buildings

Article

Modelling Framework for Reducing Energy Loads to Achieve Net-Zero Energy Building in Semi-Arid Climate: A Case Study

Umair Azam [1], Muhammad Farooq [1,*], Muhammad Adeel Munir [1], Fahid Riaz [2], Muhammad Sultan [3], Ateekh Ur Rehman [4] and Muhammad Imran [5]

1 Centre for Energy Research and Development (CERAD), Faculty of Mechanical Engineering, University of Engineering and Technology, Lahore 54890, Pakistan; umairazam555@gmail.com (U.A.); adeel.munir@uet.edu.pk (M.A.M.)
2 Department of Mechanical Engineering, Abu Dhabi University, Abu Dhabi P.O. Box 59911, United Arab Emirates; fahid.riaz@adu.ac.ae
3 Department of Agricultural Engineering, Bahauddin Zakariya University, Multan 60800, Pakistan; muhammadsultan@bzu.edu.pk
4 Department of Industrial Engineering, College of Engineering, King Saud University, Riyadh 11421, Saudi Arabia; arehman@ksu.edu.sa
5 Department of Mechanical, Biomedical and Design Engineering, College of Engineering and Physical Sciences, Aston University, Birmingham B4 7ET, UK; m.imran12@aston.ac.uk
* Correspondence: engr.farooq@uet.edu.pk

Abstract: Buildings consume a significant 40% of global energy, where, reducing the building energy consumption to a minimum, virtually zero, has become a thriving research area. Accordingly, this research aimed to determine and portray the huge potential of energy conservation in existing structures by making a retrofit at relatively low costs in finance strained economies. A walk-through of the survey of energy consuming appliances determined the energy consumption based on the power rating; the appliances were then virtually replaced and the reduced energy consumption was determined in terms of the cooling loads. Modelling these intervention using the hourly analysis program (HAP) showed significantly positive results. The pre- and post-retrofit model analysis of an institutional building in Pakistan exhibited significant potential for reducing the cooling load of 767 kW (218 TON) to 408 kW (116 TON) with an investment payback period of 2.5 years. The additional benefit is the reduced greenhouse gas (GHG) emissions which reduce the overall energy requirements. The study continues with the design of a solar energy source using the system advisor model (SAM) for the reduced energy demand of a retrofitted building. It is then concluded that using the available area, a solar energy source with a capital payback period of 5.7 years would bring an institutional building within its own energy footprint making it a net-zero building, since it will not be consuming energy from any other source outside of its own covered area. The study has the limitation to exposure and climate related conditions. In addition, the decline in heating and cooling loads represents model values which may vary when calculated after an actual retrofit for the same structure due to any site related issues.

Keywords: energy efficiency; net-zero building; cooling load; retrofit; building envelope; payback period

check for updates

Citation: Azam, U.; Farooq, M.; Munir, M.A.; Riaz, F.; Sultan, M.; Rehman, A.U.; Imran, M. Modelling Framework for Reducing Energy Loads to Achieve Net-Zero Energy Building in Semi-Arid Climate: A Case Study. *Buildings* **2023**, *13*, 2695. https://doi.org/10.3390/buildings13112695

Academic Editors: Antonio Caggiano and Hua Ge

Received: 4 August 2023
Revised: 14 October 2023
Accepted: 18 October 2023
Published: 26 October 2023

1. Introduction

Global warming refers to the increase in the average mean temperature of the earth and it is considered as one of the major consequences of greenhouse gas (GHG) emission [1]. As a result of this warmth hike, the energy demand is also increasing day by day, creating stress for power generation through non-renewable sources [2]. The enhanced demand on non-renewable sources in turn, is causing more GHG emission. The future projections in this regard do not have a brighter side [3,4]. Hence there is a dire need to strengthen the efforts being made to reduce GHG emissions. A major portion of generated power goes to the building sector for heating and cooling purposes. Studies reveal that one third of total greenhouse gases is emitted by the building sector itself [5,6]. On the other hand, approximately 40% of all global energy is used in the building sector, out of which over 60% energy is consumed for the heating and cooling of buildings [7]. This establishes that the impacts of energy consumption in the building sector on the environment and climate are twofold.

One of the easiest and cost-effective ways of reducing the greenhouse gas emission and addressing climate change is by optimizing our building sector to be energy efficient [8,9]. A building structure having a responsible energy consumption refers to an energy efficient building [10]. There are several ways to make a building energy efficient, which include but are not limited to energy efficient design and architecture, using material that withstands more temperature variations, installing energy efficient appliances, improving the heat envelope or installing on site a renewable energy source such as photovoltaic panels [11,12]. The energy consumption of a building structure can be reduced by 57% merely by its retrofitting [13]. Nearly 60% energy saving and CO_2 emission reduction were observed in a school building in Turkey by applying energy efficiency measures to the building envelope, mechanical system, and lighting arrangements, where, the payback period for these efficiency measures was less than seven years [14].

The idea of energy efficiency is reinforced by a similar case study from Italy, where an office building cut short its energy usage and emission to an extent of about 40% solely by retrofitting [15,16]. Another Canadian study came up with the conclusion that energy consumption can be reduced by 45%, only by insulating the roof and walls and replacing the windows of an office building in Vancouver city. The return on investment for this building was 7.7 years. An integrated solar powered energy source to transform this building into a net-zero energy building ended up with payback period of 7.6 years against the invested capital. Similar energy conservation measures applied on another building in Montreal exhibited saving in energy consumption of up to 39%. The insulation effect may slightly vary from location to location but improving the building envelope has been proved to be the best solution for energy saving in the building sector [17].

Since its emergence, the idea of energy efficiency has had prime importance. One of the outcomes of this extensive research related to energy efficiency of existing structures is the net-zero energy building, where the idea revolves around the philosophy of bringing energy consumption to the minimum possible level without compromising quality and human comfort. A net-zero energy building is such a building that has reduced energy demand as compared to a traditional building. It has an on site electricity generation facility for its usage and the net-energy cost is almost zero in addition to having minimum greenhouse gas (GHG) emissions [18,19]. Net-zero energy buildings (NZEBs) have been considered as a best solution to control energy consumption and greenhouse gas emission in the building sector [20].

Pakistan has very high vulnerability to climate change and the associated risks, leading it to have a higher cost of living with risks and hazards [21–23]. Periodic extreme weather conditions, with events and climatic disasters in recent decades have created a dire need to strive for and explore new and cost effective ways to tackle extreme weather conditions [24,25]. The higher the risks, the greater will be the number of adaptation and mitigation measures thus further straining energy demand. There is already a significant gap between demand and supply of energy required for cooling in buildings which is ultimately increasing the issue of load shedding in the country. This load shedding in some areas is experienced ffor 10 to 12 h per day, making equal and equitable development more difficult. Power generation capacity is increasing at a rate of 7% annually at the supply end, while the demand is increasing at a much higher rate. The demand is expected to exceed 45,000 MW by 2030. The issue may continue, although the change in approach from non-renewable to renewable generation has potential to alter the situation. The available potential of renewable energy is above 167 GW, which can fulfill the demand for several decades if proper utilization of resources is carried out [26].

Green energy production is a major area of concern as well as the focus of global infrastructure development initiatives. Since the establishment of the Kyoto Protocol in 1997 and its implementation from 2005, countries have started taking compact measures to reduce emissions, such as generation of electricity from renewable energy resources, which not only help to reduce greenhouse gas emissions significantly but also lead to make the environment sustainable. Governments are making efforts through legislation and financial incentives offered, to encourage investors to invest in renewable energy sources [27]. About 40% less greenhouse gases are emitted by integrating a renewable energy source for the production of electricity as compared to obtaining electricity from the grid [28]. Being a signatory of the Kyoto Protocol and many other global forums that aim to reduce GHG emissions, Pakistan stands by its commitments to implement the UN sustainable development goals to reduce emissions and work for the green and clean environment [23].

