Development of An Energy Audit Tool for Commercial Buildings in Bangladesh

Inspiring Excellence

A Thesis

Submitted to the EEE Department of BRAC University

by

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DECLARATION

This is to declare that this thesis named "Development of An Energy Audit Tool for Commercial Buildings in Bangladesh" is submitted by the authors listed for the degree of Bachelor of Science in Electrical and Electronics Engineering to the Department of Electrical of Electronics Engineering under the School of Engineering and Computer Science, BRAC University. We hereby affirm that the research work and result was conducted solely by us and no other. Materials of the study and work found by other researchers have been properly referred and acknowledged. This thesis paper, neither in whole nor in part, has been previously submitted elsewhere for appraisal.

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ABSTRACT

Bangladesh as a developing country, is progressing at a fast pace due to the increase in industries and technologies. However, the country has been facing a severe energy crisis for several years to meet the growing needs. Day by day, the gap between energy demand and supply is ramping up. One effective way to minimize the gap is to conduct energy audit in all sectors in regular basis. Energy audit helps to identify the loss, wastage and provides room for improvements in usage. The aim of our thesis work is to perform energy audit in commercial buildings, to find out the energy loss, provide methods and techniques to compensate the loss and to present an energy audit tool. The energy audit tool has been developed by using MS Excel and Macros and it is named as 'EnergyWise'. 'EnergyWise' uses categorization process which enables the energy auditors to calculate the energy loss for three predominant factors of an energy audit. The data entries are facilitated by user forms. The processed data are then automatically summarized and transferred to the spreadsheets. It also generates graphs and pie charts to point the highest energy consumed sector. The thesis also focuses on the energy saving opportunities and the potentials to reduce early operating cost. This is done by replacing conventional lighting and other important equipment with more energy efficient appliances to increase the efficiency. The result of our study showed that, a substantial amount of energy and money can be conserved if thorough energy audit is practiced and executed.

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ABBREVIATIONS

ANN	Artificial Neural Network
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BLDC	Brushless Direct Current
BNBC	Bangladesh National Building Code
BTU	British Thermal Unit
CFL	Compact Fluorescent Lamp
CFL	Compact Fluorescent light
CFM	Cubic Feet per Minute
CRT	Cathode Ray Tube
EER	Energy Efficiency Ratio
EPA	Energy Power Agency
EPB	Energy Performance of Buildings
EPBD	Energy Performance of Buildings Directive
ERBM	Energy Rating Mark
ESCO	Energy Services Companies
EU	European Union
FL	Fluorescent Lamps
FL	Fluorescent light
HER	Heat Energy Rating
HFO	Heavy Fuel Oils
HID	High Intensity discharge lamp
HL	Halogen Lamp
HPSL	High Pressure Sodium lamp
HVAC	Heating Ventilation Air Conditioner
kWh	Kilo Watt Hour
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LPSL	Low Pressure Sodium Lamp
LRV	Light Reflection Value
NBN	Bureau voorNormalisatie
SAP	Standard Assessment Procedure
SEER	Seasonal Energy Efficiency Ratio
TCF	Trillion Cubic Feet
VBA	Visual Basic Applications
VBE	Visual Basic Editor

1. INTRODUCTION

Electrical energy is one of the vital means for modern life and plays a crucial role as an infrastructural input for economic development of a country. In all economic sectors, households and commercial, demand for electrical energy is extensive. Global consumption of electrical energy has already reached to 4185.1 tons of oil and 3030.4 tons of natural gas by 2013 which is 1.4% more than the year 2012 [1]. This indicates that mostly our energy is supplied by fossil fuels or from crude oils, both of them are non-renewable. Although many alternatives such as-wind, solar, geothermal, tidal, wave and biomass energy concepts have developed as renewable source; no sustainable solution to reduce dependency on fossil fuels has developed yet!

In Bangladesh, annual peak demand of power has increased to 10806 MW [2]. According to Bangladesh Power Development Board, the installed power generation capacity is about 11532 MW, out of which 250 MW is generated by coal-fired power plants,7278 MW from thermal or gas power plants, 3274 MW from HFO and HFD, 230 MW from hydro power stations and 500 MW are imported as of July 2015 [3]. Regardless of this, Bangladesh still suffers from major shortage of electricity generation to satisfy the daily demand.

Bangladesh, the seventh-largest producer of natural gas in Asia [4], is greatly dependent upon natural gas for its power generation. Estimation shows that, it has reserve of 15 Tcf to meet the immediate future but not to meet the long term necessitate. International energy experts suggested that, the reserve may last for nearly next two decades and after that Bangladesh will have to look for substitutes in terms of non-renewable sources. [5]

During the last six years, the electricity users in the country has elevated from 47% to 64% and by 2019, the number is expected to outreach to 90%. It is anticipated that by 2040, the electricity demand will extend to 63600 MW with an annual increase of 8% [2]. In a June 2006 report, it was stated that for year 2004-2005, Bangladesh agricultural and industrial demand accounted for nearly 48%, domestic purpose accounted for nearly 42.4%, commercial purposes accounted for nearly 7.63% and others miscellaneous activities accounted for the rest [6].

Thus, energy conservation and improvement of efficiency can be the cheapest and fastest solution to overcome all the energy demands. Energy conservation means reduction in energy usage by less energy service and energy efficient means less energy for a constant output. Although the two concepts differ from each other but can me merged together by Energy Audit. Energy Audit is an assessment, survey and analysis of energy flows for energy conservation in a building, to reduce the amount of energy input into the system without having adverse effects on output.

1.1 Energy Audit Definition

According to the Energy Conservation Act, 2001 of India, the term Energy Audit is defined as "the verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption" [7]. In Bangladesh, the energy efficiency and conservation rules were passed in 22nd October, 2012 from the Ministry of Power, Energy and Mineral Resources. The draft illustrates on energy audit and conservation on its section 4, clearly stating that all the commercial buildings must comply the rules and use efficient, and cost-effective life cycle appliances following Bangladesh National Building Code (BNBC) [8]. Although rules on energy audits were from 2012, comprehensive studies have not been published accordingly in Bangladesh.

1.2 Literature Review

The study of energy audit has been an area of interest for many electrical engineers and building specialists for long time. However, the pioneering work got started on 1973 [9] and flourished on later years due to energy crisis.

European Union Directive Building Conduct

On 16th December, 2002 European Union Directive on Energy Performance on Buildings was proposed (EPBD). Later, this became major areas for future studies on energy performance on buildings. The main goal of EPBD was to improve the energy performances on the building considering indoor and outdoor conditions. EPBD mentioned some requirement such as-an outline of integrated energy performance of a building, minimum use of appliances, minimum requirements of energy performance in major buildings that are subjected to renovation, regular inspection of boilers and heaters also provide energy efficiency certificates for the buildings. One salient up-turn of EPBD is the inevitable national energy performance calculation procedure on buildings, for both new and existing buildings. Performance analysis is followed by improvement techniques, certification and assessment on HVAC installations. [10]

After the release of EU directive on performance of buildings; in terms of energy, many countries followed the rules such as UK, Denmark, Ireland, Netherlands, France, Belgium, and Germany. [11]

Since 1995, for energy conservation, Standard Assessment Procedure (SAP) and building regulations-Part L (a section which states energy conservation of houses) are obligatory for new buildings in United Kingdom. SAP is mainly concerned on annual cost of heating, lighting, building envelope insulation, efficiency of heating and domestic hot water system and the fuel prices affect the SAP rating, which ranges from 1-100. SAP does not include location, consumption on domestic appliances and does not suggest for making buildings more energy efficient. Statistics shows that, applying SAP on 17,000 houses per year, almost three million buildings can be audited [12].

In Europe, energy audit and the rating assessment were first initiated by Denmark and they have provided a benchmark for other states to continue. They introduced a mandatory energy analysis in 1985 and "Act on Promotion of Energy and Water Conservation in Buildings" is divulged in 1996, which officially commissioned on 1997. This act promoted different types of audit, EM/EK and certifications on mainly industrial buildings. Around 45,000 to 50,000 audits are performed per year, and energy consumption is estimated to drop near 20%, for 70% single family residence [12].

In 1997 and later on in 1992, HER (Heat Energy Rating) and ERBM (Energy Rating Mark) were introduced in Ireland and was compulsory for all newly constructed buildings. ERBM is extensively used by fuel suppliers and house builders to provide low energy consumption in the buildings. It accounts for annual CO_2 emission and consumption of energy while considering the outputs of HVAC appliances that are in the buildings. It also provides suggestion and improvement on building envelope, heating process and also estimates savings. [13]

The current regulation for the buildings of Netherlands is EPA (Energy Prestatie Advise- 'Energy Performance Study'). EPB (Standard Energy Performance) is introduced for new buildings. This encourages on energy conservations and savings. It focuses on energy consumption for heating (hot water), lighting system, water pumps and fans. [12]

For new non-industrial buildings, Decree 2000-1153 is set-up by the Ministry of housing and Transport of France so that all the new buildings comply with regulations. While the buildings follow the rules and regulations, two methods are introduced for calculation purpose. First one is a precise, intricate process, developed for expertise and the second one is for amateur, non-experts or for common people. [14]

Since 1987, NBN B62-002 and NBN B62-004 regulations have commenced in Belgium and are obligatory for all buildings in residential areas. It is also compulsory for non-industrial in some region such as Brussels and Walloon. They are mainly concerned with the heat transfer coefficient for a building, and the legislation limited to $0.55W/m^2$ degree Celsius. However, the legislation varies for the newly built non- industrial buildings. [15]

From 1982, Germany has started to work on energy efficiency and a legislation named "Energy Saving Decree" was endorsed in the year 2001. The two important consequences from this legislation was- yearly energy consumption limited to 7 liters of oil equivalent fuel for every m^2 and mandatory replacement of old boilers. The latter one started from 1978. [12]

Energy Conduct Studies

Since the concept developed around 1970[9], many surveys and assessment has been conducted to find different parametric solutions.

According to Mungwititikul and Mohanty (1996), an energy audit on the consumption of office, performance pattern revealed that 25% of electricity can be saved by controlling sleep modes or idle times of the office appliances [16]. As per Fumo (2009), a study was conducted in the different cities of USA and was simulated by a tool EnergyPlus. The aggregate heating and cooling was obtained from the EnergyPlus and the result was scaled to primary energy source for each city. The different calculations from the power generation unit showed that using primary energy source results in good proportion of energy saving and also it is economically feasible [17]. Aktacir (2008), investigated on air-conditioners and various operation pattern for different designs. Thus, a sample building was chosen somewhere near Adana (a geographically hot region) for developing cooling loads relationships with capacity of air conditioners. Using the simplified version of ASHRAE heat balance method the results were concluded that outdoor conditions are very important for the size selection of air conditioners [18]. Also as per Di Stefano (2000), a study was conducted on lighting system at Melbourne University, Australia. The study replaced conventional lights by 1.2 meter of fluorescent with different ballast. The study showed that up to 64% energy can be saved and carbon dioxide emissions could be reduced to 10%. However, high cost installments of light and ballast were the main problem to deal with and much further investigations are required [19]. Mendis and Perara, studied energy conservation measures for a textile- industrial buildings. The detailed audit was conducted on Sri Lanka and the paper proposed some approach for savings in the consumption of electrical equipment [20]. Another study was carried in the province of China, Jilin which found out the five effective solutions to minimize the energy consumption in China by enhancing supervision and executive of energy consumption and curtailing the energy wastage [21]. Wang, Huang and Cao, audited commercial buildings in Shanghai presented the findings of energy consumption, focusing mainly on electrical equipment such as air conditioner, elevators and also on lighting system. According to their study, climate and occupancy rate were the predominant factors for total energy consumption. They also deduced that air conditioner consumes around 45% and lighting system consumes 10% of the net energy usage [22]. Singh, conducted a case study to reduce the lighting consumption by formulation for load management in industries. There is ample scope to save in lighting luminaries and gears besides the proper operational practices. The paper suggested that incorporating energy audit can actually boost the plant efficiency and scale down the energy wastage [23].Chhetri, Wangchuk and Sastry audited the residential buildings in Bhutan and analyzed the energy patterns in the houses of Phuentsholing, a place in Bhutan. Proper measures and recommendations can be effective for energy efficiency for lowering bills [24].

In USA, Mauriello, Norooz and Froehlich studied that 41% of their primary energy is consumed by the building sectors. The paper presented the idea of using thermography-infrared (IR cameras) to uncover the thermal defects and inspect building efficiencies. Two cases were studied: one with five automated with 10 professional auditors and other one included a case study of a simple residential audit. The paper suggested incorporating automated thermography tool designers robots and computer science for energy analysis [25]. An evaluation study conducted in Germany by Gruber and his team members stated that, by surveying online audited companies, regional partners and consultants of energy auditing, they have found that there is a great potential of saving energy by energy assessment. Estimation showed in their study that about 1.4TWh energy can be saved, 470,000 tons of CO_2 can be reduced with 480 million Euros and energy savings cost could be of 80 million Euros if energy audit is performed properly [26]. Another study was conducted on energy efficiency measures of large scale industries and large service sectors of different categories of company in Germany. The paper deduced reduction in greenhouse gases, energy saving potentials and economic profitability by introducing effective management system, automatic and non-automatic switch on and off of unused electrical equipment, staff trainings and guidelines[27]. A joint study of Switzerland and Germany for Energy Efficiency networks showed that, auditing can double their energy efficiencies and improve existing energy networks [28]. Pollard and Stocklein, from Auckland, New Zealand investigated the relationship between indoor temperature level of a building and external environmental temperature of a building for energy flows in residential buildings. A trained neural network on a selection of data and the network's predictions were matched with temperature that was measured [29]. Aue and Pierce from China uncovered the savings by energy auditing in a paper mill. Several comprehensive steps were followed in their study and an estimation of 4,000 pounds savings per hour steam, improvements in sheet quality and machine efficiency was observed. If energy auditing is done in such type of mills then, $100,000 to over $1 million per year can be saved. Machine efficiency is also expected to rise by 20% [30].

Another study in China showed one of the technical instruments of energy saving in energy audit. A steel plant of China was chosen as a sample site and analysis was done for energy consumption and substantial amount of energy was saved by their activities for example- in management sector and using intelligent methods [31].Crawley et al. studied twenty simulation programs which are commonly used, for example-Blast, EnergyPlus, IES, Ecotect, DOE and compared their operating ability with their features. General feature includes building envelope treatment, infiltration and ventilation rates, day lighting, zone loads, electrical equipment, HVAC system and environmental emissions and many factors were discussed [32]. Crognati et al, focused on the impact of internal temperature conditions of a building with a simulation performance. An initial set of test room was chosen and simulation was done by EnergyPlus for both heating and cooling conditions. The important result of their paper was using an optimum and operative temperature instead of air temperature for the controlling purpose [33].

Conceicao and Lucio investigated the thermal performance of a school building in Portugal. The study was conducted in the exposure of high solar radiation. EnergyPlus was used to simulate the data from the buildings and comfort and uncomfortable temperature zones were identified. The study proposed the improvements in the thermal comfort [34]. In Greece, multi apartment and buildings which consume different fuels were identified. The results after simulations were obtained in terms of primary energy, CO_2 emission and cost [35]. To establish Building energy code for all type of building, Becker and Goldberger performed analysis on energy efficiency thermal comfort internal air quality problems. School buildings were chosen as a sample site to achieve thermal comfort in summer season. Simulations were done by considering different important parameter such as ventilation and infiltration rate, climate control, location and orientation of a building, occupancy period, lighting control, internal gain and building construction feature. Outcomes of their study were up to 30% to 18% of energy can be saved by having proper installed ventilation schemes in northern and southern oriented buildings respectively [36]. A simulation study using TRNSYS software in typical houses provided economic viability after retrofit consideration were taken into account. The result of this study calculated the payback periods of roof insulations for hot climates and solar shadings. An estimation in the study showed payback period for solar shadings were 3-5 years whereas roof insulation were up to 10 years[37].To determine the optimum thickness of an insulation detailed study was conducted in Turkey by Ucar and Balo. The optimum thickness was found to be 1-7 cm with savings of $47 per square meter [38]. Lukman et al. assessed the thermal performance of the University of Maribor which considered the construction, heating, lighting, water consumption and maintenance of a building. In order to reduce environmental effects conventional boilers were suggested to replace by wood and solar heating boilers which would down the greenhouse gas emission by 82% [39]. Coskun and Oktay studied energy audit on Engineering Faculty of Balikesir University. They suggested three measures, which are-external insulation on building envelope, higher efficient boilers and natural lighting system can reduce CO_2 by 82 tons and deduced that energy saving potential can be up to 32% [40]. A simple artificial network, AAN and Simulation software EnergyPlus was used to predict energy consumption considering physical properties of building. Sample building for the observation was an office building. Error occurred due to electrical equipment usage, occupancy and lighting levels. The observation deduced that both AAN and EnergyPlus can be a good way to predict energy demand and usage if proper calibration can be done [41].

1.3 Thesis Objective

The objective of this paper is to study the energy flows in commercial buildings and reduce the usage in most efficient way to have constant desired output. However, due to innumerable limitations and shortcomings of instruments, our comprehensive study has been confined to some major areas which will be discussed in the following chapters.

1.4 Thesis Organization

In the first chapter, we have only discussed the scenarios of overall energy crisis and also defined energy audit and subsequent energy studies. The second chapter of our thesis paper will mainly discuss the significance of energy audit and the basic steps to perform an energy audit for a building. Chapter three entirely focuses on our energy audit tool and explains the working principle. The fourth chapter is based on the representation of data for BRAC

University, after energy audit is performed. The fifth chapter discusses all the possible retrofits and savings that can be achieved after a complete energy audit. The last chapter is the conclusion part where further research topics and developments are stated.

2. SIGNIFICANCE OF ENERGY AUDIT

Energy Audit is considered to be one of the fundamental and necessary components to save energy bills and to conserve national energy resources of a country. So, a country like Bangladesh, which has a population over 170 million and greatly relies upon natural resources for power generation; energy audit can be an effective tool to intuit and accomplish a comprehensive energy management program.

2.1 Energy Auditing Basics

Energy audits are important tools to reduce the operational cost of electrical appliances, to cut down the electrical bill and hence save our money and electricity. Quality of energy audit is solely depended on the cost and the experience of the auditors. Simple energy audit provides building owner with a list of no cost or low cost recommendation which can be implemented by operations and maintenance staff. Complex energy audit is typically a part of the larger energy management program. Energy auditing services are offered by energy services companies (ESCOs), energy consultants and engineering firms. In order to conduct the auditing the whole process is divided into three levels. They are as follows:

Level 1: Site Assessment or Preliminary or Walk-Through Audit

Walk-through audit is physical site inspection of the building. At this level the auditors find the areas where energy is being properly used and the areas where the savings opportunities can be applied. The activities include an assessment of electric bill, collections of necessary data and minimal interviews with site operating personnel. Typically, major problems area will be uncovered during this type of audit.

Level 2: Standard or General Energy Audit

Standard audit is the expansion of preliminary audit. Standard audits include an in-depth analysis of energy cost, energy usage, review and analysis of equipment, systems and building characteristics. In depth, interviews are conducted with facility operating personnel to understand the major energy consuming system as well as variations in daily and annual energy consumption and demand. Utility bills of 12 to 36 months are collected to evaluate the facility demand rate structure and energy usage profile. This type of audit is helpful to find the energy and cost savings for facilities of the building by using energy engineering calculations based on the information taken from the site.

Level 3: Computer Simulation or Detailed Energy Audit

Detailed energy audit is also called comprehensive audit or investment grader audit. It estimates the energy input for different processes and it is a collection of past data on specific energy consumption. It provides a dynamic model of energy use characteristics of both the existing facility and all energy conservation measures identified. In order to perform this activity, the auditors need to develop computer simulation software that will predict year round energy use for weather and other variables. To compare the operating savings for proposed measures a realistic baseline of actual utility is determined against which comparison is made. Finally the auditors need to prepare a professional energy audit report, including all the data, savings and a list of recommendations to save the energy.

From the above three levels, the auditing phases and activities can be summarized in Table 2.1:

Table 2.1: Audit Phase

Auditing Level	**Activities**
Level 1:Walk-Through Audit	1.Collect and analyze utility data 2.Assess energy efficiency improvement potential 3.Visually inspect building and key systems
Level 2: Standard Audit	1.Interview building staff 2.Evaluate utility and site data 3.Analyze energy and cost savings

Auditing Level	Activities
Level 3: Detailed Energy Audit	1.Develop simulation tool 2.Summarize findings 3.Present recommendations 4.Prepare professional report

2.2 Survey Instrumentation

Auditors need some instruments to collect the data to identify and analyze the present energy consumption and to find the approximate saving from the analysis. The common things required to find for a commercial building are the area of windows and rooms, leakage, air flow through leakage, light intensity, temperature and heat flow, liquid flow, gas flow etc.

Commonly used instruments are mentioned below.

Lux Meter

It comprises of a photocell which measures the output lights and expresses the measurement as lux to find the illumination level of light in a room.

Leak Detectors

If there is any leaks in ceiling or walls or doors, compressed air of air conditioner will go outside the room through the leaks resulting in losses of energy. Leak detectors are used to find out the leaks which are impossible to identify with human eyes.

Water Flow Meter

The meter consists of a transmitter and receiver situated on the opposite side of the pipe which gives the reading of the water or other fluid that flows directly using the Doppler Effect.

Infrared Thermometer

This instrument is used to measure the surface temperature of a hot body e.g. walls to find out the heat transfer through the walls. It shows the direct temperature reading of any heat source.

Anemometer

During energy audit of commercial buildings, anemometer is used to find the velocity and pressure of air that passes through the leaks.

In addition to the instruments specified above there may be other instruments like pyrite, fuel efficiency monitor, combustion analyzer etc. depending on the complexity of the auditing. Insulated hand gloves and aprons are used for additional safety.

Due to many limitations and lack of availability of instruments we only used, Lux-meter, Infrared Thermometer and measuring tapes for our audit purpose.

2.3 Lighting Audit

Although per capita energy consumption in Bangladesh is one of the lowest in the world (321 kWh), only 62% of the total population has the access to electricity [42]. Lighting takes a larger portion of generated power. Lighting consumes about 25% to 35% of the total generated power in the world [43]. For residential buildings and commercial buildings, the occupied energy for lighting is 15% and 30% respectively [43]. Nowadays, people prefer Fluorescent Lamps (FLs) and Compact Fluorescent Lamp (CFLs) to Incandescent Lamps due to three to four times higher efficiency and two to three times higher lifetime for getting same luminous level [43]. FLs and CFLs are discharged lamps and they require ballast. Ballast generates high initial voltage across lamp tube for required lamp ignition and to limit the lamp current [44]. Magnetic ballast is bulky for using iron-core transformer and it causes extra heat losses across the ballast [44]. Electronic ballast is much more efficient than Magnetic ballast though lifetime of Electronic ballast is lower than the Magnetic ballast [45]. By energy auditing auditors can find the ways for efficient use of electricity. Auditors can easily come up with some fruitful recommendations based on the findings during energy audit. Lighting energy usage can be reduced by 75% to 90% compared to the conventional practice [46]. This will help us to save our cost and electrical energy. It will also enlarge the community of people getting access in electricity.

2.4 Electrical Audit

It is essential to audit the electrical equipment which means those equipment that we use in our daily life and which are greatly related to the electrical energy consumption. Lights, fan includes ceiling fan and stand fan, computer, air conditioner, refrigerator, elevators etc. are the common electrical appliances used in any type of building such as- in residential, commercials and in industries. In our work we have separated the lighting section from the electrical equipment and we have audited it differently than the electrical equipment one. So, electrical equipment audit means auditing any equipment powered by the electricity or electrical appliances. Some factor which influence these audits are number of equipment, wattage ratings and operation time.

It is definite that the electrical equipment will consume more electricity than other two factors which are- lighting and envelope. As the electrical equipment are the reason of most of our electricity bills, there is more opportunity for us to save electricity from this portion of the energy audit. So, it is obvious that the electrical equipment audit is the most significant part of the energy audit.

Nowadays, our life is completely depended upon the latest technologies and human effort reducing equipment. All the latest technologies, gadgets and equipment consume electricity. So, in short we are depending on the electricity for our daily life. In offices and industries there are more electricity consuming equipment than the office furniture. This increasing equipment results in increase in the amount of energy consumption. This is one of the primary reason to initiate energy saving and thus electrical equipment auditing is very necessary.

Sometimes the appliances we use in our buildings consume extra electricity which leads to the wastage of electrical energy, adding more to energy bills. While electrical appliances get older it takes much energy than it used to at the start. As a result, the consumer does not get the desired output. Instead, they get the amplified electricity bills. By electrical equipment audit, we can find out the areas where we need to focus and improve the quality of the equipment so that the owners get benefit from the electrical equipment and save the energy bill at the same time.

Humans tend to commit mistake and also to be forgetful. Sometimes, the electrical equipment are switched on for long time and we forget to switch off even after we are done with the use. The electricity bills depend on how long we use the appliances. So we have to have self-conscious, so that we can use the appliances when it is necessary. Even some specified appliances need to be well maintained to reduce the operational hour and how to achieve this are discussed later.

Moreover, one of the burning and most widely discussed topic is global warming and CO_2 emission. Unfortunately, the appliances we use emit CO_2 and other harmful gasses. In addition to that, if the appliances are not maintained properly then there is a chance of getting shock as equipment possesses some internal wear and tear. Thus, to reduce the impact of this harmful gas and to make our home or workplace safer and better, electrical equipment audit is very essential.

2.5 Envelope Audit

The building envelope is the boundary between the indoor interior and the outdoor of a building. There are some components of the building envelope which are building's roof, sub floor, ceiling, exterior doors, windows and exterior walls. Building's envelope is one the most important part of our audit because we can save energy by maintaining proper and ideal envelope from a building which is good for the owner's wallet. Energy loss through the building envelope is highly variable and depends on numerous factors, such as building age and type, climate, construction technique, building orientation and geographical location. [47]

Building envelope is not directly related to electricity bill or energy consumption but it plays a vital role for lights and the cooling equipment to work hard. These factors are added in the electricity bills and we have to pay some unnecessary money from our hard worked earnings. About 40% of worldwide energy consumption is related to building [48]. As a matter of great regret, most of the energy losses related to the envelope are invisible to us. By envelope audit, we can find out the cracks and gaps that cause us to pay more.

Building orientation and geographical location is the most important factor in case of envelope audit. The heating and cooling capability of the building is the prime factor for our comfort. We invest a lot of money into our heating and cooling appliances, but still maximum efficiency cannot be obtained. One of the biggest reasons behind this is- the roof, walls surrounded the room, windows and the doors are not well insulated or the envelope of the building is not appropriate to get the desired output and ultimately there is a loss of energy. The solution of this problem can be founded by envelope audit.

As previously said, building envelope is the reason for our lights to work hard. If the envelope of the building is not efficient then we have to switch on the lights all the time. Not only that, number of lights required in a building is also depended on building envelope, as the reflection of the walls and ceilings greatly affect the intensity of the lights. So, envelope audit can give us good idea about our walls, ceilings, painting of the walls, windows and doors if they are feasible for our desired output or not and at the same time, whether we can save money from the lighting bills or not.

Another factor of the envelope audit is that, sometimes we pay much more bills as more electricity is consumed. For example, in most of the offices or industries we use air-conditioners, which are much larger in size compared to the size of the room or vice versa. In both cases we are losing some valuable energy and extra bills are needed to pay. In case of larger cooling system compared to the operational space, the cooling system takes some extra energy which was not required and in the case of smaller cooling system compared to the operational space, the cooling system have to work more time to cool down the space. As a result, the operation time of the cooling system increases and the energy is lost. In addition to that, there are some other factors for cooling or heating depending upon the weather, where we can save energy which is discussed in the later part of this paper. Thus, it is clear to us the building envelope audit has much significance to save the energy consumption as well as the energy bills.

