DOI: 10.36297/vw.jei.v4i2.44 ISSN: 2582-5615

VW Applied Sciences, Volume: 4, Issue: 2, 130-145

Passive Retrofit Strategies as an Intervention in Building Efficiency in Winter Season

Navneet Sharma [1*], Tabish Alam [2]

[1]Institute of Environmental Studies, Kurukshetra University, Kurukshetra 136119, India
[2]Building Energy Efficiency, CSIR-Central Building Research Institute, Roorkee 247667, India
*Corresponding Authors Email: navneet.shrama46@gmail.com

Received: June 10, 2022
Accepted: July 02, 2022
Published online: July 07, 2022

Abstract: In this work, a small office building located in Roorkee (29° 52′ 29.48″ N, latitude & 77° 53′ 23.73″ E, longitude), India, has been simulated to calculate the heating load in the winter season. The office building has a net floor area of 13.14 m^2, an air-conditioned volume of 39.4,2 m^3 and a total window area of 12.79 m^2, the proportion of windows to walls is forty-five percent on SW and SE facades, leading to high heating demands in the winter period. The computer simulation for the reduction of the building heating demand has been carried in Design Builder software. Five different passive strategies have been implemented to reduce the building heating demand. These passive cooling techniques include retrofit techniques such as glazing, roof, wall thermal insulation, reflective coating, and windows frame. It has been found that the building annual heating demand of 450 kWh in the base case (without retrofit) has been reduced by 75%-85% with the application of improved glazing, roof, wall thermal insulation, reflective coatings and improved window frames. The net savings in this analysis refer to the energy savings. The savings are calculated over a 5-month period, from November to March. Total electric unit of 352 can be saved over the course of five months. Also, CO_2 emission during winter period can reduce by 718 kg by implementing these strategies per winter season.

Keywords: Retrofit Strategies, Building Envelope, Glazing, Insulation, Passive

1. Introduction

In the 1960s and 1970s, the globe was experiencing an energy crisis. The experts determined that traditional fuel sources would not be able to provide for our needs for an extended As a result, it became critical to seek non-renewable energy sources that might meet our needs. It was evident that the technology was not yet ready to harness these resources, so a focus on making optimal use of what was available became critical. Buildings are the world's third-largest energy consumer, adding to global carbon emissions. This is an important consideration while developing sustainable development plans. If we can reduce the amount of energy needed by buildings, we will be able to reduce our reliance on conventional fuels significantly [1].

Retrofitting office buildings has gained popularity in recent years, owing to the growing energy crisis. Architectural and engineering firms have been hard at work retrofitting office buildings and improving their energy efficiency. The findings suggest that cost-effective energy reductions of 20–30% may be obtained in office buildings, with the possibility of much larger savings from significant retrofitting projects. Various national and international organizations have developed standards for energy-efficient office building retrofitting based on previous experience [2], [3].

Existing energy-related retrofitting initiatives mostly focus on more efficient energy consumption in office buildings, while overlooking issues such as passive solar heating. Scientific research has recently studied submissive cosmic heat also methods that have as expanded our understanding of these areas. Studies into the energy-saving possibilities of combination actions implemented in existing buildings are now being conducted as part of retrofitting research. Retrofitting entails a combination of interventions on the building's key energy-related components, such as the exterior envelope and existing heating systems, as well as the simultaneous use of a submissive plan with approaches. The purpose of such a renovation is to increase its building's power efficiency while also providing obvious alleviation to its tenants' thermal comfort [3].

The success of reassembling scenarios on an office building's energy performance is determined by unique architectural qualities, operating factors, and proximity to the surrounding environment. Despite the diversity of office buildings across the world, a typology may be defined, dividing existing structures into groups with similar energy-related characteristics. This categorization allows researchers to look into the energy behavior sorts of structures as well as evaluate their responses to various reassembling procedures [3].

On such a worldwide scale, the elevated level of our developing human population in urban areas has heightened interest in cities' involvement in climate change adaptation and mitigation and also reaching larger ecological developmental aims. Even though urban areas are blamed for many serious environmental and resource degradation issues, they can also give answers through creativity, such as a lot of technology [4] with the opportunity for creative expression [5], [6].

In recent decades, modernization and technological innovation have caused a massive rise in non-renewable sources' consumption. Non-renewable energy sources, which are hazardous to the environment, account for the majority of energy use. As a result, there is a growing focus on lowering global non-renewable energy consumption [7], [8]. The desire to reduce fossil fuel consumption and CO_2 emissions can contribute to increased energy efficiency in both existing and new constructions. These projects could be expanded to include existing building energy performance measurement and monitoring, as well as retrofit techniques [9]. Sustainable structures should satisfy present demands without jeopardizing future usage, The Brundtland Commission's definition of sustainable development is as follows: [10], Structures that can adapt to future changes will not become outdated; as a result, essential decisions on building energy performance should be built to withstand long-term changes in climate from the outset.

The concept of a net-zero energy building [9], [11] has developed in popularity over the last decade as a strategy for increasing power savings in the construction sector and also as a framework for making sustainable communities. Given India's high energy consumption, incorporating the net-zero energy building idea into business retrofits is important, because it will help with both embedded design power saving and operational power reduction. Whole proven to enhance through updating or renovating historic structures, which opens up new opportunities to revitalize the enormous building inventory and strengthen regional economy over time [12]–[14]. Generally, having achieved net-zero energy buildings necessitates upgrades to building enclosures, lighting reduction, electric loads, Heating and cooling systems, and submissive design methods, which allow its expected power balance to also be adjusted to renewable power sources like wind turbines or solar photovoltaic panels.

Because existing structures face greater limitations than new construction, attaining net-zero power targets for them is a much more compelling aim. The construction industry consumes over 40% of total energy in most nations, and it rises at a pace of 2.2 percent each year [15]. Buildings release Greenhouse Gases (GHGs), which contribute to global warming, in addition to energy usage. Building carbon emissions would equal 42.4 billion tonnes in 2035, up 43 percent from 2007 [16], [17]. Operational challenges have arisen as a result of technological advancement, making it critical to pick the finest designs and invent strategies for lowering energy consumption in the construction sector [18]. On the other hand, the interplay between layout considerations, HVAC systems, weather fluctuations, various users, and so on is exceedingly involved and best seen by modelling all aspects affecting the energy performance of buildings. This may be done with software programs, but there are many different kinds of software solutions accessible inside this sector, and they should be deliberately chosen [19]–[21].

On the market today, there is a variety of building retrofit technologies. Choosing which remodel innovation (or monitor) to be used for a specific project, on the other hand, is just a multi-objective optimization method with many restrictions, such as particular building character traits, budget plan accessible, task goal, construction management types, and performance, building form, etc. When it comes to choosing retrofit technology, the financial advantage isn't the only consideration. A compromise among several concerns both connected to an unrelated to energy, such as power, economics, and technology, the environment, regulations, and social concerns, is the ideal response [22].

