applied sciences

MDPI

Article

Investigating the Energy-Efficient Structures Using Building Energy Performance Simulations: A Case Study

Safeer Abbas [1,*], Omer Saleem [2], Mujasim Ali Rizvi [1], Syed Minhaj Saleem Kazmi [3,*], Muhammad Junaid Munir [3] and Shahid Ali [2]

[1] Faculty of Civil Engineering, University of Engineering and Technology, Lahore 54890, Pakistan
[2] Civil Engineering Department, National University of Computer and Emerging Sciences (FAST-NU), Lahore 54770, Pakistan
[3] School of Engineering, RMIT University, Melbourne, VIC 3001, Australia
* Correspondence: safeer.abbas@uet.edu.pk (S.A.); syed.kazmi@rmit.edu.au (S.M.S.K.)

Abstract: The use of energy efficient structures in the local construction industry assists in promoting green building concepts, leading to economical and eco-friendly solutions for self-sustained structures. The main aim of this study was to examine and compare the energy performance of various local buildings. Detailed 3D building models (house, office, and warehouse buildings) were constructed and investigated for their cost and energy savings using building energy simulation tools (green building studio and insight). Moreover, the effects of various building materials for walls, window panels, and roof construction were explored, and a life-cycle cost analysis was performed. It was observed that the effect of the window-to-wall ratio was less severe in term of energy use in office buildings compared to normal houses due to the larger amount of space available for air circulation. Furthermore, the most efficient location for windows was found to be at the middle of the wall in comparison with the top and bottom positions. The effect of the orientation mainly depended on the symmetry of the building. More symmetric buildings, i.e., tested warehouse buildings (rectangular structure), showed an energy use difference of around 7 MJ/m^2/year for a 360° orientation change. Tested house buildings exhibited an energy use difference of up to 25 MJ/m^2/year. Three-pane glass windows also showed major improvements, and the total energy consumption for houses was reduced to 14%. Furthermore, wood walls showed comparable energy performance with brick walls without the use of insulation. According to US-LEED guidelines, the tested house, office, and warehouse buildings achieved 79, 89, and 88 points, respectively. The cost recovery period for house, office, and warehouse buildings was estimated to 54, 13, and 14 years, respectively, including running and maintenance costs. It can be argued that the Insight and Green Building Studio packages can assist construction stakeholders to determine the energy efficiency of the modeled building as well as to help in the selection of materials for optimized and improved design.

Keywords: energy-efficient structures; ASHARE; US-LEED guidelines; building materials; cost recovery period

check for updates

Citation: Abbas, S.; Saleem, O.; Rizvi, M.A.; Kazmi, S.M.S.; Munir, M.J.; Ali, S. Investigating the Energy-Efficient Structures Using Building Energy Performance Simulations: A Case Study. *Appl. Sci.* **2022**, *12*, 9386. https://doi.org/10.3390/app12189386

Academic Editor: Maria da Glória Gomes

Received: 18 August 2022
Accepted: 16 September 2022
Published: 19 September 2022

1. Introduction

Today, it is widely assumed that modern construction techniques and building styles deplete natural resources abruptly, thereby leading to the disturbance of the ecosystem balance. Therefore, it is of the utmost need to use self-sustaining and green energy concepts in the construction of new infrastructure [1–9]. Furthermore, clients, consultants, engineers, and other stakeholders are encouraged to design buildings for their relevant climatic conditions and to manage natural resources as efficiently as possible, as well as to incorporate the locally available materials. Energy crisis is the major issue faced by developing countries; therefore, energy-efficient buildings are the only solution. It was estimated that buildings consumed around 40% of total energy production [10]. Various countries have developed their green building codes depending on their environmental conditions and needs (Table 1).

Table 1. Green building codes developed in different countries.

Countries	Codes
United States	Leadership in Energy and Environmental Design (LEED)
United Kingdom	Building Research Establishment Environmental Assessment Method (BREEAM)
Canada	Continental Automated Building Construction (CABA)
Hong Kong	Building Environmental Assessment Method (BEAM)
Australia	National Australian Built Environment Rating System (NABERS)
Singapore	Green Mark for Buildings (GMB)
China	Shanghai Construction Council
Netherland	Environmental Performance Express of Buildings
Germany	German Green Building Council
Japan	Comprehensive Assessment System for Building Environmental Efficiency (CASBEE)
Spain	VERDA Green Building System
Korea	Assessment Standards for Certifying Intelligent Buildings (ASCIB)
Pakistan	Building Energy Code

Green buildings require usually higher initial cost than a conventional building, but in the long run, recovery is eminent. The clients are reluctant to spend more money at the start of the project, and they tend to avoid hiring specialized consultants who can give them estimates for cost recovery. Achieving energy-efficient designs in large-scale projects is difficult, while most small-scale projects rarely have a budget enough for hiring professional consultants. For this problem, energy-efficient buildings are the ideal solution, along with the use of efficient materials. Unlike ordinary buildings, the design for energy-efficient buildings must start early in the conceptual stage and should involve interdisciplinary teamwork.

Architecture, engineering, and construction (AEC) decisions can be precisely integrated such that the initial cost of constructing green buildings can be minimized. The integration of AEC decisions was a difficult process in the past; however, the introduction of the Building Information Modeling (BIM) technique has made it more convenient, reliable, and efficient. Several efficient software utilities for BIM modeling, from software corporations such as Autodesk (San Rafael, CA, USA), EnergySoft (Novato, CA, USA), and Trimble (Sunnyvale, CA, USA), are commercially available. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) [11] has developed codes that refine the requirements for an effective green building. ASHRAE green building guides [11] have become the accepted standards for achieving energy-efficiency levels necessary for a green building. The United States has also started programs such as the Leadership in Energy and Environmental Design (LEED) [12] to certify green buildings and to provide verifications for the design. BIM combined with energy-efficiency tools can provide a life-cycle cost analysis (LCCA) for a building throughout its lifespan. This ease in providing a clear cost estimation has helped usher a gradual shift towards green buildings. Moreover, various materials to be used can be altered and the most effective design can be selected.

ASHRAE [11] provides guidelines for achieving green buildings. These codes can be applied to new construction and existing buildings. This standard provides the minimum requirements for the architectural design, planning, and construction of green buildings. ASHRAE also have separate requirements for different building types, such as school buildings, office buildings, retail buildings, warehouses, and storage buildings. These codes provide guidelines for achieving the sustainability of resources, water, and energy-efficiency designs as well as indoor environmental quality (IEQ) design improvements. Similarly, LEED certification is based on a rating system. Credits can be earned based on factors that contribute to global climate change, which enhance human health, and protect water and material resources. There are four possible levels of LEED certification: Certified (40–49 points), Silver (50–59 points), Gold (60–79 points), and Platinum (80 points and above).

The Initial design for a green building requires the introduction of a better ventilation system. In this regard, Kim [10] has carried out extensive research on the size, position, and orientation of windows for achieving a green building. Sixty-five various cases were developed using Revit by changing their window sizes, window positions, and building orientations, and which conducted energy calculations on Green Building Studio. Test results showed that the window size has a significant impact on the energy load. Furthermore, the most efficient position of windows was in the middle of a wall. Vladimir [13] used a BIM-based methodology to perform energy simulations. The traditional process of performing building simulations was compared, and an analysis was carried out using the Lawrence Berkeley National Laboratory (LBNL) methodology [13]. The LBNL methodology was used to semiautomate building energy performance (BEP) simulations. The EnergyPlus software (Orlando, FL, USA) was used to perform the energy simulations. The preparation of input files for building design showed dramatic (70–80%) savings in time compared to the traditional process of preparing the same input files. Azhar [14] studied the relationship between the BIM and LEED rating processes. He studied the case of a business school building located on Salisbury University's campus in Salisbury. A virtual environment (VE) was used for the sustainability analysis of the building. He concluded that the software could handle the US-LEED certification effectively. Kim [15] utilized EnergyPlus for a simulation tool to evaluate the performance of a building. A three-dimensional model was created in the Revit program and which exported the gbmxl file to the ECOTECT software. From ECOTECT, the file was further exported to the EnergyPlus software in the IDF format. The building's window sizes were altered and the orientation of the building was changed. He automated the process and concluded that the self-activating energy simulation analysis can be very helpful to save time. Brown [16] carried out a study on a residential building with a floor area of 220 m^2. The house was a single story with a basement. The overhangs were provided for the building's windows. The windows were also glazed to avoid heat transfer. Various case scenarios were created. The insulations were studied and the conductivity of the floor, roof, and walls were checked. He concluded that the simulation tools utilized earlier in the project could help to understand the building performance so that the alterations for the design can be carried out for the project in the preconstruction phase. The final design demonstrated an energy-efficient building with recoverable costs.

