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Impact of Passive Energy Efficiency Measures on Cooling Energy Demand in an Architectural Campus Building in Karachi, Pakistan

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Abstract: Electric appliances for cooling and lighting are responsible for most of the increase in electricity consumption in Karachi, Pakistan. This study aims to investigate the impact of passive energy efficiency measures (PEEMs) on the potential reduction of indoor temperature and cooling energy demand of an architectural campus building (ACB) in Karachi, Pakistan. PEEMs focus on the building envelope's design and construction, which is a key factor of influence on a building's cooling energy demand. The existing architectural campus building was modeled using the building information modeling (BIM) software Autodesk Revit. Data related to the electricity consumption for cooling, building masses, occupancy conditions, utility bills, energy use intensity, as well as space types, were collected and analyzed to develop a virtual ACB model. The utility bill data were used to calibrate the DesignBuilder and EnergyPlus base case models of the existing ACB. The cooling energy demand was compared with different alternative building envelope compositions applied as PEEMs in the renovation of the existing exemplary ACB. Finally, cooling energy demand reduction potentials and the related potential electricity demand savings were determined. The quantification of the cooling energy demand facilitates the definition of the building's electricity consumption benchmarks for cooling with specific technologies.

Keywords: hot and humid climate; energy demand for cooling; energy efficiency; building envelope; insulation; thermal mass

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1. Introduction

High fossil energy consumption for the heating, cooling, lighting, and ventilation of buildings and related greenhouse gas emissions contributes significantly to climate change and resource depletion [1,2]. Buildings account for one-third of the final global energy consumption [3]. Around 39% of CO_2 emissions and 36% of the global energy consumption are attributed to the building sector [3]. The building sector in Great Britain accounts for around 27% and that in the US for 38% of CO_2 emissions [1]. Buildings are a major contributor to global environmental impact due to their high energy consumption [1,4]. The building sector consumes more energy than any other sector in Pakistan [5]. Pakistan's highest annual increase in electric energy consumption was 8.4% in the domestic sector, followed by 7.5% in the commercial sector, 5.6% in the agriculture sector, and 4.2% in the industrial sector during 2017–2018 [6]. Generally, the major end-use activities in the building sector are space cooling, space heating, cooking, lighting, and refrigeration. However, the main contributors to the increased electricity consumption in Karachi, Pakistan, are lighting and the energy-inefficient fans used for cooling [5,7].

There is a significant rise in building energy consumption in developing countries, driven by improved access to centralized electricity supply [3]. The operational electricity consumption by buildings has the largest negative impact on the environment [1]. A major proportion of electricity in Pakistan is consumed for the provision of thermal comfort, such as space heating and cooling [1,4]. Personalized heating technologies, such as radiant heaters with a coefficient of performance (COP) of 0.85 [8], and cooling technologies, such as split air conditioners with an energy efficiency ratio (EER) of 2.7 and fans [8,9], which increase energy usage, are common in Pakistan. Therefore, passive energy efficiency measures (PEEMs) to reduce the cooling and heating energy demands of buildings are a primary research topic both in Pakistan and globally. However, PEEMs for reducing cooling energy demand are desired in Karachi. In a study, Ahsan et al. applied passive cooling techniques to reduce operational energy consumption in Pakistan. The results indicated energy savings of 35% using passive cooling techniques [4]. Sadineni et al. studied the potential of PEEMs for indoor environmental quality (IEQ), and thermal and visual comfort. The study concluded that the building envelope is a crucial PEEM for energy savings, for IEQ, and for thermal and visual comfort [10]. Okba indicated the building envelope design as a significant factor in determining the amount of energy a building consumes during its operation phase [11].

The energy conservation potential of an improved building envelope design can be achieved by retrofitting existing structures. For example, adding thermal mass and thermal insulation to existing building envelopes and installing low-emissivity and high-efficiency windows can improve building envelope efficiency. Examples show that electricity demand for heating or cooling can be reduced by as much as 20% [5]. Iwaro and Mwasha studied the impact of the building envelope design on building sustainability and energy efficiency. The results revealed that the higher the energy efficiency of a building envelope design, the higher the sustainable performance and building sustainability [12]. A number of studies have been conducted globally based on energy efficiency, building envelope, and passive design improvement measures of buildings. The studies concluded that the building envelope plays an essential role in the energy consumption of the building [10,13–21].

Building envelope codes and policies have been improved worldwide over the years. In the UK and USA, the building envelope standards have been substantially revised, and emphasize the growing need for energy conservation [10]. Similarly, in Pakistan, the National Energy Efficiency and Conservation Authority (NEECA), formerly known as the National Energy Conservation Centre (ENERCON), formulated the Building Code of Pakistan (Energy Provisions-2011) with the help of the Pakistan Engineering Council (PEC), having provisions for employing energy efficiency in the building sector of Pakistan. The Pakistan Green Building Council (PGBC) establishment is also a constructive step towards improved energy efficiency in the building sector [5]. Mahar et al. reviewed the energy efficiency policies in Pakistan and concluded that there is a lack of implementation and practice of energy efficiency policies [22]. Pakistan's poor energy policies have plunged the country into a severe economic crisis since 2006 [22,23]. The 2006 financial crisis started with a shortage of electrical energy and its insufficient production to meet the increased demand [8,23], which later changed to problems in the transmission and distribution of electrical energy [24]. The demand for electricity in Pakistan is relatively determined by concerns such as electricity prices, economic expansion, and rapid population growth. However, Pakistan's peculiar issues and its short-term power crisis emerged from illegal electricity grid connections, lack of government interest in encouraging energy-efficient buildings, and electricity consumption in buildings exceeding the maximum grid capacity [23]. In addition to the limited grid capacity, Pakistan's energy distribution and transmission networks are generally old and inefficient, resulting in significant line losses, such as 18.3% from 2018 to 2019 [8]. Pakistan produces its maximum electricity share from the combustion of fossil energy carrier coal (20.4%) and gas (38%). The remaining electricity is generated by hydroelectric (30.9%), nuclear (8.2%), and renewable energy (only 2.5%) sources [25]. Increased electricity prices have caused an immense burden of utility bills on the public since 2019, due to the reduction of government subsidies [8,26]. On the other hand, 73% of the population of Pakistan experienced electricity blackouts for an average of 2 h per day in 2006 [5], while in Karachi the electricity outage has increased to an average of 12–15 h a day in 2020 [27].

The development of energy-efficient and environmentally sound new building constructions and energy-efficient technical equipment for building operation has progressed worldwide [28]. However, existing buildings, which account for two-thirds of the final energy consumption in Pakistan, have low thermal performance [4]. The retrofitting of existing buildings offers an opportunity to transform them into energy-efficient and environmentally sound buildings [28]. Poel et al. observed that retrofitting existing buildings will improve the energy efficiency in these buildings [28], since the existing buildings in Pakistan are energy inefficient [4]. Saleem undertook a pilot study of a college building in Mianwali, Pakistan, to investigate building energy-efficient approaches and proposed solar renewable energy sources for electricity generation [29]. Kazmi et al. investigated passive cooling, IEQ, user comfort, and energy efficiency in public buildings in Multan, Pakistan. The results showed that by adopting passive measures in the building envelope, significant energy savings for heating, cooling, lighting, and appliances could be achieved while creating a thermally comfortable indoor environment [30]. Several studies in Pakistan examined the relationship between IEQ, thermal comfort, and passive design measures [8,22,31–35]. However, no research on reducing the indoor temperature and energy demand for cooling through the building envelope and PEEMs in educational buildings in Karachi, Pakistan, has been conducted. Therefore, this research focuses on reducing the indoor temperature and energy demand for cooling through the building envelope and PEEMs in educational buildings, using the example of an architecture campus building. There are three public sector architectural campus buildings (ACB1, ACB2, and ACB3) in Karachi. ACB1 and ACB3 are located in East Karachi, while ACB2 is located in South Karachi. The aim of this research is to determine the electricity demand for cooling, and to identify different alternative building envelope compositions for the cooling energy demand reduction of an existing exemplary architectural campus building. The objectives of this research include (i) determination of the electricity demand in the existing exemplary architectural campus building, (ii) identification of alternative building envelope compositions as PEEMs in the existing exemplary architectural campus building, and (iii) determination of cooling energy demand reduction potentials through specific PEEMs.

2. Materials and Methods

This research is based on the analysis and optimization of ACB1 due to the following reasons. ACB2 is a listed heritage site [36] and was excluded from the analysis, since the retrofitting strategies for heritage buildings are different from those for other buildings. Therefore, the findings cannot be transferred to other buildings. The construction materials used in ACB2 are also not exemplary.

During the field visit conducted on the architectural campus buildings by the authors, ACB3 was found to be a shared building with the fine arts department. ACB3 has only one hall for the Department of Architecture. ACB3 mostly serves the Departments of Fine Arts and Design. Since this research's scope is the study of an exemplary architectural campus building in Pakistan, the authors focused within this research on ACB1 to investigate the potential of PEEMs. Figure 1 presents the conceptual study framework of this study, which is based on six axes, which are described in the following sections.

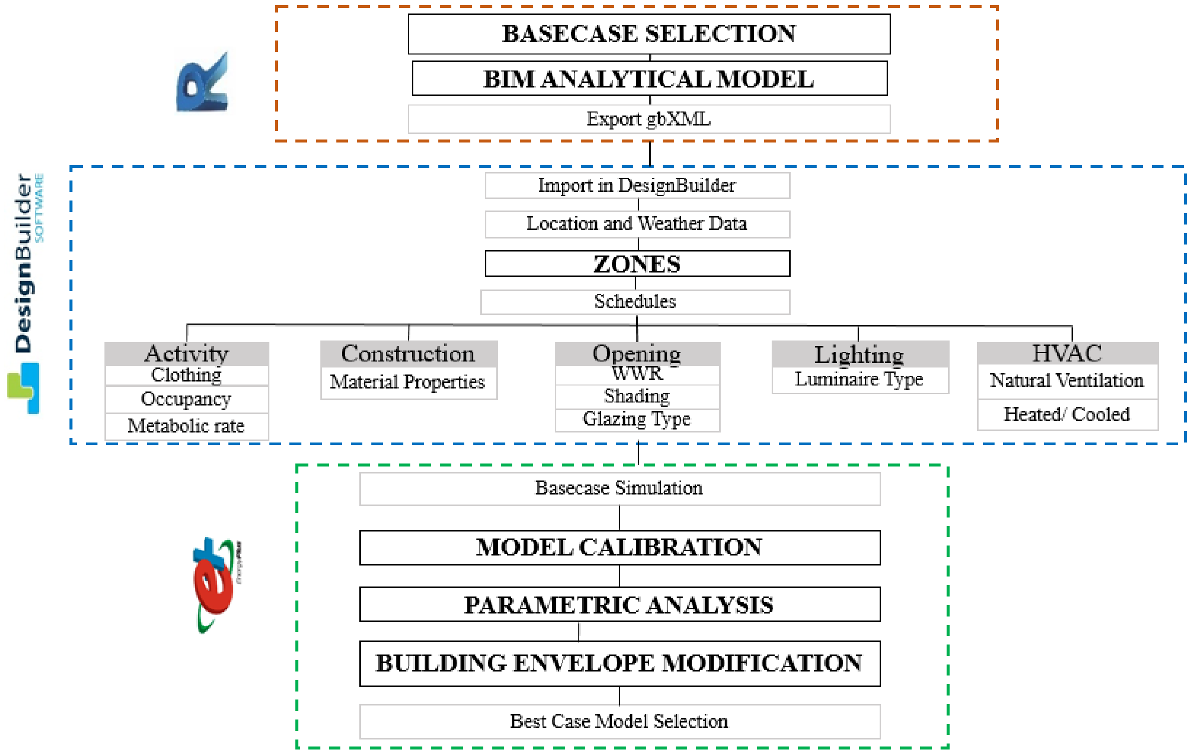


Figure 1. The conceptual study framework. Legend: BIM, building information modeling; gbXML, Green Building Extensible Markup Language; WWR, window-to-wall ratio; HVAC, heating, ventilation, and air-conditioning.