Zhou et al. [23] analyse a ways for designing power-efficient remodeling depending on one year of observations. Many viable energy-efficient retrofitting solutions were developed based on the characteristics of a study building. Based on the results of the simulation, comparison, and analysis, the best plan was chosen. The results showed that the building operation can fulfil staff demands following the refurbishment. Similarly, when evidenced by the high standard of office spaces in China, annual energy consumption might be reduced by 57 percent.

Albatayneh [24] investigated techniques to reduce the amount of energy consumed for heating in housing constructions within Ma'an Town, a cold temperate region in Jordan's Saharan Mediterranean. The many design factors of the building envelope (WWR, window shading control schedule, G.F. construction, flat roof structure, localized shade style, hydraulic conductivity (ac/h), glazed category, site orientation, and external wall construction) were maximized to achieve the goal. A simulation model (SA) for 12 model parameters was done using the Design-Builder program (version 6.1) for investigating its influence on thermal loads. The total annual energy consumption was determined to be 1186.21 kWh, with the heating load accounting for 833.18 kWh. This was compared to the energy usage of a baseline building, which was 9969.38 kWh/year split by 3878.37 kWh/year for warmth. As a consequence, 88.1 percent of overall energy consumption and 78.5 percent of heating load were saved, respectively.

Albatayneh [25] offers an optimization of the characteristics of the single-story terrace structure's construction envelope in Amman, Jordan's semi-arid and mild Mediterranean climatic zone. The purpose is to show that by using mechanical heating systems, it is possible to reduce thermal demands while maintaining the current effect on thermal satisfaction. To test the influence of changing design factors on total thermal performance, a standard Jordanian residential apartment structure with measurements of 187 m2 was used. The optimization method began with a simulator with Design Builder software, which was proceeded by parameter estimation of 12 layout factors to determine their significance for heating loads. The genetic algorithm was then used to do an optimization. According to the final results, overall energy consumption may be decreased to 293.74 kWh/year (193.95 kWh/year for heat), relative to 5225.97 kWh/year for the base case model (4075.41 kWh/year for heating).

Sajjadian et al. [10] conducted a styudy with an aims to demonstrate how energy consumption in high construction methods can vary when the environment changes. With Design-Builder tools, which utilizes Energy Plus as one of its calculation engines, current and projected weather data were used to predict the performance of a modest construction in Manchester and London. The energy consumption of something like the five main commonly used high construction technologies were investigated in this model, and the results of the simulation quantified construction system behavior based on power usage. Wood frame structures used the most energy, whilst insulation panel systems used the least.

The practical obstacle of remodeling existing buildings is most serious concerns towards reducing power consumption and greenhouse gas emissions. It also increases people's comfort while assisting a country's power security and reducing its vulnerability to energy price swings. Climate change, industries, social interactions, federal mandates, and other variables all impact retrofit technology choices, either indirectly or directly [26]. Other obstacles that lead activities to be delayed include financial limits, extended payback timeframes, and structure operators' willing to spend for refurbishments. Existing structures can be adapted or renovated to meet functional requirements while cutting costs, reducing energy usage, increasing tenant satisfaction, and reducing environmental impact.

The application was intended to measure and analyze the energy usage of buildings. The Design-Builder program would be used to assess the architectural design idea in order to measure energy consumption, after which the design may be adjusted to further minimize energy use [27]. Dascalaki and Santamouris [2] investigated built environment alterations, Heating, and cooling systems, or different lighting solutions, and also the introduction of submissive heating elements. Interventions that have an impact on the overall performance of the building were also assessed. The practicality of retrofitting actions indicated for each building type was evaluated using slightly elevated computational methods and climatic data across ten locations in the Mediterranean, Continent, Mid-Coastal, & North-Coast European. The findings revealed comparable trends with in fuel efficiency of a wide range of construction types, allowing for data extrapolation on the best retrofitting options for each. Global retrofitting was shown to have the largest reduction in overall energy demand across all climate zones and building types.

Lee et al. [28] centered their research on a remodel project sponsored by the government in Korea in acquiring insight into the process and identifying helpful and transferrable advice for other remodels in similar circumstances. The study used archival research on green remodeling about government policies and regulations, investigations of mechanisms, strategies, and initiatives of a major infrastructure power remodel as a research study, and simulation software analyzing going to compare real and predicted structure power uses by determining buildings' thermal loads to assess the effectiveness of green remodeling in its local context. The data show that by improving building envelop components, the examined sustainable remodelling was successful in decreasing thermal performance, leading to energy loss. A 40% reduction in heating energy usage is projected with improved materials as well as the installation of panoramic windows.

Silenzi et al. [29] present a strategy for optimizing the retrofit intervention selection process, which they apply to a research study of Monoblocco Pavilion only at San Martino Hospital in Genova, Italy. The thermal behavior of the building is continuously evaluated using a Design builder design to predict overall energy required for heating. The base case situation is analyzed in terms of critical success factors (Performance targets) and reference values can be compared to identify the appropriate intervention strategies. The new retrofit alternatives for such case analysis under consideration include facade gap insulation material, smart revolving window featuring varying emittance glazing, and daylight conveying fiber optics paired with a dimming Led light. Finally, after implementing retrofit choices based on the particular local environment, the installation of adaptive revolving windows results in considerable energy savings while being less expensive than traditional retrofit methods. Furthermore, given the present lighting system's lack of automated control and reliance on traditional bulbs, the implementation of an innovative idea is required to reduce power usage and keep overall remodel activity inexpensively.

In the view of the present literature and keeping the eyes on the gaps, the passive retrofit strategies such as wall insulation, roof material, various glazing options, coating on external walls, and changing the window frame on monthly and annual energy heating demand in winter season starting from November to March are investigated by exploiting the simulation results. Their performance in terms of electricity consumption and CO_2 emission reduction have been evaluated to determine best retrofit strategy.

1.1. Characteristics of Roorkee climate

Roorkee is located at 29° 52′ 29.48″ N, latitude & 77° 53′ 23.73″ E, longitude and 218 m above mean sea level, with a composite climate consisting mostly of three distinct seasons: steamy, sunny, and cool-dry, with extended progress times in the middle between. The majority of India has a mixed environment, which means that thermal and cool addition or loss via walls and ceiling is a serious issue. Temperature swings form 22°C to 35°C during the common day. The maximum and minimum temperature range in winter day are 10–25°C, and 2–10°C, respectively with the mercury dropping to approximately 1°C. The precipitation is around 660 mm per year, as well as humidity levels ranges start from 60 to 80 percent throughout the rainy season. During the dry season, the airflow is warm and sandy. The winds blow are fierce and consistent. The rains of the monsoon are torrential and linger for days. During the dry times, there seems to be extremely little rain. Structures and retrofits must be able to withstand not just the sunny and hot dry seasons, but also effective for cold seasons. As a consequence, the method of modification was selected as a solution to all these problems [30], [31].