In pursuance of the quest towards clean and cost-effective power generation, efforts have been in progress for a long time by the Pakistani government. This includes the increase in hydro power generation capacity and the gradual increment in solar and wind power generation [29,30]. Since there is a huge amount of capital involved, which hinders the trend shift, the need of the hour is to cut down energy consumption. As the margin of reduction lies in the building sector, the easy and cost-effective approach is to make buildings energy efficient. Numerous research studies have been carried out in this regard such as those held in Qatar, Australia, Canada, and the USA, but they are different in terms of the resources and exposure conditions of Pakistan [31]. Consequently, the potential of energy efficiency claimed in previous studies cannot be generalized for local context. Therefore, introducing it in a developing country like Pakistan, where not only the strong problem statement for soliciting this idea exists but where the research application is controlled by the availability of resources, needs a systematic approach to be developed using a practical model. The goal of this study was to establish a step-by-step process of converting existing structures into net-zero energy buildings in the local context in the light of available literature and to quantify the economic and ecological benefits associated with it.

A simple approach to achieve an energy efficient building through retrofit is to identify the sources that consume energy more than the requirement to serve the purpose. The studies show that the replacement of conventional electrical appliances with energy efficient devices can reduce a reasonable amount of energy [32,33]. A study conducted in Pakistan stated that there is a potential of 40 to 60 percent of energy conservation merely by replacing the installed traditional electrical appliances [34]. The retrofitting is not only limited to the replacement. A proper thermal transmittance in a building significantly reduces the energy consumption and improves energy performance [35]. According to an Indian case study, by improving the envelope of a building, heat gain is reduced by up to 33.5% and 9.2 kWh/day of electricity saving can be achieved [36]. A case study of Turkey showed that by improving the windows, walls, and roof of a building, heating energy demand can be reduced by 21%, 34%, and 50%, respectively, with favorable payback periods [37]. Another case study from Egypt concluded that 23% energy consumption can be reduced by solar shading, 8% reduction is achieved by window glazing, and about 25% reduction in energy consumption is achieved through airtightness [38].

A building envelope refers to a barrier between the internal building and the external environment and climate [39]. The higher the thermal quality of the building envelope the less are the heating and cooling loads [40]. For example, a correctly directed window with a dual glazed glass frame would bring the cooling load to 4.5% less than a single glazed window. A 12% reduction in load was achieved by changing the color of the external envelope. Cooling load can be reduced by 14% if the indoor temperature is set at 24 °C instead of 22 °C. By applying all such measures together, the cooling load of a building in Qatar was reduced by 53% [41]. As such, the energy consumption of a building is first reduced and then an alternate renewable energy source is linked with the structure to make it a net-zero building [11]. Building an integrated photovoltaic thermal (BIPVT) system is one of the systems adopted for an energy efficient source [42]. Another method is integrated PV window panels which are installed in residential and institutional buildings [43]. A combined heating and power system is another sustainable method serving as an energy source in a building structure [44].

The photovoltaic panel finds its application as one of the most common renewable energy sources because of the comparatively reduced cost and the potential for serving as shading when installed on the building. The other sources are renewable, but they are often required to be integrated with fuel-based systems and are complex to apply. Therefore those renewable sources find less applicability as compared to a photovoltaic panel based energy source for converting a building structure into a net-zero energy building [45,46]. The study also utilized a photovoltaic source for supplying energy to the building for analysis purposes. In addition, the increasing trend in the country and the facilitation being provided by the government for such an initiative of solar panel installation, have also led to analysis of the structures with regard to a solar based renewable energy source.

The prime objective of this study was to test the applicability of established knowledge in the local context for the local community to bring energy efficiency measures in traditionally constructed buildings. Another important aspect was instigation of the greenhouse gas emission calculation, to reflect the environmental impact potential of energy retrofit measures. The city of Lahore is one of the worst cities on the scale of the air quality index. Thus, the measurement of each reduced ton of GHGs is vitally important. In an energy-strained country, where increased energy consumption is being met by fossil fuel-based power plants and has the highest circular debt in the energy sector, bringing energy efficiency to public buildings can have impactful results. So, the research was conducted as a case study to establish indigenous evidence and a knowledge base to meet the energy related challenges.

The manuscript starts with an introduction section, which discusses the limitations of applicability in the context of climatic condition and where the nature of the building reflects the fact that previous studies in this regard have selected a single office, multiple offices, or residential units for the study of energy efficiency through retrofit. It is followed by the section describing the method adopted and material used for this particular study, leading towards the results and associated discussion on the results. Based on the results and related discussion, the study establishes a framework for transforming an institutional building situated in a semi-arid climate into a net-zero energy building. Accordingly, the study presents decisive scientific conclusions, followed by recommendations for the future.

2. Materials and Method

In order to evaluate the effects of energy conservation measures on cost, an institutional building from the provincial capital city Lahore in Pakistan was identified as a study subject. There are two key climate indicators (temperature and precipitation) and their maximum and minimum values for each month of the year along with the year when the maximum value is available online [47].

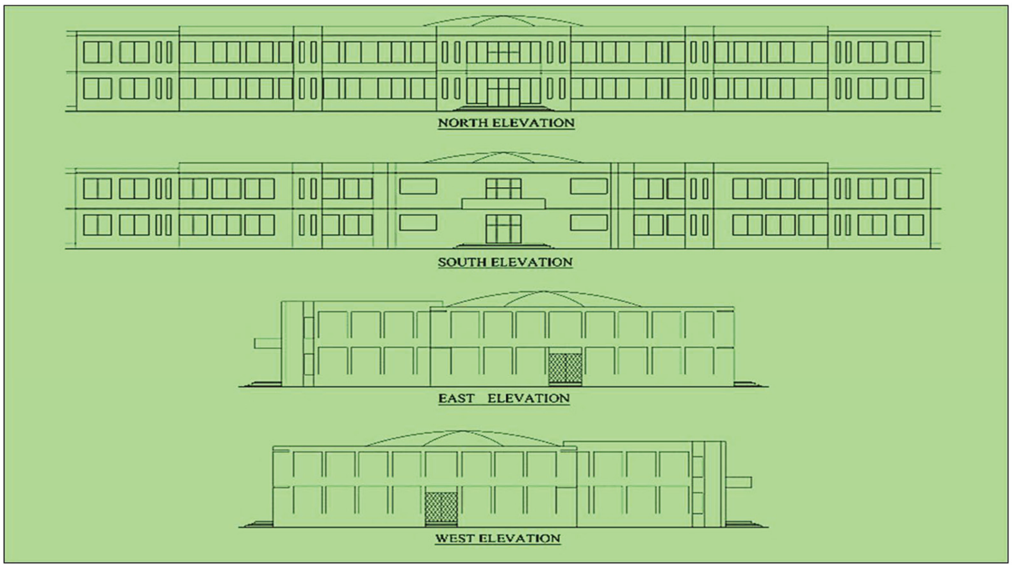
The research process comprised the collection of all necessary information including building dimensions, building material, quantity and rated power of all installed electrical devices, and information about components that potentially contribute to energy consumption. A comparison of the rated power of installed electrical devices and proposed energy efficient electrical devices was drawn up. The next task was to calculate and compare the cooling load of the building, for which simulation was carried out using the hourly analysis program (HAP). After incorporating the suggested retrofitting measures for electrical load reduction of the building, the system advisor model (SAM) was used to design a solar energy system for the decreased load. This was followed by an economic analysis of the retrofit and solar energy design using the prevailing market prices in the Lahore region.

An analysis, related to the impact on climate change through reduction in GHG emissions, was also the part of research-study findings.

