of Things (IoT) paradigm. It’s modern grids using the most secure and trustworthy ICT technology to control and optimize energy generation, T&D grids, and end usage. By connecting many smart meters, a smart grid develops a multi-directional flow of information, which can be used for optimal management of the system and efficient energy distribution (Orlando et al., 2021).

2.4.4 SCADA (supervisory control, and data acquisition)

Application of Supervisory control and data acquisition in energy sector started in the 1990s. SCADA is the early version of IoT. It actually automates industrial processes. Its main functions are - supervision of the operation through programmable logic controllers (PLCs) by collecting data about the underlying process, analyzing the data, and sending commands to control the processes (Loshin, 2021).

Value-added services for the organization can be derived by SCADA platform. It also acts as a gateway to offer and monitor the process, but it is not in charge of performing any control over appliances or actuators directly.

2.4.5 Smart Energy Monitoring

Smart energy monitoring is the integrated collection sensors, microcontroller routers and other devices. It is an ideal solution for monitoring real-time energy consumption while providing the level of awareness of energy performance (Bhardwaj, 2015; Karnouskos et al., 2009). With the support of IoT technology, i.e. energy sensor, energy consumption data can be collected in real-time at different levels, such as machine, production line or facility level (Tao, Zuo, Da Xu, & Zhang, 2014).

2.4.6 Smart Street Lighting

The concepts evolve from remote peer to peer computer-based network (P2P) control. It is used to share resources among the stakeholders. Smart street lighting concept is an approach which is the combination of sensors (typically cameras) advanced communication systems (high-speed power line networks or Zigbee), interact with an intelligent control unit. Sensors and other technologies are connected 'smart and multifunctional' lamp poles. Therefore, the system is able to create a profile of the activities (people, vehicles, emissions) taking place on streets in real time.

Smart street lighting system consists of three parts. The smart module, represented by the number 1, is connected between the luminaire and the power grid and it has the prior function to receive commands from the central supervisory system, providing measurement data from the electrical network, such as sags, swells or possible failures as well as to perform automatic control dimming.

In order to ensure an uninterrupted and isolated power source, this smart module has a backup battery, which is represented by the number 2, where it allows the system to maintain the communication with the central supervisory in case of failures, assuring the fault detection. The number 3 is the LED driver that is responsible to receive the control signals from the central supervisory and to deliver the respective and adequate power to the LED lamp. It is worth to notice that this smart module has several sensors, such as photocell to detect ambient light, presence sensor to detect pedestrians and voltage and current sensors to monitor the system operation.

With the data acquired from the sensor and using the control interface, it is possible to operate remotely in order to manage and control the luminaire parameters as well as to provide information concerning the power grid.

Through the usage of this smart equipment, it is also possible to implement complex dimerization strategies that could change the luminaires behavior based on pedestrians' detection, ambient light, time or network demand. Another intelligent feature includes the detection of defective lamps, which is based on the drained current and weather information measurement, such as temperature, humidity and solar incidence (Gagliardi et al., 2020)

Smart street lighting ensures adaptive and automatic point-to-point flux adjustment to take place all year round. As a result, it can improve the energy performance in a significant way. It is worth noting that the system can save higher amount energy.

2.5 Related Previous Studies

Various studies on many issues regarding use of IoT in energy management have been performed. A study conducted by Ben-Nakhi and Mahmoud (2004) where a general regression neural networks (GRNN) algorithm were used. The study helped to predict cooling load and optimize the heating, ventilation and air condition system for buildings. Fortino et al. (2012) proposed an IoT system that is multilayer agent-based architecture. It is a proactive, cooperating, and context-aware smart objects. The architecture of the smart objects ranges from reactive to proactive, from small to very large, and from stand-alone to social.

Borowski, et al. (2020) proposed a dynamic control strategy to participate in demand response schemes by using a simple model of an air conditioning unit which was then further scaled to include many such units. The accuracy and performance of these models rely heavily on the thermal dynamic models and mathematics behind it. However, the occupant's comfort level and the temperature of the building are affected by several random variables that are very difficult to model accurately.

Therefore, "it is often intractable to develop a building dynamics model that is both accurate and efficient enough for effective run time of HVAC control"(Oh et al., 2010). This nonlinear and highly complex relationship between the environment and energy consumption of the HVAC system has encouraged researchers to actively explore the use of real-time data-driven methods with the use of Reinforcement machine learning models to approach the problem (Gubbi et al., 2013).

Gubbi et al. (2010) proposed a cloud based Internet of Things . The key enabling technologies and applications of IoT are discussed in the paper. Atzori et al. (2007) discussed about the technology and showed the energy cost management aspects of

HVAC systems. The article also mentioned the technology has recently attracted the researchers' attention.

Moreover, in (Noh et al., 2011), a dynamic IoT system is proposed and specified that energy consumption varies according to the user satisfaction, However, neither (Ha et al., 2007) nor (Noh et al., 2011) clearly consider a dynamic pricing cost.

In (Nguyen et al., 2013), relationship between smart pricing and the energy cost optimization are elaborated. It also said that the user comfort is not explicitly incorporated in the algorithm, as the authors consider that the HVAC is turned on/off when the indoor temperature is outside the margin of comfort.

In (Mohsenian-Rad et al., 2010), proposed an IoT based system that depends on (i) the past temperatures, (ii) the outdoor temperature, and (iii) the HVAC power. However, this heuristic approach seems hardly applicable in general scenarios.

In (Nguyen et al., 2013), an IoT based HVAC system that delineated linear relationship between energy consumption and cost function. In another study it is mentioned that quadratic or two-step piecewise linear functions are more common in practice (Salcedo-Sanz et al., 2014).

In (Doukas et al., 2007), a rule based decision support system was used to manage building energy consumption. The system also incorporated the requirements in both guaranteeing of the desirable levels of living quality in all building's rooms and the necessity for energy savings.

Another study shows that building intelligence can be improved using Various WSN applications, application of the XBee WSN for temperature monitoring presented in (Chavali et al., 2014) Chavali et al. (Cirani et al., 2014; Voulodimos et al., 2010) . The essence of these articles are a distributed home energy management framework and a distributed algorithm of appliance. The objectives of the study were to get a schedule the system and model the cost function.

The WSN application helps to maintain users comfort level as well as minimizes energy consumption of the devices. The study also considered occupancy pattern and air flow through the deployment of wireless sensor and Actuator network (Chavali et al., 2014) .

In (Han et al., 2011) a ZigBee-based HEMS IoT system are presented in which impact of IoT in consumer electronics are shown. Fortino et al. (2012) proposed a framework which stand on multiplatform domain based system. It is also known as a wireless sensor and actuator networks (WSANs). The objective of the study was to determine efficient and effective building management as well as minimalization of cost with the help of IoT technology.

In Zhao et al. (2013) HANs based IoT system are shown. They proposed an optimal power scheduling method for demand response (DR) in a HEMS. Niyato et al. (2011) proposed an IoT system which is machine-to-machine (M2M) network architecture for a HEMS. The study tried to collect energy consumption demand and status from household electronic devices.

Chavali et al. (2014) proposed an IoT based system which is a distributed home energy management framework. The study used distributed algorithm for scheduling the appliances and model of cost function. Hu and Li (2013) proposed a smart HEMS (SHEMS) .The systems attempted to sense, communicate and tried to implement machine learning.

In another study Ozturk et al. (2013) proposed a DR based IoT for residential users. The study aimed to forecast energy demand with regard to user lifestyle and environmental aspects. It is an adaptive neural fuzzy inference system- (ANFIS-) based home energy controller system for optimum energy consumption.

The proposed systems discussed above focus on reducing energy consumption. All these systems are based on fixed network infrastructure of which end-components of HEMS such as home appliances, smart meters, PV system. The system is also connected to a central management server. Thus, a wireless sensor and actuators network (IoT) helps a single device to command several air conditioners in a smart building.

From last decade importance of energy efficiency in building environment has been increased dramatically (Agarwal et al., 2010; Lindberg et al., 2004; Pettersen, 1994). Various approaches use predictive modeling for efficient energy consumption. It also considers usage profile, climate data and building characteristics. On the other hand, studies determine a relationship between public information to occupants and individual behavior with a view to obtain energy savings (Darby, 2006; Fischer, 2008).

Nevertheless, most of the studies focused only a partial solution rather than a wholistic solution to the overall problem of energy efficiency in buildings. As a result, a comprehensive approach is important for having a clear-cut model regarding IoT and optimum energy consumption and cost savings. vision is required to provide accurate models of the energy consumed in buildings (Voss et al., 2010).

IoT services design and implementation deserve well thought economic analysis. It should consider installation optimization, distribution and use of the service. Economic approaches include several approaches. Some of the related studies regarding economic analysis of IoT base services are discussed below.

Cost-Benefit Analysis (CBA): here benefits and costs from IoT systems and its services are determined. In (Uckelmann, 2012), the paper discussed the cost and benefits of implementing RFID enabled logistic firms and tried to rationalize of IoT investment. In the study several metrics and cost benefit elements i.e., total cost of ownership, economic value added, return on investment, net present value etc. have been used to explain IoT potentials.

User Utility: It represents the choices of product and services which is based on the amount of satisfaction generation. Another study focuses on user satisfaction and preference of user's choices on IoT enabled services. Here the author tries to quantify QoS performance of the data that have been collected from sensors which are attached to various devices of a smart. (Al-Fagih et al., 2013). The authors in the study explained law of diminishing return, relationship between delay and utility, and so on.

Other studies focus on market and pricing of IoT technology applications (Munjin & Morin, 2012). Market can be viewed as anything like economic systems, procedures, social relations and infrastructure that are set to facilitate goods and service exchange.

In another study the authors (Chavali & Nehorai, 2012) adopted monopoly settings i.e. one sellers and many users, where market equilibrium, that is same as to the Walrasian equilibrium theory, is that point where supply and demand intersect. Here pricing is determined for IoT-based multi-modal sensor networks. The model emphasis on demand from buyers and supply from sellers, respectively. The supply increases as the price increases while demand decreases.

The authors in (Feng et al., 2014) study the monopoly and oligopoly markets. Here the authors tried to determine cloud resource pricing to support IoT services in oligopoly and monopoly market. The study showed how the user select the sellers. For example, users select the seller who provide maximum satisfaction in comparison to other seller in oligopoly setting.

Auctions are also adopted in IoT services (Cao et al., 2015) particularly for crowdsourcing of target tracking applications. IoT technology applications and auction details are well explained in (Zhang et al., 2013). The study focuses on solving the multiple-choice knapsack problem in order to calculate auction value through fusion center bids.

The global energy demand jumped to 2.3% in 2018 compared to 2017, that is the biggest jump in demand since 2010 (Zhang et al., 2013). As a result, CO_2 emissions from the energy sector hit a new record in 2018. Compared to the pre-industrial temperature level, global warming is approaching 1.5℃, most likely before the middle of the 21 Century (Xu et al., 2015). This trend let global warming exceeds the 2℃ targets, which will have a severe impact on the planet and human life.

Urgent need for more efficient use of energy and the use of renewable energy sources are a crying need because of the environmental concerns, such as global warming and local air pollution, scarcity of water resources for thermal power generation, and the limitation of depleting fossil energy resources, (RESs).

Increasing level of $CO2$ emission is the main reason of global warming. At present, nearly 50 % to the anthropogenic greenhouse effect is caused by CO_2 (Demirbaş, 2003). It is clear that from the existing energy system fossil fuels burnt CO_2 is the main environmental threat which is seriously changing the climate. Fossil fuels also increase the risk of acidification and dispersion of metals. (Balat et al., 2003). Global warming is increasing largely because of CO_2 and CO. These are the two main greenhouse gases (GHGs) associated with global warming and climate change. Another study showed that coal is al responsible for 30–40% of world CO_2 emissions (Balat et al., 2003; Balat & Ayar, 2004; Demirbaş, 2003).

Another study found that CO_2 emissions throughout the world resulted from burning fossil fuel jumped from 20.7 billion tons in 1990 to 23.7 billion tons in 2011. It means there is a alarming growth in CO_2 emissions which is approximately 14.6% (OECD, 2017).

The costs of emission were calculated with respect to the impact of pollutants on human health, crops, damage to materials, and loss of biodiversity caused by acidification and eutrophication. For all these categories of impact the following air pollutants are considered (CASES, 2008): Ammonia (NH_3), Non-methane volatile organic compounds unspecified (NMVOC), Nitrogen oxides (NO_x), Particulates (PPMco e between 2.5 and 10 um, and PPM25 e less than 2.5 um), Sulphur dioxide (SO_2).

In addition, the cost of Sulphur dioxide and nitrogen oxides emissions in the atmosphere is calculated with respect to the damage to materials. Results for damage costs related to impacts on human health, environment, crops and materials are regionally detailed and are available for each EU-27 country and for the EU27 as an average. For these costs different values, corresponding to conditions in 2010 and values corresponding to possible conditions in 2020, are proposed. It is assumed that in most cases the emissions in 2020 are lower than in 2010.

Since no further reduction of emissions costs are foreseen after 2020, all marginal external costs estimated for 2020 are used also to calculate values for 2030. Then estimated values are not affected by the assumption of an arbitrary year, but they reflect more typical and average conditions (CASES, 2008).

External costs related to human health were also assessed per unit of emission for formaldehyde and the following heavy metals: Cadmium (Cd), Arsenic (As), Nickel (Ni), Lead (Pb), Mercury (Hg), Chromium, (Cr) Chromium IV (Cr-IV). This set of marginal external costs is not country specific, hence the same value for each EU-27 country is considered.

In addition, since variation of these values with time is not foreseen, the same result is used to estimate full costs for present (2005e2010), 2020 and 2030. An additional set of pollutants for which a generic marginal external cost is estimated for all Europe and for the whole period 2005e2030 consists of the following radionuclides (Streimikiene & Alisauskaite-Seskiene, 2014): Aerosols, radioactive, unspecified into air, Carbon-14 into air and water, Hydrogen-3, Tritium into air and water, Iodine-129 into air, Iodine-131 into air, Krypton-85 into air, Noble gases, radioactive, unspecified into air, Radon-222 into air, Thorium-230 into air and water, Uranium-234 into air and water.

An important component of the total external cost of electricity production is the cost of greenhouse gases. The following Table no presents the results of costs in Euro 2010 per ton of emissions. The costs developed by NEEDS (2007) and CASES (2007) projects were recalculated in 2010 to adjust the inflation.

Table 2.3. Average external cost of climate change

Average external costs of climate change, EUR(2010)/t.

GHG emissions	2010	2015	2020	2025	2030	2040	2050
CO_2	25	25	25	27	36	54	72
CH_4	522	522	522	572	746	1144	1517
N_2O	7710	7710	7710	8444	11014	16888	22395

Source: (CASES, 2007, 2008; NEEDS, 2007)

2.6 Gaps in Literature

However, the majority of the methods that have been put out so far only offer partial answers to the IoT in the energy sector's overall prospects. Therefore, there is a lack of analyzing IoT prospects in energy sector. Few studies have been conducted to find economic and overall efficiency of IoT use in different electronic appliances.

This research tries to address the gaps in the literature and seeks to analyze prospects of IoT in energy sector of Bangladesh. This research focuses on three major points: a) Technological b) Economical; and c) Measuring Environmental impact in terms of carbon di oxide emission level for IoT introduction in Energy sector.

CHAPTER THREE

RESEARCH METHODOLOGY

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RESEARCH METHODOLOGY

3.0 Introduction:

Research is a procedure through which a researcher tries to get a better understanding of any particular situation, phenomenon or conditions and it helps to take action based on knowledge (Marshall & Rossman, 2010). Marshall & Rossman (2010) claims that in a research paper, methodology chapter is devoted to explaining the design of the research and how the research will be conducted. The following aspects were taken into account when designing this chapter: general research method principles and the use of various methodologies in ICT research. Techniques and justification of selecting the method have been explained in this chapter.

3.1 Philosophical Aspects

Different techniques and procedures have been employed in all fields of research to analyze diverse phenomena; each field of study (environment) has distinctive characteristics that call for the employment of certain approaches for examination. Understanding these characteristics enables researchers to choose the best techniques and strategies for their study. A set of approaches, that are used in data gathering and analysis is known as methods. The data acts as the foundation for deduction, understanding, justification or prediction (Cohen et al., 2000) that is, research exploits all those methods and techniques (Kothari, 2004).

The word methodology is derived from the Greek ‘meta hodos’ meaning ‘the way along which’. In more everyday language it means ‘a system of methods and principles for doing something’ (Sinclair, 1987). A methodology presupposes that the researcher must follow a logical process in order to arrive at a specific planned outcome (e.g., knowledge, insight, design, intervention, change). Methodology is all about defining and defending the rationale of this logical order. The objective of M*ethodology* is to use sets of methods according to specific research paradigms and approaches. This will help the researcher to understand the phenomenon under study (Kaplan, 2017). Differences between research methods and research methodology are shown in the following table (Bhasin, 2019).

Table.3.1. Contrast between research methods and methodology

Research Methods	**Research Methodology**
Research methods are the methods used by researchers to collect data to conduct research on a particular research topic.	A Research methodology is systematic approach to solve the research problem and to reach a new conclusion.
Research methods are useful to apply during the latter stage of the research process.	Research methodologies are applied in the initial stage of the research being conducted.
Research methods aim at outcome solutions to research problems.	Research methodology aims at the employment of the correct procedures to find out solutions.
Research methods consist of various techniques where various studies and experiments are used to conduct research and reach an appropriate conclusion.	Research methodologies are used applied during the initial stage of the research to explain the purpose of chosen methods and how they will serve its function.
Research methods are small part of research methodology.	A Research methodology is a multi-dimensional concept.
Research methods consist of different investigation techniques.	Research methodologies is a systematic strategy to achieve the decided objective.

Research method encompasses of carrying out an experiment, survey, test and so on.	Research methodology encompasses different techniques which are used during the performance of the experiment, surveys, and test, etc.

Source: Bhasin, 2019

3.2 Qualitative and Quantitative Methods:

According to philosophical debates on research technique, both quantitative and qualitative methodologies have undergone a great deal of academic "terminology" in the field of ICT. Both qualitative and quantitative research methodologies fall under a wide category that is now employed by many researchers.

Research methods selection, techniques and procedures of research depend on the intention of the researchers. These will attempt to match perfectly with researchers needs and demands (Creswell, 2003). Usually, researcher follows three major types of research methods such as qualitative methods, quantitative methods and mixed methods.

Qualitative research method seeks to emphasis on observations and words. It also tries to present reality and tries to explain their universal situations (Amaratunga et al., 2002). Techniques like inductive reasoning are used in qualitative research (Teddlie & Tashakkori, 2009). Pattern identification, themes discovering and categorizing one’s data. are some of the important objectives of this type of study. (Gillham, 2000). Social science discipline can also use this technique. (Ticehurst & Veal, 2000).

For quantitative methods number and statistical means are focused whereas mixed methods incorporate the both methods. The table below shows the difference between quantitative and qualitative research.

Table 3.2: Distinction between Qualitative and Quantitative Research

Criteria	**Qualitative Research**	**Quantitative Research**
Purpose	To understand & interpret social interactions this method is used.	To test Hypotheses and a cause-and-effect analysis
Group Studied	Small & not selected randomly.	It is large & selected randomly.
Variables	An aggregate study, not confined to variables.	It is confined to variable that means more specific & concise
Type of Data Collected	Word, image or objects are data type in nature.	Quantitative numbers and statistical means.
Form of Data Collected	Field study in the form of respondent interviews, observation, note system and reflection of image is determined. Open ended questionnaire can be used.	Considered detailed measurements using structured i.e. close ended questionnaire & authorized data-collection instruments quantitative data are collected.
Data Analysis	Data pattern, shape, features, and thoughts are mandatory.	Statistical relationships looked thoroughly.
Objectivity and Subjectivity	Subjectivity is a concern over here	Objectivity is critical in this study.

Researcher role	Rresearcher and participants know each other. Here researcher know participants characteristics.	The participants in the study do not know researcher & their biases. Here participant characteristics are deliberately hidden to the researcher. It is also known as double blind studies.
Results	Particular or specialized findings that do not take a broad view.	Generalized findings which is practical to other populations.
Scientific Method	From the data collected data researcher generates new hypothesis and theory. Exploratory in nature also called bottom up.	It is also known as Confirmatory or top-down approach. Here the investigator tests hypothesis and theory with the collected data.
View of Human Behavior	Human behavior viewed as dynamic, situational, communal, & personal.	Regular & probable.
Most Common Research Objectives	Explore dramatically, & construct.	Depicts the facts, explain, & anticipate.
Nature of Observation	Natural environment setting for the study	Stud is done in controlled conditions; separate causal effects.
Final Report	More narrative, Contextual description & direct quotations are present in report.	Correlations, comparisons of means, & statistical significance are present in report.

Source: (Johnson & Christensen, 2014).

All types of research, either qualitative or quantitative, depend on the underlying assumptions about which research form will be valid and what type of research method will be appropriate for the research (Yin et al., 2010). The philosophical assumptions which are related to the underlying epistemology are the most relevant to the research. Epistemology is considered as the assumptions made about knowledge and the way it can be obtained (Association for Institutional Research., 1973).

There can be three types of research philosophy, interpretive, critical and positivist (Yin et al., 2010) To conduct this research an interpretive paradigm has been selected. The following epistemological and ontological positions are undertaken for the study:

- Epistemological position- Interpretive paradigm (the way knowledge can be gained about that reality).
- Ontological position- subjective (knowledge of reality, the reality of the subject, varying opinions about the nature of reality).

3.3 Research Design

Research design is the collection of techniques and processes used to gather and analyze data on the selected variables that are detailed in this research problem. It is a comprehensive plan of solving the research problems or questions. Research design helps the researcher in the identification of the problem, data collection as well as the types of statistical tools to be used to interpret the result. Though research design and research method cast-off interchangeably, Muaz in (Yin et al., 2010) showed in his study that they are found to be separate concepts. In this chapter, the mechanisms for this research are developed and tested.

The research design is the rational construction of the study which articulates the data requirement from whom to collect data and answer the questions (Association for Institutional Research., 1973). However, the manner or way of assembling is discussed in the research methods which can quantitative or qualitative or both (Yin et al., 2010). Research design can be qualitative or quantitative or a researcher may select to employ both methods on his study (Bancroft et al., 1997). Twelve major types of research design available for researcher's disposal (Mingers, 2001) adapted from Labaree (2022).

i. Action research design: It follows a typical cycle in which an experimental posture is first adopted, where a problem is understood and preparations are created for a potential intervention ARY approach. The activity (the "action" in Action Research) is then carried out, and throughout this time, significant observations are gathered in number of ways. Interventional tactics which is new in nature are implemented, and this cycle is repeated until the issue is sufficiently understood (or a workable implementation solution is found). The iterative or cycle approach starts with conceiving and focusing on the problem before progressing through various treatments and assessments in an effort to promote greater knowledge of a particular scenario.

ii. A case study: This is a detailed examination of a single research issue. It is completely different from a broad statistical survey or in-depth comparative analysis. It is frequently used to condense a vast area of inquiry into one or a small number of easily researchable instances. This type of design is also helpful for evaluating the applicability of a given theory and model to events that occur in the real world. When not much is known about a problem or phenomena, this design is helpful.

iii. Causality studies can be regarded of as attempts to explain phenomena using conditional assertions of the type "If X, then Y." Causality research is designed to assess how a particular change would affect accepted beliefs and norms. The majority of social scientists look for causal explanations that are consistent with testing of hypotheses (nomothetic viewpoint).

iv. Cohort study: The medical sciences often use these techniques. Social science disciplines also apply the technique. a cohort study generally refers to a study conducted over a period of time involving members of a population which the subject or representative member comes from, and who are united by some commonality or similarity. Cohorts study can be either "open" or "closed."

v. Cross-sectional research design: It has three identical features. They are- no time dimension, a reliance on existing differences rather than change following intervention; and, groups are selected based on existing differences rather than random allocation. This type of design can only measure differences between or from among a variety of people, subjects, or phenomena rather than a process of change.

vi. Descriptive research designs: Descriptive research is used to obtain information concerning the current status of the phenomena and to describe "what exists" in regard to variables or conditions in a situation.

vii. Experimental design: It helps the researcher to hold control over each and every variable that can influence the outcome of an experiment. In doing so, the investigator makes an effort to ascertain or foretell what could happen. When a causal link has a temporal priority (cause occurs before effect), is consistent (a cause always leads to the same effect), or is highly correlated, experimental study is frequently utilized. This approach is used to gain deeper knowledge about something. In other word this research helps to discover new insights and ideas as well as specify and develop techniques for locating and evaluating future data.

viii. An exploratory design: The focus is on gaining insights and familiarity for later investigation or undertaken when research problems are in a preliminary stage of investigation.

ix. The historical research design: It aims to collect, verify, and synthesize evidence from the past to establish facts that defend or refute a hypothesis. Secondary sources and a variety of primary documentary evidence are gathered from genuine and valid source.

x. A longitudinal study: Here the same sample over time are used and makes repeated observations. It describes patterns of change and help establish the direction and magnitude of causal relationships.

xi. Meta-analysis: It is an analytical methodology designed to systematically evaluate and summarize the results from a number of individual studies. As a result, the ability of the researcher to study effects of interest increases as the overall sample size expand. The purpose is not to simply summarize existing knowledge, but to develop a new understanding of a research problem using synoptic reasoning.

xii. Observations research design: It derives a conclusion by comparing subjects against a control group, in cases where the researcher has no control over the experiment. Observational designs can be of two types such as direct observations, and unobtrusive measure. In direct observation people are known about the study whereas in unobtrusive study, people do not know that they are observed.

3.4 Choice of methodology for this study

According to Zikmund (2013) a research design is all about overall plan of the research topic. Type of evidence, from where and which way data will be collected are the major concern of research design. In research design one should fix up the methodology and make a judgement about that will spell out the research project (Creswell, 2003).

This research has been conducted by different methods. The study collects primary data through experiment, observations and in-depth interview. The figure in the below shows the methods of data collection.

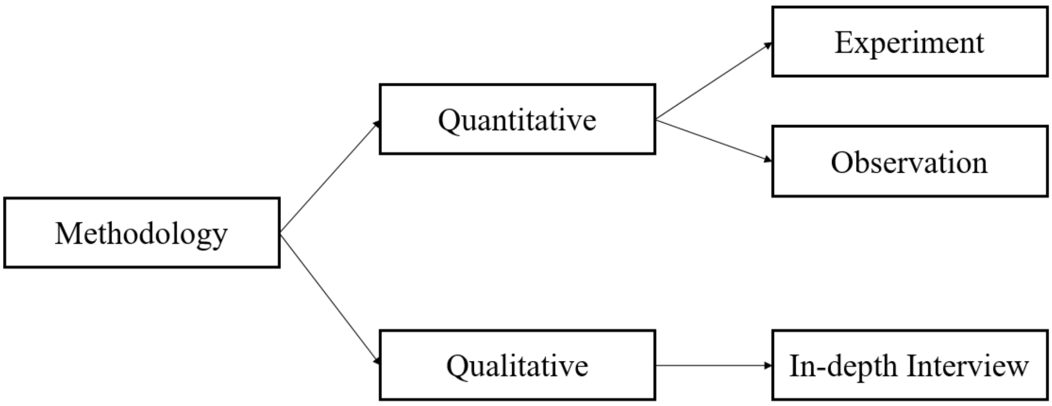


Fig 3.1-Methodology of the study
Source: Author’s own compilation from different sources.

- Experiments have been conducted to know the power consumption in different temperature settings in ACs.
- Unobtrusive observation measures are carried out to understand users preferred set temperature for ACs.
- In-depth interview is conducted to know the prospects of IoT in qualitative way

3.4.1 Experiment selections criteria/procedure

Since little is known about the potential of IoT in Bangladesh's energy industry, an "experiment research" approach will be ideal to achieve the study's goals. A plan for the process known as experimental design helps the researcher to retain control over all variables that can influence the outcome of an experiment. In doing so, the researcher makes an effort to ascertain or foretell what could happen. When a causal link has a temporal priority (cause occurs before effect), is consistent (a cause always leads to the same effect), or is highly correlated, experimental study is frequently utilized.

An experimental group and a control group are specified in the traditional experimental design. Both groups are assessed using the same dependent variable, but only the experimental group receives the independent variable. More groups and more measures over longer time periods have been employed in later experimental designs. Control, randomization, and manipulation are essential components of true experiments. Experimental studies tell the following:

- The researcher has control over the circumstances when doing experimental study. This enables scientists to respond to the question, "What are the causes of some events?"
- Enables the investigator to determine causality connections between variables and to differentiate between dummy and treatment effects.
- The capacity to restrict potential explanations and identify direct causal linkages in the study is supported by experimental research methodologies.
- Approach provides the highest level of evidence for single studies. (Experiment research is used when little information is known about the present situation or not much is known about how similar type of research issues or problems has been sought out in the past (Yin et al., 2010).
- Experiment research is mainly conducted to gain deeper knowledge about something. This research type is useful to discover new insights and ideas as well as specify and develop techniques for locating and evaluating future data.

The study   monitors and collects office energy usage data for several months i.e., March – October 2019 in Khulna University and March-July/2021 in Dhaka university. Here power consumptions of ACs have been recorded) through IoT devices and energy meter. Particular temperature. were set with regard to outside and room temperature (i.e., 24,25 etc.) degree and the consumption in kWh have been recorded.

Data regarding daily temperature (outside and room) humidity, etc. are recorded through IoT enabled sensors during the study period.

Fig. 3.2 Experiment office room with energy meter
Source: Author’s experiment setting in Khulna University

In this study IoT has been used to control and monitor user’s set temperature and its impact will be assessed elaborately. Common beliefs among the users are—Lower set temperature will give higher comfort, but as per ASHRAE (Yin et al., 2010) (American society of heating, refrigerating and air conditioning engineers) ideal temperature for thermal comfort is between 23.5 -25.5 degree centigrade. According to American Council for an Energy-Efficient Economy (ACEEE) (Malhotra et al., 2006) increase of each degree of temperature in ACs can save 3-5 % of units consumed. The study considers above factors while conducting the study.