2.1. Base Case Building Modeling and Description

The base case ACB1 (ACB) is located in Karachi, Pakistan, at 24.90° N, 67.08° E in a residential–commercial area having a courtyard as a central architectural feature. The ACB is surrounded by a mosque and a Montessori school to the north, residential quarters for the military to the south, an empty plot owned by the ACB to the east, and a primary school to the west. The surrounding buildings and vegetation do not cast shadows on the ACB façades. Figure 2 shows the localization and microclimate of the ACB in a 1.5 km radius in Gulshan-e-Iqbal district, Karachi, Pakistan. This ACB was selected as an exemplary case study based on the factors listed in Table 1, which are research findings published previously by the authors [37].

The footprint of the ACB is a simple "U" shape: the north–south façade is longer than the east–west façade. The surface-area-to-volume ratio (S/V) of ACB is 0.46 m^{-1}. Three building clusters surround the central courtyard of the ACB. The north and east clusters are four-storey high, while the west cluster is two-storey high; all clusters consist of corridors for circulation. The ground floor works as an administration floor with a computer laboratory; the second and third floors offer educational facilities, including lecture halls and offices. The fourth floor consists of laboratories in the north cluster, while the east cluster includes a display hall; the fourth floor is not in regular use. The north façade is shaded with 0.3 m fixed overhangs over the windows, and seven 0.2 m fixed vertical louvers at 5.75 m center-to-center distance between the louvers. The overhangs and louvers are provided to obstruct solar radiation through the windows. The east façade is provided with 0.3 m fixed overhangs over the windows. The east façade also consists of galleries on the first, second, and third floors with a hollow concrete mesh on external walls. The west façade consists of 0.6 m roof eaves and 0.3 m fixed overhangs over the windows. The west façade also includes a terrace on the first floor.

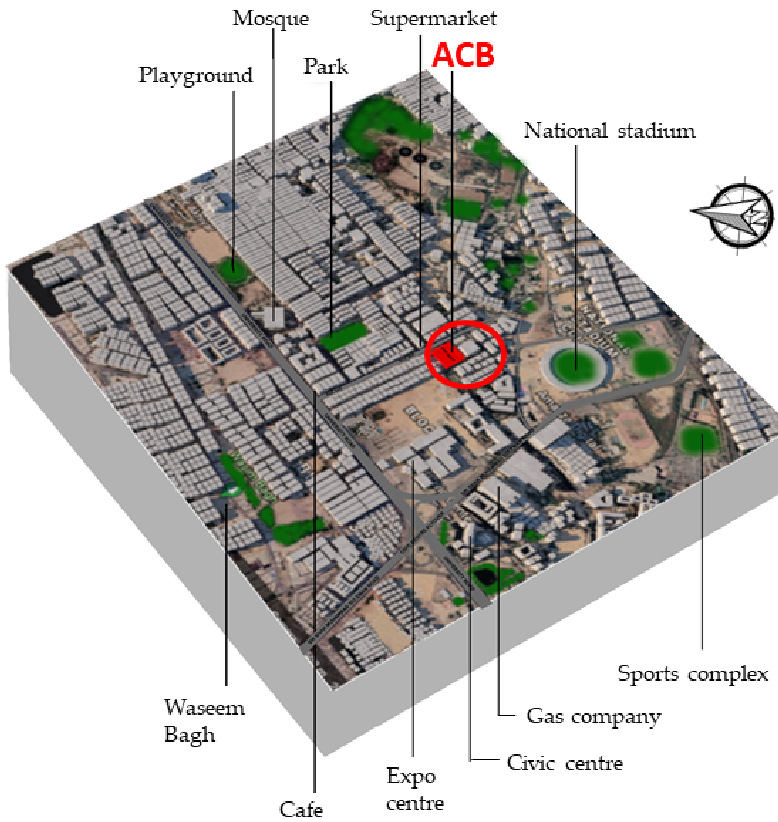


Figure 2. Location and microclimate of the ACB (1.5 km radius), Karachi, Pakistan.

Table 1. Criteria for ACBs 2 and 3 and the exemplary ACB (base case) selection.

Factors	ACBs 2 and 3	Selected Base Case ACB
HVAC systems	No	No
Thermal insulation of the building envelope	No	No
Number of occupants per batch	50	50
Availability of architectural plans	Unavailable in one ACB	Available
Being representative in terms of location	Main city districts	Main city districts
Educational level	Minimum undergraduate	Minimum undergraduate
The willingness of the campus administration to cooperate	One was unwilling to cooperate	Willing
Geometry	Varying	Varying
Use	Educational purpose	Educational purpose

Table 2 summarizes the general building description. The ACB is a hybrid building with manually operable windows and a majority of rooms dependent on fans for air circulation. The opening of doors and windows facilitates free ventilation in the ACB. Only two offices and a computer lab are cooled with personalized split air conditioners (2.7 EER). The fans function as cooling by creating a wind-chill effect for the users. The main contributors to the electricity consumption in the exemplary ACB are the fans and split air conditioners for cooling, since the standard lights were replaced with energy-efficient LED lights/energy-saving lights. Figure A8 presents the breakdown of electricity consumption of the exemplary ACB. Hence, this study focuses on the reduction of indoor temperature and cooling energy demand.

Table 2. Summarized general building description of the exemplary ACB.

Index	Value
Land plot area	1836.9 m^2
Gross building area	1166.88 m^2
Building form	Courtyard
Clusters	3
Number of floors	2 and 4
Floor-to-floor height	3.2 m
Floor-to-ceiling height	3 m

The ACB floor plan layout was drawn after conducting a field survey with measurements. The authors also conducted a field survey to collect construction data and determine component and building material specifications. The generated ACB model is a detailed reconstruction of the existing ACB. The virtual BIM reconstruction of the exemplary ACB was executed with the software Autodesk Revit 2020 [38]. Autodesk Revit uses construction component categories, families, types, and instances. Elements are grouped to form a category that uses the model or documents a building design, and families are types of elements in a category. A family categorizes elements with a standard set of parameters, similar graphical representation, and identical use [38–41]. The BIM analytical model (AM) was generated, and spaces were defined by adding each room and manually assigning the energy analysis properties, since they are significant electricity consumption factors (Figure 3). The BIM AM method gives a precise transition from the ACB Revit model to the ACB gbXML file [42]. Hence, BIM AM was used to export the ACB gbXML file. The gbXML is an industry-supported scheme used to store and share building properties between different software [43]. The ACB gbXML file was imported into DesignBuilder (DB) version 6.1.6.008 to determine the cooling energy demand. DB is specifically developed to run EnergyPlus simulations, and has been validated for accuracy and consistency [19,44]. After setting the location and weather data, discussed in the authors' previously published research, the ACB zones were specified, and ACB schedules were created for each zone.

The ACB model was divided into seven zones: naturally ventilated (NV) lecture halls, NV offices, offices having a cooling system, computer lab having a cooling system, NV common room and canteen, NV laboratories, and NV toilets. The air-conditioning system's setpoint was 25 °C, as mentioned in the Building Code of Pakistan (Energy Provisions-2011) [45]. The ACB was physically inspected to obtain information about the occupancy, lighting, and equipment with the ACB administration's cooperation. The equipment used in the ACB were computers, printers, scanners, and microwaves. The lighting power densities and equipment power densities were calculated based on ASHRAE recommendations. The authors counted the total equipment and lighting fixtures in each zone, followed by calculating equipment power densities in compliance with the ASHRAE standard.

The authors also collected electricity billing data for 72 months (January 2014 to December 2019), since the data provide information about historical annual electricity consumption. Analysis of the bills showed that the electricity consumption was low during December and January, high from February to November excluding June and October, and very low during the summer and winter vacation periods (i.e., June and October). Table 3 provides a detailed description of the zones. The thermophysical properties of ACB are based on the literature and characteristics of the most common materials in Karachi. The specification of materials, building details (size, plans, and elevations), construction techniques, and layers and thicknesses of building elements are based on the existing ACB; the data were collected through interviews with faculty members and a physical observation survey conducted by the authors. The authors also reviewed similar buildings in Karachi with the same building age to verify the composition of the building envelope components and the construction of the ACB. To determine the cooling energy demand, specific occupancy schedules were defined, which Appendix A presents. Occupancy schedules determined the presence of users in each zone, and were defined to be consistent with the users' routines. The occupancy determined the presence of users in the ACB during the working hours for students (09:00 to 16:00) and staff, including teachers (07:00 to 18:00) on working days (Monday to Friday). Holidays, other than summer and winter vacations, were defined with the value of 14 days per year, consistent with the annual academic calendar collected from the ACB. During the summers (May to August), the mean outdoor temperature is 30.7 °C with 59.7% relative humidity in Karachi [37], while the comfort range during summers is 26 to 28 °C [37]. June was excluded from the analysis, since that month is a vacation period for the ACB, and the inclusion of June might cause a discrepancy in the analysis due to the unrealistic internal heat gains/losses from non-occupancy. Table 3 presents the simulated mean indoor temperatures of the north, west, and east clusters during summer's occupied months. Temperature differences of 3.78, 2.47, and 1.45 °C, are observed from the outdoor to the indoor environment in the north, east, and west clusters, respectively. The authors assumed the building infiltration value of 2.5 air change rate (ACH), since the buildings in Pakistan are not airtight. The values are consistent with the previous studies in Pakistan [8,29]. The ventilation profiles were assumed based on physical inspection, and interviews with faculty members and students. Table 3 presents the simulated airflow rate for each cluster. The proposed airflow rate in EN 15251 is 0.007 m^3/s per person [46]. The airflow rate in ACB is higher than the proposed standards, which is attributed to the poor airtightness of ACB, free passage of air in the ACB through the semi-covered corridors located in all clusters, galleries located in the east cluster, and a terrace situated in the west cluster.