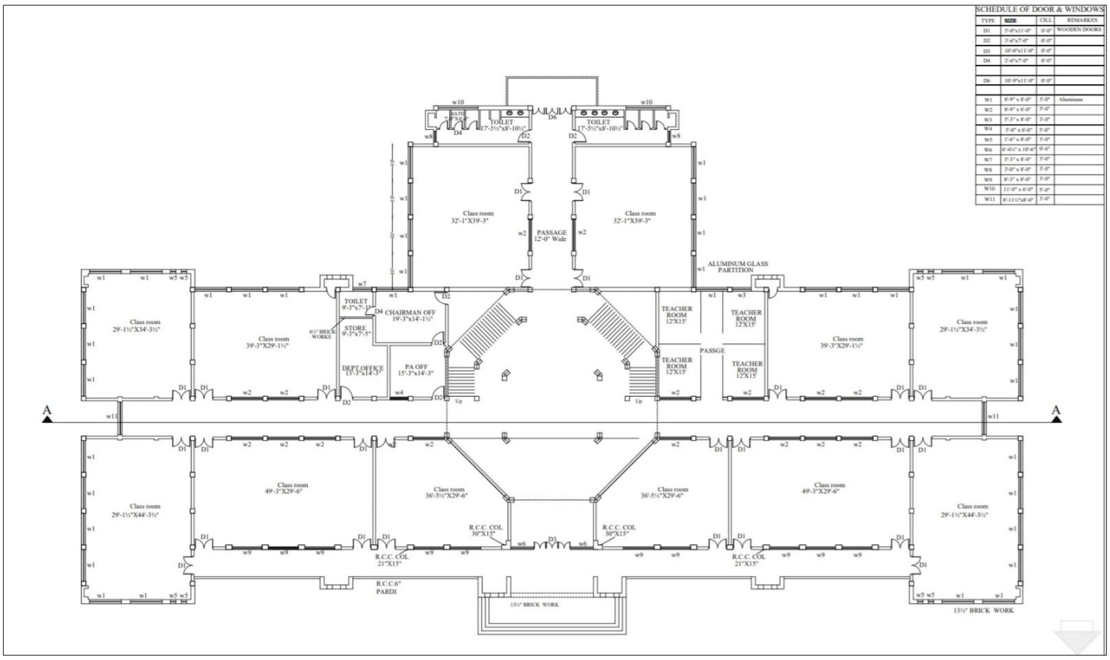
2.1. Case Study

The purpose of this study was to convert an educational institute into a net-zero energy campus. The selected building had two floors, with an area of 2191 square meters for each floor. The building was being utilized with an irregular pattern of occupant density, which varied during the timeframe of 8 a.m. to 6 p.m., 5 days a week, during the academic semester.

The elevations of the buildings are shown in Figure 1.



(**a**) Elevation



(**b**) Plan View

Figure 1. Building drawings and projection.

It was easy to obtain the required information available to study the effect of different retrofitting measures on the cooling load and having ample space and sunlight available to install a solar system. The building specifications are summarized in Table 1.

Table 1. Different conditions of the selected building.

Sr. No	Building Parameter	Values
1	Number of stories	2
2	Total Area	2191 sq. meter
3	Ceiling height	3.65 m
4	Orientation	South
5	Schedule	8 a.m. to 5 p.m.
6	Occupancies	200
7	Unconditioned Space Max Temp	40 °C
8	Unconditioned Space Min Temp	12 °C
9	Ambient at space Max (Maximum outside) Temperature	44 °C
10	Ambient at space Min (Minimum outside) Temperature 9	12 °C
11	Class Rooms/Labs occupancy	12 per Class on Each Floor
12	Offices occupancy	3 per Office on Each Floor
13	Construction Material	Double Brick Walls, Concrete Roof, Single Glazed Window, Wooden Doors

2.2. *Walk-Through Energy Audit and Data Collection*

The energy audit is the key step of energy conservation projects. It is necessary in order to collect the data of the building which is to be subjected to energy conservation measures. The energy audit includes the calculation of total energy consumption, electrical load nature, building envelope details, wastage of energy, which enables possible ways to be found by which the wastage of energy can be avoided.

The walk-through audit was carried out in two steps:

- The information on the current energy consuming points and sources
- The identification of point-to-point potential energy conservation measures with quick results

After listing the current appliances, each room of the building was examined in turn. In addition, past utility bills were also examined to discover how many appliances were present in the building and how much energy was being consumed. This also served a secondary function of data validation. The main focus during this phase was on luminaires, fans, and air-conditioning units. The detailed data of lights, fans, cooling/heating load (air conditioners) and office equipment collected are briefly mentioned in Table 2, a and b.

Table 2. (**a**) Details of the equipment used for energy audit. (**b**) Description of the electrical appliances installed in the building.

(**a**)

Audit Equipment	Purpose	Model	Range	Unit	Working Temperature
Lux meter	Intensity of light on surface	UT-381	20 Lux–20,000 Lux	Lux	0 to 40 °C
Anemometer	Wind speed and wind pressure	UT-360	0 m/s–30 m/s	m/s	0 to 40 °C
Clamp meter	Voltage	UT-203	400 mV–600 V	Volt	N/A
	Current		40–400 amp	Ampere	
	Resistance		400–40 M ohm	Ohm	
Thermal imager	Heat signal imagery	FLUKE TI 105	Focus free beyond 1.2 m	None	−20 to 150 °C
Infra-red thermometer	Temperature even from distance	UT-301C	−18 to 550 °C	Degree Celsius	N/A

(**b**)

Appliances	Rated Power (W)	Quantity	Expected Peak Power (kW)
Conventional AC 24,000 BTU	2400	1	2.4
Conventional AC 18,000 BTU	1950	1	1.95
Conventional AC 12,000 BTU	1400	1	1.4
Conventional Fan	110	114	12.54
Compact fluorescent lamp CFL	45	12	0.54
Compact fluorescent lamp CFL	25	7	0.175
Compact fluorescent lamp CFL	18	10	0.18
LED panel	36	173	6.228
Fluorescent tube lights—4 Foot	45	272	12.24
Total			37.653

2.3. Retrofitting Data Analysis

Analysis was performed on the data collected by the walk-through audit to find out where energy was being wasted and what could be the possible ways to minimize such wastage. Energy wastage is generally minimized by replacing inefficient electrical equipment by energy efficient equipment and improving the building envelope.

2.3.1. Electrical Devices

After the walk-through audit, the energy consumption was determined by noting down the rated capacity of appliances where it was found that most of the electrical devices were not energy efficient, e.g., fluorescent tube lights, old fans, and conventional air conditioners. After that, these old appliances were virtually replaced with energy efficient appliances and the difference of their rated power and associated energy consumption determined.

After replacing the conventional equipment and appliances with energy efficient ones, the potential of energy conservation was carefully examined and analyzed from the power consumption rating. The remarkable results obtained by using energy efficient appliances are demonstrated in Figures 2 and 3.

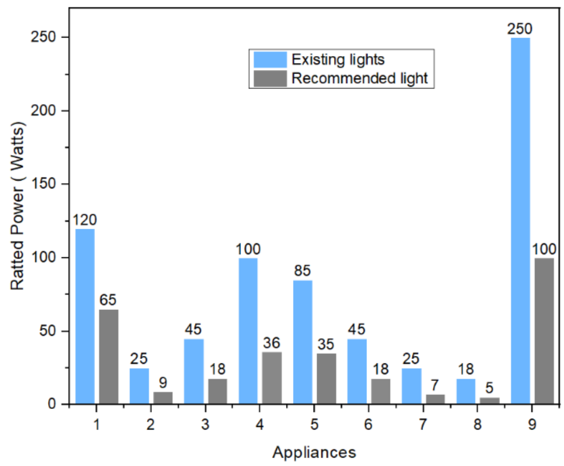


Figure 2. Comparison of power consumption of existing traditional and energy efficient lights.

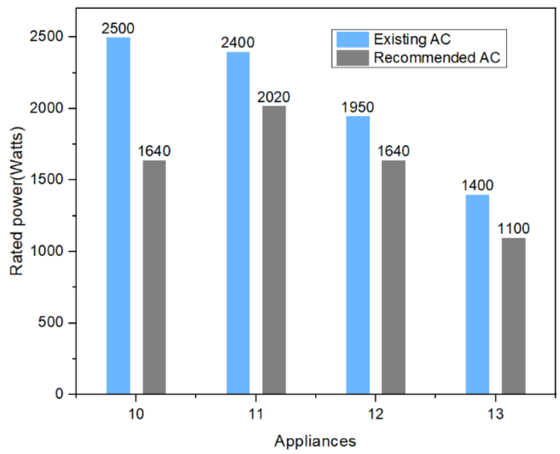


Figure 3. Comparison of existing traditional and energy efficient AC in term of power consumption.

