# INTEGRATION CHALLENGES OF ENERGY EFFICIENT BUILDING (EEB) CONCEPT IN BUILDING DESIGN: RESIDENTIAL BUILDING IN KHULNA AS CASES

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## ABSTRACT

Buildings are responsible for approximately 40% of the total world annual energy consumption (Yeang and Spector, 2011 & Gascoigne, 2001). Buildings use 50% of the world's raw materials many of which are non-renewable resources and they are responsible for 36% of all waste generated worldwide (Graham, 2002). While the building industry in the developed region has already implemented strategies to make buildings more energy efficient, developing countries are struggling to embrace and implement sustainability issues in building design. Administrative barriers, lack of monetary/budget, lack of skills of clients & professionals, lack of consciousness, and other factors make it more difficult to adopt techniques of Energy Efficient Building (EEB) construction. The study investigates the field level integration challenges of EEB concept and develops a framework that could help the corresponding authority and professionals. For data collection and analysis, the 3-steps of study used a mixed method. Firstly, three broad indicators that are related to the building's energy efficiency were selected through literature review. These indicators include water services, electricity and ventilation systems, and waste management systems. Among these indicators, the significance of the electrical system in the energy efficiency of buildings is elaborately discussed in this study. Additionally, the attributes and sub-attributes of passive and active strategies of EEB envelopes are identified based on literature review. Secondly, the field data collected under an inventory checklist. Physical study of the buildings, list down of electrical items used by residential apartments, discussion with electrical experts, and user feedback's regarding energy efficieny were also applied to gather further primary data for this research. Finally, the collected data will be analyzed following various data analysis methods such as coding, content analysis etc. As cases, more than 6-story residential buildings in Khulna, a mid-sized growing city in southwestern Bangladesh, have been taken. However, this research reveals the barriers to implement EEB concept during construction as well as several passive strategies of EEB construction. EEB's may be simply constructed by appropriately utilising such passive techniques while planning and constructing building envelopes. This study also demonstrated that by utilizing solar energy from Photovoltaic (PV) solar panels, the overall cooling and lighting energy demand for residential apartments could reduce, promoting energy efficient and sustainable building.

***Keywords:*** *Building industry, Energy saving, Energy Efficient Building (EEB), 3-Steps of study*

## 1. INTRODUCTION

Global energy demand has greatly expanded as a result of modern lifestyles, rising populations, and improved economic conditions. Like in the current situation, practically all human activities require energy to be completed. These energy-intensive activities have greatly increased the world's total energy demand and led to an unsustainable energy system as well as causing serious environmental concerns. Buildings are responsible for approximately 40% of the total world annual energy consumption (Yeang and Spector, 2011 & Gascoigne, 2001). Buildings use 50% of the world's raw materials, many of which are non-renewable resources and they are responsible for 36% of all waste generated worldwide (Graham, 2002). Additionally, the building sector is accountable for 25% to 33% of black carbon emissions, nearly two-thirds of halocarbon emissions, and around one-third of energy-related CO2 emissions. As a result, the world's least developed nations are suffering the most from the lack of energy sources since they are finding it difficult to adopt and execute concerns related to energy efficiency and sustainability in building design. According to AIA (2013), the building industry accounts for 39% of overall energy use, 68% of total electricity consumption, 30% of landfill trash, 38% of CO2 emissions, and 12% of total water use in the United States. The design, manufacturing, construction, and operation of the buildings in which we live and work are responsible for the consumption of energy and natural resources. Residential energy consumption comprises all energy consumed by households, such as heating, cooling, lighting, water heating, and other consumer demands. As a result, this industry requires immediate attention in order to enhance energy efficiency and integrate renewable energy technology. So, the adoption of energy conservation concept and implementation of EEB construction techniques would play a crucial role for fulfilling the growing energy demand of developing countries and in the creation of sustainable cities in the future.

However, energy demand will continue to rise in the future unless the building industry pays close attention to reducing demand and shifting from conventional to renewable energy sources. Furthermore, due to the rise in energy demand and consumption, there has been a corresponding rise in Greenhouse Gas (GHG) emissions and climate change concerns, which has led to the emergence of serious problems including deadly storms, heat waves, and catastrophic droughts. The fifth assessment report from the Intergovernmental Panel on Climate Change (IPCC) provided 95% assurance that GHG emissions are the primary cause of global warming. The report also reveals that using non-renewable energy sources drastically altered the climate and caused serious consequences for both humans and ecosystems that are widespread and irreversible. Therefore, it was advised in the report that suitable steps be implemented right now in order to keep the global temperature rises below 2°C compared to preindustrial levels and to mitigate the effects of climate change.