Figure 1 presents the detailed conceptual framework. Figure 3 presents the ground floor plan, north elevation, section, 3D model, and the AM of the exemplary ACB. Table 4 illustrates the base case building envelope components. The majority of buildings in Karachi are constructed using the same building materials and construction techniques. The conventional construction materials in Karachi are concrete block walls (high thermal conductivity and low specific heat capacity) with RCC slab (low specific heat capacity) roof [34]. The thermophysical properties of ACB are actual construction compositions based on interviews, the authors' observations, common practice, and literature studies in Karachi. The ACB consists of a medium-weight concrete block wall with plaster of light color on both the inside and the outside, and has a *U*-value of 2.7 W/m^2 K, which is higher than the maximum *U*-value proposed by ENERCON of 0.57 W/m^2 K for external walls [45]. The roof consists of an RCC slab, with plaster on both the inside and the outside, and has a *U*-value of 2.58 W/m^2 K, which is also higher than the maximum value proposed by ENERCON of 0.44 W/m^2 K for roofs [45]. The windows are single-glazed (*U*-value = 5.7 W/m^2 K) sliding windows with 50% opening, and have an aluminum frame with a *U*-value of 5.88 W/m^2 K. Both values are higher than the maximum value for windows of 3.5 W/m^2 K proposed by ENERCON [45]. The ACB components have highly comparable *U*-values. It is expected that modification of the ACB components will significantly impact the indoor environmental comfort, and accordingly facilitate annual electricity savings. Hence, parametric simulation was carried out using EnergyPlus software considering different parameters discussed in the subsequent sections.

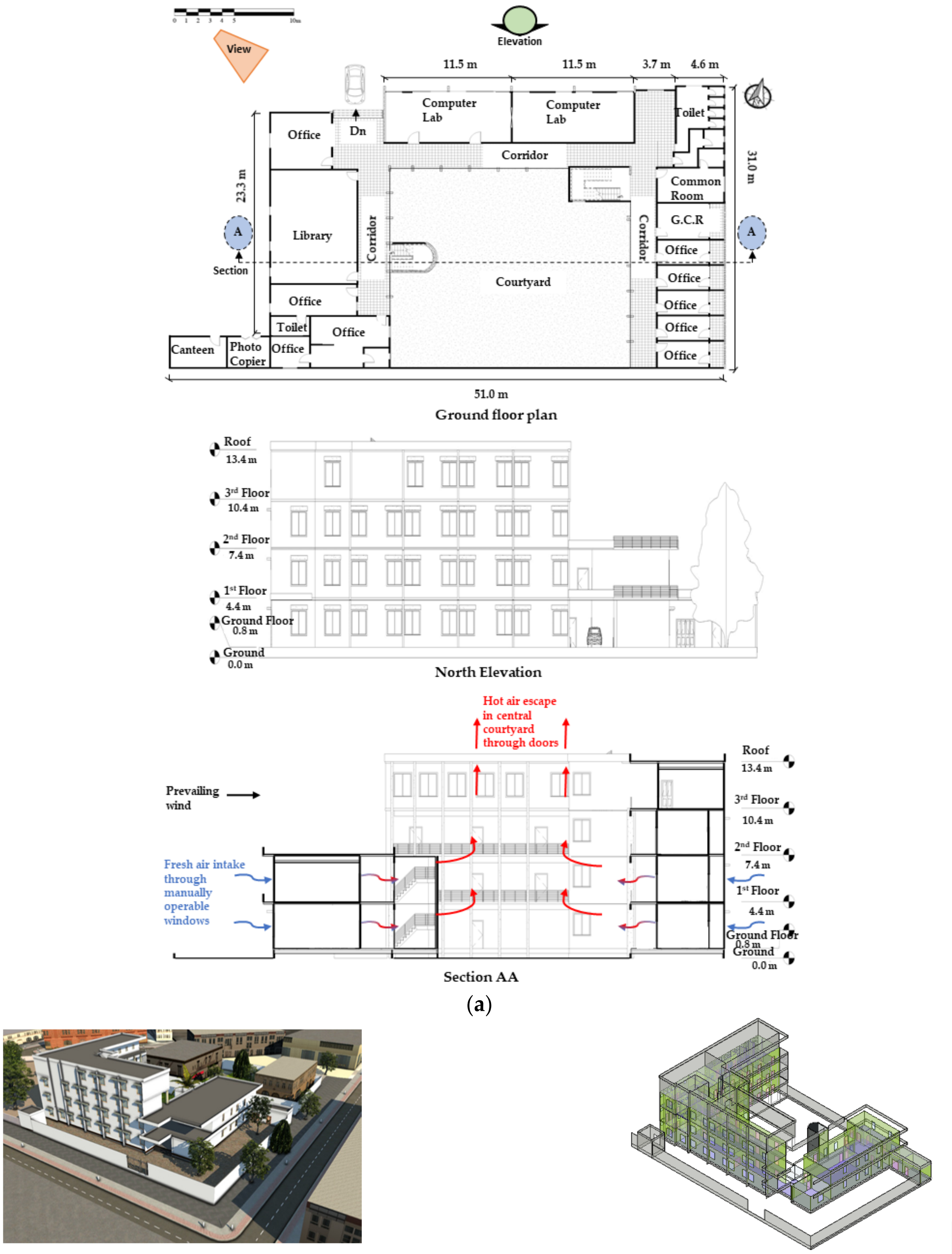


Figure 3. (**a**) Ground floor plan, north elevation, and section AA, respectively of the exemplary ACB. (**b**) Isometric view of the exemplary ACB in the north direction. (**c**) Analytical model (AM) of the exemplary ACB in the north direction.

Table 3. Building description and zone assumptions of the exemplary ACB. Legend: WWR, window-to-wall ratio; LPD, lighting power density; EPD, equipment power density; SA, surface area; V, volume; N, north cluster; W, west cluster; E, east cluster.

	Measure Category	Input Measures	Values/Parameters
Description	Building envelope	WWR (%)	North façade = 27, south façade = 5.5, east and west façades = 14
		Windows (W/m^2 K)	*U*-value = 5.7
		Shading coefficient of glass (SC)	0.7
		Solar heat gain coefficient (SHGC)	0.81
		Light transmission (LT)	0.88
		Awnings (overhangs) (m) projection above the windows on the north, east, and west façades	0.3
		Eaves (m) over the roof of the west façade	0.6
		Wall (W/m^2 K)	*U*-value = 2.7
		Roof (W/m^2 K)	*U*-value = 2.5
		Floor (W/m^2 K)	*U*-value = 1.11
		Door (W/m^2 K)	*U*-value = 2.5
		Airtightness (ACH)	2.5
	Temperature and humidity	Mean outdoor temperature (°C) during summer	30.7
		Relative humidity (%)	59.7
		Comparison of mean outdoor (°C) and indoor temperatures (°C) during summer	Figure 11
	Land plot area and building description	Land plot area of the building (m^2)	1836.9
		SA/V ratio (m^{-1})	0.46
		Building drawings	Figures 3 and A11
	Occupancy and density	Density (persons/usable building area in m^2)	0.29
		Total occupancy (people)	350
	Simulated monthly electricity demand (kWh)	January	1331.1
		February	2073.17
		March	2176.84
		April	2073.17
		May	2111.01
		June	337.29
		July	2384.15
		August	2280.49
		September	2176.84
		October	390.54
		November	2176.84
		December	1464.04
		Simulated annual electricity demand	20,975.48
		Breakdown of monthly electricity demand	Figure A8

Table 3. *Cont.*

	Measure Category	Input Measures	Values/Parameters
	Clothing and activity	Summer (clo)	0.40
		Winter (clo)	0.66
		Metabolic rate (met)	1.0
Zone	Lecture halls	Occupancy (people)	50
		Type of system (cooled, natural ventilation)	Natural ventilation. Fans used for air movement.
		Weekday occupancy schedule	Figure A1
		Airflow rate (m^3/s)	North cluster = 0.46 East cluster = 0.40 West cluster = 0.58
		Mean indoor temperature (°C) during summer	North cluster = 34.48 East cluster = 33.2 West cluster = 32.2
		Temperature thresholds for windows (°C)	Opening threshold = 23 Closing threshold = 18
		LPD (W/m^2)	10
		EPD (W/m^2)	15
	Naturally ventilated offices	Occupancy (people)	02
		Type of system (cooled, natural ventilation)	Natural ventilation. Fans used for air movement.
		Weekday occupancy schedule	Figure A2
		Airflow rate (m^3/s)	East cluster = 0.40
		Mean indoor temperature (°C) during summer	East cluster = 33.2
		Temperature thresholds for windows (°C)	Opening threshold = 23 Closing threshold = 18
		LPD (W/m^2)	10
		EPD (W/m^2)	10
	Conditioned offices	Occupancy (people)	02
		Type of system (cooled, natural ventilation)	1. Natural ventilation. Fans used for air movement. 2. Split air-conditioning (AC) used for cooling.
		Energy efficiency ratio (EER) of the cooling system	2.7
		Cooling temperature setpoint (°C)	25
		Weekday occupancy schedule	Figure A3
		Airflow rate (m^3/s)	West cluster = 0.58
		Mean indoor temperature (°C) during summer without AC turned on	West cluster = 32.2
		LPD (W/m^2)	15
		EPD (W/m^2)	15

Table 3. *Cont.*

Measure Category	Input Measures	Values/Parameters
Computer lab	Occupancy (people)	40
	Type of system (cooled, natural ventilation)	1. Natural ventilation. Fans used for air movement. 2. Split air-conditioning (AC) used for cooling.
	Energy efficiency ratio (EER) of the cooling system	2.7
	Cooling temperature setpoint (°C)	25
	Weekday occupancy schedule	Figure A4
	Airflow rate (m^3/s)	North cluster = 0.46
	Mean indoor temperature (°C) during summer without AC turned on	North cluster = 34.48
	LPD (W/m^2)	20
	EPD (W/m^2)	25
Common room and canteen	Occupancy (people)	15
	Type of system (cooled, natural ventilation)	Natural ventilation. Fans used for air movement.
	Weekday occupancy schedule	Figure A5
	Airflow rate (m^3/s)	East cluster = 0.40
	Mean indoor temperature (°C) during summer	East cluster = 33.2
	Temperature thresholds for windows (°C)	Opening threshold = 23 Closing threshold = 18
	LPD (W/m^2)	10
	EPD (W/m^2)	10
Laboratories	Occupancy (people)	25
	Type of system (cooled, natural ventilation)	Natural ventilation. Fans used for air movement.
	Weekday occupancy schedule	Figure A6
	Airflow rate (m^3/s)	North cluster = 0.46 East cluster = 0.40 West cluster = 0.58
	Mean indoor temperature (°C) during summers	North cluster = 34.48 East cluster = 33.2 West cluster = 32.2
	Temperature thresholds for windows (°C)	Opening threshold = 23 Closing threshold = 18
	LPD (W/m^2)	10
	EPD (W/m^2)	10
Toilets	Occupancy (people)	04
	Type of system (cooled, natural Ventilation)	Natural ventilation.
	Weekday occupancy schedule	Figure A7

Table 4. Detailed base case building envelope components with thermal properties and materials and their total *U*-values. Legend: PCC, plain cement concrete; RCC, reinforced cement concrete.

