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RESEARCH ARTICLE

The effects of thermal insulation on energy consumption in small office buildings in the context of subtropical monsoon climate

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Abstract

Thermal insulation plays a significant role in reducing cooling load as well as energy consumption for air conditioning of an office building in the context of subtropical monsoon climate of Bangladesh because a huge amount of heat gain occurs through building envelope in tropical climatic regions. Although the thermal insulation into the building envelope decreases the heat gain and energy consumption, the existing literature lacks in representing the quantitative measurement of the impact of thermal insulation on the energy consumption in the context of Bangladeshi climate. This study investigates the quantitative impact of thermal insulation on energy consumption of an existing commercial bank. The entire research was carried out from the perspective of energy simulation of a real existing commercial buildings using the Building Information Modeling (BIM) and Building Energy Modeling (BEM) tools. Numerous design alternatives have been developed using different types of building envelope materials for energy simulation. An extensive data analysis of simulation results was conducted to predict the quantitative impact of thermal insulation on energy consumption. This study concludes that the studied building can save 13% energy consumption annually and throughout the lifecycle by incorporating fiberglass thermal insulation and double-glazing low-e windows into the external facades of the building. The output of this work can add new knowledge to the Bangladeshi construction sector about the energy-saving potentiality of thermal insulation that has not prevailed before.

Keywords

Building envelope; Thermal insulation; Building energy efficiency; Building Information Modeling; eQUEST; Green Building Studio

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1. Introduction

The building and construction sector accounted for 36% of total energy consumption and 39% of energy and process-related carbon dioxide (CO2) emissions in 2018, according to the International Energy Agency (IEA) [1]. With economic development around the world, the construction sector's contribution to energy consumption is dramatically increasing. The huge amount of energy consumption for residential and commercial buildings increases the CO2 emissions because most of the energy is generated by the burning fossil fuels. Ultimately, the enormous amount of CO2 emissions confronts the world with great dangers, such as global warming and climate change. An energy-efficient building consumes less amount of

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energy than a conventional building for running all facilities and reduces global warming and climate change by decreasing its energy consumption. It consists of some passive technologies that can passively decrease energy consumption, such as efficient building envelopes, geometry, orientation, natural ventilation and an appropriate window-to-wall ratio. A building requires a lot of energy to keep the room temperature within a comfortable temperature which is usually fixed by the building occupants. It is estimated that about 50%-70% of building energy is consumed for ensuring thermal comfort and the rest 30% is used for lighting and other utilities [2]. Maintaining room temperature within a fixed quantity is very difficult, as heat gain or loss of the interior space of any building happens through a building envelope. In the cold climate region, building interior space always loses its heat to the outside and, for this reason, a heating system is required for building interior space to recover the loss of heat. On the other hand, in the hot climate region, indoor space gains heat from the outdoor environment and a cooling system is needed to build indoor space for balancing the heat gain. One of the most important functions of building envelopes is the control of the heat exchange between exterior and interior because individuals spend 90% of their time in a built environment within a certain thermal comfort level [3]. Thermal insulation into building envelope has a strong influence on controlling the heat flow rate and energy consumption of any building [4, 5]. The efficient thermal insulation acts as a good thermal barrier to slow down the heat flow rate and preserve the comfortable room temperature. Bangladesh is located in a tropical region where a large amount of solar heat gain occurs through the building envelope. Thermal insulation into building envelope structure and window glazing can reduce heat gain significantly and ensure a comfortable built environment passively [6]. At the same time, it reduces the energy consumption required for the air conditioning system by a significant amount [7, 8]. The effectiveness of thermal insulation in reducing energy consumption varies with the microclimate of any building site, as the outside temperature for all climatic conditions does not remain the same. This study investigates the impact of thermal insulation on energy consumption of a commercial building (Bank) located in Bangladesh using building information modeling and Building Energy Modeling (BEM) tools considering the unique subtropical monsoon climatic context of Bangladesh. In the context of the subtropical Bangladeshi climate, the energy saving potential of thermal insulation has also been discovered. For the external façade of the studied building, ten commonly available insulation materials (fiberglass, mineral wool, polyurethane, expanded polystyrene, extruded polystyrene, cellulose, cork, vermiculite, gypsum and perlite) have been investigated in this study. The output of this work can add new knowledge to Bangladesh's construction sector of the potential to save energy by applying thermal insulation to exterior walls and windows that were not previously prevalent.

2. Literature review

This study has summarized some important works on energy efficiency using thermal insulation in the context of various climatic conditions throughout the world. In China, Fang et al. [9] investigated the energy consumption between two chambers, one without thermal insulation and the other with adequate thermal insulation, and Fang et al. [9] saved 23.1% of the energy consumption for air conditioning system of the thermal insulation chamber during the summer testing period consumption. Carpenter [10] researched 25 low-energy buildings around the world and reported that dense insulation, air-tight construction, ventilation for heat recovery and high-performance windows were common techniques to reduce the energy consumption of any building [10]. In the investigation of Cheung et al. [11] of five low energy buildings, envelope design techniques are shown to have a great impact on energy efficiency, and some passive strategies are suggested, such as external wall color, wall insulation, types of glazing, window sizes and shading devices. After implementing these strategies, around 40% of cooling energy consumption is saved by Cheung et al. [11] annually. Optimal insulation strategies contribute to saving about 46.6% of energy consumption and reducing 41.3% of CO2 emissions compared to the conventional insulation process in the USA [12]. Friess et al. [13] has discovered in one of his case study on a residential building in Dubai that appropriate building insulation could save 30% energy consumption. From the analysis of Yu et al. [14], thermal insulation of walls is one of the best strategies to reduce electricity consumption for air conditioning systems by about 11.55%. In another analysis of an office building in Saudi Arabia, the integration of optimal thermal insulation into the building envelope reduces energy consumption by about 40% [15]. Thermally comfortable temperatures can be regulated between 25°C to 31°C in Malaysian residential buildings by incorporating thermal insulation on the envelope and perfect glazing materials [16]. Furthermore, another study reveals that the use of green roof technology in Bangladesh can reduce the internal temperature of 6.8°C than the external temperature in the summer season [17].