2.3.2. Building Envelope

Analyses for cooling requirement of the building were conducted using the hourly analysis program (HAP). HAP calculates and simulates hour by hour the cooling load of the building by using ASHRAE-endorsed transfer function. The calculation is simplified by HAP and HAP can calculate all loads from all parts of a building, i.e., windows, roofs, walls, etc. The building specifications, which are required by the HAP model as an input to calculate the cooling load are mentioned in Table 1.

Cooling loads were calculated by making each intervention in turn and then applying all measures collectively. A significant potential of energy conservation was observed. The next step was to design and integrate a renewable energy source in the system to turn the building into a net-zero energy building. A smart selection is desired for the selection of the renewable energy source, keeping in mind the availability of space, economic benefits, and environmental impacts. The most suitable approach is to integrate the building with PV panels. Integrated PV panels generate electricity, and also there are many other benefits associated with integrated PV panels such as the space to install a PV panel being easily available either on the roof or on a wall. The second major benefit of integrating PV panels on roofs and walls is the decrease in the cooling load of the building which is also a primary objective. The cost of provision of this energy source is part of the economic analysis and the associated cost including its payback period is provided in the Section 3 (Results and Discussion).

Electricity produced by PV panels depends upon many factors such as orientation, shading, self-shading, and collector efficiency. The direction of the selected building is towards true south; sunshine is available all day without any interruption with shade. Keeping these points in view, a solar photo voltaic system was introduced and the system analyzed for a potential net-zero energy building.

2.4. Environmental Impact Analysis

Greenhouse gases are a serious threat to human life as they seriously contaminate our surroundings. Of all the greenhouse gases, carbon dioxide has the most adverse effect on the environment, becoming a key driver of global warming. Therefore, reduction in carbon dioxide was also an object of this study.

The amount of carbon dioxide emission avoided, by making use of a renewable energy resource is determined by multiplication of the plant emission factor and electricity produced by any conventional resource. The following equation was used to calculate the avoided carbon dioxide emission:

$$E_A = P_g \times F_E$$

In the above equation P_g is the electricity generated by conventional systems (kWh) and F_E is the plant emission factor (metric tons of CO_2/kWh) which is the amount of carbon dioxide in metric tons emitted for one kilowatt hour generation of electricity by fossil-fueled plants. This factor depends on the type of fossil fuel used and on the technology which is used to convert this fossil fuel to electricity. In this study the avoided carbon dioxide emission is based on the plant emission factor 7.07×10^{-4} metric tons CO_2/kWh [32].

2.5. Economic Analysis

An economic analysis of these energy efficiency measures was also carried out, which revolved around the payback period of the capital invested for the retrofit. The cost of annual energy saving can be calculated by multiplying the amount of energy saved by the energy tariff, which in the case of Pakistan is 17.8 PKR/kWh.

3. Results and Discussion

3.1. Comparison of Existing and Recommended Appliances

The first step was to replace theoretically the conventional appliances with energy efficient appliances so as to reduce energy consumption. Figures 2 and 3 shows the difference in power rating of the existing and replaced appliances. It was found that 12 traditional fluorescent lamps require a peak power supply of 0.54 kW and if replaced with the same quantity of energy efficient LED bulbs, the peak power requirement was reduced to 0.216 kW. Similarly, if conventional AC is replaced with energy efficient inverter tech AC, the peak power consumption requirement is reduced from 2.4 kW to 2.02 kW, a drop of 0.38 kW. As far as a fan is concerned, 114 installed conventional fans if replaced with the same quantity of energy efficient fans bring the peak power down from 12.54 to 7.41 which gives a drop of 45 W per fan. Overall, with the replacement of the traditional existing electrical devices with energy-efficient devices, the building electrical load, a key indicator of building energy consumption, was found to decrease from 31.95 kW to 17.58 kW.

3.2. Effect of Retrofitting Measures on Cooling Load

After replacing the lights and AC from conventional to advanced and energy efficient types, there was a significant reduction in cooling load. The total cooling load with normal lights and fans was 218.7 Ton (769.13 kW) but it turned out to be 204 Ton (717 kW) with the replaced items. The resulting reduction in cooling load is graphically represented by Figure 4.

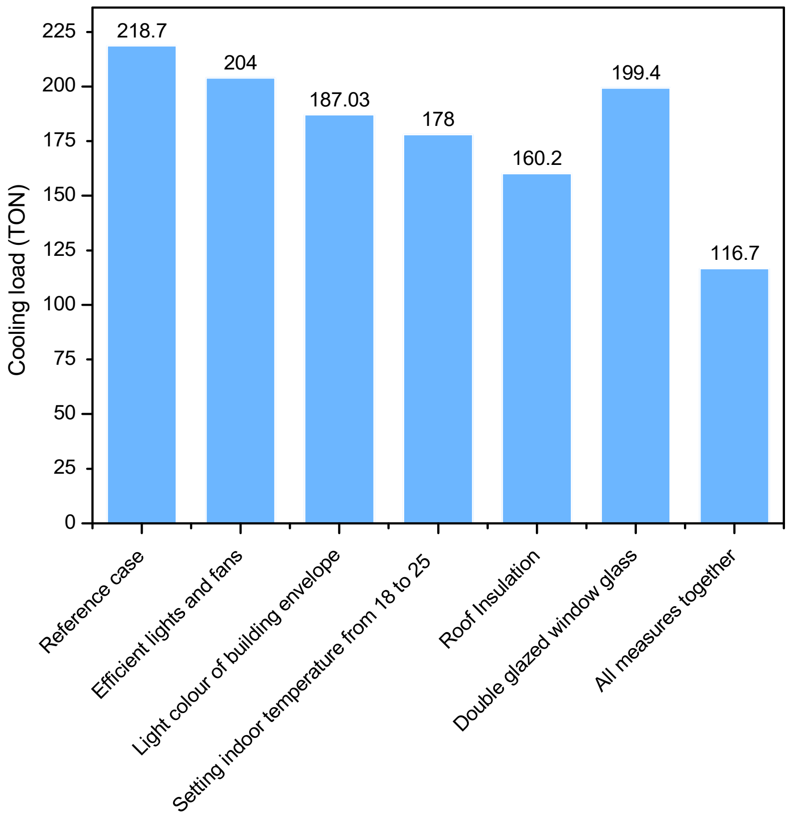


Figure 4. Effect of energy efficiency measures applied separately and collectively on cooling load.

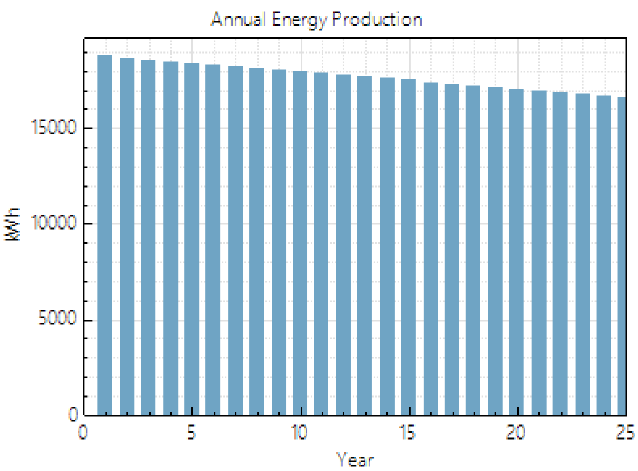
It is important to note that when all the measures were combined and applied simultaneously, the cooling load fell to a value of 408 kW (116 Ton) from 767 kW (218 Ton) load. This straight drop of about 359 kW (102 Ton) evidently supports the retrofitting model while providing an economical base with a relatively low payback period. This 47% reduction in cooling load is sufficient evidence to provide a foundation for the introduction of a renewable energy source in a system with low generation capacity and for low cost. By implementing the energy conservation mentioned above, the energy consumption of the building was reduced from 47,761.12 kWh to 25,484 kWh.