Building Elements		Conductivity (W/m K)	Specific Heat Capacity (J/kg K)	Density (kg/m^3)	Thickness (cm)
Exterior Walls (3 Layers)					
Outermost	Plaster	0.431	1088	1250	0.95
	Concrete block, medium weight	1.3	840	1800	20
Innermost	Plaster	0.431	1088	1250	0.95
U-value		2.7 W/m^2 K			
Ground Floor (5 Layers)					
Outermost	Ceramic tiles	0.39	656	1900	0.95
	PCC	0.753	656	2000	5
	Aggregate	1.8	840	2240	7
	Sand	1.74	840	2240	10
Innermost	Earth/soil	0.837	1046	1300	22
U-value		1.117 W/m^2 K			
Intermediate floors (4 Layers)					
Outermost	Ceramic tiles	0.39	656	1900	0.95
	PCC	0.753	656	2000	5
	RCC slab	0.753	656.9	2300	10
	Plaster	0.38	840	1150	0.95
U-value		1.46 W/m^2 K			
Roof (3 Layers)					
Outermost	Plaster	0.38	840	1150	0.95
	RCC slab	0.753	656.9	2300	10
Innermost	Plaster	0.38	840	1150	0.95
U-value		2.58 W/m^2 K			
Single Clear 6 mm Glass Window with Aluminum Frame					
Single clear 6 mm glass	*U*-value	5.7 W/m^2 K			
Aluminum frame	*U*-value	5.88 W/m^2 K			
Overhangs		30 cm			
Door (3 Layers)					
Outermost	Plywood	0.14	1400	530	0.31
	Air gap	5.56	1004	1.3	4.6
Innermost	Plywood	0.14	1400	530	0.31
U-value		2.5 W/m^2 K			

2.2. Calibration of the Model

The ASHRAE Guideline 14-2014 [47] was used to validate the ACB model. There are two indices mentioned in the guideline that present the variability of the measured and simulated electricity consumption data. Normalized mean bias error (NMBE) and coefficient of variation of the root mean square error (CVRMSE) are the indices that determine variability by comparing the simulation predicted electricity demand to the electricity consumption from the electricity bills. The simulated electricity demand was compared with the measured (electricity billing) data to calibrate the ACB model. The ACB model was graphically represented to analyze the difference between the simulated and measured electricity consumption. For the ACB model's calibration, some suitable modifications, including occupancy, equipment, and lighting schedule setting, were applied. A linear regression statistical approach was also used after manual calibration to assess the model's correlation and precision. According to the ASHRAE Guideline 14-2014 [47], the model is considered calibrated when the NMBE and CV (RMSE) are not larger than 5 and 15%, respectively, when the monthly data are used [8,48,49]. The mathematical equations are presented below:

Normalized Mean Bias Error

$$\text{NMBE} = \frac{\sum_{i=1}^{Np} (Mi - Si)}{\sum_{i=1}^{Np} Mi} \ (\%) \tag{1}$$

Coefficient of Variation of Root Square Mean Error

$$\text{CV(RMSE)} = \frac{1}{\text{M}} \sqrt{\frac{\sum_{i=1}^{Np} (Mi - Si)^2}{Np}} \ (\%) \tag{2}$$

In the above equations, Np is the total number of data values, Mi (where $i = 1, 2, \ldots, Np$) represents the measured data, and Si (where $i = 1, 2, \ldots, Np$) represents the simulated data.

3. Results

The climate of Karachi is hot and humid [37]; hence reducing the heat gains in buildings remains a priority for indoor environmental comfort. Conduction has a large impact on the building's load values [1,4]. The passive gains of ACB were analyzed to provide a graphical representation of contributing factors. Figure 4 indicates the monthly heat balance of the building envelope, and internal and solar gains in the base case building. It is observed that the solar gains are higher than the internal gains. This is mainly due to the conduction of the building envelope and radiation through transparent windows. Adding thermal mass and thermal insulation and improving window glazing in the existing building envelope can improve the building envelope efficiency, which will improve indoor environmental comfort, and accordingly, facilitate annual electricity savings. Low internal gains during June and October are due to the vacations in the ACB.

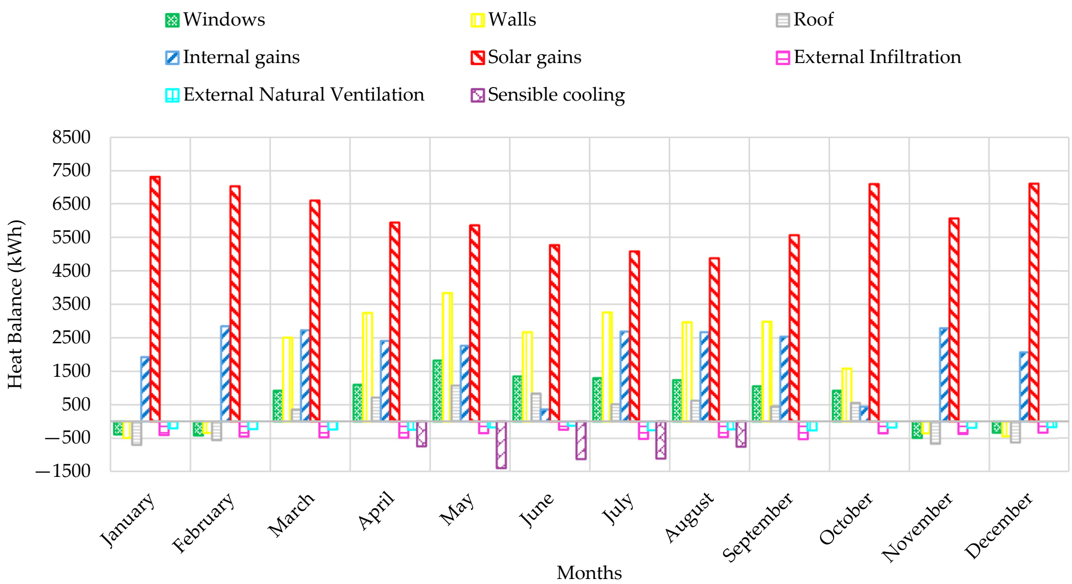
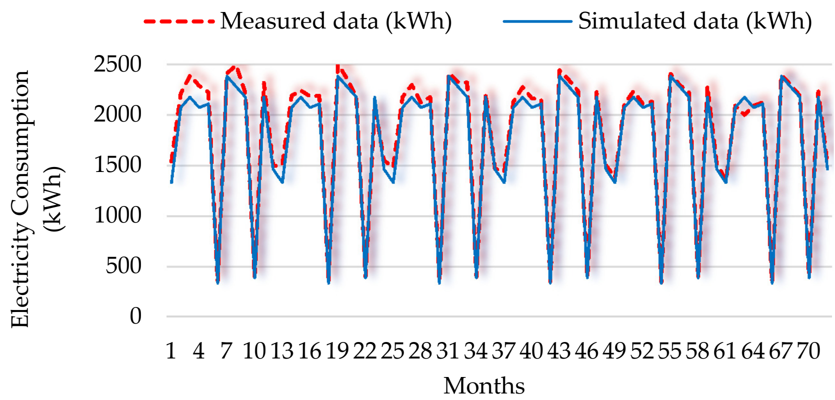


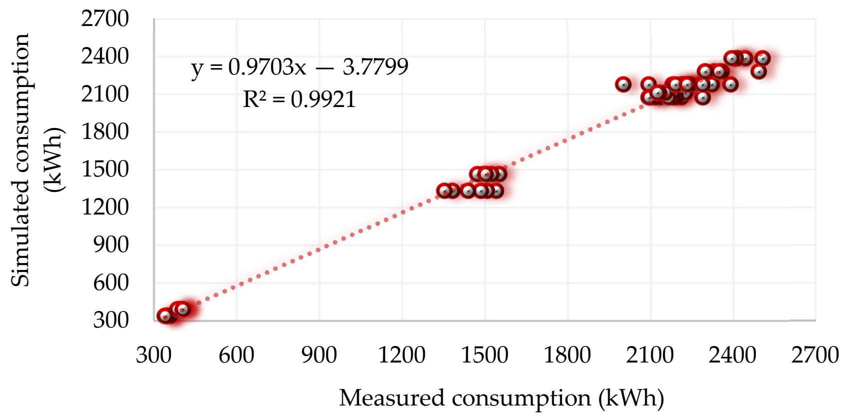
Figure 4. Heat transmission in the base case building.

3.1. Calibration of the Model

In order to calibrate the model, NMBE and CV (RMSE) equations were applied in compliance with ASHRAE standard 14-2014, considering allowable limits [47]. The model was calibrated manually, and several modifications, including occupancy, equipment, and lighting schedule setting, were applied to calibrate the model. The simulated and measured electricity consumption data were compared. Linear regression analysis was also performed to assess the accuracy, precision, and correlation of the calibration. NMBE, CV (RMSE), and the correlation coefficient (R^2) values 2.26%, 13.8%, and 0.9921 of the final simulation were found suitable to verify the simulation model's calibration. Figure 5a,b presents the calibration of the simulated model:



(**a**)



(**b**)

Figure 5. (**a**) A 72-Month (January 2014 to December 2019) comparison between the measured electricity consumption and the simulated electricity demand for cooling, lighting, and equipment. (**b**) Linear regression analysis of calibration of the simulated model (72 months).

3.2. PEEM

After the ACB model calibration, different PEEM cases for external wall, roof, windows, and doors were tested based on previous research [4,10,14,19,34,50–52] in a hot and humid climate. The authors visited local markets to check the availability of the materials in Karachi. Concrete block walls, RCC slab, and single-glazed windows having high *U*-values are common practice in Karachi, without considering the standard *U*-values defined by ENERCON [45]. Hence, considering the benchmark *U*-values by ENERCON and the material availability in Karachi, the authors chose the compositions in the following sections from previous studies in a hot and humid climate.