Windows are another component of the building envelope that can influence the energy consumption of any building. A significant amount of energy consumption may be reduced by multi-glazed insulating windows. The normal clear single glazing window transmits most of the radiant heat coming from the sun into the interior space. There is a special type of coating in the Low-e (Low emissivity) windows that can reflect most of the sun's radiant heat and decrease the internal heat gain. The best radiant heat reflectance can be provided by the lowest window emissivity value. The studied building has the potential to gain heat from the sun through windows due to microclimatic factors of the building location. For thermal insulation purposes in the studied building, a low-e (e=0.05) type window has been installed for the investigation purposes. Window opening affects thermal comfort and energy consumption in a hot and humid climate for cooling and heating for a variety of seasons [18]. Moreover, thermal comfort is affected by the glazing properties of windows which influences the heating and cooling loads in hot season [19]. Based on the experiment of Alam and Islam [20], using a double low-emitting (argon) glazing window is more beneficial to mitigate energy consumption.

From the above-mentioned works from different climatic contexts, it is clear that thermal insulation energy saving varies comprehensively within different climatic conditions of building locations. It is necessary to know, in a particular climate context, how much energy consumption can be reduced by applying thermal insulation to the exterior walls and windows of any building in order to design an energy efficient building. No quantitative study has yet been conducted in the context of the subtropical climate of Bangladesh that can indicate the energy-saving potential of thermal insulation in the unique subtropical monsoon climate context of Bangladesh. Even the Bangladesh National Building Code (BNBC) has not proposed any thermal insulation application strategies for sustainable construction design.

3. Building information modeling (BIM) and building energy modeling tools

The National Building Information Modeling Standards (NBIMS) committee of USA defines BIM as follows: "BIM is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition" [21]. BIM has quickly changed the conventional way of design, construction and operation of a facility using its revolutionary technology and process [22]. Among various construction stakeholders, some misconceptions prevail that BIM is merely a single software. However, BIM is a set of software, programs and technologies that facilitate the entire lifecycle of any construction facility for the various stakeholders. Because of the integrated database, BIM can store, represent and modify a facility's entire data [23, 24]. The BIM has an emerging impact on the research of sustainability analysis. In the last few years, various types of BIM tools have been developed by several companies for sustainability analysis. Autodesk Revit is one of the most popular and widely used BIM software among other BIM tools. From detailed architectural information, including the thermal properties of building components, Autodesk Revit can create valid energy analytical models of any building. In this research, Autodesk Revit is used as a BIM tool because it has parametric characteristics and a user-friendly interface. The primary benefit of parametric characteristics is that it is possible to change and modify the building components like a single source file. The change and modification of building components can propagate through the overall building objects due to having parametric nature of Revit. Energy simulation tools facilitate engineers, architects and designers tremendously. In order to analyze sustainability options for any building, BEM instruments can pave a productive and precise way to take decisions. Day by day, the development and application of BEM tools is increasing. In order to analyze the energy of the studied office building, this study chose Autodesk Green Building Studio (GBS) and eQUEST. GBS is a cloud-based computing service that helps perform the entire building performance analysis using a validated and proven DOE-2 simulation engine, including energy, water and carbon emissions [25]. The building data can be exported seamlessly and accurately from Autodesk Revit to GBS for energy simulation. GBS can provide valid weather data virtually for any particular location which is required for energy simulations. eQUEST is a user-friendly building energy consumption analysis tool that can generate accurate simulation results by integrating a building creation wizard, an energy efficiency measure (EEM) wizard and graphical results display module [26]. It also uses the DOE-2.2 simulation engine for energy simulation [27]. Validating the energy simulation results obtained from GBS was the reason for using two simulation tools. These simulation results were validated by comparing between GBS and eQUEST simulation results.

4. Methodology

The whole research was conducted by a case study application of a real office building in the contexts of subtropical monsoon climate of Bangladesh. Fig. 1 represents the framework of this work. The entire research work is split into four major components. The study began with a comprehensive literature review on the energy consumption impact of thermal insulation, Building Information Modeling (BIM) and Building Energy Modeling (BEM) tools.

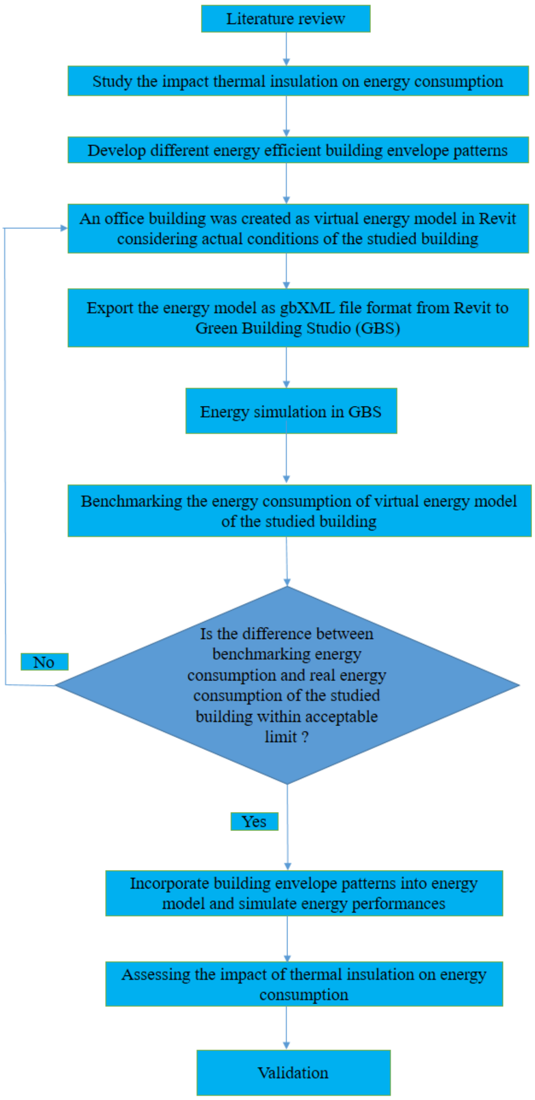


Fig. 1. Framework of the study

In order to make appropriate decisions on the application of the building envelope for the studied office building in Bangladesh, the impact of the building envelope on energy consumption in various regions was also studied. To make it easy to select appropriate tools for this study, the use of different types of BIM and BEM tools in sustainability research has also been studied. Autodesk Revit was selected as BIM tool. Autodesk Green Building Studio and eQUEST as energy simulation tools were chosen as BEM tool.