3. DEVELOPMENT OF AN ENERGY AUDIT TOOL

In order to carry out a complete energy audit for a building we need to follow the previously mentioned steps in the last chapter. In addition to this, several questionnaires for energy consumption, production rate, and list of energy sources are needed to be prepared. Then a suitable site should be chosen, to perform audits. In this study, we have chosen only commercial buildings and shopping malls as a sample site. Required data should be collected from site visit and corresponding energy losses and calculation of energy balance and energy flows for a building should be done. Only after the calculations, the energy efficiency and conservation potential sectors can be identified. Since, finding energy loss is a predominant factor for further improvements and bill reduction, we have developed a tool to compute the losses in order to avoid laborious hand calculations.

3.1 Programming Language

Energy auditing is a developing concept in our country and our main focus was to introduce this topic of energy saving to the general people. Moreover, we have audited the commercial buildings and shopping malls, where the decision makers are from the business related field. Often those people tend to be guided by illegal means of saving. Keeping the users in mind, we have selected a software, which is readily available in every computer and any basic computer skilled users can operate it.

The software we used is Microsoft Excel which comes with the Microsoft Office Software. This software is worldwide popular software and is generally used for accounting purpose. For our study purpose, this software was suitable since data or graphs can be easily generated and data analysis can be easily dealt with.

The programming language related to Microsoft excel is VBA. VBA means Visual Basic Applications. VBA has Visual Basic Editor (VBE) in excel. To communicate with excel we need Visual Basic Editor Program.

3.2 Introduction to the Tool and User Forms

The name of our developed tool is “EnergyWise”. We want people to use energy or electricity wisely, as saving electricity is possible if we use the electricity or electrical equipment wisely. Again, saving electricity reduces the electricity bills and save money. It is a wise decision to save valuable earnings by saving unnecessary energy waste. Thus, only wise people would choose to use electricity wisely or use “EnergyWise”

As our audit data collection is divided into three sectors we decided to calculate the data according to those three sectors: Lighting Audit, Electrical Equipment Audit and Envelope Audit.

To introduce the tool, we want show all the tabs and user forms first. Figure 3.1 shows the instruction page, which is the first tab of our tool.

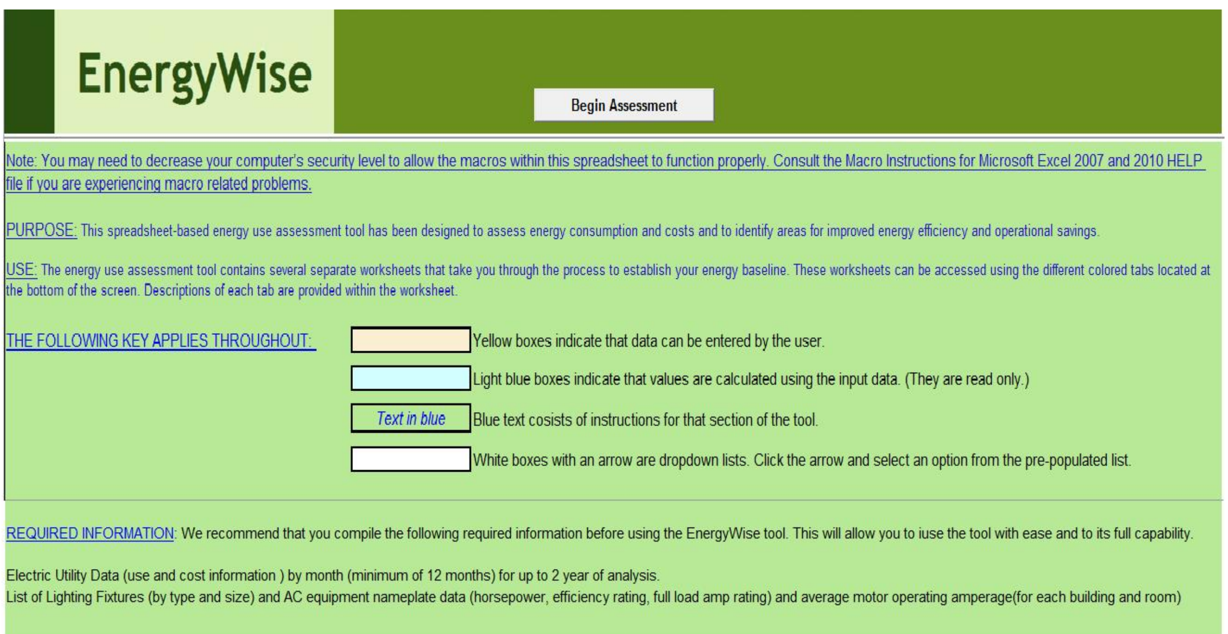


Figure 3.1: Instruction Page

In this tab, we can find some instruction how to use the tool. This tab will make the user to understand the tool and the user can easily use the tool by reading the instructions. By clicking “Begin Assessment” button we can move to the next tab where the actual data entry begins, that means it will move to the next tab. Figure 3.2 shows us the next tab, which is the background information and electricity bill page.

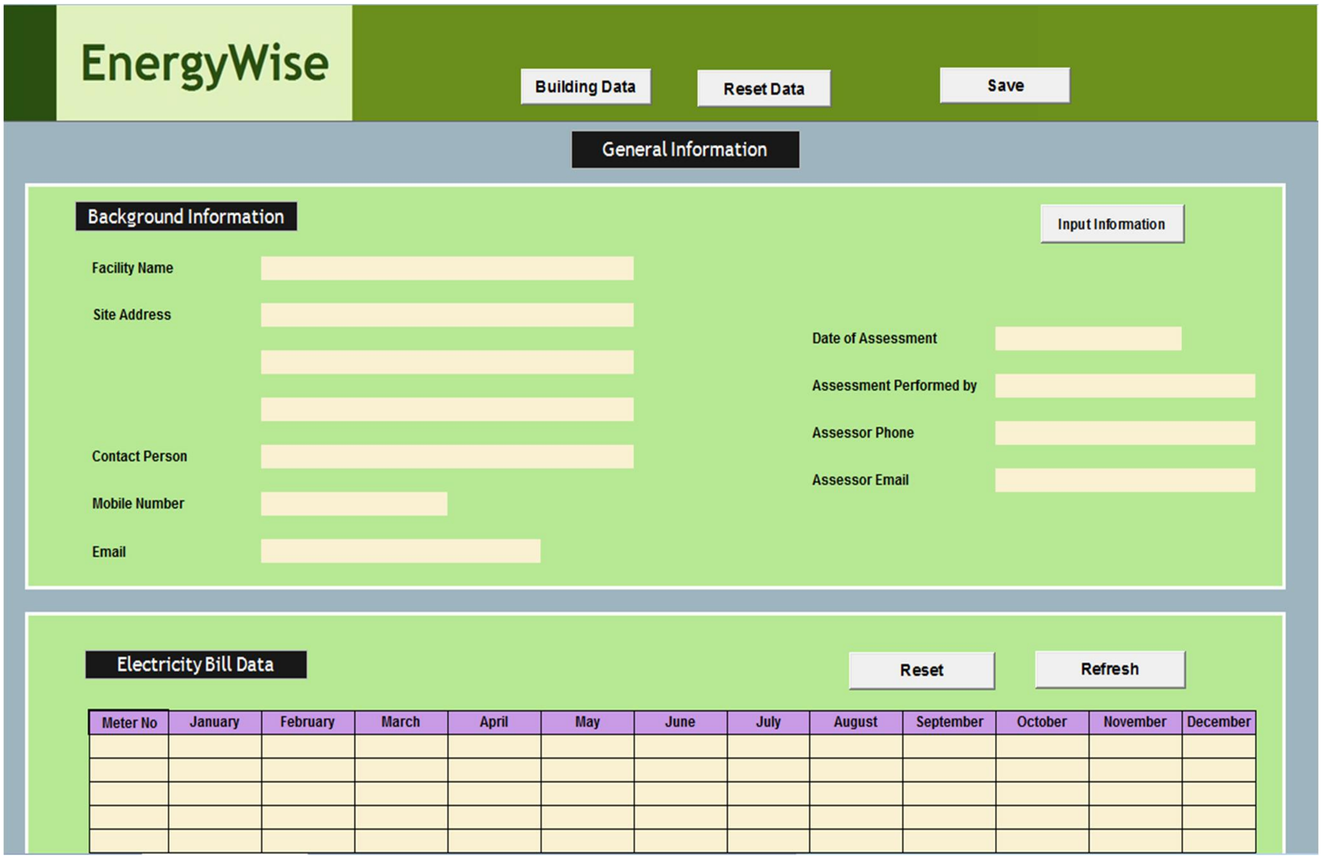


Figure 3.2: Background Information and Electricity Bill page

In this second tab, we can find the general information about the building audited, the auditors and the electricity bill of the audited building. There are three button on the top of the tab: Building Data, Reset Data and Save. Reset Data button will clear all the data put by the user in this tab. On the other hand, "Save" button will save all the work.

For calculation, the data entry is very important. Data input section is designed in such a way that user can compute the data easily in excel. We used User form option in the VBE so that the user does not get confused during data entry. Figure: 3.3 shows the data entry form, which will appear after clicking "Building Data" button in the second tab.

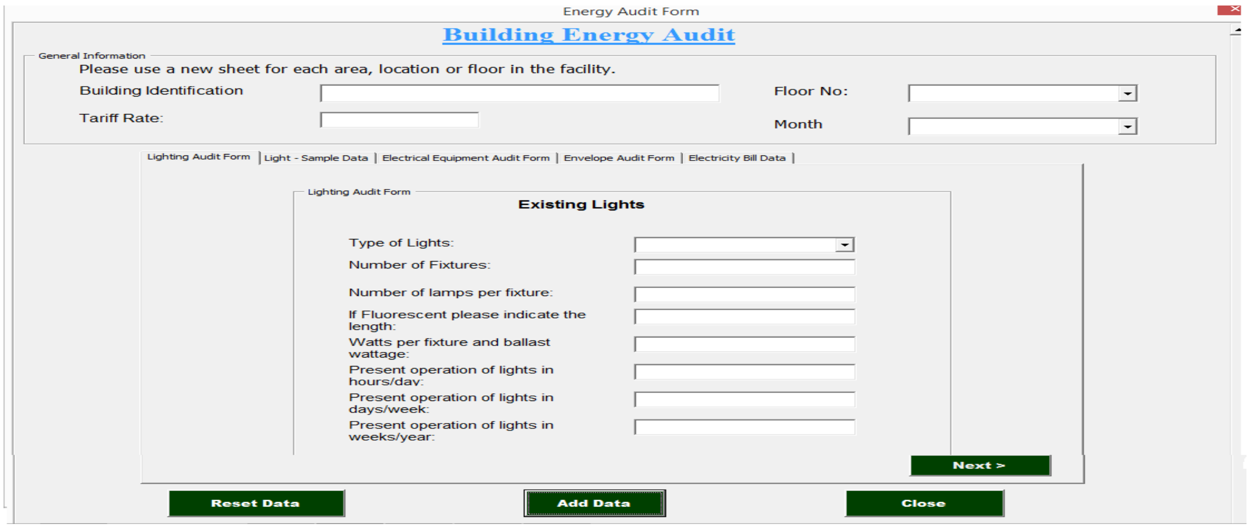


Figure 3.3: General and Lighting Data Entry Form

In this form, there are two parts: General Identification and Tabs of Forms. In the general identification part, we have to give the data about the building is audited, floor no, tariff rate and the month of audit. In the tabs part of the form, we can see there are different tabs too. Different tabs are used for different types of data. In the first tab, figure 3.3 shows us the lighting audit form, where we have to give input about the lights types, number of fixtures and lights, length of the fluorescent lights, watts of the fixtures and the lights or the ballast and operation time of the lights. In the second tab of the form, we can get the lights sample data tab, shown in the figure 3.4.

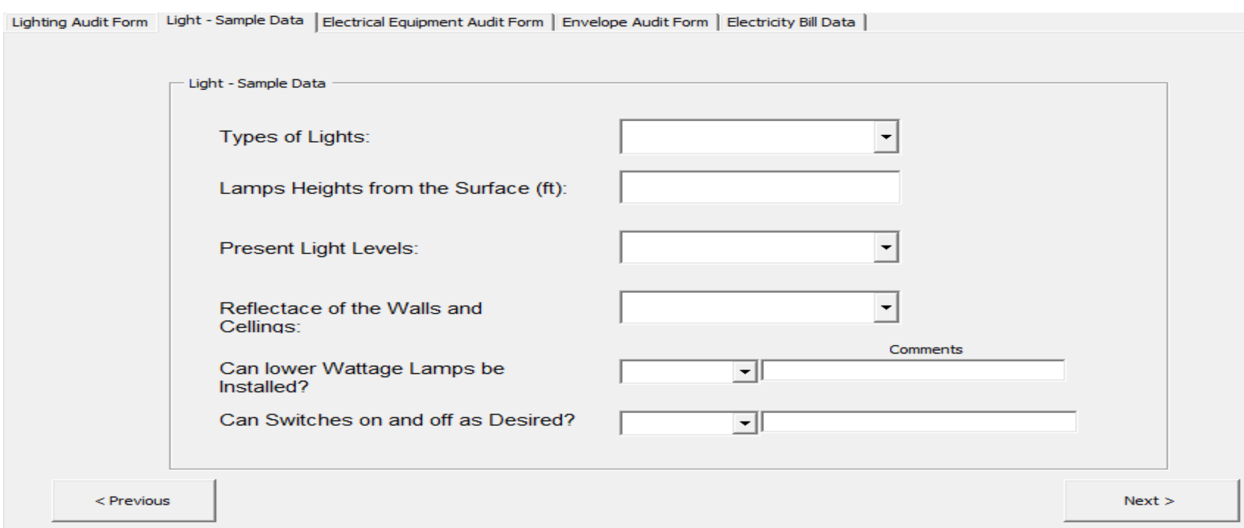


Figure 3.4: EnergyWise Light Sample Form

In this form, we have to give the height of the surface from the lights, present light level, reflectance of the walls and ceilings. Depending on the auditor's experience the data should be taken. Next tab is shown in the figure 3.5.

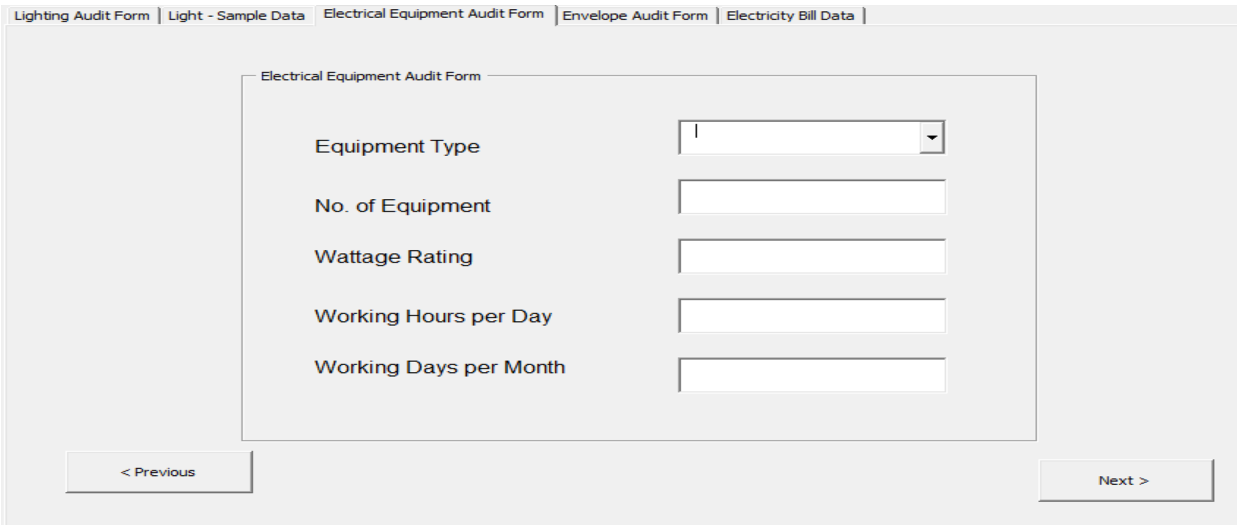


Figure 3.5: EnergyWise Electrical Equipment Audit Form

This form is called Electrical Equipment Audit form, where we have to give data about the electrical equipment that are used in the building, number of the equipment, wattage of the equipment and the operational time. Next tab is called Envelope Audit form, shown in figure 3.6.

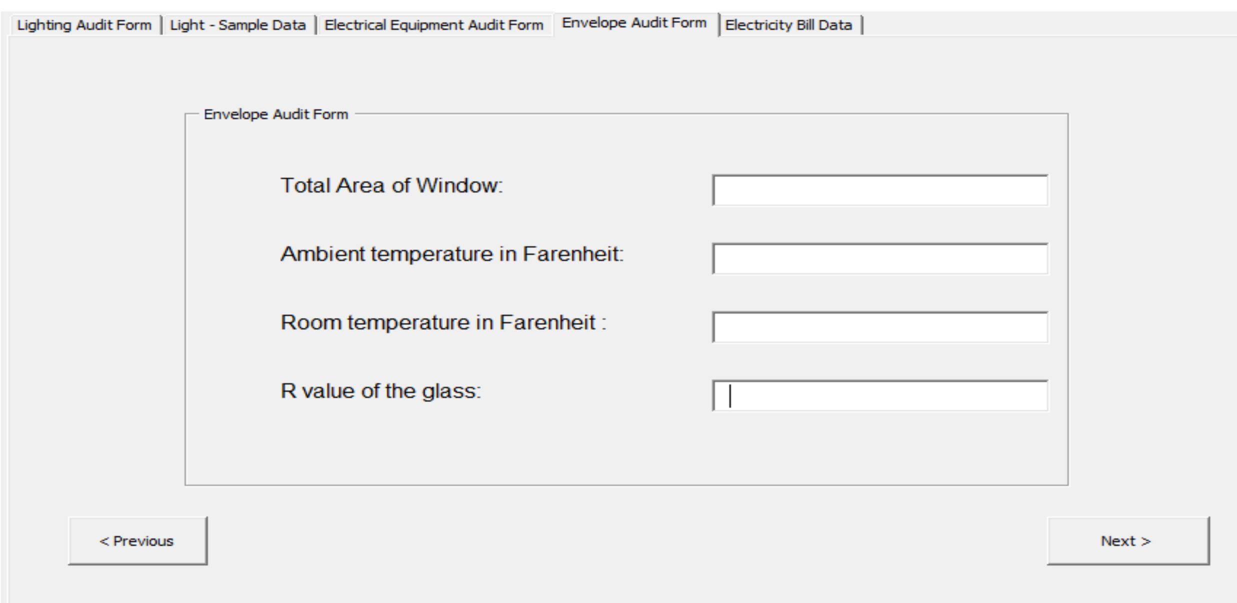


Figure 3.6: EnergyWise Envelope Audit Form

Building leakage losses will be calculated from this form's data. So, the data that the form will take is total area of the window in feet per meter square, ambient and room temperature in degree Celsius and 'R' value of the glass. The last tab of the form is Electricity Bill Data form, shown in figure 3.7.

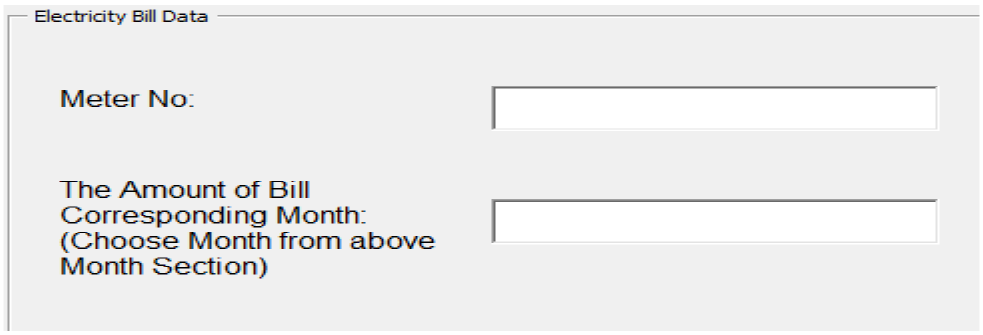


Figure 3.7: EnergyWise Electricity Bill Data Form

The Electricity Bill Data form will take the data about the meter number which is provided in the monthly electricity bill of the audited building and the amount of monthly bill for particular building. When we enter data in this form, it will appear on the second tab's lower portion of the tool, which you can see on the figure 3.2. Next, moving to the general information part, there is a button called "Input Information" which will put the information of the survey related background information. Although it is not related to the energy bills, it will help us to keep the record of the buildings that we surveyed. The "Input Information" form is given in the figure 3.8.

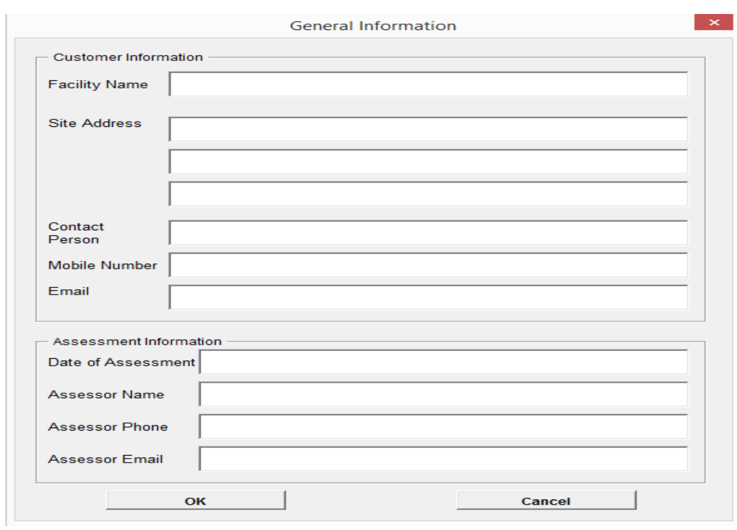


Figure 3.8: EnergyWise General Information Form

Now moving to the third tab of the tool, which is Lighting Audit tab. The tab is shown in the figure 3.9.

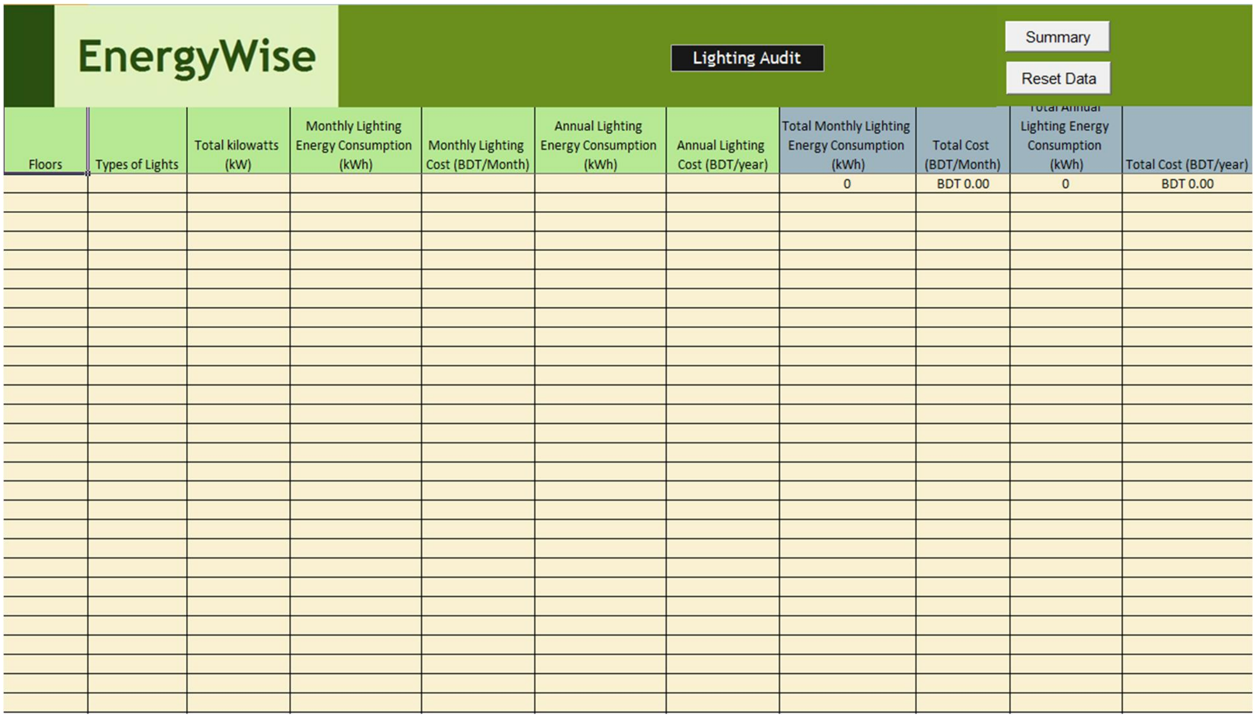


Figure 3.9: Lighting Audit Tab.

From this tab, we can see our total monthly lighting estimated cost as well as the annual lighting estimated cost. There are also "Summary" and "Reset Data" button. "Reset Data" button will simply clear all the data in this tab. "Summary" button will take us to another tab where we can see some charts of the lighting information which will be discussed later. Moving to the next tab, shown in the figure 3.10.

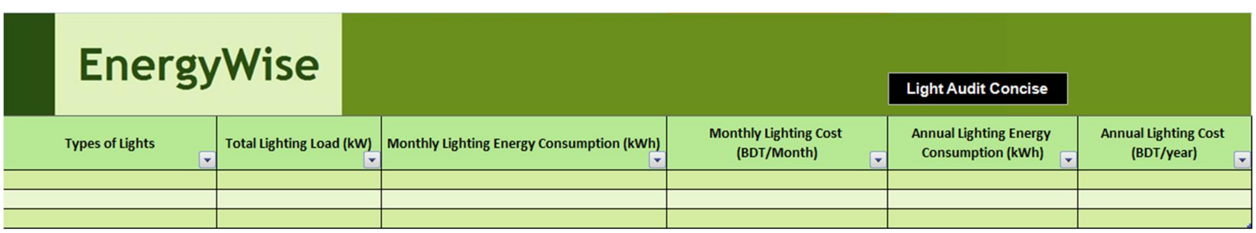


Figure 3.10: Lighting Audit Concise.

Fourth tab is Lighting Audit Concise tab. Users usually want to know the whole building's lighting cost and the whole building's lighting details. So, this tab will give us total concise lighting estimated cost. Fifth tab is about the lighting audit summary which will be shown in the next chapter as there are two pie charts about the lighting audit information. Next tab is about lighting sample, given figure 3.11

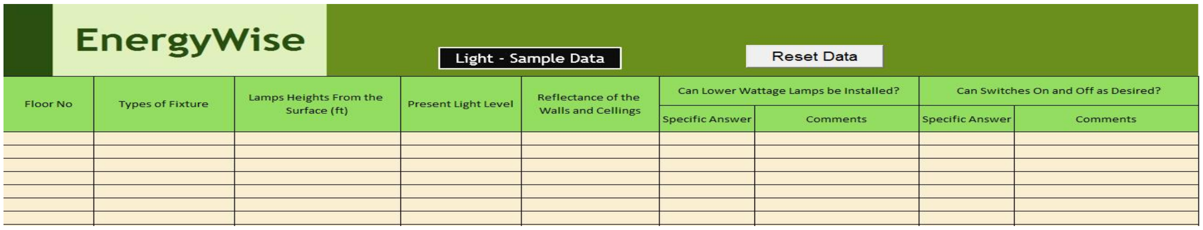


Figure 3.11: EnergyWise Light Sample Data Tab.