1.2. Information about existing building

The study's building is a single-story brick wall with a modern style that was finished in 2013. It serves as a fully functional office space, from Monday through Friday. The office's working hours are expected to be between 0900 and 1800 h. The simulation of a building is done in this study using Design Builder software version 6.1.8.021. The simulation program requires the construction specifications of the current single-story structure as inputs [30] and data on the weather is taken into consideration Ind_Uttar Pradesh_Saharanpur_ISHRAE which is a climate comparable to that seen in Roorkee is adopted for Simulations are carried out. The site orientation of the structure is 45° (entrance facing North-West). A full-scale single-story existing building of size 362.5 × 362.5 cm, 300.0 cm in elevation, has already been constructed at the Rural Park, CSIR-CBRI campus, Roorkee, Uttarakhand, India. Figure 1 depicts the building's sectional plan. The sample of the existing office building is constructed with 23.0 cm thickness burned mud-brick walls covered with 1.5 cm portland cement mortar on both surfaces in a 1:6 ratio (U-value: 2.060 W/m^2-K), and a 0.6 cm single bronze glass with an aluminum window frame (U-value: 6.121 W/m^2-K), solar heat gain coefficient: 0.620, and With RCC joists and 3.5 cm in thickness cement concrete construction, prefab brickwork panel rooftop is possible. (U-value: 3.227 W/m^2-K). The overall region of the window 12.79 m^2, with each individual window measuring 3.198 m^2. On south-west and south-east facing the wall, the proportion of window panes to wall surfaces (WWR) is 45 percent and Inputs take into account a solar overhang shading projection of 45.0 cm [31], Because of the invariability of framing materials and size, the effect of window framing is taken into account [30]. The door is made up of parts that are solid and parts that are glazed. For fresh air supply, an exhaust fan is installed in the northeast wall. The experiment was conducted in the absence of any human presence or infiltration [31].

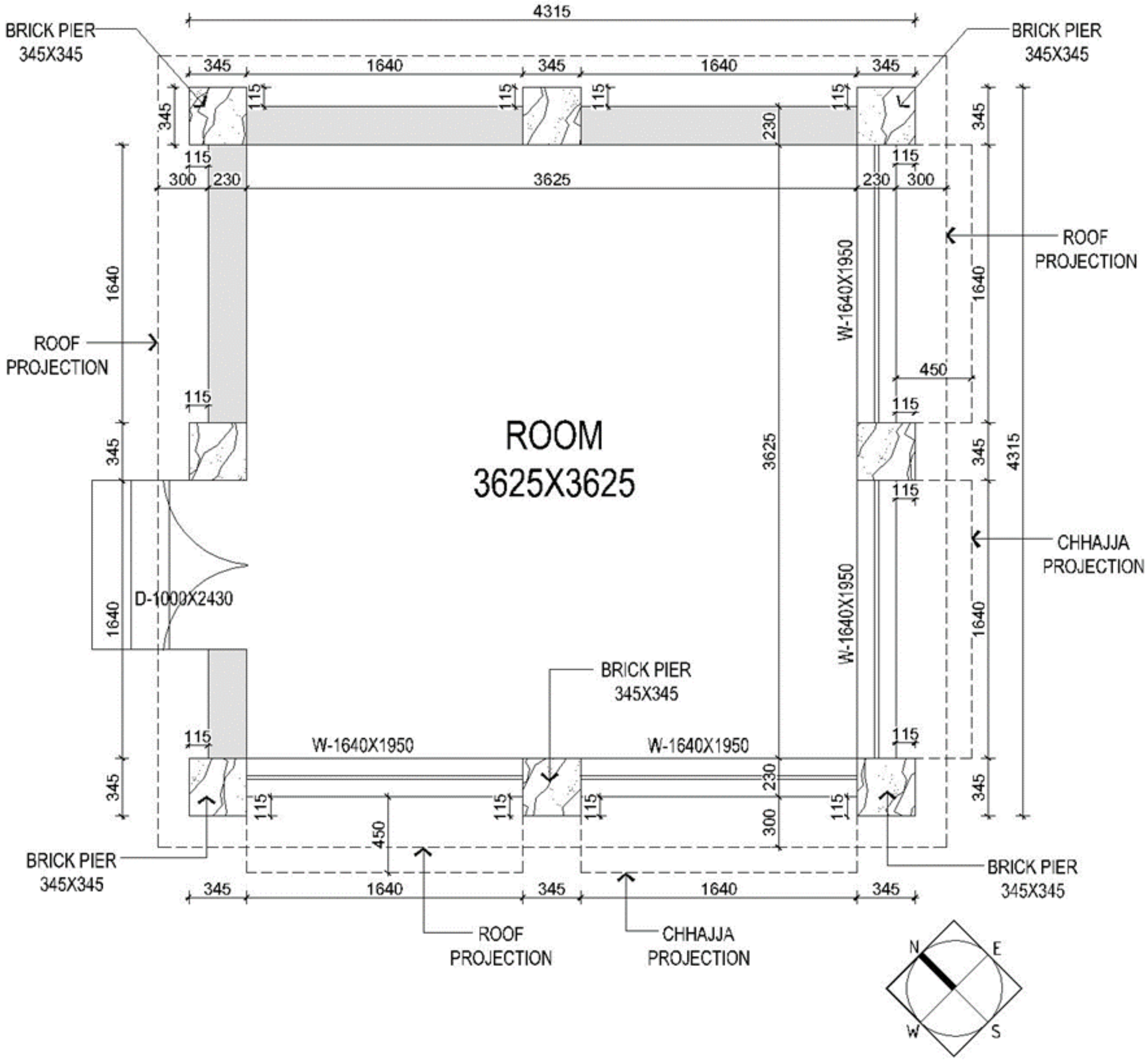

Figure 1. Building sectional plan view.

Table 1. The general components descriptions of the base case model.

Building Details	Descriptions
The direction of the entrance facing	North-West
Structure type	Low weight single-story office building
Built area (out-to-out)	18.62 m^2
Built area (in-to-in)	13.14 m^2
Volume	39.42 m^3
Exterior wall materials	23.0 cm thick brick wall with both sides 1.5 cm cement plaster.
No. of window	4
Size of windows	164.0 × 195.0 cm
Window material	Single bronze 0.6 cm glazing with aluminum frame, 45.0 cm overhang shading.
No. of door	1
Size of door	100.0 × 243.0 cm
Door material	The door is made up of parts that are solid (aluminum) and parts that are glazed with 45.0 cm overhang shading.
Roof area	21.95 m^2
Roof type	Flat roof with 30.0 cm roof projection
Roof material	Prefab brick panel 7.5 cm thick and cemented aggregate with a thickness of 3.5 cm, as well as a Portland cement mortar with a thickness of 2.5 cm and a ratio of 1:3
No. of the exhaust hole	1
Size of the exhaust hole	30.0 × 30.0 cm provided in the N-E.

Table 2. U-value of building components in base case model.

S. no.	Building Components	U-value (W/m^2-K)
1	Wall	2.060
2	Door	2.479
3	Window (Glass)	6.121
4	Window (frame)	5.874
5	Roof	3.227
6	Ground	2.164

2. Methods and Algorithms

2.1 About the Simulation Tool

The DesignBuilder software version 6.1.8.021 is a sophisticated graphical user in-terface created specifically for running Energy Plus Simulations. The DesignBuilder Interface can also be used to generate Energy Performance Certificates (EPCs) and demonstrate compliance with building regulations for users in the UK and Republic of Ireland. A state-of-the-art software program called DesignBuilder may be used to evaluate a building's performance in terms of power, CO2, lighting, and comfort. With DesignBuilder, which was developed to make building energy simulation simpler, you can evaluate the functionality and performance of building techniques fast and receive results that are both on schedule and within your budget. DesignBuilder combines quick building modelling and user-friendliness with cutting-edge dynamic energy simulation. The DesignBuilder is straightforward to use. Its innovative productivity features enable non-expert users to quickly model even complex buildings. The DesignBuilder is the Energy Plus dynamic thermal simulation engine's first comprehensive user interface.