The second major part is the benchmarking of the energy consumption of the studied building's virtual energy model. To measure the effect of thermal insulation on energy consumption while adopting thermal insulation through the virtual energy model of the studied building, energy consumption benchmarking is required. For this reason, prior to energy simulation, it was essential to create a virtual energy model of the studied building that represented the actual condition. The studied building was observed and investigated very carefully to gather analytical properties of it required for energy simulation. The analytical properties of the studied building such as building envelope materials, occupant number, occupancy schedule, lighting schedule, equipment power loads and schedules were incorporated likewise actual conditions while creating a virtual energy model of the studied building into the BIM tool (Autodesk Revit) for energy simulations. The third step was the whole building energy simulation using Autodesk Green Building Studio and eQUEST. Thermal insulation measures were also incorporated into building envelopes before energy simulation. Two different tools were used for energy simulation to validate and acquire accurate simulation results. Autodesk Green Building Studio was used as the main simulation tool, and eQUEST validated the simulation results by comparing simulation results obtained from two different tools. A simulation result from GBS and eQUEST of a particular run was accepted only when it varied within an acceptable limit. Fourth step, validation of the computational results, the computed energy consumption result of base run compared with real energy data of the studied building to be validated. This comparison with real energy consumption data validated the whole computational data.

4.1. Building descriptions and boundary conditions for energy simulations

The building under study is a two-storey office building called Janata Bank Limited, KUET Branch. The building is located on the campus of Khulna Engineering & Technology University (KUET), Khulna, Bangladesh (22.9005° N, 89.5024° E). Fig. 2 on Google Map shows the geographic location of the building. Though the bank has two floors, the bank authority has occupied only first floor for banking purposes. The floor plan (Fig. 3) represents the three main zones of the bank such as manager zone, bank staff zone and customer zone. The building was also divided into three major zones likewise the floor plan for energy simulation because occupant number, occupancy schedule, lighting schedule, office equipment schedule, sensible heat gain, latent heat gain and other thermal comforting factors were not same for three major zones. Although the total employees of this bank are fifteen, the number of occupants varies between zones according to their purpose. The Manager Zone area is 212 square feet and one person is the number of occupants. The area of the personnel zone is 673 square feet and the number of occupants is fourteen. The customer zone area is 848 square feet and the number of occupants varies at various times of the day.

Fig. 2. Geographic position of the studied building

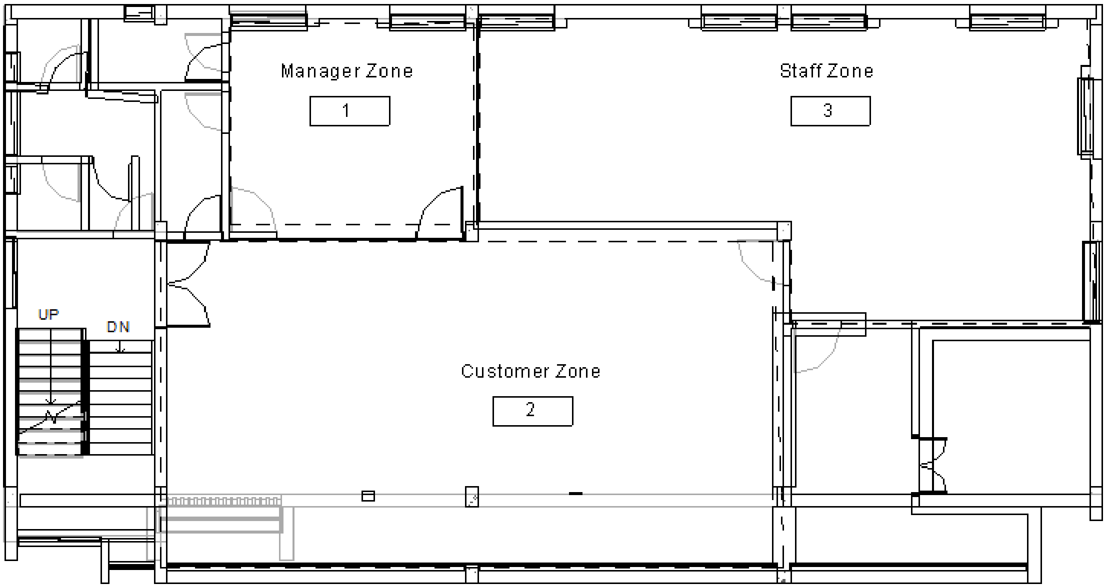


Fig. 3. Floor plan and zone division of the studied building

In addition, after several meetings with him the bank manager gained data about office staff occupancy, lighting and equipment schedule.

Geographic position of Bangladesh is in subtropical monsoon climate which is distinguished by wide seasonal variations in rainfall, high temperatures and humidity. There are three unique seasons in Bangladesh: a hot, humid summer from March to June; a cool, rainy monsoon season from June to October; and a cool, dry winter from October to March. Generally temperatures in summer vary between 30°C and 40°C. April is the warmest month in most parts of the country. The coldest month is January and the average temperature of this month for most of the country is about 10°C. Bangladesh remains hot and humid most of the time in one year. All three zones are directly exposed through the roof and wall to external environments. The building under study does not have thermal insulation materials into the roof and wall. In Bangladesh National Building Code (BNBC), there are no specific documents or regulations about optimum thermal insulation thickness in building envelope. This study therefore considered two inches (0.0508 meter) of external envelope insulation thickness following some reviewed case studies [28-30].

For the transmission of solar radiation into conditioned space, the glazing of the window was adequately clear. In the context of the subtropical Bangladeshi climate, heat gain from building envelopes is important and plays an important role in the dimensioning of air conditioning systems and energy consumption. The studied building adopted an air conditioning system only for cooling to ensure the thermal comfort of the occupants of the building. Though weather conditions have transient nature, the simulations were performed considering steady state condition of weather. Considering above descriptions of the studied building, the boundary conditions are described in Table 1. It is important to set the actual orientation of the building before energy simulation, because orientation could impact the simulation results. The studied building is faced to the actual orientation representing in Fig. 4.