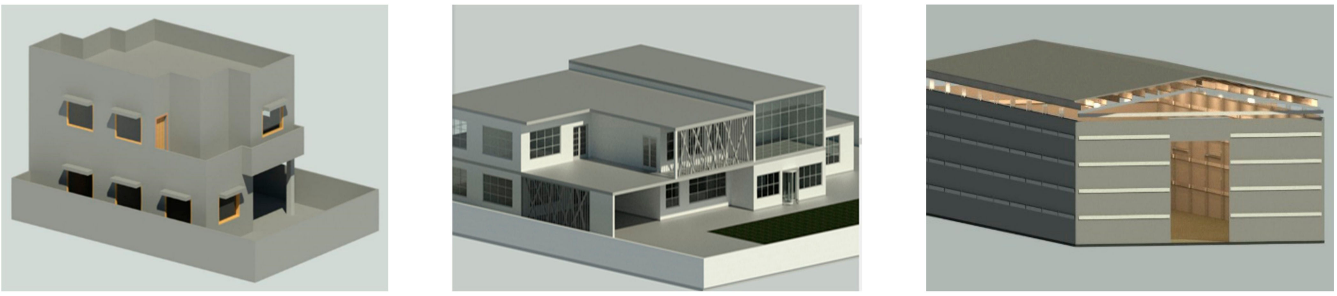
Total energy consumption was considered more in residential buildings than in the commercial, government, and industrial buildings due to their greater number of units. Shah et al. [17] reviewed machine learning and the Internet-of-Things to achieve smart and energy-efficient buildings. Various sensors, gateways, clouds, and network infrastructures were identified, and their role in smart buildings were discussed [17]. Various challenges, including huge data analysis, network services and its security, an efficient energy management system, easy visibility and accessibility, the type and nature of the controlling sensors, the effect of resident behavior, among others, were encountered when making the buildings smart and energy-efficient [17–24]. Rousali and Besseris [25] explored the effectiveness of various retrofitting techniques that influence the energy consumption in an apartment building. Factors which contributed more towards the energy consumption included the requirement of hot water, as well as automation in the heating and cooling systems [25–28]. Jara et al. [29] studied the performance of wood materials for roofing with respect to its thermal efficiency. Alshibani [30] investigated the factors that influence the energy consumption in a school building constructed in a hot climate region. A neural network model was used for optimizing the various factors. It was concluded that the input parameters showed a poor correlation for the school type and air conditioning capacity, while it exhibited a good correlation between the number of classrooms, the total area, and the number of students. It was reported that the air conditioning capacity is the most significant factor influencing the energy consumption [30]. Oprea et al. [31] studied the energy consumption management system and proposed measures for its improved efficiency. They utilized three models and algorithms for optimizing the energy loads. These algorithms were validated for various datasets and implemented to achieve a reduction in the energy costs, thereby leading to the improved efficiency of the system [31]. Silvero et al. [32] reviewed the energy-efficiency policies against climate change in Paraguay. Initially, various climate scenarios and their effects on buildings were discussed in the study. Several activities were suggested for improved energy efficiency against climate change so to address the encountered challenges [32]. Tian et al. [33] conducted a validation study on two office buildings during the summer and winter seasons using energy simulations. It was reported that the proposed schemes could save energy up to 22%, and the study demonstrated the efficacy of data-driven smart building designs [33]. Doan et al. [34] compared various rating systems for green buildings. The main strength, weaknesses, similarities, differences, and sustainability aspects among the various rating systems were identified, and economical aspects were discussed [34]. Chen et al. [35] also reviewed the various rating tools for green buildings based on passive design techniques. Heydari et al. [36], using the DesignBuilder software, studied various configurations of windows on energy consumption. It was concluded that the thickness of glass has a direct influence on the cooling and heating requirements. Furthermore, double-pane windows showed the shortest return period [36]. Riaz et al. [37] explored the feasibility of using energy generation through facade-mounted photovoltaic chambers under various whether conditions. Vosoughkhosravi et al. [38] studied the effect of the LEED certification on the energy performance of a college building. It was reported that the building having a LEED certification showed improved performance and satisfaction due to improved internal environmental conditions. Panagiotou and Dounis [39] studied the energy performance of a hospital building using various algorithms, including artificial neural networks, an adaptive neuro-fuzzy inference system, and a long-short term memory. Borowski [40] presented energy retrofit mechanisms on a historic building used as a hotel. Using various energy retrofit scenarios, a reduction in the overall energy consumption up to 73% could be achieved [40].

Based on the literature survey, it can be argued that very scant literature is available on the energy-efficiency evaluation of local buildings following green building concepts. Moreover, the effects of various local building materials for windows, walls, and roof systems against local weather conditions on energy performance are missing. Therefore, the main goal and contribution of this study was to investigate the energy consumption of various local buildings incorporating different materials and using energy performance tools. Three types of buildings (house, office, and warehouse) were analyzed which incorporated the green elements from the US-LEED and ASHRAE guidelines. Initially, ASHRAE 140 [41] validation tests were conducted for the removal of all potential mistakes. The material effects with various design alternatives on the total energy consumption of the selected buildings using Revit and Insight were analyzed. Moreover, the life-cycle cost analysis (LCCA) and energy efficiency using building energy performance simulations was performed. This study will facilitate the potential use of green building concepts in local industry for stakeholders constructing economical and self-sustained buildings.

2. Materials and Methods

2.1. Description of Case Studies

Three cases were considered for this study: a house, office building, and warehouse, representing small, medium, and large sized areas, respectively (Figure 1). The selected house had passages on two sides. Windows of normal size were available on the east and west sides to provide good lighting for the house. The window glass was an ordinary glass. The windows were without shades. The architect suggested that it was an old fashion now and is disappearing from Pakistan, but shades are recommended as per the ASHRAE code because shades reduce direct sunlight to all windows. The washroom size and ventilation were adequately designed with low-flow taps to save water. The concept of recycled water and rain storage was not applied to the selected house. The ASHRAE code encourages exposure to greenery and the outside environment to increase work potential and creativity. The lawn was kept in the design to ensure a healthy environment. The bins were added into many corners of the house to ensure clean environment and to gain US LEED points. Table 2 shows the details of the selected buildings.



(a) (b) (c)

Figure 1. Model of the case study buildings: (**a**) House; (**b**) Office; (**c**) Warehouse.

Table 2. Details of case study buildings.

Parameters	**House**	**Office**	**Warehouse**
Number of stories	2	2	1
Total area	1980 ft^2	27,000 ft^2	20,000 ft^2
Total covered area	1050 ft^2	9000 ft^2	16,000 ft^2
Ceiling height	10 ft	10 ft	27 ft (inclined roof)
Orientation	South	South-East	North
People occupancy	8 a.m. to 10 p.m.	8 a.m. to 5 p.m.	8 a.m. to 10 p.m.
Lighting schedule	6 a.m. to 8 a.m./ 6 p.m. to 11 p.m.	7 a.m. to 6 p.m.	24 h
HVAC	9 p.m. to 8 a.m.	7 a.m. to 6 p.m.	8 a.m. to 10 p.m.
Occupancies	1 family, 7 people	50 employees	150 employees
Indoor design temperature	26 °C	26 °C	26 °C
Water heating service	Yes/Winters	Yes	Yes/Winters

Though initially there did not seem to be much of a difference between an office building and a house, there were a lot of differences, the majority of which applied to the operation timings. Unlike a house, a major consumption of electricity and fuel was attributed to day timing for the office building. A good daytime work environment requires certain temperature levels to be maintained. This requires air conditioners to bring rooms to a comfortable temperature. In the winter season, rooms require heaters which may run on gas or electricity. In an office building, dedicated separate restrooms properly placed outside the main building were designed. They not only have low flush toilets and low flow sinks, but also have recycled stormwater capability. The water from the kitchen and other uses was redirected to be used in the flushing of toilets. Glass materials for windows were high-heat emittance and low-absorption materials. The insulations were provided for the walls and roof. The permanent bin locations were added for the parking and interior galleries. The selected warehouse was a bulk storage place for a company. Solar panels were used on the roofs. The roofs and walls were provided with the effective insulation. Energy-efficient electric equipment and low-flow sinks and toilets were used. The cost was further recovered via the daytime operation of electricity generated by the solar panels.

It is very complicated to manually verify energy calculations. ASHRAE recommended to develop an alternate quasianalytic solution called the standard method of testing (SMOT). For this, a 3D model of a room with the dimensions 8.0 m × 2.0 m × 2.7 m (ASHARE base model) was developed and compared in the results. This test verified the software output results without performing complex formulations and checked them against the cooling and heating requirements.

2.2. Materials

Various material types for windows, walls, and roofs were investigated for the selected house, office, and warehouse buildings. Various types of low emissivity glass were compared with ordinary window glass (Table 3). Conventional masonry walls were compared with other types of insulted walls or wall panels (Tables 4 and 5). Figure 2 shows the schematic of various types of walls for the office and warehouse buildings.

Table 3. Different types of window materials.

Window Types	Material Description	U-Value (W/m^2K)	R-Value (W/m^2C)	Solar Heat Gain	Visible Light Transmittance (%)
WN1	Ordinary glass (base model)	1.20	0.84	0.88	89
WN2	Low emissivity clear	0.48	2.08	0.76	81
WN3	Low-emissivity hot climate	0.31	3.22	0.68	74
WN4	Low-emissivity insulated (filled with argon gas)	0.26	3.84	0.68	79
WN5	Low-emissivity 3-pane	0.33	3.03	0.67	81
WN6	Vitro glass (coated)	0.12	8.06	0.31	54
WN7	Translucent wall panel	0.34	2.94	0.66	80

Table 4. Different types of wall materials for office building.

Wall Types	Material Description	U-Value (W/m^2K)
WO1	Masonry wall without insulation	2.00
WO2	Masonry wall with insulation	0.18
WO3	Wood frame wall without insulation	2.80
WO4	Wood frame wall with insulation	1.20
WO5	Straw bale wall	0.17
WO6	Structurally insulated panels 4.5″	0.34
WO7	Structurally insulated panels 8.25″	0.28
WO8	Insulated concrete foams 10″	0.19
WO9	Insulated concrete foams 14″	0.21

Table 5. Different types of wall materials for warehouse building.

Wall Types	Material Description	U-Value (W/m^2K)
WH1	Metal frame wall without insulation	2.35
WH2	Metal frame wall with high insulation	1.81
WH3	Structural insulated panel 8.25″	0.28
WH4	Structural insulated panel 12.25″	0.21
WH5	Insulated concrete form 12″	0.20
WH6	Straw Bale Wall	0.17

Similarly, various types of roof materials were investigated for the office and warehouse buildings (Tables 6 and 7). Figure 3 shows the schematic of various types of tested roofs. Wall materials for the office building were also tested for the house building.