- To get precise information on environmental performance and gorgeous pro-duced visuals at any point throughout the design phase.
- Streamline the design and evaluation processes by providing performance data early in the design process, when it is most needed.

- The DesignBuilder is reasonably priced and, more importantly, easy to learn and use. Because DesignBuilder is so simple to use, you'll be able to provide advanced sim-ulation on even the smallest project without going over budget.
- At the point when utilized as a learning device in colleges and schools, Design-Builder natural UI and shrewd defaults permit understudies to focus on coursework without becoming mixed up in the subtleties of utilizing the product.
- It aids in the design of environmentally friendly buildings [20].

2.1.1 Features

1. The DesignBuilder includes an easy-to-use Open GL solid modeller that allows users to assemble models in 3-D space by placing, extending, and cutting 'blocks.' There are no geometric form or surface shape limits, and realistic 3-D elements offer visual input of actual element thickness and room sizes and volumes.
2. You may use ArchiCAD, Micro station, Revit, and any other BIM programme that supports the gbXML standard to import 3-D CAD models.
3. By selecting from drop-down options, you may load popular building structures, activities, HVAC, and lighting systems into your design. If you frequently work on similar sorts of structures, you may also upload your templates. When this is paired with data inheritance, global modifications may be done at the building, block, or zone level. You may also adjust the degree of detail in each building model, allowing you to utilise the tool at any point throughout the design or review process.
4. With a single click, switch between Model Edit View and Environmental Perfor-mance Data – data is presented without the need to launch additional modules or im-port data, and any simulations necessary to create the data are instantly begun [20].

2.1.2 Procedure of Analysis

1. AUTOCAD is used to plot the current building's sectional layout.
2. The 3-D model of the existing building is made as per the sectional plan in the simulation tool.
3. Site orientation and region are selected in the simulation tool.
4. The kind of structure, the operational schedule of the building is filled in the ac-tivity tab as input.
5. Details of construction material, opening, and HVAC system of the existing building are selected from the material library which is available in the simulation tool.
6. To ensure that the architectural aspects of the building are correct, visualizations are created.
7. After completing the basic case model's criteria, click on the simulation tab of the software for output result in terms of heating load. This is done for the specified week, month, and year.
8. Step 7 is repeated after implementing various strategies like glazing, roof materials, insulation, coating and window frames on the base case model through the material library, which is available in the software.
9. The result of each retrofitting that will come after applying various strategies is compared with the result of the base case model.
10. After comparing the results, the best possible strategy are selected from each type of retrofit strategy.
11. The best possible strategies are selected from each type of retrofit strategy used to create the combined case, and all the best strategies are applied together to form the combined case.
12. Again, simulate the combined case and compare the results with the base case model.

3. Heating Load Calculations

A number of energy modeling techniques are created to assist creators of structures, builders, as well as architecture in calculating heating loads. Many researchers have employed recently created DOE, TRANSYS, and DESIGN BUILDER is examples of power assessment computational programs, to determine the energy requirements of buildings by simulating them hourly, daily, monthly, and annually. The program employed in this study, Design Builder, might be used to determine the heating load [30]. Since the tool has been developed to provide flexible geometry input as well as broad material libraries and load profiles. The integration of Energy Plus (version 8.9) into Design-Builder allows us to run entire simulations without leaving the interface. Data is thoroughly evaluated and simulation results are properly shown. In comparison to the stand-alone Energy Plus, Design Builder features quality control methods that ensure the findings are accurate [31]. Design-Builder is a modular simulation program that simply requires the user to enter particular information about the building, such as Design specifications, usage statistics, atmospheric characteristics, with the kind of Heating and cooling system, among other. In addition, the time necessary to acquire the projected outcome is significantly reduced. In this study, the following six cases are simulated and discussed [30]:-

Case 1: Base Case model
Case 2: Effect of Glazing

Case 3: Effect of Roof Materials
Case 4: Effect of Wall Insulations
Case 5: Effect of Coating on External Walls.
Case 6: Effect of Window Frames

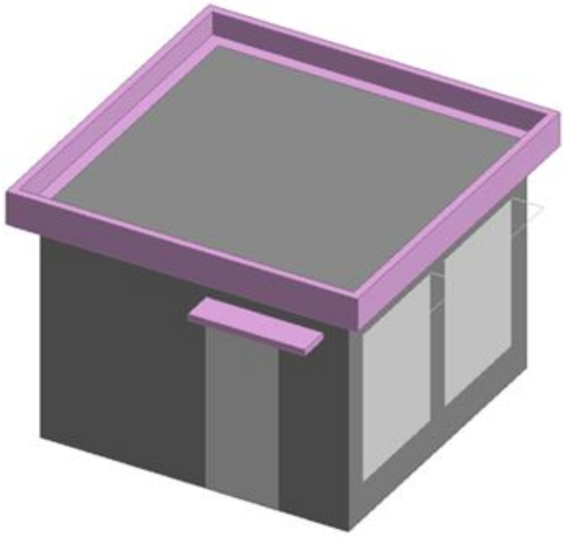

Figure 2. Base Case Model.

Figure 3. Actual Picture of Demo Building.

4. The Simulation's Results and Discussion

4.1. Case 1: Base Case model

The current state of the office building is used as the base case, and the heating demand is computed 450.4 kWh. Figures 4 illustrate the monthly heating load patterns, with the greatest heating load occurring in January (167.94 kWh) and the lowest in March (23.24 kWh). The graph shows that heating is necessary for almost 4-5 months from November to March.

 DOI: 10.36297/vw.jei.v4i2.44 ISSN: 2582-5615

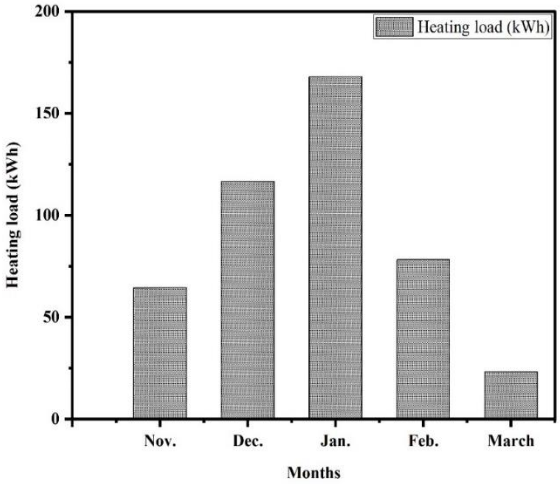

Figure 4. Monthly heating load profile for base case model.