Seventh and eighth tab are about the Electrical Equipment Audit and Electrical Equipment Audit Concise, Shown in the figure 3.12 and 3.13 respectively.

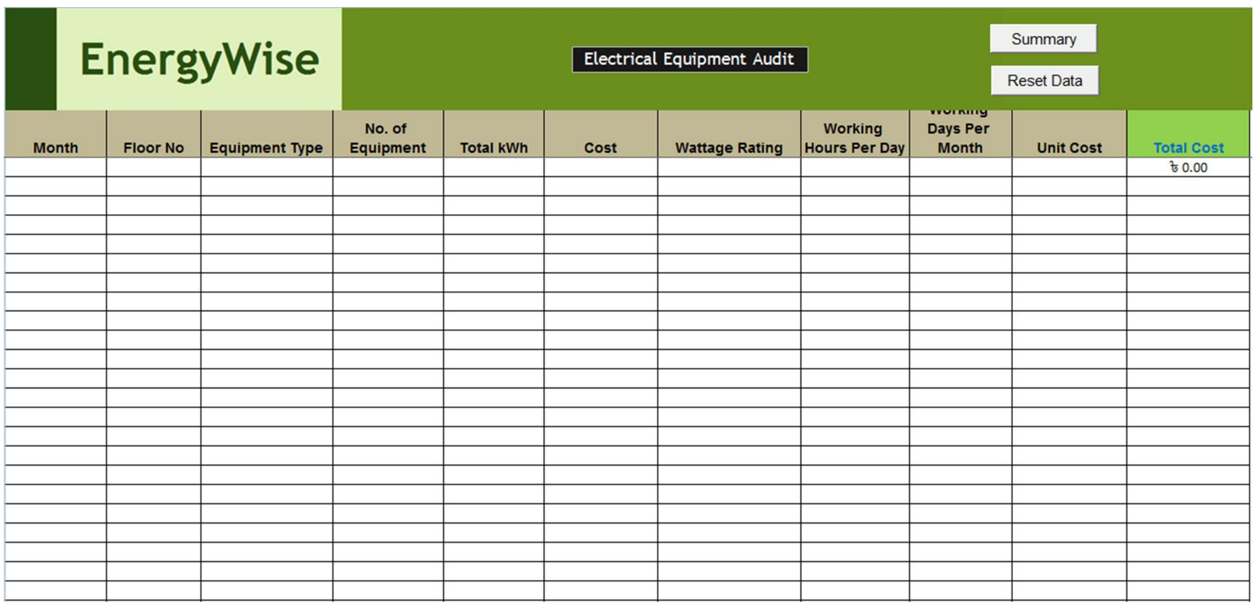


Figure 3.12: Electrical Equipment Audit Tab

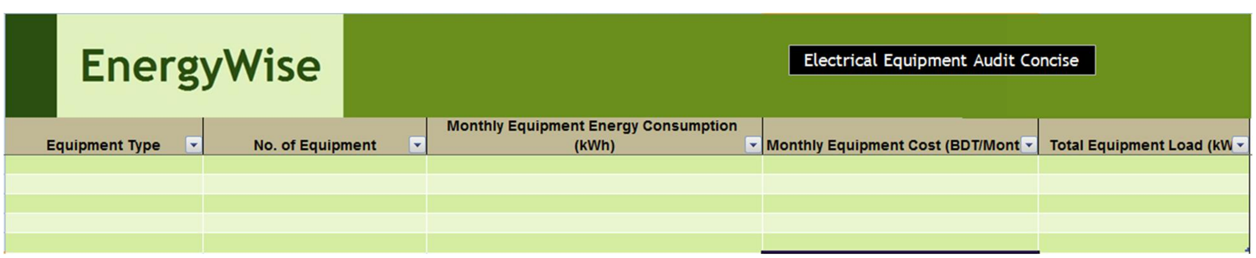


Figure 3.13: Electrical Equipment Audit Concise.

Ninth tab is about Electrical Equipment Audit Summary, which is consist of two graphs again and the tab will be shown later. Tenth tab is about the Envelope Audit, shown in figure 3.14.

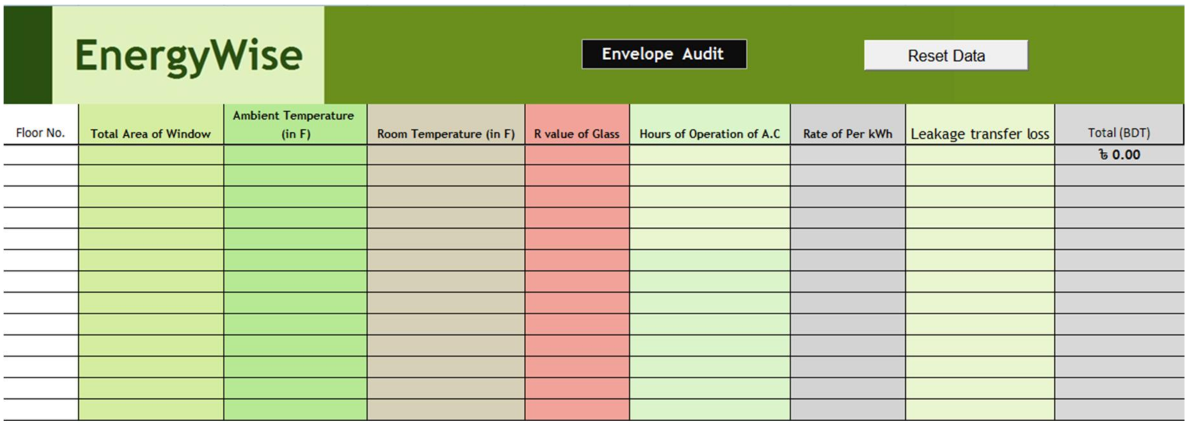


Figure 3.14: Envelope Audit Tab

Last tab is "Summary Report", where we can find electricity bill data bar graph, annual lighting cost and percentage of total cost in pie charts. Those graphs and charts will also be shown later part of the thesis.

3.3 Major Codes and Program Operating Methods

In calculation part, first comes lighting audit calculation which is generated the following codes:

```
Sheets("LightingAudit").Cells(lr + 1, "C").Value = (Val(NoF.Text) * Val(NoL.Text) * Val(Ratings.Text))
/ 1000
Sheets("LightingAudit").Cells(lr + 1, "D").Value = Sheets("LightingAudit").Cells(lr + 1, "C").Value *
Val(Hr.Text) * Val(Dys.Text) * 4.348
Sheets("LightingAudit").Cells(lr + 1, "E").Value = Sheets("LightingAudit").Cells(lr + 1, "D").Value *
cmdUC.Value
Sheets("LightingAudit").Cells(lr + 1, "F").Value = Sheets("LightingAudit").Cells(lr + 1, "C").Value *
Val(Hr.Text) * Val(Dys.Text) * Val(WKS.Text)
Sheets("LightingAudit").Cells(lr + 1, "G").Value = Sheets("LightingAudit").Cells(lr + 1, "F").Value *
cmdUC.Value
```

In column C, we converted all the wattage ratings in kW by multiplying number of lights with its corresponding watts and dividing it by 1000. Then, in column D, we find the total monthly lighting energy consumption, which is multiplications of total kW found in C, number of hours in a day that lights worked, number of days in a week the light worked and 4.348 which is number of average weeks in a month. Monthly lighting energy cost calculated in column E, by multiplying lighting energy consumption with tariff rate of the specified building. Then, we find out the annual lighting consumption similar to the monthly consumption but in this case, one change is made which is we multiplied number of weeks in the whole year the lights worked rather than number of week in a month.

Secondly, the Electrical Equipment Audit calculation, based on the electricity consuming appliances. The calculated information is generated by the given codes:

```
Sheets("EquipmentAudit").Cells(eRow, 5).Value = (Sheets("EquipmentAudit").Cells(eRow, 4).Value *
Sheets("EquipmentAudit").Cells(eRow, 7).Value * Sheets("EquipmentAudit").Cells(eRow, 8).Value *
Sheets("EquipmentAudit").Cells(eRow, 9).Value) / 1000
Sheets("EquipmentAudit").Cells(eRow, 6).Value = Sheets("EquipmentAudit").Cells(eRow, 5).Value *
Sheets("EquipmentAudit").Cells(eRow, 10).Value
```

In this portion of code, firstly, we calculated the total electricity consumption in kWh by summing up the similar equipment and multiplying it with the wattage of each similar equipment. Then, we multiply the operation time of each device in a month and convert the watt-hour in kWh. Finally, to find monthly cost due to electrical equipment we multiplied the tariff rate with total kWh.

Last part is Envelope Audit calculation, which is slightly different from our other calculations. As we said before the energy loss due to envelope is not directly related to our electricity bills but has a contribution in mounting the bills. Here, data taken by the auditor should have experience on energy auditing. But, we developed the tool for general people. So, we only put one of the part of the leakage loss related to windows to simplify the things to user. Leakage loss generated by these codes:

```
ws.Cells(iRow, 8).Value = ((Val(textbox_wind) * (Val(textbox_amtemp) - Val(textbox_roomtemp))) /
(Val(textbox_rvalue))) * ws.Cells(iRow, 6).Value * 30 * 0.00029307107017 * Val(cmdUC)
```

The formula we used here to find leakage loss is valid only for the air condition facilitated room or floor. First, we have to find the difference between ambient temperature and room temperature. Ambient temperature is the temperature we need in the room or our comfort temperature. Room temperature is the temperature of the room or the outside environment temperature which vary with the weather. Then, the difference of temperature is multiplied with window area of the air conditioned facilitated room. Then, we have to divide it by the R value of the glass used in the window. The operation hour will be the operation hour of the air conditioner pre-specified in the electrical equipment audit. The formula we used is in the unit of BTU. So, convert it to kWh we multiplied .000293071017 and then multiplied the tariff rate to find monthly leakage loss due to envelope. For other rigorous codes see on Appendix A.

3.4 Charts and Graphs

Since the tool is developed under three considerations as mentioned before and our objective was to identify the prominent energy loss medium, we have tried to develop graphs and chart on that basis. Our graphs and charts are evolved in such a way, so that user can spot the improvement sector at a glance.

The first pie-chart [Total Lighting Load (kW)] in the fifth tab of our tool generates, the lighting summary which depicts the total lighting load (kW) of a building. This chart is designed with different shades of color, each of which indicates a particular light bulb. The result is generated in percentage which takes in account of the overall lighting system of a building.

The second pie-chart [Monthly Lighting Cost] in the fifth tab of the tool corresponds to monthly lighting cost which is in the unit of BDT/month. This chart has also same designated colors which would indicate the corresponding cost for each particular light bulb. This is also expressed in terms of percentage, taking the overall cost for lighting system of a building.

The third and the fourth one in the ninth tab portrays the equipment summary. It is very similar to the lighting one. The pie-chart is generated with the same concepts. It shows the total electrical equipment load in kW and monthly equipment cost in BDT/month. Color schemes are also kept pretty straight forward to avoid the disorder.

The fifth and sixth one are a bar chart which is generated in the Summary Report section of our tool. The fifth bar chart is considered to be one of the useful one since it renders with electricity bill consumption and plots meter number against amount of money (BDT for Bangladesh currency).The bar chart has labeled color schemes which would help us to show the consumption for the whole year. The color scheme table can be found on our list of table. The sixth one illustrates the annual lighting consumption in terms of money so that one can easily decide which type of light should be encouraged to use.

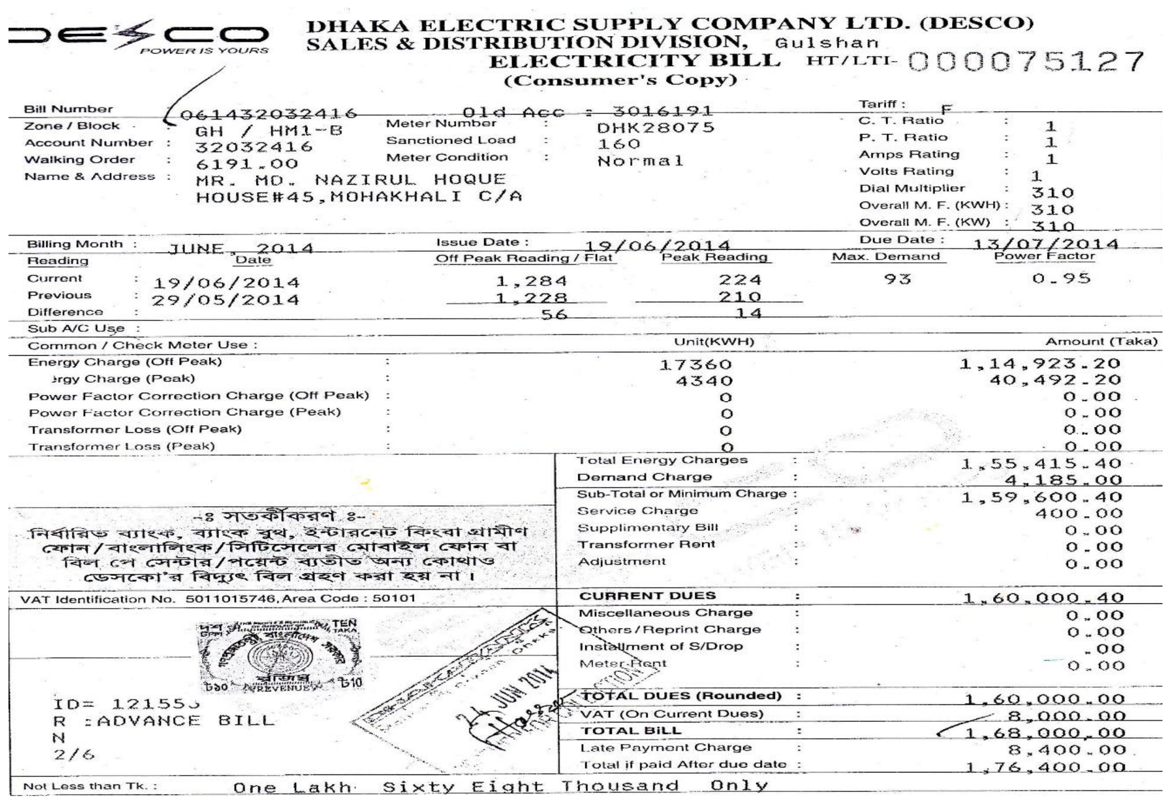
The seventh one, which is the last pie-chart is also in the last tab of the tool, unfolds the total cost or the energy consumption in percentage. From this chart, one can identify that which sector is computing more electrical energy consumption. After identification, the user may opt the possible methods of replacement so that electrical bills can be reduced.

4. AUDITING OF BRAC UNIVERSITY BUILDINGS

After developing the tool, the first thing to do is to examine and check how the output is shown by the tool. So, to verify our tool as well as part of our thesis we surveyed several commercial buildings and shopping malls. In this chapter, we will show the audit process, data collection and the output processed by the tool for BRAC University building 3 and 5.

4.1 BRAC University Building 5 Audit

As we have discussed the audit processes, we have audited in similar fashion. To start the audit, we need some specification about the building. So, first of all, we collected the electricity bill of BRAC University building 5. Electricity bill of June in shown in the figure 4.1



DESCO POWER IS YOURS
DHAKA ELECTRIC SUPPLY COMPANY LTD. (DESCO)
SALES & DISTRIBUTION DIVISION, Gulshan
ELECTRICITY BILL HT/LTI- 000075127
(Consumer's Copy)

Bill Number : 061432032416 Old Acc : 3016191
Zone / Block : GH / HM1-B
Account Number : 32032416
Walking Order : 6191.00
Name & Address : MR. MD. NAZIRUL HOQUE HOUSE#45,MOHAKHALI C/A
Meter Number : DHK28075
Sanctioned Load : 160
Meter Condition : Normal
Tariff : F
C. T. Ratio : 1
P. T. Ratio : 1
Amps Rating : 1
Volts Rating : 1
Dial Multiplier : 310
Overall M. F. (KWH) : 310
Overall M. F. (KW) : 310

Billing Month : JUNE, 2014 | Issue Date : 19/06/2014 | Due Date : 13/07/2014

Reading	Date	Off Peak Reading / Flat	Peak Reading	Max. Demand	Power Factor
Current	19/06/2014	1,284	224	93	0.95
Previous	29/05/2014	1,228	210		
Difference		56	14		

Sub A/C Use :
Common / Check Meter Use :

	Unit(KWH)	Amount (Taka)
Energy Charge (Off Peak)	17360	1,14,923.20
Energy Charge (Peak)	4340	40,492.20
Power Factor Correction Charge (Off Peak)	0	0.00
Power Factor Correction Charge (Peak)	0	0.00
Transformer Loss (Off Peak)	0	0.00
Transformer Loss (Peak)	0	0.00

Total Energy Charges	1,55,415.40
Demand Charge	4,185.00
Sub-Total or Minimum Charge	1,59,600.40
Service Charge	400.00
Supplimentary Bill	0.00
Transformer Rent	0.00
Adjustment	0.00
CURRENT DUES	1,60,000.40
Miscellaneous Charge	0.00
Others / Reprint Charge	0.00
Installment of S/Drop	.00
Meter Rent	0.00
TOTAL DUES (Rounded)	1,60,000.00
VAT (On Current Dues)	8,000.00
TOTAL BILL	1,68,000.00
Late Payment Charge	8,400.00
Total if paid After due date	1,76,400.00

-ঃ সতর্কীকরণ ঃ-
নির্ধারিত ব্যাংক, ব্যাংক বুথ, ইন্টারনেট কিংবা গ্রামীণ ফোন/বাংলালিংক/সিটিসেলের মোবাইল ফোন বা বিল পে সেন্টার/পয়েন্ট ব্যতীত অন্য কোথাও ডেসকো'র বিদ্যুৎ বিল গ্রহণ করা হয় না।

VAT Identification No. 5011015746, Area Code : 50101

ID= 12155
R :ADVANCE BILL
N
2/6

Not Less than Tk. : One Lakh Sixty Eight Thousand Only

Figure 4.1: BRAC University Building 5 Electricity Bill of June

From the electricity bill, we have a precise idea about the building's energy consumption. Although we did not get much idea about variation of energy consumption due to seasonal change as we did not get the 12 month electricity bill. We get the electricity bill of March, April, May and June. According to our assumption, the electricity bill of those months is higher compared to the other month as summer season is consist of those months. However, data is entered to "EnergyWise" and it generates corresponding chart which will be shown later in this chapter.

After that, we need the floor plan of this building to get idea about the building orientation and the envelope system. Figure 4.2 shows us the 4^{th} floor plan of the Building 5.

BRAC University building 5 located at Mohakhali and the building is east facing. The rooms are separated by some hardboards and has narrow space. From the floor plan we get the actual length and size of the rooms, windows and doors which are necessary for calculation of our envelope losses.

Next comes data collection, where we used lighting and envelope audit manual forms. Figure 4.3 and 4.4 shows the lighting audit form and envelope audit form respectively.

The forms are hand written and to fill the form we take the help of the floor in charge, security guards and other personnel related with the building. Lighting audit form is similar to our tool's lighting audit form. But we took both sample and lighting in one manual hand written form and there are two separate forms for the light sample and lighting audit so that the user can easily give input.

On the other hand, the manual hand written form of envelope audit has no connection with "EnergyWise" envelope form. Manual form has too much data for keeping record for future implementation and our tool is designed in such a way that it can analyze the give data and can give some useful output about the audited building.

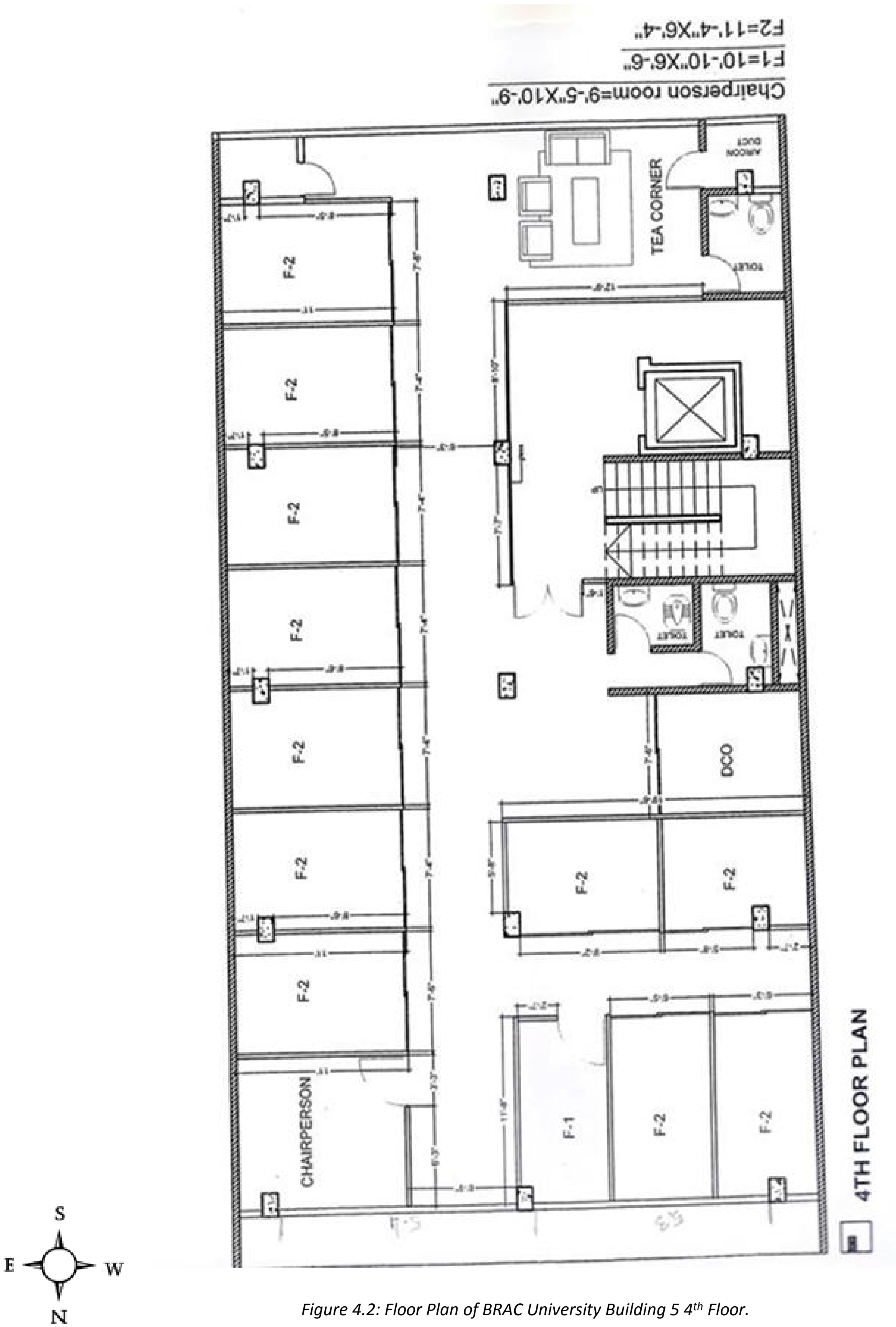


Figure 4.2: Floor Plan of BRAC University Building 5 4th Floor.

Building Energy Audit

Lighting

Building Identification: Building 5 Floor No: 5th floor.

Please use a new sheet for each area, location or room in the facility.

Existing lights and controls

	Type 1	Type 2	Type 3	Type 4
Type of fixtures	D			
Number of fixtures:				
Number of lamps per fixture:	40	3		
If fluorescent indicate length of lamps (2 ft, 3ft, 4ft, 8ft):		2ft		
Watts per fixture: (Include ballast wattage if known)	23W	15		
Fixture height from work surface(ft/m)	10ft	6ft		
Present operation of lights - hours/day	13hrs	13hrs.		
Present operation of lights - days/week	5	5		
Present operation of lights – weeks/year	45	45		
Present operation of lights - hours/day				
Present operation of lights - days/week				

Present light levels: Bright_____ Adequate _____ Dim_____
Reflectance of walls and ceilings: Good_____ Average_____ Poor_____
Can lights be switched on and off as desired? Yes_____ No _____ Comment:_____
Can lower wattage lamps be installed? Yes____ No____ Comment:_____

Notes: _____

Lighting Legend

A.- Incandescent **B.**- Fluorescent T-12 **C.**- Fluorescent T-12 HO (High Output)**D.**- Compact Fluorescent **E.**- Mercury Vapour**F.**- Fluorescent T-12VHO (VH Output)**G.**- High Pressure Sodium **H.**- Low Pressure Sodium **I.**- Metal Halide (White Light)**J.**- Fluorescent T-8 **K.**- Quartz Halogen **L.**- LED **M.** Other-specify _____

Figure 4.3: Lighting Audit Form of 5th Floor of BRAC University Building 5.

Building Energy Audit

Envelope

Building Info & Floor no: 5, 2nd floor **Direction Wall Faces** East & West

For each wall area of facility (front, sides and back of a building) please use one sheet.

Windows

No of windows	Do windows open?	Window Area (sq-ft)	Type of glass used	Description of window type	Window fit (poor, fair, good)	Is there opening between window frames? Comment on airtightness.	Any Curtains Used? Type and color details
2	Yes	61.8	Single glazing	Steel frames, not airtight, has openings	Fair	Yes	white/louvered solar screen.
1	Yes	~~ft.~~ 59.7	Single glazing	steel frames	Fair	Yes	"

Doors

No. of doors	Is door Insulated? Airtightness (comment)	Description of door type	Condition of door	Is it Glass Door? Glass type..	Notes
3	Not insulated	Tinted white glass door swing door	Fair	Yes, single glazed	Not rubber insulation.

Number/Location of broken or cracked windows: No cracked windows.

Description of door or window repairs or replacements needed (including door closers): Rubber strips or door sweep should be installed

Observatory Description

Wall Color, comments on wall condition: Grey white

Floor type (mosaic, tiled, wooden, plain cemented): tiled

Ceiling type and condition (bare ceiling, insulation used, décor, false foam ceiling): bare ceiling.

Comment on ventilation, space or opening: No proper ventilation or space opening.

Air Conditioning

Number of units: 3 Make, type, size, location of each: 4 ton each 3 on top of windows and one on East wall.

Frequency of servicing: ______ Date of last servicing: ______

Figure 4.4: Envelope Audit Form of 2nd Floor of BRAC University Building 5

4.2 Calculations of BRAC University Building 5

The data we have collected from the building, we put them into "EnergyWise" to get calculations and the output of the tool for the building.

Starting the process with lights, figure 4.5 shows the concise lighting information of the BRAC University building 5.

EnergyWise

Types of Lights	Total Lighting Load (kW)	Monthly Lighting Energy Consumption (kWh)	Monthly Lighting Cost (BDT/Month)	Annual Lighting Energy Consumption (kWh)	Annual Lighting Cost (BDT/year)
Compact Fluoroscent	2.928	934.463464	8952.159985	9996	95761
Fluoroscent T-12	4.428	753.68232	7220.276626	7800	74727
Fluoroscent T-8	0.255	69.1332	662.296056	716	6854

Figure 4.5: Concise Lighting Audit Calculation of BRAC University Building 5

From the "EnergyWise" we get monthly lighting cost of 8952.16BDT for CFL, 7220.28BDT for FL T-12 and 662.23BDT for FL T-8. The monthly energy consumption of CFLs, FL T-12 and FL T-8 are 934.46kWh, 753.68232kWh and 69.13kWh respectively. Moreover, the total monthly lighting cost is 16,834.73BDT and annual lighting cost is 1,77,341.95BDT. From lighting summary fifth tab of the tool, we get two pie charts, shown in figure 4.6 and 4.7.