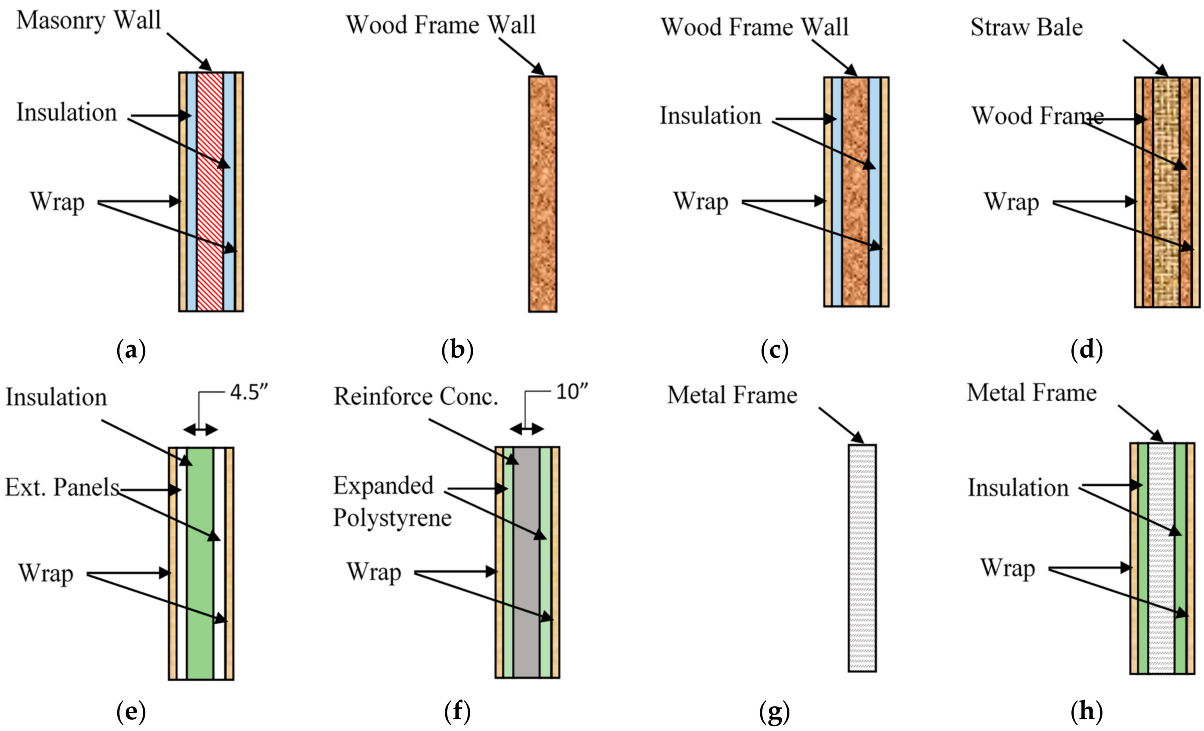


Figure 2. Different types of walls for office and warehouse buildings. (**a**) WO2: Masonry wall with insulation; (**b**) WO3: Wood wall without insulation; (**c**) WO4: Wood wall with insulation; (**d**) WO5: Straw bale wall; (**e**) WO6: Structurally insulated panel; (**f**) WO8: Insulated concrete foam; (**g**) WH1: Metal frame wall without insulation; (**h**) WH2: Metal frame wall with insulation.

Table 6. Different types of roof materials for office building.

Roof Types	Material Description	U-Value (W/m^2K)
RO1	Continuous deck roof without insulation	2.60
RO2	Continuous deck roof with insulation	0.70
RO3	Wood frame roof without insulation	2.80
RO4	Wood frame roof with high insulation	0.81
RO5	Cool roof-R11 insulation over roof deck	0.78
RO6	Cool roof-R20 insulation over roof deck	0.68
RO7	Structural insulated panel roof 6.25″	0.81
RO8	Structural insulated panel roof 10.25″	0.78

Table 7. Different types of roof materials for warehouse building.

Roof Types	Material Description	U-Value (W/m^2K)
RW1	Metal frame roof without insulation	3.20
RW2	Metal frame roof with insulation	1.52
RW3	Wood frame roof without insulation	2.80
RW4	Wood frame roof with insulation	0.81
RW5	Cool Roof-R11 insulation	0.78
RW6	Cool Roof-R20 insulation	0.68
RW7	Structural insulated panel roof 6.25″	0.81
RW8	Structural insulated panel roof 10.25″	0.78

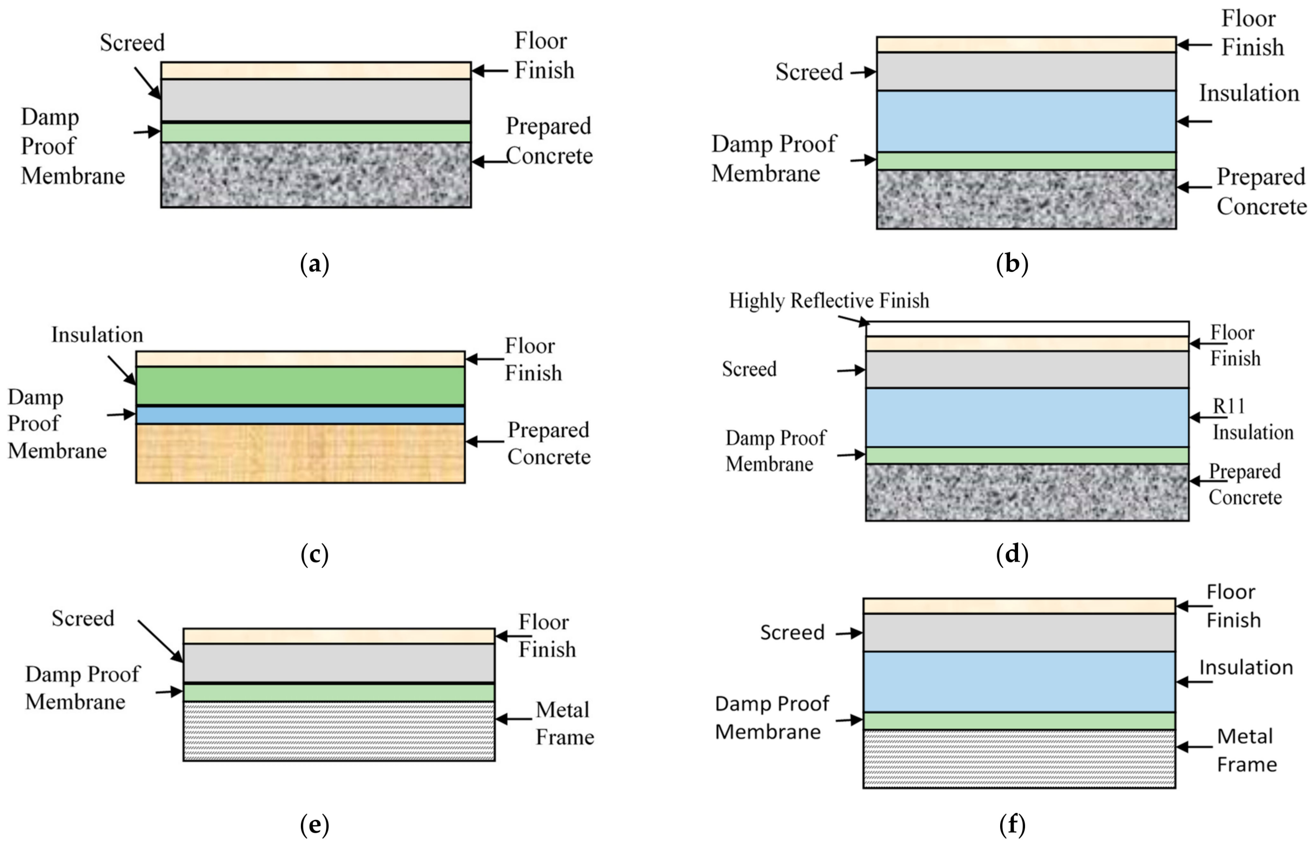


Figure 3. Different types of roof materials for office and warehouse buildings. (**a**) RO1; (**b**) RO2; (**c**) RO4; (**d**) RO5; (**e**) RW5; (**f**) RW6.

2.3. Methodology

In this study, the US LEED rating system was employed due to its focus towards energy consumption and for being a widely used system in the local environment. For modeling, Autodesk Revit was selected due to its building information modeling (BIM) compatibility which can not only communicate with energy software, but also structural software such as ETABS and SAP2000. For the energy analysis, Green Building Studio was chosen because of its easy information sharing between various programs. The model was made in Revit and exported to a gbxml file for the energy analysis.

The US LEED codes for homes and schools were utilized for the house. The US LEED-NC was utilized for the office building design, and the US-LEED Core and Shells was utilized for the warehouse design. These code requirements were incorporated in the software models while keeping in mind the ASHRAE and Energy Code of Pakistan guidelines for comparison purposes. ASHRAE 140 [41] was used for model testing. Both ASHRAE and US LEED provide different codes for different case scenarios but have similar basic approaches to achieve an energy-efficient design. Figure 4 shows the step-by-step methodology adopted in this study. The description of these steps are as follows:

1. Initially, a three-dimensional model of a room was developed in Revit as per ASHRAE 140 code requirements, and the results generated by Green Building Studio were checked. This step is important before doing the actual modeling, as energy calculations are too extensive to be checked manually.
2. Afterwards, the initial 3D model for the building was prepared in Revit from available information, plans, and sections. For this research, three models were created: a house, an office building, and a warehouse.
3. The building design is modified if required. Building orientation was changed and windows were relocated according to ASHRAE and US LEED guidelines for basic improvements. New energy-efficient materials were applied to the design.

4. The model was exported to the gbxml format and uploaded to Green Building Studio to check the building performance. This model was further analyzed with the Insight software for building improvements.
5. Based on the results, the building design was further modified inside Revit. If the building modifications were drastic, the structural stability must be checked. Models were counter-checked for stability in ETABS and SAP2000. The Revit model has the capability to export to these software with all information intact.
6. Once all the data was updated, the model was exported to Green Building Studio (GBS) for energy analysis again. Performing analysis on GBS will not only provide results but also suggestions for economizing the structure.
7. Life-cycle cost analysis was performed to check the feasibility of the project and for cost recovery.