While the building industry in the developed countries has already implemented strategies and techniques to make buildings more energy efficient and sustainable, developing countries like Bangladesh are struggling to adopt and implement the EEB construction techniques and sustainability issues in building design. Administrative barriers, lack of monetary/budget, lack of skills of clients & professionals, lack of consciousness, and other factors make it more difficult to adopt and execute techniques of EEB construction. However, the study investigates the field level integration challenges of EEB concept and also develops a framework as well as provides the necessary guidelines that could help the corresponding authority and professionals for implementing energy efficient and sustainable building construction techniques. Finally, this research reveals the barriers and hurdles to implement the EEB construction techniques due to lack of client's and practitioner's awareness, as well as lack of building industry preparedness to accept the EEB concept.

## 2. LITERATURE REVIEW

The concept of sustainable development was first proposed by the World Commission on Environment and Development (WCED), often known as the Brundtland Commission, in 1987. The WCED received widespread support for its position that development must secure the cohabitation of the economy and the environment by defining sustainable development as "development that meets the needs of the present without compromising future generations' ability to meet their own needs". There are numerous approaches to addressing the Energy sustainability issues, but achieving energy sustainability through EEB is becoming increasingly important nowadays. The building sector uses approximately 40%-50% of the natural resources available in any industrialized country. Almost half of the total energy utilized by a building is used to cool/heat the interior environment. Hence, the demand of EEB was felt strongly around the world, particularly in developing countries like Bangladesh. To put the idea of EEB into practice, there are both active and passive ways. Active strategies include Heating, Ventilation, Air-Conditioning (HVAC), and illumination while passive strategies include considerations regarding the building envelope (Table-1).

A building envelope is the surface that separates a building's indoor atmosphere from its outdoor environment. This includes walls, roofs, fenestrations, external shadings, thermal insulation, thermal mass, and so on. EEB can be built to be energy sustainable by using properly designed building envelopes. It has been revealed that specialized designs of independent building envelopes can assure approximately 31%-36% energy savings. An energy-efficient building envelope design reduced overall and peak cooling demands by up to 35% and 47%, respectively. Building envelopes therefore play a crucial part in an EEB.

## 2.1 Components of Energy Efficient Building (EEB) Envelopes

*Table 1: Characteristics of Energy Efficient Building Construction Elements*

| Broad Category | Attributes | Sub-Attributes | Descriptions | References |
|---|---|---|---|---|
| Passive Strategies | Walls | 1. Passive Wall | Passive solar walls efficiently collect and transmit solar energy. These walls are constructed with a 12” concrete thickness façade to absorb solar radiation. Trombe walls, Insulated Trombe walls, Unventilated Solar walls, and Composite Solar walls are the four major techniques to achieve energy efficiency within buildings utilizing passive solar walls. Trombe walls and Unventilated Solar walls are favored for longer summer seasons, whilst composite solar walls and insulated Trombe walls are preferable for shorter heating seasons. | 1. Zalewski L, Lassue S, Duthoit B, Butez M. Study of solar walls-Validating a Simulation Model. Buildings and Environment 2002; 37(1):109–121. |
| | | 2. Trombe Wall | PV solar cell integration on Trombe walls can produce improved outcomes in EEB. Photovoltaic Trombe wall (PV-TW), is currently used for both space heating and cooling. Phase Change Material (PCM) based Trombe walls are stronger than concrete walls. | |
| | | 3. Double Skin Wall | There is an air gap maintained in these walls. Both forced and artificial ventilations are used to ventilate the cavity that is thus produced. Energy savings expand with air gap width up to an optimum value of 0.15 m, after which they begin to decline. | |
| | | 4. Wall with Latent Heat Storage | The heat storage capability of a wall is improved via PCM impregnation. Weight-based PCM impregnation is more effective. Researchers discovered that PCM-based walls reduced maximum indoor temperatures by up to 4–4.2°C. PCM-based walls should have favorable environmental characteristics. | 2. Jie J et al. Modelling of novel Trombe walls with PV cells. Buildings and Environment 2005; 42:1544–1552. |
| | | 5. Lightweight Concrete | Concrete walls were popular due to their low cost and labor requirements during construction. These walls are thermally resistant and their thermal resistance can be increased by utilizing lightweight materials such as pumice, diatomite expanded clay, polystyrene, vermiculate, and so on. Lightweight Concrete (LWC) walls are common in places where thermally insulated walls are not generally used. | |
| | Roofs | 1. Green Roofs | Green roofs are a passive cooling method that uses vegetation on roofs to prevent solar radiation from reaching the roof surface. Green roofs are preserved in two to three layers, including a water-proofing membrane, soil layer and drainage layer. Green roofs provide multiple environmental benefits such as rainwater management, enhance air quality & roof durability, improve the aesthetic value and decrease of the urban heat island effect. Extensive and intensive green roofs are the two types of green roofs. As extensive green roofs consist of a thin substrate layer, large plants can't survive. Conversely, as intensive green roofs consist of a deep solid layer, shrubs can be grown easily. Extensive green roofs are preferable over intensive green roofs for less maintenance. | 3. Athienitis AK, Liu C, Hawes D, Banu D, and Feldman D. Investigation of the thermal performance of a passive solar test-room with wall latent heat storage. Building and Environment 1997; 32(5):405–410. |
| | | 2. Domed Roofs | Domed roofs were commonly found in traditional styles of structures in the Middle East, where the environment is extremely hot and arid. Due to greater surface area, domed roofs absorb more heat, but they also quickly radiate after sunset. | |