3.4.1.1 Experimental Design:

While conducting the study, researcher recorded humidity, outside temperature, room temperature, door state and room activity during March to October, 2019 and 2021. Subsequently AC temperature is set on a particular temperature i.e.,20 degree and resulting consumption was also recorded. Here power consumption for 18-25 degree centigrade have been observed with respect to different room parameters i.e., humidity, temperature and room activity during the study period. Based on the experiment IoT impact have been assessed.

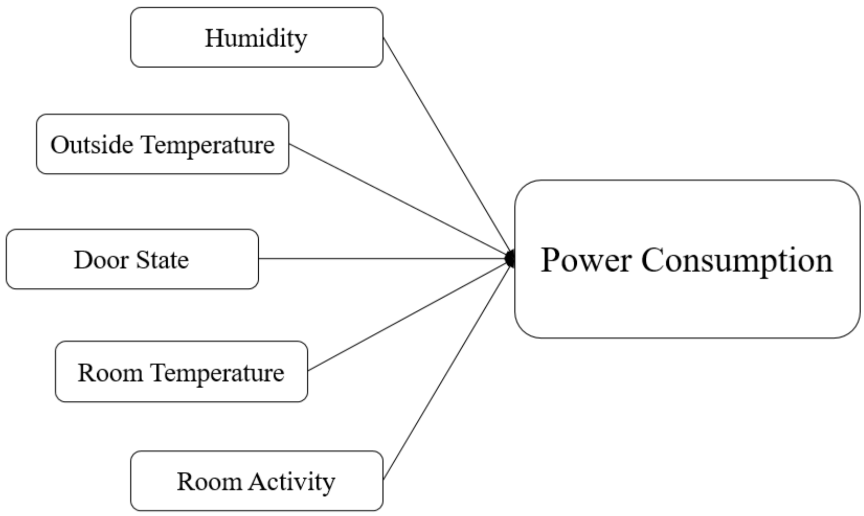


Fig.3.3 Experiment parameters
Source: Author's own compilation from different sources.

In the study primary data like building data, energy price, weather data etc. have been used to understand the prospects of IoT in energy sector of Bangladesh.

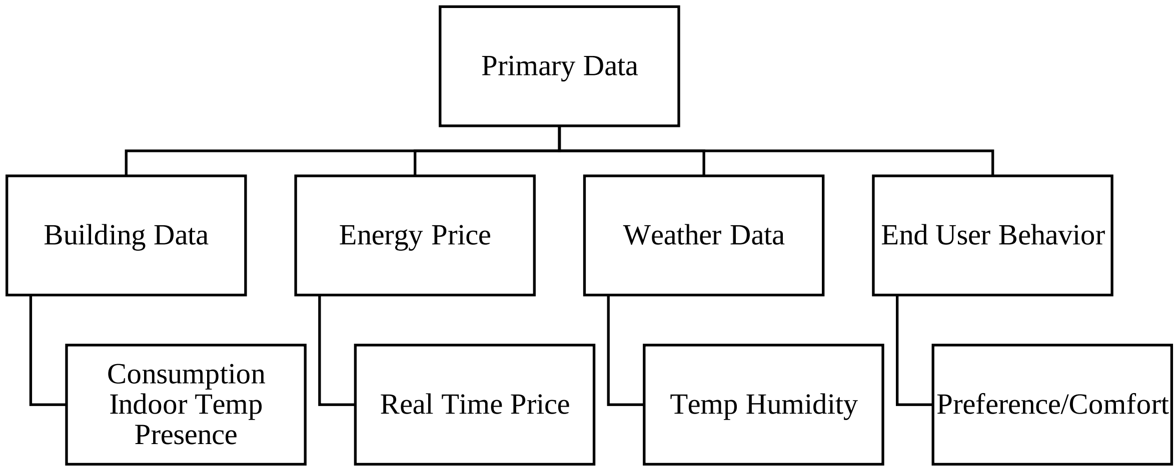


Fig.3.4 Primary data for the experiment

Source: Author's own compilation from different sources.

3.4.1.2 Hardware Specification

For ACs, the temperature and humidity information of the study was taken by DHT22 temperature-humidity sensor. The DHT-22 comes in two parts: capacitive humidity and thermistor temperature sensor. The DHT22 temperature and humidity sensor is an advanced sensor unit that provides a calibrated digital signal output. There is an 8-bit microcontroller on it and it has a short response time. It has a precise calibration and the calibration coefficient OTP is stored in some kind of program in memory.

Refer to this coefficient stored in the memory during product detection. It makes temperature measurement unit with +/- 0.5°C error between -40 and 80°C, humidity measurement between 0-100% RH with ± 2% RH error. The pins of DHT22 are designated as Vdd supply, DATA and two ground pins. Communication between the

MCU on the module and the temperature humidity measuring unit (AM2302) is provided by a 1-line bus (ARDUINO, 2018)

Fig.3.5. Instrument setting for the experiment at office room in Dhaka University

The Arduino Pro Mini, is another smart controller which plays a role of RF receiver module.Iin Figure 3.6 pin structure of Arduino pro mini is shown.

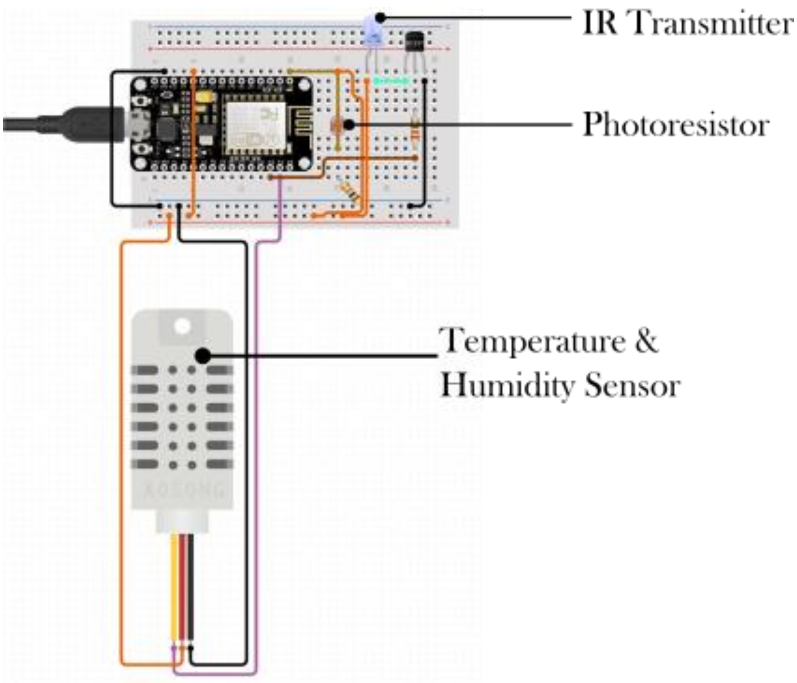


Fig.3.6 Humidity sensor structure
Source: (Taştan & Gokozan, 2018)

NodeMCU is all about embedded WiFi based IoT controller. It is a 32-bit Tensilica LX106 microcontroller running at 160 MHz (Texas Instrument, 2020).Table 3.3 shows details of this technology.

Table 3.3 NodeMCU & Arduino Pro Mini Specifications

Table 1: NodeMCU and Arduino Pro Mini Specifications

Specifications	NodeMCU v1.0	Arduino Pro Mini
MCU	32 bit Tensilica L106	8 bit ATmega328P
Frequency	80/160 MHz	16 MHz
Input-Output	17xDIO	14xDIO
ADC Pin	1x10 bit (1V)	6x10 Bit(3V3)
Operating Voltage	3.0~3.6V	3.0~3.6V
Program Memory	4MB	32kB
WiFi	IEEE 802.11 b/g/n	-

Source: (Taştan & Gokozan, 2018)

The information sent to the MCU is made up of 40 bits, 16 bits for temperature, 16 bits for relative humidity, and 8 bits for the checksum value.

3.4.1.3 System Architecture

To automate the task of optimally set air conditioner temperature that helps to minimize energy consumption, a machine learning model was designed shown in Figure below._.

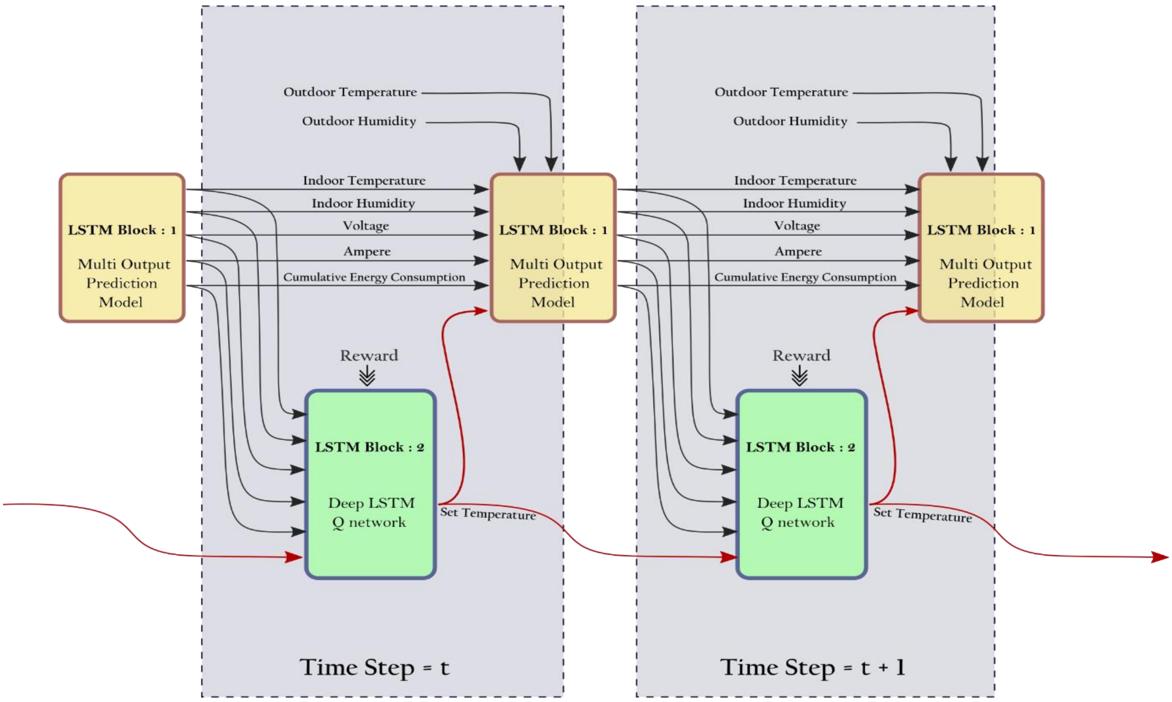


Fig 3.7. A generative model to predict environment state (LSTM Block:1) and optimal action predictor model (LSTM Block:2)

Source: Author's own compilation visualization from different sources.

System structure are shown in Figure 3.8. With the large amount of time series data, the investigator trained a deep LSTM model shown as LSTM block: 1 which predicts the next hour's room temperature, humidity, voltage level, current level and cumulative energy cost. The LSTM block: 2 then takes action. Optimal action in a particular environment state is learned by the deep Q network shown as LSTM block: 2. In Fig 3.8, LSTM block: 2 receives a reward at timestep (t+1) based on the action it took at timestep (t).

The more comfort level is ensured at (t+1) and lower the energy consumption at (t+1), the more positive reward the LSTM block: 2 receives.

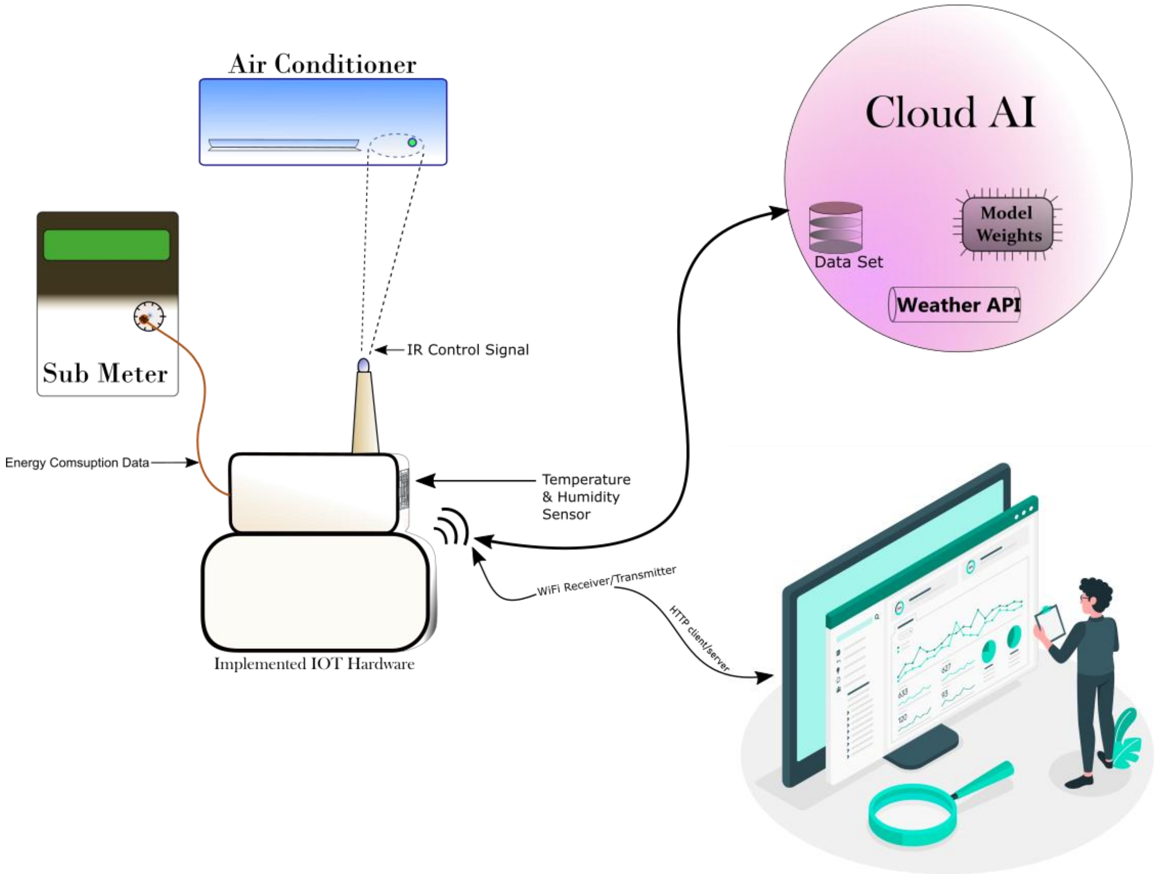


Fig.3.8. Architecture of IoT enabled ACs

Source: Author’s own compilation & visualization from different sources.

On the other hand, keeping the space outside comfort level temperature and humidity and consuming more power penalizes the AI model with negative reward. In figure 3.9 user can monitor power consumption state, observe results via connected sensors and cloud-based AI.

3.4.2 In-depth interview criteria/procedure

This research will also take up a qualitative approach because this is the appropriate approach to disclose the hidden issues behind the situation about which little is known and this approach is consistent with the rationale of exploratory research (Packer-Muti, 2009). This study aims to understand the prospects of IoT in energy sector particularly in ACs in different offices in term of technological, economic and environmental perspective. In this study, interview is chosen for its ability to make the interviewee comfortable and at ease. This generates more insightful responses about a sensitive topic like IoT prospects. In this method observing the respondents was easier. Their talking style, tone, wordings gave an unbiased insight to my desired findings. "The interview session is engaging as the questions are somehow pre- determined but the answers are not. And questions can get a new dimension depending on the answers" (Labaree, 2022).

The argument of choosing this method- is that the samples will be rich in knowledge and experienced according to the demand of this method. This is why I have taken the in-depth interview of 5 respondents who are involved with the process wholly. To avoid repetition 5 respondents with similar expertise and educational background have been selected.

Among the respondents one is renowned professor and proficient in IoT, another two are engineers and top executives from AC manufacturing plant and they are well versed of IoT, and the rest two are electrical engineers who have been selected from energy sector of Bangladesh. In order to execute the process of interview following steps were taken:

- Planning the whole process and identifying the sample to be involved.

• Developing the interviewing tool. An interview protocol was developed with the rules which guided the interview.

• Setting up the interview appointments for collecting data.

• Analyzing the data. This was done through the transcriptions of the interviews collected.

“As one of the focuses of the research is qualitative data analysis, semi-structured interviews are more appropriate for qualitative data analysis” (DeJonckheere & Vaughn, 2019). The interviews mainly consist of open-ended questions so that the interviewees can provide profound answers without any bias (DeJonckheere & Vaughn, 2019). The interviews took approximately 20-30 minutes. The plan was to take a closer and broader look of this aspect. Previously developed questionnaire helped me as a checklist to make sure all functions are covered in an interview.

I gathered some secondary data too but from a primary source about the overall situation that were needed to recognize the much-needed environment update and provided some initial level of information needed for this study too.

Based on above considerations, the research systematically identifies the energy consumption patterns and explored potential economic and environmental prospects of using IoT.

3.5 Justification of the Choice of Research Methodology

Selecting which research method to use in a research effort is dependent on certain factors. According to Bancroft et al. (1997) deciding which research method to use in a study is influenced by the degree of control that the researcher has over the experiment, and the topic or phenomenon that research the question addresses. Orlikowski & Baroudi (1991) examined 155 IT research articles published from 1983 to 1988. They indicate that IT research must not be dominated by a single research methodology since the utilization of a single research methodology can be restrictive. Orlikowski & Baroudi (1991) conclude that the positivist research methodology dominated the IT research efforts with 96.8% of all the IT research articles. Nearly 3.2% of IT research articles are carried out by following interpretive research methodology.

According to Mingers (2001) dominant methodology in IT research is positivist approach. also shares this view. The reason for the popularity of the method could be due to multiple theoretical, cultural, psychological and practical reasons (Ticehurst & Veal, 2000).

Researchers who utilize the positivist approach rely on laboratory-like experiments, surveys, or case studies, which involve collecting and manipulating data about a certain phenomenon in an effort to prove or disprove one or more hypothesis (Johnson & Christensen, 2014).

Based on the above discussion it is assumed that a combination of qualitative and quantitative methods will be appropriate for the study.

3.6 TECHNIQUES OF DATA COLLECTION

3.6.1 Primary Data: The primary data have been collected through experiment at different administrative offices in Khulna University and Dhaka University.

Primary data collection time and duration: After setting the device in both Dhaka and Khulna University, the primary data were collected during March-October, 2019 in Khulna University and during April-July, 2021 in Dhaka University.

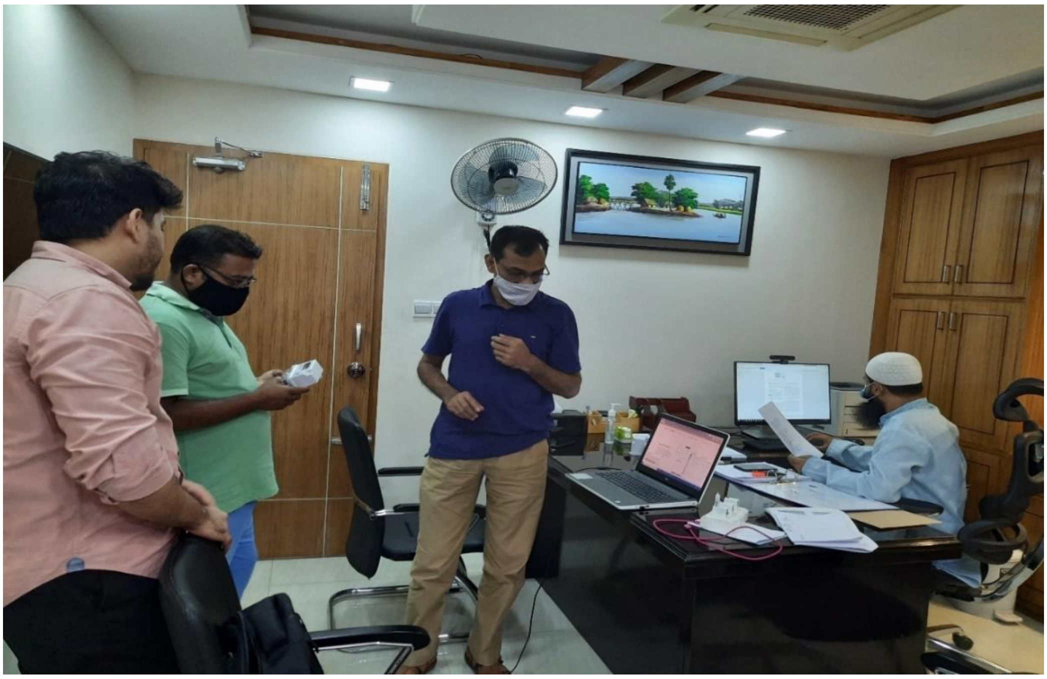


Fig.3.9. Data reading from Experiment in Dhaka University office

Primary Data collection location: Data were collected from various offices in both Dhaka and Khulna University. The university office rooms were selected from ground floor and 1st floor of Dhaka university while rooms of ground floor were selected from Khulna university for the study

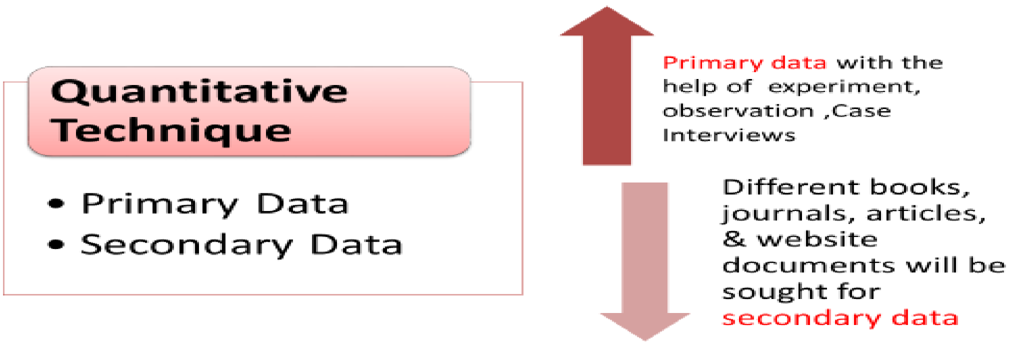


Figure: 3.10 Quantitative Technique
Source: Author's own compilation from different sources

3.6.2 Secondary Data: Secondary information primarily gathered from institutional sources. It includes information made available by Bangladesh power development board, annual report in BPDB website. Secondary data from books, reports, periodicals, newspapers, journal articles, and other sources has been gathered for the purpose of knowledge collecting and enhancement. Based on secondary data, this study's literature review section. To enhance the study report, more materials about the Internet of Things and its applications have been searched for.

3.6.3 Data Collection Instrument

This study uses different instruments for gathering the data. They are shown below.

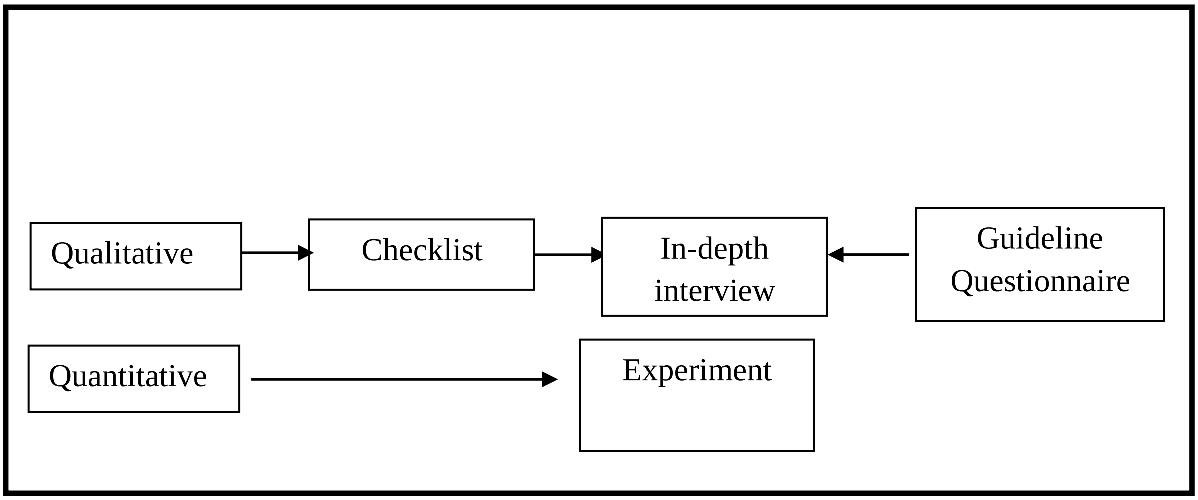


Fig3.11: Data collection Instrument
Source: Author's own compilation from different sources

3.7 Techniques of data analysis

Prejudice may exist even in a well-designed investigation. So, data analysis is considered as one of the most important phase of research. (Jozefowicz et al., 2015). Data analysis tries to establish the reliability of the theoretical model to the extent to which the independent variables seem to be influencing the dependent variable (Kong et al., 2018).

In this study, predictive modeling using the Python computer language and spreadsheet software, called MS Excel, were employed to analyze the original data. First, any missing data were found by editing, coding, and checking the obtained data. MS Excel is a method that is extensively used around the world for organizing data properly and conducting suitable analysis on it. To examine diverse data and achieve study goals, a number of financial, statistical, and mathematical tools were also applied.

3.7.1 Preliminary Data Analysis:

Sound arrangement of the indicators and transformation into an appropriate structure for the study determines the quality of data analysis (Patton, 2002). Preliminary data analysis will be performed by keeping in mind the above statement.

3.7.2 Descriptive Statistics:

Data which were collected from experiment (both in Khulna University and Dhaka university) were analyzed through regression model with spread sheet and python programming language. Different aspects of energy consumption with respect to ACs in different offices are analyzed through simple chart and tables.

3.7.3 Model Specification:

The research also uses Long Short-Term Memory (LSTM) model to find out the energy consumption in IoT enabled ACs. LSTM neural network is employed to perform the forecasting operation. The forecasting methodologies can be generally categorized into long-term (more than a year), mid-term (from a month to a year), short-term (from one day to a month) and very short-term (within 24 hours) forecasting methods. The fast development of artificial intelligence (AI) technology provides an important short-term forecasting solution for time series data compared to traditional methods, such as physical simulation models (Boyce & Neale, 2006; Saunders et al., 2009) statistical analysis (Kumar, 2005; Saunders et al., 2009) and regression models (Aaker et al., 2008; COOLEY, 1978).

Compared to traditional RNNs, Long Short-Term Memory is an enhanced recurrent neural network (RNN) architecture that was created to better accurately simulate chronological sequences and their long-range relationships. Recurrent neural networks (RNNs) are extended by LSTM networks, which were primarily developed to address RNN failure scenarios. When we talk about RNN, it is a network that operates on the current input while taking into account the prior output (feedback) and temporarily storing it in memory (short-term memory). The most well-liked uses of this technology are in the areas of non-Markovian control, speech processing, and musical creation.

RNNs do, however, have shortcomings. In the beginning, it is unable to keep data for a longer length of time. Sometimes, in order to forecast the present output, a reference to specific data that was saved a long time ago is needed. RNNs, however, are utterly unable to manage such "long-term dependencies".

Second, there is no finer control over how much of the past should be "lost" and how much of the context should be carried forward. Exploding and disappearing gradients, which happen when a network is being trained via backtracking, are another problem with RNNs (more on this later). Long Short-Term Memory (LSTM) was introduced as a result.

The training model remains unchanged, and the vanishing gradient problem has been nearly entirely eliminated.

Long short-term memory (LSTM) neural network is a special form of the recurrent neural network (RNN), which replaces the original low-cell neurons with cells consisting of more complex internal structures (Figure 2) (Lim & McAleer, 2002). First, it inherits the special property of RNN, which considers inputs as an inter-connected time series. Second, the complex internal structure of LSTM cell resolves the exploding and vanishing gradients problems (K. Liu et al., 1996). There are four important elements in the flowchart of LSTM model: cell status, input gate, forget gate and output gate (Figure 3.12).