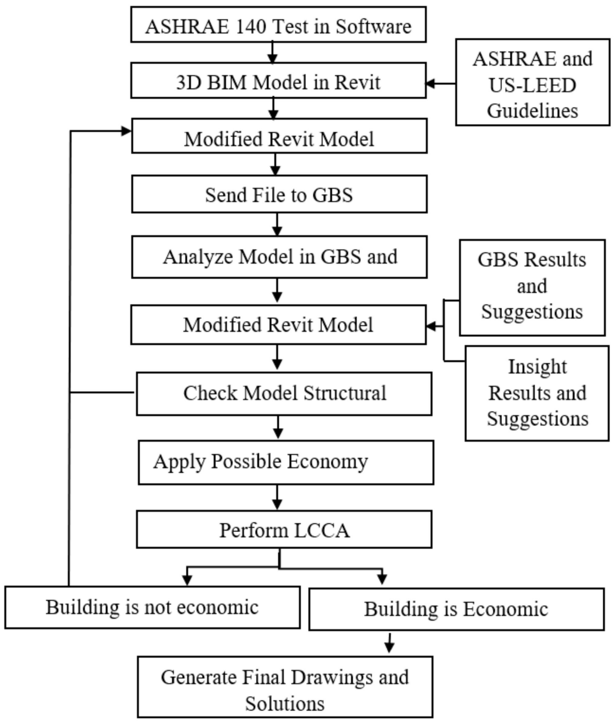


Figure 4. Flowchart of adopted methodology.

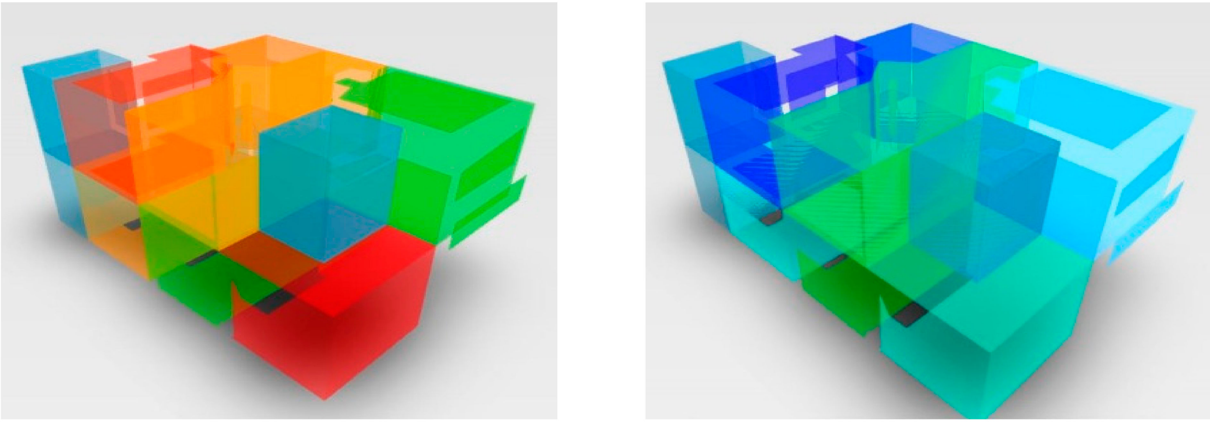
If the building is economical, the final drawings for the project are generated for the client. If the building turns out to be unfavorable, the Revit model is revisited and further modified. After many trials, it may or may not be concluded that cost recovery would be possible. The US LEED certification checklist will then be finalized and the approximate certification level will be discussed.

3. Results and Discussion

The test results for a small room in accordance with the ASHRAE code are shown in Table 8. The cooling and heating load was 5.9 kW and 3.5 kW, respectively, within the code allowance values. Figures 5 and 6 show the energy analysis conducted on the tested buildings.

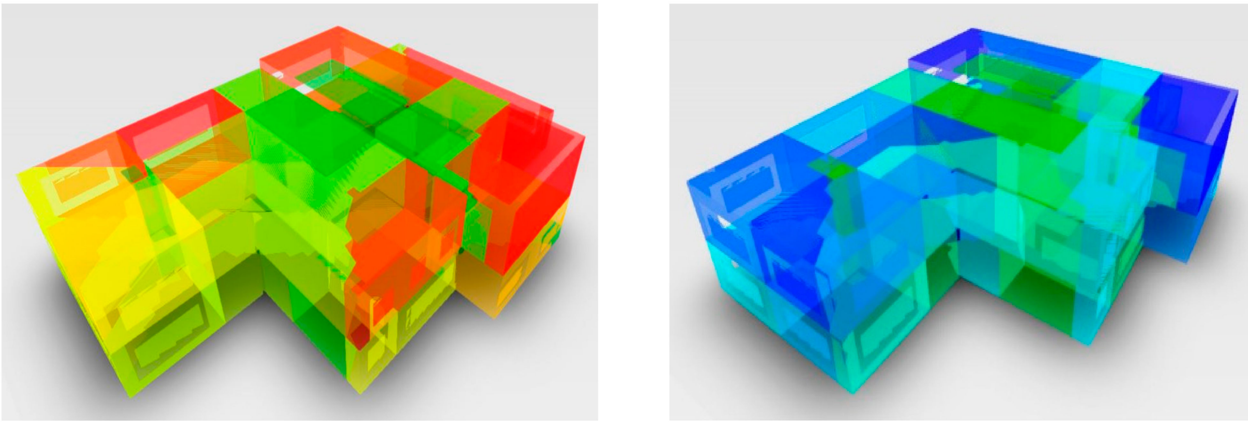
Table 8. ASHARE 140 test results.

Parameters	Results	Code Allowance
Cooling	5.9 kW	5.7 to 6.7 kW
Heating	3.5 kW	3.5 to 4.3 kW



(**a**) (**b**)

Figure 5. Insight energy analysis for house building. (**a**) Cooling load analysis; (**b**) Heating load analysis.

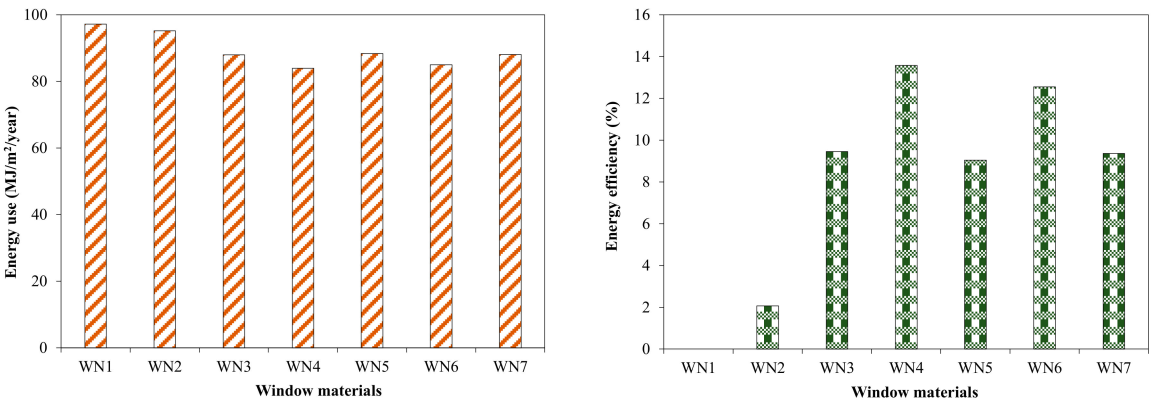


(**a**) (**b**)

Figure 6. Insight energy analysis for office building. (**a**) Cooling load analysis; (**b**) Heating load analysis.

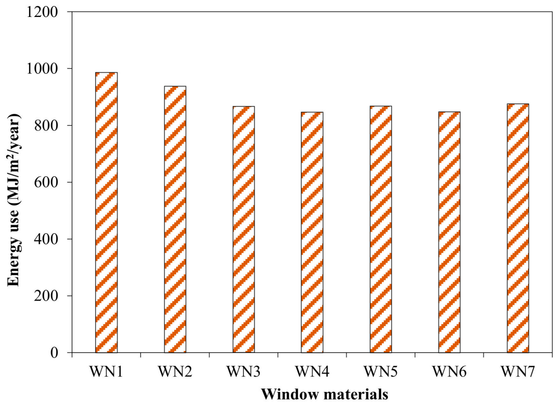
3.1. Effect of Window Materials

Figures 7 and 8 show the effect of the window materials on the energy use of the tested house and office buildings. The most energy-efficient window material in both cases was low e-insulated glass with argon gas. The three-pane glass window also showed major improvements with respect to the other window materials. The total energy consumption was reduced to approximately 15% for both the house and office buildings.

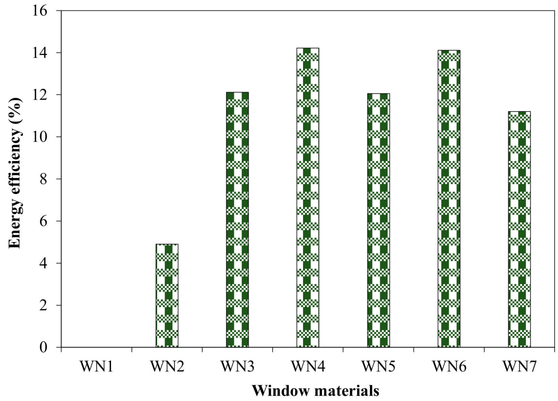


(**a**) (**b**)

Figure 7. Effect of window material on energy use in tested house building. (**a**) Energy use; (**b**) Efficiency.



(**a**)

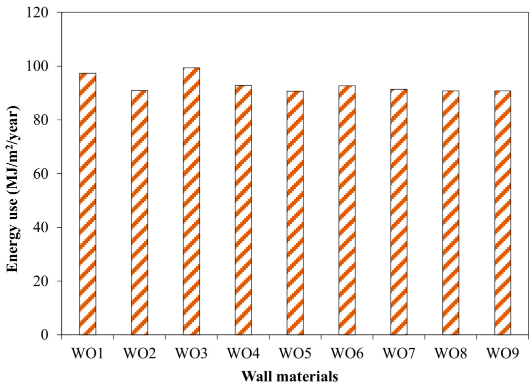


(**b**)

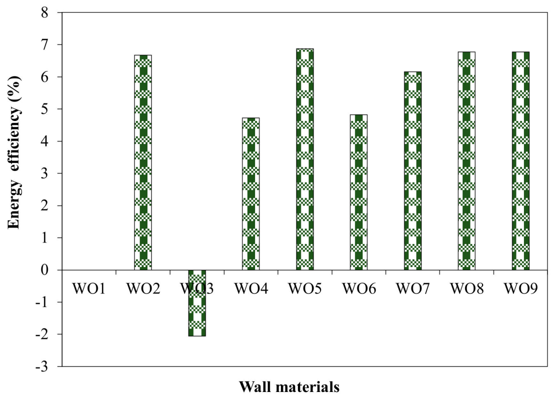
Figure 8. Effect of window material on energy use in tested office building. (**a**) Energy use; (**b**) Efficiency.