4.2. Case 2: Effect of Glazing

The glazing material employed in the building envelope has a significant impact on the heating load and solar heat loss. Table 3 lists the optical and thermal parameters of the various glazing materials that are employed. The glazing materials chosen represent a wide spectrum of glazing materials typically used in India. Solar heat gains for the office building are analyzed to see how different glass and insulation systems affect heating demand. Figure 5 shows the influence of a variety of glazing methods on heating load by outside windows. The results suggest that its greatest heating demand occurs in January for a single bronze glass 6mm (base case) window (167.94 kWh). In March, the minimum heating load is reached (23.24 kWh). The graph also shows that in January, the heating load is (152 kWh) with double, LoE (e2=.1) clear 6mm/13mm Argon gas glazing (G-1), compared to (167.94 kWh) with single bronze 6mm glass glazing (base case), a 9 percent reduction in heating load. For heating load, Different glazed techniques are employed for comparable studies. However, in comparison to the yearly heating demand, Panel solar radiation, latent loading, and interior load distribution are the most important factors, the Absolute impacts are minor. The amount of sheets of glass, especially from one to double, has a significant influence on heat transfer, which is dependent on the weather, has a significant influence on heat transfer, which is dependent on the weather.

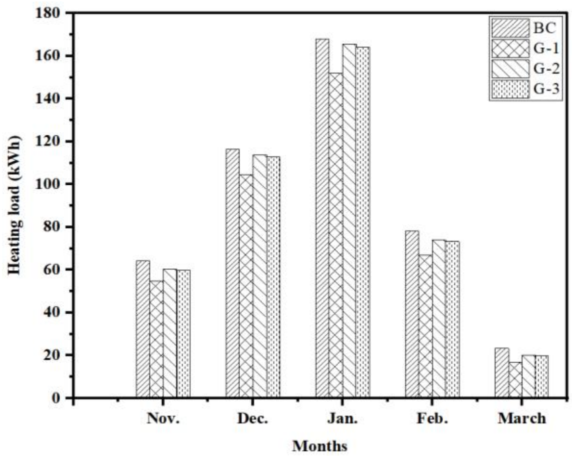

Figure 5. Monthly heating load pattern for glazed techniques for various Cases (BC) – (G-3)

Table 3. Properties of Glazing.

Cases	**Glazing type**	**τ_v**	**U (W/m²-K)**	**SHGC**
BC	Single, bronze, 6 mm	0.534	6.121	0.620
G-1	Double, 6 mm, LoE (e2=.1), 13 mm, Arg. clear	0.745	1.499	0.568
G-2	Double, Grey, 6 mm 13 mm Arg.	0.381	2.549	0.476
G-3	Double, bronze, 6 mm 13 mm Arg.	0.473	2.549	0.495

4.3. Case 3: Effects of Materials

Concrete slabs of 100–150 mm in thickness are commonly used for roof slabs in modern buildings. During the winter, the roof is much colder at night as compared to daytime. The extreme discomfort of the inside environment is caused by the low roof temperature. Table 4 displays the parameters of different rooftop materials. Using ECO roof material (Green roof), glass cellular sheets, and ceiling tiles during peak winter months can dramatically reduce the heating load. Figure 6 shows a thermal study of the building in terms of decreased heating demand. Without a retrofit (base case), the largest heating demand occurs in January (167.94 kWh) and the lowest in March (23.24 kWh). A considerable reduction in heating load might be accomplished by installing ECO roof material (Green Roof, R-1). Heating looad (110.80 kWh) in January and (10.25 kWh) in March, which is lower 34 percent and 56 percent, respectively as compared to base case. However, the overall decrease in heating load with an ECO roof material (Green Roof, R-1) is 266.35 kWh compared to 450.4 kWh, without a retrofit (base case) which is 41% reduction.

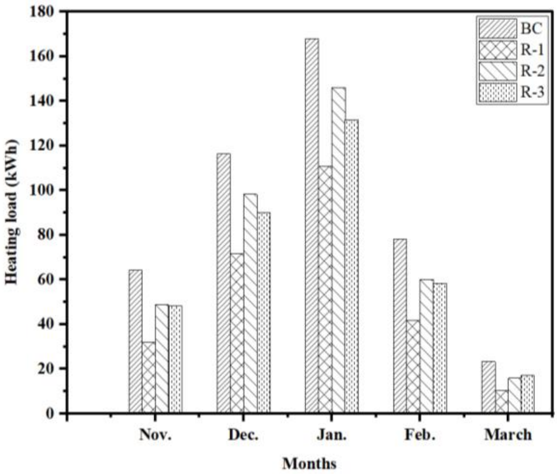

Figure 6. Monthly heating load profile by providing different roof materials (refer to table 4).

Table 4. Properties of different rooftop materials.

Cases	Kind of rooftop materials	k (W/m K)	C_p (J/kg K)	ρ (kg/m^3)
R-1	ECO roof material (Green roof)	0.3	1000	1000
R-2	Glass-cellular sheet	0.048	840	140
R-3	Ceiling tiles	0.056	1000	380

4.4. Case 4: Effect of Wall Insulations

To reduce heating and cooling loads throughout the built environment, green architecture must incorporate insulation material. Insulation acts as a thermal barrier in the winter, preventing loss of heat and lowering heat absorption in the summer to keep the house comfortable. Heat loss in buildings is mostly caused by inadequate insulation and air leakage. As a result, insulation is used in walls, ceilings, and floors. Figure 7 depicts the heat loss profile with and without wall insulation (base case). For this case study, different insulations were used with different thicknesses, which are shown in Table 5. The best results is shown by aerated concrete slab insulation with R-value of 1.735
m^2-K/W and the thickness of the aerated concrete slab is 200 mm.

In the base case (without retrofitting), the maximum heating load occurs in January (167.94 kWh), while the minimum occurs in March (23.24 kWh), but after applying insulation, the heating load is reduced by (126.10 kWh) in January, which is 25% lesser as compared without retrofitting. With the help of aerated concrete slab insulation material (IN-1), the overall reduction in heating load from November to March is 18%. However, after applying all insulation (IN-1, IN-2, and IN-3), a minor increase occurs in March compared to the base case, but in terms of overall heating load from November to March, a maximum 18% reduction in heating load has been observed.

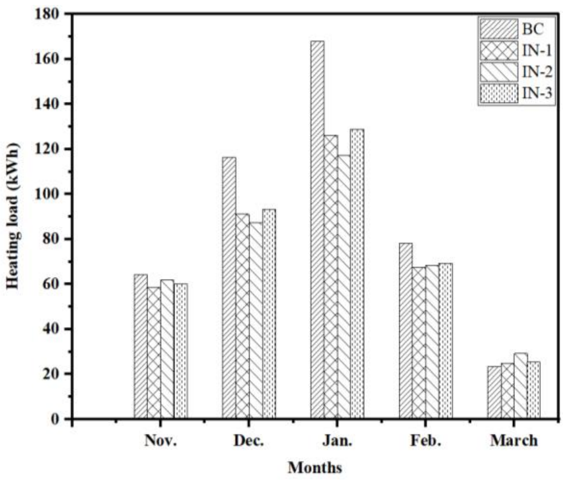

Figure 7. Monthly heating load profile by providing different insulation materials (refer to table 5).