3.2.1. PEEM Alternative #1 (Wall)

A significant amount of heat conduction in buildings is carried out through external walls [53]. Being an essential component of the building envelope, the external walls play a significant role in providing indoor environmental comfort and energy conservation [53]. The amount of heat conduction through external walls is highly dependent on the thermal mass and thermal insulation [54]. The existing wall component, medium-weight concrete block of the building, was replaced by alternative materials, such as aerated concrete block, and added thermal insulation to identify materials and insulation with better energy performance while retaining the building's existing structure.

Different thermal insulation materials were considered for the study depending on their availability in Karachi. Insulation was also applied on the outside to include thermal mass in the analysis, since in a hot and humid climate, thermal mass and night ventilation substantially impact electricity consumption [54,55].

Table 5 and Figure A9 present the alternative wall compositions. Figure 6 and Table 6 indicate that case-W7 provides the most significant reduction in cooling demand of 13.56%, while case-W1 offers no reduction in cooling demand. The thermal conductivity and specific heat capacity of thermal insulation material exert a strong influence on the energy performance; low thermal conductivity and a high specific heat capacity of external walls are favorable for energy efficiency in buildings [2,56]. Case-W7 insulation material (EPS) has the lowest thermal conductivity and the highest specific heat capacity among the investigated insulation materials and is therefore found to be the most effective insulating material in renovation systems with similar thickness. Case-W4 (glass mineral wool) and case-W5 (rock mineral wool) have similar conductivity values as EPS, but low comparative specific heat capacity. Therefore, they are less effective insulating materials as compared to EPS for energy efficiency in the ACB. Case-W1 (aerated concrete block) is the common practice in renovation strategies; however, consideration of the standard *U*-values presented by ENERCON is neglected in Karachi. It is observed that using insulation in wall composition will improve indoor environmental conditions, and accordingly will reduce cooling energy demand. Moreover, the results show that expanded polystyrene (EPS) is the most effective insulating material in lowering cooling energy demand, which is attributed to its thermophysical properties. The results are consistent with the previous study [4].

Table 5. Alternative wall compositions used in wall modification. Legend: EPS, expanded polystyrene; W, wall.

Cases		Conductivity (W/m K)	Specific Heat Capacity (J/kg K)	Density (kg/m^3)	Thickness (cm)
Case-W1					
Outermost	Plaster	0.431	1088	1250	0.95
	Concrete block aerated	0.24	1000	750	20
Innermost	Plaster	0.431	1088	1250	0.95
U-value		0.943 W/m^2 K			
Case-W2					
Outermost	Plaster	0.431	1088	1250	0.95
	Loose-fill cellulose insulation	0.04	1380	43	10
	Concrete block, medium weight	1.3	840	1800	20
Innermost	Plaster	0.431	1088	1250	0.95
U-value		0.344 W/m^2 K			

Table 5. *Cont.*

Cases		Conductivity (W/m K)	Specific Heat Capacity (J/kg K)	Density (kg/m^3)	Thickness (cm)
Case-W3					
Outermost	Plaster	0.431	1088	1250	0.95
	EPS (standard)	0.04	1500	15	5
	Concrete block, medium weight	1.3	840	1800	20
Innermost	Plaster	0.431	1088	1250	0.95
U-value		0.619 W/m^2 K			
Case-W4					
Outermost	Plaster	0.431	1088	1250	0.95
	Glass mineral wool	0.04	830	15	10
	Concrete block, medium weight	1.3	840	1800	20
Innermost	Plaster	0.431	1088	1250	0.95
U-value		0.349 W/m^2 K			
Case-W5					
Outermost	Plaster	0.431	1088	1250	0.95
	Rock mineral wool	0.038	840	140	10
	Concrete block, medium weight	1.3	840	1800	20
Innermost	Plaster	0.431	1088	1250	0.95
U-value		0.334 W/m^2 K			
Case-W6					
Outermost	Plaster	0.431	1088	1250	0.95
	EPS (lightweight)	0.046	1400	10	10
	Concrete block, medium weight	1.3	840	1800	20
Innermost	Plaster	0.431	1088	1250	0.95
U-value		0.388 W/m^2 K			
Case-W7					
Outermost	Plaster	0.431	1088	1250	0.95
	EPS (standard)	0.04	1500	15	10
	Concrete block, medium weight	1.3	840	1800	20
Innermost	Plaster	0.431	1088	1250	0.95
U-value		0.320 W/m^2 K			
Case-W8					
Outermost	Plaster	0.431	1088	1250	0.95
	EPS (standard)	0.04	1500	15	7.5
	Concrete block, medium weight	1.3	840	1800	20
Innermost	Plaster	0.431	1088	1250	0.95
U-value		0.446 W/m^2 K			

3.2.2. PEEM Alternative #2 (Roof)

The roof is the primary source of heat gains in the ACB, because of the high *U*-value in the base case. By insulating the existing roof with different materials (Table 7 and Figure A10), i.e., bitumen, EPS, and polyurethane, reductions in cooling demand of 2.3, 5.5, and 5.1%, respectively, were achieved. The roof was insulated to minimize the heat gains in the building. Case-R1 is not recommended, since the insulating layer "bitumen" has a high conductivity value compared to EPS and polyurethane and is mainly used for waterproofing. Case-R3 (polyurethane) and case-R4 (EPS) have similar construction and thickness; however, case-R4 (EPS) has a lower *U*-value and is found to be the most effective insulating material in the renovation system. Hence, case-R4 was further modified, and a significant reduction in cooling energy demand of 8.8% was achieved by using case-R5 (Figure 7, Table 8).

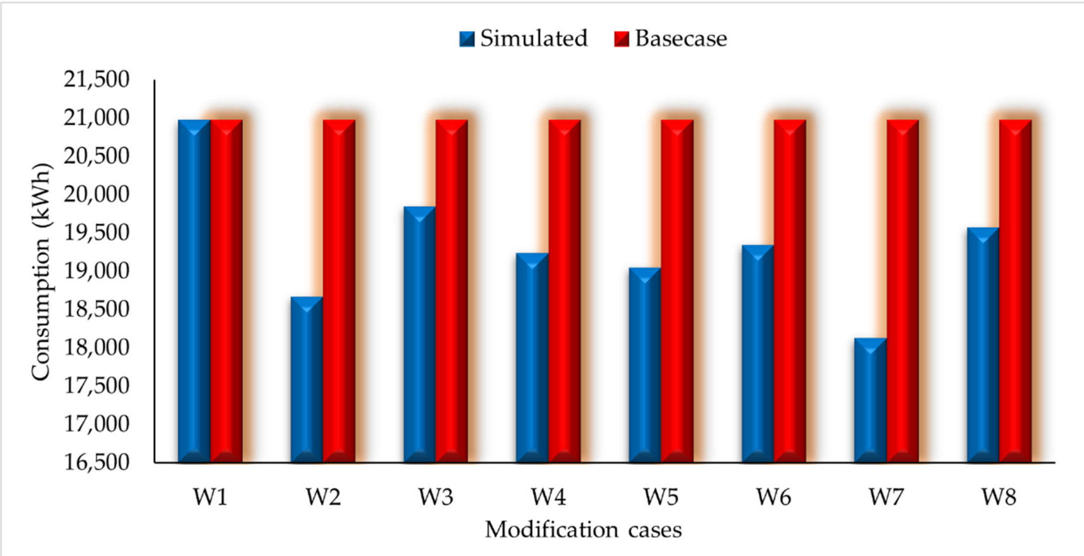


Figure 6. Alternative wall modifications presenting simulated energy demand compared to the base case.

Table 6. Impact of alternative wall compositions on the reduction of cooling energy demand. Cost of insulation acquired from the local market.

Cases	Insulation	Cost of Insulation in USD	Energy Demand (kWh)	Reduction in Energy Demand (%)
Base case	No	-	20,975.48	0
W1	No	-	20,975.48	0
W2	Loose-fill cellulose insulation	34.54 per kg	18,667.75	11.1
W3	0.05 m EPS (standard)	11–16 per m^2	19,842.35	5.4
W4	Glass mineral wool	1–3 per m^2	19,234.08	8.3
W5	Rock mineral wool	0.98–1.84 per m^2	19,045.3	9.2
W6	EPS (light weight)	11–13 per m^2	19,338.95	7.8
W7	0.1 m EPS (standard)	11–16 per m^2	18,130.79	13.56
W8	0.075 m EPS (standard)	11–16 per m^2	19,569.68	6.7

Table 7. Alternative roof compositions used in roof modification. Legend: PCC, plain cement concrete; RCC, reinforced cement concrete; R, roof.

Cases		**Conductivity (W/m K)**	**Specific Heat Capacity (J/kg K)**	**Density (kg/m^3)**	**Thickness (cm)**
Case-R1					
Outermost	Screed	0.4	840	1200	0.95
	Bitumen layer	0.5	1000	1700	0.4
	RCC slab	0.753	656.9	2300	10
Innermost	Plaster	0.38	840	1150	0.95
U-value		2.53 W/m^2 K			
Case-R2					
Outermost	Screed	0.4	840	1200	0.95
	Waterproofing layer	0.5	1800	980	0.05
	EPS (lightweight)	0.046	1400	10	10
	RCC slab	0.753	656.9	2300	10
Innermost	Plaster	0.38	840	1150	0.95
U-value		0.341 W/m^2 K			
Case-R3					
Outermost	Screed	0.4	840	1200	0.95
	Waterproofing layer	0.5	1800	980	0.05
	Polyurethane	0.05	1470	70	10
	RCC slab	0.753	656.9	2300	10
Innermost	Plaster	0.38	840	1150	0.95
U-value		0.434 W/m^2 K			
Case-R4					
Outermost	Screed	0.4	840	1200	0.95
	Waterproofing layer	0.5	1800	980	0.05
	EPS (standard)	0.04	1500	15	10
	RCC slab	0.753	656.9	2300	10
Innermost	Plaster	0.38	840	1150	0.95
U-value		0.319 W/m^2 K			
Case-R5					
Outermost	Roof tiles	0.84	800	1900	3.8
	PCC	0.209	656	950	50
	Waterproofing layer	0.5	1800	980	0.05
	EPS (standard)	0.04	1500	15	10
	RCC slab	0.753	656.9	2300	10
Innermost	Plaster	0.38	840	1150	0.95
U-value		0.214 W/m^2 K			

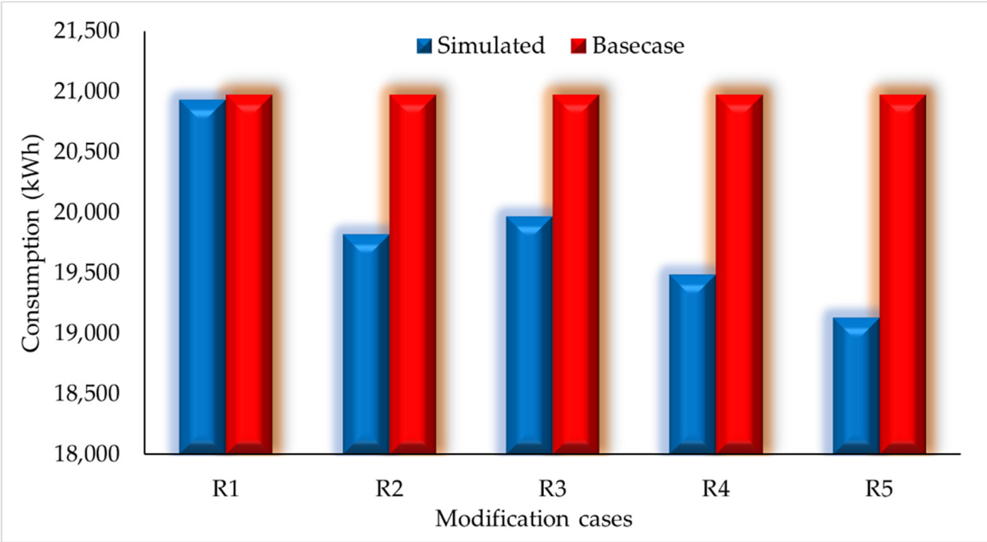


Figure 7. Alternative roof modifications presenting simulated energy demand as compared to the base case.