3.2. Effect of Wall Materials

The effect of wall materials in the energy use of the tested house, office, and warehouse buildings are shown in Figures 9–11. The wall materials for house and office buildings were same; however, different wall materials for the warehouse building were used due to their different construction method. The wood wall showed comparable energy performance with the conventional brick wall for the house and office buildings.

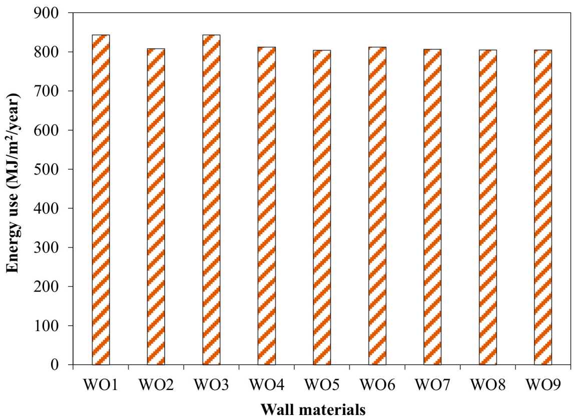


(**a**)

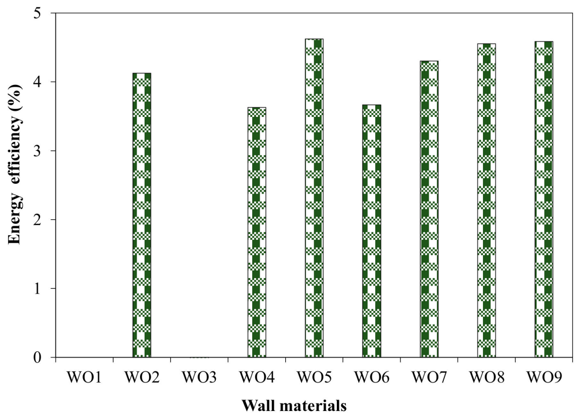


(**b**)

Figure 9. Effect of wall materials on energy use in tested house building. (**a**) Energy use; (**b**) Efficiency.

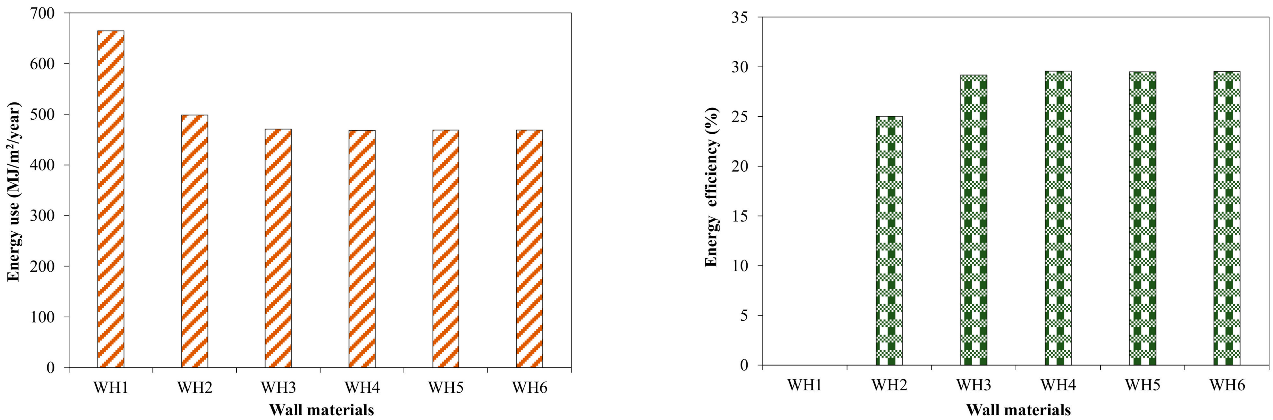


(**a**)



(**b**)

Figure 10. Effect of wall materials on energy use in tested office building. (**a**) Energy use; (**b**) Efficiency.

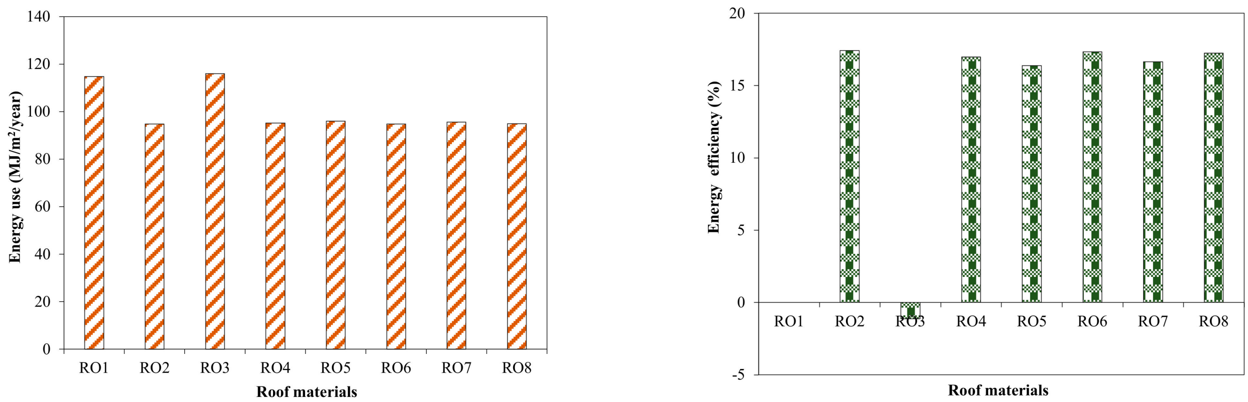


(**a**) (**b**)

Figure 11. Effect of wall materials on energy use in tested warehouse building. (**a**) Energy use; (**b**) Efficiency.

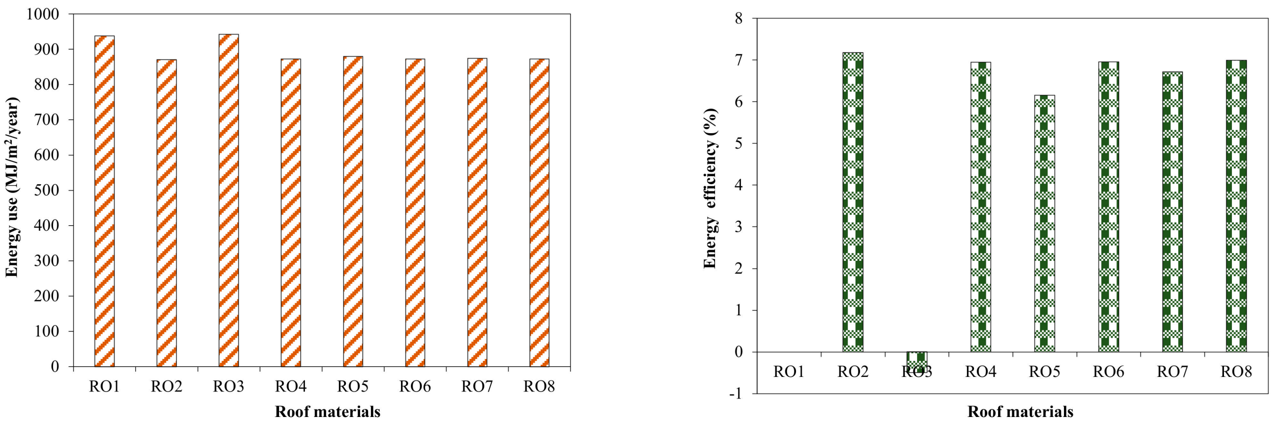
3.3. Effect of Roof Materials

Various roof materials were investigated for their energy use in the tested house, office, and warehouse buildings, and are represented in Figures 12–14. The base material selected for the house and office roof were taken as concrete slabs without insulation, while for the warehouse, the base case was taken as a metal roof without insulation.



(**a**) (**b**)

Figure 12. Effect of roof materials on energy use in tested house building. (**a**) Energy use; (**b**) Efficiency.



(**a**) (**b**)

Figure 13. Effect of roof materials on energy use in office building. (**a**) Energy use; (**b**) Efficiency.

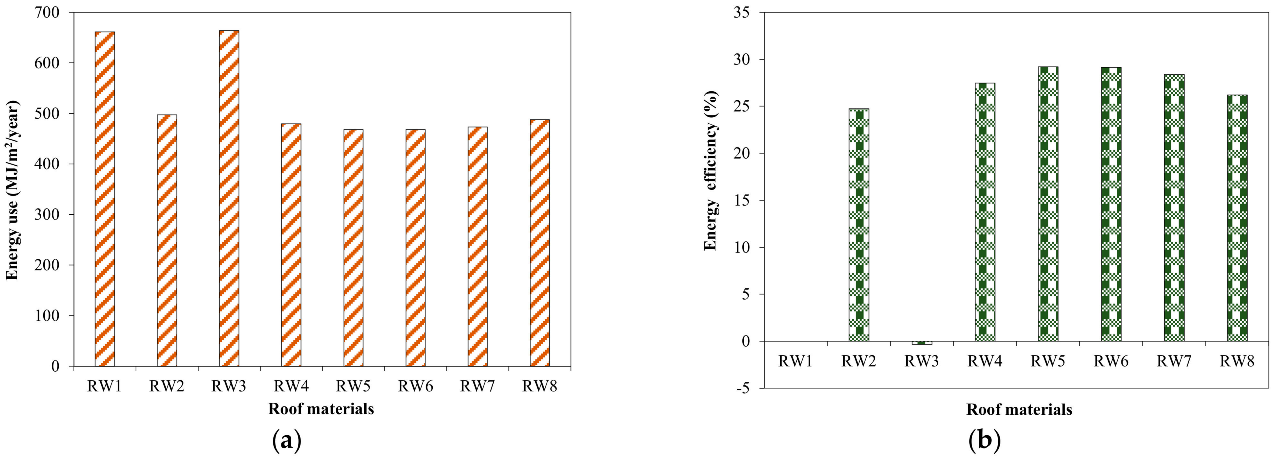


Figure 14. Effect of roof materials on energy use in tested warehouse building. (**a**) Energy use; (**b**) Efficiency.