4.2. Benchmarking the energy consumption and perform simulations

The main purpose of this study is to investigate the impact of thermal insulation on energy

Table 1. Boundary conditions for energy simulations

Building Characteristics	Descriptions
HVAC system	Residential 17 SEER split unit
Thermostat set point	For Cooling = 24 Degree Celsius (75 Degree Fahrenheit) Supply Cooled air = 16 degree Celsius (60.8 Degree Fahrenheit)
Condition type	Only cooling No heating
Infiltration	0.036 cfm/square foot through exterior wall 0.010 cfm/square foot through exterior roof
Window wall ratio	As-built condition North Side = 0.20, South Side = 0.80 East Side = 0.20 West Side = 0.23
Shading device	No shading
Occupancy schedule	9 AM to 5 PM (5 days per week)
Lighting Intensity	0.50 Watt/square foot
Office equipment loads intensity	1.8 Watt/square foot for common office activity area 1.0 Watt/square foot for manager room
Sensible heat gain	60 Watt (205 BTU/h) per person
Latent heat gain	50 Watt (170 BTU/h) per person

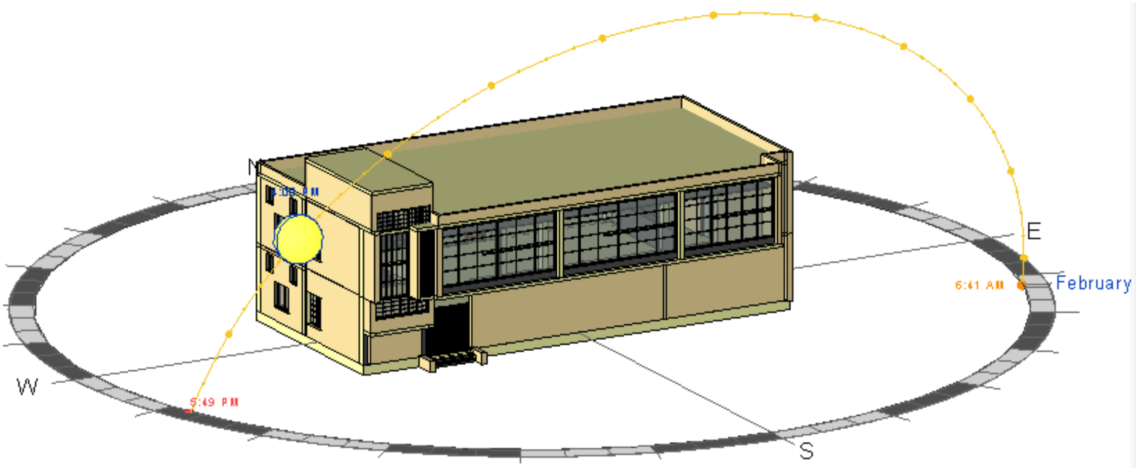


Fig. 4. South orientated energy model of Janata Bank in Autodesk Revit

consumption. To achieve this goal, a comparison between real energy consumption data before adopting thermal insulation and energy consumption data after adopting thermal insulation in the building envelope must be made. It is time consuming and difficult for this research to adopt thermal insulation in the real existing building envelope. That's why this study uses BIM and BEM tools to develop the virtual model of the real office building so that it will be very easy to implement thermal insulation into the real building virtual energy model.

It is very difficult to create a virtual energy model that represents the actual scenario of existing buildings into BIM tools. It requires enormous building information that must be recreated into any BIM software. The authors have the authority to gain an as-built floor plan of the studied building from the planning and development authority of KUET. The 3D model of Janata Bank Limited was created into Autodesk Revit following the as-built floor plan (Fig. 4). Through visiting the building several times, information about the wall, roof, window materials and other internal conditions was achieved. Fig. 5 is also a picture of the 3D energy model of the studied building that was developed in eQUEST. Building geometry and detail thermal properties of building material influences the simulation significantly. Autodesk Revit defines the actual thermal properties of building envelope materials using its parametric characteristics. Energy simulation tools (Autodesk Green Building Studio and eQUEST) consider the definition of thermal properties of each material in any analytical energy model. The annual energy consumption of the virtual model was benchmarked by comparing with real energy consumption data after developing the virtual energy model of the real building. The annual energy consumption of the virtual energy model must vary from real annual energy consumption within an acceptable limit to be benchmarked. According to Table 2, the studied building approximately consumes 18733 kWh electricity annually. 20100 kWh of electricity is consumed annually by the real building's virtual energy model. The energy consumption result of the virtual model varies 6.8% from real consumption data. The acceptable variation between simulated consumption and actual consumption is around +/-15% [31, 32]. So, it is evident that the virtual energy model actually represents the real office building. This benchmarking was done through several iterations.

Table 2. Electricity consumption of JANATA Bank KUET in year of 2018

Month name	Electricity consumption in (kWh)
January-2018	1158
February-2018	1483
March-2018	1338
April-2018	1453
May-2018	1564
June-2018	1450
July-2018	2105
August-2018	1340
September-2018 + October-2018	4105
November-2018	1427
December-2018	1310

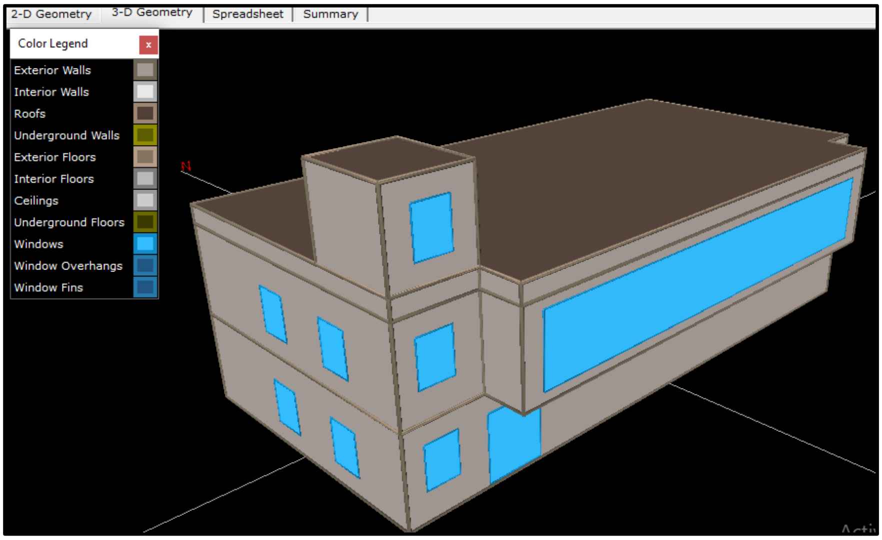
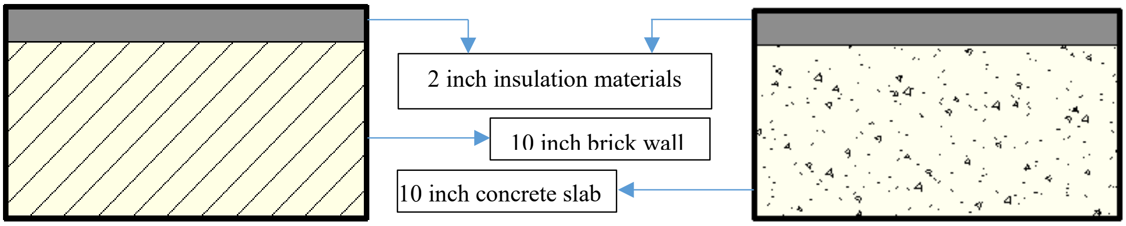