3.3. Integrating Renewable Energy

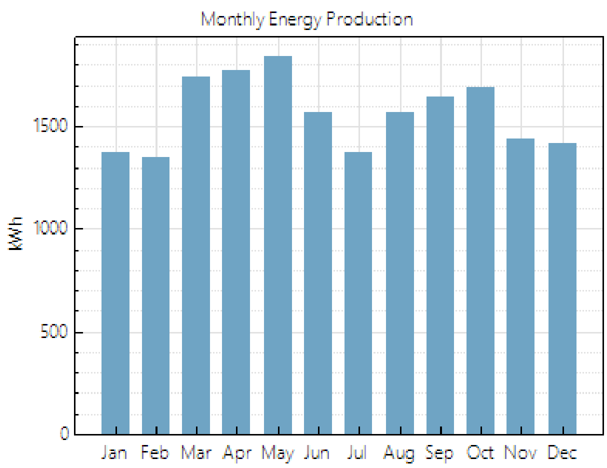
A solar based power generation and supply source was designed using the system advisor model (SAM) for the peak load of 17.58 kW. This peak load corresponds to the reduced load after the retrofit measures have been put in place. Results for the annual and monthly power generation from the solar system are shown in Figure 5. Figure 6 and Table 3 represents the cash flow for a solar system for 25 years until the 5 year cash flow is negative which means the cost retrieved by saving electricity is less than the total investment to install a solar system. After 5.7 years, the cash flow is positive, which mean now the cost to install a solar system has been recovered by the electricity generation from the solar system. When all the retrofit measures are in place, the maximum energy demand turns out to be 17.58 kW. This 17.58 kW will serve as the value of the peak capacity on the supply side. Hence a solar system was designed for a peak capacity of 17.58 kW. With a per panel capacity of 550 W, a 32 panel system having per panel a weight of 28.6 Kgs turned out to be the solar PV based energy system to meet the energy demand of the building structure.

Table 3. Energy generation by solar system and cash flow for 25 years.

No. of Years	Electricity Generation (kWh)	Cash Flow (M PKR)	Cumulative Cash Flow (M PKR)	Profit (M PKR)
0	0	0	0	−1.9338
1	18,786.9	0.3381642	0.3381642	−1.5956358
2	18,693	0.336474	0.6746382	−1.2591618
3	18,599.5	0.334791	1.0094292	−0.9243708
4	18,506.5	0.333117	1.3425462	−0.5912538
5	18,414	0.331452	1.6739982	−0.2598018
6	18,321.9	0.3297942	2.0037924	0.0699924
7	18,230.3	0.3281454	2.3319378	0.3981378
8	18,139.2	0.3265056	2.6584434	0.7246434
9	18,048.5	0.324873	2.9833164	1.0495164
10	17,958.2	0.3232476	3.306564	1.372764
11	17,868.4	0.3216312	3.6281952	1.6943952
12	17,779.1	0.3200238	3.948219	2.014419
13	17,690.2	0.3184236	4.2666426	2.3328426
14	17,601.8	0.3168324	4.583475	2.649675
15	17,513.7	0.3152466	4.8987216	2.9649216
16	17,426.2	0.3136716	5.2123932	3.2785932
17	17,339	0.312102	5.5244952	3.5906952
18	17,252.4	0.3105432	5.8350384	3.9012384
19	17,166.1	0.3089898	6.1440282	4.2102282
20	17,080.3	0.3074454	6.4514736	4.5176736
21	16,994.9	0.3059082	6.7573818	4.8235818
22	16,909.9	0.3043782	7.06176	5.12796
23	16,825.3	0.3028554	7.3646154	5.4308154
24	16,741.2	0.3013416	7.665957	5.732157
25	16,657.5	0.299835	7.965792	6.031992



(**a**)



(**b**)

Figure 5. Energy generation by solar system. (**a**) Annual energy generation; (**b**) monthly energy generation.

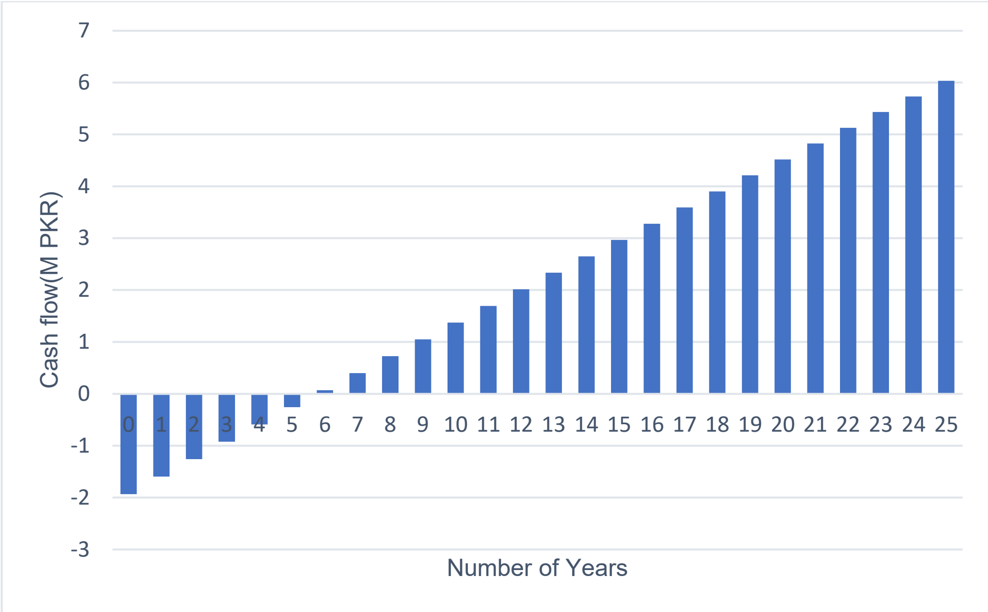


Figure 6. Cash flow for solar system in 25 years.

3.4. Net-Zero Energy Potential

An existing structure can be converted into a net-zero energy structure by minimizing the energy consumption by retrofitting for energy efficiency and then installing a renewable energy source, i.e., solar panels, to meet the energy demand.

3.5. Environmental Analysis

Retrofitting has a strong potential to reduce the carbon footprint. The study revealed that existing appliances emitted 33.76 metric tons of carbon dioxide annually but this was found to decline to 18 metric tons merely by replacement of traditional appliances with energy efficient ones as shown in Table 4.

Table 4. Reduction in carbon dioxide emission by retrofitting electrical appliances.

Appliances	Carbon Dioxide Emission for Existing Appliances (Metric Ton)	Carbon Dioxide Emission for Recommended Appliances (Metric Ton)	Reduction in Carbon Dioxide Emission (Metric Ton)	Percentage Reduction in Carbon Dioxide Emission (Percentage)
Air conditioner	5	4.14	0.86	17.2
Light	16.27	6.4	9.78	60
Fan	12.48	7.37	5.1	40.9
Net impact	33.76	18	15.74	46.6

Improving the building envelope reduces the cooling requirements of the structure. By having a suitable building envelope in place, less electrical energy is required to cool the building. Since Pakistan fulfills its energy requirements by using non-renewables, a decrease in the usage of electricity would definitely cause a decline in carbon dioxide emission. By improving the envelope of the building, carbon dioxide emission is reduced up to 46.6 Percent (Table 5).

Table 5. Reduction in carbon dioxide emission by improving building envelope.

Measures Taken	Carbon Dioxide Emission (Metric Ton)	Reduction in Carbon Dioxide Emission (Metric Ton)	Percentage Reduction in Carbon Dioxide Emission (Percentage)
Reference case	144.31284	_	_
Efficient lights and fans	134.6128	9.7	6.7
Light paint color for building envelope	123.4148627	20.9	14.47
Setting indoor temp from 18 to 25 °C	117.4562667	26.86	18.6
Roof Insulation	105.71064	38.6	26.7
Double glazed window glass	131.5774133	12.74	8.8
Installing solar wall on south	128.674	15.64	10.8
All measures together	77.00644	67.31	46.6

3.6. Economic Analysis

The decrease in the electrical load by applying all retrofitting measures is displayed in Table 6. By replacing all existing lights, air conditioners, and fans with recommended energy efficient appliances, 45% of the electrical load decreased. The expected cost required to do these efficiency measures came out to be 1.04 M PKR with a payback period of 2.30 years.