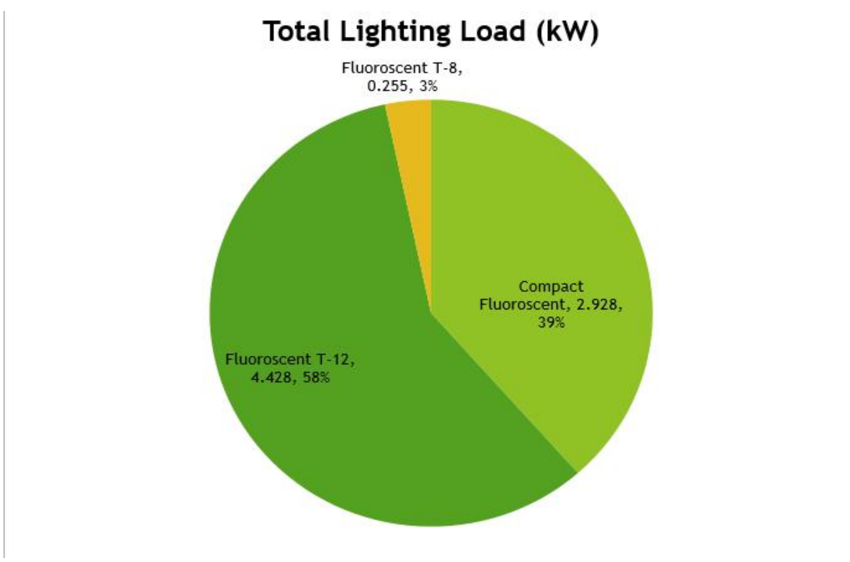


Figure 4.6: Total Lighting Load of BRAC University Building 5

In this figure we can see the total lighting load of BRAC University building 5, Where FL T-12 consumes 4.428kW which is 58% of the lighting energy consumption. FL T-8 consumes .255kW which is 3% of the lighting energy consumption and CFL consume 39% electricity of 2.928kW. During our study we have observed that, CFLs and FL T-8 are better in quality than FL T-12. But still FL T-12 is used in the most of the cases.

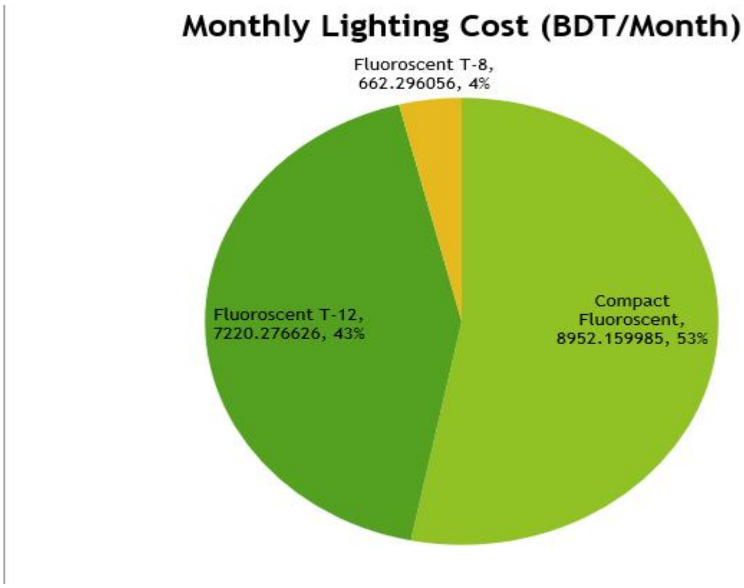


Figure 4.7: Monthly Lighting Cost of BRAC University Building 5

From this figure, we can see FL T-12, FL T-8 and CFL are responsible for 43%, 4% and 53% lighting cost respectively. Although FL T-12 consumes more electricity than CFLs but still CFLs are responsible for more costs than FL T-12 because CFLs operational hour is more than the FL T-12.

Next we move to electrical equipment calculations, figure 4.8 shows the concise information about electrical equipment.

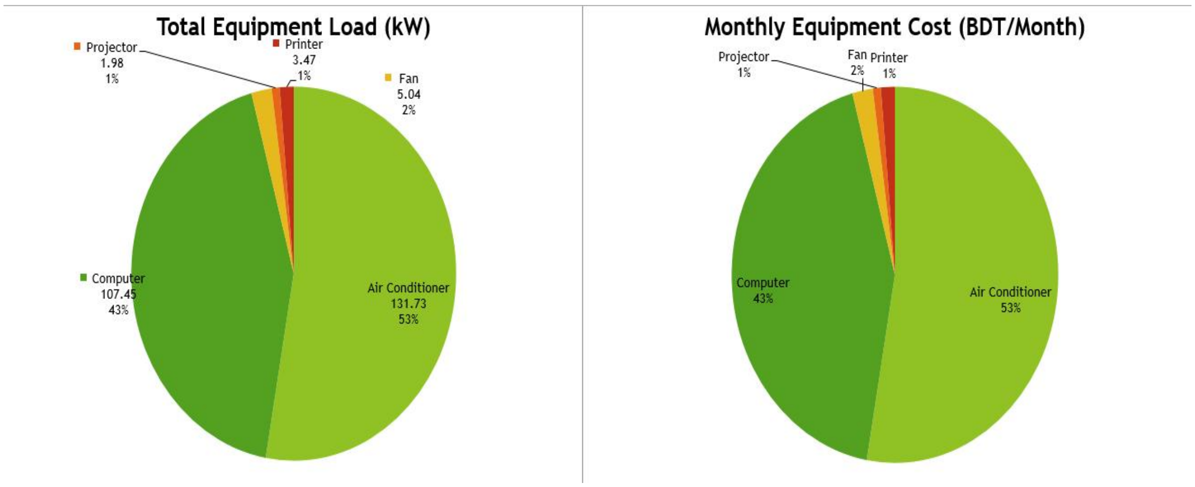
EnergyWise

Equipment Type	No. of Equipment	Monthly Equipment Energy Consumption (kWh)	Monthly Equipment Cost (BDT/Month)	Total Equipment Load (kW)
Air Conditioner	39	7904	75720.32	131.73
Computer	153	6447	61762.26	107.45
Fan	56	302.4	2896.99	5.04
Projector	4	118.8	1138.10	1.98
Printer	26	208	1992.64	3.47

Figure 4.8: BRAC University Building 5 Electrical Equipment Cost in Concise way.

From the figure we can see air conditioner consumes 7504kWh which costs 75720.32BDT per month. Computer consumes 6447kWh, costs 61762.26BDT per month. Figure 4.9 shows the pie charts of the electrical equipment summary.

Figure 4.9: Electrical Equipment Summary Pie Charts of BRAC University Building 5



From the above pie charts we can see, air conditioner consumes most of the electricity and causes electrical equipment costs which is 53% of total electrical equipment cost. Then comes computer which consumes 43% of energy and also costs 43%. Fan, projectors and printers altogether consumes 4%.

After that comes, envelope audit calculation. Figure 4.10 shows leakage loss due to envelope audit.

EnergyWise

Envelope Audit | Reset Data

Floor No.	Total Area of Window	Ambient Temperature (in F)	Room Temperature (in F)	R value of Glass	Hours of Operation of A.C	Rate of Per kWh	Leakage transfer loss	Total (BDT)
Floor 1	245.2	91.4	77	0.91	8	9.58	2643.58	৳ 9,859.09
Floor 2	121.5	91.4	77	0.91	8	9.58	1295.53	
Floor 3	157.2	91.4	77	0.91	8	9.58	1676.19	
Floor 4	152.8	91.4	77	0.91	8	9.58	1629.27	
Floor 5	61.8	91.4	77	0.91	8	9.58	2614.52	

Figure 4.10: BRAC University building 5 leakage loss by Envelope.

From the figure, we can see the 10th tab of our tool where we get the calculation of BRAC University building 5 leakage loss. The Leakage loss we get is 9,859.09BDT per month. This is the extra money we have to pay without any services.

Finally, in the last tab we get the summary report, where we can find three graphs generated by "EnergyWise". This graphs and charts and necessary for our analysis of building energy loss. Figure 4.11, 4.12 and 4.13 shows the electricity bill data in bar charts, annual lighting cost in bar charts and percentage of total cost in pie charts respectively.

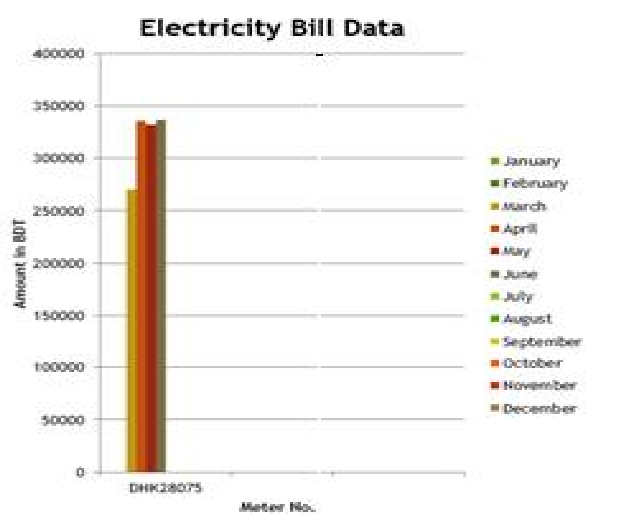


Figure 4.11: Electricity Bill Data for BRAC University Building 5

Here we have four months electricity bill data. Every bars of this charts are leveled with different colors according to the corresponding month which is shown in right side of the charts.

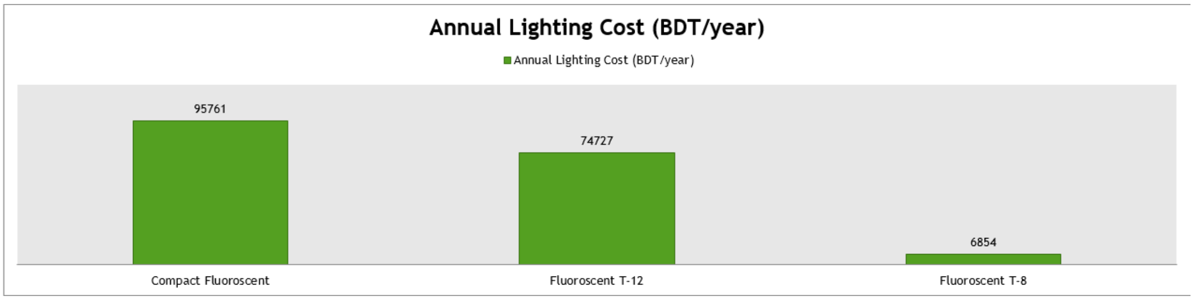


Figure 4.12: Annual Lighting Cost Bar Graph for BRAC University building 5.

This bar charts shows the comparison of different lighting cost annually and we can clearly see that CFLs are causing higher costs, then comes FL T-12 and finally FL T-8 for BRAC University building 5. In this building we have only three types of light, so we get three bars. Number of the bars increases with the types of lights increases.

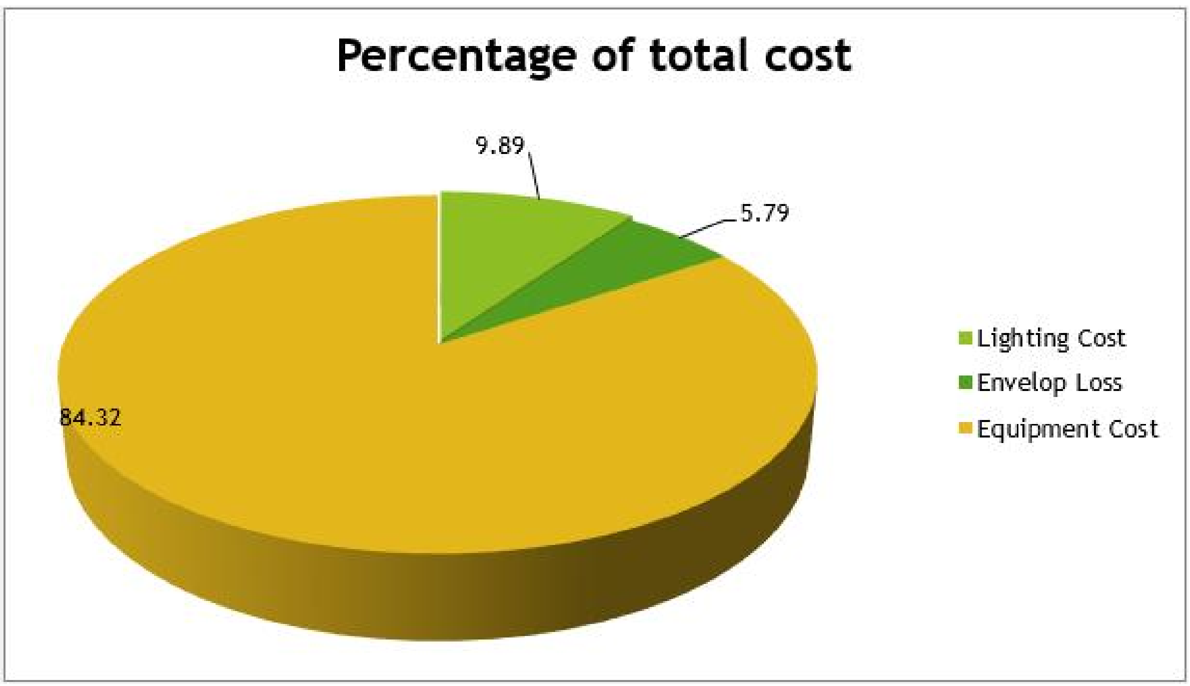


Figure 4.13: Percentage of Total Cost Energy Audit for BRAC University Building 5.

The pie charts shows lighting cost is 9.89% of the total cost. The area is market by the light green color. The most of the part are covered by the electrical equipment, which is 84.32% of the total cost and marked by yellow color. The envelope loss is marked by dark green color and get the 5.79% cost of total cost.

4.3 Calculations of BRAC University Building 3

For building-3, we have followed the same procedure and obtained the annual cost, monthly and annual consumption in similar manner. Figure 4.14 shows the concise lighting audit calculation for building-3

EnergyWise

Light Audit Concise

Types of Lights	Total Lighting Load (kW)	Monthly Lighting Energy Consumption (kWh)	Monthly Lighting Cost (BDT/Month)	Annual Lighting Energy Consumption (kWh)	Annual Lighting Cost (BDT/year)
Compact Fluoroscent	1.725	526.621064	5045.029793	5910.126	56619.00708
Fluoroscent T-12	15.984	3042.90432	29151.02339	31916.16	305756.8128
Fluoroscent T-8	0.529	100.48228	962.6202424	1062	10173.96

Figure 4.14: Concise Lighting Audit Calculation of BRAC University Building 3

The total lighting load and monthly lighting cost in BDT per month is shown in figure 4.15

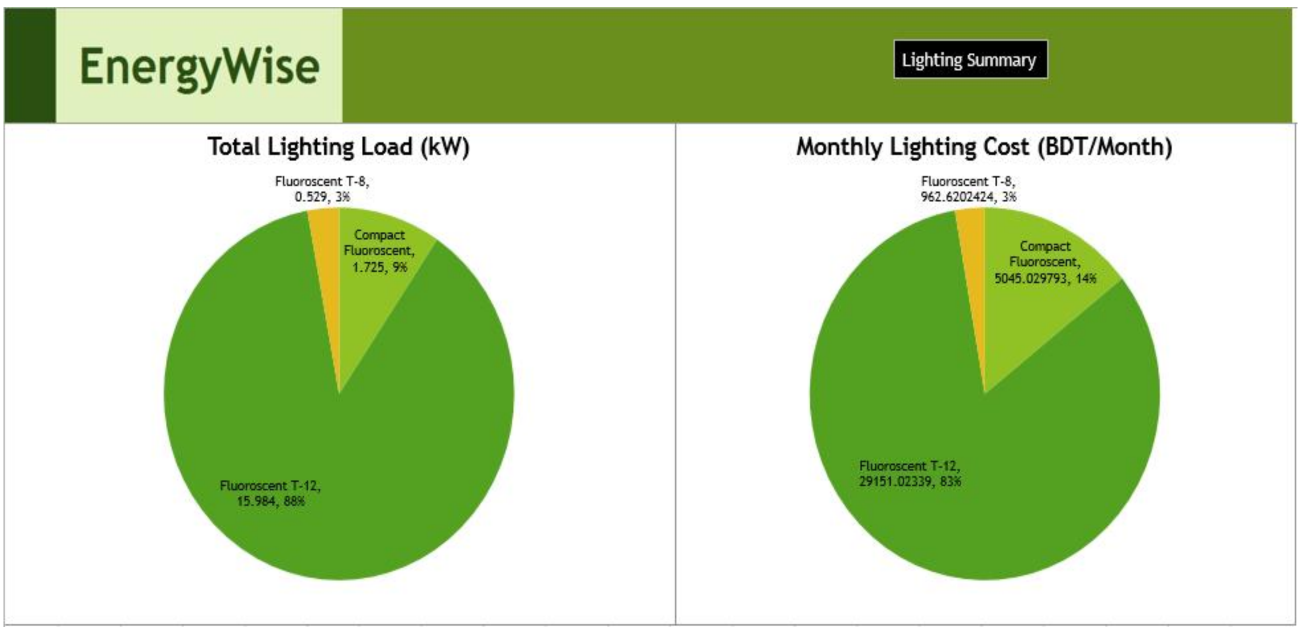


Figure 4.15: Lighting Summary pie charts of BRAC University Building 3

The electrical equipment concise for building-3 is presented in figure 4.16

Electrical Equipment Audit Concise

Equipment Type	No. of Equipment	Monthly Equipment Energy Consumption (kWh	Monthly Equipment Cost (BDT/Month	Total Equipment Load (kW)
Air Conditioner	57	21680	207694.40	361.33
Fan	172	939.4	8999.46	15.66
Air Conditioner	55	8224	78785.92	137.07
Computer	91	3185	30512.30	53.08
Projector	21	693	6638.94	11.55
Printer	12	36	344.88	0.60

Figure 4.16: BRAC University Building 3 Electrical Equipment Cost in Concise way

The equipment summary is presented on figure 4.17

Figure 4.17: Electrical Equipment Summary pie charts of BRAC University Building 3

The leakage loss for building envelope and its calculation is shown in figure 4.18

EnergyWise

Envelope Audit | Reset Data

Floor No.	Total Area of Window	Ambient Temperature (in F)	Room Temperature (in F)	R value of Glass	Hours of Operation of A.C	Rate of Per kWh	Leakage transfer loss	Total (BDT)
Floor 1	5.41	91.5	77	0.9	7	9.58	51.39	৳ 409.79
Floor 2	4.55	91.5	77	0.9	7	9.58	43.22	
Floor 3	5.82	91.5	77	0.9	5	9.58	39.49	
Floor 4	5.82	91.5	77	0.9	5	9.58	39.49	
Floor 5	5.59	91.5	77	0.9	5	9.58	37.93	
Floor 6	5.735	91.5	77	0.9	5	9.58	38.91	
Floor 7	5.59	91.5	77	0.9	5	9.58	37.93	
Floor 8	5.59	91.5	77	0.9	5	9.58	37.93	
Floor 9	5.59	91.5	77	0.9	5	9.58	37.93	
Floor 10	5.61	91.5	77	0.9	3	9.58	22.84	
Floor 11	5.585	91.5	77	0.9	3	9.58	22.74	

Figure 4.18: BRAC University building 3 leakage loss by Envelope

Annual Lighting cost for lights are just shown in figure 4.19

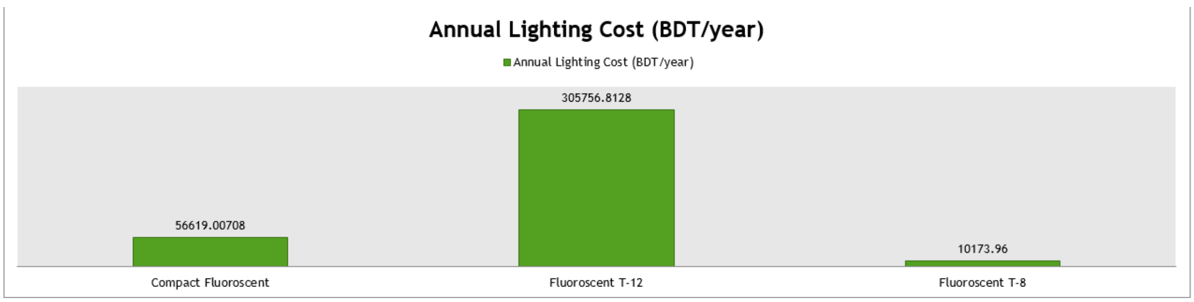


Figure 4.19: Annual Lighting Cost Bar Graph for BRAC University building 3.

Lastly, the total cost in percentage for building -3 is on figure 4.20. Like building-5 it shows equipment cost is higher than any other cost.

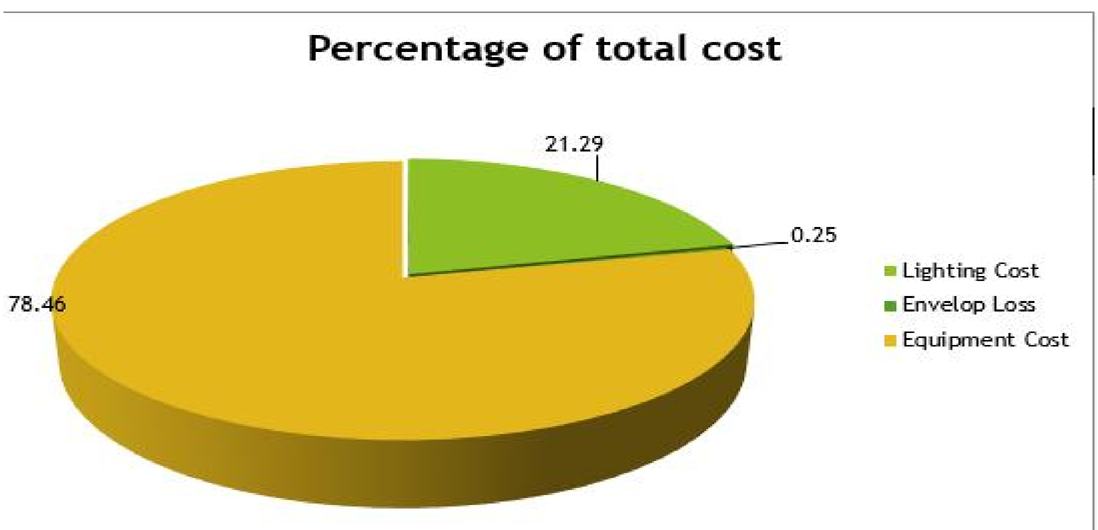


Figure 4.20: Percentage of Total Cost Energy Audit for BRAC University Building 3

4.4 Analysis in Terms of Actual Bill

Our data was collected in the month of December. December is winter season in Bangladesh. So, the cooling equipment used less than other season. As most of the electricity bills are consumed by the cooling equipment, in this season we have less electricity bills compared to the other seasons. We have found 1,70,204.14tk electricity bills from our tool for the BRAC University building 5 which is very close to the actual bill.

4.5 Comments

There is much electrical equipment for which electricity consumption cannot be measured. These types are categorized as miscellaneous in terms of energy consumption. For example, mobile chargers- this is used on daily basis to charge our mobile phones. The energy consumption of this charger is difficult to calculate. But still this use of electricity is increasing our bills. In spite of this, our calculated value is close to the original energy bills and we can assume an error percentage of our calculation to be approximately +20 to -20% due to the above mentioned problems. All data collection forms can be found on Appendix Part B.

5. RETROFIT CONSIDERATIONS

Our main goal is to save money and energy through our 'EnergyWise' audit tool. Saving Energy reduces our nation's overall demand for resources to produce energy and increasing the energy efficiency is like adding another clean energy source to our electric power grid.

5.1 Lighting Considerations

In Bangladesh, lighting system consumes more than 30% of the total electrical energy [52]. The lighting system varies from place to place and from sector to sector but it must provide a suitable condition with desired level of illumination. Simultaneously, the system needs to be designed in such a way, that it consumes minimum amount of energy and provide our desired illumination level that is maintaining the required level of output. Bangladesh, as a developing country needs to look towards energy efficient technologies due to many factors [53]. The factors are on the following:

1. Due to the high expense in constructing new power plants
2. Due to the increasing population which increases the power demand
3. Lack of capital for the investment in alternatives
4. Increased energy consumption leads to contribution of carbon emissions [53]

Thus, switching towards energy saving light technologies can save substantial amount of energy [54].

In Bangladesh, mostly Incandescent and Fluorescent lights were used [52]. Nowadays, Compact Fluorescent lights (CFLs) are used extensively. These CFLs are available in different watts with different color and lumen. The usage of CFLs can be seen in the most of the commercial buildings, such as- Shopping Malls, Industries, Universities, and Offices etc. and also in residential areas. Amongst other types of lamp are High Intensity discharge lamps (HIDs) such as, Low Pressure Sodium Lamps (LPSLs), High Pressure Sodium lamps (HPSL), Halogen Lamps (HL) which are readily available in Markets. Research has now come up with energy efficient bulbs known as Light emitting diode (LED), which claims to reduce energy consumption by 50% [55,56]

Incandescent Lights

Incandescent lights are also known as 'Edison Bulb' and they have very simple operational technology [53]. When current passed through a thin filament of tungsten wire, it gets heated up and emits the light. Due to the good proportion of heat, the lights have low efficiencies. Incandescent lights convert 5% of its input energy to useful output as visible light. The filament then moderately wears out and evaporates the metal which creates a layer inside the bulb and reduces the brightness. They are available in the range of 5, 25, 40, 60,100,200,250 Watts and above for 12 V DC operation [52]. This is the cheapest of all lights and nowadays, it is mostly used in the rural areas of Bangladesh.

Fluorescent Lights

Inside of this lamp, vapors of mercury are inflamed by the alternating current. The gas helps to emit light which hits the Fluorescent material, found inside the inner part of the tube. This causes a soft glow of light and their efficiencies are quite good [52]. Fluorescent lamps are mostly available in long cylinders ranging from 5 Watts to 40 Watts. 'Parallel length' or PL tubes are obtainable in the markets. Also 'H' and 'H' shapes of tube lights are available which contains closely packed cylinders. In Bangladesh, PL lamps range from 5,7,9,13,18, 24 and 36 Watts. [52]. Good quality ballast is needed if it is to be operated from DC source.

Fluorescent lights are also one of the extensively used lights in the commercial buildings and industries. Both 36 Watt and 40 Watt of Fluorescent lamps are available in the markets which provide same lumen output [52].

High Intensity Discharge lamps

HIDs are mainly suitable for all types of outdoor and external uses, where lamps needs to operate at extended periods of time. HPSL are considered to be source of white lights. They produce amber color and are used in street lighting [52].LPSL are also used for outdoor applications and they produce copper golden color.

Compact Fluorescent Lamps

For the last few years, usage of CFLs has been flourished in our country. In the urban areas, CFLs has already replaced many Fluorescent and the traditional incandescent lights. It is considered to be one of the best technological innovations in the lighting industries. The life-time of CFLs is 10 times longer than incandescent bulb [53]. The energy consumption of CFL in terms of Watt is also very less compared to incandescent and Fluorescent.