Table 8. Impact of alternative roof compositions on the reduction of energy demand.

Cases	Insulation	Cost of Insulation in USD per m^2	Energy Demand (kWh)	Reduction in Energy Demand (%)
Base case	No	-	20,975.48	0
R1	Bitumen	1.42–1.97	20,933.53	0.2
R2	EPS (lightweight)	11–13	19,821.8	5.5
R3	Polyurethane	2.99–5.6	19,968.66	4.8
R4	EPS (standard)	11–16	19,486.22	7.1
R5	EPS (standard)	11–16	19,129.6	8.8

3.2.3. PEEM Alternative #3 (Windows)

The glazing type and layers directly impact the amount of heat transmission through the windows by either solar radiation or conduction heat transfer mechanisms [17]. Glazing plays a crucial role in the heat balance of a building. The existing single-glazed window is the dominant type of window glazing in Karachi, with a high *U*-value (5.7 W/m^2 K) and solar heat gain coefficient (SHGC) (0.81), high heat gain, and heat transmittance. The replacement of an existing single-glazed window with other materials (Table 9), such as a double clear glass window, clear triple glass, double tinted glass, and double low-*E* clear glass, gave up to 8.6% reduction in cooling energy demand. Case-WW3 has the lowest SHGC, which makes this glazing type most suitable. However, case-WW3 also has a low light transmittance value (0.50), which is not desired in educational buildings. Case-WW1 has the highest light transmittance value (0.81) with a high SHGC (0.76). Hence this glazing is also unsuitable. Use of double low-*E* clear glass in case-WW6 provides the maximum reduction in cooling energy demand of 8.6% with SHGC (0.56) and light transmittance (0.74), and is attributed to the thermal properties of this glazing type, which prevents direct heat gain in the building (Figure 8, Table 10). Hence, case-WW6 provides a good compromise between thermal loss/gain and natural light quality [46,57]. It is found that the glazing type is the main factor that determines the energy performance of the window. Shading was also provided, keeping all other parameters as in the base case to investigate the effect of shading on the reduction of cooling energy demand. The results indicated that the longer the shading, the greater the savings. The maximum energy demand reduction of 2.5% was achieved with 1.0 m overhangs, but this is not recommended, because the effectiveness of the extended shading length starts to level off (Figure 8, Table 10). The results are in agreement with previous studies [19,20].

Table 9. Alternative window compositions and overhang sizes used in window modification. Legend: WW, window; light transmittance, LT; solar heat gain coefficient, SHGC; LoE, low emissivity.

Cases	Specifications	
Case-WW1 *U*-value = 2.7 W/m^2 K	Double clear 3 mm glass /13 mm air window SHGC = 0.76	 LT = 0.81
Case-WW2 *U*-value = 1.9 W/m^2 K	Triple clear 6 mm glass /25 mm air window SHGC = 0.60	 LT = 0.69
Case-WW3 *U*-value = 2.6 W/m^2 K	Double tinted 6 mm glass /13 mm air window SHGC = 0.49	 LT = 0.50
Case-WW4 *U*-value = 2.7 W/m^2 K	Double tinted 3 mm glass /13 mm air window SHGC = 0.62	 LT = 0.61
Case-WW5 *U*-value = 1.75 W/m^2 K	Triple clear 3 mm glass /13 mm air window SHGC = 0.68	 LT = 0.73
Case-WW6 *U*-value = 1.49 W/m^2 K	Double LoE clear 6 mm glass/13 mm argon SHGC = 0.56	 LT = 0.74
Case-O1	40 cm overhang	
Case-O2	50 cm overhang	
Case-O3	60 cm overhang	
Case-O4	100 cm overhang	

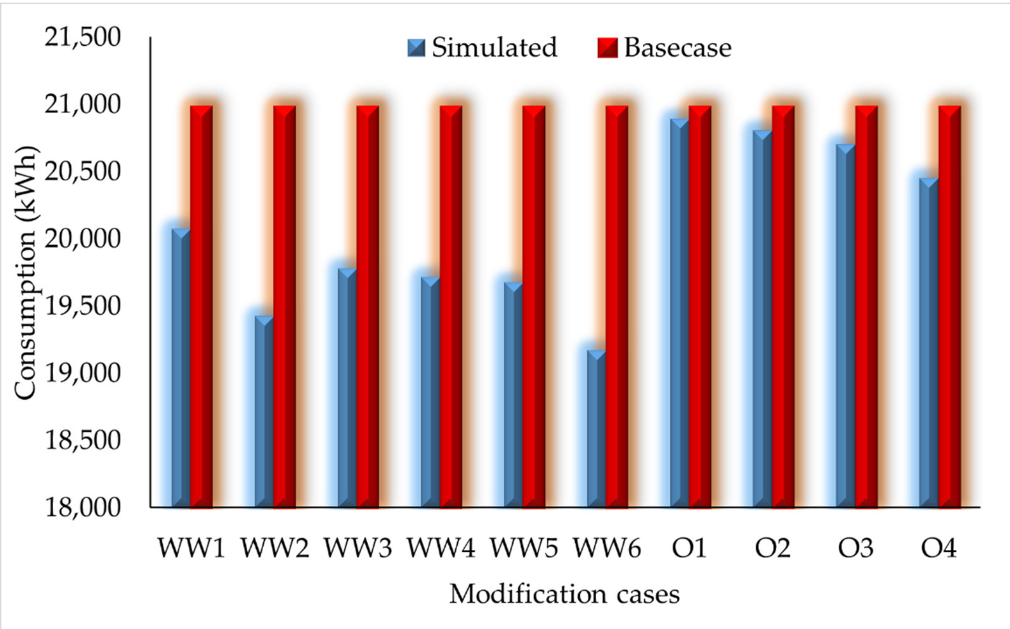


Figure 8. Alternative window modifications presenting simulated energy demand as compared to the base case.

The optimum window-to-wall ratio (WWR) at different façades was also calculated. The WWR in three façades: north, east, and west, was investigated from 0 to 100%, in steps of 5%. First, the WWR of all three façades was changed to 5%, then 10%, and so on. With 25% WWR on the north façade, the maximum cooling demand reduction of 0.1% was observed. The WWR value of 15% on the west and east façades gave a cooling demand reduction of 0.3%. The results show 5% discrepancy in the east and west façades, and no disparity in the north and south façades to the results of previous studies in the hot and humid climates of Asia [58,59]. The discrepancy is because of the different sun angles of different cities. The WWR modification is not included in the final recommendations, since the existing WWR (north façade = 27%, east and west façades = 14%) of all façades have optimum results in terms of cooling energy reduction. The existing WWR has also been proved to be effective in reducing the energy demand from previous studies in a hot and humid climate [58,59].

Table 10. Impact of alternative window compositions on cooling energy demand.

Cases	Energy Demand (kWh)	Reduction in Energy Demand (%)
Base case	20,975.48	0
WW1	20,073.5	4.3
WW2	19,423.2	7.4
WW3	19,779.8	5.7
WW4	19,716.9	6
WW5	19,675	6.2
WW6	19,171.5	8.6
O1	20,891.5	0.4
O2	20,807.6	0.8
O3	20,702.7	1.3
O4	20,451	2.5

3.2.4. PEEM Alternative #4 (Door)

Two different alternatives based on common practice in Karachi were considered substitutes for hollow core plywood doors (Table 11). Figure 9 indicates the cooling energy demand reductions achieved by using alternative doors. There is a slight reduction in cooling energy demand, and case-D2 provides a 0.2% reduction (Figure 9, Table 12).

Table 11. Alternative door compositions used in the modification of doors. Legend: D, door.

Cases	Specifications
Case-D1	3.5 cm painted oak door
U-value	2.82 W/m^2 K
Case-D2	4.2 cm painted oak door
U-value	2.557 W/m^2 K

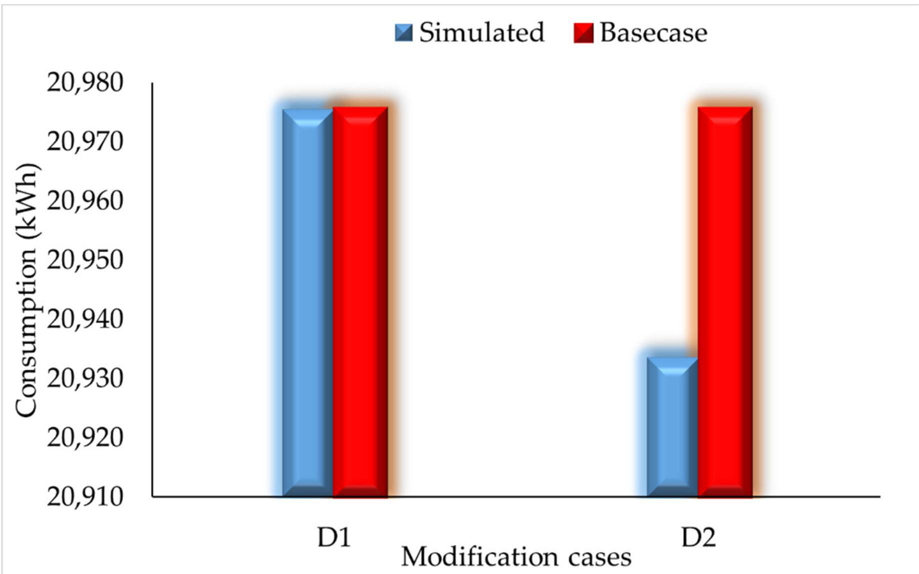


Figure 9. Alternative door modifications presenting simulated energy demand as compared to the base case.

Table 12. Impact of alternative door compositions on cooling energy demand.