| Broad Category | Attributes | Sub-Attributes | Descriptions | References |
|---|---|---|---|---|
| | | 3. Reflective Roofs | Solar reflective roofs have been referred to as cool roofs. Typical conventional roofs have solar reflection (SR) values that range up to 20%, which can be further enhanced to 60% by using aluminum coating. However, it has been found that energy savings in air cooling during the summer exceed energy use throughout the winter for warming up the indoor spaces of building. As a result, such coated roofs are more beneficial when winter does not occur properly. | 4. Williams NSG et al. Green roofs for a wide brown land: Opportunities and barriers for rooftop greening in Australia. Urban Forestry & Urban Greening 2010; 9(3):245–251.<br><br>5. Tang R, Meir IA, Wu T. Thermal performance of non-air-conditioned buildings with vaulted roofs in comparison with flat roofs. Building and Environment 2006; 41(3):268–276. |
| | | 4. Evaporative Cooling Roofs | The latent heat evaporative technique is used to cool an evaporative cooling roof. Fixed top roofing insulation and moving top thermal insulation both use shallow water reservoirs on flattop roofs. It has been found that using a roof reservoir can reduce a building's internal temperature by up to 20°C. Another method of evaporative cooling in which water saturated into bags is spread across roofs to create evaporative cooling. This technique can reduce indoor temperatures by up to 15°C. | |
| | | 5. Photovoltaic Roof Envelopes | Photovoltaic (PV) Solar Panel are one of the most popular and cost-effective renewable energy sources. This is an effective way of directly generating power from solar radiations while causing no harm to the environment. Solar panels are used in photovoltaics to generate energy from solar radiation while requiring little maintenance and lasting for a long period. PV elements are now becoming integrated components of buildings that not only meets the energy demands but also secures building envelopes, generates thermal insulation. PVs can be integrated with building envelopes in a variety of ways. These might be used to create saw tooth patterns and canopies on the outside of buildings, which would provide passive shading in addition to aesthetic appeal. | |
| Active Strategies | **HVAC System** | 1. Heating and Cooling Split System | Heating and cooling Split systems are the most frequent types of HVAC systems. As the name implies, it is divided into two independent units, one for heating and the other for cooling. In this system, a traditional thermostat is used to keep the temperature within a comfortable range. | 6. Sanjay M, Prabha C. Passive cooling techniques of buildings: Past and present—A review. ARISER 2008; 4(1):37–46). |
| | | 2. Hybrid Split System | This HVAC system has a hybrid heating system, which is one of its distinguishing characteristics that contributes to reducing energy expenses. This system is similarly reliant on standard ducts and thermostats, and it provides all of the benefits of a split system with the added bonus of conserving energy and lowering utility expenses. | |
| | | 3. Duct Free (Mini-Split) | A duct-free or mini-split HVAC system is an excellent choice for situations where traditional ducted systems are ineffective. It can also be a good replacement for current ducted HVAC systems. Ductless units are frequently put directly into the parts of a home that require heating and cooling. | |

### 2.2 Codes & Regulations Regarding Energy Efficient Building (EEB) Construction

Implementation of EEB construction techniques are not mandatory in Bangladesh since the Bangladesh National Building Code (BNBC) does not give any firm guidelines for land owners, clients, and experts about EEB construction techniques. The first Building Act is approved in 1952. The building act was modified in 1996, resulting in a comprehensive building code for building construction. Dhaka Imarat Nirman Bidhimala formed in 2008 for building developments inside Dhaka City. And, BNBC 2020 is the most recent edition of building construction codes and regulations. Although BNBC 2020 mentions the integration of green roofs, rainwater management systems, and the installation of PV Solar Panels into roofs during the construction process, it does not provide any comprehensive guidelines for land owners, clients, and professionals regarding EEB construction techniques. As a result, lack of skills of clients & professionals, lack of consciousness among land owners, clients & professionals, and other factors make it more difficult to adopt and execute techniques of EEB construction.