Table 9 shows the results of efficient materials used for windows, walls, and roofs, and their comparison with the base model.

Table 9. Results of efficient materials and comparison with base model.

Buildings	Windows	Walls	Roof
House (MJ/m^2/year)	97.2 (WN1) 84.0 (WN4)	97.4 (WO1) 90.8 (WO9)	114.8 (RO1) 94.8 (RO2)
Office (MJ/m^2/year)	987.0 (WN1) 846.7 (WN4)	843.3 (WO1) 804.6 (WO9)	937.8 (RO1) 870.5 (RO2)
Warehouse (MJ/m^2/year)	n/a n/a	665.1 (WH1) 468.4 (WH4)	661.3 (RW1) 497.6 (RW2)

n/a means not applicable.

3.4. Effect of Window Poistion

The window location was studied for three positions: top (up), bottom (down), and center (mid) of the walls for the tested house and office buildings. The difference in energy use was not significant due to the window positions. For instance, the energy use ranged from 94 to 96 MJ/m^2/year for the house building and from 851 to 875 MJ/m^2/year for the tested office building for various widow positions. However, the most efficient window location was at the middle of the wall for both building models (Figures 15 and 16).

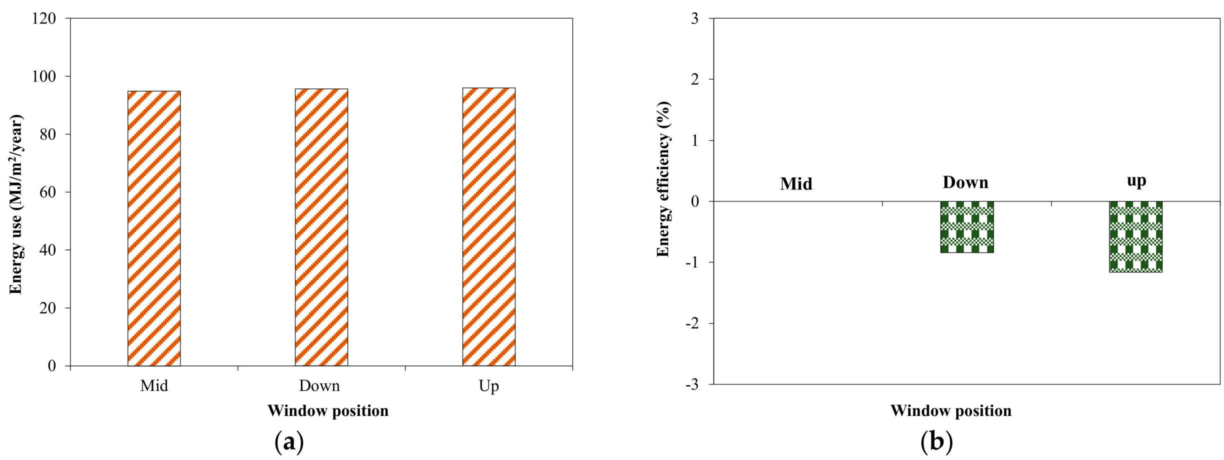


Figure 15. Effect of window position on energy use in tested house building. (**a**) Energy use; (**b**) Efficiency.

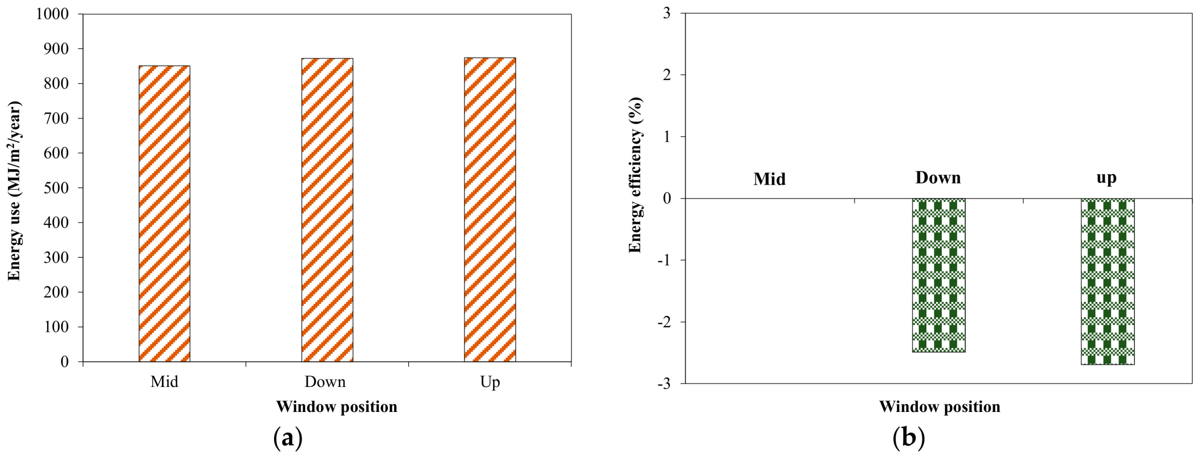


Figure 16. Effect of window position on energy use in tested office building. (**a**) Energy use; (**b**) Efficiency.

3.5. Effect of Window to Wall Ratio

Windows play an effective role in the efficiency of a building. The ASHRAE guideline hugely focuses on window design. Various window-to-wall ratios (W/W) were considered for the house and office buildings. For that case, other design parameters such as window shades, window position, and materials were kept constant. Figure 17 shows the energy use for the tested house building. An around 80% increase in energy use was observed when the W/W changed from 15 to 95% for the tested house building. This increase in energy use is also dependent on the room size and sun exposure conditions. Figure 18 shows the energy use for the tested office building. Due to the bigger rooms and air volume, the effect of the W/W was less severe. A maximum increase to around 17% in energy use was observed for the office building for a W/W of 95%.

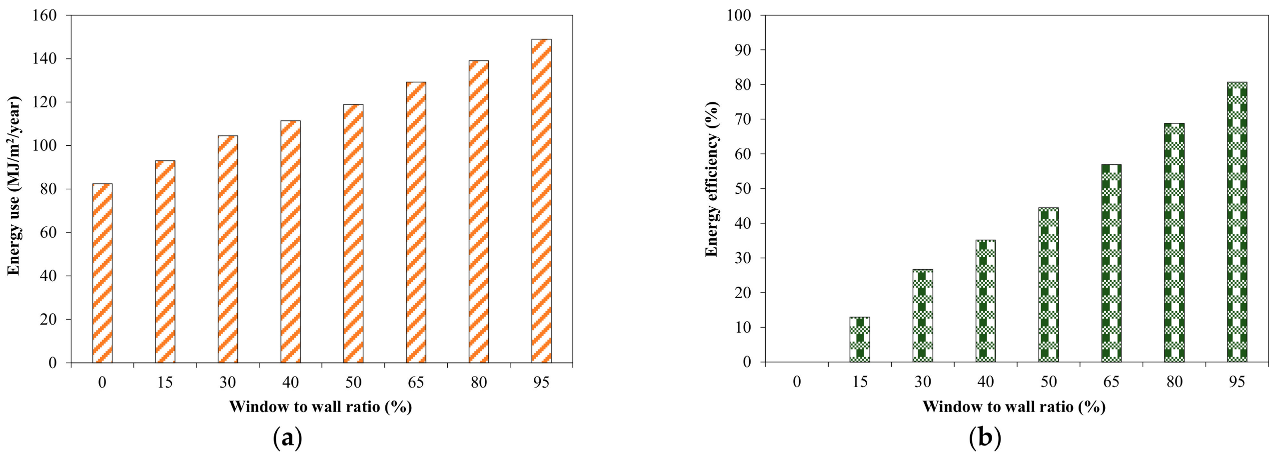
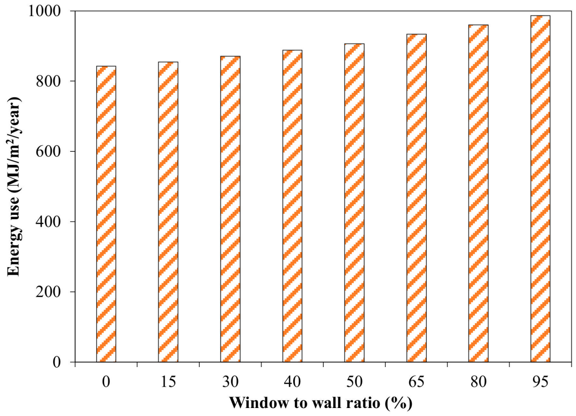


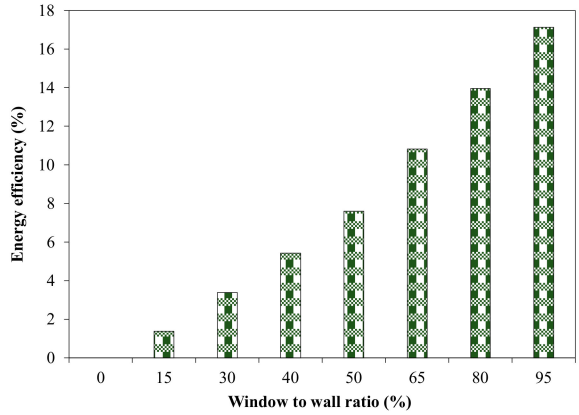
Figure 17. Effect of W/W ratio in energy use in tested house. (**a**) Energy use; (**b**) Efficiency.

3.6. Effect of Building Orientation

The building orientation was studied for all the three tested buildings. Buildings were rotated 360° and the best angle for the building was selected based on their energy use. The effect of orientation mainly depends on the symmetry of the building. In the case of a house building, the energy use difference of up to 25 MJ/m^2/year was observed when changing the building orientation (Figure 19a). This was mainly due to less symmetry in tested house building in comparison with the other tested buildings. The tested office building was more symmetrical and it showed an energy use difference of around 7 MJ/m^2/year (Figure 19b). The warehouse was a rectangular structure and it showed a minimal difference of 0.7 MJ/m^2/year for various building orientations (Figure 19c). It should be noted that new construction can take advantage of orienting a building in a way that considers energy benefits and cost savings, while modifying the already existing building is more challenging.