LED

The LED is also known as 'solid-state' lighting technology [53]. It radiates light from a part of semiconductor made of positively and negatively charged component. The light is radiated as the electrons transfers inside the semiconductor from negative to positive layer [53].

Studies showed that retrofitting the traditional CFLs, FLs and all other lights by LED can save a considerable amount of energy. A comparison table for different types of bulbs is on the following [57]:

Table 5.1: Comparison of Features for different types of light

Features of light	Incandescent	CFLs	LED
Life span of a typical bulb	1,200 hours	10,000 hours	50,000hrs
Watts per bulb (60 W equivalent)	60	14	10
Cost per bulb	30-50 BDT	350-650 BDT	600-1500 BDT
Turns on instantly?	Yes	Slight delay	Yes
Durability	Fragile	Fragile	Durable
Heat emissions	High (85 BTU's/hr)	Medium (15 BTU's/hr)	Low (3 BTU's/hr)

Features of light	Incandescent	CFLs	LED
Hazardous material	None	5 mg of Mercury bulb	None
Replacement Frequency (over 50 kWh)	40+	5	1

Figure 5.1: Incandescent lamps

Figure 5.2: Fluorescent tube light

Figure 5.3: LED Bulb.

Figure 5.4: Compact Fluorescent Light

A survey was conducted in several places of Dhaka, the capital city of Bangladesh to obtain the types of the light used in the commercial purposes. Table 5.2 shows the information of different types of lights used in buildings that we have audited.

Table 5.2: Data of lights in commercial buildings

Places in Dhaka	Total Number of CFLs (W)	Total number of Fluorescents-T8 and T12(W)	Total Number of Flood-light or Metal Halides (W)
BRAC University, Building-5, Mohakhali	126-(23 W) 2-(14 W)	140-(36 W)	-
BRAC University, Building3, Mohakhali	75-(23 W)	37-T 8(15 W) 410-T12(36 W)	-
Pink City, Gulshan	1890-(65 W) 199-(85 W)	40-T8(15 W)	97-(60 W)
Shimanto Square, Dhanmondi	CFL-750(23 W) CFL-43 (65 W) CFL-64 (85 W)	FL-T8-32(20 W) FL-T1250(36 W)	Incandescent-12 (15 W) Spotlight-303 (60 W)
Bangla Bazaar, Mohammadpur	110-(23 W) 2-(65 W)	FL-T12-50 (36 W)	5-(32 W)

The illumination levels of corresponding buildings are also measured by Digital Lux meter which can measure up to a range of 200000 Lux.

Table 5.3 represents the data of luminous level in lux collected from our field visit.

Table 5.3: Average Luminous Level measured by Light meter.

Places in Dhaka	Average luminous level in working spaces of per room/shop (in lux)
BRAC University, Building-5,Mohakhali	743.02
BRAC University Building -3,Mohakhali	895.03
Pink City, Gulshan-1	3800
Shimanto Square, Dhanmondi	2832

Places in Dhaka	Average luminous level in working spaces of per room/shop (in lux)
Bangla Bazaar, Mohammadpur	2890

One of the main problems that were identified during our visit was the quality of the lighting products. The lighting companies of Bangladesh do not maintain standard quality control over the manufactured lighting products. As a result, cheap and low quality ballasts are provided which causes the lighting system inefficient and losses in terms of money.

Retrofit

Retrofit is the process of replacing inefficient light systems with more advanced and high efficiencies systems. This also depends upon various parameters such as policies and regulations, occupant's expectation, building specification and human factors [58].

However considering above factors, we have observed that by replacing all types of bulbs by LED, the output efficiency of the lights can be improved.

Table 5.4 shows an equivalent replacement of conventional light bulbs by energy efficient LED lamps.

Table 5.4: Replacement of typical lamps by LED lamps

Type of lights	Replacements
T8 (15 W)	LED tube lights (8 W)
T12 (36 W)	LED tube lights (16 W)
CFL (14 W)	LED lamps (9 W)
CFL (23 W)	LED lamps (14 W)
CFL (65 W)	LED lamps (33 W)
Flood light (32 W)	LED lamps of standard screw niche (10 W)
Spot lights/ Others	LED reflector lights

The data that we have accumulated are mostly for the classrooms and laboratories of University Buildings (BRAC University, Building-5 and 3) and for commercial spaces such as-Shopping Malls (Pink City, Shimanto Square and Bangla Bazaar).

Table 5.5 below exhibits the actual recommended illumination level for these buildings. According to Bangladesh National Building Code, BNBC (2011), the illumination level [82] of our sites should be –

Table 5.5: Recommended Illumination Level by BNBC

Places in Dhaka	Recommended illumination level (Lux)
BRAC University, Building-5	300 (per classroom)
BRAC University-Building-3	300 (per classroom)
Pink City, Gulshan-1	150-300 (per store/shop)
Shimanto Square, Dhanmondi	150-300(per store/shop)
Bangla Bazaar, Mohammadpur	150-300(per store/shop)

The unit Lux is defined as lumens per square meter. Thus, the recommended values stated by BNBC already considered the floor area for every classroom and shop.

The quality of lights should be improved by the manufacturer. Electronic ballast could be used where FL are used. This draws much less current and causes less loss than the conventional magnetic ballasts.

Smart switching sensors can be used to automatic switch off when there are no occupants in the room. A new type of light known as T5-improved and modified version of FL is now claiming that it has less heat dissipation, cheaper and has higher efficiencies than LEDs[87]. Future replacements can be done with T5 if it proves to be efficient. In that case payback period might reduce significantly

5.2 Electrical Equipment Considerations

Electric bills become heavy in amount due to electrical appliances other than lighting because most of the appliances consume high electric power. The common electrical appliances used in commercial areas (excluding industrial areas) are Air conditioner, Ceiling fan, Stand fan, Computer, Elevator, Close circuit camera, Refrigerator etc. For the technological advancement most of these have been updated to a newer version which consumes less power without degrading service quality in comparison to conventional ones. To save electrical power consumption in commercial areas we have to retrofit energy efficient appliances over older ones.

Replacement of air conditioner

As a tool to modify the natural environment, air conditioning has very broad application. Its operation is based on the temperature, humidity, cleanliness, freshness and air flow in a room or enclosed space to maintain the comfort zone for humans or requirements of a technical process. If anyone buys a bigger air conditioner than the actual sized unit it will cool less efficiently than the properly sized unit. Several types of air conditioner include window type, split (mini and central) type air conditioner.

The key parameters for choosing air conditioners include [59]:

- Cooling capacity
- Power consumption
- EER & SEER
- Air flow
- Noise
- Dehumidification

From the point of view of establishing energy efficiency the main parameters are:

Cooling capacity

The cooling capacity of an air conditioning system is expressed in BTU's or tons. Cooling capacity is defined as the heat load in a room that has to be removed to attain a certain room temperature and humidity. The typical design is to set 24°C and 55% relative humidity which are most conducive to human body [60].One ton of cooling capacity equals 12,000 BTU's/hour of cooling capacity. The higher the rate of BTU/hour, the greater the cooling capacity is. Before replacing the air conditioner cooling capacity needed for a room should be measured to be more efficient. Steps to calculate cooling capacity [60]:

Step 1

Find the volume of the room in cubic feet.

Volume = Width ×Length× Height (cubic feet)

Step 2

Multiply this volume by 6

C1 = Volume × 6

Step 3

Estimate the number of people (N) that will usually occupy this room. Each person produces about 500 BTU/hour of heat for normal office-related activity. Multiply this two figures together.

C2 = N × 500 BTU/hour

Step 4

Add C1 and C2 together and you will get a very simplified cooling capacity needed for the room.

Estimated Cooling Capacity needed = C1 + C2 (BTU/hour)

Power consumption

The total amount of power consumed while operating in cooling or heating mode specified in electrical Watts (Welec). The lower the power consumption, the higher is the efficiency of the air conditioner.

EER & SEER

EER (energy efficiency ratio) is the ratio between the cooling capacity and total power input and is denoted by EER = Rated cooling capacity/input power. The larger the value of EER, the more efficient the air conditioner is. SEER (Seasonal Energy Efficiency Ratio) is obtained by dividing the total cooling that the equipment is able to provide over the entire season (Btu) over the total energy in Watt-hours it will consume. For more efficient equipment, SEER will be higher.

Air flow

Under rated conditions in cooling mode, the volume of air flow into an enclosed room within a specified period of time.

Noise and Dehumidification

These two items are directly related to the comfort of the end-users. The main source of noise in an air conditioner is the fan and the compressor, the dehumidification capacity measures the amount of latent heat (i.e., humidity) removed from the enclosed space.

Besides the specified specifications above, energy star rating air conditioner has implemented inverter technology to achieve better efficiency.

What does Inverter technique do in air conditioner?

An inverter model means that the compressor is powered by a variable speed drive or 'inverter', which enables the compressor to run at a range of speeds from slow to fast, to match the output required. Most conventional compressors run at a constant speed and these types of units vary their capacity by switching on and off at different intervals. Inverters are a sophisticated piece of technology which improve the performance and energy efficiency of air conditioners under normal use.

Finally we can reduce air conditioning energy use by 26%-45% [61] by switching to high-efficiency air conditioners of various brands keeping the above specification in mind.

Another electrical appliance which is responsible for consuming a significant amount of electricity is circulating fans. Besides it emits CO_2. Circulating fans include ceiling fan, table fan, floor fan, window fan and fans mounted to poles or walls. Both the power consumption and CO_2 emission can be reduced by using energy efficient fans, maintaining proper installation rules from the user's point of view and using energy efficient components in making fans from producer's point of view. In the summer, a running ceiling fan can raise your thermostat setting by 4°F [62] without hampering your comfort which can cut your cooling cost by at least 4%-6% and in some cases by 8% [63]. Therefore choosing appropriate fans is important to save energy.

Several factors to keep in mind to buy and install ceiling fans in order to make them more efficient:

Fan size and Blade angle

Fan size refers the diameter of the circle that rotating blades make. The larger the room the larger the fan size is. It is best practice to follow the followings [66]:

- Room less than 80 sq. ft.: 24-42" blade
- Room which is 100-150 sq. ft.: 44-50" blade
- Room which is 150-300 sq. ft.: 52-60" blade
- Room greater than 300 sq. ft.: 62" blade span

Choose blade angle of 12-14° otherwise it will be flat and reduce air flow [66].

Fan Installation

Installing the proper sized fans in proper position we can make the fans more efficient. Table 5.6 represents the suggested lengths of drop rod for fan installation for different ceiling heights [65]:

Table 5.6: Length of Drop Rod for different heights

Ceiling Height (feet)	Drop Rod Length (inches)
9	12
10	18

Ceiling Height (feet)	Drop Rod Length (inches)
11	24
12	36
13	48

Noise Levels

The lesser the noise produced by the fans the more comfort we feel. Fans are rated with their noise levels. Very quiet fans are rated at 0.5 to 1.5 tones [63].

CFM

It measures the air flow in cubic feet per minute. We should select higher CFM to reduce the cooling cost which should be at least 6000-7000 CFM [66] for the best results. The required CFM for a room is calculated in the following way [63]:

Volume of the room, V = Square feet of the floor × room height in feet

Then multiply it by 30 or 60 air changes per hour and divide by 60 to get the required CFM.

CFM required = (V × 30 or 60)/60

Motors

Fans with BLDC (Brushless DC) motor are more efficient than the fans with split phase induction motor. The reason is that induction motor does not maintain synchronous speed with the generated magnetic field whereas BLDC motors maintain synchronous speed by reducing the friction of the rotor. A ceiling fan with BLDC motor consumes power about 50% that of a fan with split phase induction motor [64]. At high speeds, power consumption can be reduced from 70-75W to 45-50W [64].

Table 5.7 shows the criteria for ceiling fan in order to be ENERGY STAR* certified [67]:

Table 5.7: Specifications of ENERGY STAR rated Ceiling Fan

Equipment	Specification
Ceiling fans	Specification defines residential ceiling fan airflow efficiency on a performance basis: CFM* of air flow per watt of power consumed by the motor and controls. Efficiency is measured on each of 3 speeds. At low speed, fans must have a minimum air flow of 1250 CFM* and an efficiency of 155CFM/Watt. Qualifying ceiling fan models must come with a minimum 30-year motor warranty; one year components warranty and a 2-year light kits warranty. At high speed, fans must have a minimum airflow of 5000 CFM* and an efficiency of 75 CFM/Watt.

Finally if we can implement energy efficient technique in all fans sold by 2020 globally and install them properly, we can save 70 terawatt hours per year (TWh/year) and can reduce 25 million tons of CO_2 emission [62].

For other appliances like Computer Monitor, Refrigerator etc. try to get the energy star rated appliances because it will cut your electricity bill to some extent. Think about computer monitors. CRT (cathode ray tube) monitors consume about 100W or more depending on the size of the monitors and LCD monitors consume less power than CRT [68]. LED monitors are more efficient than CRT and LCD because it consume lesser power. ENERGY STAR*rated computer monitors consume power depending on their resolutions or megapixels and the maximum consumed power in on mode for different resolution is determined by the two criteria specified in ENERGY STAR* site [69]. The two criteria are as follows

Criterion 1

In order to be ENERGY STAR* certified maximum active mode power must not exceed the equation: Y = 38X + 30 where X is number of mega-pixels in decimal form and Y is rounded up to the nearest whole number and expressed in watts.

Criterion 2

If X<1 then Y=23 and if X>= 1 then Y = 28X where X is number of mega-pixels in decimal form and Y is rounded up to the nearest whole number and expressed in watts.

This power will obviously be lesser than the power used in conventional monitor. Therefore using ENERGY STAR* rated appliances we can save our money as well as electricity.

In addition to this, installing automated sensor based fans and setting timers in air conditioner and setting the monitors in optimum brightness level which is about 15-30 percent for each LCD [7] monitors can effectively reduce power.

5.3 Building Envelope Considerations

Starting with the windows, windows are the most important part of a building envelope. Window is the great source of day lighting, ventilation and the heat from the sun in the winter. On the other hand, in summer air conditioners must work harder to cool from sunny window. Unfortunately, windows are responsible for 10%-25% of heating bill by letting heat out. [71] In our country most of the glasses are single glazed with low insulation which contributes a lot in energy leakage. Moreover, doors also can contribute significantly to air leakage and can also waste energy through conduction. Specially, when it is old, not insulated, improperly installed or improperly air sealed. Sliding glass doors lose much more heat than other types of doors because glass is a very poor insulator. It is almost impossible to stop all the air leakage around the weather stripping on a sliding glass door. [72] In this case swinging doors can offer tighter seal than sliding types but again there are problems with this type of doors because most of the swinging doors are single glazed and not properly insulated. In addition, building orientation and location can contribute in the energy saving process. It is very obvious that the south facing buildings can have much air which can actually decrease the demand of the cooling energy. Building’s location is an important factor in case of lighting energy consumption if daylight can enter in the building then we can reduce the light energy by 40%-50%. Lastly, any kind of crack in the wall or ceiling is the reason to air leakage. Mostly, in

the old buildings we can find cracks but in the new buildings we can also have cracks as a result of different construction work.
There are many factors upon which envelope audit depends on such as U-factor, R-factor, fenestration rate etc. As our calculation is based on the R-factor so we emphasized on the R-factor. Unfortunately, we have limitation on our equipment so we ignore the other factors.

There are different types of operable windows available but we usually use horizontal slider. In some cases we also use tilt and turn windows. Anyway, the point is that all the windows that we use are single glazed and not properly insulated which is causing our air condition to work hard and leak the cold air as well as we cannot have our desirable temperature in our room or it takes longer to cool down. Now, in market there are some available windows which can actually increase its efficiency which are multiple glazed windows. As the glaze of the window increases the R-value also increase as a result the leakage decreases. As for the doors there are two operable styles: swinging and sliding. The swinging doors are more efficient than the sliding doors but there are Energy Star rated efficient doors and windows are available in the market. One of the sophisticated ways to save the energy bill is using insulated curtains. Insolated curtains are very useful in a way that they are not only energy saver but also improve the comfort and beauty of the rooms. To prevent air leakage there are four separate layers in the insulated curtains. [73] First, a core layer of high density foam that insulates windows from exchange heats. Secondly, a vapor barrier blocks the foam's absorption of moisture. Thirdly, a layer of reflective film that deflects heat back into the room. Fourth, an outer layer with a decorative fabric. There are some different kinds of insulated curtains like roman shades, hobbled shades, side draw shades and classic curtains. [73] Next, one the significant factor is reflectance of the wall. If wall painting or color has low LRV (Light Reflection Value) then it must be absorbing your lights. [74] As a result you need more lights which are not efficient at all.

From our surveys, we found some typical areas of building envelope which must be replaced to improve the energy efficiency. First of all, we need to replace the windows which are very low quality and single glazed. Even, they are not properly insulated. Thus we have replaced them by energy efficient multiple glazed windows which are available on the market. Furthermore, there are ENERGY STAR rated windows are available in the market. Same goes for the doors, especially the sliding doors must be replaced by the new swinging energy efficient doors and as for the existing swinging doors they are not properly insulated. So, proper insulation will increase the efficiency. Replacing the windows and the door could save about 16% of the total energy bills. [72]

The biggest reason of the air leakage is the cracks or holes in the walls or ceilings. So, we have to repair any kind of cracks and holes available in the building. Besides, the crack in the wall, the paint of the wall is also a factor to save energy bills. White paints reflects 80% of the light while black reflects only 5%, cool colors, such as blues and greens, to be 6-10 degrees Fahrenheit cooler than the actual temperature and worm colors, such as red and oranges, will result in a 6-10 degrees Fahrenheit warmer. [75] So, keeping this mind we have to choose our wall paint color. Lastly, replacing old curtains with new energy efficient insulated curtains can be useful. According to the U.S. Department of Energy, white plastic curtains backing could reduce home heat in take by 33%. Addition to that, closing curtains could save up to 10% in heat loss. [76]

Overall, we can save up to 50% of the lighting and heat energy depending on area where the energy efficient product are use including insulation of the building, efficient windows, doors and curtains, color used , type of the construction amount of ventilation etc. [77]

5.4 Saving on Lightings

As we discussed on our previous chapters, our study was confined to two academic buildings of BRAC University and three shopping malls. Amongst them, full assessment and energy losses were calculated for BRAC University buildings. Lighting audits were conducted for Shopping malls due to limited access to the sites.

Fluorescent tubes are to be replaced by LED tubes available in 8 and 16 Watt which can replace all traditional 23 Watt and 36 Watt T8/T10/T12 respectively.

After inspection of BRAC University, Building 5 we have seen only T8/T12 of fluorescent types is available.

Thus, we calculate the savings by replacing the most efficient lamps that are available now and our calculation method is [78]-

- Considering wattage of T8/T12 lights = 36 W
- Wattage of LED tube lights = 16 W
- The wattage difference we get = 36-16 W

  = 20 W

- Number of tube lights = 140
- Wattage Saving = $\frac{140\times20}{1000}$

  = 2.8 kW

- Average working hours = $\frac{7+5}{2}$

  = 6 hours

- Total number of days the lights are active

  = 225 days

- Saving in unit = $2.8 \times 6 \times 225$

  = 3780 kWh

- Cost of electricity@ BDT 9.58/unit = **36212.4 BDT**

Compact Fluorescent lamps (CFLs) are to be replaced by LED bulbs available in 14 and 9 Watt, which can replace 23 Watt and 15 Watt of CFL respectively to get 1450 lumens.

- Considering wattage of a CFL = 23 W
- Wattage of LED lamps = 14 W
- The wattage difference we get = 23-14

  = 9 W

- Number of tube lights = 126
- Wattage Saving = $\frac{126\times9}{1000}$

  = 1.134 kW

- Working hours = $\frac{7+5}{2}$

= 6 hours

- Total number of days the lights are active

  = 225 days

- Saving in unit = $1.134 \times 6 \times 225$

  = 1530.9 kWh

- Cost of electricity@ BDT 9.58/unit = 9.58×1530.9

  = **14666.02 BDT**

- Considering wattage of a CFL = 15 W
- Wattage of LED lamps = 9 W
- The wattage difference we get = 15-9 W

  = 6 W

- Number of tube lights = 2
- Wattage Saving = $\frac{2\times 6}{1000}$

  = 0.012 kW

- Working hours = $\frac{7+5}{2}$

  = 6 hours

- Total number of days the lights are active

  = 225 days

- Saving in unit =$0.012 \times 6 \times 225$

  = 16.2 kWh

- Cost of electricity at BDT 9.58/unit = 9.58×16.2

  = **155.196 BDT**

After replacement with above mentioned types, total annual saving for building -5 would be

= 36212.4+14666.02+155.196

= **51033.62 BDT**

From our worksheet, the total annual cost for lighting was calculated

$$= \mathbf{177, 341.95\ BDT}$$

Therefore, after replacements with LED we can annually save

$$= \frac{51033.62}{177341.95} \times 100$$

$$= \mathbf{28.8\%}$$

Similar calculation method is used to calculate for other buildings too. Table 5.8 illustrates savings for lighting audit for BRAC University building-3 & building-5, Pink City, Shimanto Square and Bangla Bazaar.

Table 5.8: Savings from Lighting Audit.

Name of the buildings	Types of lights used and corresponding Wattage	Replacement lights and corresponding Wattage	Savings after retrofits
BRAC University, Building-05,Mohakhali	CFL-126 (23 W)	LED (15 W)	28.8%
	CFL-2 (15 W)	LED (9 W)	
	FL-140 (36 W)	LED (16 W)	
BRAC University, Building-03,Mohakhali	CFL-75 (23 W)	LED (14 W)	41.5%
	FL-37 T8 (15 W)	LED (9 W)	
	FL-410 T12 (36 W)	LED (16 W)	
Pink City, Gulshan	CFL-1890 (65 W)	LED (33 W)	51.7%
	CFL-199 (85 W)	LED (43 W)	
	FL-40 T8 (15 W)	LED (9 W)	
	HIDS/Flood lights (60W)	LED Reflector bulbs (13 W)	
Shimanto Square, Dhanmondi	CFL-750 (23 W)	LED (14 W)	63.5%
	CFL-43 (65 W)	LED (33 W)	
	HIDS/Flood light-15 (60 W)	LED Reflector bulbs (13 W)	

Name of the buildings	Types of lights used and corresponding Wattage	Replacement lights and corresponding Wattage	Savings after retrofits
	CFL-64 (85 W)	LED (43 W)	
	FL-T8-32 (20 W)	LED (9 W)	
	FL-T12-50 (36 W)	LED (16 W)	
	Incandescent-12 (15 W)	LED (9 W)	
	Spotlight-303 (60 W)	LED (13 W)	
Bangla Bazaar, Mohammadpur	CFL-110 (23 W)	LED (14 W)	30.2 %
	CFL-2 (65 W)	LED (33 W)	
	HIDS/Flood light-5 (60 W)	LED Reflector bulbs (13 W)	

5.5 Saving from Electrical Equipment

Terminologies used for calculation of saving from electrical equipment

Q_a= Quantity of air conditioner

Q_f= Quantity of fan

Q_m = Quantity of computer monitor

WH_d = Working hours per day

WD_m = Working days per month

U_c = Unit cost of electricity for commercial building

P_{exist} = Power rating of existing appliance

P_{star} = Power rating of ENERGY STAR* rated appliance

P_{con}^{exist} =Power consumption of existing appliance

P_{con}^{*} = Power consumption of ENERGY STAR* rated appliance

P = Saving in power consumption

Saving calculation for BRAC University building-5 for electrical appliances:

Saving from the replacement of conventional air conditioner by ENERGY STAR* rated air conditioner:

Q_a = 39

WH_d = 6.2 hour

WD_m = 20 day

P_{exist} = 4000 W

P_{star} = 3800 W (Source: [80])

$P^{*}_{con} = Q_a \times P_{star}$

$= 39 \times 3800$

$= 148.2$ kW

$P^{exist}_{con} = Q_a \times P_{exist}$

$= 39 \times 4000$

$= 156$ kW

U_c = 9.58 BDT

$P = P^{exist}_{con} - P^{*}_{con}$

$= 7.8$ kW

Saving in BDT/Month

$= P \times WH_d \times WD_m \times U_c$

$= 7.8 \times 6.2 \times 20 \times 9.58$

= **9265.78 BDT/Month**

Saving from the replacement of conventional fan by ENERGY STAR* rated fan:

Q_f = 56

WH_d = 3.8 hour

WD_m = 20 day

P_{exist} = 70 W

P_{star} = 50 W (Source: [81])

P^*_{con} = $Q_f \times P_{star}$

= 56×50

= 2.8 kW

$P^{exist}_{con} = Q_f \times P_{exist}$

= 56 × 70

= 3.92 kW

U_c = 9.58 BDT

P = P^{exist}_{con} - P^*_{con}

= 1.12 kW

Saving in BDT/Month

= P × $WH_d \times WD_m \times U_c$

= 1.12 × 3.8 × 20 × 9.58

= **815.45 BDT/Month**

Saving from the replacement of conventional computer monitor by ENERGY STAR* rated computer monitor:

Q_m = 153

WH_d = 6.2 hour

WD_m = 20 day

P_{exist} = 40 W

P_{star} = 25 W

P^{*}_{con} = $Q_m \times P_{star}$

= 153 × 25 = 3.825 kW

P^{exist}_{con} = $Q_m \times P_{exist}$

= 153 × 40

= 6.12 kW

U_c = 9.58 BDT

P = P^{exist}_{con} - P^{*}_{con}

= 2.295 kW

Saving in BDT/Month

= P × $WH_d \times WD_m \times U_c$

= 2.295 × 6.2 × 20 × 9.58

= **2726.28 BDT/Month**

Total cost for electrical appliances for Building-5

= **143510.32 BDT/Month**

Total saving for electrical appliances for Building -5

= 9265.78 + 815.45 + 2726.28

= **12807.51 BDT/Month**

It is **8.9%** of the total cost of electrical appliances.

Annual Saving would be

= 12807.51 × 12

= **153,690.12 BDT/year**

Similar calculations are made for all of the buildings.

Table 5.9 summarizes the saving of power consumption per month for electrical appliances for BRAC University bilding-5.

Table 5.9: Savings of Power Consumption for BRAC University Building -5

Electrical Appliances	**Q**	P_{star}**(W)**	P_{exist}**(W)**	P^{*}_{con}**(kW)**	P_{con}^{exist}**(kW)**	**P(kW)**
Air Conditioner	39	3800	4000	148.2	156	7.8
Fan	56	50	70	2.8	3.92	1.12
Computer Monitor	153	25	40	3.825	6.12	2.295

Table 5.10 summarizes the saving of money in BDT/month for the electrical appliances for BRAC University building-5.

Table 5.10: Savings of Money from BRAC University Building 5

Electrical Appliances	WH_d	WD_m	U_c	**Saving in BDT/month**
Air Conditioner	6.2	20	9.58	9265.78
Fan	3.8	20	9.58	815.45
Computer Monitor	6.2	20	9.58	2726.28
Total Saving				**12807.51**

Table 5.11 summarizes the saving of power consumption per month for electrical appliances for BRAC University bilding-3.

Table 5.11: Savings of Power Consumption for BRAC University Building -3

Electrical Appliances	**Q**	P_{star}**(W)**	P_{exist}**(W)**	P^{*}_{con}**(kW)**	P^{exist}_{con}**(kW)**	**P(kW)**
Air Conditioner	61	3800	4000	231.8	244	12.2
Fan	172	50	70	8.6	12.04	3.44
Computer Monitor	91	25	40	2.28	3.64	1.36

Table 5.12 summarizes the saving of money in BDT/month for the electrical appliances for BRAC University building-3.