Table 6. Cost benefit analysis for electrical appliances.

Appliance	Load Reduction (Percentage)	Load Reduction (kW)	Expected Cost (M PKR)	Expected Payback Period (Years)
Lights	60	7.88	0.32	1.35
Air conditioners	17	0.99	0.24	4.07
Fans	41	5.13	0.48	1.5
Net impact	45	14.00	1.04	2.30

The estimation of the cooling load of the building was performed for all possible measures mentioned in Table 7. All the retrofitting measures have their own impact on the cooling load. The results from all the proposed measurements were compared with the reference case in turn and collectively. By applying all the measures, it was found that the cooling load could be reduced by up to 46.64%. The total cost required to carry out these measures turned out to be PKR 4,291,034 with a payback period of 2.5 years. It was found that some improvements required a cost whereas several were related to human behavior, i.e., indoor temperature. Some improvements are a bonus because their cost is already included in retrofitting of the electrical appliances, i.e., efficient lights and fans.

Table 7. Economic analysis for improving the building envelope.

Measures Taken	Load Reduction (Percentage)	Cooling Load (kW)	Retrofitting Cost (M PKR)	Pay Back Period (Years)
Reference case	-	765.45	-	-
Efficient lights and fans	6.73	714	-	-
Light paint color for building envelope	14.50	654.6	0.43	0.8

Table 7. *Cont.*

Measures Taken	Load Reduction (Percentage)	Cooling Load (kW)	Retrofitting Cost (M PKR)	Pay Back Period (Years)
Setting indoor temp from 18 to 25 °C	18.61	623	-	-
Roof insulation	26.75	560.7	2.4	2.4
Double-glazed window glass	8.83	697.9	1.45	4.4
Installing solar wall on south	10.84	682.5	-	-
All measures together	46.64	408.45	4.28	2.5

3.7. Comparison of the Case Study

A similar study was conducted in Qatar, where a common residential stand-alone building with dimensions 12 × 12× 3 m in a cooling dominated area was subjected to retrofitting in order to convert it into a net-zero energy building. A comparison is drawn up in the following section in order to have a comparative overview of the local environment within a global scenario. The results are summarized in Table 8.

Table 8. Comparison between two case studies from Lahore, Pakistan (current) and Doha, Qatar (previous).

Measures Taken	Load Reduction	
	Current Case Study Lahore, Pakistan (Percentage)	Previous Case Study Doha, Qatar (Percentage)
Efficient lights and fans	6.73	10
Light paint color for building envelope	14.50	12
Setting indoor temp 24 °C	18.61	14
Roof insulation	26.75	28
Double-glazed window glass	8.83	4.5
All measures together	46.64	53

Comparison of both studies shows the following:

- The reduction in the cooling load by replacing lights and fans with efficient ones for Lahore Pakistan was 6.73%, while for Doha, Qatar it was 10%.
- By changing the outside color from dark to light, 14.50% cooling load reduction was achieved in the current study whereas it was 12% for the previous study.
- By increasing the set temperature from 18 to 24 °C, the cooling load was decreased by up to 18.61% for Lahore, Pakistan while it was 14% for Doha, Qatar.
- Adding a 2 cm layer of polyurethane on the roof caused a 26% decline in the cooling load for Pakistan while 28% for Qatar.
- Replacing a single-glazed window with double-glazed window, reduced thecooling load up to 8.83% for current study while it was 4.5% for the previous study.
- By implementing all retrofitting measures together, the cooling load for Lahore, Pakistan was found to exhibit a drop of 46.64% with a payback period of 2.5 years while for Doha, Qatar it was 53%, as represented in Figure 7.
- The payback period for all these measures in Lahore, Pakistan was about 2.5 years while for Doha Qatar it was about 1.5 years.

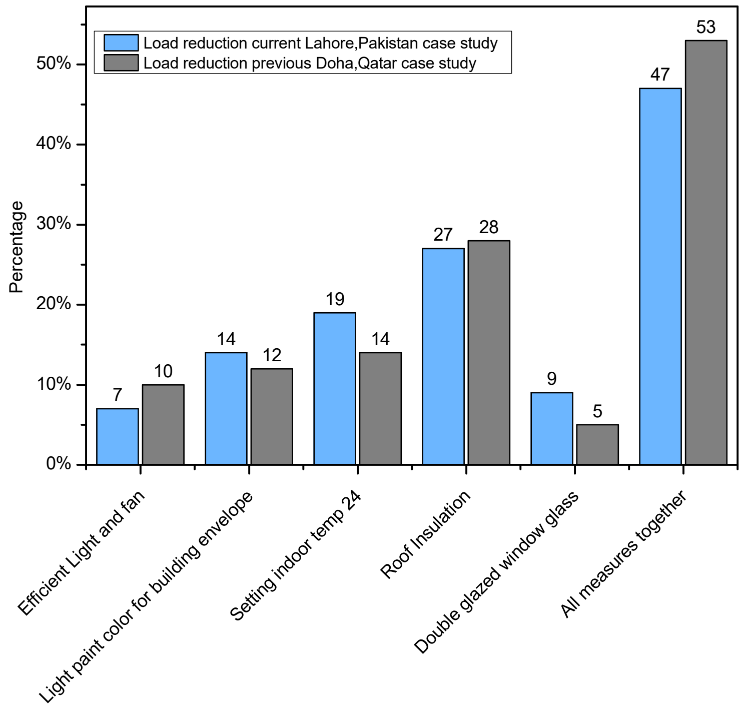


Figure 7. Comparison between Doha, Qatar and Lahore, Pakistan case studies.

3.8. Practical Implication of This Study

This research finds potential applications which spread from a global to an individual level. On the one hand, it provides a framework to achieve a key sustainable development goal (SDG) of clean energy directly at local level, on the other hand it has a strong potential to contribute to climate action by causing a significant reduction in GHG emissions. The research study also provides an insight into new research areas related to a net-zero energy building. For example, the study recommends that another renewable energy source that operates at low budget in the community, may be tested for its use as a source of renewable energy, such as a biogas plant. The study provides a methodological approach to bring energy efficiency to buildings through small steps of visionary action. The first step is to reduce energy consumption by making use of energy efficient appliances and this is to be followed by introducing a renewable source of energy in the system. There is a twofold reduction in GHG emissions. First, by reducing the energy demand which is generated through non-renewable means and second by using a renewable source of energy instead of the traditional ones with GHG emissions. The research suggests a practical and practicable approach to address one of the key socio-economic issues of developing countries like Pakistan, i.e., the ever increasing energy demand. The study throws light on the exploration of new small scale renewable energy sources. The insight for future research may include a comparative study of energy efficient architecture with inefficient architecture and design, energy efficiency and sustainable material use, studying the impact of using energy efficient appliances in an ecofriendly building vs. those in a non-ecofriendly building, combining the effect of all retrofits on an energy efficient design vs. an inefficient design, exploring more small scale renewable sources for net-zero buildings and studying the impact on building a micro-climate after making retrofits or a net-zero building.