(a)



(b)

Figure 18. Effect of W/W ratio in energy use in tested office building. (**a**) Energy use; (**b**) Efficiency.

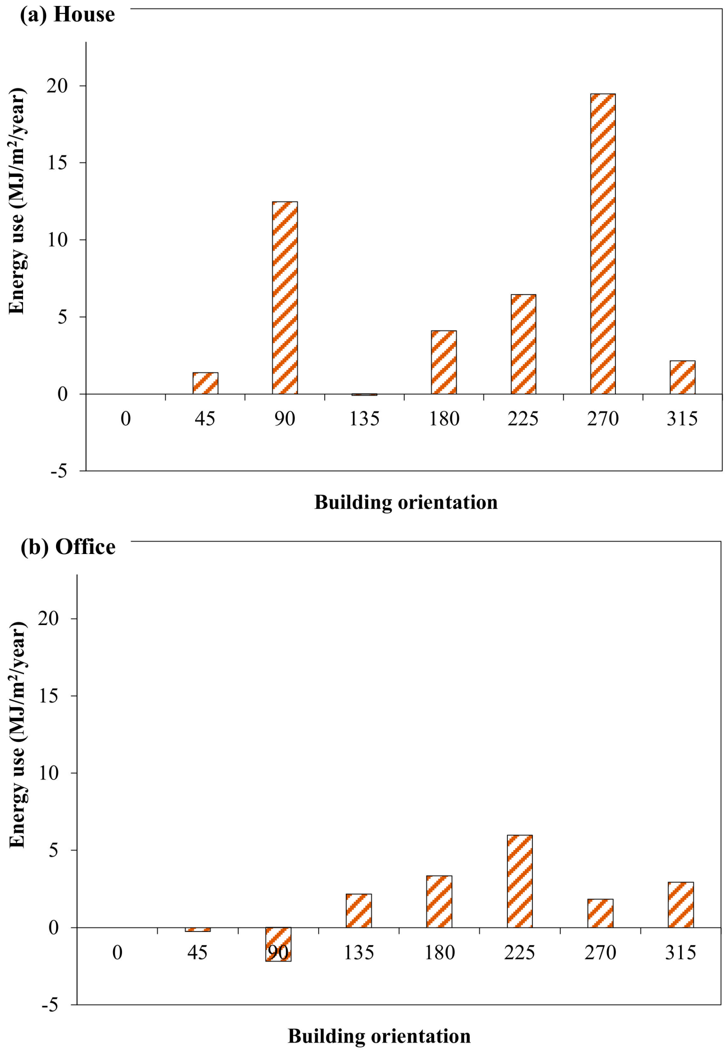


Figure 19. *Cont.*

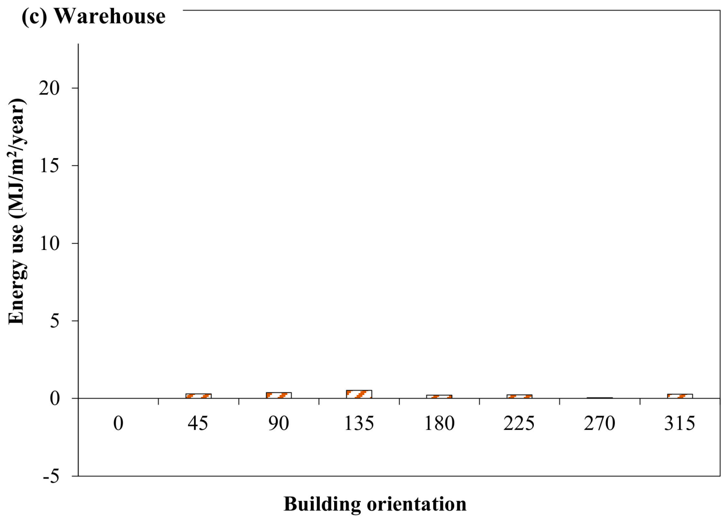


Figure 19. Effect of building orientation in energy use. (**a**) House; (**b**) Office; (**c**) Warehouse.

3.7. Life-Cycle Cost Analysis

The water efficiency design was also carried out and incorporated into the life-cycle cost analysis. The tested buildings were considered in the Lahore region, where the availability of water is not an issue. That is why the cost of water is very low. The savings in the cost due to water was not significant but lead to a gain in LEED points. The water efficiency was applied to the house, office, and the warehouse buildings, and results are reported in Table 10.

Table 10. Water savings for the tested buildings.

Buildings	Water Saved (%)
House	12
Office	21
Warehouse	6

A detailed point-based analysis was conducted for the US-LEED certification on the tested buildings. The water efficiency, energy-efficient design, and site design helped to achieve the certification points. The fee for certification was also calculated and included in the life-cycle cost analysis (LCCA) of the building. The points for an open space design and carbon offsets were also considered. US LEED gives 18 points for optimizing the energy performance for the building and 5 points for LCCA, which has been carried out for the buildings. The expected results for the certification are reported in Table 11.

Table 11. Certification of the tested buildings.

Buildings	LEED Points	Expected Certification
House	79	Gold
Office	89	Platinum
Warehouse	88	Platinum

For the life-cycle cost analysis, the base model and the final configured model were utilized. Windows that pointed towards the sun and caused direct exposure was replaced with optimized wall, window, and roof materials. Table 12 shows the used optimized combinations for LCCA.

Table 12. Combinations used for LCCA.

Buildings	Windows	Walls	Roofs
House	WN1 and WN4	WO1 and WO9	RO2
Office	WN1 and WN4	WO1 and WO9	RO2
Warehouse	n/a	WH1 and WH4	RW2

The simple payback time (*SPBT*) and return on investment (*ROI*) was calculated using the following equations (Equations (1) and (2)), and the results are reported in Table 13.

$$SPBT = \frac{Invested\ to\ be\ recovered}{Annual\ recovery} \tag{1}$$

$$ROI = \frac{Annual\ savings}{Invesment\ to\ be\ recovered} \times 100 \tag{2}$$

Table 13. Payback time and return on investment results.

Buildings	Simple Payback Time (*SPBT*) (Years)	Return on Investment (*ROI*) (%)
House	54	1.85
Office	13	7.69
Warehouse	14	7.14

It should be noted that the client has to monitor and share the data for energy consumption for next 5 years with US-LEED to continue the certification. Based on LCCA, the cost recovery period for the tested house building was estimated to 54 years, for the office building it was 13 years, and it was 14 years for the tested warehouse building, including the running and maintenance costs. If the LEED certification is considered, an extra cost needs to be added, which makes it longer for structures to recover the cost. The US-LEED certification cost is almost 1.5% of the estimated house cost, 1% of the office cost, and 0.8% of the total warehouse cost. This percentage is very high as compared to the United States, where construction is more expensive due to very high labor costs.

It can be seen that around 54 years was required for the tested house building to recover the initial cost. This was due to the fact that the main energy costs for house building were attributed to the night energy usage in summers and winters. The office and warehouse buildings take advantage of a fast cost recovery because the main usage for them is daytime usage, which can be recovered through solar panels. Although there are advantages to the house investment which cannot be denied, due to the very slow recovery costs, they do not seem very feasible. Therefore, in developing countries, the US-LEED certification is recommended for office and warehouse and other large-scale buildings.

4. Conclusions

This research explored the potential of building energy performance simulations as a viable solution for the design of energy-efficient buildings. The research included an operating facility from a small house to a big storage place. Tested buildings included a house, office, and warehouse. Various window, wall, and roof materials were investigated in order to compare their energy efficiencies. Moreover, the orientation of the buildings were also examined for optimum performance. The ASHRAE and US-LEED guidelines were followed and the results generated through Green Building Studio and Insight were evaluated. Initially, ASHRAE 140 was used for the model testing of a small room.

The cooling and heating load analysis of the tested small model were within the ASHRAE 140 limitations. It was observed that low e-insulated glass with argon gas was the most energy-efficient window material. Similarly, the three-pane glass window also showed major improvements. It should be noted that the tested wall materials for the house and office buildings were the same, but different wall materials were investigated for the tested warehouse building. Walls made with wood exhibited comparable performance with the conventional brick wall for the tested house and office buildings. A wooden roof without insulation showed higher energy consumption for the tested buildings. It was observed that the windows-to-wall ratio (W/W) played a significant role in the consumption of energy for the house building. For instance, an approximately 80% increase in energy was observed for a W/W of 95% for the tested house building. However, for the office building, a relatively lesser effect of the W/W was observed. Moreover, the position of windows showed a lesser effect on the energy performance of the tested buildings. The most optimum position was at the center of the wall in comparison with top and bottom locations. The energy use ranged from 94 to 96 MJ/m^2/year and from 851 to 875 MJ/m^2/year for the house and office building, respectively. The orientation of a building depends on the symmetry of the structure. The tested office building was more symmetrical, and therefore less of an energy difference was observed due to the various orientations.

A detailed point-based analysis for the US-LEED certification showed that the tested building may achieve Gold certification and Platinum certification for the tested office and warehouse buildings. The life-cycle cost analysis (LCCA) showed that around 54 years was required for the tested house building to recover the initial cost due to its higher energy consumptions during nighttime. On the other hand, the office and warehouse building takes the advantage of a fast cost recovery because the main usage for them is daytime usage, which can be recovered through solar panels.

It can be concluded that the simple design implementations can ensure less energy costs and a better living environment. Energy-efficient designs are the viable solution to the energy crisis in developing countries such as Pakistan and should be further encouraged. The Building Energy Performance Simulations (BEPS) make the energy calculations easier. The Green Building Studio is user friendly and provides concise results. The Insight software not only provides results but also suggestions for improvements. The US-LEED certifications is a very good initiative. Developed countries are providing benefits for clients who achieve this certification. Governments in developing countries must also promote energy-efficient designs by providing benefits to the clients who achieve these green designs.