Table 5. Properties of different insulation materials.

Cases	Insulation type	Thickness (mm)	U-value (W/m^2-K)	R-value (m^2-K/W)
IN-1	Aerated concrete slab	200	0.576	1.735
IN-2	Cellulose, recycled paper	200	0.182	5.485
IN-3	Aerated concrete slab	150	0.703	1.423

4.5. Case 5: Effect of Coating on External Wall

Exterior walls exposed to the environment can transmit a significant quantity of heat from a structure, affecting the temperature of the interior rooms and perhaps reducing comfort levels. In addition to lowering heating demands, the different coatings on outer walls can help minimize heat transmission, properties of various coating have been listed in Table 6. The effect of each coating on energy usage measured in this research using three distinct types of coating. Perlite plastering is the initial form, followed by vermiculite plastering, and finally, acoustic tiles. These various types of coatings were applied to walls to estimate energy efficiency. The heating load profile with each coating and without coating (base case) on the outer walls is shown in Figure 8. According to the findings, the average monthly decrease in heat loss is 5.94 percent. Furthermore, the study discovered a 5.71 percent decrease in heating load from November to March. As a result of this study, it is clear that covering the building with coatings can limit the amount of heat that passes from the interior to the exterior. This affects the building's temperature and increases occupant comfort.

In the base case (without retrofitting), the maximum heating load occurs in January (167.94 kWh), while the minimum occurs in March (23.24 kWh), but after applying coating on outer walls (with retrofitting, C-1), the heating load is reduced by (159.20 kWh) in January and (21.81 kWh) in March, respectively, which is 5.20% and 6.15% less as compared to base case in January and March, respectively.

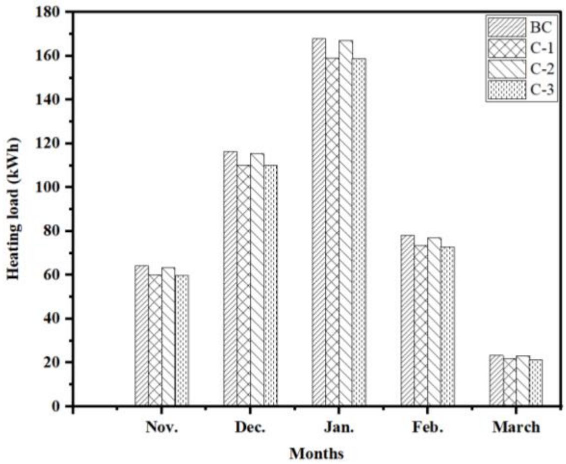

Figure 8. Heating load profile by providing a different coating on exterior walls (refer to table 6).

Table 6. Properties of different coating materials.

Cases	Different coating type	Thickness (mm)	U-value (W/m²-K)	R-value (m²-K/W)
C-1	Perlite plastering	12	1.574	0.635
C-2	Vermiculite plastering	11	1.850	0.540
C-3	Acoustic tiles	05	1.745	0.573

4.6. Case 6: Effect of Window Frame

The window frame also affects the heating load of the structure. In the winter months between January and March, more heat loss from the interior to the exterior, causes the heating load of the building to rise and affects the energy consumption. In the base case, an aluminium window frame is used. Because of this, the maximum heating load is 167.94 kWh in January, while the minimum heating load is 23.24 kWh in March. In this study, three different types of window frames, i.e., painted wooden window frames, UPVC window frames, and wooden window frames, which are shown in Table 7 with their properties and also a heating load profile by providing different window frames, shown in Fig. 9, which helps to reduce the heating load.

After changing the aluminium window frame to a painted wooden window frame, it can be seen that maximum heating load is 165.92 kWh in January, while the minimum is 22.67 kWh in March, which is reduced in January by 2.02 kWh and in March by 0.57 kWh. Overall effect in heating load reduction from November to March is 6.33 kWh, which is less than the base case.

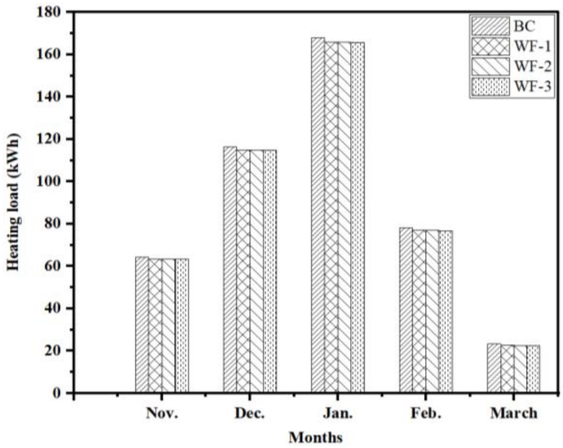

Figure 9. Heating load profile by providing different window frames (refer to table 7).

Table 7. Properties of different window frames.

Cases	Window frame type	Thickness (mm)	U-value (W/m²-K)	R-value (m²-K/W)
BC	Aluminum frame	40	5.874	0.170
WF-1	Painted oak wooden frame	40	2.628	0.381
WF-2	UPVC frame	40	2.467	0.405
WF-3	Wooden frame	40	2.628	0.381

5. Retrofitting Strategies/Methodologies

The following retrofitting alternatives are used in the current building: varied glazing systems (G-1); different roof materials (R-1); inner wall insulation (IN-1); coating on exterior walls (C-1); and modifying the window frame (WF-1). With rapid growth in the number of remodelling options and increased awareness of sustainability requirements, experts are looking for ways to optimise existing structures globally, which necessitates multiple comparisons between different conceivable versions. In terms of heat loss and heating load (kWh), it is expected that a considerable decrease in the office building may be accomplished. Fig. 10 indicates the peak heating month of January, the heating demand without and with retrofitting is 167.94 kWh and 41.50 kWh, alternately. A save of 126 units of power is achieved, contributing to a 75% reduction in energy use, which is shown in Table 8. Using various strategies, a significant decrease in heating load can be obtained.

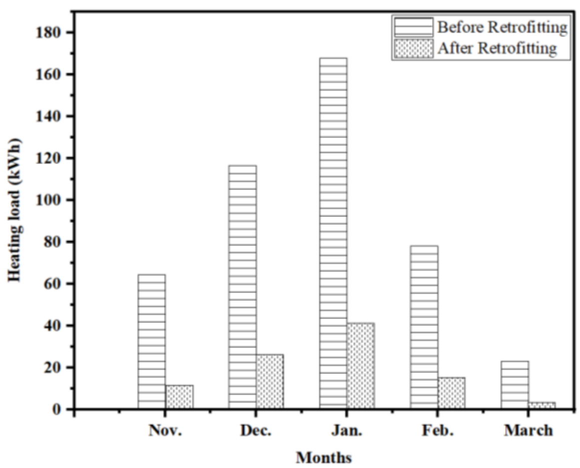

Figure 10. Monthly heating demand pattern of existing office building without and with retrofitting strategies (refer to table 8).

Table 8. Monthly heating demand pattern of office building without and with retrofitting.