## 3. METHODOLOGY

The case-based exploratory study took the residential buildings from the Khulna context for data collection. Khulna, a coastal city in the Southwestern part of Bangladesh, is considered a fast-growing city for infrastructural developments. Additionally, the climate migrants from the coastal region put excessive pressure on the city's growth. In recent times, the city has experienced immense built-environment growth more than ever before. It’s very important to consider energy efficiency ideology in construction to face present and future resource use and management.

For data collection, firstly, the study reviewed the research articles and building codes related to Energy Efficiency. Secondly, the survey was conducted considering the building energy consumption, construction materials, and other factors. Discussions with architects, owners, and experts were also performed to get in-depth information regarding the energy efficiency of the building.

## 4. FINDINGS AND ANALYSIS

Findings regarding’s passive and active design strategies of the case study buildings (Table 2), energy consumption of the case study buildings (Table 4&5) is discussed below:

## 4.1 Findings Regarding Design Strategies of the Case Study Buildings

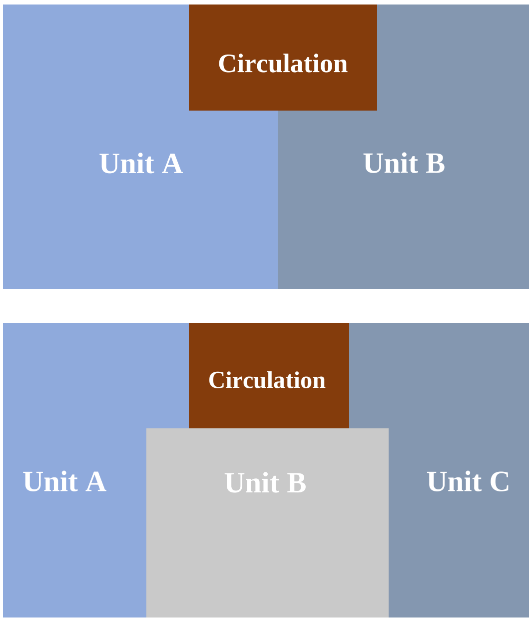
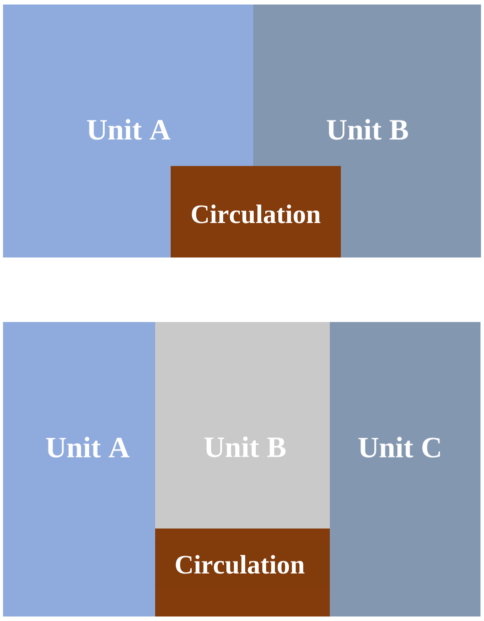
*Table 2: Design Components & Their Standards of Case Study Buildings*

| Broad Category | Attributes | Sub-Attributes | Descriptions | Standards |
|---|---|---|---|---|
| Passive Strategies | Walls | 1. Brick Masonry Wall | Maximum external walls of the case study buildings are of 250mm & 125mm solid brick. Both the external and internal walls have a cement plaster finish over the brick and white wall treatments. During the interview, some residents complained about the excessive and unpleasant solar heat gain on the western and eastern side of the buildings due to the lower thickness (125mm) of the wall. They now feel that if the exterior walls on the western and eastern side had been 250mm thicker, the solar heat gain would have been reduced. | The typical heat resistance value of 250mm thick solid brick walls is 0.325 m2KW-1. 250mm thick solid brick walls Solid walls can account for up to 45% of total heat loss in a builiding. |
| | | 2. Brick Cladding Wall | Some exterior walls of the case study buildings that face the roadside are clad with light colored facing bricks. As the case study buildings are located in a busy urban area, the use of brick cladding wall offers structures with better insulation from both noise and heat gain. Even with the exception of fixing the mortar in the grooves between the bricks, brick cladding walls also require very little maintenance. Therefore, it may be concluded that the occupants of the brick-clad structures would have benefited more. | Clay brick wall with plastered on both sides cuts over 50% of the noise from outside. Ambient noise is lowered from approximately 65dB (moderate to loud) to less than 20dB (barely audible). |
| | Roofs | 1. Gravel Roof | Some roofs of the case study buildings are flat and approximately 150 mm thick which is constructed of reinforced concrete slab (R.C.C Slab) and gravel course to protect the underlying layer of roofing materials. To protect the roof from ultraviolet (UV) rays, a layer of gravel, or small stones, is put on top of the final coat of asphalt on roofs. The weatherproofing layer of gravel increases the life of the roof's surface by preventing cracking, blistering, and deterioration. | The top layer of a gravel roof is gravel, which protects the underlying layers from UV rays and weather damage. The gravel also provides a slip-resistant surface. Gravel roofs can last for 20-25 years with proper maintenance. |
| | | 2. Flexible Roofing Compound | Some roofs of the case study buildings are flat and approximately 150 mm thick that is constructed of reinforced concrete slab (R.C.C Slab) and roof coating course. Flexible Roofing Compound is an outstanding roof coating that seals and prevents moisture infiltration from the outer surface, keeping the roof protected. Flexible Roofing Compound has an outstanding value of Total Solar Reflectance (TSR). It offers good levelling, opacity, and water repellency, as well as anti-algal and anti-carbonation qualities. | Flexible Roofing Compound can reflect 75% to 84% of solar radiation in the shade, which helps to lower surface temperature by up to 3° Celsius when compared to conventional coatings. |
| Active Strategies | HVAC System | 1. Heating and Cooling Split AC | According to the field survey, Heating and Cooling Split 1Ton A.C. is used in some case study dwelling units. Heating and cooling Split systems are the most frequent types of HVAC systems. As the name implies, it is divided into two independent units, one for heating and the other for cooling. | |