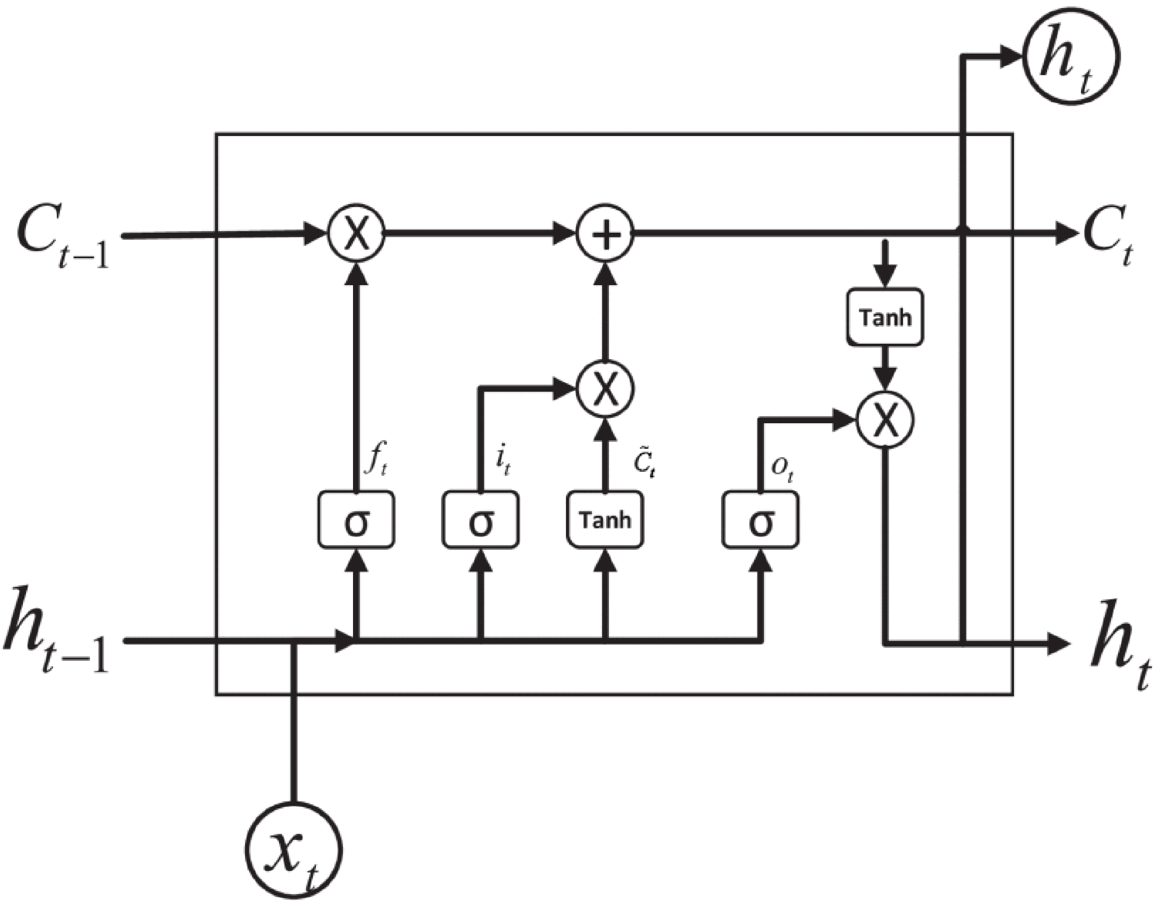


Fig. 3.12 Flowchart of LSTM
Source: (Qiu et al., 2020)

The input, forget and output gates are used to control the update, maintenance and deletion of information contained in cell status. The forward computation process can be denoted as:

$$f_t = \sigma(W_f \cdot [h_{t-1}, x_t] + b_f), \quad (1)$$
$$i_t = \sigma(W_i \cdot [h_{t-1}, x_t] + b_i), \quad (2)$$
$$\bar{C}_t = tanh(W_C \cdot [h_{t-1}, x_t] + b_C), \quad (3)$$
$$C_t = f_t \cdot C_{t-1} + i_t \cdot \bar{C}_t, \quad (4)$$
$$o_t = \sigma(W_o \cdot [h_{t-1}, x_t] + b_o), \quad (5)$$
$$h_t = tanh(C_t), \quad (6)$$

where Ct , Ct−1 and Ct~ represent current cell status value, last time frame cell status value and the update for the current cell status value, respectively. The notations ft, it and ot represent forget gate, input gate and output gate, respectively. With proper parameter settings, the output value ht is calculated based on Ct~ and Ct−1 values according to Eqs. (K. Liu et al., 1996; Mantovani et al., 2015). All weights, including: Wf , Wi , WC and Wo , are updated based on the difference between the output value and the actual value following back-propagation through time (BPTT) algorithm (Kavasseri & Seetharaman, 2009).

Following the process of data collection throughout blazing summer in Dhaka city, data set for machine learning were generated via preprocessing. For instance, closing hour or idle hours were filtered out and interval was set to 60 minutes. Using predictive model, we wanted to forecast the indoor temperature, humidity, voltage level, current level & cumulative energy after 60 minutes as a function of *X*. here, *X* is the input features denoted as,

X **= (indoor temp(t), indoor humid(t), Volt(t), Current(t), Kilo Watt(t), outside temp, outside humid, operating temp)**

X includes indoor and outdoor temperature-humidity, voltage, current, energy level & the current operating temperature of air conditioner. The term (t) refers to present hour.

The output of regression model is defined as,

Y = (indoor temp (t+1), indoor humid(t+1), Volt(t+1), Current(t+1), Kilo Watt(t+1))

Since, X and Y follows a time dependency therefore, it requires to have an autoregressive model. For instance, what happened in the afternoon would have impact on the evening's environmental state, if it was raining 5 hours ago or not etc. information is useful to make an accurate prediction. Proposed LSTM block for 5 tuple output prediction is shown in Figure 2. As illustrated, LSTM cell maintains a cell state which contributes to each output. Whether to forget a past state or not is decided by the forget decision maker which is a sigmoid function in (i) on the weighted sum of Input for Current Hour and Output from last Hour.

$$forget\ decision = \sigma(weights \cdot (\text{input}, \text{previous output}) + bias) \dots \dots \dots \dots (i)$$

The New State is typically a tanh function in (ii) applied on current input and output from last hour.

$$New\ State = \tanh(weights \cdot (\text{input}, \text{previous output}) + bias) \dots \dots \dots \dots (ii)$$

⊗ sign is a dot multiplication operation on input vectors.

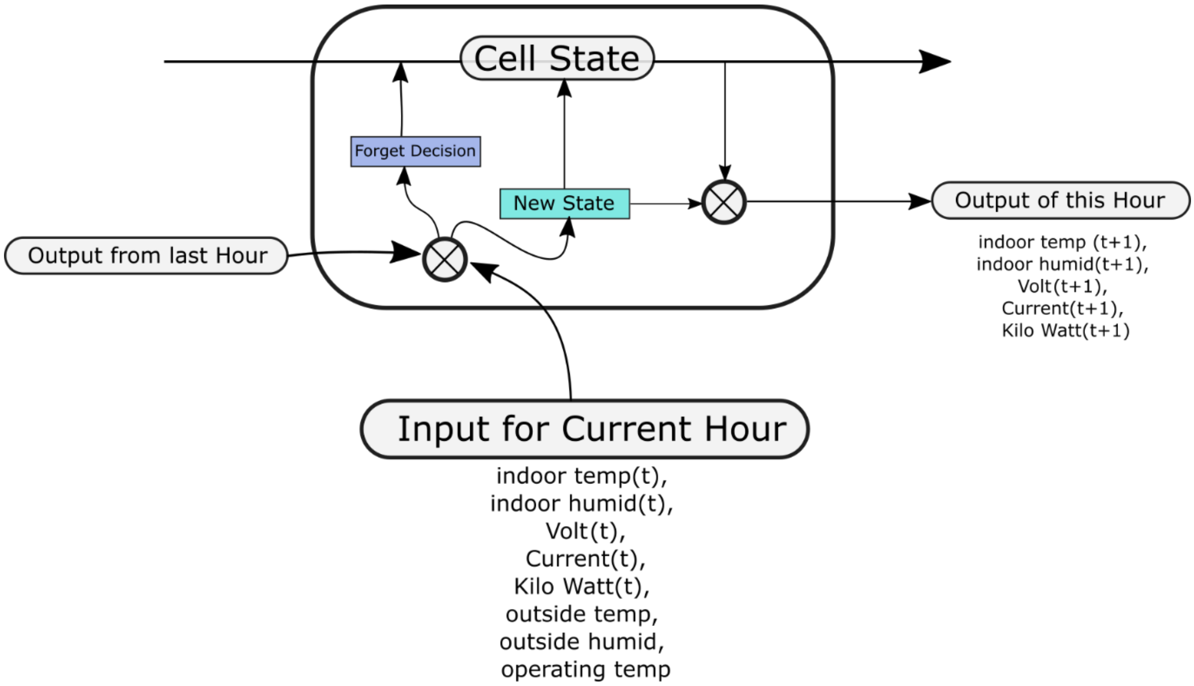


Fig3.13. Long Short-Term Memory cell for prediction

Source: Author's own drawing based on different sources

Using Python programming, a deep LSTM network was constructed with 6 hidden layers each having 1000 neurons. As a cost function, Mean Squared Error was chosen. Since, our dataset was a timeseries data, no random selected was allowed. 70% of the time series sequence were used to train the model while the rest was applied for evaluation.

3.7.4 Justification of the choice of Technique

The short-term and very short-term energy consumption forecasting techniques are useful for various aspects of energy sector i.e. energy demand-side management, electricity price market design, energy efficiency and maintenance scheduling of large-scale complex smart power grids (W. Wang et al., 2018; Y. Wang et al., 2019; Werbos, 1990).

Along with the fast development of artificial intelligence (AI) technology, the extended deep learning methods nowadays are capable of performing very short-term energy consumption forecasting results with spectacularly high prediction accuracy (Amasyali & El-Gohary, 2018; Gagliardi et al., 2020; Guo et al., 2019; Kong et al., 2018). Hence, the regression model should presumably make better forecast if there is a memory to hold sequential information. For this reason, Long Short-Term Memory (LSTM) network was best suited for the research.

CHAPTER FOUR

DIGITAL TRANSFORMATION IN ENERGY SECTOR: BANGLADESH PERSPECTIVE

CHAPTER -FOUR

DIGITAL TRANSFORMATION IN ENERGY SECTOR: BANGLADESH PERSPECTIVE

4.1 Digital Technology in Energy sector.

Today's Value chain of energy sector is augmented and interconnected by digital technologies. It actually expedites the process of power and information in multiple direction. As a result, the digital technology helps to add value to the entire value chain system. Therefore, information sharing, openness, collaboration, coordination, and the right set of incentives in right time right way ensure overall efficiency and resilience of the system (Trabish, 2015).

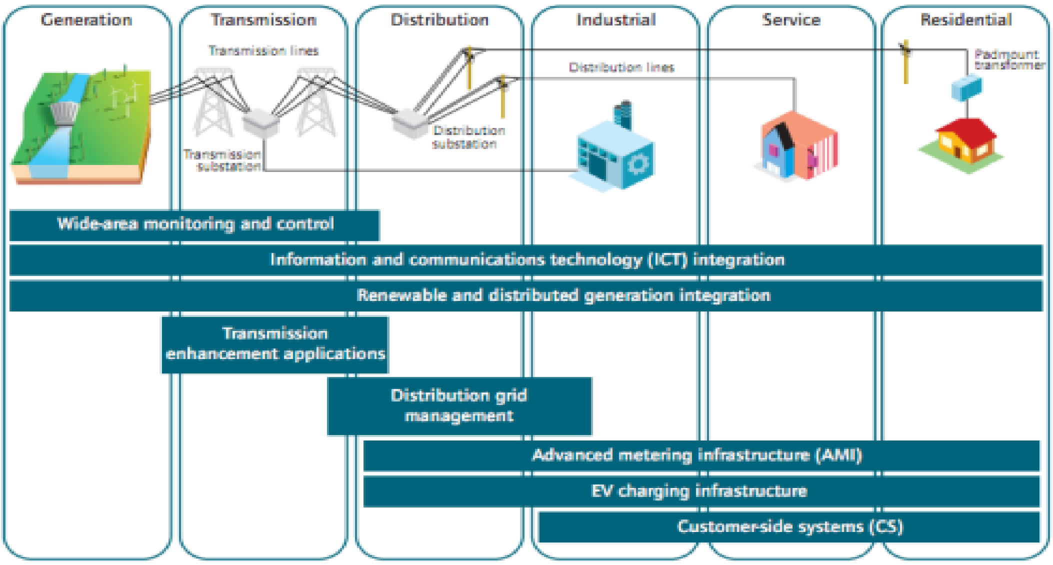


Fig.4.1: Stages of Energy sector

Source:(Trabish, 2015)

The ultimate result will be a system that delivers power in the most dependable, environmentally friendly, and cost-effective way possible. Three crucial components are included, and they are noted below:

i. A major component of digital generating that uses both fossil fuels and renewable energy sources. To achieve the requisite step change in performance, fossil-fuel plants should embark on a transformation that combines digitization and advanced analytics with classic lean operations. Although investing large capital sums in transformation may seem daunting in what appears to be a declining sector, as discussed above, many assets will continue to operate in the medium to long term.

Through a carefully targeted deployment of technology-enabled lean operations, such as work-flow optimization, condition-based maintenance, process digitization, and agile working, utilities can increase plant efficiency (heat rate) by up to 3 percent, reduce the average all-in cost of generation (excluding fuel) by 10 to 20 percent for coal and 5 to 15 percent for gas, all while improving safety. A full lean transformation supported by technology solutions could also unlock significant value in incremental earnings. The following figure shows how digital technology drive value to power plant (Guzman, 2019)

Area of impact	Safety	Heat rate	Availability and unplanned downtime	Other O&M[2] costs
Examples of potential value	• Minimize distractions and near misses	• Minimize variability and reduce heat rate by 2–5% beyond traditional operations improvement	• Reduce EFOR[1] to <1% with reduced capital costs	• Reduce spend by as much as 50% in some categories
Sample applications	• Robots tackle tasks in confined spaces • Radio-frequency identification (RFID) tracking prevents congestion and risk • Advanced analytics prevents accidents due to fatigue, distraction, or high-risk situations	• Advanced analytics and machine learning used to optimize parameters • Multiple smart sensors and actuators installed in boilers for remote monitoring and automation • Smart valves that self-report and repair leakages	• Smart sensors and machine-learning predictive models identify next failure mode • Automation increases maintenance efficiency: work-order generation, lockout/tagout, kitting, and execution • Remote expert support provided via augmented- and virtual-reality devices	• Use of augmented and virtual reality and RFID in contractor management • Back-office automation in purchasing • Automation of mining equipment and warehouse • Introduction of machine-learning model to automate chemical injection

Source: (Guzman, 2019)

Power sector companies started their digital transformations with technological solutions such as data models. This transformation helps to optimize set points, enable better dispatch decisions, and support maintenance strategies and operating-mode selection. However, Forward-looking companies have recently started using visualization tools to manage real-time generation performance and digital control software to relay predictive data to control rooms. The figure in the below shows next generation digital technologies and optimization of targeted area of operation (Maciel, 2020).

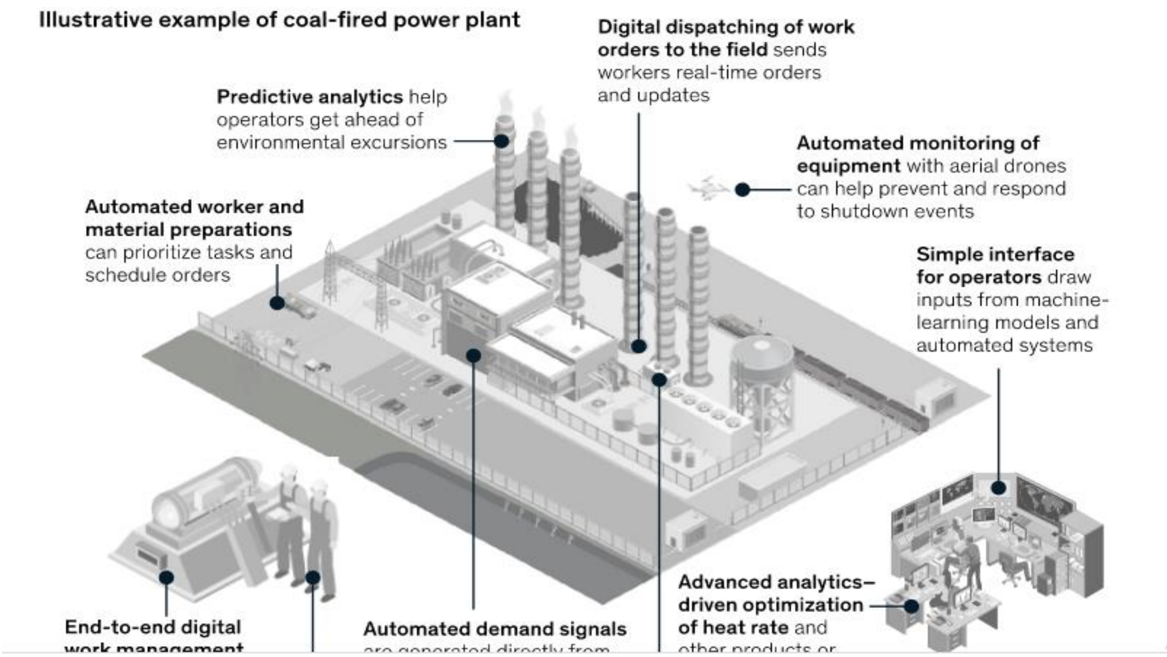


Fig.4.2 Digital technologies and optimization of energy sector
Source: (Maciel, 2020)

ii. A digital grid that links production and consumption and allows for bidirectional energy and information transfers. Nowadays, a lot of nations manage their electricity sector utilizing smart grid. Electricity systems in smart grid is enhanced by communications networks, monitoring and control systems, "smart" devices, and end-user interfaces are known as "smart grids." The IEA offers the following definition, which is useful in directing this report's examination of ICT applications and combines functions and components:

An energy network known as a "smart grid" employs digital and other cutting-edge technology to monitor and regulate the conveyance of power from all generation sources in order to satisfy the various electricity needs of end users. Technically speaking, a "smart grid" is a concept for conventional networks that incorporates modern, automated technologies to increase their sustainability and dependability.

We can compare conventional grid with smart grid. In conventional grids we can just transmit and distribute the electric power but smart grid can communicate, store or even decide according to the situation. Therefore, according to Strategic Deployment Document for Europe's Electricity Networks of future, a Smart Grid is an intelligent network of electricity that integrate the actions of all the stakeholders that are generators, consumers and one who does both in order to supply electricity with efficiency, sustainability, economically and securely (Majeed Butt et al., 2021). So, smart Grid is not a single technology that is to be implemented. Its vastness and dependency increase by its stakeholders as shown in 4.3.

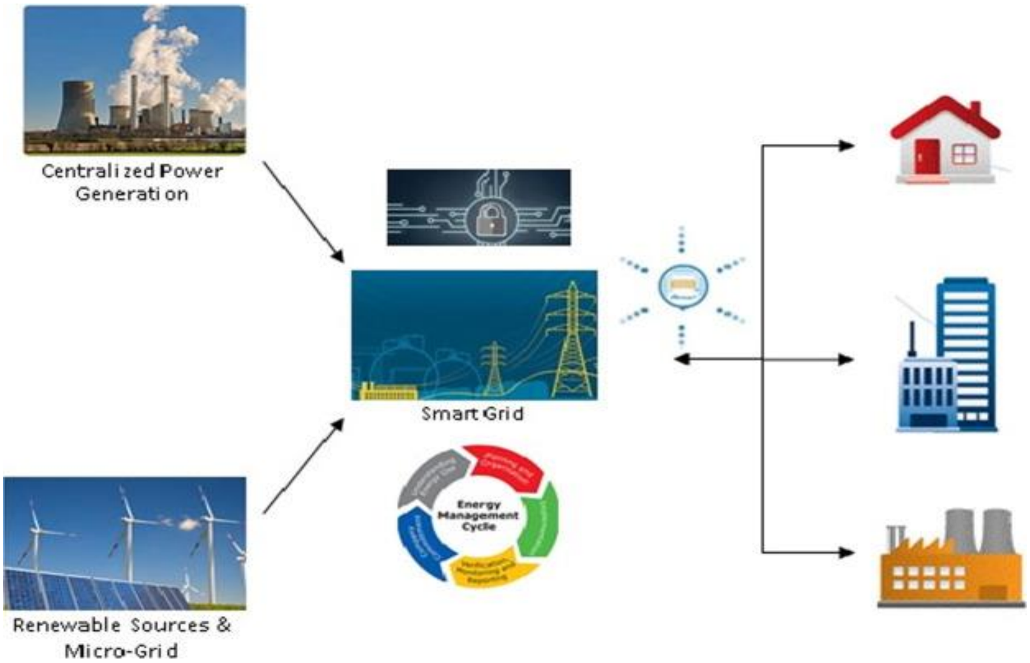


Fig. 4.3. Smart grid
Source: (Majeed Butt et al., 2021)

Smart grids ensure co-ordination among the various machine and equipment including different stakeholders. It also makes sure system efficiency with minimization of cost, and environmental impact while ensuring maximization of system reliability, resilience and stability." (Trabish, 2015). Digital grid will be the backbone of future energy network, which will enable two-way electricity flows, communicate information and price signals, and guarantee the best possible supply and demand balance. Together, these improvements will increase grid dependability, lower losses, and incorporate dispersed resources that can aid in the system's decarbonization.

iii. To accomplish these goals, a substantial number of digital technologies will be used. The management of outages, customer information, maintenance schedules, and meter data are just a few of the IT tools that utilities use today to manage their T&D operations. By employing digital tools and intelligent monitoring equipment energy sector can manage reliability, handle customer problems and ensure optimum energy distribution.

iv. The fourth pillar, digital consumption, will be crucial in enhancing consumption habits as well as increasing generation and storage capacity.

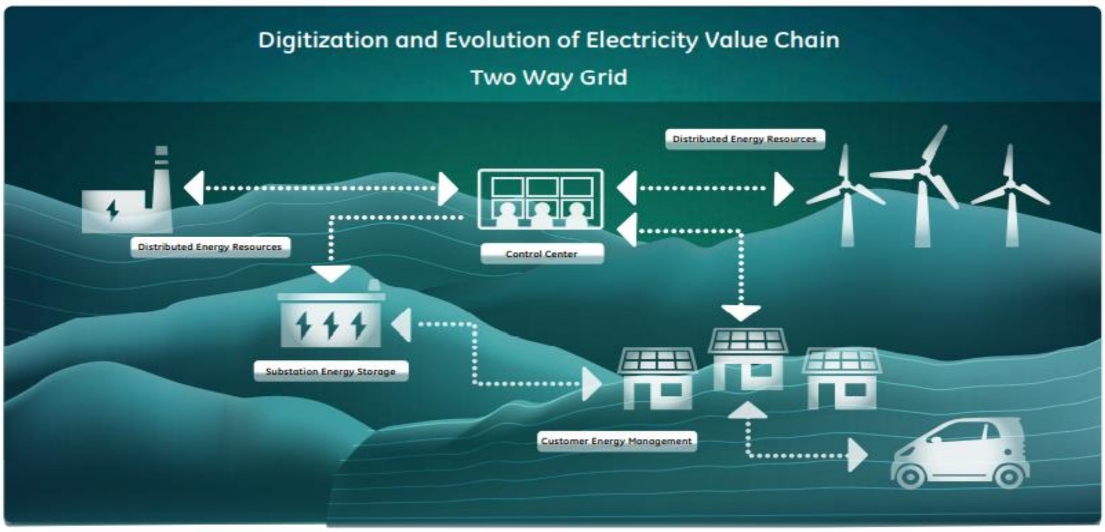


Fig.4.4, Digitalization and evolution of electricity value chain
Source: (Trabish, 2015)

4.2 Digitalization of Energy sector in Bangladesh

Bangladesh Power Development Board (BPDB) is a statutory body which has been established in May 1, 1972, by presidential Order No. 59. Installed Generation capacity of BPDB was only 200 MW at the beginning of its operation. At present its generation capacity has increased to **12,725 MW** as of June 4, 2022 (BPDB, 2020).

As part of reform and restructuring a number of Generation and Distribution companies have been created. The subsidiaries of BPDB are:

- Ashuganj Power Station Company Ltd. **(APSCL)**
- Electricity Generation Company of Bangladesh **(EGCB)**
- North West Power Generation Company Ltd. **(NWPGCL)**
- West Zone Power Distribution Company Ltd. **(WZPDCL)**

The BPDB is responsible for major portion of generation and distribution of electricity mainly in urban areas except Dhaka and West Zone of the country. The Board is under the Power Division of the Ministry of power, Energy and Mineral Resources, Government of Bangladesh. BPDB has introduced following IT based services for customer satisfaction (BPDB, 2020; Schneider Electric, 2018):

i. Energy mobility starts with the transmission of electricity, which includes high-voltage transmission lines (above ground, below ground, and beneath the seabed) that commonly employ alternating current (AC). When the locations of generation and consumption are far apart, high voltage and direct current (HVDC) transmission systems are a crucial component (e.g., off-shore wind parks or hydro power).

- Electricity distribution refers to the place of consumption is referred to as electricity distribution, and this is done via medium and low voltage power lines that nearly exclusively employ alternating current (AC). These distribution lines, which originate at substations that convert high voltage power into medium and low voltage energy and finish at electricity meters at the client site.

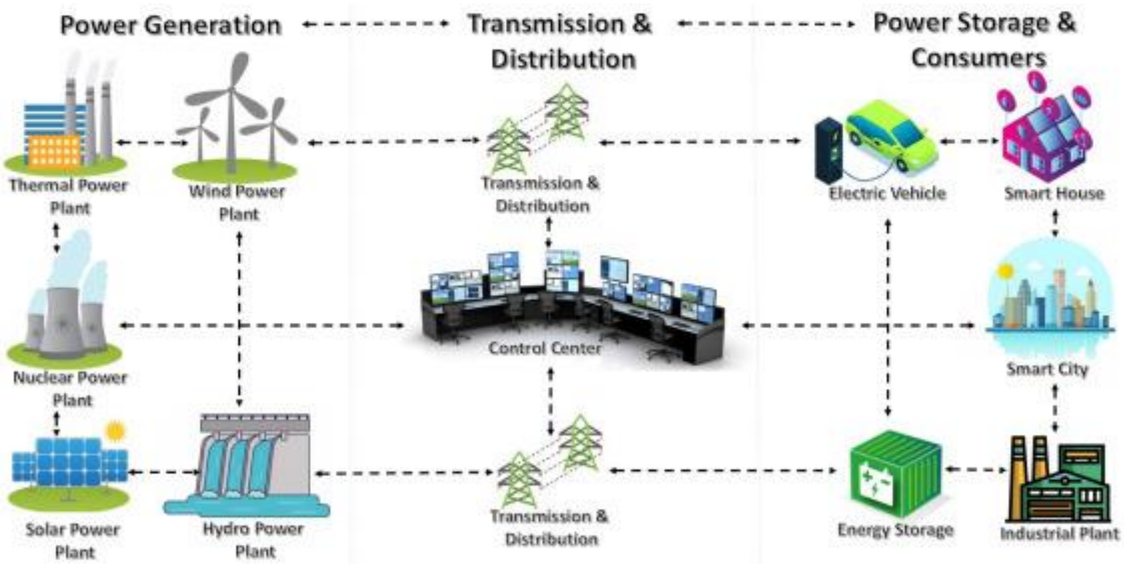


Fig.4.5 General framework including Power Generation, Transmission & Distribution, and Power storage & Consumers

Source: (Maruf et al., 2020)

Last but not least, electricity consumption includes all uses of power that occur on the customer's account or property. The line is drawn at the energy meter, which is normally where utility discretion ends and only the customer has the authority to switch on or off items that use power.

Changes on the consumption side may have hastened the energy system's evolution. Traditional energy consumers are now able to become energy producers because to developments in solar and energy storage. Energy management systems, linked gadgets, and advanced meters are giving customers more insight and control over their energy consumption. Together, these developments will enable customers to reduce their energy costs while also benefiting the system as a whole by reducing peak demand and delivering more affordable energy and related services.

Digital transformation in energy sector is crucial to remain competitive. Some the important step towards digital transformation in energy sector are discussed below.

- Bill on Web / Consumer Electricity Bill
- Pre-payment metering system
- Computerized billing system
- Digital Services of BPDB
- Supervisory Control and Data Acquisition (SCADA)
- IoT introduction

4.2.1 Pre-payment metering system

Approximately 27 lac people are Bangladesh Power Development Board users. By December 2021, there will be around 35,75,500 consumers in 4 zones, assuming a 9% growth rate. In the interim, 8,74,890 pre-paid meters have been placed out of a total of 11,437,377 pre-paid meters that have been agreed to be installed. Prepaid meters will be installed by BPDB for all 24,75,500 consumers in the future.

- Ensures complete revenue collection with no receivables.
- Prevents the customer from utilizing more load than is allowed.
- Prevents theft of electricity after the meter.
- Offers hassle-free billing/collection services, including those for false billing and erroneous meter reading.
- Offer the benefit of controlling customer energy use.

For transforming into an SG system, one of the primary requirements is to install Smart Metering (SM) system. Fundamentally, SM is an electronic digital device that is connected to a network to measure the consumption of electrical energy (Arif et al., 2013). Every electronic device of a house that uses electricity is also connected with this network. The SM receives the information of power demand and supply of the house and sends it to the service provider as well as displays that on the dashboard screen.

As it works bi-directionally, it makes it convenient to collect real-time power demand and supply information. This important piece of information can be used to optimally decide the cost of energy in peak hours and off-peak hours. Research had been conducted in 2013 (Arif et al., 2013) where the researchers proposed a smart meter that is communicating via wirelessly between the consumer and supplier.

In some areas of Dhaka, the smart card metering system is being successfully deployed. The main benefits of using this metering system are the transparent billing system where the consumers can control their energy consumption, receive warnings of low credit, store consumption data and be able to pay online through mobile apps. Due to this technology, meter tampering has also been significantly reduced in those areas reducing the loss of government revenue (Arif et al., 2013).

The smart card prepaid meter and SM are different in that the prepaid meter lacks the ability to obtain information on the real-time energy usage of household appliances since it is not connected to a home network. It is unable to coordinate the demand and supply for power in real time. In comparison to SM, the information displayed on the smart card prepaid meter's display is likewise insufficient. Customers may monitor the energy use of any individual device with the smart metering system, which is not possible with the prepaid metering system.