Author Contributions: Conceptualization, S.A. (Safeer Abbas) and O.S.; methodology, S.A. (Safeer Abbas), S.A. (Shahid Ali) and O.S.; software results and validation, O.S.; formal analysis and investigation, O.S., M.A.R., S.M.S.K. and M.J.M.; resources, O.S. and S.A. (Shahid Ali); original manuscript preparation, S.A. (Safeer Abbas), S.A. (Shahid Ali) and O.S.; review and editing of the manuscript, M.A.R., S.M.S.K., S.A. (Safeer Abbas) and M.J.M.; supervision, S.A. (Safeer Abbas) and S.A. (Shahid Ali). All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Akadiri, P.O.; Chinyio, E.A.; Olomolaiye, P.O. Design of a sustainable building: A conceptual framework for implementing sustainability in the building cector. *Buildings* **2012**, *2*, 126–152. [CrossRef]
2. Abidin, N.Z. Investigating the awareness and application of sustainable construction concept by Malaysian developers. *Habitat Int.* **2010**, *34*, 421–426. [CrossRef]
3. John, G.; Clements-Croome, D.; Jeronimidis, G. Sustainable building solutions: A review of lessons from natural world. *Build. Environ.* **2005**, *40*, 319–328. [CrossRef]
4. Pitt, M.; Tucker, M.; Riley, M.; Longden, J. Towards sustainable construction: Promotion and best practices. *Constr. Innov.* **2009**, *9*, 201–224. [CrossRef]

5. Thormark, C. The effect of material choice on the total energy need and recycling potential of a building. *Build. Environ.* **2006**, *41*, 1019–1026. [CrossRef]
6. Dimoudi, A.; Tompa, C. Energy and environmental indicators related to construction of office buildings. *Resour. Conserv. Recycl.* **2008**, *53*, 86–95. [CrossRef]
7. Gencel, O.; Kazmi, S.M.S.; Munir, M.J.; Kaplan, G.; Bayraktar, O.Y.; Yarar, D.O.; Karimipour, A.; Ahmad, M.R. Influence of bottom ash and polypropylene fibers on the physico-mechanical, durability and thermal performance of foam concrete: An experimental investigation. *Constr. Build. Mater.* **2021**, *306*, 124887. [CrossRef]
8. Munir, M.J.; Kazmi, S.M.S.; Wu, Y.-F.; Patnaikuni, I.; Wang, J.; Wang, Q. Development of a unified model to predict the axial stress–strain behavior of recycled aggregate concrete confined through spiral reinforcement. *Eng. Struct.* **2020**, *218*, 110851. [CrossRef]
9. Munir, M.J.; Kazmi, S.M.S.; Khitab, A.; Hassan, M. Utilization of rice husk ash to mitigate alkali silica reaction in concrete. In Proceedings of the 2nd International Multi-Disciplinary Conference (IMDC 2016), University of Lahore, Gujrat, Pakistan, 19–20 December 2016.
10. Kim, S.; Zadeh, P.A.; Staub-French, S.; Froese, T.; Cavka, B.T. Assessment of the impact of window size, position and orientation on building energy load using BIM. *Procedia Eng.* **2016**, *145*, 1424–1431. [CrossRef]
11. *ANSI/ASHRAE/USGBC/IES Standard 189.1*; Standard for the Design of High-Performance Green Buildings. ASHRAE: Atlanta, GA, USA, 2009.
12. LEED. *LEED v4 for Building Design and Construction*; LEED: San Francisco, CA, USA, 2018.
13. Vladimir, B. *IFC BIM-Based Methodology for Semi-Automated Building Energy Performance Simulation*; Lawrence Berkeley National Laboratory: Berkeley, CA, USA, 2008; p. 11. Available online: https://escholarship.org/uc/item/0m8238pj (accessed on 24 July 2022).
14. Azhar, S.; Carlton, W.A.; Olsen, D.; Ahmad, I. Building information modeling for sustainable design and LEED rating analysis. *Autom. Constr.* **2010**, *20*, 217–224. [CrossRef]
15. Kim, Y.J.; Oh, S.M.; Park, C.S.; Kim, I.H.; Kim, D.W. Self-activating uncertainty analysis for BIM based building energy performance simulations. In Proceedings of the 12th Conference of International Building Performance Simulation Association, Sydney, Australia, 14–16 November 2011; pp. 847–854.
16. Brown, N.; Ubbelohde, M.S.; Loisosa, G.; Philipa, S. Quick design analysis for improving building energy. *Energy Procedia* **2014**, *57*, 3041–3050. [CrossRef]
17. Shah, S.F.A.; Iqbal, M.; Aziz, Z.; Rana, T.A.; Khalid, A.; Cheah, Y.-N.; Arif, M. The Role of Machine Learning and the Internet of Things in Smart Buildings for Energy Efficiency. *Appl. Sci.* **2022**, *12*, 7882. [CrossRef]
18. Nappi, I.; de Campos Ribeiro, G. Internet of Things technology applications in the workplace environment: A critical review. *J. Corp. Real Estate* **2020**, *22*, 71–90. [CrossRef]
19. Khajenasiri, I.; Estebsari, A.; Verhelst, M.; Gielen, G. A review on Internet of Things solutions for intelligent energy control in buildings for smart city applications. *Energy Procedia* **2017**, *111*, 770–779. [CrossRef]
20. Javed, A.; Larijani, H.; Wixted, A. Improving energy consumption of a commercial building with IoT and machine learning. *IT Prof.* **2018**, *20*, 30–38. [CrossRef]
21. Eini, R.; Linkous, L.; Zohrabi, N.; Abdelwahed, S. Smart building management system: Performance specifications and design requirements. *J. Build. Eng.* **2021**, *39*, 102222. [CrossRef]
22. Daissaoui, A.; Boulmakoul, A.; Karim, L.; Lbath, A. IoT and big data analytics for smart buildings: A survey. *Procedia Comput. Sci.* **2020**, *170*, 161–168. [CrossRef]
23. Saini, K.; Kalra, S.; Sood, S.K. Disaster emergency response framework for smart buildings. *Future Gener. Comput. Syst.* **2022**, *131*, 106–120. [CrossRef]
24. Dong, B.; Prakash, V.; Feng, F.; O'Neill, Z. A review of smart building sensing system for better indoor environment control. *Energy Build.* **2019**, *199*, 29–46. [CrossRef]
25. Rousali, C.; Besseris, G. Lean Screening for Greener Energy Consumption in Retrofitting a Residential Apartment Unit. *Appl. Sci.* **2022**, *12*, 6631. [CrossRef]
26. Allouhi, A.; El Fouih, Y.; Kouskou, T.; Jamil, A.; Zeraouli, Y.; Mourad, Y. Energy consumption and efficiency in buildings: Current status and future trends. *J. Clean. Prod.* **2015**, *109*, 118–130. [CrossRef]
27. Ascione, F.; Bianco, N.; Mauro, G.M.; Vanoli, G.P. A new comprehensive framework for the multi-objective optimization of building energy design: Harlequin. *Appl. Energy* **2019**, *241*, 331–361. [CrossRef]
28. Sorrell, S. Reducing energy demand: A review of issues, challenges and approaches. *Renew. Sustain. Energy Rev.* **2015**, *47*, 74–82. [CrossRef]
29. Rodríguez Jara, E.Á.; Ruiz-Pardo, Á.; García, M.C.; Ríos, J.A.T. Effect of Wood Properties and Building Construction on Thermal Performance of Radiant Floor Heating Worldwide. *Appl. Sci.* **2022**, *12*, 5427. [CrossRef]
30. Alshibani, A. Prediction of the Energy Consumption of School Buildings. *Appl. Sci.* **2020**, *10*, 5885. [CrossRef]
31. Oprea, S.-V.; Bâra, A.; Reveiu, A. Informatics Solution for Energy Efficiency Improvement and Consumption Management of Householders. *Energies* **2018**, *11*, 138. [CrossRef]
32. Silvero, F.; Rodrigues, F.; Montelpare, S. Energy Efficiency Policies to Face Buildings' Climate Change Effects in Paraguay. *Appl. Sci.* **2020**, *10*, 3979. [CrossRef]

33. Tian, Z.; Shi, X.; Hong, S.-M. Exploring data-driven building energy-efficient design of envelopes based on their quantified impacts. *J. Build. Eng.* **2021**, *42*, 103018. [CrossRef]
34. Doan, D.T.; Ghaffarianhoseini, A.; Naismith, N.; Zhang, T.; Ghaffarianhoseini, A.; Tookey, J. A critical comparison of green building rating systems. *Build. Environ.* **2017**, *123*, 243–260. [CrossRef]
35. Chen, X.; Yang, H.; Lu, L. A comprehensive review on passive design approaches in green building rating tools. *Renew. Sustain. Energy Rev.* **2015**, *50*, 1425–1436. [CrossRef]
36. Heydari, A.; Sadati, S.E.; Gharib, M.R. Effects of different window configurations on energy consumption in building: Optimization and economic analysis. *J. Build. Eng.* **2021**, *35*, 102099. [CrossRef]
37. Riaz, A.; Zhou, C.; Mubin, S.; Ali, F.; Pie, B.; Liang, R.; Wang, P.; Zhang, J. Performance evaluation of façade mounted photovoltaic integrated air chamber assisted by heat pump. *Energy Environ.* **2022**, 0958305X221120932. [CrossRef]
38. Vosoughkhosravi, S.; Dixon-Grasso, L.; Jafari, A. The impact of LEED certification on energy performance and occupant satisfaction: A case study of residential college buildings. *J. Build. Eng.* **2022**, *59*, 105097. [CrossRef]
39. Panagiotou, D.K.; Dounis, A.I. Comparison of Hospital Building's Energy Consumption Prediction Using Artificial Neural Networks, ANFIS, and LSTM Network. *Energies* **2022**, *15*, 6453. [CrossRef]
40. Borowski, M. Hotel Adapted to the Requirements of an nZEB Building—Thermal Energy Performance and Assessment of Energy Retrofit Plan. *Energies* **2022**, *15*, 6332. [CrossRef]
41. *ASHRAE 140*; Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs. ASHRAE: Atlanta, GA, USA, 2017.