## 4.2 Findings Regarding Energy Consumption of the Case Study Buildings

The case study buildings are located in Sonadanga Residential Area, an upper-income neighbourhood in the city centre of Khulna. Khulna Development Authority (KDA), an autonomous body, holds responsibility for the Sonadanga Residential Area. At first, we selected thirty residential buildings following random sampling process from the Sonadanga Residential Area and found approximately eighty apartments. Among them we randomly picked thirty apartments/units for unit level details data collection. Those apartments were broadly classified into two categories 3BHK Unit & 2BHK Unit (Table 3). The following table (Table 3) shows the attributes of the buildings, and other details including functions and planning schemes of residential apartments.

*Table 3: Details and Planning Schemes of Case Study Buildings*

| Broad Category | House Details | Basic Functions | Planning Schemes |
|---|---|---|---|
| **3BHK Unit (Type-I)** | Name: SAYED VALLEY<br>Location: Sonadanga Residential Area<br>Address: Holding No. 286/3, Plot No-09, Road No-05, Sonadanga Residential Area, Khulna-9203, Khulna.<br>Height: Seven-Storied Multi-Unit Residential Building<br>Dwelling Units: 14 Nos. | Living Room<br>Bedroom (02)<br>Master Bedroom with Attached Toilet<br>Dining Room<br>Kitchen<br>Common Toilet<br>Balcony (02) |  |
| **2BHK Unit (Type-II)** | Name: TALUKDER PALACE<br>Location: Sonadanga Residential Area<br>Address: Holding No. 189/2, Plot No-04, Road No-02, Sonadanga Residential Area, Khulna-9203, Khulna.<br>Height: Eight-Storied Multi-Unit Residential Building<br>Dwelling Units: 16 Nos. | Living Room<br>Bedroom (01)<br>Master Bedroom with Attached Toilet<br>Dining Room<br>Kitchen<br>Common Toilet<br>Balcony (01) |  |

### 4.2.1 Total Energy Consumption of the Case Study Buildings

The total energy usage of the case study buildings dwelling units is determined by unit size, occupancy pattern, appliances utilized, power rating of the appliances, and length of use. As the study focuses on energy efficiency factors that may be addressed though planning and design, it excludes the energy efficiency of various electrical equipment's and energy efficiency linked to everyday behaviours that cannot be impacted by design. The energy consumption of dwelling units was computed for a normal summer month, when the highest temperature might reach 35-40°C. The monthly total energy consumption for a typical summer month for 3BHK unit with 2Nos. AC, 3BHK unit without AC, & 2BHK unit is calculated as follows:

#### *4.2.1.1 For 3BHK Unit (1040Sq.Ft with Circulation)*

A standard 3BHK dwelling unit comprises three bedrooms, a living room or hall room and a kitchen. From field survey, these basic functions are found in 3BHK unit of case study buildings. The lighting equipment's (LED Bulb, Tube Light) in the 3BHK unit of the case study buildings is from the Osaka Company, while the cooling equipment's (Ceiling Fan) is from the BRB company. Power of different electrical equipment's for 3BHK unit is mentioned in the Table 4. To calculate the total energy consumption for a typical summer month for 3BHK Unit with 2Nos. AC, 3BHK Unit without AC, the following equation is used.