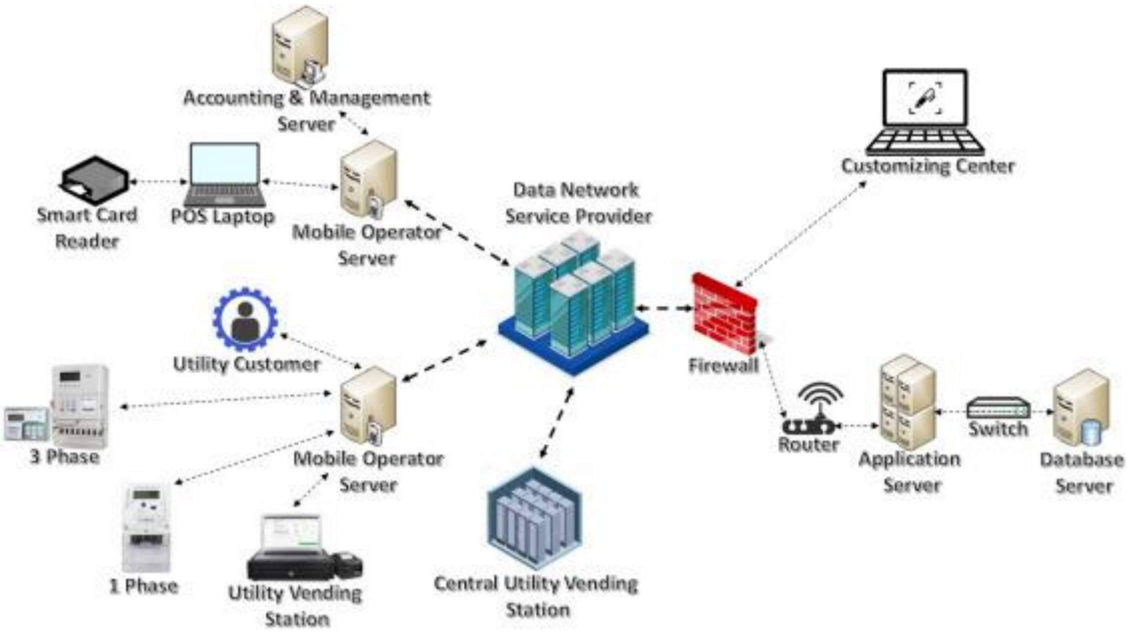


Fig.4.6. Diagrammatic view of smart metering system of Bangladesh.
Source: (Maruf et al., 2020)

4.2.2 Computerized Billing system

In its six distribution zones, BPDB has implemented a computerized invoicing system with 100% consumer participation. For the purpose of customer acknowledgment, each electronic bill displays the current month's billing amount, the previous month's payment, and the status of any arrears. Compared to the old manual billing system, it assures better customer service, increases revenue collection, lowers system loss, and enhances billing system.

The overall number of connections granted by BPDB during this fiscal year is 2,12,802, and the total number of users has climbed to 2,48,1957. The yearly increase was 9.38 percent in FY 2016.(BPDB, 2020).

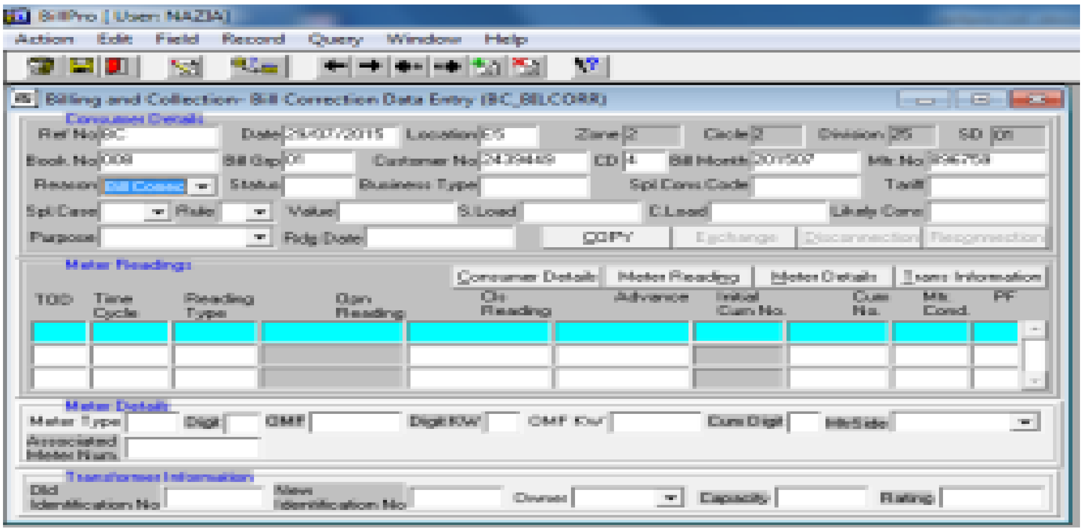


Fig.4.7. Computerized billing system
Source: (BPDB, 2022)

Easy bill pays: In its six distribution zones, BPDB has implemented a quick bill payment method through mobile phone. Even on vacations, consumers may pay their power bills by using the designated mobile phone provider round-the-clock.

4.2.3 Online application for Pre-payment/ metering

To give its customers hassle-free service, BPDB has implemented one-stop services in each S&D division and ESU. There is a designated desk for one-stop servicing in each S&D division and ESU. Any customer can file a complaint on the desk, and the officer in charge is given the authority to take any action required to handle the issues.

4.2.4 Supervisory Control and Data Acquisition (SCADA)

It has begun operating in the four BPDB zones of Chittagong, Sylhet, Mymensingh, and Comilla for system control and data collecting of the networks and distribution systems that fall under them from a single point in each zone. Assuming that the SCADA of each zone is linked to the 34 substations within the Chittagong zone, the 18 substations within the Sylhet zone, the 17 substations within the Mymensingh zone, and the 10 substations within the Comilla zone.

This actually guarantees complete revenue collection and absence of any accounts receivable, prevents the customer from utilizing more load than is authorized. stops power theft after the meter. eliminates hassles in the billing and collection process, including as false billing and faulty meter reading.

Additionally, BPDB intends to centrally monitor and manage all of its SCADA systems by establishing one SCADA in Dhaka. The main duties of SCADA are to supervise/monitor the networks that it is in charge of continually on computer monitors around-the-clock and to systematically manage the networks' power supply from the supervisors' desk as needed.

Preparing and reporting to the appropriate authorities on a daily and monthly basis the power supply, demand, load shedding, line shut-down, etc. of each circuit of the networks under it for system planning.

Creating a report for any specific time period as requested by the relevant authorities for system planning, including reports on power supply, demand, load shedding, line shutdown, etc.

Data collection and recording of power flow/supply status through each circuit of the entire networks on an hourly basis around the clock is done for reporting to the appropriate authorities and for intelligent SCADA system management by analyzing demand, power factor, and other essential components of each circuit.

In order to maintain the overall system's health, load management must be coordinated with power generation as directed by the NLDC or other relevant authorities, delivering all pertinent system-related information to the appropriate authorities as and when necessary.

4.2.5 Present status of IoT

Now a days different industries consider IoT as a disruptive technology. The technology works as catalyst which is designed to ensure low power consumption, low emission and machine to machine communication for receiving and sending data. (Souders, 2015). Essential tasks of disruptive technologies are capturing and analyzing more relevant data (Wasserman & Mahmoodi, 2017). With the advancement of smart grid and its components, a technology like IoT is desperately needed to interact these components in an efficient, reliable and in more smart way.

IoT has a promise to full fill all these characteristics taking smart grid into new era. But with this new technology, some serious security concern emerged which include impersonation, data tampering, overdoing, authorization, privacy issue and cyber-attack (Bekara, 2014). Connectivity that IoT provides to customer, enhance their experience and efficiency. It allows customer a flexible and easy interaction with the grid in order to reduce cost by diagnostics and neighborhood-wide meter reading capability (Shah & Patel, 2016).

By considering all these Bangladesh power development board is considering seriously to cope up with this technology.

4.2.6 Other Digital services

BPDB has adopted some important digital services for their day-to-day activities. Some of the important services are explained bellow (BPDB, 2020).

4.2.6.1 Online store management system: BPDB has introduced online store management system to smoot material acquisition, allocation and real time stock status information.

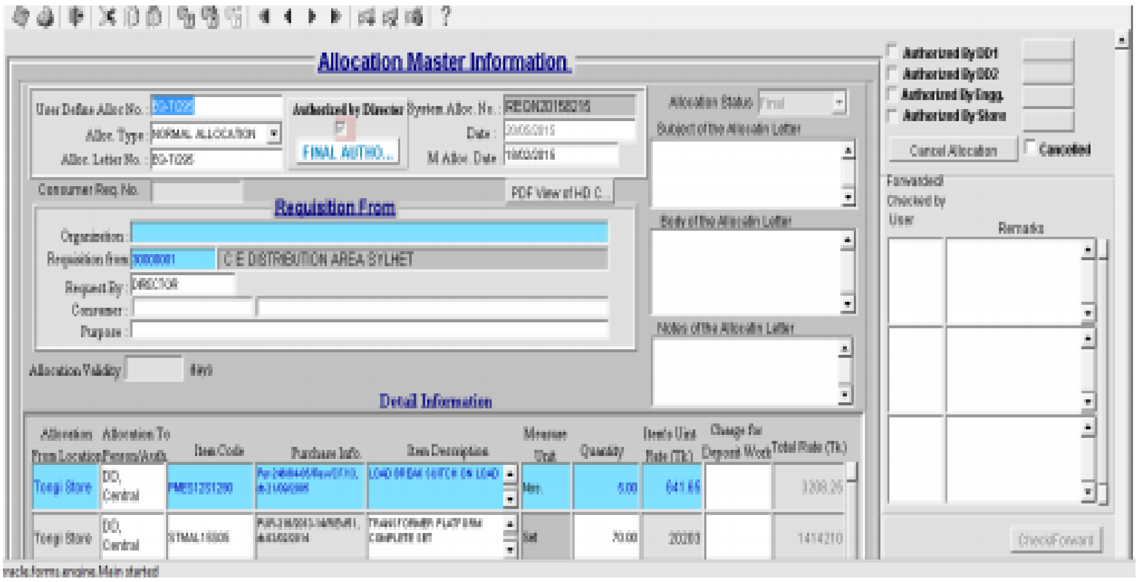


Fig.4.8 Online store management system
Source: (BPDB, 2022)

4.2.6.2 E-bank management system: This has been introduced with a view to monitor revenue collection and better coordination with the field level employees and other stakeholders.

Fig.4.9 E bank management system
Source: (BPDB, 2022)

*4.2.6.3 KPI System***:** The system is akin to executive dash board from where top authority can understand make decision on various important aspects of power sector. The system helps Bangladesh power development boar authority to understand key performance indications in various sector in real time basis. Particularly the system shows key performance indicators in procurement and project management, sales, distribution, HRM, finance and other operations.

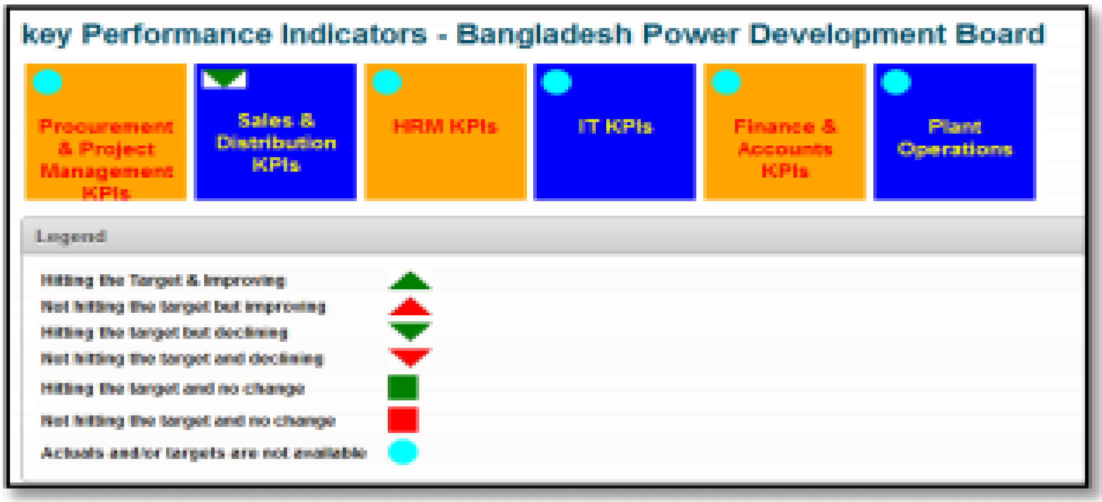


Fig.4.10. Screen shot of KPI
Source:(BPDB, 2022)

4.2.6.4 Unified PIMS (Personnel Information Management System): This will let the authority to know the status of each employee of the organization. With this system BPDB can monitor performance of all employees across various departments and units.

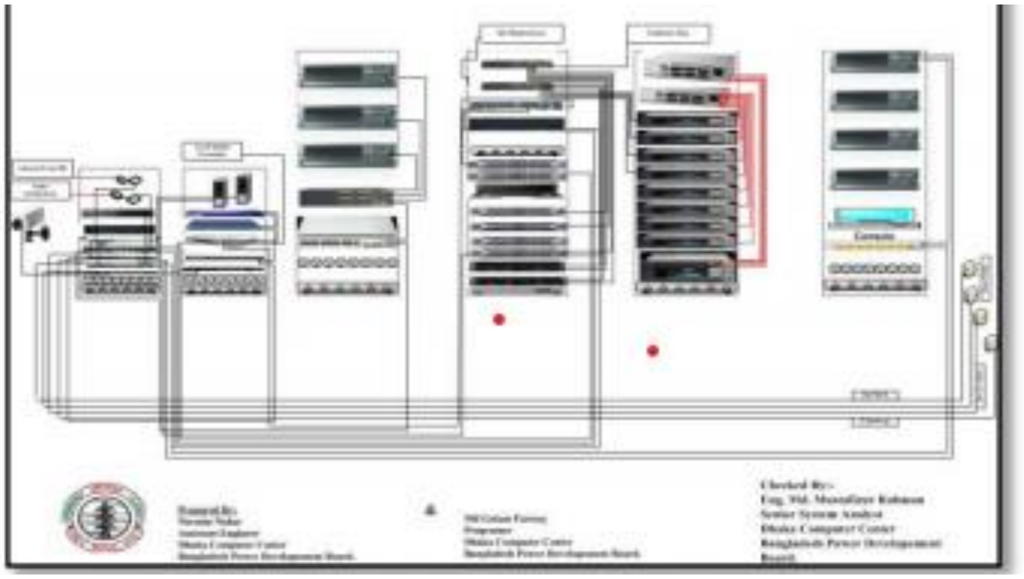


Fig. 4.11 PIMS (Personnel Information Management system

Source: (BPDB, 2022)

*4.2.6.5 Online application for electricity connection***:** Earlier getting an electricity connection was a big hassle. At present application for new connection become easier, smarter and less bureaucratic. The present system plays a major role for consumers satisfaction in getting new connections.

Fig.4.12 Online application for new connection
Source: (BPDB, 2022)

4.2.6.6 Online training management system: The system will facilitate the training and development of the employees of BPDB.

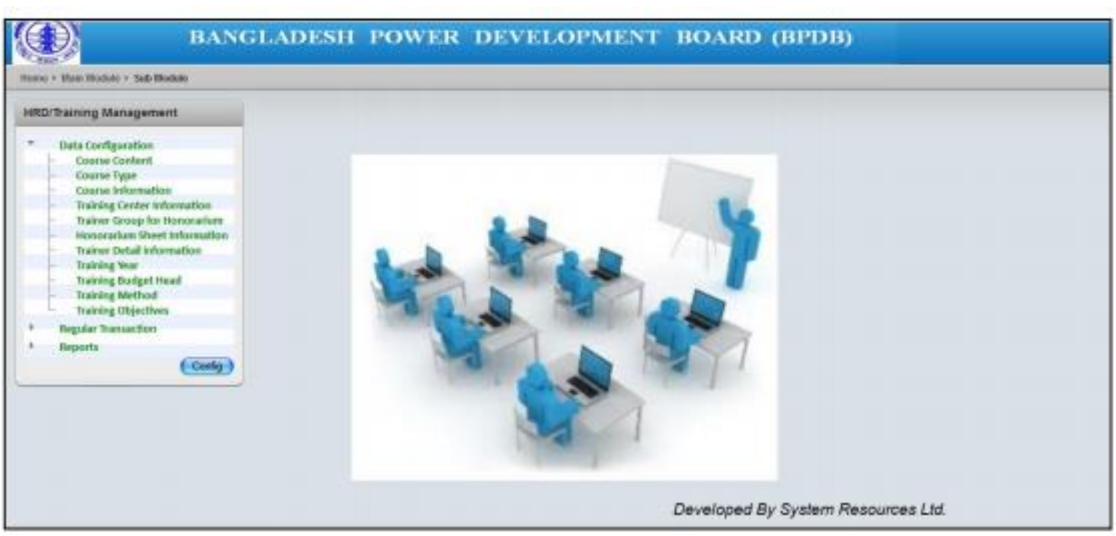


Fig.4.13 Online training management
Source:(BPDB, 2022)

4.2.6.7 DBMS connectivity upgradation: Connectivity in various location have been completed. At least ten data point are connected with the system. The upgradation makes BPDB more flexible, reliable and agile in providing services to its clients.

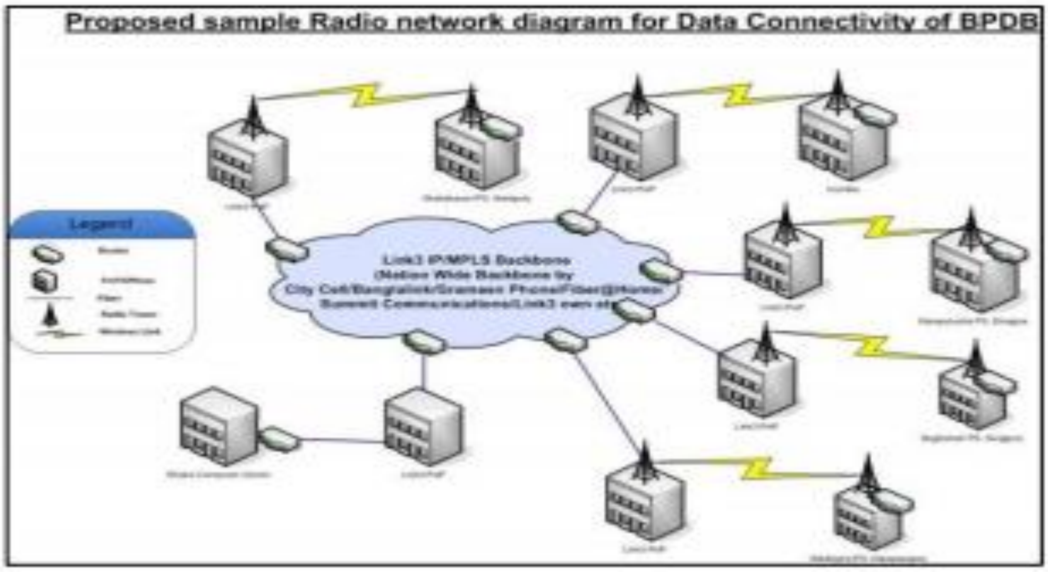


Fig.4.14 DBMS connectivity

Source: (BPDB, 2022)

CHAPTER FIVE

DATA ANALYSIS AND PRESENTATION

CHAPTER FIVE

DATA ANALYSIS AND PRESENTATION

5.0 Introduction

In this chapter, data collected through experiment and observations has been analyzed by using different statistical tools and techniques. The study integrates cross domain data i.e., building data, energy prices, weather data and end-users' behavior. The chapter explains experiment result, observation data regarding users' preferred set temperature, cost benefit analysis, return on investment and finally it shows impact of IoT enabled ACs in environment.

5.1: Experiment Result

Data have been collected from March-October 2019 in different offices of Khulna University and April to July,2021 in different offices in University of Dhaka with the help energy meters and IoT devices. Different office room parameters are observed while collecting the data. The parameters are indoor and outdoor temperature-humidity, voltage, current, energy level & the current operating temperature of air conditioner. Here AC is set on 20-25℃ gradually and power consumption recorded for each degree changed. Following table shows the summary result of the experiment. As for example, in the table below total electricity consumptions in March,2019 was 231.73 kWh, when AC's Temperature is set on 20℃.

Table 5.1: Experiment Data during March-October/2019

Month	**No of Days**	**Consumption on set Temperature(kWh)**			**Savings(kWh)**	
		20°	24°	25°	24°	25°
March	20	231.73	166.9	153.9	64.83	77.83
April	20	301.88	230.64	215.54	71.24	86.34
May	20	296.80	223.96	215.41	72.84	81.39
June	20	308.41	235.9	222.25	72.51	86.16
July	20	311.72	235.76	211.72	75.96	100
August	20	299.25	243.7	215.05	55.55	84.2
Sept	20	244.22	186.73	163.34	57.49	80.88
Oct	20	230.2	173.63	165.5	56.57	64.7

Source: Experimental Data

The above table shows that maximum power consumption takes place in July while lowest power consumption observed in October 2019.The maximum power savings took place in July which saves 100 kWh for 25℃ setting while 75.96 kWh for 24℃ settings. Whereas lowest saving took place in October for both 24℃ and 25℃ settings and the savings was 56.57 kWh and 64.7 kWh respectively. So, it is concluded that significant power savings can be obtained if we introduce IoT in AC's and control temperature in between 24℃ - 25℃.

5.2: Preferred set temperature by Users

Several offices of both Khulna and Dhaka have been observed in between March-October in 2019.This has been done in order to know the users' preferred set temperature in ACs. Obtrusive observation measures have been used to know users' set temperature in ACs. The offices include bank, university, mobile phone operators of Khulna and Dhaka city. These offices are used by managers, professors, executive officers of both public and private organization. Observed result are shown in the following chart. The chart shows the average set temperature by the users of each month in 2019. The figure also shows that in July and August users normally set lower temperature while in March and October users set a bit higher temper for their comfort.

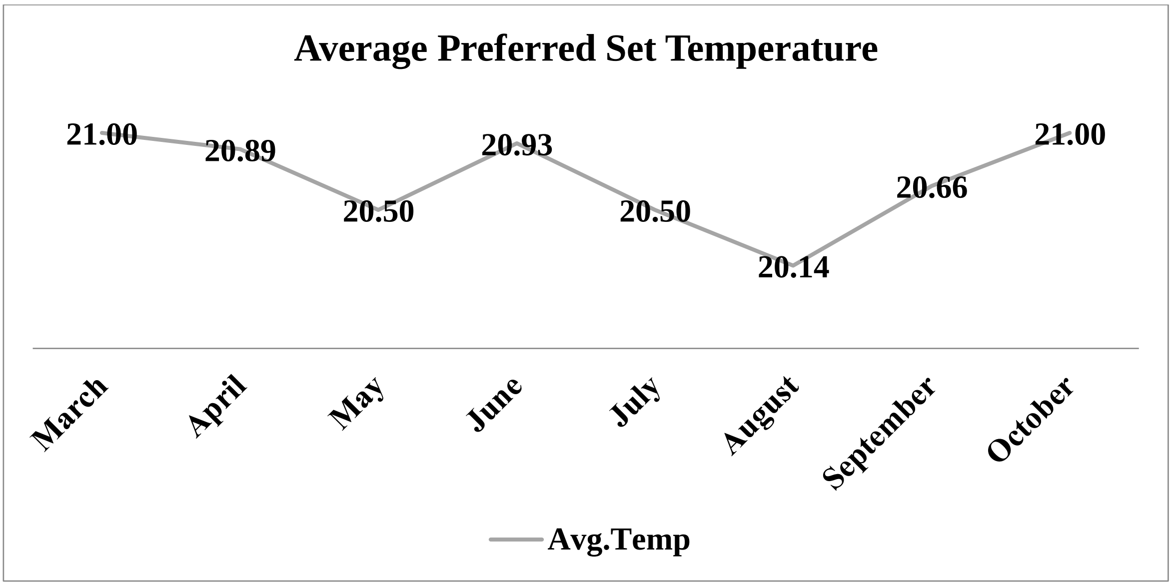


Figure 5.1: Avg. users' preferred set temperature
Source: Experimental data

5.3: Power consumption in various modes

Experiment have been conducted in various modes i.e., luxury, moderate, frugal and always on in 24 and 25℃. Set temperature in luxury, moderate, frugal mode was 20℃.

Here luxury s luxury, moderate, frugal mode means always on during 9 am-4 pm, 6 hours and 4 hours AC use in offices and it is observed that power consumptions are lower in 24 or 25℃ than the other three modes. In the figure one can see that if we set the AC in frugal mode i.e., always on for 9am to 4 pm, the consumption is 231.73 kWh, but if AC runs only 6 and 4 hours, power consumptions are 185.384 kWh and 162.211 kWh respectively. The figure below shows detail findings which is estimated based on experiment.

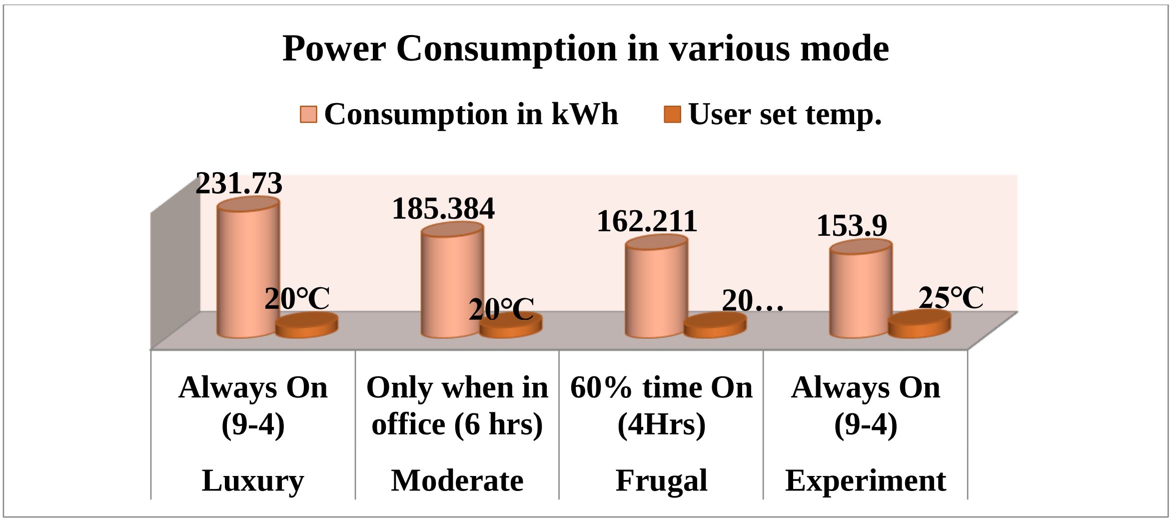


Figure 5.2: Power consumption in various mode
Source: Experimental data

Instead of 20℃ setting if user sets the temperature in 25℃ and keeps the AC on for 9 am to 4 pm, the consumption would be even lower than the three modes i.e., luxury- always on, Moderate-6 hours and Frugal- 4 hours. The experiment also shows that even if we set temperature in 24℃ the consumption for eight hours is lower than the three modes. In the chart 5.3 consumption for luxury mode is231.73 kWh whereas consumption for 24℃ is 166.9 kWh

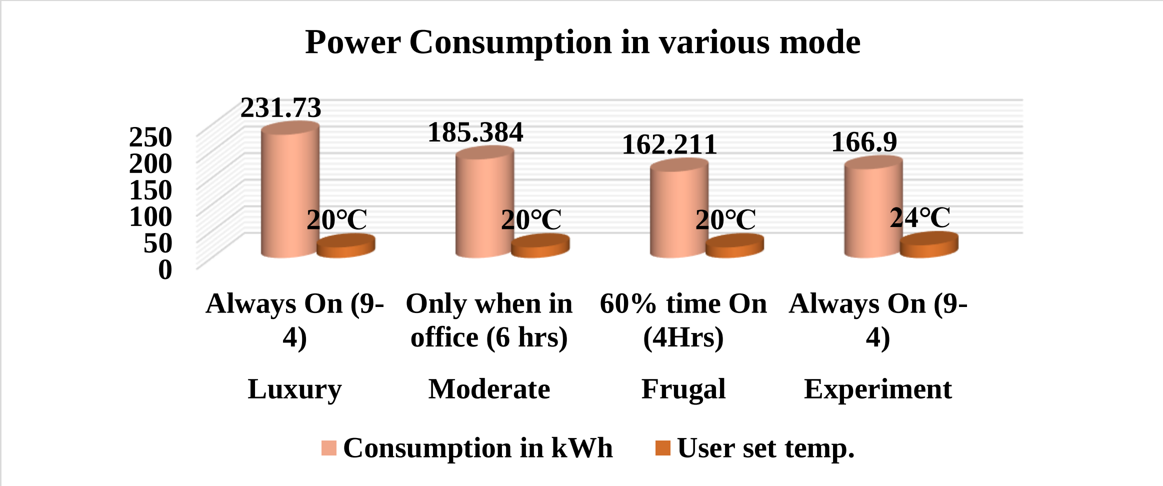


Figure 5.3: Power consumption in various mode
Source: Experimental data

5.4: Power savings of a single AC during the study period

The study shows power consumption by a single 1.5-ton AC in 25-degree setting. The study reveals that total savings during March to October 2019 are 664.25 kWh. The experiment identifies that in March a single AC of 1.5 ton can save up to 78 kWh approximately. The figure below also shows that during June, July and august highest amount of energy savings can be obtained via IoT enabled ACs.