Fig. 5. Energy model of Janata bank developed in eQUEST

In the virtual energy model of the real office building, various types of thermal insulation materials were incorporated for simulations. The simulation process was classified into two cases in Table 3. Case 1 represents the benchmark condition of Janata Bank Limited. The second case of simulation is the application of building thermal insulation into the exterior roof, walls and windows. Using Autodesk Revit, an energy model was developed considering the actual location, orientation, wall construction, roof construction, window construction, number of occupants, occupancy schedule, lighting schedule and schedule of equipment for case 1. The placement techniques and analytical properties of thermal insulation affect the simulation results. Although there are many techniques to implement thermal insulation, this study simply attached thermal insulation to the inner side of the exterior building envelope. Thermal insulation materials were added to the exterior roof and wall for case 2 likewise Fig. 6 (a) and Fig. 6 (b). Table 3 shows the names of energy simulation runs and also reflects the thermal insulation consideration for exterior wall and roof construction. Using ten insulation materials, the building envelope patterns were developed. Only ten insulation materials with lower thermal conductivity than other thermal insulation materials were selected in this study, despite having many insulation materials on the market.

Table 3. Simulation run names for different cases

Case Name	Simulation Run Name	Wall Construction (Exterior)	Roof Construction (Exterior)	Window Construction
Case 1 (Actual Condition)	Base Run	10 inch Brick	6 inch Concrete	Single Glazing, Clear Enough to Transmit Solar Radiation
Case 2 (Application of Thermal Insulation)	Run 1	10 inch Brick + 2 inch Fiberglass	6 inch Concrete + 2 inch Fiberglass	Double Glazing, Blue-green Color and Low e = 0.05
	Run 2	10 inch Brick + 2 inch Rockwool	6 inch Concrete + 2 inch Rockwool	
	Run 3	10 inch Brick + 2 inch Cellulose	6 inch Concrete + 2 inch Cellulose	
	Run 4	10 inch Brick + 2 inch Polyurethane	6 inch Concrete + 2 inch Polyurethane	
	Run 5	10 inch Brick + 2 inch Polystyrene (Expanded)	6 inch Concrete + 2 inch Polystyrene (Expanded)	
	Run 6	10 inch Brick + 2 inch Polystyrene (Extruded)	6 inch Concrete + 2 inch Polystyrene (Extruded)	
	Run 7	10 inch Brick + 2 inch Cork	6 inch Concrete + 2 inch Cork	
	Run 8	10 inch Brick + 2 inch Vermiculite	6 inch Concrete + 2 inch Vermiculite	
	Run 9	10 inch Brick + 2 inch Gypsum Board	6 inch Concrete + 2 inch Gypsum Board	
	Run 10	10 inch Brick + 2 inch Perlite	6 inch Concrete + 2 inch Perlite	



(a) Exterior wall **(b)** Exterior roof

Fig. 6. Thermal insulation

Eleven energy models of the office building were created in Revit, taking into account previous building descriptions (Section 4.1) and Table3. Then each energy model was transferred to Autodesk Green Building Studio as gbxml file format for energy simulation. As presented in Table 3, a total of eleven simulations were performed to compare and observe the effect of the building envelope on energy consumption. Green Building Studio can automatically obtain relevant weather information of any particular location of the building that is required for energy simulation. Again, the virtual energy model was also created in eQUEST considering actual location, orientation, wall construction, roof construction, window construction, occupant number, occupancy schedule, lighting schedule and equipment schedule representing in Fig. 5. Although there are visual differences between the two energy models from two different tools (Figs. 4-5), the analytical characteristics required for energy simulation were the same for both tools. In eQUEST, a total of eleven simulations were also performed for validation purposes. By comparing the energy simulation results from Green Building Studio and eQUEST, the validation was carried out. Validation was completed when the simulation results from the two tools were almost the same. Simulation results validation is required for the accuracy and acceptability of the simulation results. Green Building Studio has interoperable characteristics for transferring data to eQUEST. Sometimes, interoperability causes misleading to export exact geometry and other analytical information of any building. That's why; this study selected two different energy simulation tools for energy simulations. The building envelope patterns were constructed layer by layer with basic wall construction materials and thermal insulations. Because of the different thermal properties of each combination, each combination was assessed differently by BEM tools during energy simulation.

5. Result and discussion

In this section, the simulation results are presented, analyzed and discussed in order to perceive the link between the building envelope and the energy consumption of an office building in Bangladesh. The analysis is carried out on the basis of two parameters, such as annual energy consumption and life-cycle energy consumption. Green Building Studio assumes that the studied building has a 30 year life cycle period. For analysis, only primary energy consumption is taken into account and the loss of energy through electronic transmission is ignored. The simulation results for different run names are presented in Figs. 7-8. The case scenarios are discussed below:

This study developed a constant base case that represented the virtual environment of the studied building to understand the impact of the building envelope on energy consumption for various insulation measures. The base case was developed considering actual location, orientation, wall construction, roof construction, window construction, occupant number, occupancy schedule, lighting schedule and equipment schedule for the studied building. Non-insulated exterior wall, clear single glazing window and south-facing orientation are the characteristics of the studied in base case condition. In this base case scenario, it is obtained from the simulation result of GBS that annual and lifecycle energy consumptions are 20100 kWh and 602991 kWh respectively.