E=PT, where, E= Amount of Energy Consumption, P= Power of Electrical Equipment's & T= Time

*Table 4: Power of Electrical Equipment's for 3BHK Unit*

| Function | Size | Power of Electrical Equipment's | Function | Size | Power of Electrical Equipment's |
|---|---|---|---|---|---|
| Living Room | 10'6"x14' | LED Bulb - 01(40W)<br>Tube Light - 01(40W)<br>Ceiling Fan - 01(75W)<br>TV - 01(150W) | Dining Room | 10'x12' | Tube Light - 01(40W)<br>Ceiling Fan - 01 (75W)<br>Refrigerator - 01 (900W)<br>Washing Machine - 01 (1200W) |
| Bedroom - 01 | 11'x13' | LED Bulb - 01(40W)<br>Tube Light - 01(40W)<br>Ceiling Fan - 01(75W)<br>Split 1Ton A.C - (1250W) | Common Toilet | 4'x8' | LED Bulb - 01(15W) |
| Bedroom - 02 | 10'x13' | LED Bulb - 01(40W)<br>Tube Light - 01(40W)<br>Ceiling Fan - 01 (75W) | Kitchen | 8'8"x11' | LED Bulb - 01(25W)<br>Rice Cooker - 01(1000W) |
| Master Bedroom with Attached Toilet | 11'x14' | LED Bulb - 01 (40W)<br>Tube Light - 01(40W)<br>Ceiling Fan - 01 (75W)<br>Split 1Ton A.C - (1250W)<br>Bulb (Washroom) - 15W | Balcony (02) | 4'x8' | LED Bulb - 02(30W) |
| | | | | | Total Power of Electrical Equipment's = 6600W |
| | | | | | Total Power of Electrical Equipment's without AC = 4100W |

Considering that all of these electrical equipment's, with the exception of the A.C, washing machine, and rice cooker, are used for 6hours per day. Assume that, the A.C operates 3hours per day, washing machine operates 30 minutes once a week, and the rice cooker operates 1hours per day.

So, Total Energy Consumption per day for 3BHK unit (2 AC) = (1870*6) + (2500*3) + (1200*0.07) + (1000*1) =19804watt-hour =19.8KWh.

Now, Total Energy Consumption per month for 3BHK unit (2 AC) = (19.8*30) =594KWh.

Again, Total Energy Consumption per day for 3BHK unit (Without AC) = (1870*6) + (1200*0.07) + (1000*1) =12304watt-hour =12.3KWh.
Now, Total Energy Consumption per month for 3BHK unit (Without AC) = (12.3*30) = 369KWh.

#### *4.2.1.2 For 2BHK Unit (780Sq.Ft with Circulation)*

A standard 2BHK dwelling unit comprises two bedrooms, a living room or hall room and a kitchen. From field survey, these basic functions are found in 2BHK unit of case study buildings. The lighting equipment's (LED Bulb, Tube Light) in the 2BHK unit of the case study buildings is from the Osaka Company, while the cooling equipment's (Ceiling Fan) is from the BRB company. Power of different electrical equipment's for 2BHK unit is mentioned in the Table 5. To calculate the total energy consumption for a typical summer month for 2BHK Unit, the following equation is used.

E=PT, where, E= Amount of Energy Consumption, P= Power of Electrical Equipment's & T= Time

*Table 5: Power of Electrical Equipment's for 2BHK Unit*

| Function | Size | Power of Electrical Equipment's | Function | Size | Power of Electrical Equipment's |
|---|---|---|---|---|---|
| Living Room | 12'x12' | LED Bulb - 01(50W)<br>Ceiling Fan - 01 (75W)<br>TV - 01 (100W) | Dining Room | 10'x10' | LED Bulb - 01(40W)<br>Ceiling Fan - 01 (75W)<br>Refrigerator - (800W)<br>Washing Machine - 01 (1000W) |
| Bedroom – 01 | 10'x12' | LED Bulb - 01(40W)<br>Ceiling Fan - 01 (75W) | Common Toilet | 4'x6' | LED Bulb - 01(10W) |
| Master Bedroom with Attached Toilet | 12'x12' | LED Bulb - 01 (40W)<br>Ceiling Fan - 01 (75W)<br>Bulb (Washroom) - 10W | Kitchen | 7'x10' | LED Bulb - 01(20W)<br>Rice Cooker - 01(1000W) |
| Balcony (01) | 4'x8' | LED Bulb - 01(10W) | | | |
| | | | | | Total Power of Electrical Equipment's = 3420W |

Considering that all of these electrical appliances, with the exception of the washing machine, and rice cooker, are used for 6hours per day. Assume that, the washing machine operates 30 minutes once a week, and the rice cooker operates 1hours per day.

So, Total Energy Consumption per day for 2BHK unit= (1420*6) + (1000*0.07) + (1000*1) = 9590watt-hour =9.60KWh.
Now, Total Energy Consumption per month for 2BHK unit= (9.6*30) = 288KWh.