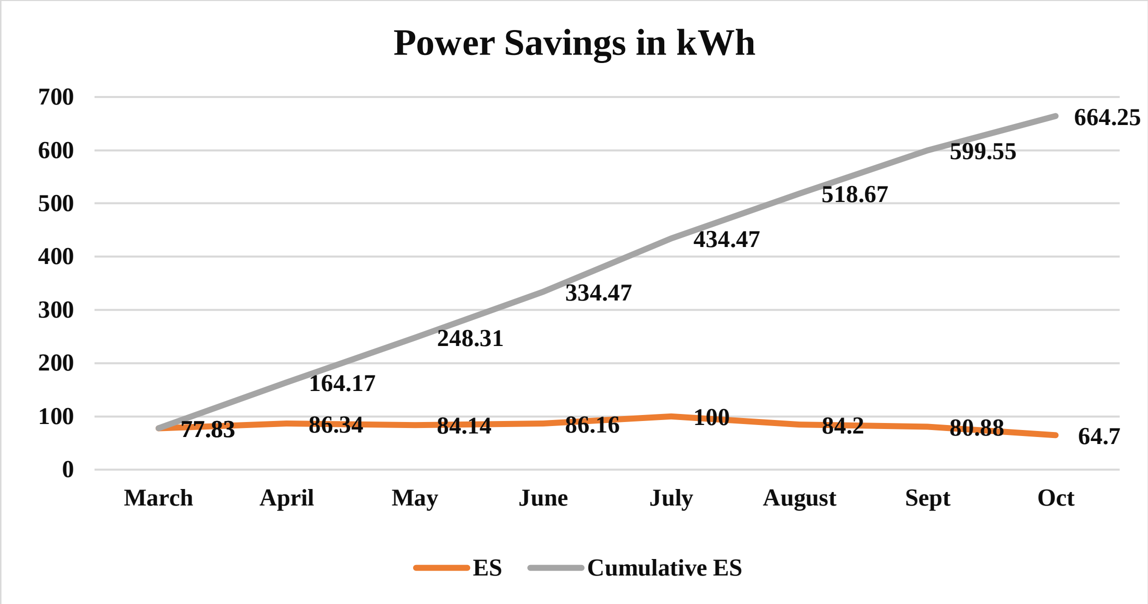


Figure 5.4: Power Savings of a single AC when AC is set on 25℃
Source: Experimental data

5.5: Impact of IoT for a certain percentage of annual ACs demand

Energy consumption of different Upazillas of Khulna district have been collected to understand the impact of IoT in energy sector in Bangladesh. Khulan has been selected for convenience and better access to power sector's employee. Table 5.2 shows the number of Upazillas in Khulna district and its power consumption in both peak and off-peak demand. It also shows the total number of subscribers and electricity demand in each Upazilla. The data have been collected through interaction with a field level employee of Bangladesh rural electrical board.

Table 5.2: Daily Electricity Demand in some Upazillas of Khulna District

Name of Upazila	Peak Demand (MW)	Off-peak demand (MW)	Avg. Demand (MW)	No of Subscribers
Paikgacha	**9**	**6**	**7.5**	**55000**
Rupsha	**10**	**5**	**7.5**	**35000**
Koyra	**9**	**4**	**6.5**	**30000**
Terokhada	**7**	**4**	**5.5**	**32000**

Source: Experimental data

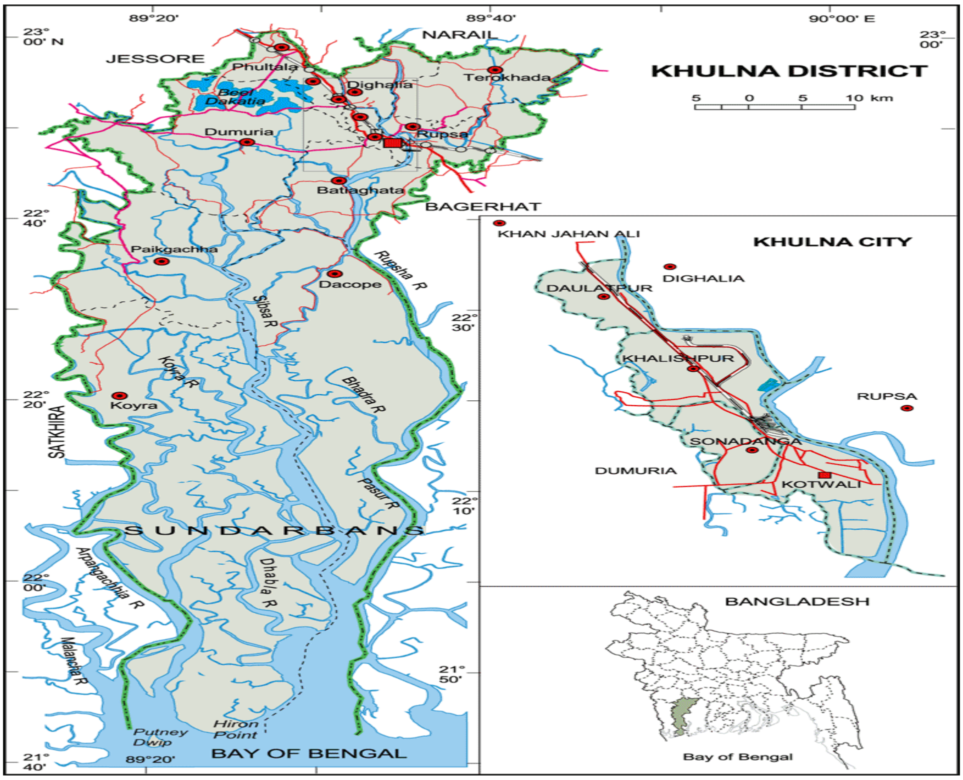


Fig 5.5: Location Map Khulna District

Table 5.3: National AC Demand

World Air Conditioner Demand by Region

June 2019

JRAIA 一般社団法人 日本冷凍空調工業会

The Japan Refrigeration and Air Conditioning Industry Association

3-5-8, Shibakoen, Minato-ku

Tokyo, 105-0011 JAPAN

TEL : Tokyo (03)3432-1671 FAX : Tokyo (03)3438-0308

https://www.jraia.or.jp

(1) Overall AC demand

(in thousands)

	2013	2014	2015	2016	2017	2018	y/y
World total	104,367	103,790	99,355	102,312	110,972	110,971	100
Japan	9,817	9,336	8,899	9,146	9,744	10,521	108
Overseas	94,550	94,454	90,456	93,166	101,229	100,450	99
China	43,308	42,477	39,222	40,587	45,945	44,633	97
Asian countries	13,672	14,540	15,146	16,411	17,604	17,817	101
India	3,633	3,862	4,063	4,507	5,394	5,241	97
Indonesia	2,246	2,287	2,202	2,300	2,337	2,339	100
Vietnam	998	1,229	1,607	1,984	1,943	2,037	105
Thailand	1,163	1,315	1,388	1,561	1,536	1,493	97
Taiwan	952	1,014	1,014	1,005	1,090	1,097	101
Malaysia	902	898	878	936	970	1,002	103
Philippines	664	687	717	800	867	955	110
Pakistan	613	672	675	720	774	824	106
South Korea	1,236	1,236	1,253	1,252	1,263	1,263	100
Hong Kong incl. Macao	539	538	531	530	585	604	103
Myanmar	123	180	181	206	224	226	101
Bangladesh	156	170	183	185	188	202	108
Cambodia	81	85	90	110	119	130	109
Singapore	163	162	158	157	143	142	100
Sri Lanka	80	81	84	88	101	108	107
Laos			0			84	-
Others	123	123	123	71	73	69	96

Source: (JRAIA, 2022)

National AC demand of Bangladesh has been identified from Japan refrigeration and air conditioning industry association (JRAIA). In 2018, AC demand in Bangladesh was 202000 units (approximately) as per Japan refrigeration and air conditioning industry association (JRAIA) (JRAIA, 2022).

Experiment result shows in Table 5.4 that in March 2019, IoT enabled ACs can save 11500-megawatt electricity if 70% of JRAIA estimated ACs are sold out in Bangladesh. This saved energy is equal to electricity demand of 55 Upazillas of Bangladesh as per table no 5.2. The result is significant as it helps to supply electricity in some new areas that are not under electricity coverage.

Table 5.4: Impact of IoT in 25°C for 70% ACs Demand of JRAIA estimation

Month	No of Days	Energy Savings for 25c (kWh)	Total savings for 70% AC Demand estimated by JRAIA (kWh)	Mega Watt	No of Upazilla's demand can be met
March	20	77.83	**11005162**	11005	55
April	20	86.34	**10464408**	10464	52
May	20	84.14	**10197768**	10198	51
June	20	86.16	**10442592**	10443	52
July	20	100	**12120000**	12120	60
August	20	84.2	**10205040**	10205	51
Sept	20	80.88	**9802656**	9803	49
Oct	20	64.7	**7841640**	7842	39

Source: Compiled by the author

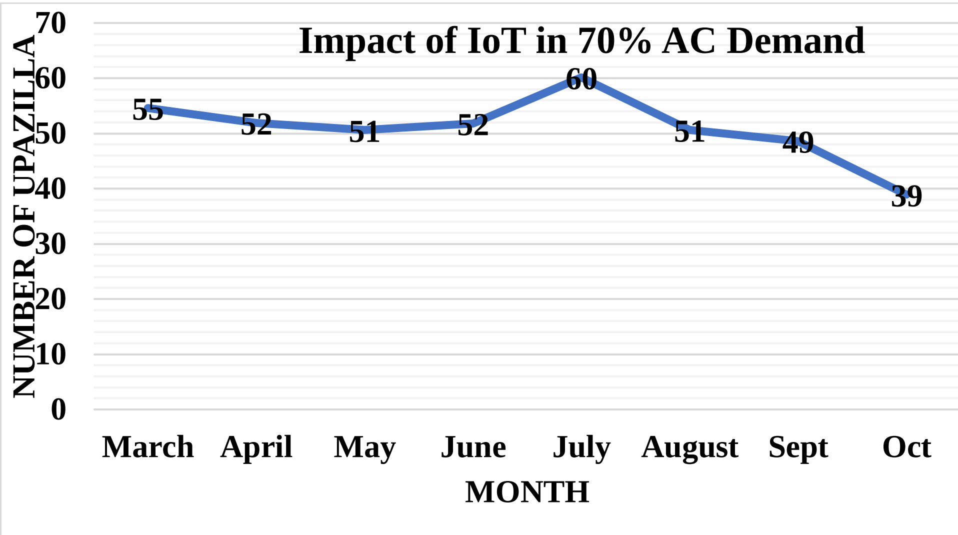


Figure 5.6: Impact of IoT in 25°C for 70% ACs Demand
Source: Compiled by the author

For 80 % of total demand estimation by JRAIA, if user install IoT enabled ACs the total savings and its impact are shown in the following chart. The chart shows that in July if user set their AC temperature in 25 degree the amount of saved energy can be used to fulfill the demand of 52 to 80 Upazillas of Bangladesh. This estimate is made on the basis of the electricity demand of Khulna district.

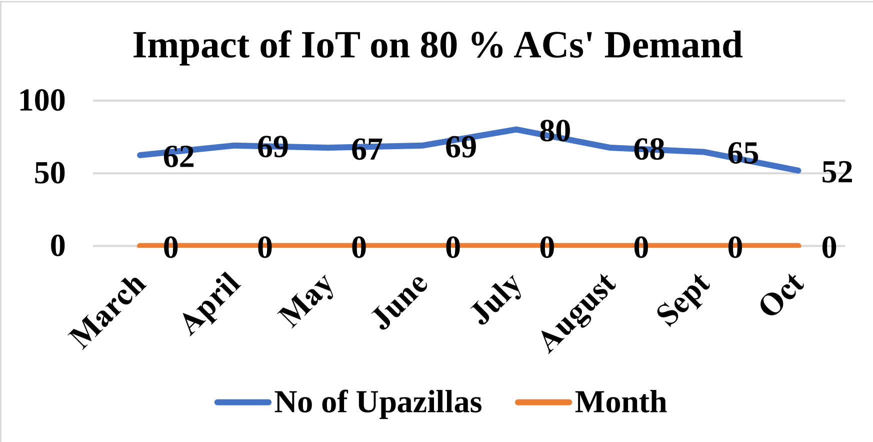


Figure 5.7: Impact of IoT in 25°C for 80%, ACs Demand
Source: Compiled by the author

The following figure 5.8 shows three scenarios where 80%,70% and 60% ACs demand have been calculated and impact of IoT on those ACs are shown based on JRAIA estimate when the AC temperature is set to 24°C. For example, in case of 80% ACs demand in our country and use of IoT in those ACs can help to cover 52 number of more Upazillas in March while in July maximum number of Upazillas like 61 Upazillas electricity demand can be fulfilled.

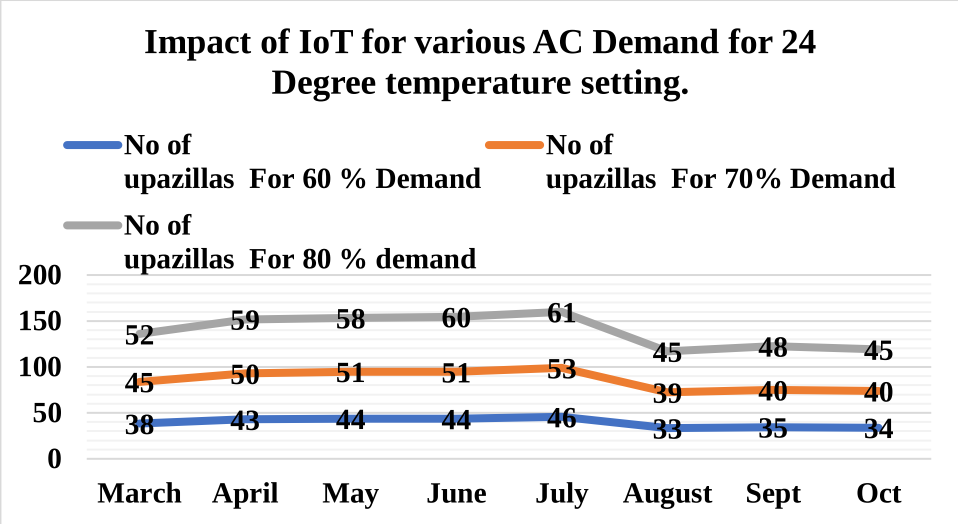


Figure 5.8: Impact of IoT for 24℃ in 80%, 70% & 60% ACs Demand
Source: Compiled by the author

5.6: IoT and savings scenario in percentage

The following table shows electricity consumption for 20℃, 24℃ and 25℃ set temperature in 1.5-ton ACs. In addition to that the table specifies energy savings in percentage for 24 and 25 ℃. The study reveals if AC is set on 24 or 25℃ instead of 20℃, the power saving is within 18-33 % approximately. This much of saving can be done with IoT enable ACs. Please see the table below.

Table 5.5 IoT and Saving Scenario in percentage

Month	Consumption (kWh)			Savings in %	
	20°	24°	25°	24°	25°
March	231.73	166.9	153.9	27.98	33.59
April	301.88	230.64	215.54	23.6	28.6
May	296.8	223.96	215.41	24.54	27.42
June	308.41	235.9	222.25	23.51	27.94
July	311.72	235.76	211.72	24.37	32.08
August	299.25	243.7	215.05	18.56	28.14
Sept	244.22	186.73	163.34	23.54	33.12
Oct	230.2	173.63	165.5	24.57	28.11

Source: Calculation based on experimental data

5.7: **Economic Impact of IoT enabled ACs**

The following financial analysis has been done to understand economic prospects of IoT in terms of cost benefit analysis in Business Administration Discipline of Khulna University. The Business Administration Discipline has been selected for author's convenience and better access. The calculation is based on the cost of different sensors, IoT hardware & software and its installation cost.

Table 5.6 Cost of Smart AC Controller

Sl. No	Provider	Price/$	BDT
1	Honeywell D6	64.99	5492
2	Tado Smart AC Control V3+	90.28	7629
3	Ecosense 5000	153.51	12972
4	Sensibo	99	8366

** $1 = 84.50 BDT (Approximate)

Source: Based on various web site

Table 5.7: Cost of IoT and savings

SL	Room	No of ACs	No of Sensors	Cost of IoT (Sensors & S/H)	Installation cost	Savings in BDT
1	Chairman	2	4	9152	800	7596
2	Conference Room	1	2	8576	400	3798
3	Lounge	1	2	8576	400	3798
4	Teachers Room	20	40	19520	8000	75961
5	BBA Class Room	15	30	16640	6000	56971
6	MBA Class Room	4	8	10304	1600	15192
7	MIS Lab	2	4	9152	800	7596
	Total	45	90	81920	18000	170913

Source: Calculation based on experimental data

$$Savings = No.of\ ACs\ \times Yearly\ Savings\ \times Unit\ Price\ of\ the\ AC$$

As for example, total savings for Chairman/Head's room in above table is 2*664 kWh *5.72=7596 (see figure 5.4 for energy savings). So, total savings from 45 ACs are BDT 170913. Here the study considers set temperature of AC is 25 ℃ & unit price is taken from Bangladesh Energy regulatory Commission. Electricity unit price chart is shown in Appendix A[4].

5.8: Return on Investment

The Return on Investment for IoT enabled ACs in Business Administration Discipline, Khulna University has been calculated based on the following formula:

$$Consumption\ Cost = \sum_{1}^{n} PCt \times RTPt \quad \ldots\ldots\ldots\ldots\ \ldots\ldots\ldots (1)$$

Where PCt = Power consumption at time t & RTPt = Real time price at time t

$$RoI = \frac{Cost\ Savings - Investment}{Investment} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\text{Where } Investment = N_{sensors} \times C_{sensor} + C_{installation} \ \ldots (3)$$

Based on the formula (1), (2) & (3) we calculated Return on Investment (RoI) of Business Administration Discipline of Khulna University of Bangladesh are shown in the following table:

Table 5.8: Business Administration Department ROI for 2020

Total operating cost savings	170913.6
TIC (Total Investment cost)	99920
Benefit cost ratio	1.71
Return on Investment	0.71

Source: Calculation based on experimental data

5.9 Environmental Impact of IoT enabled ACs:

This section tries to give an idea of emission reduction for IoT enabled ACs. At first, attempts have been taken to explain different types of chemical emission because of power plant and level of carbon di oxide emission in Bangladesh. Later amount of CO_2 emissions reduction and cost are calculated.

Emissions from the power plant or other points along its fuel chain are one of the main ways that electricity generating has an impact on the environment. These emissions range from gaseous to radioactive to solid. In a broad sense, the consequences of energy production also include aesthetic elements (like the visual effects of the power plant and transmission lines), physical impacts (such increased ground pressure as a result of the building of a dam), and discharges like noise. The following are a few examples of typical emissions and wastes produced by power plants themselves:

- Sulfur dioxide, nitrogen oxides, hydrocarbons, carbon dioxide, and carbon monoxide are all gases.
- Water waste is a liquid.
- Solid: solids collected as ash from the plant and particles emitted from the chimney stack that are transported as gases and remain suspended in the air.
- Secondary components: in addition to the direct emissions, the atmosphere also produces secondary components as a result of chemical interactions between the emissions and other airborne constituents. These secondary pollutants include sulphate particles from sulfur dioxide, ozone from nitrogen oxides and volatile organic compounds (VOCs), and acid rain from sulfur dioxide and nitrogen oxides.
- Other: Additional burdens include aesthetic issues including the plant's visible "intrusion," noise, smoke, and heat rejection from the cooling circuit.

Greenhouse gases are generating more extreme weather, such as changing precipitation patterns and storm intensity, rising temperatures, trapping heat in the atmosphere, and raising sea levels. All these result alarming level of global warming and a rapid climate change.

Huge concentration of main gases in atmosphere such as carbon di oxide, methane and nitrous oxide-that are leading disproportionate level of warming in earth and extreme weather events

Levels of CO_2 resulted from burning fossil fuels reached towards a new record of 410.5 parts per million(ppm) in 2019 (WMO, 2022).

Carbon dioxide (CO_2) is a gas that occurs in nature and is converted into organic matter during photosynthesis. It is a result of burning fossil fuels and burning biomass, and it is also released with changes in land use and other industrial activities. It is the main greenhouse gas produced by humans that has an impact on the planet's radiative balance. Since it serves as the benchmark for measuring other greenhouse gases, it has a global warming potential of 1. Since the industrial revolution, using carbon-based fuels has quickly increased atmospheric carbon dioxide concentrations, accelerated global warming and contributed to anthropogenic climate change.

Since it dissolves in water to produce carbonic acid, it is also a significant contributor to ocean acidification. The earth's radiative equilibrium is upset by the atmospheric accumulation of greenhouse gases created by humans. As a result, the earth's surface temperature is rising, which has an impact on the climate, sea level rise, and global agriculture. Burning wood, trash, and fossil fuels for energy generation, as well as industrial activities like cement manufacture, all result in CO_2 emissions. Only one greenhouse gas—carbon dioxide—is indicative of a nation's emissions.

Gases like methane and nitrous oxide should be considered to provide a fuller picture of how a nation affects climate change. In agricultural economies, this is particularly crucial. Emission intensity is the ratio of the average pollutant emission rate from a given source to the intensity of a certain activity. The comparison of the environmental effects of various fuels or activities also makes use of emission intensities. The phrases "emission factor" and "carbon intensity," which are related, are sometimes used interchangeably.

Carbon dioxide's impacts on the environment are highly interesting. The majority of greenhouse gases that contribute to global warming and climate change are composed of carbon dioxide (CO_2). All additional greenhouse gases (methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)) may be compared and their individual and combined effects on global warming can be calculated by converting them to carbon dioxide (or CO_2) equivalents. The Kyoto Protocol is an environmental agreement that aims to reduce CO_2 emissions globally. It was approved in 1997 by a number of UNFCCC countries. (World bank, 2018).

The primary environmental hazard from the current energy system is seen to be the possibility of climate change brought on by CO_2 emissions from fossil fuels. Acidification, and dispersion of metals resulting from fossil fuels are other environmental problems. (Balat et al., 2003).

The kind of fuel or energy source, as well as the design and efficiency of an electric power plant, all affect emissions. For the same amount of energy used in burning, different fossil fuels produce varying amounts of carbon dioxide: coal releases nearly twice as much carbon dioxide as oil, which releases around 50% more than natural gas.

The average value of Carbon dioxide emissions for Bangladesh during 2011-2018 period was 24702 kt with a minimum of 54420 kt in 2011 and a maximum of 82760 kt in 2018. For comparison, the world average in 2018 based on 186 countries is 192252 kt.

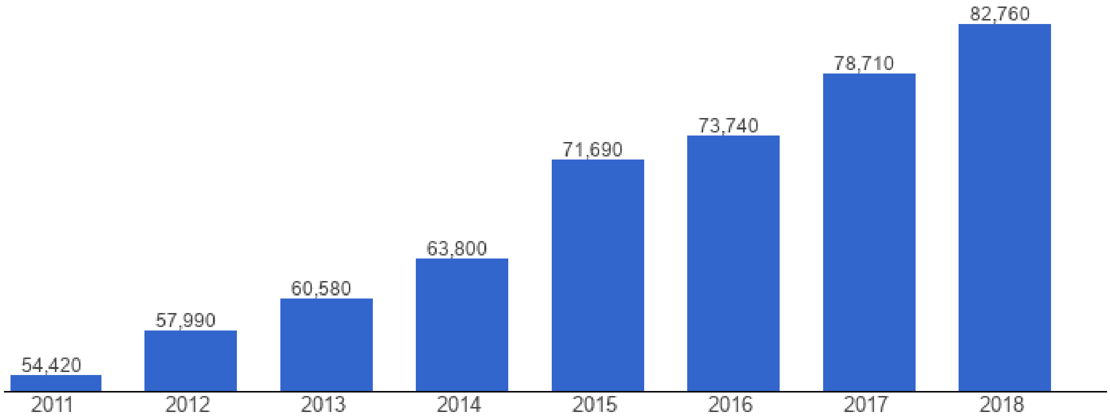


Fig.5.9 Carbon dioxide emissions, thousands of tons

Source:(EIA/*Bangladesh Carbon Dioxide (CO2) Emissions - Data, Chart*, 2018)

On an Average 2.11 pounds of CO_2/kWh for fossil fuel (*U.S. Energy Information Administration (EIA)*, 2022)

Another study in Malaysia found 1.21 kg CO_2/kWh

CO_2 (kg/life) =1.21 (kg\kWh) *E(kWh\year) *n(year).source: (Saidur, 2009)

By considering the Malaysia's study CO_2 emission reduction level can be determined. The table in the next page shows total kWh saved by IoT enabled ACs and later CO_2 emission reduction amount is calculated.

Tble.5.9. Cumulative energy savings

Month	No of Days	Energy Savings for 25℃	Cumulative Energy Savings	Total savings for 80% AC demand	Cumulative Energy Savings(kWh)
March	20	77.83	77.83	12577328	12577328
April	20	86.34	164.17	13952544	26529872
May	20	84.14	248.31	13597024	40126896
June	20	86.16	334.47	13923456	54050352
July	20	100	434.47	16160000	70210352
August	20	84.2	518.67	13606720	83817072
Sept	20	80.88	599.55	13070208	96887280
Oct	20	64.7	664.25	10455520	107342800

Source: Authors compilation based on experimental data

Table 5.10: Co_2 emission reduction from Energy savings for 80 % ACs demand

In the study saved energy on 80 % AC demand= 107342800 kWh

Total CO_2 Emission Reduction=107342800*1.21kgs	129884788 kgs

Total CO_2 Reduction in Tons =129884788/1000=	129885 Tons

Referring to the tables **Table.5.11** and **Table.5.12** in **Appendix A[3],** average external cost of climate change can be calculated. Here it is approximately 323 million Taka. At least this amount can be saved if we use IoT in ACs. The amount would be much higher if we consider existing ACs with this year new demand. If we calculate other emitted poisonous chemicals as mentioned above, cost would be much higher than the calculated amount.

Average external cost of climate change (2020): (Total CO_2 Reduction in Tons × Avg. External Cost of Climate change per ton)	BDT. 323607949

**1 Euro=USD1.18= BDT 84*1.18=BDT99.12 as of October 23,2021

CHAPTER SIX

EXPERIMENTAL DATA ANALYSIS WITH LSTM MODEL

CHAPTER SIX

EXPERIMENTAL DATA ANALYSIS AND FINDINGS

6.0 Introduction

In previous chapter quantitative analysis are performed by using some statistical and financial techniques. The present chapter also analyzes collected data in quantitative way. In this chapter quantitative analysis is done by applying Long Short-Term Memory (LSTM) model and find out the energy efficiency in IoT enabled ACs. The chapter begins with the descriptions about the LSTM and prediction through some statistical and machine learning models.

Compared to traditional recurrent neural networks, LSTM is a sophisticated recurrent neural network (RNN) architecture that was created to more accurately simulate chronological sequences and their long-range relationships (RNNs). Recurrent neural networks (RNNs) are extended by LSTM networks, which were primarily developed to address RNN failure scenarios. When we talk about RNN, it is a network that operates on the current input while taking into account the prior output (feedback) and temporarily storing it in memory (short-term memory).

Data have been collected through secured http connection; the raw data were kept in a password protected computer. The time series data were stored as comma separated values or 'csv' format. The research used the tensorlow (Abadi et al., 2016) package with Python programming for executing the LSTM algorithm. Tensorflow is a Python module that provides an inference for deep neural network models. It has been used for research and for putting machine learning systems into use in more than a dozen fields outside of computer science, including robotics, speech recognition, computer vision, natural language processing, information retrieval, geographic information extraction, and computational drug discovery.

A sample code using python programming language is shown below.

```
#Attributes & Target declaration:
X = ['Temperature.now','Humidity.now','SetTemperature.now','Energy.now','Voltage.now','Ampere.now']
y = merged[['Temperature.next', 'Humidity.next', 'Voltage.next', 'Ampere.next', 'Energy.next']]
# Seperating Train and Test Data:
X_train, X_test, Y_train, Y_test = train_test_split(X, y, test_size=0.3, shuffle=False, random_state=0)
# Initializing LSTM model:
model = Sequential()
model.add(LSTM(neurons, batch_input_shape=(batch_size, X.shape[1], X.shape[2])))
model.add(Dense(y.shape[2]))
# Training LSTM :
model.fit(X_train, Y_train, epochs=1000, batch_size=200, verbose=0, shuffle=False)
# Prediction with Test Data:
pred = model.predict(X_test)
```

Fig.6.1. Sample code for data analysis

Brief information of the measured data is shown in Table 6.1. The actual room temperature during data collection varied between (20.6-30.4 degrees), room humidity varied from (43.1-84.1%), Air Conditioner voltage fluctuation was between (217.8-234.6 volt), from 0.04 up to 7.65 Amp current was drawn during the data collection phase and, cumulative energy increased from 1.4 kWh to 100.6 kWh. The study in (N. Wang et al., 2013) considered the time interval as 1h for simplicity.

Although our IoT device was capable of a second, minute, or hour interval data collection, for a like-for-like comparison with (*U.S. Energy Information Administration (EIA)*, 2022) the dataset was produced with time interval=1h. Ideally, the commercial buildings in this research were operating the ACs for approximately 600 hours per month.

Table 6.1: Summary Statistics of Dataset

	Room Temp.	Room Humidity (%)	Outside Temp.	Outside Humidity (%)	Set Temp	Voltage	Ampere	Energy
Mean	27.29	72.64	33.3	74.08	21.4	224.07	4.49	56.01
Std	1.73	8.83	2.83	8.77	2.01	3.28	2.46	31.43
Min	20.6	43.14	25.98	52	18	217.87	0.04	1.4
25%	25.61	68.02	31.75	68.52	19.99	222.62	2.41	26.88
50%	25.92	77	33.14	74.38	21.04	223.82	5.06	56.9
75%	27.5	78.26	35.21	78.95	23.5	225.61	6.65	87.77
Max	30.45	84.1	41.85	94	27	234.65	7.65	100.6

Source: Calculation based on experimental data

6.1: Prediction curve fittings

From the dataset collected over the 5 months, 80% of the data points were used for training our constructed long-short term memory network. Therefore, data from March-June was provided to the LSTM model to minimize its mean squared loss function. Once the mean squared error function converged to its minimum, the rest of the 20% data for July month was fitted using the trained model. The evaluation for last month or 600h is illustrated in Figure 3.

To illustrate the accuracy of regression model, the predicted data points are compared with measured data points as shown in Figure 6.1(a)-6.1(e). This sequential prediction model was applied to predict energy saving for each set temperature. The accuracy of the LSTM regressor is evaluated with an R-square score. Ideally, the R square close to 100 indicates a 100% accurate forecast with fully capable of capturing the variance of target variables. The prediction model achieved an R square value of 80.70 while predicting unseen data.

The ambient temperature forecast line was able to capture the variance of measured reading as shown in the subplot Figure 6.1(a). There is a seasonality in room temperature reading which can be observed in bare eyes from subplot 6.1(a). During the hot summer, users would not usually prefer room temperature close to 30°, hence, the study can interpret that- it was the office starting hour when the room temperature is at 30° in 6.1(a). Right after the starting hour of the office, the ambient temperature was usually reduced to 24°-26° by the AC compressor.