Table 5.12: Savings of Money for BRAC University Building -3

Electrical Appliances	WH_d	WD_m	U_c	**Saving in BDT/month**
Air Conditioner	5.2	20	9.58	12155.1
Fan	4.25	20	9.58	2801.2
Computer Monitor	5	20	9.58	1302.88
Total Saving				**16259.18**

Total cost for electrical appliances for BRAC University building-3 = 129573.34BDT. Saving is **12.55%** for electrical appliances for BRAC University building-3.

Table 5.13 summarizes the saving of power consumption per month for electrical appliances for Pink City Shopping mall.

Table 5.13: Savings of Power Consumption for Pink City Shopping Mall

Electrical Appliances	**Q**	P_{star}**(W)**	P_{exist}**(W)**	P^{*}_{con}**(kW)**	P^{exist}_{con}**(kW)**	**P(kW)**
Air Conditioner	40	9500	10000	380	400	20
Fan	50	50	70	2.5	3.5	1.0
Computer Monitor	46	25	40	1.15	1.84	0.69

Table 5.14 summarizes the saving of money in BDT/month for the electrical appliances for Pink City Shopping mall.

Table 5.14: Savings of Money for Pink City Shopping mall

Electrical Appliances	WH_d	WD_m	U_c	**Saving in BDT/month**
Air Conditioner	11	30	9.58	42152
Fan	11	30	9.58	3161.4
Computer Monitor	11	30	9.58	2181.37
Total Saving				**47494.77**

Total cost for electrical appliances for Pink City = **1604631.8 BDT**

Saving is **2.96%** of the total cost for electrical appliances for Pink City.

5.6 Saving on Building Envelope Audit

Single glazed windows can be replaced by the ENERGY STAR* rated double or triple glazed windows which we talked about in our previous chapter. Now, this replacement will give us 16% saving on the existing leakage loss by the windows as we said earlier.

From the worksheet of energy audit tool we get envelope leakage loss for BRAC University building-5 = 9859.09 BDT/month

So, saving by replacing windows of building-5 of BRAC University

$$= 9859.09 \times 16\%$$

= **1577.45 BDT**

We can save **1577.45 BDT/month** by replacing windows from Building 5.

Similarly, we can save about **65.56 BDT/month** for building 3 of BRAC University.

Annual saving for Building-5 = 1577.45 × 12

= **18,929.4 BDT/month**

Total cost of electricity consumption for building-5, BRAC University

= 143510.31 + 16834.73

= 160345.04 BDT/month

Total saving for building-5, BRAC University

$$= \frac{51033.62}{12} + 12807.51 + 1577.45$$

= 18637.76

Overall saving for building-5, BRAC University

$$= \frac{18637.76}{160345.04} \times 100$$

= 11.62% of the total cost of electricity consumption.

Figure 5.5 and 5.6 show the percentage of cost of BRAC University Building 5 before saving and after saving respectively.

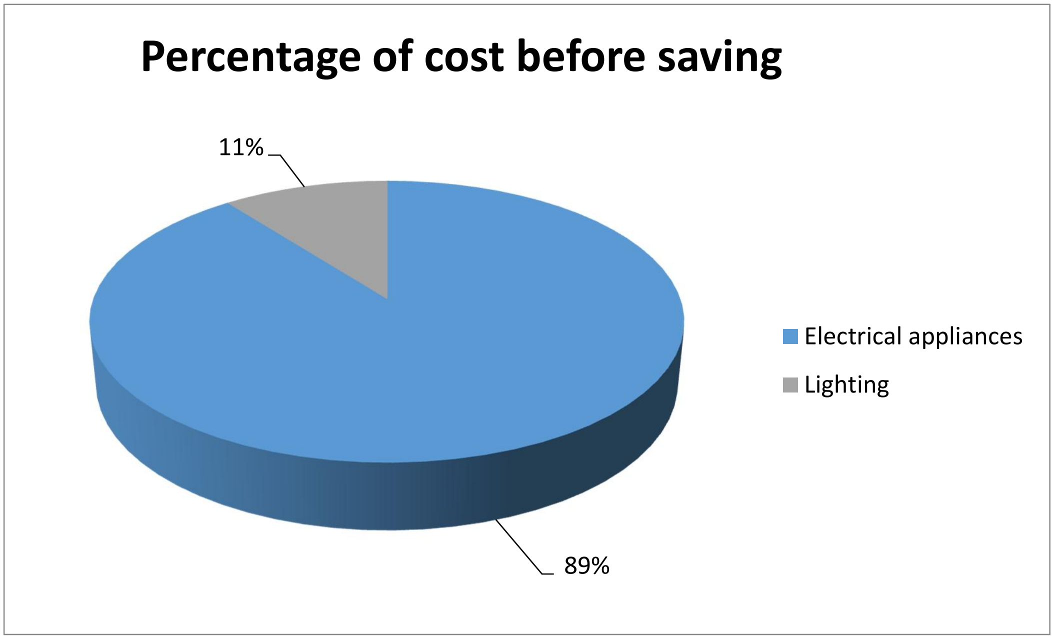


Figure 5.5: Percentage of cost before saving for BRAC University building-5

Figure 5.5 illustrates that electrical appliances contribute 89% and lighting system contributes 11% to the total cost before finding saving.

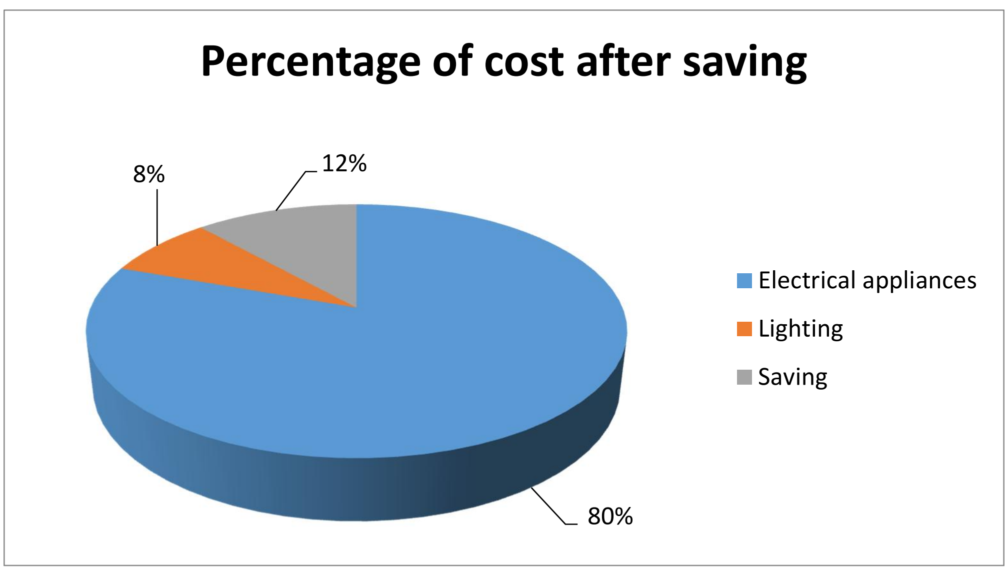


Figure 5.6: Percentage of cost after saving for BRAC University building-5

Figure 5.6 shows that the contribution of electrical appliances and lighting systems to total cost reduces due to saving of 12%.

5.7 Payback Periods

We know that, payback period in year = Total annual investment/ net annual savings [79]

We will only analyze the payback period for Building-5.

Table 5.15: Payback Period for Lights, Electrical Equipment and Envelope for BRAC University Building 5

Name of the components and quantity		**Price in BDT for per piece**	**Investment in BDT**
LED Lamps	15W(126)	775	(775*126)=97,650
	9 W (2)	465	(465*2)=930
	16 W(140)	827	(827*140)=115,780
Air conditioner (Star rated) [84]Quantity-39		98,000	38,22,000
Fan (Star rated), Quantity-56[85]		3200	179,200
Monitor(Star rated)[86] Quantity-153		17,500	2,677,500
Energy Efficient Windows for the building(6 storied-one sided)[83]		9600	57,600

.

Total lighting system investment for Building 5 = 214,360 BDT/year

So, payback period for lighting system would be = 214,360/66,326.7396

= **3.23 years or 38.76 month**

Total electrical system investment for Building 5 = 66,787,700BDT/year

Payback period for electrical system would be = 66,787,700/153,690.12

= **43.4 years or 520 month**

Total envelope investment for Building 5 = 57,600 BDT/year

Payback period for envelope system Building 5 = 57,600/18,929.4

= **3.04 years or 36.48 month**

6. CONCLUSION

In today's world, the usage of electrical energy is ascending everyday due to increasing demand in both developing and under developing countries. The price hike of fuel has now become a common phenomenon and this leads to the increase in the generation cost of electricity. Increase in the generation cost proportionally increases the tariff rates and the consequences are reflected in our monthly energy bill. Although, energy auditing does not provide the exact solution to reduce the usage but then again it provides several opportunities for improving our usage which may lead to a good proportion of saving. The techniques and calculation method that are used for small scale audit may not be appropriate for large scale industrial audits. In this study, we have discussed the fundamental steps and instruments required to start any scale audit. We have mainly focused on BRAC University Building-5 and 3 and some other commercial buildings- with the objective of calculating energy loss, designing an actual retrofit scenario, calculating the potential electricity saving in percentage and finally the payback period. The tool 'EnergyWise'-that we have developed analyzes the building losses and estimates the annual consumption from lighting, electrical equipment and envelope sectors. Our study depicted that reasonable amount of energy can be saved if the energy audit is performed properly. However, due to limitations and insufficient measuring equipment we could not consider many factors such as infiltration rate, fenestration factors and others. Water consumption is also one of the important factors for a building which contributes in the electrical bill. Subsequent studies in this area may result in optimistic savings. Also additional research and data is required to produce better results and can devise an effective method to conserve energy. There is much further scope of our work to conduct in future, which may include considering fenestrations, improvements in infiltration and ventilation rate, calculations of heat flow due to conduction of material for windows, increasing motor efficiencies for water pumps, elevators and escalators. It is well known that, conservation of every kilowatt of energy reduces significant amount of carbon emission and carbon footprint. Thus, for a sustainable environment and to contribute towards carbon neutrality, it is very much crucial to introduce energy audit in every sector with few changes in existing system to cut the growing demand in Bangladesh. The government of Bangladesh may decide the policies so that all industries and commercial buildings undergo energy audit and this will definitely enhance our economical standing in world market.

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APPENDIXES

APENDIX A. CODES

A.1 Electricity Bill Refresh Code

```
Sheets("General_Information").Range("C26:O35").Select
Selection.ClearContents
Sheets("General_Information").Range("C26").Consolidate Sources:=Array( _
"'D:\[EnergyWise.xlsm]Electricity Bill Data'!R2C1:R653C13"), Function:=xlSum _
, TopRow:=False, LeftColumn:=True, CreateLinks:=False
```

A.2 Light Sample Code

```
Dim LRowAs Long
LRow = Sheets("Light - Sample Data").Cells(Rows.count, "F").End(xlUp).Row
If LRow> 3 Then
   Dim L2 As Long
   L2 = LRow
   Do While L2 > 3
      If Sheets("Light - Sample Data").Cells(L2, "A").Value = """" Then
      L2 = L2 - 1
ElseIfSheets("Light - Sample Data").Cells(L2, "A").Value = ComboBox1.Value Then
Sheets("Light - Sample Data").Cells(LRow + 1, "A").Value = """"
      Exit Do
      Else
Sheets("Light - Sample Data").Cells(LRow + 1, "A").Value = ComboBox1.Value
      Exit Do
      End If
   Loop
```

```
Else
Sheets("Light - Sample Data").Cells(LRow + 1, "A").Value = ComboBox1.Value
End If
Sheets("Light - Sample Data").Cells(LRow + 1, "B").Value = CB1.Value
Sheets("Light - Sample Data").Cells(LRow + 1, "C").Value = LH.Value
Sheets("Light - Sample Data").Cells(LRow + 1, "D").Value = CB5.Value
Sheets("Light - Sample Data").Cells(LRow + 1, "E").Value = CB6.Value
Sheets("Light - Sample Data").Cells(LRow + 1, "F").Value = CB7.Value
Sheets("Light - Sample Data").Cells(LRow + 1, "G").Value = Comment1.Text
Sheets("Light - Sample Data").Cells(LRow + 1, "H").Value = CB8.Value
Sheets("Light - Sample Data").Cells(LRow + 1, "I").Value = Comment2.Value
```

A.3 Text Box Control Code

```
If (KeyAscii> 47 AndKeyAscii< 58) Or KeyAscii = 46 Then
KeyAscii = KeyAscii
Else
KeyAscii = 0
MsgBox "You Have to Enter Numerical Value only"
End If
If cmdWD.Value = 0 OrcmdWD.Text = "" Then
cmdWD.Text = ""
ElseIf (cmdWD.Value> 31) Then
MsgBox "Invalid Value"
cmdWD.Text = ""
End If
```

A.4 Envelope Audit Code

```
Dim iRow As Long
Dim wsAs Worksheet
Set ws = Worksheets("EnvelopeAudit")

'find first empty row in database
iRow = Sheets("EnvelopeAudit").Cells(Rows.count, 1).End(xlUp).Offset(1, 0).Row

'check for a Name number
If Trim(Me.textbox_wind.Value) = "" Then
Me.textbox_wind.SetFocus
MsgBox "Please complete the form"
Exit Sub
End If

Dim fRow As Long
fRow = Sheets("EquipmentAudit").Cells(Rows.count, 1).End(xlUp).Offset(1, 0).Row
Dim count As Long
Dim ci As Long
Dim watt As Double
Dim watthour As Double
Dim hour As Double
For count = 3 TofRow
   If Sheets("EquipmentAudit").Range("B" & count) = Me.ComboBox1.Text Then
ci = count
   End If
Next
If (ci > 0 And ci <fRow) Then
```

```
While Sheets("EquipmentAudit").Range("B" & ci).Value = Me.ComboBox1.Text Or
Sheets("EquipmentAudit").Range("B" & ci).Value = """"

If Sheets("EquipmentAudit").Range("C" & ci).Value = "Air Conditioner" Then

watt = watt + ((Sheets("EquipmentAudit").Range("D" & ci).Value) *
(Sheets("EquipmentAudit").Range("G" & ci).Value))

watthour = watthour + ((Sheets("EquipmentAudit").Range("D" & ci).Value) *
(Sheets("EquipmentAudit").Range("G" & ci).Value) * (Sheets("EquipmentAudit").Range("H" &
ci).Value))

ci = ci + 1

End If

ci = ci + 1

Wend

'copy the data to the database

ws.Cells(iRow, 1).Value = Me.ComboBox1.Text

ws.Cells(iRow, 2).Value = Me.textbox_wind.Value

ws.Cells(iRow, 3).Value = Me.textbox_amtemp.Value

ws.Cells(iRow, 4).Value = Me.textbox_roomtemp.Value

ws.Cells(iRow, 5).Value = Me.textbox_rvalue.Value

hour = watthour / watt

ws.Cells(iRow, 6).Value = hour

ws.Cells(iRow, 7).Value = Me.cmdUC.Value

ws.Cells(iRow, 8).Value = ((Val(textbox_wind) * (Val(textbox_amtemp) - Val(textbox_roomtemp))) /
(Val(textbox_rvalue))) * ws.Cells(iRow, 6).Value * 30 * 0.00029307107017 * Val(cmdUC)


Else

MsgBox ("Please Enter The Air Conditioner Operating Time and Quantity in Electrical Equipment
Form for this particular floor")

End If
```

APENDIX B. DATA COLLECTION FORMS

B.1 Lighting Audit Forms for Building 5

Building Energy Audit

Lighting

Building Identification: Building 5 Floor No: Ground Floor

Please use a new sheet for each area, location or room in the facility.

Existing lights and controls

	Type 1	Type 2	Type 3	Type 4
Type of fixtures	D	B		
Number of fixtures:				
Number of lamps per fixture:	12	6+1		
If fluorescent indicate length of lamps (2 ft, 3ft, 4ft, 8ft):		4ft		
Watts per fixture: (Include ballast wattage if known)	23	36		
Fixture height from work surface(ft/m)	12ft	12ft		
Present operation of lights - hours/day	24hrs.	15hrs.		
Present operation of lights - days/week	7	5		
Present operation of lights – weeks/year	52	45		
× Present operation of lights - hours/day				
× Present operation of lights - days/week				

Present light levels: Bright______ Adequate ______ Dim______
Reflectance of walls and ceilings: Good______ Average______ Poor______
Can lights be switched on and off as desired? Yes____ No ____ Comment:______
Can lower wattage lamps be installed? Yes____ No____ Comment:______

Notes: ______

Lighting Legend

A.- Incandescent **B.**- Fluorescent T-12 **C.**- Fluorescent T-12 HO (High Output)**D.**- Compact Fluorescent **E.**- Mercury Vapour**F.**- Fluorescent T-12VHO (VH Output)**G.**- High Pressure Sodium **H.**- Low Pressure Sodium **I.**- Metal Halide (White Light)**J.**- Fluorescent T-8 **K.**- Quartz Halogen **L.**- LED **M.** Other-specify ______

Building Energy Audit

Lighting

Building Identification: Building 5 Floor No: 1st Floore

Please use a new sheet for each area, location or room in the facility.

Existing lights and controls

	Type 1	Type 2	Type 3	Type 4
Type of fixtures	D	D	B	
Number of fixtures:				
Number of lamps per fixture:	6	1	38	3
If fluorescent indicate length of lamps (2 ft, 3ft, 4ft, 8ft):			4	2
Watts per fixture: (Include ballast wattage if known)	23	15	36	15
Fixture height from work surface(ft/m)	10ft	6ft	10ft	6ft
Present operation of lights - hours/day	12hrs	12hrs.	8hrs.	18hrs
Present operation of lights - days/week	5	5	5	5
Present operation of lights – weeks/year	45	45	45	45
Present operation of lights - hours/day				
Present operation of lights - days/week				

Present light levels: Bright_______________ Adequate ____________ Dim______________________
Reflectance of walls and ceilings: Good________________ Average_______________ Poor_________
Can lights be switched on and off as desired? Yes_______ No _______Comment:___________________
Can lower wattage lamps be installed? Yes____ No____Comment:_______________________________

Notes: ____

Lighting Legend

A.- Incandescent **B.**- Fluorescent T-12 **C.**- Fluorescent T-12 HO (High Output)**D.**- Compact Fluorescent **E.**- Mercury Vapour**F.**- Fluorescent T-12VHO (VH Output)**G.**- High Pressure Sodium **H.**- Low Pressure Sodium **I.**- Metal Halide (White Light)**J.**- Fluorescent T-8 **K.**- Quartz Halogen **L.**- LED **M.** Other-specify Flurescent T-12

Building Energy Audit

Lighting

Building Identification: Building 5 Floor No: 2nd Floor

Please use a new sheet for each area, location or room in the facility.

Existing lights and controls

	Type 1	Type 2	Type 3	Type 4
Type of fixtures	D	D	B	
Number of fixtures:				
Number of lamps per fixture:	6	1	28	3
If fluorescent indicate length of lamps (2 ft, 3ft, 4ft, 8ft):			4	2
Watts per fixture: (Include ballast wattage if known)	23	15	36	15
Fixture height from work surface(ft/m)	10ft	6ft	10ft	6ft
Present operation of lights - hours/day	12hrs.	12hrs.	8hrs.	12hrs.
Present operation of lights - days/week	5	5	5	5
Present operation of lights – weeks/year	45	45	45	45
Present operation of lights - hours/day				
Present operation of lights - days/week				

Present light levels: Bright______________ Adequate ___________Dim_____________________

Reflectance of walls and ceilings: Good_________________ Average______________ Poor________

Can lights be switched on and off as desired? Yes_______ No ______Comment:_________________

Can lower wattage lamps be installed? Yes____ No____Comment:______________________________

Notes: ____

Lighting Legend

A.- Incandescent **B.**- Fluorescent T-12 **C.**- Fluorescent T-12 HO (High Output)**D.**- Compact Fluorescent **E.**- Mercury Vapour**F.**- Fluorescent T-12VHO (VH Output)**G.**- High Pressure Sodium **H.**- Low Pressure Sodium **I.**- Metal Halide (White Light)**J.**- Fluorescent T-8 **K.**- Quartz Halogen **L.**- LED **M.** Other-specify _______________

Building Energy Audit

Lighting

Building Identification: Building 5 Floor No: 3rd Floor

Please use a new sheet for each area, location or room in the facility.

Existing lights and controls

	Type 1	Type 2	Type 3	Type 4
Type of fixtures	D	B	B	
Number of fixtures:				
Number of lamps per fixture:	20	30	3	
If fluorescent indicate length of lamps (2 ft, 3ft, 4ft, 8ft):		4ft	2ft	
Watts per fixture: (Include ballast wattage if known)	23	36	15	
Fixture height from work surface(ft/m)	10ft	10ft	6ft	
Present operation of lights - hours/day	12 hrs.	7hrs	12hrs.	
Present operation of lights - days/week	5	5days	5	
Present operation of lights – weeks/year	45	45 weeks/yr	45	
Present operation of lights - hours/day				
Present operation of lights - days/week				

Present light levels: Bright______ Adequate ______ Dim______
Reflectance of walls and ceilings: Good______ Average______ Poor______
Can lights be switched on and off as desired? Yes____ No ____ Comment:______
Can lower wattage lamps be installed? Yes____ No____ Comment:______

Notes: ______

Lighting Legend

A.- Incandescent **B.**- Fluorescent T-12 **C.**- Fluorescent T-12 HO (High Output)**D.**- Compact Fluorescent **E.**- Mercury Vapour**F.**- Fluorescent T-12VHO (VH Output)**G.**- High Pressure Sodium **H.**- Low Pressure Sodium **I.**- Metal Halide (White Light)**J.**- Fluorescent T-8 **K.**- Quartz Halogen **L.**- LED **M.** Other-specify T10/T8

Building Energy Audit

Lighting

Building Identification: Building 5 Floor No: 4th floor

Please use a new sheet for each area, location or room in the facility.

Existing lights and controls

	Type 1	Type 2	Type 3	Type 4
Type of fixtures	D			T-8/10
Number of fixtures:				
Number of lamps per fixture:	37			3
If fluorescent indicate length of lamps (2 ft, 3ft, 4ft, 8ft):				2ft
Watts per fixture: (Include ballast wattage if known)	23			15
Fixture height from work surface(ft/m)	10ft			6ft
Present operation of lights - hours/day	13hrs			13hrs
Present operation of lights - days/week	5			5
Present operation of lights – weeks/year	45			45
Present operation of lights - hours/day				
Present operation of lights - days/week				

Present light levels: Bright______ Adequate ______ Dim______
Reflectance of walls and ceilings: Good______ Average______ Poor______
Can lights be switched on and off as desired? Yes______ No______ Comment:______
Can lower wattage lamps be installed? Yes____ No____ Comment:______

Notes: ______

Lighting Legend

A.- Incandescent **B.**- Fluorescent T-12 **C.**- Fluorescent T-12 HO (High Output)**D.**- Compact Fluorescent **E.**- Mercury Vapour**F.**- Fluorescent T-12VHO (VH Output)**G.**- High Pressure Sodium **H.**- Low Pressure Sodium **I.**- Metal Halide (White Light)**J.**- Fluorescent T-8 **K.**- Quartz Halogen **L.**- LED **M.** Other-specify ______

Building Energy Audit

Lighting

Building Identification: Building 5 Floor No: 5th floor.

Please use a new sheet for each area, location or room in the facility.

Existing lights and controls

	Type 1	Type 2	Type 3	Type 4
Type of fixtures	D			
Number of fixtures:				
Number of lamps per fixture:	40	3		
If fluorescent indicate length of lamps (2 ft, 3ft, 4ft, 8ft):		2ft		
Watts per fixture: (Include ballast wattage if known)	23W	15		
Fixture height from work surface(ft/m)	10ft	6ft		
Present operation of lights - hours/day	13hrs	13hrs.		
Present operation of lights - days/week	5	5		
Present operation of lights – weeks/year	45	45		
Present operation of lights - hours/day				
Present operation of lights - days/week				

Present light levels: Bright_______ Adequate _______ Dim_______
Reflectance of walls and ceilings: Good_______ Average_______ Poor_______
Can lights be switched on and off as desired? Yes______ No ______ Comment:_______
Can lower wattage lamps be installed? Yes____ No____ Comment:_______

Notes: _______

Lighting Legend

A.- Incandescent **B.**- Fluorescent T-12 **C.**- Fluorescent T-12 HO (High Output)**D.**- Compact Fluorescent **E.**- Mercury Vapour**F.**- Fluorescent T-12VHO (VH Output)**G.**- High Pressure Sodium **H.**- Low Pressure Sodium **I.**- Metal Halide (White Light)**J.**- Fluorescent T-8 **K.**- Quartz Halogen **L.**- LED **M.** Other-specify _______

Building Energy Audit

Lighting

Building Identification: Building 5 Floor No: 6th floor

Please use a new sheet for each area, location or room in the facility.

Existing lights and controls

	Type 1	Type 2	Type 3	Type 4
Type of fixtures	B	D		
Number of fixtures:	10			
Number of lamps per fixture:	2 = 20	4+1	2	
If fluorescent indicate length of lamps (2 ft, 3ft, 4ft, 8ft):	4ft		2ft	
Watts per fixture: (Include ballast wattage if known)	36	23	15	
Fixture height from work surface(ft/m)	10ft	10ft	6ft	
Present operation of lights - hours/day	6 hrs	13 hrs	13 hrs.	
Present operation of lights - days/week	5	5	5	
Present operation of lights – weeks/year	45	45	45	
Present operation of lights - hours/day				
Present operation of lights - days/week				

Present light levels: Bright______ Adequate ______ Dim______

Reflectance of walls and ceilings: Good______ Average______ Poor______

Can lights be switched on and off as desired? Yes____ No ____ Comment:______

Can lower wattage lamps be installed? Yes____ No____ Comment:______

Notes: ______

Lighting Legend

A.- Incandescent **B.**- Fluorescent T-12 **C.**- Fluorescent T-12 HO (High Output)**D.**- Compact Fluorescent **E.**- Mercury Vapour**F.**- Fluorescent T-12VHO (VH Output)**G.**- High Pressure Sodium **H.**- Low Pressure Sodium **I.**- Metal Halide (White Light)**J.**- Fluorescent T-8 **K.**- Quartz Halogen **L.**- LED **M.** Other-specify ______

B.2 Envelope Audit Form

Building Energy Audit

Envelope

Building Info & Floor no: 5; 1st floor **Direction Wall Faces** East fac

For each wall area of facility (front, sides and back of a building) please use one sheet.

Windows

	No of windows	Do windows open?	Window Area (sq-ft)	Type of glass used	Description of window type	Window fit (poor, fair, good)	Is there opening between window frames? Comment on airtightness.	Any Curtains Used? Type and color details
Lab01	1	×	761.8ft²	Single glazing	Steel frames, not airtight, has cracks	Fair	Yes	White louver solar screen
Lab02	1	×	761.8ft²	Single glazing	"	"	"	"
Lab03	1	×	92.3ft²	"	"	"	"	"

Doors

No. of doors	Is door Insulated? Airtightness (comment)	Description of door type	Condition of door	Is it Glass Door? Glass type..	Notes
1	Not insulated	Tinted white glass doors	Fair	Yes, single glazed	No rubber insulation
1	"	"	"	"	"

Number/Location of broken or cracked windows: No, cracked windows.