### 4.2.2 Energy Consumption for Cooling

According to the following table, the percentage of cooling energy consumption for 3BHK unit (2 AC), 3BHK unit (Without AC) and 2BHK unit is 49.20%, 18.30%, and 18.75% respectively (Table 6). As, 3BHK unit (2 AC) are more dependent on cooling, so, the percentage of cooling energy consumption for 3BHK unit (2 AC) is comparatively very higher than 3BHK unit (Without AC) and 2BHK unit. The percentage of cooling energy consumption for 3BHK unit (Without AC) and 2BHK unit is almost same.

*Table 6: Calculation of Energy Consumption for Cooling*

| Energy Used | 3BHK Unit (2 AC) | 3BHK Unit (Without AC) | 2BHK Unit |
|---|---|---|---|
| Cooling Energy Consumption per month | 292.5KWh | 67.5KWh | 54KWh |

| | | | |
|---|---|---|---|
| Total Energy Consumption per month in KWh | 594KWh | 369KWh | 288KWh |
| Energy Consumption for Cooling in % | 49.20% | 18.30% | 18.75% |

### 4.2.3 Energy Consumption for Lighting

The energy consumed for lighting the residential buildings varies significantly. Lighting consumes 12% of the energy used by a residential building in the United States (UNEP, 2007), while lighting accounts for 9% of the energy used in residential buildings in India. In Taiwan, however, lighting accounts for 40% of all residential sector power usage in buildings (Yang and Hwang, 1993). According to Nagarajan (2006), compact fluorescent light (CFL) is energy efficient and consumes 80% less electricity than incandescent light. The energy consumed for lighting in case study building dwelling units is shown below that is vary depending on the types of light, the number of lights, the power rating, and the usage of lights.

*Table 7: Calculation of Energy Consumption for Lighting*

| Types of Lighting | 3BHK Unit (2 AC) | 3BHK Unit (Without AC) | 2BHK Unit |
|---|---|---|---|
| LED Bulb | 08 | 08 | 07 |
| Fluorescent (Tube Light) | 05 | 05 | None |
| Total Number of Artificial Lights | 13 | 13 | 07 |
| Energy Consumption for Lighting per month in KWh | 80.1KWh | 80.1KWh | 39.6KWh |
| Total Energy Consumption per month in KWh | 594KWh | 369KWh | 288KWh |
| Energy Consumption for Lighting in % | 13.48% | 21.70% | 13.75% |

According to the above table, the percentage of lighting energy consumption for 3BHK unit (2 AC), 3BHK unit (Without AC) and 2BHK unit is 13.48%, 21.70%, and 13.75% respectively (Table 7). The percentage of lighting energy consumption for 3BHK unit (2 AC) and 2BHK unit is almost same. As, 3BHK unit (2 AC) are consumes more energy for cooling rather than lighting, thus, the percentage of lighting energy consumption 3BHK unit (2 AC) is lower than 3BHK unit (Without AC). So, it is possible to utilize less lights while maintaining adequate indoor artificial lighting settings. The extra lights in 3BHK unit (Without AC) for aesthetic reasons and, to some part, to indicate the status of the households. Gut and Ackerknecht (1993) advised against using excessive lighting since it contributes to interior heat accumulation.

### 4.3 Conceptualization from Energy Efficient Perspectives

After designing a low-energy building, emphasis could be directed to renewable energy sources to partially supply the energy needs of the building. The energy that is used in the manufacturing and shipping process that makes up renewable energy equipment itself is an energy penalty that is somewhat mitigated by the energy that it generates. The use of biomass for heating can be considered as a renewable energy source. Geothermal heat pumps are occasionally referred to be a renewable energy technology. Solar energy is the primary renewable energy source addressed in this section. Solar energy can be utilised to generate electricity using solar PV systems or to generate heat using solar thermal systems. Module is a term used frequently to describe solar PV panels. There are no moving parts in PV systems. The modules produce direct current (DC) power, which is electricity. An inverter is a control device that transforms this DC power into the alternating current (AC) power used in buildings. The expected production of electricity and the use of a well-established and dependable technology are the advantages of solar PV systems. Breakdown to modules and inverter challenges are among the reliability threats, however they are usually negligible.

According to the Table 6&7, 3BHK unit and 2BHK unit use almost 35-40% of total energy for cooling (fan) and lighting purposes. So, if we can supply these used energies by renewable energy sources (solar energy) through roof-mounted solar panel installations into this case study buildings, these case study buildings will be more energy efficient. Solar panels can provide the necessary cooling (fan) and lighting energy for approximately 30-35% time of a day. Thus, through integrating solar panels into this case study buildings, total energy consumption per day and month for 3BHK units and 2BHK units can be easily reduced to some amount. The required number of solar panels for a 3BHK unit and a 2BHK unit is calculated as follows:

### 4.3.1 Calculation of PV Solar Panels for 3BHK Unit & 2BHK Unit

The following equations are used to calculate the number of solar panels needed to deliver the required cooling (fan) and lighting energy for a 3BHK unit and a 2BHK unit.