During this time, the current draw was at the peak in 6.1(d). In 6.1(a), around the 100th hour, the room temperature was kept in between 24°-25°. The average room temperature was at 27°. The periodic change of room temperature w.r.t outside weather set temperature and previous ambient weather was predicted in 6.1(a) that fits the true reading quite well.

As the LSTM model has a memory element that can remember and process previous sequential states, thus the model could forecast the ambient temperature during a new month relatively close to the measured data.

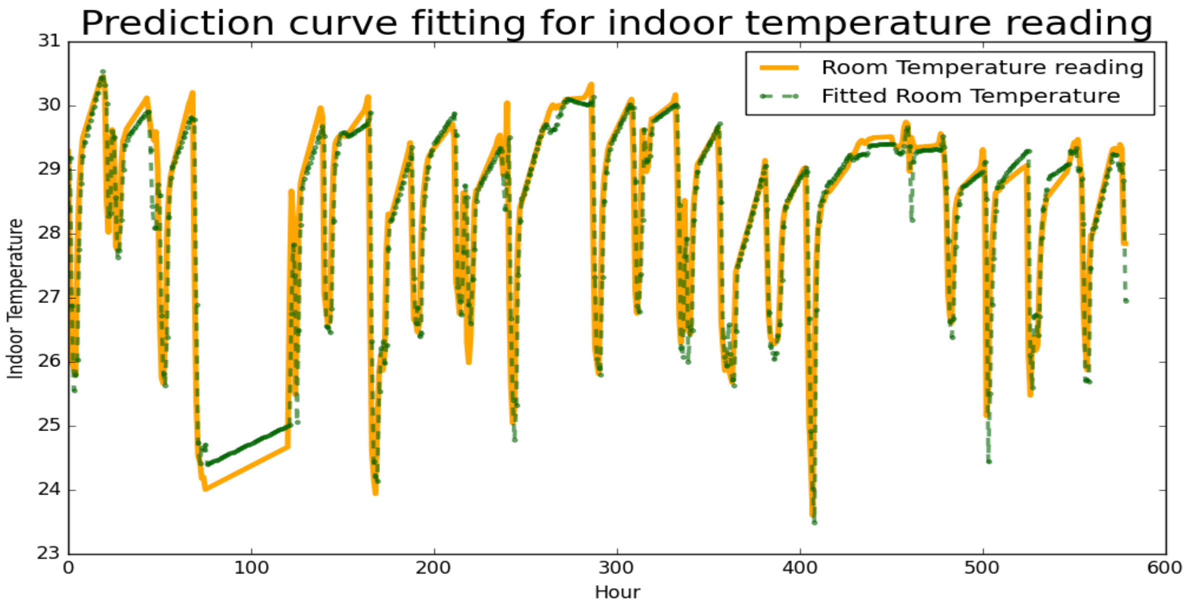


Fig 6.1(a). Comparison of measured room temperature and prediction from fitted model
Source: Drawn by author based on experimental data

The ambient temperature (in Celsius scale) and humidity (in percentage) were highly correlated in July. Similar to the room temperature reading in 6(a), the study can also interpret the humidity reading in 6.1(b). As shown in 6.1(b), the starting hour of the office had the highest humidity level as the AC compressor was off. The humidity prediction in subplot 6.1(b) was ideally well fitted with the reading.

Presumably, during the rainfall, the humidity level dropped below 46% which was not being predicted by the LSTM model. However, our study does not require to have a high precision forecasting model for ambient weather. Instead, the focus is to have a reliable prediction model which can be used for calculating energy cost for various conditions of weather and temperature set points.

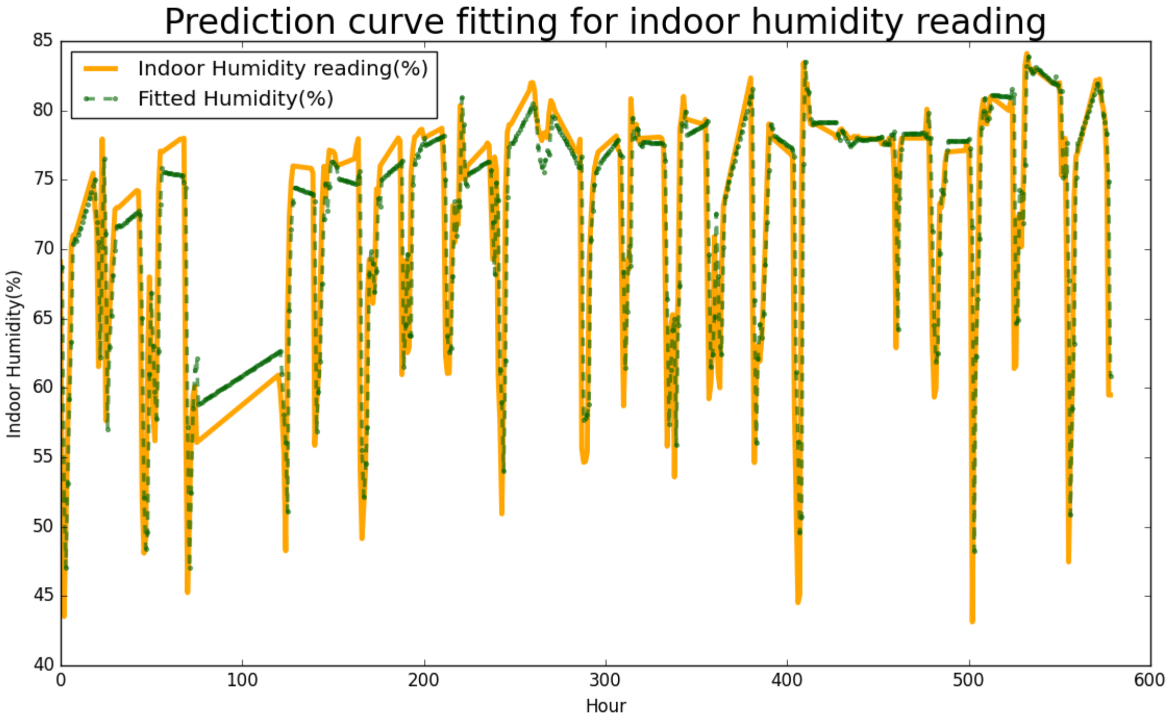


Fig 6.1(b). Comparison of measured room humidity and prediction from fitted model
Source: Drawn by the author based on experimental data.

As the air conditioner is a dynamic electronic load, The voltage and current reading in the time series data fluctuated a lot.

In figure 6.1(c), the average voltage at each hour is illustrated as the actual reading line plot. On the other hand, the LSTM model prediction of the average voltage value for the time-series data is shown as a fitted line plot. High voltage was required when the compressor was starting to operate. However, the voltage was not 0 as the IoT system collected only during office hours.

In figure 6.1(d), the current draw in Ampere was depicted for the test data. It can be interpreted that while the AC compressor was not doing the heavy work, the current draw level was below 1 Amp.

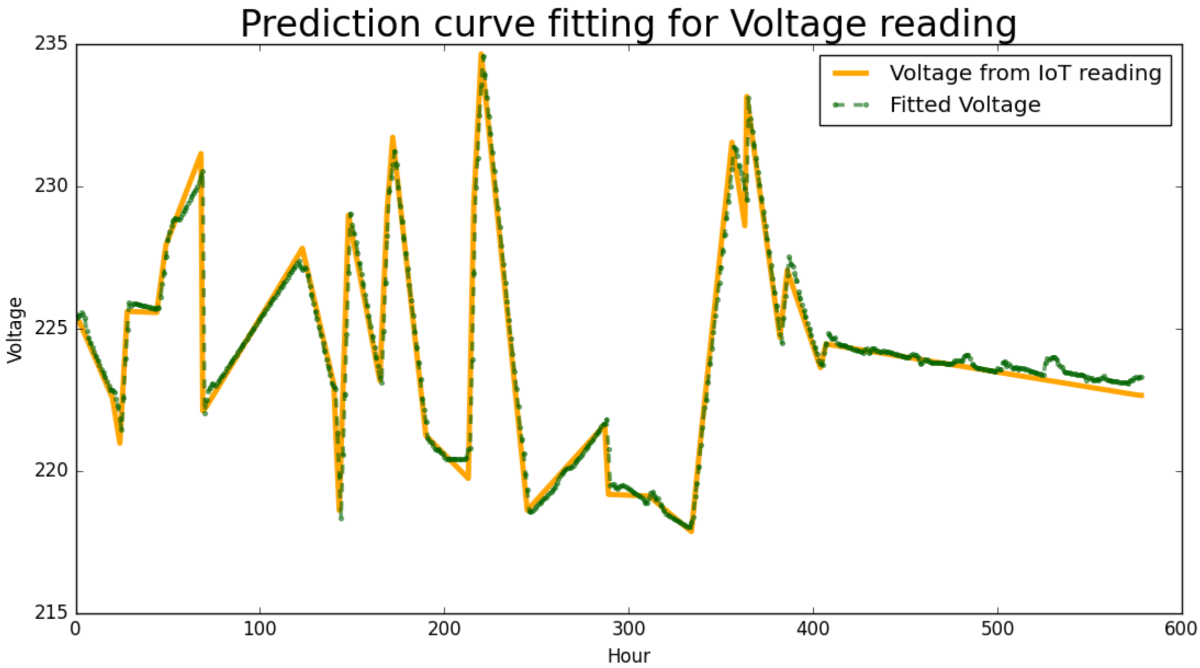


Fig 6.1(c). Comparison of measured voltage and prediction from fitted model
Source: Drawn by the author based on experimental data.

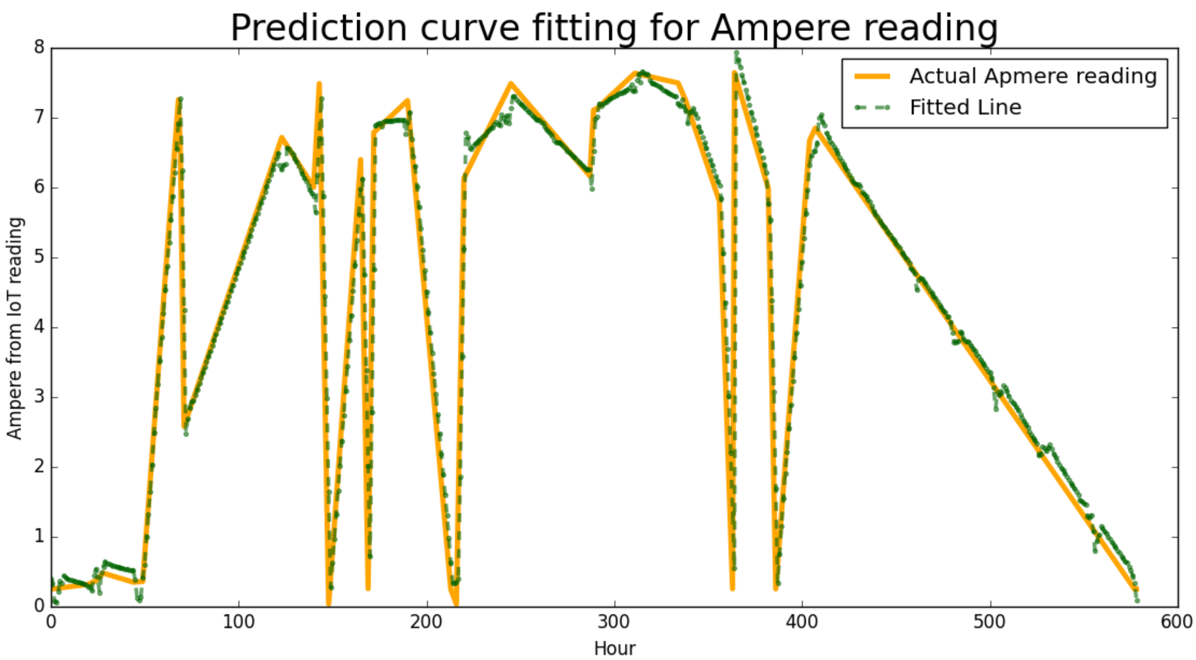


Fig 6.1(d). Comparison of measured current draw and prediction from fitted model
Source: Drawn by the author based on experimental data.

After the 400th hour in both 6.1(c) and 6.1(d), the rate of change was linear which indicated that energy consumption was stable at the time. The LSTM model predicted the

1h interval voltage and current draw illustrated in subplots 6.1(c) and 6.1(d). The forecasted Voltage and Current could be used for calculating energy consumption at a specific time as the following equation:

$$E = V \times I \ldots \ldots (iii)$$

However, the model prediction about the power consumption as the subplot 6.1(e) depicted less error than the calculated power from equation (iii). The energy at time t is simply the cumulative energy denoted as $E_t = E_{\Delta t} + E_{t-1}$ .As illustrated in figure 6.1(e), the slope of the energy curve is not stationary, it varies over time. The LSTM model predicts total energy consumption sequentially based on the feature attributes.

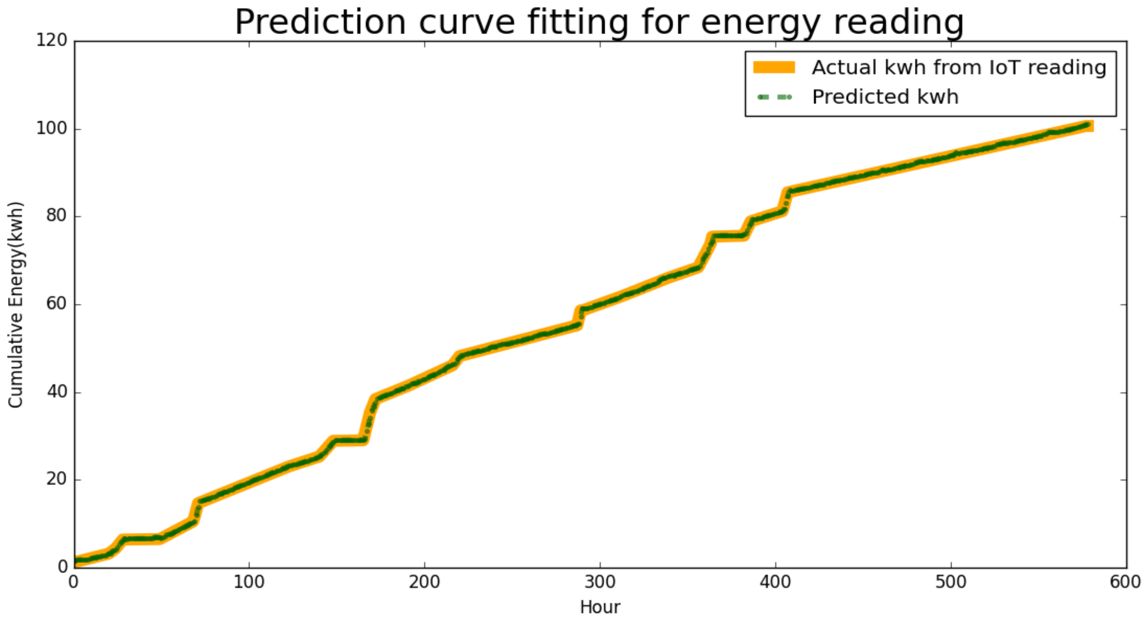


Figure 6.1(e). Comparison of measured energy and prediction from fitted model
Source: Drawn by the author based on experimental data.

The study shows that training a machine learning model with a large number of measured data points could learn to estimate the energy expenditure of fixed time intervals. Additionally, the model estimated the ambient weather, voltage, and current level as well. The main focus of this study is the target variable $E_{(t+1)}$. For the sequential prediction of the energy expenditure, we also need the other four variables. Estimating these 5 variables with one calculation model as in (N. Wang et al., 2013) would increase the complexity significantly.

Subsequently, the reliable trained LSTM was applied for determining whether operating temperature impacts the energy consumption level. At each timestep, the indoor weather and air conditioner's voltage, the current level will be generating by the LSTM model. Moreover, the outdoor weather values will be given to the LSTM model as predictors by sampling from the dataset.

Each of the simulation for a fixed temperature set point was run over 30 times. Equation iv. Tells that the average power consumption at the end use of each episode where the delta is the difference of energy consumption relating to its upper operating temperature setpoint. For example, if we compare 24° set temperate with 25° then delta is simply calculated as,

$$\delta = E_{24} - E_{25} \ldots (iv)$$

The simulation of the summer season depicts, the lowest energy consumption by an air conditioner was 76.38 kWh at an operating temperature of 27°. Simulating with an operating temperature of 26° showed the monthly energy consumption became 79.99 kWh.

As the set temperature point dropped by 1°, the energy consumption increased by,

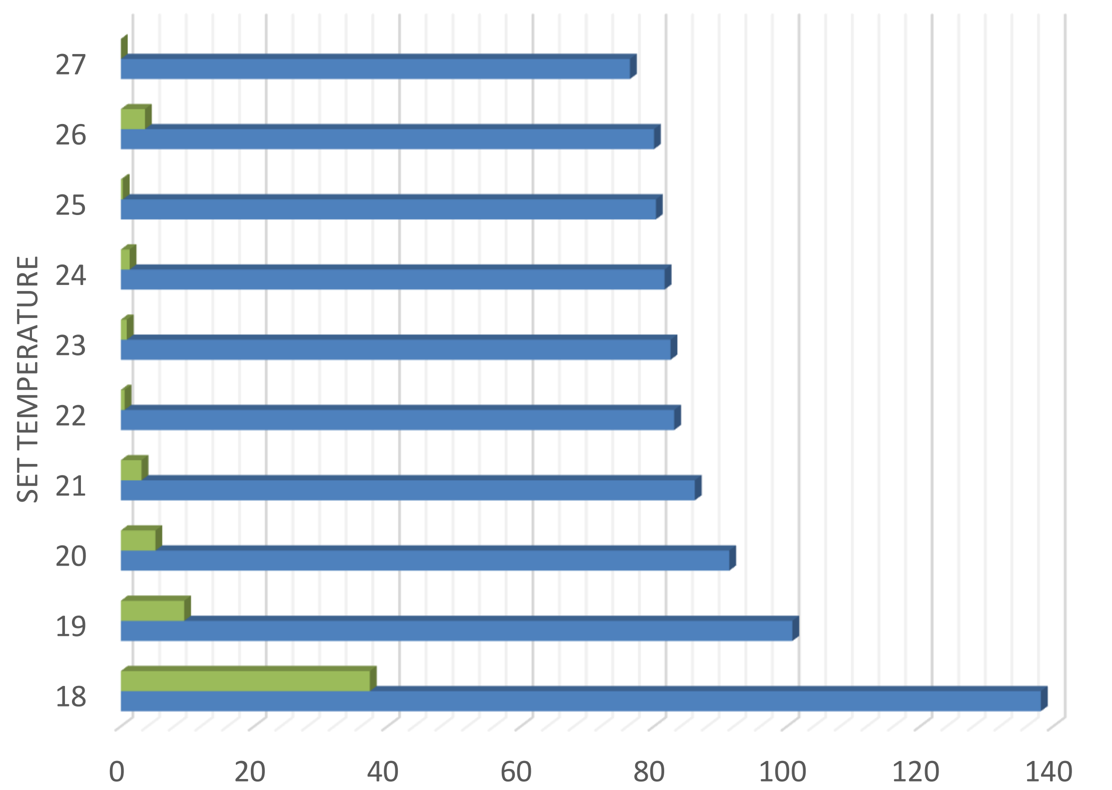
$$E_{26} - E_{27} / E_{27}$$

$$or, \quad \frac{\delta}{E_{27}}$$

$$or, \quad \frac{3.61}{76.38}$$

$$or, \quad 4.7\%$$

Similarly, delta is calculated for each setpoint change relative to its previous set point. Considering 27 degrees as the initial set temperature point, the change in energy consumption for a one-degree lower set temperature is shown as the delta in Figure 6.2. Delta has always been positive and an increasing trend is observed from the finding. The highest chance of energy consumption was observed between 19° and 18° set points. The arithmetic mean of the delta values would be pulled from the center because of the large delta between 19° and 18°. Therefore, the calculated median of the rate of change for energy consumption from figure 6.2.



	18	19	20	21	22	23	24	25	26	27
delta	37.35	9.49	5.18	3.1	0.55	0.89	1.31	0.29	3.61	0
kwh	138.15	100.8	91.31	86.13	83.03	82.48	81.59	80.28	79.99	76.38

delta kwh

Fig 6.2. Energy consumption benchmarking of finalized model
Source: Drawn by the author based on experimental data.

6.2: Energy consumption and savings scenario

The Median value was 3.73% that supported the findings which are presented in Table 6.1 Therefore, it can be interpreted that each increase of Air-Conditioner set temperature could save 3.73% of energy consumption. This finding for commercial buildings with 30000BTU Split-type AC indicates that there is scope to reduce the cost of energy by optimally setting the temperature of such dynamic load electronic device. Because of the official formal dress code, the staffs tend to set the operating temperature between 18°-24°. When outside weather is not excessively hot and humid, the room set temperature can be raised to 25° or 26° without creating any adverse effect to the indoor environment. Thus, the IoT system with a cloud dashboard to control AC set temperatures can be efficient to reduce the energy expenditure from office service equipment. For instance, one can control the set temperature to 24° instead of allowing the equipment to operate at 18° thus, expectedly save 7×3.73 or, 26.1% energy consumption during the summer. The knowledge discovery was possible as the implemented LSTM model could make the minimal error prediction.

The developed LSTM model is a vital component for such an IoT system as it helps to decide its prediction ability. Therefore, a machine learning model supplementing IoT systems can help us reduce energy wastage. Thus, significant level of CO_2 emissions reduction is possible as IoT enabled ACs help reduce energy consumption.

CHAPTER SEVEN

QUALITATIVE DATA ANALYSIS AND FINDINGS

CHAPTER SEVEN

QUALITATIVE DATA ANALYSIS AND FINDINGS

7.0 Introduction

Here qualitative data that have been collected from the experts are analyzed. This chapter analyzes the experts' opinion regarding prospects of Internet of things in Air Conditioners in Bangladesh. Experts have been asked to give opinion on various aspects of Internet of Thing and its prospects in ACs. There are several types of outcomes appeared from the interview. Some of the important outcomes are: ***cost, user comfort, environmentally friendly, productivity, system security, connectivity, change management, network facilities etc.***

This chapter attempts to explain prospects of IoT in energy sector through open-ended questions like the value user consider, key issues on IoT in energy sector and the overall prospects of IoT in ACs in different offices in Bangladesh.

7.1 Data collection method and instrument

Qualitative method has been used to collect the data for the study. In-depth interview was administered among the experts to know the outcome about the topic. Experts have been selected from Energy sector, University and AC manufacturer. A set questionnaire has been used to gather data from experts. This section tries to explain the values, benefits, types of barriers and overall comments from the experts regrading Internet of Things and its prospects in ACs. The following table shows the selected experts' details in brief.

Table 7.1: Expert Details

Profession & Number of Experts	Designation	Company/Organization
One Academician	Professor	Khulna University
Two Electrical Engineer	Executive Engineer	West Zone Power Distribution
One Engineer	Head of AC Unit	Walton Bangladesh Ltd
One Researcher cum Engineer	Additional Research Director	Walton Bangladesh Ltd

7.2 Values users consider while using IoT in ACs

Experts' comments on IoT enabled ACs and its value

Experts have been asked to opine on the value the user will consider while using IoT enabled ACs. They consider it is an important issue in energy sector in Bangladesh. Values can be defined as what is important to user's mind for a particular product. Different experts' views are given below

Mr. Debasis Paul, an executive engineer of West Zone Power Distribution (WZPDL), said that

> *"While using IoT in ACs user will give more importance on cost for setting and operating the technology. Users seldom prefer to spend more on installing new technology. So, it is important that the technology like IoT enabled AC should not more expensive. Another consideration among the users would be level of comfort they are getting. form the IoT enabled ACs. Comfort is something users don't sacrifice. So, new technology will ensure same or more comfort for the users.*

Another respondent, Mr. Subroto additional director of research and development of Walton Bangladesh, viewed differently. He opined that

"Users will give more importance on comfort while cost and productivity will come later while using IoT in energy sector. Those who use ACs are in lower midle to upper class people. So, they don't want to compromise with comfort and quality of the product. For this reason manufacturers should more priority on comfort of the product."

Mr. Waliul Azom, system control engineer of West Zone Power Distribution (WZPDL), another respondent, added that

"There are number of values users will consider while using IoT in energy sector. He thinks that number one priority is on low investment cost, then comfort and productivity will come for using IoT in ACs. Investment cost for both buying and setting should be as minimum as possible for the Internet of things enabled Air conditioners. ACs are designed to ensure comfort for the users so, it is another important aspect that should be ensured in new technology to win hearts and mind of the users."

7.3 Major Issues while using IoT in ACS:

Dr Shamim Ahsan, Professor and expert in drone and IoT, currently working as Head of Electronics and communication department of Khulna University opined that:

"There are number of issues that we need to deal while introducing IoT in energy sector. According to him integration and connectivity are important for the successful implementation of IoT in ACs. Integration is very important as there are hundreds of thousands of ACs are in use. So, technology should have the retrofitting capacity that means IoT can be installed in existing ACs to get wider acceptance among the users."

On that point, Mr. Md. Arifuzzaman, Head of Air Conditioner services of Walton Bangladesh, added that synchronization and cyber security are something provider should consider while introducing IoT in any sector. As ACs will be connected with the Internet so, there is risk of cyber-attack like manipulation of temperature setting, system outage and other types of malpractices by the hackers. For that matter, technology provider should emphasis more on cyber security while introducing Internet of Things in ACs.

On the other hand, Mr. Debasis Paul of WZPDL said:

> *"I think cyber security trouble shooting and connectivity are something that providers shall manage effectively to implement the technology. Users may encounter problems or face hardship while using internet of things enabled ACs. There will be proper documentation of the product for ensuring users confidence regarding IoT run ACs."*

Mr. Waliul Azam of WZPDL said:

> *"Replacement of legacy equipment, system security and scalable technology are essential for successful IoT implementation. To expedite the use of the technology providers should take necessary steps to replace legacy equipment. One way can be to offer buy back and install new technology."*

Mr. Subroto, additional research director of Walton ACs opined that user's attitude is a major concern for introducing IoT in energy sector. He also said that legacy equipment/retrofitting ACs with IoT is a concern but if the providers ensure it with free of cost or with minimum cost then users adoption of IoT would be easier.

7.4 Overall comments on the prospects of IoT in energy sector:

Experts have given positive and interesting opinions regarding the prospects of IoT in energy sector. Some of the important comments are discussed below.

. Mr. Md Arifuzzaman said:

> *"In 2019-20 IoT based AC sales growth was just-5% but in 2021 the growth rate is 40-50%. In this regard he also mentioned that as many people specially 30+ year old users are widely using smart phone so there is an ample scope of IoT enabled ACs. IoT adoption in energy sector in particular household and office will be increasing day by day as the technology is cheap and simple."*

On that point, Mr Subroto opined that "users will have positive attitude towards the technology as it saves energy consumption and user friendly. He also added that due to same level of comfort, lower cost and availability of technology will further ensure the adoption of IoT enabled ACs in different households and offices."

Mr. Waliul Azom of WZPL said:

> *"End users' interest is important for the prospects of IoT in ACs. For this if the authority and providers promote the concept through various media the acceptance of the new technology will be higher. In this regard he also suggests that cost of the technology should be lower to get more acceptance. In addition to that, he also recommends that due to low carbon emission it will get much popularity for the conscious users."*

Professor Dr. Shamim Ahsan of Khulna University said:

"Due to low operating and set up cost prospects of IoT is high in energy sector. He also added that at present industries like power and electronics are mature so, IoT penetration in energy sector would be easy. He also focused retrofitting capacity and scalability of the technology for positioning this technology among the users"

Speaking about this, Mr Debashish Paul, Executive Engineer of energy sector said,

> *"People usually want to adopt new technology if the cost and benefit is in favor of the users. As the technology reduces cost dramatically and ensures same level of comfort so, there is huge potential of these technology in energy sector. He also added popularity of IoT among the users will be increasing dramatically just like the acceptance level of todays' smart phone. What we need is to enhance the awareness regarding the technology among the AC users.*

7.5 IoT present status

The table summarizes the present status of Internet of things in Energy sector. Experts have given valuable comments on different dimensions. One important finding on this aspect is that there is a less initiative from both energy and regulatory body.

Table – 7.2: IoT present status

(In-depth Interview with Experts)

Dimensions	**Status**
IT Infrastructure (speed, Connectivity, hardware and software etc.)	Up to the mark
Users' knowledge of IoT	Moderate
Manufacturer's activities	Moderate
Initiative of the energy sector	Not up to the mark
Regulatory authority's initiative	Not visible
IoT Presence in Energy sector	Reasonable

Source: Author's compilation based on qualitative survey

7.6 Overall comments on the prospects of IoT in energy sector

In-depth interview with the respondents of various sectors yields important findings. Experts have suggested that there is a big concern over IoT enabled ACs and its security. As things/objects will be connected in Internet so, there is a possibility of hacking and manipulation of the device by others. Interviewees consider other aspects like change management, retrofitting, operational performance are vital for the prospects of IoT in energy sector. Experts' comments on overall prospects of IoT in ACs are summed up in the following table.

Table 7.3 Overall comments on the prospects of IoT in energy sector

Dimensions	**Feedback**
Attitude towards the technology	Good
Connectivity	Satisfactory
Security issues	Major concern
Retrofitting	Important
Change management	Easy
Operational Performance	High
Acceptance level	High

Source: Author’s compilation based on qualitative survey

CHAPTER EIGHT

FINDINGS, CONCLUSION & POLICY RECOMMENDATIONS

CHAPTER EIGHT

CONCLUSION AND POLICY RECOMMENDATIONS

8.1 Conclusion

Internet of Things are getting an unparallel attention to various sectors like energy, healthcare, transportation, agriculture, and manufacturing. It is considered as the life blood of those sector, e.g., energy, manufacturing, healthcare, transportation. The most promising Several research identifies major application of IoT are smart homes, health sectors, banking and financial sectors, smart manufacturing, smart transportation, smart utilities, and smart logistics. Internet of things (IoT) is expected to be a fourth industrial revolutionary technology that will help businesses run more efficiently.