Description of door or window repairs or replacements needed (including door closers): Rubber strips or door sweep should be installed

Observatory Description

Wall Color, comments on wall condition: Grey white

Floor type (mosaic, tiled, wooden, plain cemented): tiled

Ceiling type and condition (bare ceiling, insulation used, décor, false foam ceiling): bare ceiling

Comment on ventilation, space or opening: No proper ventilation or space opening

Air Conditioning

Number of units: ~~3~~ 4 Make, type, size, location of each: 4ton at upper part of windows

Frequency of servicing: Date of last servicing:

Building Energy Audit

Envelope

Building Info & Floor no: 5, 2nd floor **Direction Wall Faces** East & West

For each wall area of facility (front, sides and back of a building) please use one sheet.

Windows

No of windows	Do windows open?	Window Area (sq-ft)	Type of glass used	Description of window type	Window fit (poor, fair, good)	Is there opening between window frames? Comment on airtightness.	Any Curtains Used? Type and color details
2	Yes	61.8	Single glazing	Steel frames, not airtight, has openings	Fair	Yes	white/louvered solar screen.
1	Yes	~~6t.~~ 59.7	Single glazing	steel frames	Fair	Yes	"

Doors

No. of doors	Is door Insulated? Airtightness (comment)	Description of door type	Condition of door	Is it Glass Door? Glass type..	Notes
3	Not insulated	Tinted white glass door swing door	Fair	Yes, single glazed	Not rubber insulation.

Number/Location of broken or cracked windows: No cracked windows.

Description of door or window repairs or replacements needed (including door closers): Rubber strips or door sweep should be installed

Observatory Description

Wall Color, comments on wall condition Grey white

Floor type (mosaic, tiled, wooden, plain cemented) tiled

Ceiling type and condition (bare ceiling, insulation used, décor, false foam ceiling): bare ceiling.

Comment on ventilation, space or opening No proper ventilation or space opening.

Air Conditioning

Number of units: 3 Make, type, size, location of each: 4 ton each 3 on top of windows and one on East wall.

Frequency of servicing: ______ Date of last servicing: ______

Building Energy Audit

Envelope

Building Info & Floor no: 5, 3rd Floor **Direction Wall Faces** East facing.

For each wall area of facility (front, sides and back of a building) please use one sheet.

Windows

	No of windows	Do windows open?	Window Area (sq-ft)	Type of glass used	Description of window type	Window fit (poor, fair, good)	Is there opening between window frames? Comment on airtightness.	Any Curtains Used? Type and color details
Lab02	1	X	61.8ft²	Single glazing	Steel frames, not airtight, has cracks	Fair	Yes	white/ louvered solar screen.
Lab03	1	X	61.8ft²	Single glazing	steel frames, not airtight gaps & cracks	Fair	Yes	"
TA room	1	X	33.6ft²	"	"			X "

Doors

No. of doors	Is door Insulated? Airtightness (comment)	Description of door type	Condition of door	Is it Glass Door? Glass type..	Notes
1	Not insulated	Tinted white glass doors	Fair	Yes, single glazed	Not rubber insulation.
1	"	"	fair	"	"

Number/Location of broken or cracked windows: No cracked windows

Description of door or window repairs or replacements needed (including door closers): Rubbers strips or door sweep should be ~~ad~~ installed

Observatory Description

Wall Color, comments on wall condition: Grey white

Floor type (mosaic, tiled, wooden, plain cemented): tiled

Ceiling type and condition (bare ceiling, insulation used, décor, false foam ceiling): bare ceiling

Comment on ventilation, space or opening: No proper ventilation or space opening

Air Conditioning

Number of units: 3 Make, type, size, location of each: 4ton, 1ton, 4ton Upper part of top of the windows,

Frequency of servicing: ____________ Date of last servicing: ____________

Building Energy Audit

Envelope

Building Info & Floor no: 5, 4th floor **Direction Wall Faces** East facing

For each wall area of facility (front, sides and back of a building) please use one sheet.

Windows

	No of windows	Do windows open?	Window Area (sq-ft)	Type of glass used	Description of window type	Window fit (poor, fair, good)	Is there opening between window frames? Comment on airtightness.	Any Curtains Used? Type and color details
Chairperson confroom	1	✗	76.4ft²	single glazed	steel frames, not airtight, has cracks	fair	Yes	white/color louvered screen
Faculty room	1	✗	76.4ft²	"	"	"	"	"

Doors

No. of doors	Is door Insulated? Airtightness (comment)	Description of door type	Condition of door	Is it Glass Door? Glass type..	Notes
1	Not insulated	Tinted white glass doors	fair	Yes, single glass	No rubber insulation
2	"	"	"	"	"

Floor has 13 doors

Number/Location of broken or cracked windows: No cracked windows.

Description of door or window repairs or replacements needed (including door closers): Rubber strips or door sweep should be installed

Observatory Description

Wall Color, comments on wall condition: Grey white

Floor type (mosaic, tiled, wooden, plain cemented): tiled

Ceiling type and condition (bare ceiling, insulation used, décor, false foam ceiling): bare ceiling

Comment on ventilation, space or opening: No, proper ventilation or space opening

Air Conditioning

Number of units: 13 Make, type, size, location of each: 4 tons.

Frequency of servicing: ______ Date of last servicing: ______

Building Energy Audit

Envelope

Building Info & Floor no: 5, ~~to~~ 5th floor **Direction Wall Faces** East & west

For each wall area of facility (front, sides and back of a building) please use one sheet.

Windows

No of windows	Do windows open?	Window Area (sq-ft)	Type of glass used	Description of window type	Window fit (poor, fair, good)	Is there opening between window frames? Comment on airtightness.	Any Curtains Used? Type and color details
2	No.	61.8 sq-ft	~~Sin~~ Single glazing	~~steel~~ frame, not airtight.	Fair	Yes	white solar screens

Doors

No. of doors	Is door Insulated? Airtightness (comment)	Description of door type	Condition of door	Is it Glass Door? Glass type..	Notes
14	Not insulated	Sliding door, tinted glass door	Fair	Yes, single glazed	No rubber sweep between two slides

Number/Location of broken or cracked windows: No cracked windows or doors.

Description of door or window repairs or replacements needed (including door closers): Requires rubber sweep between the sliding doors.

Observatory Description

Wall Color, comments on wall condition Grey white

Floor type (mosaic, tiled, wooden, plain cemented) tiled

Ceiling type and condition (bare ceiling, insulation used, décor, false foam ceiling): bare ceiling

Comment on ventilation, space or opening No proper ventilation or space opening.

Air Conditioning

Number of units: 14 Make, type, size, location of each: 1 ton each on East side wall.

Frequency of servicing: Date of last servicing:

Building Energy Audit

Envelope

Building Info & Floor no: 5, 6th floor **Direction Wall Faces** East facing.

For each wall area of facility (front, sides and back of a building) please use one sheet.

Windows

	No of windows	Do windows open?	Window Area (sq-ft)	Type of glass used	Description of window type	Window fit (poor, fair, good)	Is there opening between window frames? Comment on airtightness.	Any Curtains Used? Type and color details
Lab02	1	X	76.5ft	Single glazed	Steel frames, not airtight, has cracks	fair	Yes	White / solar tapered screen
lab01	1	X	76.4ft	"	"	"	"	"
lab03	1	X	92.3ft	"	"	"	"	"

Doors

No. of doors	Is door Insulated? Airtightness (comment)	Description of door type	Condition of door	Is it Glass Door? Glass type..	Notes
1	Not insulated	Tinted white glass doors	fair	Yes, single glazed	No rubber insulation
1	"	"	"	"	"

Number/Location of broken or cracked windows: No cracked windows

Description of door or window repairs or replacements needed (including door closers): Rubber strip or door sweep should be installed

Observatory Description

Wall Color, comments on wall condition Grey white.

Floor type (mosaic, tiled, wooden, plain cemented) tiled.

Ceiling type and condition (bare ceiling, insulation used, décor, false foam ceiling): Bare ceiling

Comment on ventilation, space or opening No proper ventillation or space opening

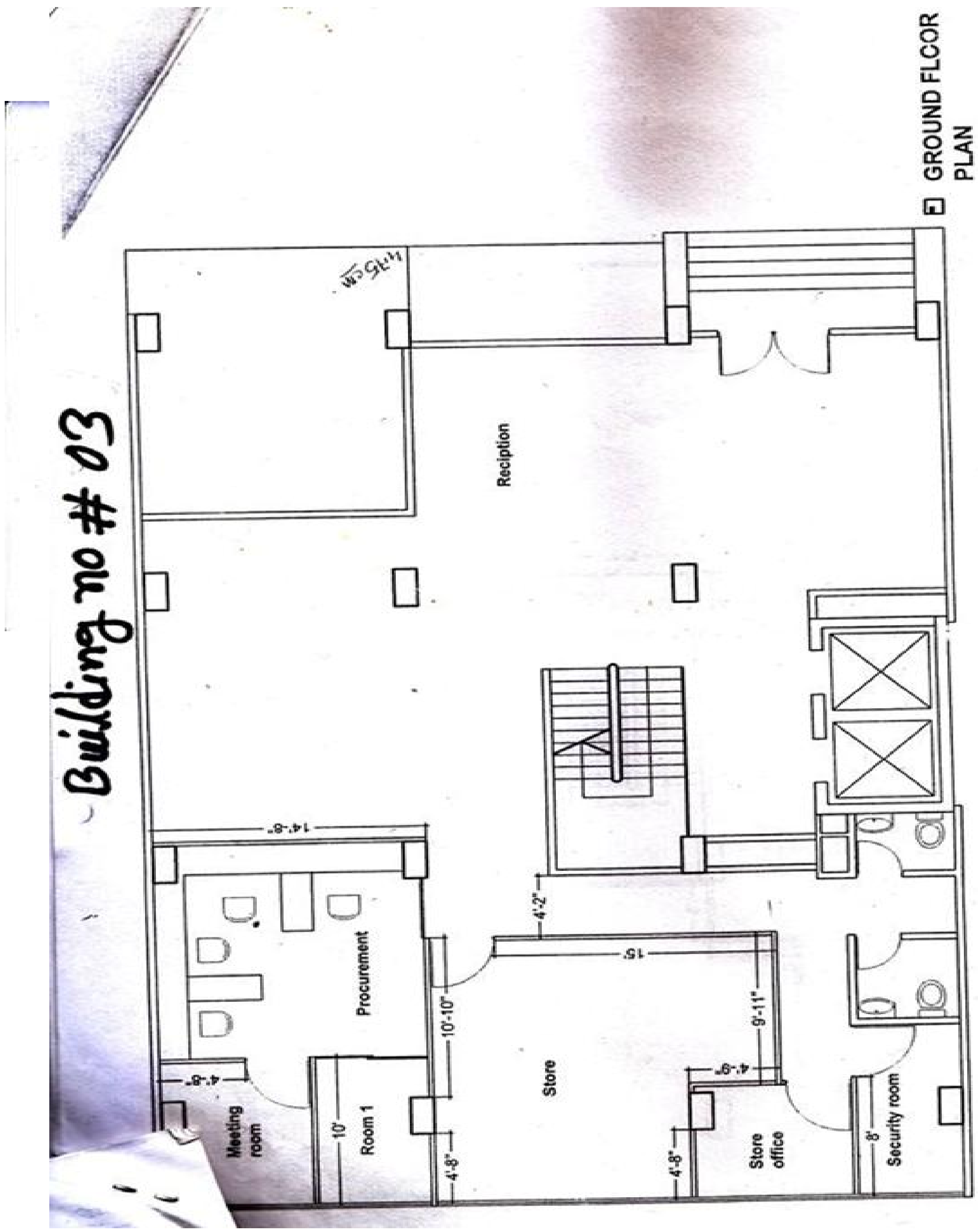
Air Conditioning

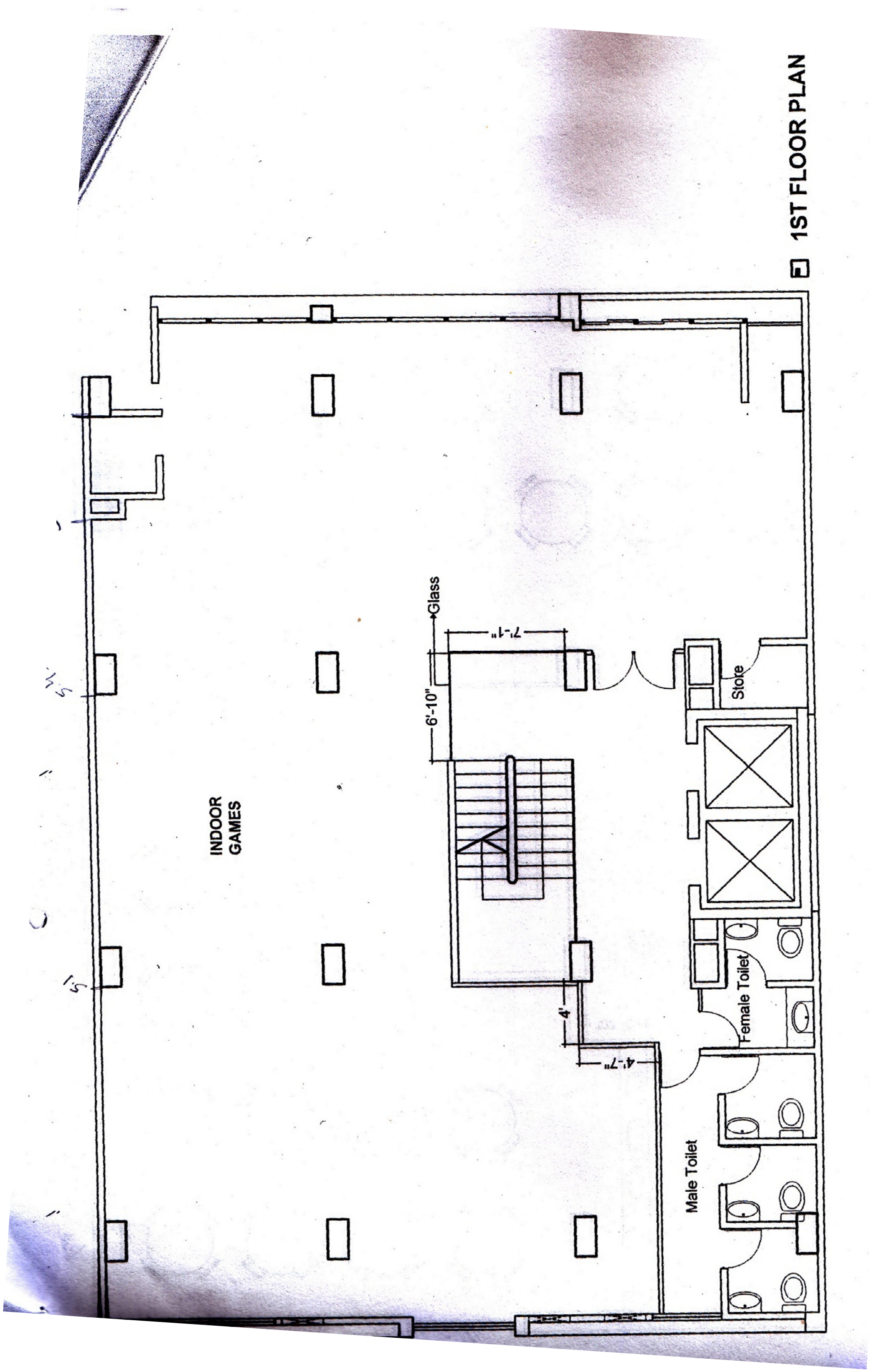
Number of units: 3 Make, type, size, location of each: 4 tonne.

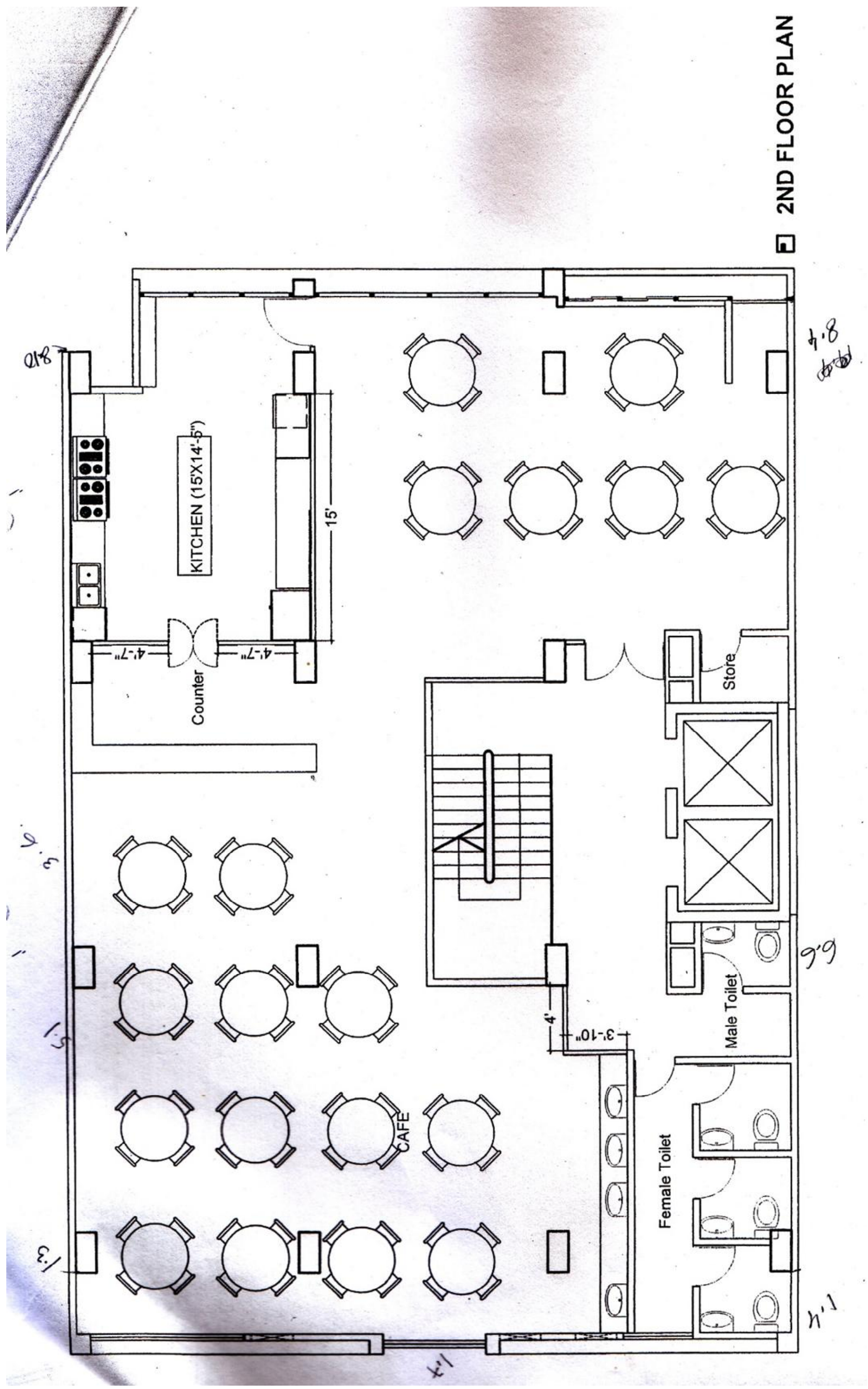
Frequency of servicing: ______ Date of last servicing: ______

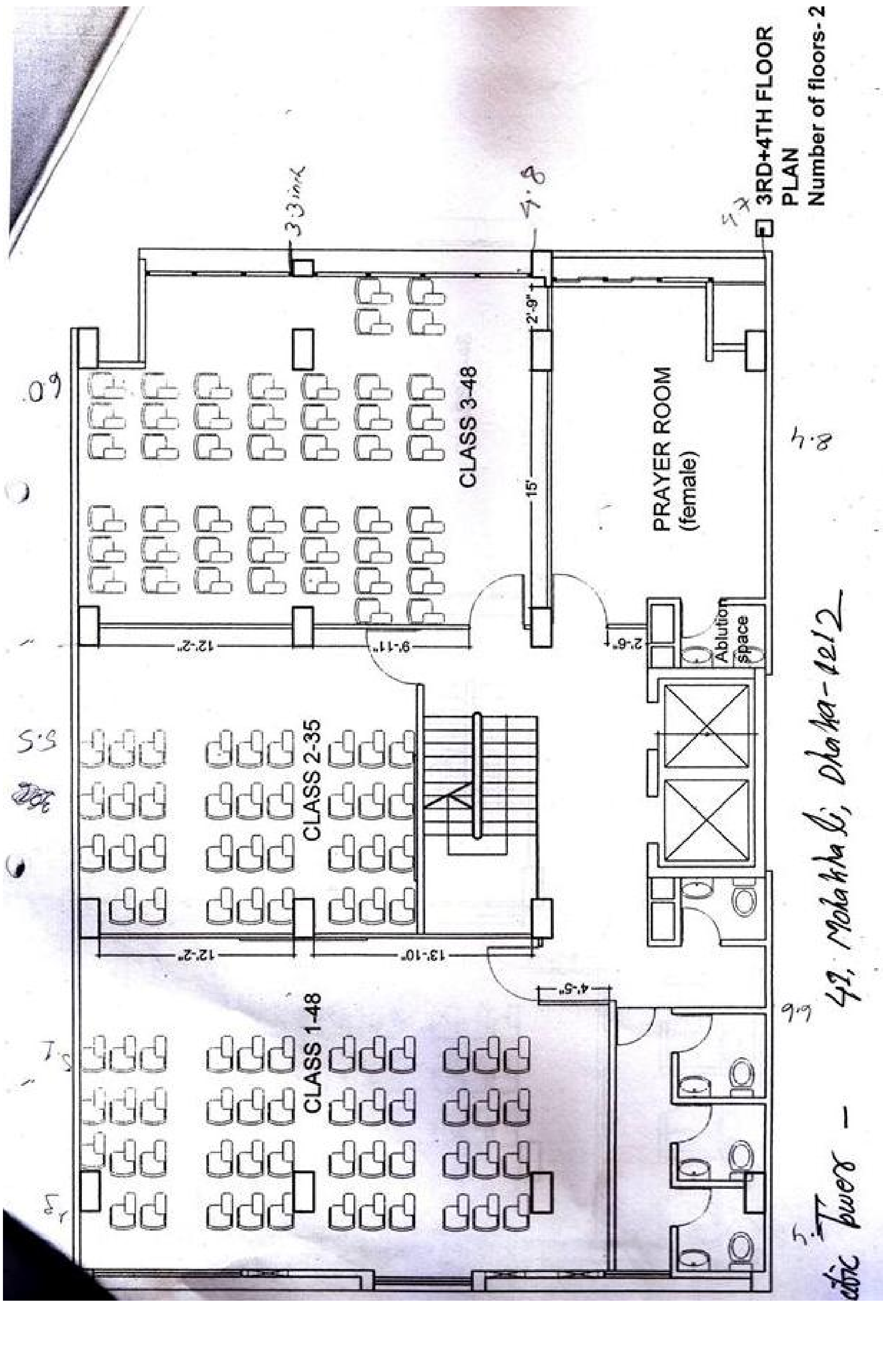
APENDIX C. FLOOR PLAN

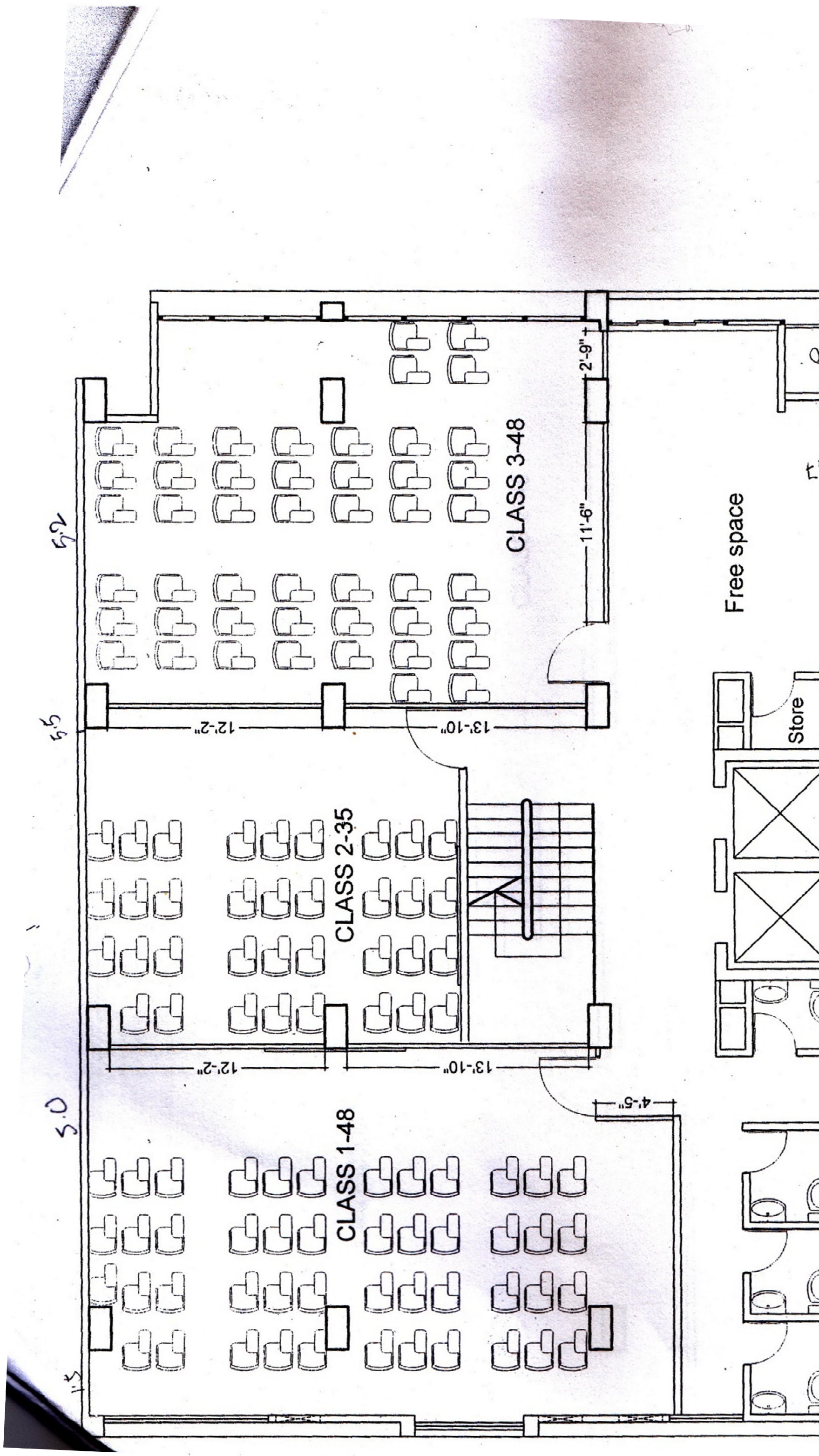
C.1 BRAC University Building 3 Floor Plan