4. Conclusions

It is correctly said that one kWh conserved is cheaper than one kWh generated. As a cash-strained developing economy with high circular debt in the energy sector, there is no option left for Pakistan but to move quickly towards efficient energy conservation measures especially in the building sector. This study explores one potential way towards achieving energy efficiency by making a case study of an existing institutional building and conducting a model study to convert this building into a net-zero energy building. The entire process involved in this research concluded with the establishment of a step-by-step process to convert a building into a net-zero energy building. It exhibited a significant reduction in the energy demand of a building when traditional electrical appliances were replaced with modern energy saving appliances and the building envelope was improved, subject to the local conditions of the area where the study was conducted. The analysis and design process enabled the study to reach the following concrete conclusions:

- Electricity consumption was reduced by up to 45% by replacing existing electrical appliances with energy efficient appliances. Carbon emission declined by up to 46.6%. The required capital for this change was calculated as 1.04 M PKR with a payback period of 2.30 years.
- The improving building envelope for energy efficiency led to 46.6% reduction in cooling load and carbon dioxide emission, with a capital investment of PKR 4.28 M with a 2.5 year payback period.
- The addition of a solar energy source for achieving the net-zero level required a cost of PKR 1.9 M, with a required time of recovery of 5.78 years.
- In addition to the above stated reduction in carbon emissions, this intervention would reduce 13.2 metric tons additional carbon dioxide emission annually, a significant amount for a single building.

The above stated facts, achieved through experimental work, lead us towards establishing the following evidence based guide for practical implementation and further exploration:

- Retrofitting of an existing structure has potential for energy conservation of more than 40 percent. No matter how small it is, a simple energy retrofit measure contributes greatly towards a green world and therefore must be implemented and used.
- Energy conservation starts from the design phase. All process designs must undergo a strong energy efficiency audit and the suggested measures must be implemented for the improved design.
- Building envelopes have a strong ability to determine the energy consumption pattern of a building. Therefore, it must be a hot topic of debate for building information models and designs. As some modern practices depict, the use of solar plates for creating a building envelope can be adopted to obtain improved results.

Limitations

- It is important to mention that the reported reduction of electricity consumption after retrofitting shows the value from a software model and the actual intervention on the structure may vary due to multiple factors related to installation and fixation in addition to the lack of control over exposure conditions.
- The impact of the building type based on the nature of occupancy, i.e., residential, commercial, or institutional, of the building is beyond the scope of the current study.
- The payback period in comparison to the invested capital corresponds to the average prevailing market rates at the time of research and may vary in the current scenario

5. Recommendations

Amid global warming, climate change, and energy crises issues in Pakistan, it is highly recommended that all new constructions in the building sector must be forced to use energy efficient appliances. These should be promoted and encouraged to be used in order to reduce energy wastage. In all the previously constructed public sector buildings appliances should gradually be replaced with energy efficient appliances in addition to improving their building envelopes. Incentives like subsidies and tax relaxations should be offered to promote and encourage such initiatives. More rational and practical research should be carried out in making a building energy efficient. This refers to implementing retrofit intervention practically and then studying the results on how much energy efficiency and cost effectiveness is actually achieved. The idea of a net-zero energy building must be piloted by federal and provincial governments and should be supported by nonprofit organizations working on climate change and associated issues. Multidisciplinary research comprising researchers from fields such as civil engineering, architecture, planning, electrical engineering, and climate change should be carried out in Pakistan by considering each aspect as equally weighted for such an energy efficient net-zero energy building so as to meet the future challenges.

Author Contributions: Conceptualization, U.A. and M.F.; methodology, U.A. and M.A.M.; software, F.R.; validation, M.F., A.U.R. and M.I.; formal analysis, U.A. and M.S.; investigation, U.A. and M.F.; resources, M.F. and A.U.R.; data curation, U.A. and M.F.; writing—original draft preparation, U.A. and M.F.; writing—review and editing, U.A., M.S., M.A.M., F.R. and M.F.; visualization, M.A.M.; supervision, M.F.; project administration, M.F. and A.U.R.; funding acquisition, F.R. and A.U.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research is funded by the Researchers Supporting Project number (RSPD2023R701), King Saud University, Riyadh, Saudi Arabia. Also, the present research is funded by Abu Dhabi University's Office of Research and Sponsored Programs.

Data Availability Statement: Data will be available on request.

Acknowledgments: The authors extend their appreciation to the researchers supporting Project number (RSPD2023R701), King Saud University, Riyadh, Saudi Arabia.

Conflicts of Interest: There are not known conflict of interest.

References

1. Bhatla, R.; Verma, S.; Ghosh, S.; Gupta, A. Abrupt changes in mean temperature over India during 1901–2010. *J. Earth Syst. Sci.* **2020**, *129*, 166. [CrossRef]
2. Liu, Z.; Li, H.; Hou, K.; Xu, X.; Jia, H.; Zhu, L.; Mu, Y. Risk assessment and alleviation of regional integrated energy system considering cross-system failures. *Appl. Energy* **2023**, *350*, 121714. [CrossRef]
3. Clarke, L.; Eom, J.; Marten, E.H.; Horowitz, R.; Kyle, P.; Link, R.; Mignone, B.K.; Mundra, A.; Zhou, Y. Effects of long-term climate change on global building energy expenditures. *Energy Econ.* **2018**, *72*, 667–677. [CrossRef]
4. Liu, Z.; Tang, P.; Hou, K.; Zhu, L.; Zhao, J.; Jia, H.; Pei, W. A Lagrange-multiplier-based Reliability Assessment for Power Systems Considering Topology and Injection Uncertainties. *IEEE Trans. Power Syst.* **2023**, *early access*. [CrossRef]
5. Mastouri, H.; Bahi, H.; Radoine, H.; Benhamou, B. Improving energy efficiency in buildings: Review and compiling. *Mater. Today Proc.* **2020**, *27*, 2999–3003. [CrossRef]
6. Riaz, F.; Tan, K.H.; Farooq, M.; Imran, M.; Lee, P.S. Energy Analysis of a Novel Ejector-Compressor Cooling Cycle Driven by Electricity and Heat (Waste Heat or Solar Energy). *Sustainability* **2020**, *12*, 8178. [CrossRef]
7. Li, X.; Wang, F.; Al-Razgan, M.; Awwad, E.M.; Abduvaxitovna, S.Z.; Li, Z.; Li, J. Race to environmental sustainability: Can structural change, economic expansion and natural resource consumption effect environmental sustainability? A novel dynamic ARDL simulations approach. *Resour. Policy* **2023**, *86*, 104044. [CrossRef]
8. Irfan, M.; Abas, N.; Saleem, M.S. Thermal performance analysis of net zero energy home for sub zero temperature areas. *Case Stud. Therm. Eng.* **2018**, *12*, 789–796. [CrossRef]
9. Xiao, Z.; Li, H.; Jiang, H.; Li, Y.; Alazab, M.; Zhu, Y.; Dustdar, S. Predicting Urban Region Heat via Learning Arrive-Stay-Leave Behaviors of Private Cars. *IEEE Trans. Intell. Transp. Syst.* **2023**, *24*, 10843–10856. [CrossRef]
10. Jiang, H.; Xiao, Z.; Li, Z.; Xu, J.; Zeng, F.; Wang, D. An Energy-Efficient Framework for Internet of Things Underlaying Heterogeneous Small Cell Networks. *IEEE Trans. Mob. Comput.* **2022**, *21*, 31–43. [CrossRef]
11. AlAjmi, A.; Abou-Ziyan, H.; Ghoneim, A. Achieving annual and monthly net-zero energy of existing building in hot climate. *Appl. Energy* **2016**, *165*, 511–521. [CrossRef]
12. Imani, N.; Vale, B. A framework for finding inspiration in nature: Biomimetic energy efficient building design. *Energy Build.* **2020**, *225*, 110296. [CrossRef]
13. Cai, T.; Dong, M.; Chen, K.; Gong, T. Methods of participating power spot market bidding and settlement for renewable energy systems. *Energy Rep.* **2022**, *8*, 7764–7772. [CrossRef]
14. Jiang, J.; Zhang, L.; Wen, X.; Valipour, E.; Nojavan, S. Risk-based performance of power-to-gas storage technology integrated with energy hub system regarding downside risk constrained approach. *Int. J. Hydrogen Energy* **2022**, *47*, 39429–39442. [CrossRef]
15. Ferrari, S.; Beccali, M. Energy-environmental and cost assessment of a set of strategies for retrofitting a public building toward nearly zero-energy building target. *Sustain. Cities Soc.* **2017**, *32*, 226–234. [CrossRef]
16. Riaz, F.; Yam, F.Z.; Qyyum, M.A.; Shahzad, M.W.; Farooq, M.; Lee, P.S.; Lee, M. Direct Analytical Modeling for Optimal, On-Design Performance of Ejector for Simulating Heat-Driven Systems. *Energies* **2021**, *14*, 2819. [CrossRef]