The following subsections cover the findings in terms of economic and environmental prospects of IoT in energy sector, policy suggestions, study limitations, and future research directions.

8.2 Findings

The study discovers that by encouraging and promoting behavioral change among building occupants, the usage of Internet of Things in the energy sector, namely in ACs, may considerably contribute to energy savings. In this regard, the suggested IoT-based solution enables energy end-users to drastically lower energy usage by guaranteeing the same degree of user pleasure. The major findings of the study are shown in the below.

8.2.1 Energy savings:

To know the amount of energy savings, the study uses the long short-term memory regressor model to predict energy consumption for various levels of air-conditioner operating modes. The machine learning model implemented in this research can leverage the decision-making ability of our IoT device aiming to optimize energy consumption. Significant level of energy saving is attained through the IoT enabled ACs. It is found that 20-30% less energy consumption is possible without sacrificing comfort or warmth of the user. Through LSTM model it is found that IoT enabled AC can save up to 26.1% energy.

8.2.2 Cost savings:

Users enjoy decreased energy usage due to IoT-enabled AC units and sophisticated management systems to regulate them, which has positive effects on the economy and the environment. The study reveals that IoT management solutions for air conditioners provide real-time modifications that lower use and consequently costs. The study shows that 45 number of IoT enabled ACs can save about one lac and seventy thousand taka annually. To be specific approximately 1.5-ton single AC can save up to three thousand and eight hundred takas approximately per year.

8.2.3 Comfortable Convenience:

Controlling ACs through IoT is simple. You can lie in bed, sit at your desk at work, or even be on your phone on a remote place and still have access to your device. You don't need to physically move from room to room when you forget to turn the device. The study finds that the user doesn't need to sacrifice both comfort while living with IoT enabled ACs.

8.2.4 Carbon Emission Reduction:

Half of the carbon emissions created is generated from the production of electricity. The analysis shows that if 80 % of Japan Refrigeration and Air Conditioning Industry Association (JRAIA) estimated IoT enabled ACs are sold, that can reduce significant level of CO_2 emission. The study finds that 129885 tons of CO_2 reduction is possible through IoT enabled ACs in Bangladesh.

8.2.5 Findings of Qualitative Study:

Qualitative study based on the interview with the experts from various organizations i.e., University, AC manufacturers & BPDB. They expressed that IoT enabled ACs in energy sector has a huge prospect in Bangladesh. It also reveals that IoT implementation in ACs would not be difficult as the technology is available, cheaper and getting greater acceptance to the consumers.

In fine, it can be inferred that the technical, economic and environmental prospect of IoT in energy sector of Bangladesh is very high. There is an ample scope of the aforesaid technology acceptance among the consumers.

8.3 Policy Recommendations:

Number of recommendations based on the findings for various stakeholders in energy sector are given below. However, all these practical implications must be viewed with regard to the limitations of the study.

i. For technology users: Before introducing IoT in ACs or other appliances they must identify the possible alternatives and its cost and benefit. They also evaluate the alternative providers from multiple perspectives. For example, consider how the operational efficiency can offset cost for that introduction.

ii. For technology providers: To enhance connected industry eco system and platform, technology providers must collaborate in various areas for winning the hearts and mind of the users. Special attention must be given on interoperability, security, human factor engineering and overall cost minimization of the technology. One important recommendation can be, share best practices throughout the industry supply chain. Cultivate brownfield innovation. Industrial goods are durable items that are "made to last" for many years, if not decades.

    Technology suppliers must shift from a "planned obsolescence" product lifecycle mindset to one that prioritizes sustaining already-in-use equipment. Such as, consider what types updated hardware/software, sensors and gadgets can be added without risking the reliability of the current devices. Providers should think about new value-added services to increase the productivity and efficiency of today's equipment and facilities. They should also incorporate artificial intelligence into current devices to accommodate new opportunities for the users.

iii. For public policy-makers: Policy makers like Ministry of energy, energy regulatory body and other policy makers should take necessary steps to pave the way for IoT introduction in various offices and households. It would be sensible to establish interim measures to direct the market and encourage innovation up until the full impact is properly known. Moreover, decision-makers should consider whether legacy technology will facilitate or obstruct the adoption of IoT in the energy industry.

Government should also invest in digital infrastructure, so that, users can avoid costly retrofitting, reduce the taxes for sensors and embedded technology.

Regulatory body may also motivate the users by number of measures such as incentives, awareness building e.g., it's a green technology as it reduces carbon emission, reduce cost through advertising and promotions. These capabilities provide a foundation for the technology among the users

8.4 Limitations of the study

The study findings should be considered with some cautions. The following limitations can be considered while generalizing the study outcome.

- The data have been collected from two major location of Bangladesh namely Dhaka and Khulna though it has some diversity still there is a shortcoming for generalizing the findings.
- The findings is based on consumption side of energy sector in Bangladesh. As there are other areas like generation and distribution in energy sector therefore the study findings fall short of entire energy sector.
- Finally, the data have been collected from March to October of some years. This may not reflect the prospects of Internet of things in energy sector in remaining months of the year.

While acknowledging such limitations this research demonstrates a tremendous prospect of internet of Things in energy sector, particularly IoT enabled ACs in different offices and households in Bangladesh.

8.5 Future Research Directions

There should be additional research about this topic because this paper cannot cover all the aspects of using IoT in energy sector. Based on this study's findings and taking into account its limitations, the researcher might recommend some areas for further investigation.

i. This research only focused on IoT enabled ACs in different offices of Dhaka and Khulna University which certainly condones other aspects of distribution side. Therefore, any future research direction could be important to incorporates other aspects such as IoT enabled household electronic appliances and its prospects. This will obviously let others to compare and contrast the findings of this study.

ii. Energy sector comprise of power generation, distribution and consumption. This research focuses only on consumption side so, future study on the other two aspects is important to encapsulate the overall prospects of IoT in energy sector.

iii. This research is mostly based on experiment and observations and some qualitative analysis. Future research can be directed to know the different stakeholders' responses regarding IoT prospects through survey and other types of methods.

iv. Humidity, room activity and other factors in large settings can be included to know the impact of IoT in ACs for further studies.

v. Finally, and precisely this research is conducted in office buildings in different cities of Bangladesh. However, a large number of ACs are used in residential buildings, therefore a separate analysis of commercial and residential IoT enabled ACs could be a more robust approach in future research direction.

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Appendix - A[1]

Sample In-depth Interview Guide

Research Title:
Prospects of Internet of Things in Energy Sector of Bangladesh

Researcher:
Md. Khashrul Alam
Professor
Business Administration Discipline
Khulna University
Cell: 01778-455955

IN-DEPTH INTERVIEW GUIDE

Department of Management Information Systems
University of Dhaka
Dhaka-1000, Bangladesh

Name of Interviewer : Md. Khashrul Alam

Date :

Name of Interviewee :

Designation of Interviewee :

Start Time :

End Time :

INTERVIEW GUIDELINE

This questionnaire was designed by Md. Khashrul Alam, a PhD student of Management Information System Department of Dhaka University with a view to complete PhD Thesis. The responses from this questionnaire shall facilitate in conducting the research, "Prospects of Internet of Things in Energy sector of Bangladesh". Your response will only be used for survey purposes and shall be kept in strict confidence. Thank you very much for your time and patience.

The following guidelines are followed for collecting data through 'In-depth' interview. Experts from different organization have been asked about what, and how questions to give more insight information.

CONCEPT:

- Internet of Things,
- Energy sector of Bangladesh
- Internet of Things and its' prospects in ACs
- Major issues in IoT implementation

STRATEGIC ESSENCE:

- Prospects of IoT in energy sector
    - Technical aspects of IoT
    - Economic prospects
    - Environmental Impact of IoT in ACs

    - Overall prospects of IoT in ACs

FRAMEWORK:

- Current status of IoT
    - Existing IoT facilities
    - Users' involvement in using IoT in electronics appliances
    - Role of regulatory authority in using the technology
- Existing infrastructure of IoT
    - Sensors
    - Cloud computing
    - Networks
    - Level of expertise (Users and providers)
    - Machine learning and data analytics
- awareness level of the technology
- Issues encountered

Appendix - A^2

In-depth interview guideline (Experts)

Question: What do you think about the introduction of IoT in energy sector?

Question: What is the present status of IoT in energy sector?

Question: What are the values users will consider while adopting IoT in Energy sector

Question: What can provider do to facilitate IoT adoption in energy sector?

Question: What are the enablers that drive User to adopt IoT

Question: What is the actions govt. can take to adopt IoT

Question: What are the barriers to IoT adoption?

Question: What are your overall comments in terms of the followings on the prospects of IoT in energy sector particularly in ACs

Appendix – A[3]

Table.5.11 Average external costs of climate change

Average external costs of climate change, EUR(2010)/t.

GHG emissions	2010	2015	2020	2025	2030	2040	2050
CO_2	25	25	25	27	36	54	72
CH_4	522	522	522	572	746	1144	1517
N_2O	7710	7710	7710	8444	11014	16888	22395

Source:(NEEDS, 2007)

Table.5.12 Average external health cost

Average external health costs of heavy metals releases for EU-27 during 2020–2030, EUR(2010)/t.

Heavy metals	External costs, EUR/t
Cd	46,200
As	94,700
Ni	4700
Pb	710,600
Hg	10,421,800
Cr	37,300
Cr-IV	284,200
Formaldehyde	236,900
Dioxine	4,40E+13

Source: (NEEDS, 2007)

Appendix – A[4]

Bangladeh Energy Regulatory Commission
TCB Bhaban (3rd Floor) 1, Karwan Bazar, Dhaka-1215
website: www.berc.org.bd

Notification

No.-28.01.0000.012.04.013.12-***6487*** Date : 09 *Agrahayon* 1424 / 23 November 2017

In exercise of power conferred by section 22 (b) and 34 of the Bangladesh Energy Regulatory Commission Act, 2003 'Retail Electricity Tariff' of Bangladesh Power Development Board, PBSs under Bangladesh Rural Electrification Board, Dhaka Power Distribution Company Limited, Dhaka Electric Supply Company Limited, West Zone Power Distribution Company Limited and Northern Electricity Supply Company Limited has been determined as follows with effect from bill month December 2017:

Retail Electricity Tariff

A. Low Tension (LT): 230/400 Volt

Electricity Supply : **Low Tension AC single phase 230 Volt & 3 phase 400 Volt**
Frequency : **50 Hz**
Sanction Load : **Single Phase 0-7.5 kW & 3 Phase 0-50 kW**

	Consumer Class	Energy Rate/Charge (Tk./kWh)	Demand Rate/Charge [Tk./kW (Sanction Load)/Month]
1	**LT—A: Residential**		25.00
	Life Line : 0-50 Unit	3.50[1]	
	First Slab : 0-75 Unit	4.00	
	Second Slab : 76-200 Unit	5.45	
	Third Slab : 201-300 Unit	5.70	
	Fourth Slab : 301-400 Unit	6.02	
	Fifth Slab : 401-600 Unit	9.30	
	Sixth Slab : Above 600 Unit	10.70	
2	**LT-B: Irrigation/Pump for Agriculture**	4.00	15.00
3	**LT—C 1: Small Industry**		15.00 (Applicable for Consumers' for sanction load upto 25 kW) 25.00 (Applicable for Consumers' for sanction load above 25 kW)
	Flat	8.20	
	Off-Peak	7.38	
	Peak	9.84	
4	**LT—C 2: Construction**	12.00	80.00
5	**LT—D 1: Education, Religious & Charitable Institutions and Hospital**	5.73	25.00
6	**LT—D 2: Street Light, Water Pump & Battary Charging Station**	7.70	40.00
7	**LT—E: Commercial & Office**		30.00
	Flat	10.30	
	Off-Peak	9.27	
	Peak	12.36	
8	**LT—T: Temporary**	16.00	100.00

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Source:(BERC, 2022)

Appendix - B[1]

Data captured from experiment

Dhaka University

Department of Management Information Systems

PhD Research Data captured over cloud computing

S.N. of office:	
Month of Data Capture :	____/____/______
Time Line of Data capture :	

This data will be used only for research purpose.

Title: The Prospects of Internet of Things (IoT) in Energy Sector of Bangladesh.

Sample Data (out of 4500+ pages): Captured from Experiment

Date Time	Room Temperature	Room Humidity (%)	Outside Temp	Outside Humid (%)	T. Offset	Office Hour	AC State	H. Offset
5/31/2021 13:57:44	28.2	69	31.75	78	3.55	No	Off	9
5/31/2021 13:57:55	28.2	69	31.75	78	3.55	No	Off	9
5/31/2021 13:58:06	28.2	69	31.75	78	3.55	No	Off	9
5/31/2021 13:58:18	28.2	68	31.75	78	3.55	No	Off	10
5/31/2021 13:58:29	28.3	69	31.75	78	3.45	No	Off	9
5/31/2021 13:58:41	28.3	68	31.75	78	3.45	No	Off	10
5/31/2021 13:58:53	28.2	68	31.75	78	3.55	No	Off	10
5/31/2021 13:59:05	28.2	68	31.75	78	3.55	No	Off	10
5/31/2021 13:59:16	28.2	68	31.75	78	3.55	No	Off	10
5/31/2021 13:59:27	28.2	68	31.75	78	3.55	No	Off	10
5/31/2021 13:59:38	28.2	68	31.75	78	3.55	No	Off	10
5/31/2021 13:59:50	28.3	68	31.75	78	3.45	No	Off	10
5/31/2021 14:00:01	28.3	68	31.75	78	3.45	No	Off	10
5/31/2021 14:00:12	28.4	68	31.75	78	3.35	No	Off	10
5/31/2021 14:00:30	28.4	68	31.75	78	3.35	No	Off	10
5/31/2021 14:00:41	28.5	69	31.75	78	3.25	No	Off	9
5/31/2021 14:00:52	28.6	69	31.75	78	3.15	No	Off	9
5/31/2021 14:01:02	28.7	69	31.75	78	3.05	Yes	Off	9
5/31/2021 14:01:14	28.8	69	31.75	78	2.95	Yes	Off	9
5/31/2021 14:01:31	28.9	69	31.75	78	2.85	Yes	Off	9
5/31/2021 14:01:41	29	68	31.75	78	2.75	Yes	Off	10
5/31/2021 14:02:18	29.1	68	31.75	78	2.65	Yes	Off	10
5/31/2021 14:02:29	29.3	68	31.75	78	2.45	Yes	Off	10
5/31/2021 14:02:40	29.3	69	31.75	78	2.45	Yes	Off	9
5/31/2021 14:02:51	29.4	69	31.75	78	2.35	Yes	Off	9
5/31/2021 14:03:01	29.4	69	31.75	78	2.35	Yes	Off	9

5/31/2021 14:03:12	29.4	69	31.75	78	2.35	Yes	Off	9
5/31/2021 14:03:24	29.5	69	31.75	78	2.25	Yes	Off	9
5/31/2021 14:03:37	29.5	69	31.75	78	2.25	Yes	Off	9
5/31/2021 14:03:47	29.5	69	31.75	78	2.25	Yes	Off	9
5/31/2021 14:04:00	29.5	69	31.75	78	2.25	Yes	Off	9
5/31/2021 14:04:11	29.5	69	31.75	78	2.25	Yes	Off	9
5/31/2021 14:04:22	29.6	69	31.75	78	2.15	Yes	Off	9
5/31/2021 14:04:33	29.6	69	31.75	78	2.15	Yes	Off	9
5/31/2021 14:04:44	29.7	69	31.75	78	2.05	Yes	Off	9
5/31/2021 14:04:56	29.6	69	31.75	78	2.15	Yes	Off	9
5/31/2021 14:05:07	29.7	69	31.75	78	2.05	Yes	Off	9
5/31/2021 14:05:18	29.7	69	31.75	78	2.05	Yes	Off	9
5/31/2021 14:05:29	29.8	69	31.75	78	1.95	Yes	Off	9
5/31/2021 14:05:40	29.7	69	31.75	78	2.05	Yes	Off	9
5/31/2021 14:05:51	29.8	69	31.75	78	1.95	Yes	Off	9
5/31/2021 14:06:02	29.8	70	31.75	78	1.95	Yes	Off	8
5/31/2021 14:06:12	29.8	70	31.75	78	1.95	Yes	Off	8
5/31/2021 14:06:23	29.8	70	31.75	78	1.95	Yes	Off	8
5/31/2021 14:06:35	29.9	70	31.75	78	1.85	Yes	Off	8
5/31/2021 14:06:46	29.9	70	31.75	78	1.85	Yes	Off	8
5/31/2021 14:06:58	29.9	70	31.75	78	1.85	Yes	Off	8
5/31/2021 14:07:10	29.9	70	31.75	78	1.85	Yes	Off	8
5/31/2021 14:07:21	30	69	31.75	78	1.75	Yes	Off	9
5/31/2021 14:17:06	29.3	72	31.75	78	2.45	Yes	Off	6
5/31/2021 14:17:18	29.3	72	31.75	78	2.45	Yes	Off	6
5/31/2021 14:17:29	29.4	72	31.75	78	2.35	Yes	Off	6
5/31/2021 14:17:40	29.4	72	31.75	78	2.35	Yes	Off	6
5/31/2021 14:17:51	29.4	72	31.75	78	2.35	Yes	Off	6
5/31/2021	29.5	72	31.75	78	2.25	Yes	Off	6

14:18:03								
5/31/2021 14:18:14	29.5	72	31.75	78	2.25	Yes	Off	6
5/31/2021 14:18:26	29.5	72	31.75	78	2.25	Yes	Off	6
5/31/2021 14:18:36	29.6	72	31.75	78	2.15	Yes	Off	6
5/31/2021 14:18:48	29.6	72	31.75	78	2.15	Yes	Off	6
5/31/2021 14:19:00	29.6	72	31.75	78	2.15	Yes	Off	6
5/31/2021 14:19:11	29.7	72	31.75	78	2.05	Yes	Off	6
5/31/2021 14:19:22	29.7	72	31.75	78	2.05	Yes	Off	6
5/31/2021 14:19:33	29.7	72	31.75	78	2.05	Yes	Off	6
5/31/2021 14:19:45	29.8	72	31.75	78	1.95	Yes	Off	6
5/31/2021 14:19:55	29.8	72	31.75	78	1.95	Yes	Off	6
5/31/2021 14:20:06	29.8	72	31.75	78	1.95	Yes	Off	6
5/31/2021 14:20:18	29.9	72	31.75	78	1.85	Yes	Off	6
5/31/2021 14:20:29	29.9	72	31.75	78	1.85	Yes	Off	6
5/31/2021 14:20:42	29.9	72	31.75	78	1.85	Yes	Off	6
5/31/2021 14:20:53	29.9	71	31.75	78	1.85	Yes	Off	7
5/31/2021 14:21:03	29.9	71	31.75	78	1.85	Yes	Off	7
5/31/2021 14:21:14	30	70	31.75	78	1.75	Yes	Off	8
5/31/2021 14:21:26	29.9	71	31.75	78	1.85	Yes	Off	7
5/31/2021 14:21:37	29.9	71	31.75	78	1.85	Yes	Off	7
5/31/2021 14:21:48	30	70	31.75	78	1.75	Yes	Off	8
5/31/2021 14:21:59	30	70	31.75	78	1.75	Yes	Off	8
5/31/2021 14:22:11	30	70	31.75	78	1.75	Yes	Off	8
5/31/2021 14:22:21	30	70	31.75	78	1.75	Yes	Off	8
5/31/2021 14:22:33	30.1	70	31.75	78	1.65	Yes	Off	8
5/31/2021 14:22:44	30.1	70	31.75	78	1.65	Yes	Off	8
5/31/2021 14:22:55	30	70	31.75	78	1.75	Yes	Off	8
5/31/2021 14:23:06	30.1	70	31.75	78	1.65	Yes	Off	8
5/31/2021 14:23:17	30	70	31.75	78	1.75	Yes	Off	8
5/31/2021	30	70	31.75	78	1.75	Yes	Off	8

14:23:29								
5/31/2021 14:23:40	29.9	72	31.75	78	1.85	Yes	Off	6
5/31/2021 14:23:51	29.9	71	31.75	78	1.85	Yes	Off	7
5/31/2021 14:24:02	29.7	71	31.75	78	2.05	Yes	Off	7
5/31/2021 14:24:13	29.7	71	31.75	78	2.05	Yes	Off	7
5/31/2021 14:24:32	29.6	71	31.75	78	2.15	Yes	Off	7
5/31/2021 14:24:44	29.6	70	31.75	78	2.15	Yes	Off	8
5/31/2021 14:24:55	29.4	69	31.75	78	2.35	Yes	Off	9
5/31/2021 14:25:06	29.2	69	31.75	78	2.55	Yes	Off	9
5/31/2021 14:25:17	29.2	69	31.75	78	2.55	Yes	Off	9
5/31/2021 14:25:27	29	69	31.75	78	2.75	Yes	Off	9
5/31/2021 14:25:41	28.9	69	31.75	78	2.85	Yes	Off	9
5/31/2021 14:25:52	28.8	68	31.75	78	2.95	Yes	Off	10
5/31/2021 14:26:03	28.9	68	31.75	78	2.85	Yes	Off	10
5/31/2021 14:26:18	28.8	68	31.75	78	2.95	Yes	Off	10
5/31/2021 14:26:29	28.7	67	31.75	78	3.05	Yes	Off	11
5/31/2021 14:26:40	28.6	67	31.75	78	3.15	Yes	Off	11
5/31/2021 14:26:51	28.5	66	31.75	78	3.25	Yes	Off	12
5/31/2021 14:27:03	28.4	66	31.75	78	3.35	Yes	Off	12
5/31/2021 14:27:14	28.4	66	31.75	78	3.35	Yes	Off	12
5/31/2021 14:27:25	28.3	65	31.75	78	3.45	Yes	Off	13
5/31/2021 14:27:36	28.3	65	31.75	78	3.45	Yes	Off	13
5/31/2021 14:27:48	28.2	64	31.75	78	3.55	Yes	Off	14
5/31/2021 14:27:59	28.1	64	31.75	78	3.65	Yes	Off	14
5/31/2021 14:28:10	28	64	31.75	78	3.75	Yes	Off	14
5/31/2021 14:28:21	27.9	64	31.75	78	3.85	Yes	Off	14
5/31/2021 14:28:31	28	63	31.75	78	3.75	Yes	Off	15
5/31/2021 14:28:42	27.8	64	31.75	78	3.95	Yes	Off	14
5/31/2021 14:28:53	27.7	64	31.75	78	4.05	Yes	Off	14
5/31/2021	27.8	64	31.75	78	3.95	Yes	Off	14

14:29:04								
5/31/2021 14:29:16	27.7	63	31.75	78	4.05	Yes	Off	15
5/31/2021 14:29:27	27.7	63	31.75	78	4.05	Yes	Off	15
5/31/2021 14:29:39	27.7	63	31.75	78	4.05	Yes	Off	15
5/31/2021 15:31:42	28.4	68	31.75	78	3.35	Yes	Off	10
5/31/2021 15:31:54	28.4	65	31.75	78	3.35	Yes	Off	13
5/31/2021 15:32:05	28.4	64	31.75	78	3.35	Yes	Off	14
5/31/2021 15:32:16	28.4	63	31.75	78	3.35	Yes	Off	15
5/31/2021 15:32:27	28.4	63	31.75	78	3.35	Yes	Off	15
5/31/2021 15:32:37	28.4	63	31.75	78	3.35	Yes	Off	15
5/31/2021 15:32:48	28.4	63	31.75	78	3.35	Yes	Off	15
5/31/2021 15:32:59	28.4	63	31.75	78	3.35	Yes	Off	15
5/31/2021 15:33:11	28.3	63	31.75	78	3.45	Yes	Off	15
5/31/2021 15:33:21	28.4	63	31.75	78	3.35	Yes	Off	15
5/31/2021 15:33:32	28.4	63	31.75	78	3.35	Yes	Off	15
5/31/2021 15:33:43	28.4	63	31.75	78	3.35	Yes	Off	15
5/31/2021 15:33:53	28.4	63	31.75	78	3.35	Yes	Off	15
5/31/2021 15:34:04	28.4	63	31.75	78	3.35	Yes	Off	15
5/31/2021 15:34:15	28.4	63	31.75	78	3.35	Yes	Off	15
5/31/2021 15:34:26	28.3	63	31.75	78	3.45	Yes	Off	15
5/31/2021 15:34:36	28.3	63	31.75	78	3.45	Yes	Off	15
5/31/2021 15:34:48	28.3	63	31.75	78	3.45	Yes	Off	15
5/31/2021 15:35:15	28.3	63	31.75	78	3.45	Yes	Off	15
5/31/2021 15:35:30	28.2	63	31.75	78	3.55	Yes	Off	15
5/31/2021 15:35:41	28.3	62	31.75	78	3.45	Yes	Off	16
5/31/2021 15:35:52	28.3	61	31.75	78	3.45	Yes	Off	17
5/31/2021 15:36:02	28.3	61	31.75	78	3.45	Yes	Off	17
5/31/2021 15:36:13	28.2	60	31.75	78	3.55	Yes	Off	18
5/31/2021 15:37:05	28.2	60	31.75	78	3.55	Yes	Off	18
5/31/2021	28.1	59	31.75	78	3.65	Yes	Off	19

15:37:17								
5/31/2021 15:37:28	28.1	57	31.75	78	3.65	Yes	Off	21
5/31/2021 15:37:39	28.1	57	31.75	78	3.65	Yes	Off	21
5/31/2021 15:37:50	28.1	56	31.75	78	3.65	Yes	Off	22
5/31/2021 15:38:15	28.1	56	31.75	78	3.65	Yes	Off	22
5/31/2021 15:38:26	28.1	55	31.75	78	3.65	Yes	Off	23
5/31/2021 15:38:38	28.1	55	31.75	78	3.65	Yes	Off	23
5/31/2021 15:38:48	28.1	54	31.75	78	3.65	Yes	On	24
5/31/2021 15:38:59	28.1	54	31.75	78	3.65	Yes	On	24
5/31/2021 15:39:10	28.1	54	31.75	78	3.65	Yes	On	24
5/31/2021 15:39:21	28.1	53	31.75	78	3.65	Yes	On	25
5/31/2021 15:39:31	28.1	53	31.75	78	3.65	Yes	On	25
5/31/2021 15:39:42	28.2	53	31.75	78	3.55	Yes	On	25
5/31/2021 15:39:54	28.2	53	31.75	78	3.55	Yes	On	25
5/31/2021 15:40:05	28.1	52	31.75	78	3.65	Yes	On	26
5/31/2021 15:40:16	28.1	52	31.75	78	3.65	Yes	On	26
5/31/2021 15:40:27	28	52	31.75	78	3.75	Yes	On	26
5/31/2021 15:40:40	28.1	52	31.75	78	3.65	Yes	On	26
5/31/2021 15:40:51	28.2	51	31.75	78	3.55	Yes	On	27
5/31/2021 15:41:02	28.1	51	31.75	78	3.65	Yes	On	27
5/31/2021 15:41:13	28.1	51	31.75	78	3.65	Yes	On	27
5/31/2021 15:41:24	27.9	51	31.75	78	3.85	Yes	On	27
5/31/2021 15:41:35	27.8	51	31.75	78	3.95	Yes	On	27
5/31/2021 15:41:46	27.8	51	31.75	78	3.95	Yes	On	27
5/31/2021 15:41:56	27.8	50	31.75	78	3.95	Yes	On	28
5/31/2021 15:42:33	27.8	50	31.75	78	3.95	Yes	On	28
5/31/2021 15:42:44	27.9	51	31.75	78	3.85	Yes	On	27
5/31/2021 15:42:55	27.9	50	31.75	78	3.85	Yes	On	28
5/31/2021 15:43:06	27.9	51	31.75	78	3.85	Yes	On	27
5/31/2021	27.9	50	31.75	78	3.85	Yes	On	28

15:43:18								
5/31/2021 15:43:31	27.8	49	31.75	78	3.95	Yes	On	29
5/31/2021 15:43:41	27.9	49	31.75	78	3.85	Yes	On	29
5/31/2021 15:43:53	27.8	49	31.75	78	3.95	Yes	On	29
5/31/2021 15:44:04	27.8	49	31.75	78	3.95	Yes	On	29
5/31/2021 15:44:14	27.8	49	31.75	78	3.95	Yes	On	29
5/31/2021 15:44:25	27.8	48	31.75	78	3.95	Yes	On	30
5/31/2021 15:44:37	27.8	48	31.75	78	3.95	Yes	On	30
5/31/2021 15:44:48	27.7	48	31.75	78	4.05	Yes	On	30
5/31/2021 15:45:00	27.7	48	31.75	78	4.05	Yes	On	30
5/31/2021 15:45:11	27.7	48	31.75	78	4.05	Yes	On	30
5/31/2021 15:45:22	27.7	47	31.75	78	4.05	Yes	On	31
5/31/2021 15:45:33	27.7	47	31.75	78	4.05	Yes	On	31
5/31/2021 15:45:44	27.7	47	31.75	78	4.05	Yes	On	31
5/31/2021 15:45:55	27.8	48	31.75	78	3.95	Yes	On	30
5/31/2021 15:46:06	27.9	47	31.75	78	3.85	Yes	On	31
5/31/2021 15:46:17	27.8	47	31.75	78	3.95	Yes	On	31
5/31/2021 15:46:27	27.8	47	31.75	78	3.95	Yes	On	31
5/31/2021 15:46:38	27.9	48	31.75	78	3.85	Yes	On	30
5/31/2021 15:46:50	27.8	47	31.75	78	3.95	Yes	On	31
5/31/2021 15:47:01	27.7	47	31.75	78	4.05	Yes	On	31
5/31/2021 15:47:12	27.3	46	31.75	78	4.45	Yes	On	32
5/31/2021 15:47:23	27.2	46	31.75	78	4.55	Yes	On	32
5/31/2021 15:47:34	27.2	46	31.75	78	4.55	Yes	On	32
5/31/2021 15:47:45	27.2	45	31.75	78	4.55	Yes	On	33
5/31/2021 15:47:56	27.3	46	31.75	78	4.45	Yes	On	32
5/31/2021 15:48:07	27.1	45	31.75	78	4.65	Yes	On	33
5/31/2021 15:48:18	27.3	45	31.75	78	4.45	Yes	On	33
5/31/2021 15:48:29	27.2	45	31.75	78	4.55	Yes	On	33
5/31/2021	27	44	31.75	78	4.75	Yes	On	34