S. no.	Months	Heating load before retrofitting (kWh)	Heating load after retrofitting (kWh)	Reduction in heating load (kWh)	Percentage (%) of reduction
1	November	64.41	11.55	52.86	82.07
2	December	116.54	26.44	90.1	77.31
3	January	167.94	41.50	126.44	75.29
4	February	78.27	15.51	62.76	80.18
5	March	23.24	3.39	19.85	85.41

Furthermore, Fig. 10 shows an average savings of 75-85 percent from November to March. Retrofitting buildings with various basic technologies reduces average heating demand by 80 percent during the specified heating season of November to March and also saves the 352 units of electricity in the overall heating season from November to March, which is shown in Fig. 11.

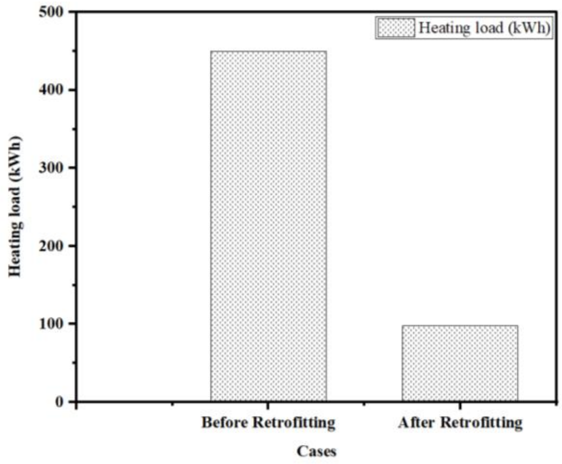

Figure 11. Overall heating load profile of office building from November to March before and after retrofitting with all the strategies.

6. CO_2 Emission Reduction and Carbon Credit Equivalent:

In the modern period, reducing global emissions that cause climate change is a critical undertaking. The global carbon credit industry is growing, and it is currently assisting in the transition away from fossil fuels and toward renewable energy and a low-carbon economy. According to this estimate, moving to less carbon-intensive processes has the potential to reduce CO_2 emissions even further. The preceding section emphasizes the need to lower carbon emissions and the repercussions of doing so in terms of obtaining carbon credits [30]. In this study, we have saved 352 units of electricity in the overall heating season from November to March.

The average carbon dioxide equivalent intensity of coal-fired power generation is 0.982 kg of CO_2 per kilowatt-hour at the source. However,

transmission and distribution losses account for 40%, while inefficient electric equipment accounts for 20%. The total amount of carbon dioxide produced per kilowatt-hour is thus 2.04 kg [32]. The CO_2 emissions in the basic instances (without retrofitting) are 918 kg, but the CO_2 emissions following retrofitting procedures are 200 kg. There is a large decrease of 718 kg (0.718 tonnes per season). CO_2 emission reduction by retrofitting = Euro 21.54, which amounts to Carbon credit earned= Rs. 1769 per season, if CO_2 emission reduction is currently traded at Euro 30 per tonne [33].

7. Cost Analysis in Term of Electricity

Table 9 shows the decreasing in the heating load and savings of the same magnitude. Before and after retrofitting, the heating load was 450.4 kWh and 98.39 kWh, respectively, resulting in a 352.01 kWh reduction in heating load. The net savings in this analysis refer to the energy savings. The savings are calculated over a 5-month period, from November to March. The cost of power per unit is estimated to be Rs. 5.80/kWh, and the total number of units saved over the course of five months is 352.01 units, or Rs. 2041.

Table 9. Heating load and cost analysis of the office building.

S. no.	Particulars	Heating load (kWh)	Cost (Rs.)
1	Before retrofitting	450.4	2,612
2	After retrofitting	98.39	570
3	Savings	352.01	2041

8. Conclusions

The simulation results are allowed researchers to examine the challenges and establish an evaluation system that considers both environmental and economic factors. A remodelling work will inevitably result in a renovation idea, which must be selected or not only on the basis of results but also on the level of degradation and design flexibility. Simple strategies are utilized in the current study to lower the monthly heating demand for the months of November to March when space heating is most important. In a nation like India, where the environment is composite, heating is essential for about 4-5 months of the year. The current study employed a variety of retrofitting strategies, and the simulated findings led to the following conclusions:

- According to the findings, the best potential retrofitting solution is to use aerated concrete slab on the wall as insulation, ECO roof material (Green roof) on the roof, and Double, 6 mm, LoE (e2=.1), 13 mm, Arg. clear glass.
- Retrofitting a building with the passive strategies decreases the overall heating demand by 75-85%.
- CO_2 emissions are 918 kg/s in the basic scenarios (without retrofitting) and 200 kg/s once retrofitting procedures are implemented. A carbon credit is also acquired as a result of this retrofitting procedure.
- With the help of retrofitting, carbon emissions are reduced, which reduces the negative impact on our environment.
- The retrofitting technique also reduces the cost of the electricity consumption up to 78%–80%.

References

[1] K. Sharma and S. Jamal, "RS," vol. 17, no. I, 2019.

[2] E. Dascalaki and M. Santamouris, "On the potential of retrofitting scenarios for offices," *Build. Environ.*, vol. 37, no. 6, pp. 557–567, 2002, doi: 10.1016/S0360-1323(02)00002-1.

[3] W. H. Correale, "Energy Conservation in Modern Office Buildings.," *J. Environ. Syst.*, vol. 3, no. 4, pp. 307–316, 1973, doi: 10.2190/2L53-DUCW-J1B8-MMYW.

[4] H. Zahmatkesh and F. Al-Turjman, "Fog computing for sustainable smart cities in the IoT era: Caching techniques and enabling technologies - an overview," *Sustain. Cities Soc.*, vol. 59, p. 102139, Aug. 2020, doi: 10.1016/J.SCS.2020.102139.

[5] B. D. Deebak and F. Al-Turjman, "A novel community-based trust aware recommender systems for big data cloud service networks," *Sustain. Cities Soc.*, vol. 61, p. 102274, Oct. 2020, doi: 10.1016/J.SCS.2020.102274.

[6] P. Chithaluru, F. Al-Turjman, M. Kumar, and T. Stephan, "I-AREOR: An energy-balanced clustering protocol for implementing green IoT in smart cities," *Sustain. Cities Soc.*, vol. 61, p. 102254, Oct. 2020, doi: 10.1016/J.SCS.2020.102254.

[7] M. Zune, C. A. J. Pantua, L. Rodrigues, and M. Gillott, "A review of traditional multistage roofs design and performance in vernacular buildings in Myanmar," *Sustain. Cities Soc.*, vol. 60, p. 102240, Sep. 2020, doi: 10.1016/J.SCS.2020.102240.

[8] A. Dhalluin and E. Bozonnet, "Urban heat islands and sensitive building design – A study in some French cities' context," *Sustain. Cities Soc.*, vol. 19, pp. 292–299, Dec. 2015, doi: 10.1016/J.SCS.2015.06.009.

[9] S.-J. Kwon, "Effect of mineral admixture on CO 2 emissions and absorption in relation to service life and varying CO 2 concentrations," *Int. J. Sustain. Build. Technol. Urban Dev.*, vol. 7, no. 3–4, pp. 165–173, Oct. 2016, doi: 10.1080/2093761X.2016.1237393.