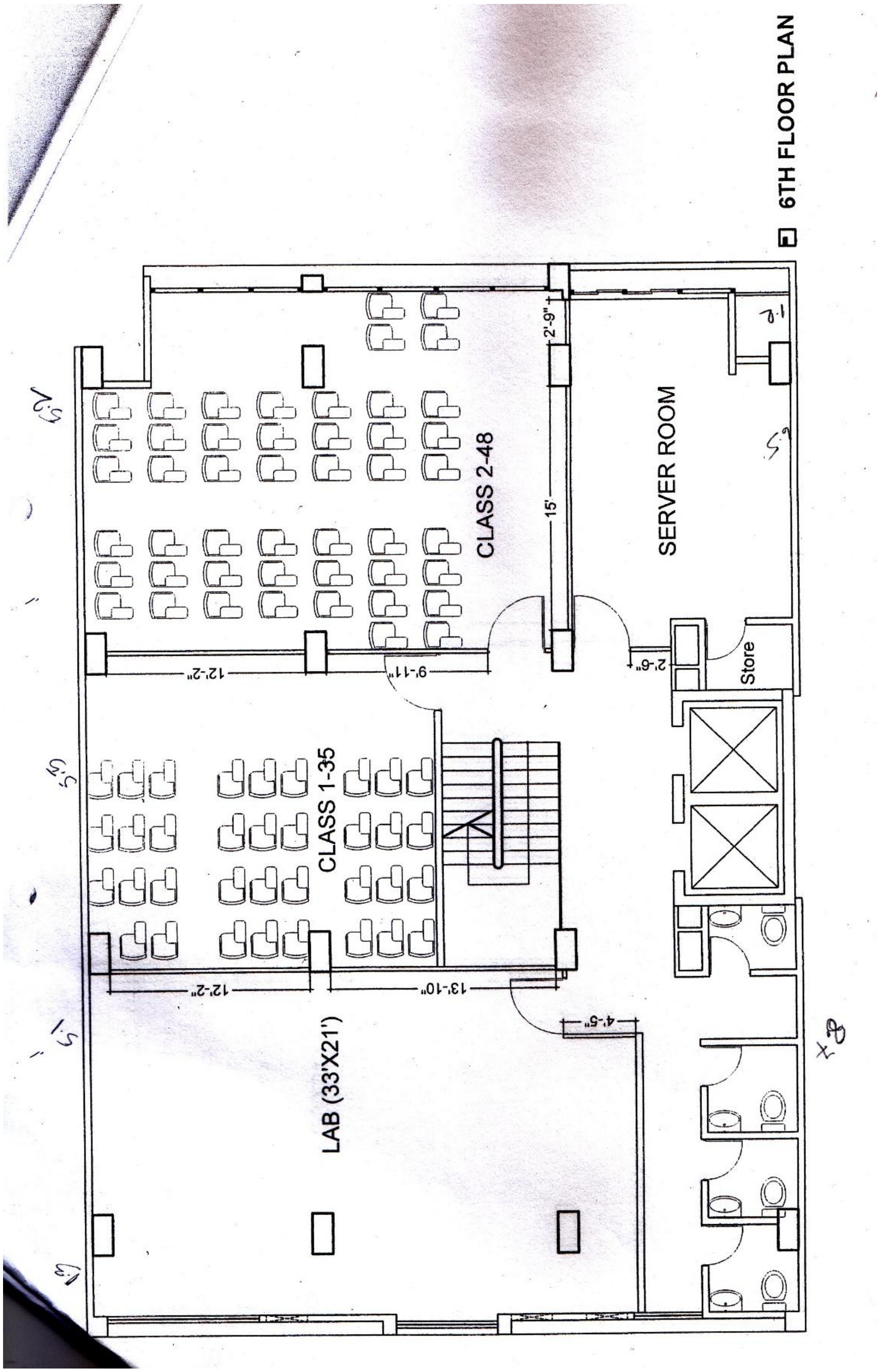

1ST FLOOR PLAN
INDOOR GAMES
Glass
7'-1"
6'-10"
Store
4'
4'-7"
Female Toilet
Male Toilet

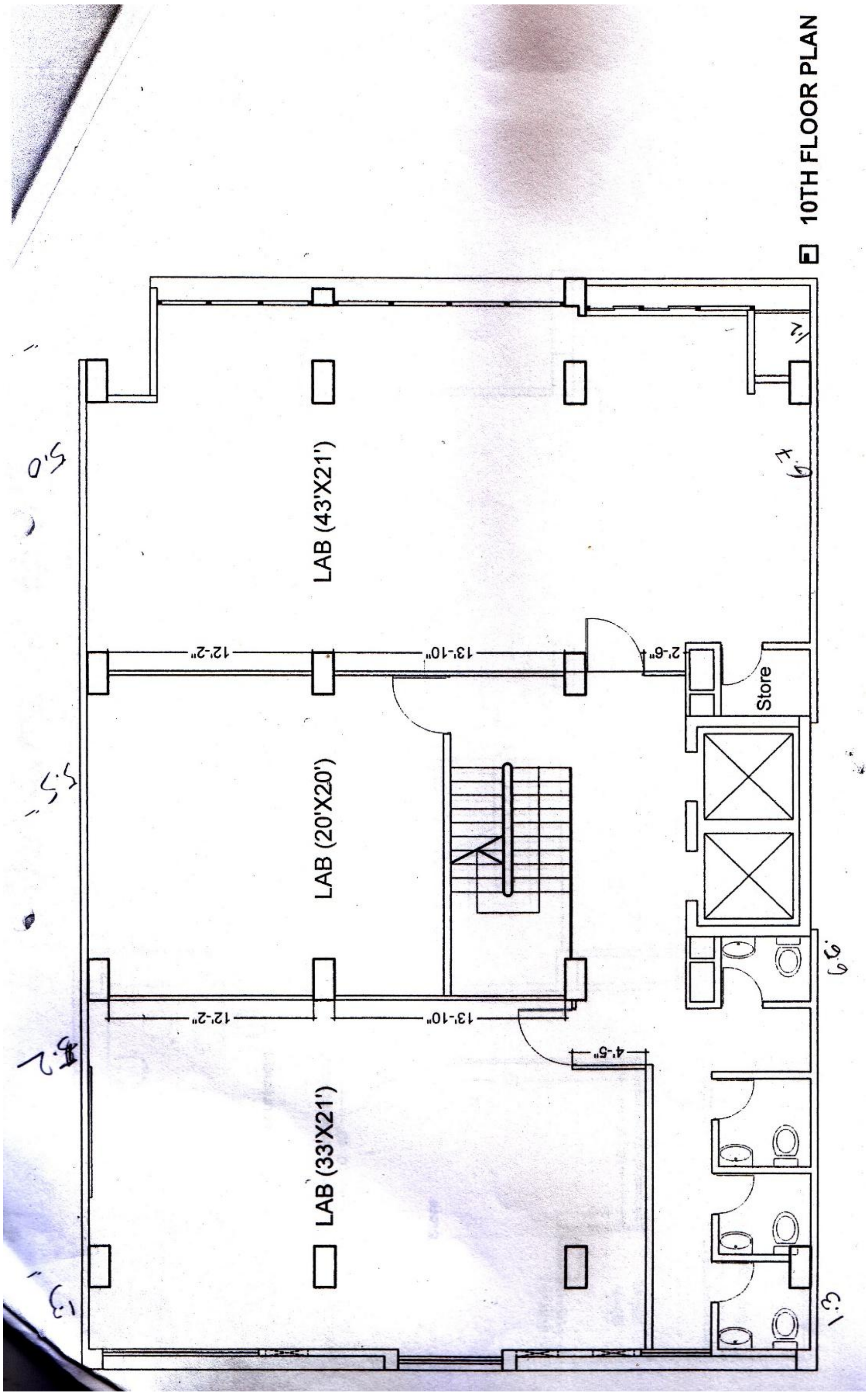

2ND FLOOR PLAN
KITCHEN (15'X14'-5")
15'
4'-7"
4'-7"
Counter
Store
CAFE
Male Toilet
Female Toilet
4'
3'-10"


3RD+4TH FLOOR PLAN
Number of floors- 2
CLASS 3-48
PRAYER ROOM (female)
Ablution space
CLASS 2-35
CLASS 1-48
2'-9"
15'
12'-2"
9'-11"
2'-6"
13'-10"
4'-5"
42, Mohakhali, Dhaka-1212

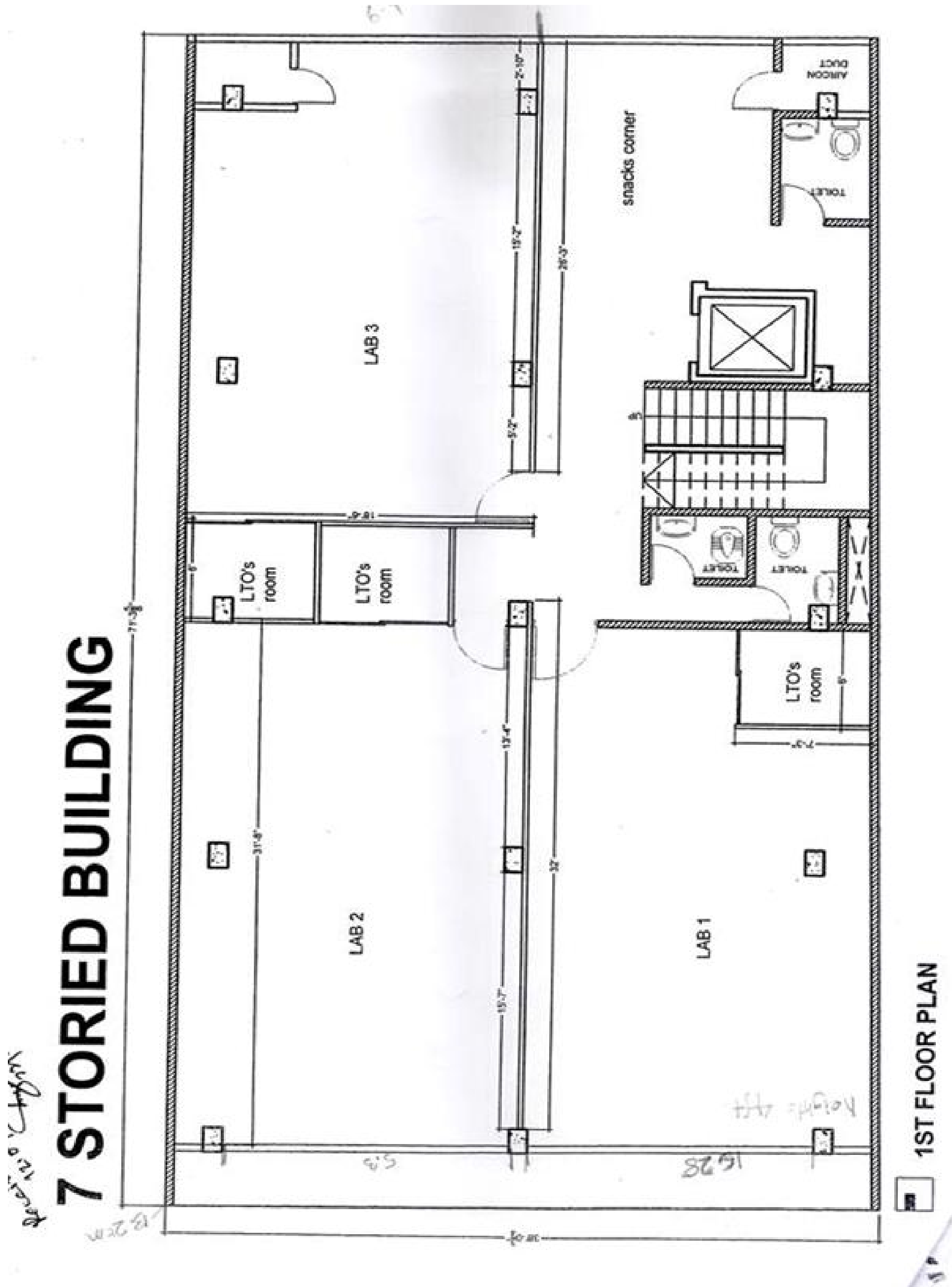


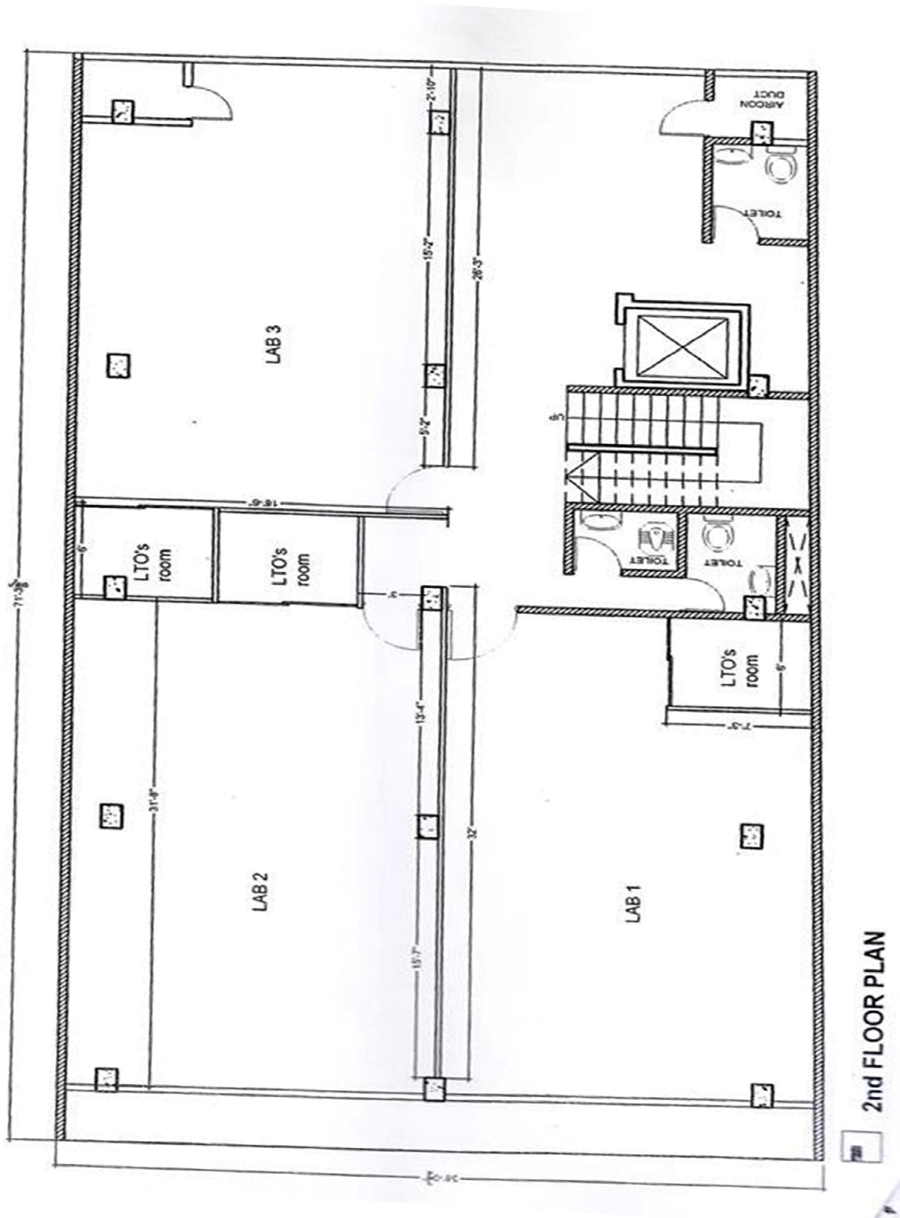
5TH,7TH,8TH,9TH FLOOR PLAN
Number of floors-


6TH FLOOR PLAN
CLASS 2-48
SERVER ROOM
CLASS 1-35
LAB (33'X21')
Store
2'-9"
15'
12'-2"
9'-11"
2'-6"
12'-2"
13'-10"
4'-5"

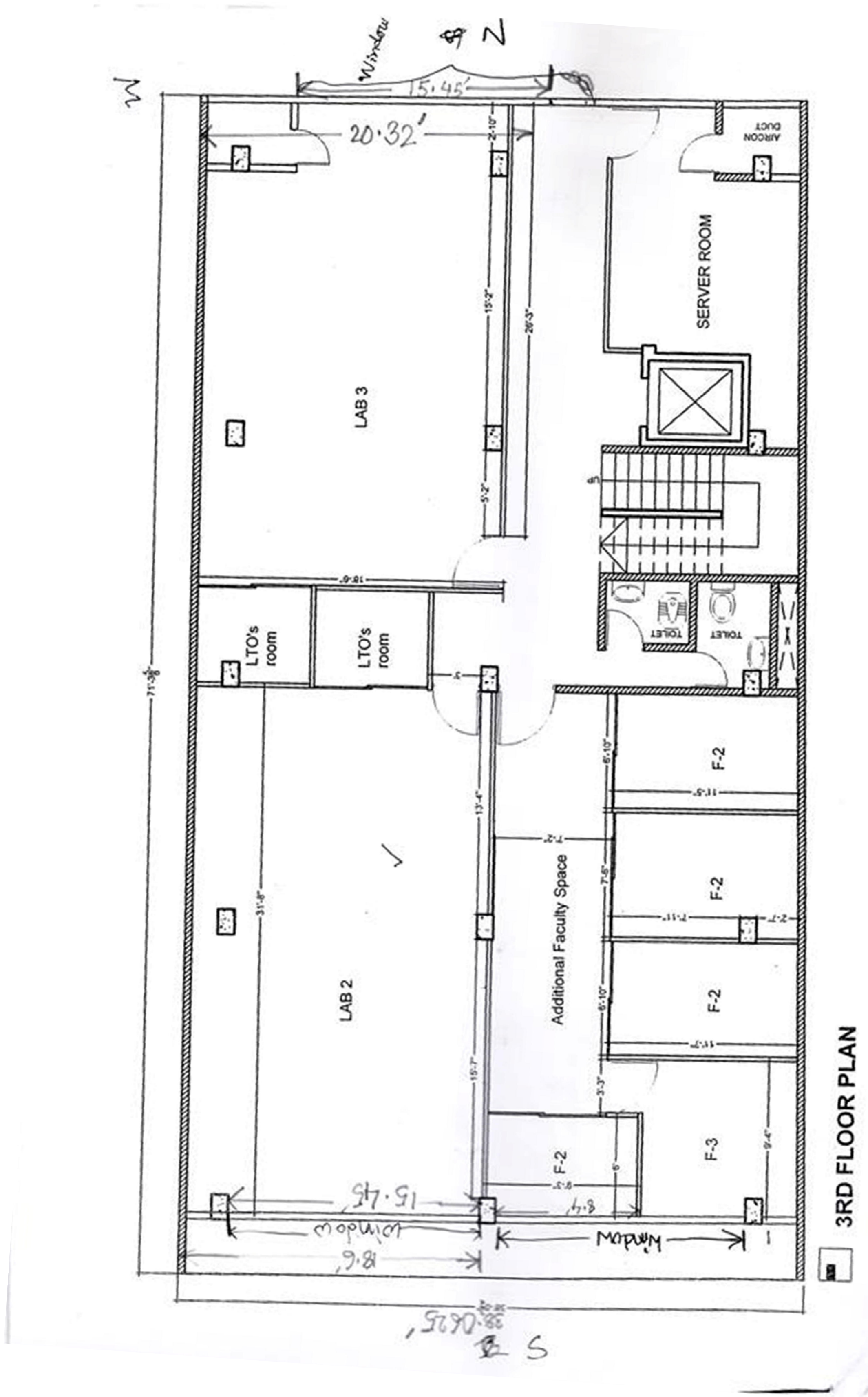

10TH FLOOR PLAN
LAB (43'X21')
LAB (20'X20')
LAB (33'X21')
Store
12'-2"
13'-10"
2'-6"
12'-2"
13'-10"
4'-5"

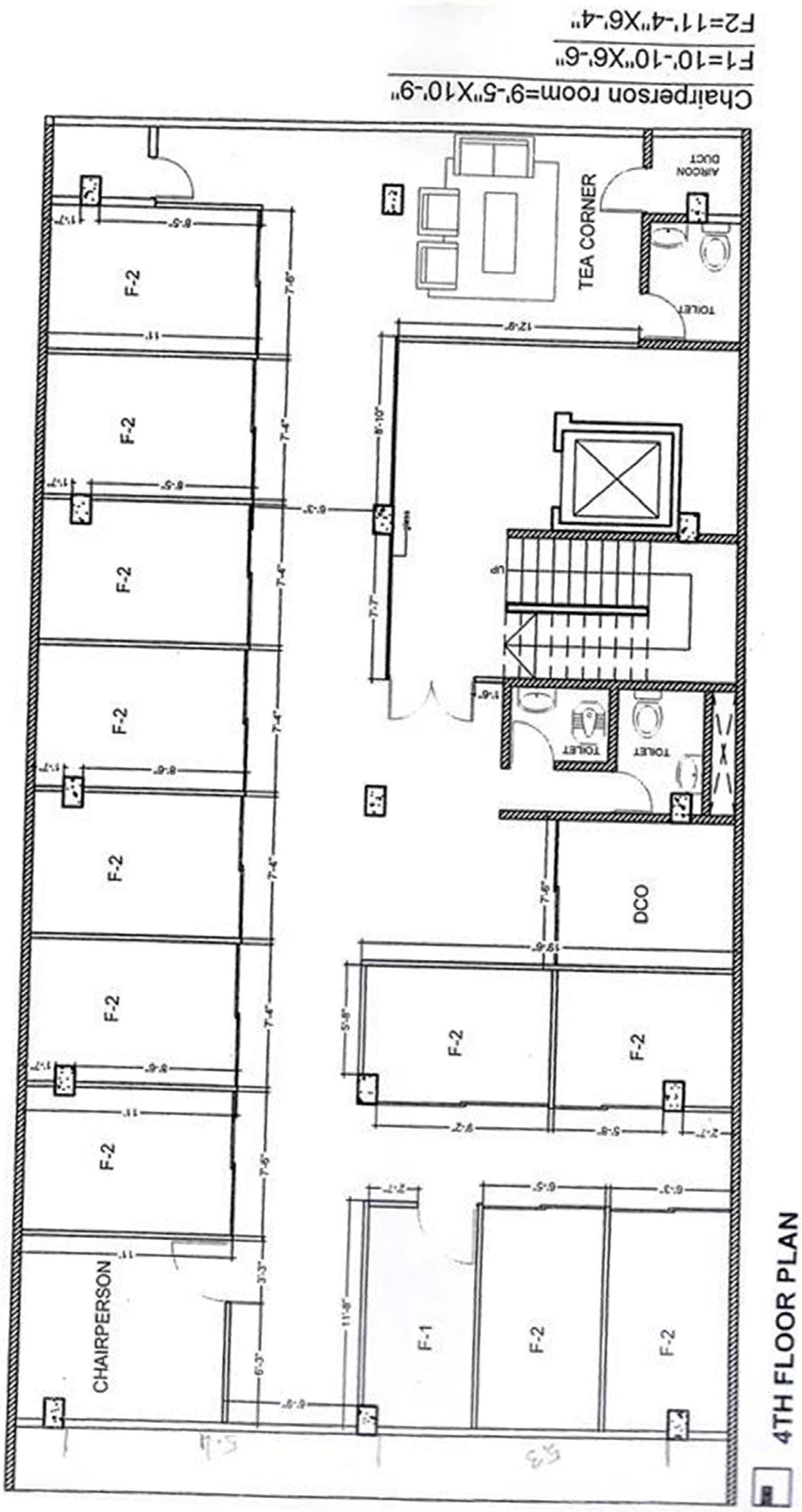
C.2 BRAC University Building 5 Floor Plan

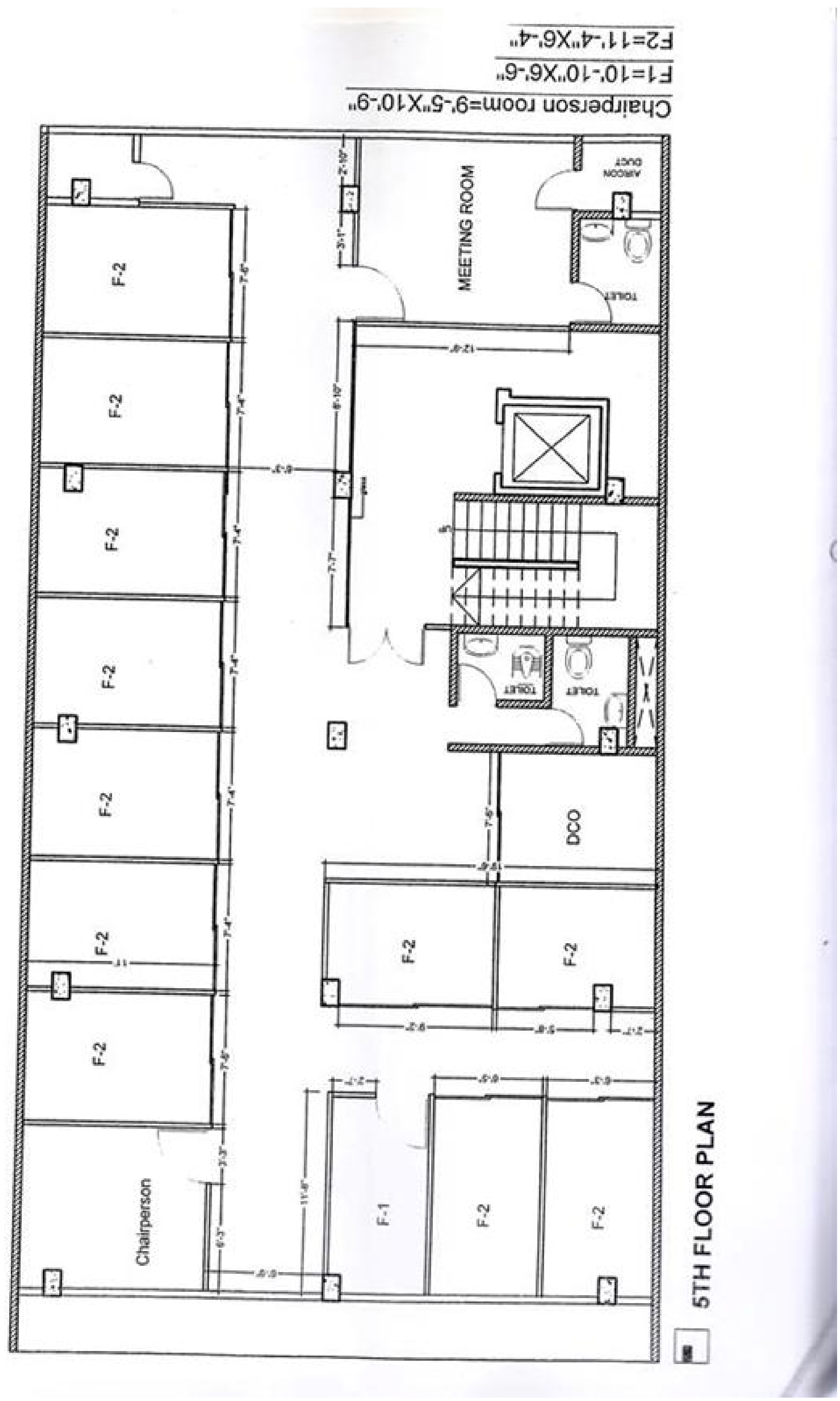




2nd FLOOR PLAN


3RD FLOOR PLAN
LAB 3
LAB 2
SERVER ROOM
AIRCON DUCT
LTO's room
LTO's room
TOILET
TOILET
Additional Faculty Space
F-2
F-2
F-2
F-2
F-3
Window
20·32'
15·45'
18·6'
8·4'
38·0625'
N
S
E
W


4TH FLOOR PLAN
Chairperson room=9'-5"X10'-9"
F1=10'-10"X6'-6"
F2=11'-4"X6'-4"
TEA CORNER
AIRCON DUCT
TOILET
UP
DCO
CHAIRPERSON
F-1
F-2



Chairperson room=9'-5"X10'-9"
F1=10'-10"X6'-6"
F2=11'-4"X6'-4"
MEETING ROOM
TOILET
AIRCON DUCT
F-2
F-2
F-2
F-2
F-2
F-2
F-2
Chairperson
DCO
F-2
F-2
F-1
F-2
F-2
TOILET
TOILET
5TH FLOOR PLAN