Cases	Energy Demand (kWh)	Reduction in Energy Demand (%)
Base case	20,975.48	0
D1	20,975.48	0
D2	20,933.53	0.2

3.2.5. PEEM Alternative #5 (Combination of Modifications)

After investigating the modification strategies for each element of the ACB, the combined effect of all these modification strategies in reducing cooling energy demand and comfort temperature of the ACB was studied. Table 13 presents a combination of the modifications: airtightness, airflow, indoor temperature, and cooling energy demand reduction achieved by modifying the existing building envelope. The combination can reduce the cooling energy demand by 31.96% annually. Cases A and B illustrate a cooling energy demand reduction of 31.96% each, but case A is recommended, since case B includes an O4 (1 m overhangs) modification strategy, which is not recommended, as discussed in Section 3.2.3. Figure 10 represents the temperature curve for the outdoor and indoor temperatures with a comfortable temperature range in Karachi of 26–28 °C. In Karachi, there is a need for frequent and balanced airflow and air change [60]; however, high airflow was observed in the base case ACB. Natural ventilation rooms are dependent on outdoor temperatures and the existence of openings allowing airflow between the rooms and adjacent environments [61]. Case A is suitable for ACB modification, since it gives the highest reduction in energy demand and is the closest to the comfortable temperatures, and the airtightness standard of 0.6 ACH [62,63] and the airflow standard of 0.35 m^3/s [46] in Karachi. Figure 11 presents the heat transmission in the modified building envelope. The modified building envelope minimizes the heat transfer through walls by 51%, windows by 50%, and roof by 30%. Solar gains are also minimized by 57% (Figure 10).

Table 13. Effect of modification strategies on the indoor temperature, airtightness, airflow, and total reduction of energy demand (%). Legend: N, north cluster; E, east cluster; W, west cluster.

Case	Combination of Modifications	Reduction of Energy Demand (%)	Indoor Temperature(°C)	Airtightness (ACH)	Airflow (m^3/s)
	Base case	0	34.3	2.5	N = 0.46, E = 0.40, W = 0.58
A	W7, R4, WW6, O2, D2	31.96	29.4	1.2	N = 0.40, E = 0.35, W = 0.45
B	W7, R5, WW6, O4, D2	31.96	29.5	1.3	N = 0.42, E = 0.36, W = 0.49
C	W8, R4, WW2, O2, D2	24.9	31	2	N = 0.43, E = 0.37, W = 0.51
D	W8, R5, WW2, O2, D2	23.2	31.5	1.5	N = 0.44, E = 0.38, W = 0.53

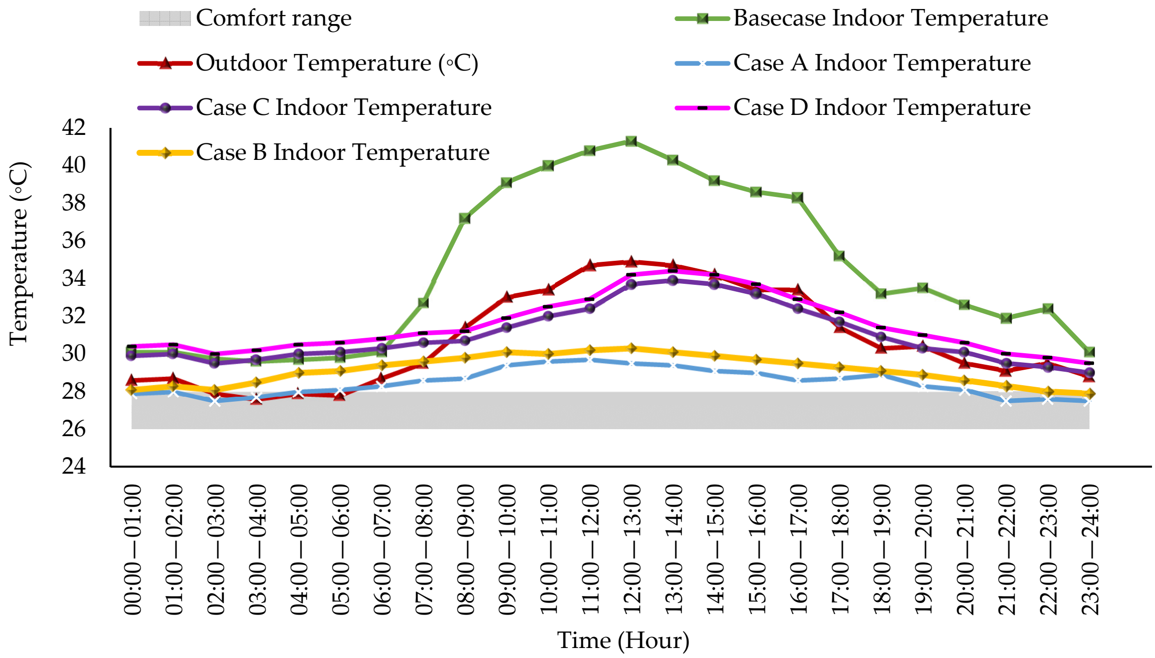


Figure 10. Temperature curve for the outdoor temperature, base case indoor temperature, and modified building envelope's indoor temperature during summer (May to August).

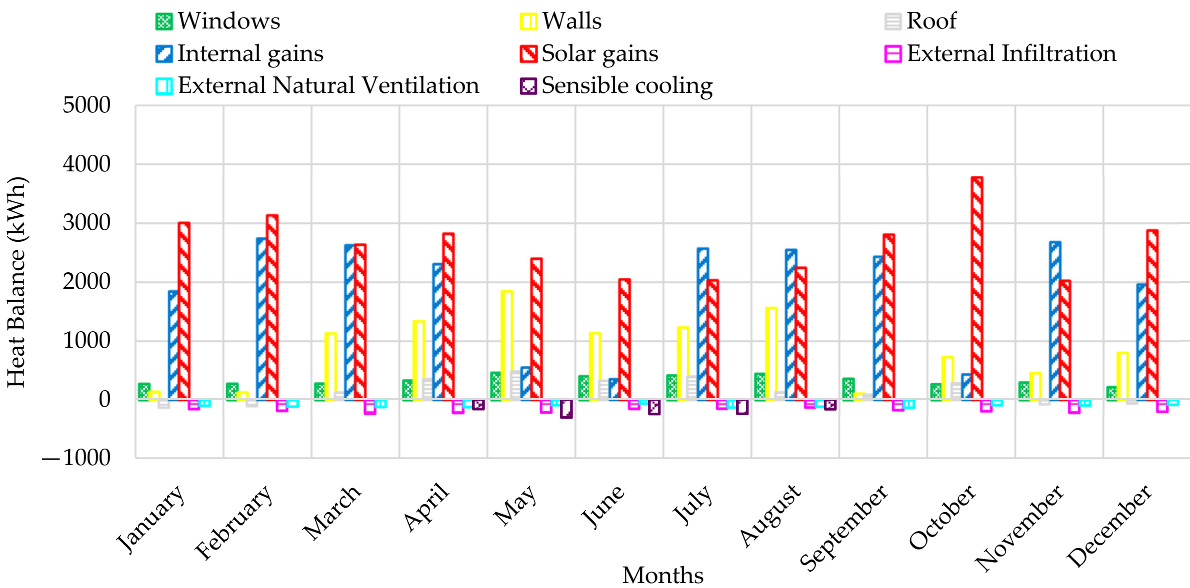


Figure 11. Heat transmission in the modified building envelope.

4. Discussion

4.1. Key Findings and Recommendations

The study selected an exemplary ACB, which was simulated, and then calibrated using electricity billing data. PEEMs were applied to identify the best case for reducing indoor temperature and energy demand for cooling. Modification measures of walls, roof, windows, and doors were considered with better energy performance while retaining the building's existing structure. The results showed that thermal insulation in the wall is the best modification measure for reducing energy demand for cooling. It was found that PEEM plays a crucial role in reducing energy demand for cooling in the exemplary ACB.

The study proved that PEEM is significantly effective in improving indoor environmental comfort, and accordingly, minimizing electricity demand in ACB. The results showed that using insulation in the building envelope positively impacts indoor environmental comfort, and reduces the energy demand for cooling. Moreover, the results revealed that among the investigated insulation materials, EPS had the lowest thermal conductivity and the highest specific heat capacity, and was therefore the most effective insulating material in renovation systems with similar thickness for reducing the indoor temperature and the related energy demand for cooling.

The following recommendations are given based on the significant findings as resources to help architects in setting out the design plan for existing educational buildings using PEEMs in a hot and humid climate:

- Building users consume a major proportion of electricity for thermal comfort, such as cooling in Karachi. This consumption can be reduced by using PEEMs. Building envelope modification is a crucial PEEM for thermal comfort and reduction in energy demand for cooling. By using PEEMs, a 31.96% reduction in energy demand for cooling can be achieved.
- Thermal insulation of 100 mm outside the thermal mass (200 mm) in the wall plays a significant role in reducing the maximum indoor temperature in hybrid buildings, and accordingly, reducing the electricity demand of a building.
- The common practice in Karachi is the use of single-glazed windows with high *U*-values (5.7 W/m^2 K). By replacing the single-glazed windows with double-glazed low-*E* reflective glass windows, the cooling energy demand can be reduced by 8.6%.
- Awnings (overhangs) above the windows are provided to reduce heat gains in the building. This study showed that the longer the overhangs, the greater the reduction in energy demand for cooling. However, long fixed overhangs are not practical, because they limit the solar heat gain in winter, as well as natural light. Hence, adjustable shading devices can be useful, since adjustable shading devices allow greater flexibility to make adjustments in response to changing weather conditions.
- Pakistan's urban population experiences 12–15 h of electricity blackout (load shedding) per day. Hence, reliance on active systems is not possible, and PEEMs are recommended. Retrofitting existing buildings to improve building energy efficiency is a better solution to such problems, since the existing buildings in Pakistan are energy inefficient.

4.2. Strengths and Limitations

In this study, the possibility and capability of BIM and building performance simulation (BPS) to virtually model and assess building energy demand against modification strategies, such as PEEMs, offer the opportunity to explore alternatives for an existing ACB. This provides an excellent opportunity to avoid mistakes that might arise when the building is being assessed using manual or traditional techniques. Furthermore, when such errors occur, it is difficult to correct them when the building has already been modified. The study used a virtual model based on physical observations and surveys, which was calibrated using actual data by validated calibration methods. Using advanced building performance simulation provided reliable results to understand the electricity demand and potential reduction in electricity demand for cooling by applying PEEMs.

The strength of this study is associated with the selection of the base case ACB. Furthermore, the novelty of this study lies in the context, climate, and building type. The findings not only investigate the potential of PEEMs in reducing energy demand for cooling, but can set live (good-practice) examples for students (future architects) who are studying ACB to design the buildings considering PEEMs.