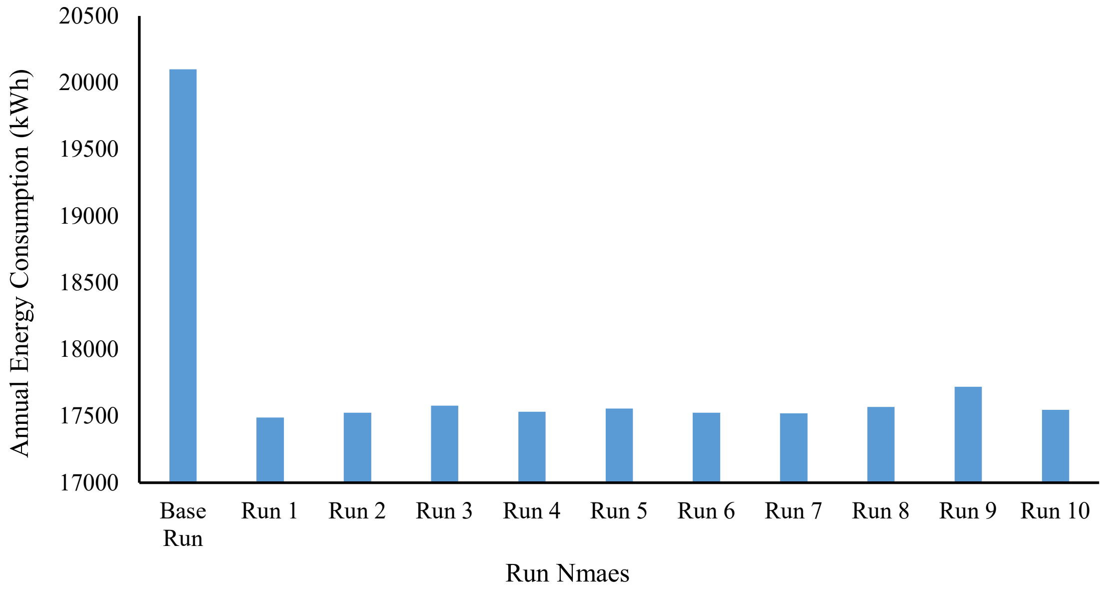


Fig. 7. Annual energy consumption of different Run names

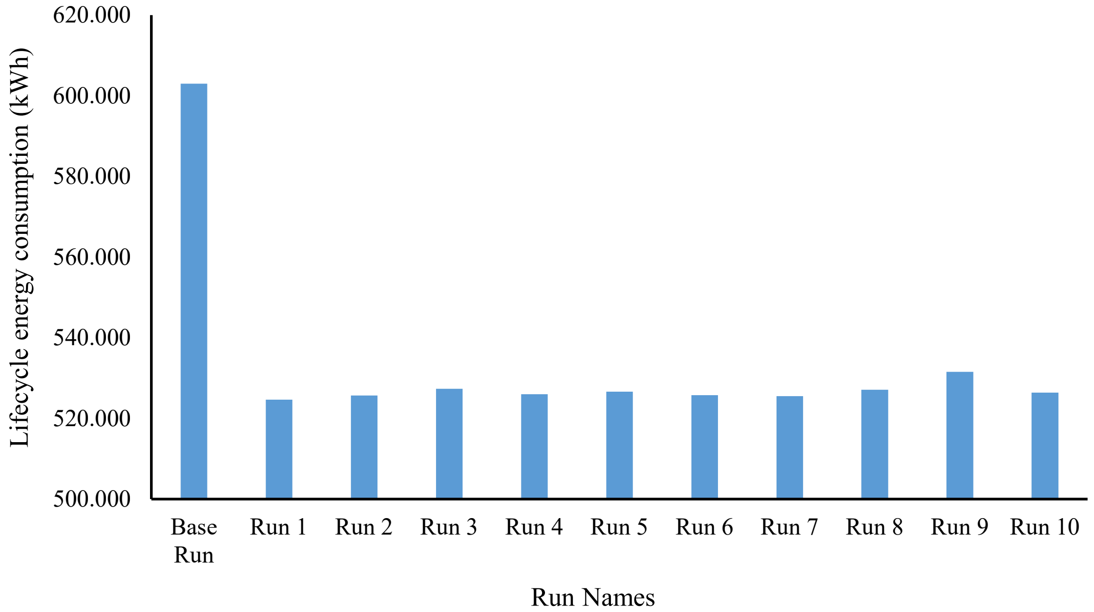


Fig. 8. Lifecycle energy consumption of different Run names

The application of thermal insulation measures was incorporated into the building envelope from Run 1 to Run 10. Thermal insulation was added to the building envelope as shown in Table 3, keeping all analytical parameters constant, with the same base case or case 1. The difference between the base case and the Run 1 energy consumption result is a measure of the impact of thermal insulation on energy consumption. In Run 1, building exterior roof and walls were insulated with 2-inch fiberglass (foil-faced). Fiberglass is a form of blanket insulation and can be used to fill voids in metal building walls and roofs as additional insulation. The average thermal conductivity of this type of insulation varies from 0.033 W/m.K to 0.030 W/m.K. The base window type is also replaced by double glazing low-e blue-green windows. In this Run 1 case, it is exhibited by simulation result from GBS that annual and lifecycle energy consumptions are 17489 kWh and 524571 kWh respectively.

The exterior roof and walls of the building were insulated with 2 inch Rockwool insulation materials in the Run 2 case scenario. Rock wool is also named as slag wool or mineral wool insulation. It is made of rock, blast furnace, sand and other raw materials. Rockwool is used as a type of mats or bats insulation. This type of insulation has an average thermal conductivity of 0.037 W/m.K. Window type was kept same as Run 1. For the Run 2 case scenario, the studied building's annual and lifecycle energy consumptions are 17524 kWh and 524709 kWh respectively.

The building exterior roof and walls were insulated with 2 inch Cellulose insulation materials for Run 3 case scenario. Cellulose thermal insulation is produced using the mass of reused paper or wood fibers It can be used for hard boards and as filler materials. The mean thermal conductivity of this cellulose ranges from 0.046 W/m.K to 0.054 W/m.K. The window type is maintained in the same way as Run 1. The simulation result of Run 3 is obtained from GBS that annual and lifecycle energy consumptions of the studied building are 17577 kWh and 527317 kWh respectively.

Keeping the window types the same as Run 3, the building exterior roof and walls were insulated with 2 inches Polyurethane insulation material for Run 4 case scenario. Normally Polyurethane is used for manufacturing high resilience foam seating, surface coating and mostly for insulation of buildings. It is also used to fill up the cavities of windows and doors. Average thermal conductivity of Polyurethane is 0.032 W/m.K. The simulation result of Run 4 is achieved from GBS that annual and lifecycle energy consumptions of the studied building are 17532 kWh and 525968 kWh respectively.

In the Run 5 case scenario, building exterior roof and walls were insulated with 2 inch Expanded Polystyrene (EPS) insulation materials, keeping the window types the same as before. Small polystyrene spheres are used to generate expanded polystyrene. All the tiny spheres are interconnected so that very dense bats or mats can be made. Although EPS is manufactured as an insulation for hard boards, it has a partially open pore structure. Average thermal conductivity of EPS is 0.0375 W/m.K. The simulation result of Run 5 is obtained from GBS that annual and lifecycle energy consumption of the studied building are 17555 kWh and 526565 kWh respectively.

Extruded Polystyrene (XPS) is used as insulation materials into building exterior roof and walls in Run 6 case scenario keeping the window types the same as before. XPS has closed pore space and its surface is smoother than EPS. The average XPS thermal conductivity ranges from 0.030 W/m.K to 0.032 W/m.K. The simulation result of Run 6 is obtained from GBS that annual and lifecycle energy consumptions of the studied building are 17526 kWh and 525768 kWh respectively.