- I=P/V, where, I= Amount of DC current, P= Power of cooling (fan) and lighting equipment's, and V= Battery voltage
- I'=I+I", where, I'= Required current from solar panels, I= Amount of DC current, and I" = Charging current of battery
- P'=V*I', where, P'= Required power from solar panels, V= Battery voltage, I'= Required current from solar panels

*Table 8: Calculation of Required Current & Power from Solar Panels*

| Unit Type | Power of Cooling(fan) and Lighting Equipment's, P | Battery Size | Amount of DC Current, I | Charging Current of Battery, I" | Required Current, I' | Required Power, P' |
|---|---|---|---|---|---|---|
| 3BHK Unit | 820Watt | 48V 150Ah Lithium Ion Battery | I=P/V =820/48 =17Amp | Charging current for 150Ah Battery, I" =150*10%=15Amp | I'=I+I" =17+15 =32Amp | P'=V*I' =48*32 =1536W |
| 2BHK Unit | 520Watt | 48V 90Ah Lithium Ion Battery | I=P/V =520/48 =11Amp | Charging current for 90Ah Battery, I" =90*10%=9Amp | I'=I+I" =11+9 =20Amp | P'=V*I' =48*20 =960W |

Now, most residential solar panels on the market today are rated to produce between 250W and 400W each. We consider the solar panels that can generate 340W per panel since its dimension is 66" by 39", which is the standard residential solar panel size.

So, Nos. of Solar Panels for a single 3BHK Unit= Required power from solar panels, P'/Power of individual solar panel= 1536/340= 4.5

As, the case study (G+7storied) buildings (Table 3) include 14Nos. 3BHK dwelling units. So, 63 solar panels of 340W are required for this building to supply the necessary cooling (fan) and lighting energy for 8 hours. As, each solar panel of 340W is almost 18 Sq. Ft in size, so, the needed space for the installation of 63 solar panels of 340W on the roof is 1134 Sq. Ft, nearly 55% of the total roof area. Residents can utilize the remaining roof surface (45%) for hanging clothes and as a gathering space.

Again, Nos. of Solar Panels for a single 2BHK Unit= Required power from solar panels, P'/Power of individual solar panel= 952/340= 2.8

As, the case study (G+8storied) buildings (Table 3) include 16Nos. 2BHK dwelling units. So, 45 solar panels of 340W are required for this building to supply the necessary cooling (fan) and lighting energy for 8 hours. As, each solar panel of 340W is almost 18 Sq. Ft in size, so, the needed space for the installation of 45 solar panels of 340W on the roof is 810 square feet, nearly 52% of the total roof area. Residents can utilize the remaining roof surface (48%) for hanging clothes and as a gathering space.

## 5. DISCUSSION AND CONCLUSION

Building industry requires immediate attention in order to enhance energy efficiency and integrate renewable energy technology as this industry accounts for 39% of overall energy use, 68% of total electricity consumption worldwide. So, the implementation of EEB construction techniques would play a crucial role for fulfilling the growing energy demand of developing countries and in the creation of sustainable cities in the future.

Bangladesh, a developing country of South-East Asia are struggling to adopt and implement the EEB construction techniques and sustainability issues in building design. Implementation EEB construction techniques are not mandatory in Bangladesh since the BNBC does not give any firm guidelines for land owners, clients, and experts about EEB construction. Administrative barriers, lack of monetary/budget, lack of skills of clients & professionals, lack of consciousness, lack of guidelines and other factors make it more difficult to adopt and execute EEB construction techniques.

Some EEB construction techniques, such as the application of brick cladding walls, gravel roofs, flexible roofing compound, PV solar panels, and the use of locally accessible and energy efficient building materials, are currently being used. Because of the high cost of the battery needed to charge the PV solar panels, affordability may become an issue for PV solar panel installation. As a result, further research should be undertaken to determine the appropriateness of the battery used to charge the PV solar panels.

Furthermore, this study focuses on several passive strategies of the EEB envelopes. EEB may be simply constructed by appropriately utilising such passive measures while planning and constructing building envelopes. This study also demonstrates that by installing PV solar panels in both newly constructed and existing structures, the overall cooling and lighting energy consumption for residential dwellings may be decreased to some extent. However, this research is limited to a small portion of Bangladesh and uses certain residential structures as samples. So, if this study can be conducted across a vast region, then the results of the research can contribute to meeting Bangladesh's expanding energy demand as well as boosting awareness among clients, professionals, and designers about EEB construction.

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