15:48:43									
5/31/2021 15:48:54	27	44	31.75	78	4.75	Yes	On	34	
5/31/2021 15:49:04	27	44	31.75	78	4.75	Yes	On	34	
5/31/2021 15:49:15	26.9	44	31.75	78	4.85	Yes	On	34	
5/31/2021 15:49:26	26.8	44	31.75	78	4.95	Yes	On	34	
5/31/2021 15:49:41	27	44	31.75	78	4.75	Yes	On	34	
5/31/2021 15:49:53	27	44	31.75	78	4.75	Yes	On	34	
5/31/2021 15:50:05	27	44	31.75	78	4.75	Yes	On	34	
5/31/2021 15:50:16	27	44	31.75	78	4.75	Yes	On	34	
5/31/2021 15:50:28	26.8	44	31.75	78	4.95	Yes	On	34	
5/31/2021 15:50:39	26.7	44	31.75	78	5.05	Yes	On	34	
5/31/2021 15:50:49	26.9	44	31.75	78	4.85	Yes	On	34	
5/31/2021 15:51:03	26.9	44	31.75	78	4.85	Yes	On	34	
5/31/2021 15:51:14	27	44	31.75	78	4.75	Yes	On	34	
5/31/2021 15:51:25	26.8	44	31.75	78	4.95	Yes	On	34	
5/31/2021 15:51:36	26.8	44	31.75	78	4.95	Yes	On	34	
5/31/2021 15:51:47	26.9	44	31.75	78	4.85	Yes	On	34	
5/31/2021 15:51:58	26.7	43	31.75	78	5.05	Yes	On	35	
5/31/2021 15:52:09	26.8	44	31.75	78	4.95	Yes	On	34	
5/31/2021 15:52:20	26.9	43	31.75	78	4.85	Yes	On	35	
5/31/2021 15:52:32	26.8	43	31.75	78	4.95	Yes	On	35	
5/31/2021 15:52:43	26.8	43	31.75	78	4.95	Yes	On	35	
5/31/2021 15:52:57	26.8	43	31.75	78	4.95	Yes	On	35	
5/31/2021 15:53:32	26.7	43	31.75	78	5.05	Yes	On	35	
5/31/2021 15:53:45	26.5	43	31.75	78	5.25	Yes	On	35	
5/31/2021 15:53:56	26.6	43	31.75	78	5.15	Yes	On	35	
5/31/2021 15:54:07	26.5	43	31.75	78	5.25	Yes	On	35	
5/31/2021 15:54:18	26.7	43	31.75	78	5.05	Yes	On	35	
5/31/2021 15:54:29	26.6	43	31.75	78	5.15	Yes	On	35	
5/31/2021	26.7	43	31.75	78	5.05	Yes	On	35	

15:54:40									
5/31/2021 15:54:52	26.5	42	31.75	78	5.25	Yes	On	36
5/31/2021 15:55:04	26.3	42	31.75	78	5.45	Yes	On	36
5/31/2021 15:55:15	26.5	43	31.75	78	5.25	Yes	On	35
5/31/2021 15:55:25	26.5	43	31.75	78	5.25	Yes	On	35
5/31/2021 15:55:36	26.1	43	31.75	78	5.65	Yes	On	35
5/31/2021 15:55:47	26.1	44	31.75	78	5.65	Yes	On	34
5/31/2021 15:56:00	26.2	43	31.75	78	5.55	Yes	On	35
5/31/2021 15:56:11	26.2	43	31.75	78	5.55	Yes	On	35
5/31/2021 15:56:22	26.1	43	31.75	78	5.65	Yes	On	35
5/31/2021 15:56:32	26.2	43	31.75	78	5.55	Yes	On	35
5/31/2021 15:56:50	26.1	43	31.75	78	5.65	Yes	On	35
5/31/2021 15:57:01	26.2	43	31.75	78	5.55	Yes	On	35
5/31/2021 15:57:12	26.3	43	31.75	78	5.45	Yes	On	35
5/31/2021 15:57:23	26.3	43	31.75	78	5.45	Yes	On	35
5/31/2021 15:57:34	26.4	43	31.75	78	5.35	Yes	On	35
5/31/2021 15:58:01	26.2	43	31.75	78	5.55	Yes	On	35
5/31/2021 15:58:12	26.3	43	31.75	78	5.45	Yes	On	35
5/31/2021 15:58:23	26.3	43	31.75	78	5.45	Yes	On	35
5/31/2021 15:58:34	26.3	43	31.75	78	5.45	Yes	On	35
5/31/2021 15:58:45	26.2	43	31.75	78	5.55	Yes	On	35
5/31/2021 15:58:57	26.2	43	31.75	78	5.55	Yes	On	35
5/31/2021 15:59:09	26.2	42	31.75	78	5.55	Yes	On	36
5/31/2021 15:59:20	26	42	31.75	78	5.75	Yes	On	36
5/31/2021 15:59:31	26	42	31.75	78	5.75	Yes	On	36
5/31/2021 15:59:43	26.1	43	31.75	78	5.65	Yes	On	35
5/31/2021 15:59:54	26.1	43	31.75	78	5.65	Yes	On	35
5/31/2021 16:00:07	26.2	43	31.75	78	5.55	Yes	On	35
5/31/2021 16:00:18	25.9	43	31.75	78	5.85	Yes	On	35
5/31/2021	26	42	31.75	78	5.75	Yes	On	36

16:00:29								
5/31/2021 16:00:40	26.2	43	31.75	78	5.55	Yes	On	35
5/31/2021 16:00:52	26.1	42	31.75	78	5.65	Yes	On	36
5/31/2021 16:01:02	26.3	42	31.75	78	5.45	Yes	On	36
5/31/2021 16:01:13	26.5	42	31.75	78	5.25	Yes	On	36
5/31/2021 16:01:24	26.4	42	31.75	78	5.35	Yes	On	36
5/31/2021 16:01:35	26.5	42	31.75	78	5.25	Yes	On	36
5/31/2021 16:01:46	26.3	42	31.75	78	5.45	Yes	On	36
5/31/2021 16:01:57	26.2	42	31.75	78	5.55	Yes	On	36
5/31/2021 16:02:08	26	42	31.75	78	5.75	Yes	On	36
5/31/2021 16:02:19	26.3	42	31.75	78	5.45	Yes	On	36
5/31/2021 16:02:31	26.2	42	31.75	78	5.55	Yes	On	36
5/31/2021 16:02:42	26.3	42	31.75	78	5.45	Yes	On	36
5/31/2021 16:02:53	26.3	42	31.75	78	5.45	Yes	On	36
5/31/2021 16:03:04	26.5	42	31.75	78	5.25	Yes	On	36
5/31/2021 16:03:15	26.8	42	31.75	78	4.95	Yes	On	36
5/31/2021 16:03:26	26.5	41	31.75	78	5.25	Yes	On	37
5/31/2021 16:03:40	26.4	41	31.75	78	5.35	Yes	On	37
5/31/2021 16:03:51	26.3	41	31.75	78	5.45	Yes	On	37
5/31/2021 16:04:02	26.4	41	31.75	78	5.35	Yes	On	37
5/31/2021 16:04:13	26.4	41	31.75	78	5.35	Yes	On	37
5/31/2021 16:04:25	26.4	41	31.75	78	5.35	Yes	On	37
5/31/2021 16:04:35	26.5	41	31.75	78	5.25	Yes	On	37
5/31/2021 16:04:46	26.5	41	31.75	78	5.25	Yes	On	37
5/31/2021 16:04:58	26.6	41	31.75	78	5.15	Yes	On	37
5/31/2021 16:05:09	26.7	41	31.75	78	5.05	Yes	On	37
5/31/2021 16:05:19	26.8	41	31.75	78	4.95	Yes	On	37
5/31/2021 16:05:30	26.6	40	31.75	78	5.15	Yes	On	38
5/31/2021 16:05:41	26.5	40	31.75	78	5.25	Yes	On	38
5/31/2021	26.3	40	31.75	78	5.45	Yes	On	38

16:05:52								
5/31/2021 16:06:03	26.3	40	31.75	78	5.45	Yes	On	38
5/31/2021 16:06:14	26.3	40	31.75	78	5.45	Yes	On	38
5/31/2021 16:06:25	26.3	40	31.75	78	5.45	Yes	On	38
5/31/2021 16:06:37	26.3	40	31.75	78	5.45	Yes	On	38
5/31/2021 16:06:49	26.1	41	31.75	78	5.65	Yes	On	37
5/31/2021 16:07:00	26.1	41	31.75	78	5.65	Yes	On	37
5/31/2021 16:07:11	26.3	41	31.75	78	5.45	Yes	On	37
5/31/2021 16:07:22	26	41	31.75	78	5.75	Yes	On	37
5/31/2021 16:07:32	26	41	31.75	78	5.75	Yes	On	37
5/31/2021 16:07:44	26.2	41	31.75	78	5.55	Yes	On	37
5/31/2021 16:07:55	26.2	41	31.75	78	5.55	Yes	On	37
5/31/2021 16:08:06	26.4	41	31.75	78	5.35	Yes	On	37
5/31/2021 16:08:17	26.5	41	31.75	78	5.25	Yes	On	37
5/31/2021 16:08:28	26.3	41	31.75	78	5.45	Yes	On	37
5/31/2021 16:08:39	26.3	42	31.75	78	5.45	Yes	On	36
5/31/2021 16:08:50	26.3	42	31.75	78	5.45	Yes	On	36
5/31/2021 16:09:03	26.1	41	31.75	78	5.65	Yes	On	37
5/31/2021 16:09:14	26.1	41	31.75	78	5.65	Yes	On	37
5/31/2021 16:09:25	26.2	41	31.75	78	5.55	Yes	On	37
5/31/2021 16:09:59	26.1	40	31.75	78	5.65	Yes	On	38
5/31/2021 16:10:10	26	40	31.75	78	5.75	Yes	On	38
5/31/2021 16:10:22	25.9	40	31.75	78	5.85	Yes	On	38
5/31/2021 16:10:32	26.2	40	31.75	78	5.55	Yes	On	38
5/31/2021 16:10:43	26.2	41	31.75	78	5.55	Yes	On	37
5/31/2021 16:10:54	26	40	31.75	78	5.75	Yes	On	38
5/31/2021 16:11:06	26	40	31.75	78	5.75	Yes	On	38
5/31/2021 16:11:17	25.9	40	31.75	78	5.85	Yes	On	38
5/31/2021 16:11:28	25.7	40	31.75	78	6.05	Yes	On	38
5/31/2021	25.6	40	31.75	78	6.15	Yes	On	38

16:11:39								
5/31/2021 16:11:51	25.4	40	31.75	78	6.35	Yes	On	38
5/31/2021 16:12:02	25.4	40	31.75	78	6.35	Yes	On	38
5/31/2021 16:12:13	25.5	41	31.75	78	6.25	Yes	On	37
5/31/2021 16:12:24	25.6	41	31.75	78	6.15	Yes	On	37
5/31/2021 16:12:37	25.4	41	31.75	78	6.35	Yes	On	37
5/31/2021 16:12:49	25.5	41	31.75	78	6.25	Yes	On	37
5/31/2021 16:13:01	25.6	41	31.75	78	6.15	Yes	On	37
5/31/2021 16:13:12	25.6	42	31.75	78	6.15	Yes	On	36
5/31/2021 16:13:23	25.6	42	31.75	78	6.15	Yes	On	36
5/31/2021 16:13:33	25.9	42	31.75	78	5.85	Yes	On	36
5/31/2021 16:13:44	26	43	31.75	78	5.75	Yes	On	35
5/31/2021 16:13:55	26.1	44	31.75	78	5.65	Yes	On	34
5/31/2021 16:14:06	26.1	44	31.75	78	5.65	Yes	On	34
5/31/2021 16:14:18	26.3	44	31.75	78	5.45	Yes	On	34
5/31/2021 16:14:29	26.3	44	31.75	78	5.45	Yes	On	34
5/31/2021 16:14:39	26.3	45	31.75	78	5.45	Yes	On	33
5/31/2021 16:14:52	26.3	45	31.75	78	5.45	Yes	On	33
5/31/2021 16:15:04	26.1	46	31.75	78	5.65	Yes	On	32
5/31/2021 16:15:15	26.1	47	31.75	78	5.65	Yes	On	31
5/31/2021 16:15:27	26.2	47	31.75	78	5.55	Yes	On	31
5/31/2021 16:15:37	26.2	48	31.75	78	5.55	Yes	On	30
5/31/2021 16:15:49	26.2	48	31.75	78	5.55	Yes	On	30
5/31/2021 16:16:18	26.1	48	31.75	78	5.65	Yes	On	30
5/31/2021 16:16:33	26.5	48	31.75	78	5.25	Yes	On	30
5/31/2021 16:16:44	26.5	48	31.75	78	5.25	Yes	On	30
5/31/2021 16:16:56	26.5	47	31.75	78	5.25	Yes	On	31
5/31/2021 16:17:12	26.5	47	31.75	78	5.25	Yes	On	31
5/31/2021 16:17:23	26.5	47	31.75	78	5.25	Yes	On	31
5/31/2021	26.5	47	31.75	78	5.25	Yes	On	31

16:17:34								
5/31/2021 16:17:46	26.4	47	31.75	78	5.35	Yes	On	31
5/31/2021 16:17:57	26.2	47	31.75	78	5.55	Yes	On	31
5/31/2021 16:18:08	26.2	47	31.75	78	5.55	Yes	On	31
5/31/2021 16:18:19	26.3	47	31.75	78	5.45	Yes	On	31
5/31/2021 16:18:30	26.2	46	31.75	78	5.55	Yes	On	32
5/31/2021 16:18:41	26.2	47	31.75	78	5.55	Yes	On	31
5/31/2021 16:18:52	26.3	47	31.75	78	5.45	Yes	On	31
5/31/2021 16:36:05	24.7	46	31.75	78	7.05	Yes	On	32
5/31/2021 16:36:16	24.7	47	31.75	78	7.05	Yes	On	31
5/31/2021 16:36:27	24.7	47	31.75	78	7.05	Yes	On	31
5/31/2021 16:36:43	24.8	47	31.75	78	6.95	Yes	On	31
5/31/2021 16:36:54	24.9	48	31.75	78	6.85	Yes	On	30
5/31/2021 16:37:05	24.9	48	31.75	78	6.85	Yes	On	30
5/31/2021 16:37:17	24.9	49	31.7	78	6.8	Yes	On	29
5/31/2021 16:37:28	24.9	49	31.75	78	6.85	Yes	On	29
5/31/2021 16:37:38	25	49	31.75	78	6.75	Yes	On	29
5/31/2021 16:37:49	25	49	31.75	78	6.75	Yes	On	29
5/31/2021 16:38:00	25	49	31.75	78	6.75	Yes	On	29
5/31/2021 16:38:11	25.1	50	31.75	78	6.65	Yes	On	28
5/31/2021 16:38:22	25.1	50	31.75	78	6.65	Yes	On	28
5/31/2021 16:38:32	25.1	50	31.75	78	6.65	Yes	On	28
5/31/2021 16:38:43	25.1	51	31.75	78	6.65	Yes	On	27
5/31/2021 16:38:55	25.2	51	31.75	78	6.55	Yes	On	27
5/31/2021 16:39:06	25.2	51	31.75	78	6.55	Yes	On	27
5/31/2021 16:39:17	25.2	50	31.7	78	6.5	Yes	On	28
5/31/2021 18:24:40	24.2	59	33.49	74	9.29	Yes	Off	15
5/31/2021 18:24:52	24.2	60	33.49	74	9.29	Yes	Off	14
5/31/2021 18:25:04	24.2	60	33.45	74	9.25	Yes	Off	14
5/31/2021	24.3	61	33.49	74	9.19	Yes	Off	13

18:25:15								
5/31/2021 18:25:26	24.3	61	33.45	74	9.15	Yes	Off	13
5/31/2021 18:25:36	24.3	61	33.45	74	9.15	Yes	Off	13
5/31/2021 18:25:47	24.2	60	33.45	74	9.25	Yes	Off	14
5/31/2021 18:25:58	24.2	60	33.49	74	9.29	Yes	Off	14
5/31/2021 18:26:10	24.2	59	33.49	74	9.29	Yes	Off	15
5/31/2021 18:26:21	24.2	59	33.49	74	9.29	Yes	Off	15
5/31/2021 18:26:32	24.2	59	33.49	74	9.29	Yes	Off	15
5/31/2021 18:26:43	24.1	58	33.49	74	9.39	Yes	Off	16

Sample Data of Energy Savings: Data Captured from experiment

Date Time	Saving (%) of last hour	Saving (kWh) of last hour	Saved Amount BDT
5/31/2021	0.37	1.6354	9.370842
5/31/2021	0.455	2.0111	11.523603
5/31/2021	0.51	2.2542	12.916566
5/31/2021	0.55	2.431	13.92963
5/31/2021	0.57	2.5194	14.436162
6/1/2021	0.585	2.5857	14.816061
6/1/2021	0.59	2.6078	14.942694
6/1/2021	0.605	2.6741	15.322593
6/1/2021	0.61	2.6962	15.449226
6/1/2021	0.63	2.7846	15.955758
6/1/2021	0.62	2.7404	15.702492
6/1/2021	0.625	2.7625	15.829125
6/1/2021	0.64	2.8288	16.209024
6/1/2021	0.64	2.8288	16.209024
6/1/2021	0.65	2.873	16.46229
6/1/2021	0.63	2.7846	15.955758
6/1/2021	0.42	1.8564	10.637172
6/1/2021	0.38	1.6796	9.624108
6/1/2021	0.53	2.3426	13.423098
6/1/2021	0.56	2.4752	14.182896
6/1/2021	0.6	2.652	15.19596
6/1/2021	0.355	1.5691	8.990943
6/1/2021	0.41	1.8122	10.383906
6/1/2021	0.415	1.8343	10.510539
6/1/2021	0.5	2.21	12.6633
6/1/2021	0.53	2.3426	13.423098
6/1/2021	0.55	2.431	13.92963
6/1/2021	0.55	2.431	13.92963
6/1/2021	0.575	2.5415	14.562795
6/2/2021	0.59	2.6078	14.942694

6/2/2021	0.585	2.5857	14.816061
6/2/2021	0.59	2.6078	14.942694
6/2/2021	0.585	2.5857	14.816061
6/2/2021	0.59	2.6078	14.942694
6/2/2021	0.61	2.6962	15.449226
6/2/2021	0.595	2.6299	15.069327
6/2/2021	0.6	2.652	15.19596
6/2/2021	0.605	2.6741	15.322593
6/2/2021	0.61	2.6962	15.449226
6/2/2021	0.59	2.6078	14.942694
6/2/2021	0.57	2.5194	14.436162
6/2/2021	0.56	2.4752	14.182896
6/2/2021	0.52	2.2984	13.169832
6/2/2021	0.56	2.4752	14.182896
6/2/2021	0.56	2.4752	14.182896
6/2/2021	0.265	1.1713	6.711549
6/2/2021	0.155	0.6851	3.925623
6/2/2021	0.185	0.8177	4.685421
6/2/2021	0.24	1.0608	6.078384
6/2/2021	0.405	1.7901	10.257273
6/2/2021	0.46	2.0332	11.650236
6/2/2021	0.5	2.21	12.6633
6/2/2021	0.51	2.2542	12.916566
6/3/2021	0.54	2.3868	13.676364
6/3/2021	0.56	2.4752	14.182896
6/3/2021	0.56	2.4752	14.182896
6/3/2021	0.58	2.5636	14.689428
6/3/2021	0.575	2.5415	14.562795
6/3/2021	0.58	2.5636	14.689428
6/3/2021	0.58	2.5636	14.689428
6/3/2021	0.6	2.652	15.19596
6/3/2021	0.59	2.6078	14.942694
6/3/2021	0.62	2.7404	15.702492
6/3/2021	0.615	2.7183	15.575859

6/3/2021	0.305	1.3481	7.724613
6/3/2021	0.115	0.5083	2.912559
6/3/2021	0.055	0.2431	1.392963
6/3/2021	0	0	0
6/3/2021	0.035	0.1547	0.886431
6/3/2021	0.04	0.1768	1.013064
6/3/2021	0.02	0.0884	0.506532
6/5/2021	0.23	1.0166	5.825118
6/5/2021	0.45	1.989	11.39697
6/5/2021	0.52	2.2984	13.169832
6/5/2021	0.095	0.4199	2.406027
6/5/2021	0.195	0.8619	4.938687
6/5/2021	0.4	1.768	10.13064
6/5/2021	0.47	2.0774	11.903502
6/5/2021	0.52	2.2984	13.169832
6/5/2021	0.53	2.3426	13.423098
6/6/2021	0.55	2.431	13.92963
6/6/2021	0.55	2.431	13.92963
6/6/2021	0.56	2.4752	14.182896
6/6/2021	0.57	2.5194	14.436162
6/6/2021	0.57	2.5194	14.436162
6/6/2021	0.59	2.6078	14.942694
6/6/2021	0.585	2.5857	14.816061
6/6/2021	0.59	2.6078	14.942694
6/6/2021	0.6	2.652	15.19596
6/6/2021	0.6	2.652	15.19596
6/6/2021	0.3	1.326	7.59798
6/6/2021	0.29	1.2818	7.344714
6/6/2021	0.225	0.9945	5.698485
6/6/2021	0.25	1.105	6.33165
6/6/2021	0.4	1.768	10.13064
6/6/2021	0.5	2.21	12.6633
6/6/2021	0.53	2.3426	13.423098
6/6/2021	0.545	2.4089	13.802997

6/6/2021	0.55	2.431	13.92963
6/6/2021	0.55	2.431	13.92963
6/6/2021	0.55	2.431	13.92963
6/6/2021	0.55	2.431	13.92963
6/6/2021	0.55	2.431	13.92963
6/6/2021	0.57	2.5194	14.436162
6/7/2021	0.56	2.4752	14.182896
6/7/2021	0.57	2.5194	14.436162
6/7/2021	0.57	2.5194	14.436162
6/7/2021	0.56	2.4752	14.182896
6/7/2021	0.56	2.4752	14.182896
6/7/2021	0.575	2.5415	14.562795
6/7/2021	0.57	2.5194	14.436162
6/7/2021	0.6	2.652	15.19596
6/7/2021	0.6	2.652	15.19596
6/7/2021	0.6	2.652	15.19596
6/7/2021	0.61	2.6962	15.449226
6/7/2021	0.295	1.3039	7.471347
6/7/2021	0.085	0.3757	2.152761
6/7/2021	0.03	0.1326	0.759798
6/7/2021	0.015	0.0663	0.379899
6/7/2021	0.06	0.2652	1.519596
6/7/2021	0.165	0.7293	4.178889
6/7/2021	0.195	0.8619	4.938687
6/7/2021	0.205	0.9061	5.191953
6/7/2021	0.175	0.7735	4.432155
6/7/2021	0.37	1.6354	9.370842
6/7/2021	0.43	1.9006	10.890438
6/7/2021	0.45	1.989	11.39697
6/7/2021	0.48	2.1216	12.156768
6/8/2021	0.48	2.1216	12.156768
6/8/2021	0.5	2.21	12.6633
6/8/2021	0.5	2.21	12.6633
6/8/2021	0.5	2.21	12.6633

6/8/2021	0.5	2.21	12.6633
6/8/2021	0.535	2.3647	13.549731
6/8/2021	0.55	2.431	13.92963
6/8/2021	0.56	2.4752	14.182896
6/8/2021	0.53	2.3426	13.423098
6/8/2021	0.525	2.3205	13.296465
6/8/2021	0.4	1.768	10.13064
6/8/2021	0.28	1.2376	7.091448
6/8/2021	0.25	1.105	6.33165
6/8/2021	0.235	1.0387	5.951751
6/8/2021	0.265	1.1713	6.711549
6/8/2021	0.4	1.768	10.13064
6/8/2021	0.45	1.989	11.39697
6/8/2021	0.48	2.1216	12.156768
6/8/2021	0.51	2.2542	12.916566
6/8/2021	0.52	2.2984	13.169832
6/8/2021	0.52	2.2984	13.169832
6/8/2021	0.535	2.3647	13.549731
6/8/2021	0.55	2.431	13.92963
6/8/2021	0.55	2.431	13.92963
6/9/2021	0.54	2.3868	13.676364
6/9/2021	0.54	2.3868	13.676364
6/9/2021	0.55	2.431	13.92963
6/9/2021	0.56	2.4752	14.182896
6/9/2021	0.56	2.4752	14.182896
6/9/2021	0.56	2.4752	14.182896
6/9/2021	0.56	2.4752	14.182896
6/9/2021	0.56	2.4752	14.182896
6/9/2021	0.57	2.5194	14.436162
6/9/2021	0.59	2.6078	14.942694
6/9/2021	0.305	1.3481	7.724613
6/9/2021	0.3	1.326	7.59798
6/9/2021	0.305	1.3481	7.724613
6/9/2021	0.415	1.8343	10.510539

6/9/2021	0.47	2.0774	11.903502
6/9/2021	0.5	2.21	12.6633
6/9/2021	0.195	0.8619	4.938687
6/9/2021	0.24	1.0608	6.078384
6/9/2021	0.235	1.0387	5.951751
6/9/2021	0.28	1.2376	7.091448
6/9/2021	0.46	2.0332	11.650236
6/9/2021	0.47	2.0774	11.903502
6/9/2021	0.48	2.1216	12.156768
6/9/2021	0.485	2.1437	12.283401
6/10/2021	0.5	2.21	12.6633
6/10/2021	0.5	2.21	12.6633
6/10/2021	0.505	2.2321	12.789933
6/10/2021	0.51	2.2542	12.916566
6/10/2021	0.52	2.2984	13.169832
6/10/2021	0.52	2.2984	13.169832
6/10/2021	0.53	2.3426	13.423098
6/10/2021	0.53	2.3426	13.423098
6/10/2021	0.54	2.3868	13.676364
6/10/2021	0.56	2.4752	14.182896
6/10/2021	0.55	2.431	13.92963
6/10/2021	0.48	2.1216	12.156768
6/10/2021	0.5	2.21	12.6633
6/10/2021	0.52	2.2984	13.169832
6/10/2021	0.62	2.7404	15.702492
6/10/2021	0.23	1.0166	5.825118
6/10/2021	0.135	0.5967	3.419091
6/10/2021	0.08	0.3536	2.026128
6/10/2021	0.19	0.8398	4.812054
6/10/2021	0.36	1.5912	9.117576
6/10/2021	0.41	1.8122	10.383906
6/10/2021	0.45	1.989	11.39697
6/10/2021	0.465	2.0553	11.776869
6/10/2021	0.495	2.1879	12.536667

6/11/2021	0.515	2.2763	13.043199
6/11/2021	0.51	2.2542	12.916566
6/11/2021	0.52	2.2984	13.169832
6/11/2021	0.53	2.3426	13.423098
6/11/2021	0.53	2.3426	13.423098
6/11/2021	0.54	2.3868	13.676364
6/11/2021	0.54	2.3868	13.676364
6/11/2021	0.54	2.3868	13.676364
6/11/2021	0.55	2.431	13.92963
6/11/2021	0.55	2.431	13.92963
6/11/2021	0.56	2.4752	14.182896
6/11/2021	0.57	2.5194	14.436162
6/11/2021	0.59	2.6078	14.942694
6/11/2021	0.595	2.6299	15.069327
6/11/2021	0.59	2.6078	14.942694
6/11/2021	0.6	2.652	15.19596
6/11/2021	0.59	2.6078	14.942694
6/11/2021	0.6	2.652	15.19596
6/11/2021	0.605	2.6741	15.322593
6/11/2021	0.595	2.6299	15.069327
6/11/2021	0.61	2.6962	15.449226
6/11/2021	0.6	2.652	15.19596
6/11/2021	0.6	2.652	15.19596
6/11/2021	0.59	2.6078	14.942694
6/12/2021	0.59	2.6078	14.942694
6/12/2021	0.6	2.652	15.19596
6/12/2021	0.59	2.6078	14.942694
6/12/2021	0.61	2.6962	15.449226
6/12/2021	0.61	2.6962	15.449226
6/12/2021	0.6	2.652	15.19596
6/12/2021	0.61	2.6962	15.449226
6/12/2021	0.6	2.652	15.19596
6/12/2021	0.62	2.7404	15.702492
6/12/2021	0.62	2.7404	15.702492

6/12/2021	0.63	2.7846	15.955758
6/12/2021	0.63	2.7846	15.955758
6/12/2021	0.625	2.7625	15.829125
6/12/2021	0.25	1.105	6.33165
6/12/2021	0.185	0.8177	4.685421
6/12/2021	0.16	0.7072	4.052256
6/12/2021	0.16	0.7072	4.052256
6/12/2021	0.39	1.7238	9.877374
6/12/2021	0.46	2.0332	11.650236
6/12/2021	0.5	2.21	12.6633
6/12/2021	0.51	2.2542	12.916566
6/12/2021	0.53	2.3426	13.423098
6/12/2021	0.54	2.3868	13.676364
6/12/2021	0.56	2.4752	14.182896
6/13/2021	0.57	2.5194	14.436162
6/13/2021	0.57	2.5194	14.436162
6/13/2021	0.58	2.5636	14.689428
6/13/2021	0.57	2.5194	14.436162
6/13/2021	0.58	2.5636	14.689428
6/13/2021	0.58	2.5636	14.689428
6/13/2021	0.59	2.6078	14.942694