GBS obtained the simulation result of the Run 7 case scenario that the studied building's annual and lifecycle energy consumptions are 17519 kWh and 525563 kWh respectively. This simulation result is the consequence of adding Cork as thermal insulation into the studied building envelope. Cork is generally used in the building's celling and façade walls. Cork can be produced as filler materials and plastic boards. Depending on the requirement, it can be cut and perforated into various sizes without altering its thermal properties. The thermal conductivity of cork is around 0.040 W/m.K.

In Run 8 case scenario, a new layer of 2 inch Vermiculite insulation is added to the building exterior roof and walls, considering all conditions the same as before. The thermal conductivity of Vermiculite is around (0.063 – 0.068) W/m.K. Annual and lifecycle energy consumptions of the studied building for this run are 17569 kWh and 527078 kWh respectively.

In Run 9 case scenario, the building exterior roof and walls are insulated with 2 inch Gypsum Board insulation materials. Gypsum wallboard is used for room dividers, roofs, walls and surface decorating purposes. Pre-decorated gypsum board is also used as surface dividers, roofs, or segments. The average thermal conductivity of this type of insulation is 0.45 W/m.K which is higher than other insulation materials. The simulation result for Run 9 is generated by Green Building Studio that the annual and lifecycle energy consumptions of the studied building are 17719 kWh and 531564 kWh respectively.

In the Run 10 case scenario, annual and lifecycle energy consumptions of the studied building are 17719 kWh and 531564 kWh respectively for using Perlite as insulation materials into exterior roof and wall. Thermal conductivity of Perlite varies between 0.04 W/m.K to 0.06 W/m.K.

5.1. Compared energy consumptions of scenarios

The annual and lifecycle energy consumptions of the studied building are 20100 kWh and 602991 kWh for case 1 or base case. The base case reflects the actual and benchmarking condition of the studied building that is not insulated. From Run 1 to Run10, various thermal insulation materials are gradually added, maintaining all analytical parameters constant. The comparison of energy consumption between different runs based on the annual and lifecycle time periods is shown in Figs. 7-8. From Figs. 7-8, it is evident that Run 1 represents minimum annual and lifecycle energy consumption. The annual and lifecycle energy consumptions of the studied building for Run 1 are 17524 kWh and 524709 kWh respectively. The difference of annual and lifecycle energy consumptions between base run and Run 1 are 2574 kWh and 78282 kWh respectively. The studied building saves 2574 kWh annual and 78282 kWh lifecycle energy consumption by incorporating thermal insulation consideration into the building envelope. After comparing and analyzing simulation data, it is clear that by integrating fiberglass thermal insulation and low-e double glazing blue-green windows into the building envelope, the studied building can save approximately 13 percent energy consumption annually and through the lifecycle time period.

The above phenomena of this result is illustrated by Fourier forth law of heat transfer by conduction of any materials considering steady state condition. Fourier one-dimensional heat transfer at steady state condition is represented in Eq. (1).

$$Q = kA * \frac{T_1 - T_2}{x} = \frac{T_1 - T_2}{x/_{kA}} = \frac{T_1 - T_2}{R} \tag{1}$$

$$R = \frac{x}{kA} \tag{2}$$

$$R_{total} = R_{plaster(ex)} + R_{main\ wall} + R_{plaster(in)} + R_{\ insulation}$$
$$= \frac{x_{plaster(ex)}}{kA} + \frac{x_{main\ wall}}{kA} + \frac{x_{plaster(in)}}{kA} + \frac{x_{\ insulation}}{kA} \tag{3}$$

Where,

Q is the amount of heat transferred through any materials

k is the thermal conductivity, W/(m·K) or Btu/(h·ft·°F)

T_1 is the higher temperature, K or °F

T_2 is the lower temperature, K or °F

A is the area through which conduction occurs, m^2 or ft^2

x is the thickness of material in which conduction occurs, m or ft

R is the thermal resistance of any materials, [(m^2.K)/W] in SI units or [(ft^2·°F·hr)/Btu].

From Eq. (2), thermal resistance is proportional to thickness and disproportional to thermal conductivity and surface area of any object. Composite walls were developed by mixing with plaster, main wall or roof, plaster and thermal insulation for different run names of this study. The thermal resistance of composite wall acts like Eq. (3). This work has kept the area (A) and thickness (x) constant for the selection of suitable thermal insulation material, except for the thermal conductivity of the insulation materials. The thermal resistance of the composite wall varies with the thermal conductivity of different types of thermal insulation materials, except for the thermal conductivity of the insulation in Eq. (3). It is clear from the above description that fiberglass represents the lowest thermal conductivity among other thermal insulation materials. The Run 1 combination is made of fiberglass thermal insulation and has the highest thermal resistance. The highest amount of heat transmission through the exterior wall can be obstructed by Run 1. For this reason, with the Run 1 combination, the studied building gains less heat from outside than the studied building with other combinations. Besides, the Run 1 causes minimum annual and lifecycle energy consumption among other Run names.

5.2. Validation

Two methods of validation have been adopted in this study. The first validation of computational results was performed by comparison of simulation results from eQUEST and GBS. The second validation was completed by comparing the annual energy consumption results for the base run of GBS with the studied building's real energy consumption. By comparing the two simulation results from GBS and eQUEST in this study, the computational results of distinct run names were validated. The same geometry and material properties of each run name were provided to GBS and eQUEST for energy simulation to investigate the variations of simulation results obtained from two different tools. Table 4 shows the simulation results from GBS and eQUEST for each run. The approximate variation of simulation result between GBS and eQUEST is 2.96% representing Table 4. Compared with the findings of other case studies, the 2.96 percent variation is acceptable. In a case study of Reeves et al. [32], annual cooling energy for the same case study represented different amount of cooling energy consumptions for using three different energy simulation software, i.e. Ecotect, IESVE (Environmental Solutions-Virtual Environment), Green Building Studio. The variation of simulations results from actual annual cooling energy to Ecotect, IES-VE and Green Building Studio were 3.86%, 45.1% and 72.83% respectively. The variation of simulation results of two different tools is small in this study because both eQUEST and GBS use DOE 2 simulation engine.

The study adopted another validation process, which compared the computational results with the actual energy consumption data.