[10] S. M. Sajjadian, J. Lewis, and S. Sharples, "Heating and Cooling Loads in High Performance Construction Systems- Will Climate Change Alter Design Decisions?," *Procedia Eng.*, vol. 118, pp. 498–506, 2015, doi: 10.1016/j.proeng.2015.08.467.

[11] K. Parrisha, R. Singh, and S. C. Chien, "The role of international institutional partnerships in delivering low-energy building design: A case study," *Sustain. Cities Soc.*, vol. 14, no. 1, pp. 383–389, Feb. 2015, doi: 10.1016/J.SCS.2014.05.007.

[12] Z. Wang, D. Jiang, F. Wang, Z. Lv, and R. Nowak, "A polymorphic heterogeneous security architecture for edge-enabled smart grids," *Sustain. Cities Soc.*, vol. 67, p. 102661, Apr. 2021, doi: 10.1016/J.SCS.2020.102661.

[13] E. K. Zavadskas, Z. Turskis, J. Šliogerienė, and T. Vilutienė, "An integrated assessment of the municipal buildings' use including sustainability criteria," *Sustain. Cities Soc.*, vol. 67, p. 102708, Apr. 2021, doi: 10.1016/J.SCS.2021.102708.

[14] K. D. Buck, J. K. Summers, and L. M. Smith, "Investigating the relationship between environmental quality, socio-spatial segregation and the social dimension of sustainability in US urban areas," *Sustain. Cities Soc.*, vol. 67, p. 102732, Apr. 2021, doi: 10.1016/J.SCS.2021.102732.

[15] M. Mustafa, S. Ali, J. R. Snape, and B. Vand, "Investigations towards lower cooling load in a typical residential building in Kurdistan (Iraq)," *Energy Reports*, vol. 6, no. October, pp. 571–580, 2020, doi: 10.1016/j.egyr.2020.11.011.

[16] J. Zuo and Z. Y. Zhao, "Green building research-current status and future agenda: A review," *Renew. Sustain. Energy Rev.*, vol. 30, pp. 271–281, 2014, doi: 10.1016/j.rser.2013.10.021.

[17] U. S. E. I. Administration, “Energy Information Administration,” *Choice Rev. Online*, vol. 44, no. 07, pp. 44-3624-44–3624, 2007, doi: 10.5860/choice.44-3624.

[18] R. B. C. da Cruz, K. R. de C. Marins, and F. A. Kurokawa, “Multicriteria methodological-rational model to evaluated urban areas: A case study of the São Paulo City/Brazil,” *Sustain. Cities Soc.*, vol. 67, p. 102718, Apr. 2021, doi: 10.1016/J.SCS.2021.102718.

[19] Y. Guo *et al.*, “Assessing and controlling infection risk with Wells-Riley model and spatial flow impact factor (SFIF),” *Sustain. Cities Soc.*, vol. 67, p. 102719, Apr. 2021, doi: 10.1016/J.SCS.2021.102719.

[20] G. A. Azunre, O. Amponsah, S. A. Takyi, and H. Mensah, “Informality-sustainable city nexus: The place of informality in advancing sustainable Ghanaian cities,” *Sustain. Cities Soc.*, vol. 67, p. 102707, Apr. 2021, doi: 10.1016/J.SCS.2021.102707.

[21] A. E. Torkayesh, S. Hashemkhani Zolfani, M. Kahvand, and P. Khazaelpour, “Landfill location selection for healthcare waste of urban areas using hybrid BWM-grey MARCOS model based on GIS,” *Sustain. Cities Soc.*, vol. 67, p. 102712, Apr. 2021, doi: 10.1016/J.SCS.2021.102712.

[22] Z. Ma, P. Cooper, D. Daly, and L. Ledo, “Existing building retrofits: Methodology and state-of-the-art,” *Energy Build.*, vol. 55, pp. 889–902, 2012, doi: 10.1016/j.enbuild.2012.08.018.

[23] Z. Zhou, S. Zhang, C. Wang, J. Zuo, Q. He, and R. Rameezdeen, “Achieving energy efficient buildings via retrofitting of existing buildings: a case study,” *J. Clean. Prod.*, vol. 112, pp. 3605–3615, Jan. 2016, doi: 10.1016/J.JCLEPRO.2015.09.046.

[24] A. Albatayneh, “Optimising the parameters of a building envelope in the east mediterranean Saharan, cool climate Zone,” *Buildings*, vol. 11, no. 2, pp. 1–23, 2021, doi: 10.3390/buildings11020043.

[25] A. Albatayneh, “Optimisation of building envelope parameters in a semi-arid and warm Mediterranean climate zone,” *Energy Reports*, vol. 7, pp. 2081–2093, 2021, doi: 10.1016/j.egyr.2021.04.011.

[26] I. Pluchinotta *et al.*, “A participatory system dynamics model to investigate sustainable urban water management in Ebbsfleet Garden City,” *Sustain. Cities Soc.*, vol. 67, p. 102709, Apr. 2021, doi: 10.1016/J.SCS.2021.102709.

[27] B. Pawar and P. Kanade, “Energy Optimization of Building Using Design Builder Software,” *Int. J. New Technol. Res.*, vol. 4, no. 1, p. 263152, 2018.

[28] J. Lee, M. McCuskey Shepley, and J. Choi, “Exploring the effects of a building retrofit to improve energy performance and sustainability: A case study of Korean public buildings,” *J. Build. Eng.*, vol. 25, p. 100822, Sep. 2019, doi: 10.1016/J.JOBE.2019.100822.

[29] F. Silenzi, A. Priarone, and M. Fossa, “Hourly simulations of an hospital building for assessing the thermal demand and the best retrofit strategies for consumption reduction,” *Therm. Sci. Eng. Prog.*, vol. 6, pp. 388–397, 2018, doi: 10.1016/j.tsep.2018.01.015.

[30] K. Kulkarni, P. K. Sahoo, and M. Mishra, “Optimization of cooling load for a lecture theatre in a composite climate in India,” *Energy Build.*, vol. 43, no. 7, pp. 1573–1579, Jul. 2011, doi: 10.1016/j.enbuild.2011.02.015.

[31] A. Kumar, R. Deoliya, and P. S. Chani, “Evaluation on Thermal Behavior of a Green Roof Retrofit System Installed on Experimental Building in Composite Climate of Roorkee, India,” *J. Inst. Eng. Ser. A*, vol. 96, no. 4, pp. 277–284, Dec. 2015, doi: 10.1007/s40030-015-0132-0.

[32] M. J. Ahmad, G. N. Tiwari, B. Energy, and H. N. Singh, “Heating/cooling potential and carbon credit earned for dome shaped house,” vol. 2, no. January, pp. 6–14, 2010.

[33] F. Dong, Y. Gao, Y. Li, J. Zhu, M. Hu, and X. Zhang, “Exploring volatility of carbon price in European Union due to COVID-19 pandemic,” *Environ. Sci. Pollut. Res.*, vol. 29, no. 6, pp. 8269–8280, 2022, doi: 10.1007/s11356-021-16052-1.