17. Charles, A.; Maref, W.; Ouellet-Plamondon, C.M. Case study of the upgrade of an existing office building for low energy consumption and low carbon emissions. *Energy Build.* **2019**, *183*, 151–160. [CrossRef]
18. D'Agostino, D.; Mazzarella, L. What is a Nearly zero energy building? Overview, implementation and comparison of definitions. *J. Build. Eng.* **2019**, *21*, 200–212. [CrossRef]
19. Wells, L.; Rismanchi, B.; Aye, L. A review of Net Zero Energy Buildings with reflections on the Australian context. *Energy Build.* **2018**, *158*, 616–628. [CrossRef]
20. Yin, L.; Wang, L.; Huang, W.; Liu, S.; Yang, B.; Zheng, W. Spatiotemporal Analysis of Haze in Beijing Based on the Multi-Convolution Model. *Atmosphere* **2021**, *12*, 1408. [CrossRef]
21. Yin, L.; Wang, L.; Zheng, W.; Ge, L.; Tian, J.; Liu, Y.; Yang, B.; Liu, S. Evaluation of Empirical Atmospheric Models Using Swarm-C Satellite Data. *Atmosphere* **2022**, *13*, 294. [CrossRef]
22. Hussain, M.; Liu, G.; Yousaf, B.; Ahmed, R.; Uzma, F.; Ali, M.U.; Ullah, H.; Butt, A.R. Regional and sectoral assessment on climate-change in Pakistan: Social norms and indigenous perceptions on climate-change adaptation and mitigation in relation to global context. *J. Clean. Prod.* **2018**, *200*, 791–808. [CrossRef]
23. Riaz, F.; Qyyum, M.A.; Bokhari, A.; Klemeš, J.J.; Usman, M.; Asim, M.; Awan, M.R.; Imran, M.; Lee, M. Design and Energy Analysis of a Solar Desiccant Evaporative Cooling System with Built-In Daily Energy Storage. *Energies* **2021**, *14*, 2429. [CrossRef]
24. Yin, L.; Wang, L.; Huang, W.; Tian, J.; Liu, S.; Yang, B.; Zheng, W. Haze Grading Using the Convolutional Neural Networks. *Atmosphere* **2022**, *13*, 522. [CrossRef]
25. Chen, J.; Liu, Z.; Yin, Z.; Liu, X.; Li, X.; Yin, L.; Zheng, W. Predict the effect of meteorological factors on haze using BP neural network. *Urban Clim.* **2023**, *51*, 101630. [CrossRef]
26. Rafique, M.M.; Rehman, S. National energy scenario of Pakistan—Current status, future alternatives, and institutional infrastructure: An overview. *Renew. Sustain. Energy Rev.* **2017**, *69*, 156–167. [CrossRef]
27. Adam, A.D.; Apaydin, G. Grid connected solar photovoltaic system as a tool for green house gas emission reduction in Turkey. *Renew. Sustain. Energy Rev.* **2016**, *53*, 1086–1091. [CrossRef]
28. Vares, S.; Häkkinen, T.; Ketomäki, J.; Shemeikka, J.; Jung, N. Impact of renewable energy technologies on the embodied and operational GHG emissions of a nearly zero energy building. *J. Build. Eng.* **2019**, *22*, 439–450. [CrossRef]
29. Zafar, U.; Rashid, T.U.; Khosa, A.A.; Khalil, M.S.; Rashid, M. An overview of implemented renewable energy policy of Pakistan. *Renew. Sustain. Energy Rev.* **2018**, *82*, 654–665. [CrossRef]
30. Mirza, F.M.; Kanwal, A. Energy consumption, carbon emissions and economic growth in Pakistan: Dynamic causality analysis. *Renew. Sustain. Energy Rev.* **2017**, *72*, 1233–1240. [CrossRef]
31. Feng, W.; Zhang, Q.; Ji, H.; Wang, R.; Zhou, N.; Ye, Q.; Hao, B.; Li, Y.; Luo, D.; Lau, S.S.Y. A review of net zero energy buildings in hot and humid climates: Experience learned from 34 case study buildings. *Renew. Sustain. Energy Rev.* **2019**, *114*, 109303. [CrossRef]
32. Ban, Y.; Liu, X.; Yin, Z.; Li, X.; Yin, L.; Zheng, W. Effect of urbanization on aerosol optical depth over Beijing: Land use and surface temperature analysis. *Urban Clim.* **2023**, *51*, 101655. [CrossRef]
33. Song, K.; Ahn, Y.; Ahn, J.; Kwon, N. Development of an Energy Saving Strategy Model for Retrofitting Existing Buildings: A Korean Case Study. *Energies* **2019**, *12*, 1626. [CrossRef]
34. Ali, M.R.; Shafiq, M.; Andejany, M. Determinants of consumers' intentions towards the purchase of energy efficient appliances in Pakistan: An extended model of the theory of planned behavior. *Sustainability* **2021**, *13*, 565. [CrossRef]
35. Fan, Y.; Xia, X. A multi-objective optimization model for energy-efficiency building envelope retrofitting plan with rooftop PV system installation and maintenance. *Appl. Energy* **2017**, *189*, 327–335. [CrossRef]
36. Saikia, P.; Pancholi, M.; Sood, D.; Rakshit, D. Dynamic optimization of multi-retrofit building envelope for enhanced energy performance with a case study in hot Indian climate. *Energy* **2020**, *197*, 117263. [CrossRef]
37. Gugul, G.N.; Koksal, M.A.; Ugursal, V.I. Techno-economical analysis of building envelope and renewable energy technology retrofits to single family homes. *Energy Sustain. Dev.* **2018**, *45*, 159–170. [CrossRef]
38. El-Darwish, I.; Gomaa, M. Retrofitting strategy for building envelopes to achieve energy efficiency. *Alex. Eng. J.* **2017**, *56*, 579–589. [CrossRef]
39. Granadeiro, V.; Duarte, J.P.; Correia, J.R.; Leal, V.M. Building envelope shape design in early stages of the design process: Integrating architectural design systems and energy simulation. *Autom. Constr.* **2013**, *32*, 196–209. [CrossRef]
40. Kharseh, M.; Al-Khawaja, M.; Hassani, F. Comparison between different measures to reduce cooling requirements of residential building in cooling-dominated environment. *Energy Build.* **2015**, *88*, 409–412. [CrossRef]
41. Kharseh, M.; Al-Khawaja, M. Retrofitting measures for reducing buildings cooling requirements in cooling-dominated environment: Residential house. *Appl. Therm. Eng.* **2016**, *98*, 352–356. [CrossRef]
42. Yadav, S.; Panda, S.; Tripathy, M. Performance of building integrated photovoltaic thermal system with PV module installed at optimum tilt angle and influenced by shadow. *Renew. Energy* **2018**, *127*, 11–23. [CrossRef]
43. Paydar, M.A. Optimum design of building integrated PV module as a movable shading device. *Sustain. Cities Soc.* **2020**, *62*, 102368. [CrossRef]
44. Das, B.K.; Al-Abdeli, Y.M. Optimisation of stand-alone hybrid CHP systems meeting electric and heating loads. *Energy Convers. Manag.* **2017**, *153*, 391–408. [CrossRef]

45. Kim, M.-H.; Kim, D.; Heo, J.; Lee, D.-W. Techno-economic analysis of hybrid renewable energy system with solar district heating for net zero energy community. *Energy* **2019**, *187*, 115916. [CrossRef]
46. Harkouss, F.; Fardoun, F.; Biwole, P.H. Optimal design of renewable energy solution sets for net zero energy buildings. *Energy* **2019**, *179*, 1155–1175. [CrossRef]
47. Available online: https://www.pmd.gov.pk/en/ (accessed on 30 June 2019).