Table 4. Differences of simulation Result between Green Building Studio (GBS) and eQUEST

Run Name	Annual energy consumption result from GBS (kWh)	Annual Energy Consumption Result from eQUEST (kWh)	Percentage Difference [(GBS result – eQUEST result) / GBS result] * 100
Base Run	20,100	19095.34	5.26 %
Run 1	17,489	16,590.70	5.42 %
Run 2	17,524	17,012.93	3.01 %
Run 3	17,577	17,150.56	2.48 %
Run 4	17,532	16,925.35	3.58 %
Run 5	17,555	16,455.40	6.68 %
Run 6	17,526	18,015.57	2.71 %
Run 7	17,519	17,080.60	2.57 %
Run 8	17,569	17,503.80	0.37 %
Run 9	17,719	17,686.89	0.18 %
Run 10	17,547	17,490.37	0.32 %
		Average Difference	2.96 %

By comparing the actual annual electricity consumption of the studied building with the annual electricity consumption of GBS, the results of the energy simulation have been validated. Abanda and Byers [33] and Rana et al. [34] also validated their energy simulation results by comparing the computational data with the real energy bills. The real energy bill is often called true data and comparison with real bill is a strong validation process [35]. Table 2 displays the real electricity consumption of the studied building for different months in the year 2018 and also represents the annual electricity consumption of approximately 18733 kWh. The electricity consumption data representing in Table 2 was collected from the manager of Janata Bank, KUET Branch by conducting several meetings with him. The energy model of the Janata bank building was created in Autodesk Revit in Case 1 or Base case, considering the real condition as much as possible. Energy simulation was done in GBS for base case scenario considering actual location, orientation, wall construction, roof construction, window construction, occupant number, occupancy schedule, lighting schedule and equipment schedule for the studied building. Fig. 9 shows the simulation result from the GBS interface that is 20100 kWh annually. The variation between GBS computed annual energy consumption data and real annual energy consumption data is [(20100 – 18733) / 20100] * 100 = 6.8%. The 6.8% variation with real data is acceptable compared to other case studies that were reviewed in this study [32, 36]. The acceptable variation limit of simulation results from two different tools is +/-15% [31, 32, 37]. This variation occurs due to some errors. Due to the variety of materials and human behavior, it is quite impossible to render the real condition of the studied construction into any software. Similar to real conditions, the actual thermal properties of building materials can not be installed in the energy model. Although the building envelope materials may not function as virgin materials due to wear and tear for a long time it is necessary to consider the thermal properties of building envelope parts as virgin and set thermal properties within a certain standard value. The most influencing factor of error in simulation is human behavior towards energy consumption. Considering the accurate occupancy schedule of building occupants, it is difficult to simulate the energy of any building. The human occupancy on building energy-consuming equipment varies during the different times of the day. Several surveys on the occupancy pattern of bank officers were performed in this study to create an actual virtual environment of the studied building. In software, it is impossible to create real conditions, so almost accurate assumptions should be made during any building's energy simulation.

6. Conclusion

Several factors, such as building geometry, heat insulation, orientation, occupancy behavior, components and shapes, can dominate building energy consumption. This study shows that thermal insulation has a major impact on the energy consumption of an office building in the contexts of subtropical monsoon climatic country Bangladesh.

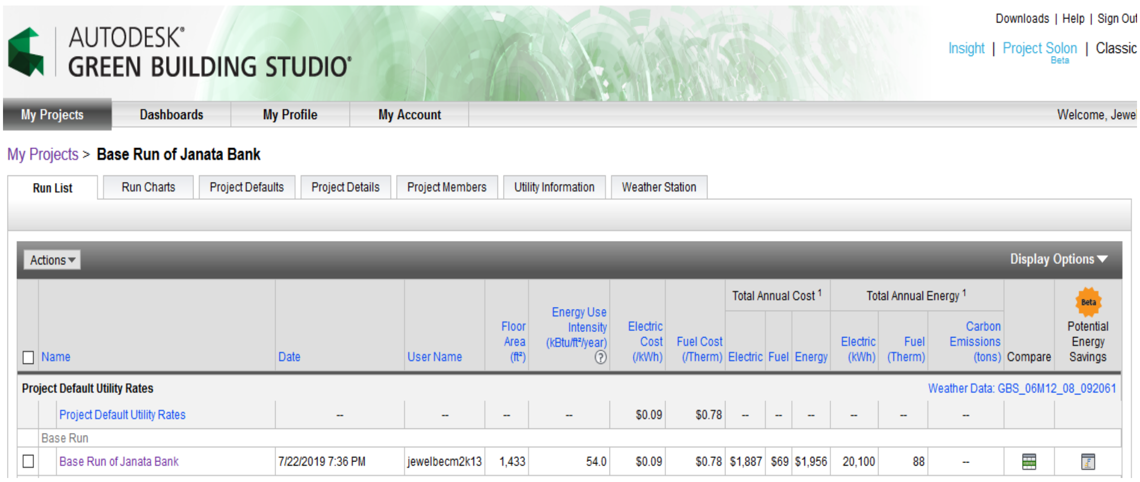


Fig. 9. Simulation result interface of Base Run in GBS

Proper installation of thermal insulation materials can reduce the size of the artificial system used for thermal comfort. The building under study is non-insulated and the exterior facades are directly exposed to the sun. This study investigates the impact of thermal insulation on the energy consumption of the studied building using BIM and BEM tools. To evaluate the impact of thermal insulation, eleven case scenarios were created. The base case energy model was created in Revit considering the as-built condition of the non-insulated studied building. Autodesk Revit as BIM tool, Green Building Studio and eQUEST as energy simulation tool has made this investigation successful by providing accurate simulation results. From the simulation results, the base case consumes 20100 kWh annually and 602991 kWh throughout the life cycle. Energy consumption is reduced by incorporating thermal insulation materials into the exterior facades of the building from Run 1 to Run 10. Among various Run names, such as from Run 1 - Run 10, the best energy efficient option is the Run 1 energy model. The annual and lifecycle energy consumptions for Run 1 are 17524 kWh and 524709 kWh respectively. This is obvious from the results and discussions section that studied building can save 13% energy consumption annually and throughout the lifecycle by incorporating fiberglass thermal insulation into the external walls and double glazing low-e blue green windows. The output of this work can add new knowledge to the construction sector of Bangladesh of energy saving potentiality of applying thermal insulation into exterior walls and windows which has not prevailed before. Huge labor was given in this study to develop an energy model into both tools separately to render actual building materials, geometry and orientation information. A future study should take in place for enhancing interoperable characteristics between BIM and BEM tools. Another research can be conducted on the investigation of some other passive technologies such as building orientation, shading devices and window to wall ratio on energy consumption in the context of Bangladeshi climate.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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