Although this research focused on one ACB in Karachi, the implications made would be helpful in creating the general performance of energy efficiency in architecture campus buildings in a hot and humid climate, which would assist architects while designing architecture campus buildings in comparable climates. However, there are limitations to the generalizability of the results, since the building use, microclimate, and design of each building is different. Consequently, it will not be advisable to develop design strategies based on the investigation of only one building. However, the method used in this research can be considered for developing design strategies in a similar climate and for similar building use. Secondly, this research focused on construction materials and thermal properties, and other associated building properties; lighting issues may be investigated for more detailed insights. Thirdly, the degree of the building's airtightness may be investigated using airtightness testing to identify air infiltration through the building envelope.

4.3. Study Implications and Future Research

Karachi is a metropolitan city, and is the most populous city of Pakistan, where most buildings are not designed considering energy efficiency. As in many other cities of Pakistan [31], the building users rely on active measures, such as personalized split air conditioners. This results in high electricity bills, which create a financial burden on the building users. These active measures do not perform during the electricity blackout hours, which decrease building users' thermal comfort. For this reason, the renovation of existing buildings through PEEMs is a more suitable solution to such problems. However, these building owners do not undertake the necessary building renovations due to upfront cost and high hurdle rates, lack of information and awareness, absence of incentives, financing difficulties, mispricing, and lack of attention and materiality [64]. The government of Pakistan should encourage energy-efficient renovations, which are uncommon in Pakistan. Future research on ACB will focus on (i) earth-to-air heat exchangers as a PEEM to improve thermal comfort and reduce energy demand in the exemplary ACB; (ii) sensitivity analysis of the impact of passive design strategies on thermal comfort and energy efficiency in the hot and humid climate of Karachi; and (iii) combining active and passive measures to achieve optimal thermal comfort in the ACB.

5. Conclusions

This research focused on PEEMs to investigate various building components with different materials to mitigate heat transmission from/into the ACB, and improve the building performance in reducing indoor temperature and energy demand for cooling with the aid of BIM and parametric analysis using building performance simulation. This research also analyzed various building envelope compositions for the reduction in energy demand for the cooling perspective. Modifications of building envelope components are generally referred to as PEEMs. The investigated ACB showed significant potential in reducing indoor temperature and energy demand for cooling by adding thermal insulation outside of the opaque building envelope. The reduction in energy demand for cooling can be achieved by replacing the clear single-glazed windows (with high U-value) to double low-E electro reflective glass windows (with low U-value). A broader conclusion can be derived that a high-thermal-mass building with thermal insulation outside of the opaque building envelope performs well in a hot and humid climate. This conclusion is in agreement with the results of previous studies conducted in a hot and humid climate [55,65,66].

Based on this research, the following conclusions are made:

1. Thermal insulation of walls is found to be the best modification measure to reduce cooling energy demand.
2. Replacing single-glazed windows with double low-E electro reflective glass gave 8.6% reduction in cooling energy demand.
3. Thermal insulation with the lowest thermal conductivity and the highest specific heat capacity with similar thickness among the investigated insulation materials is the most effective insulating material for lowering the cooling energy demand.
4. The indoor temperature of the base case ACB was 34.3 °C. The modification strategies applied in case A reduced the indoor temperature to 29.4 °C. Case B, case C, and case D reduced the indoor temperature to 29.5, 31, and 31.5 °C, respectively.

5. An architect and designer can use building thermal modeling to design an energy-efficient building by analyzing the effectiveness of various construction and material alternatives. Hence, it is recommended to use BIM and building performance simulation to investigate energy-efficient measures.
6. In Pakistan, building owners lack the knowledge, interest, expertise, and awareness in the retrofitting of buildings for energy efficiency. Therefore, the government should provide incentives to facilitate the retrofitting of buildings to achieve energy efficiency.

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Conflicts of Interest: The authors declare that they have no conflict of interest.

Nomenclature

The following abbreviations are used in this paper:

ACB	architectural campus building
AM	analytical model
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
BIM	building information modeling
BPS	building performance simulation
CV(RMSE)	coefficient of variation of root square mean error
D	door
DB	DesignBuilder
EPS	expanded polystyrene
gbXML	Green Building Extensible Markup Language
HVAC	heating, ventilation, and air-conditioning
LT	light transmission
NMBE	normalized mean bias error
O	overhang
PCC	plain cement concrete
PEC	Pakistan Engineering Council
PEEMs	passive energy efficiency measures
PGBC	Pakistan Green Building Council
R	roof
RCC	reinforced cement concrete

SHGC	solar heat gain coefficient
W	wall
WW	window
WWR	window-to-wall ratio

Appendix A. Occupancy Schedules

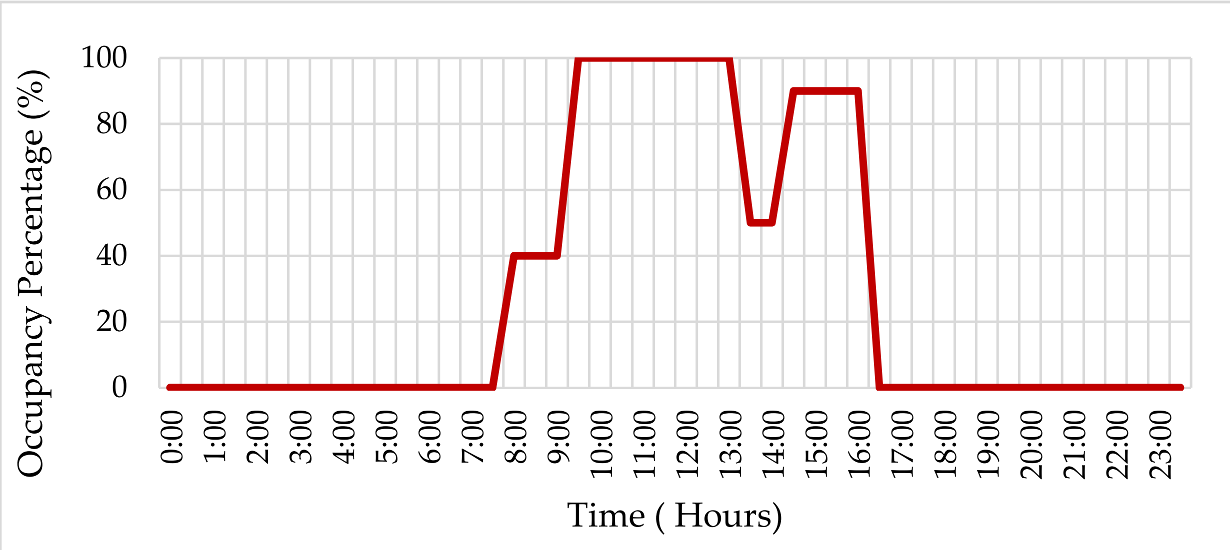


Figure A1. Lecture hall occupancy schedule.

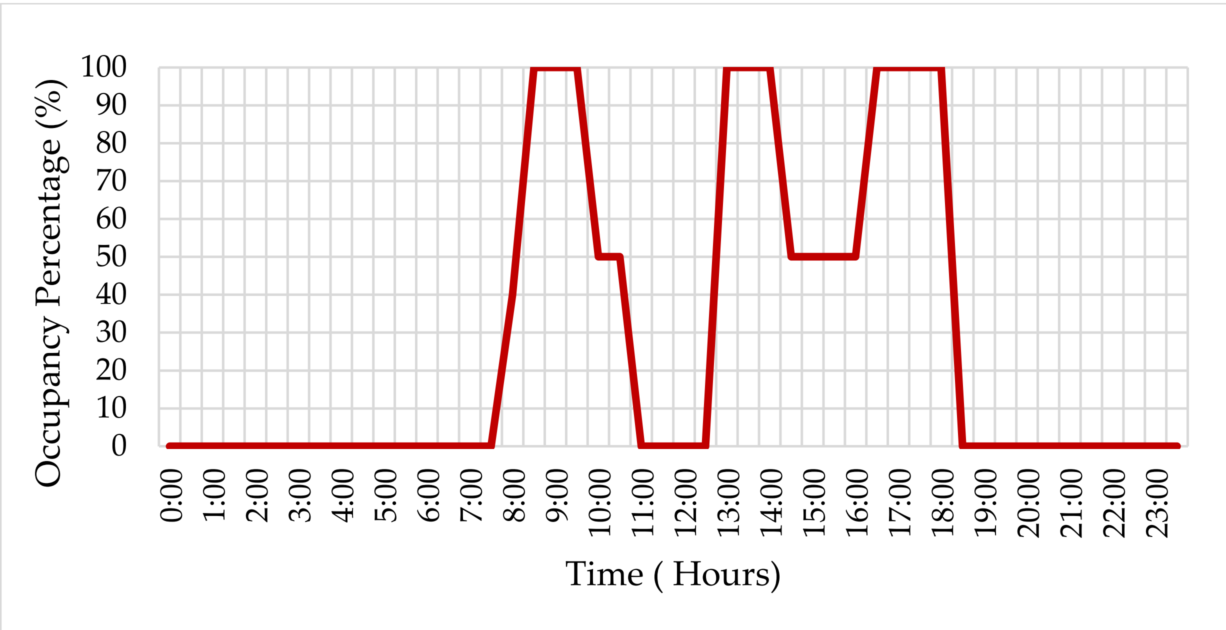


Figure A2. Naturally ventilated office occupancy schedule.

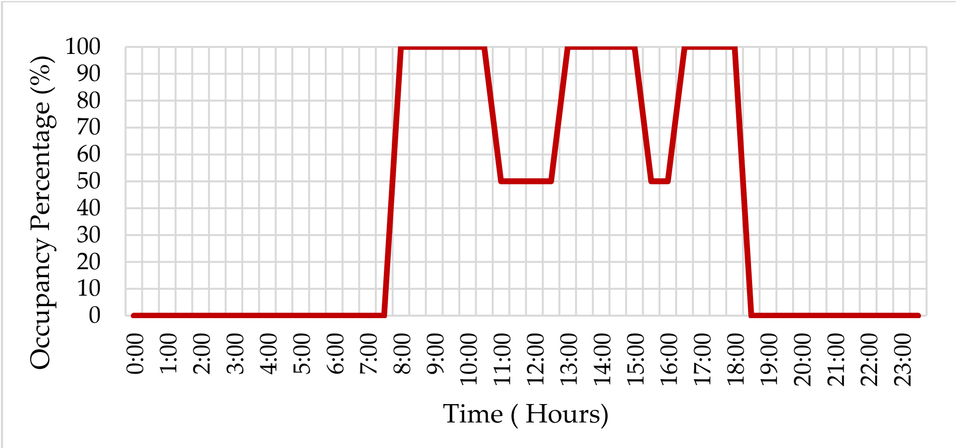


Figure A3. Conditioned office occupancy schedule.

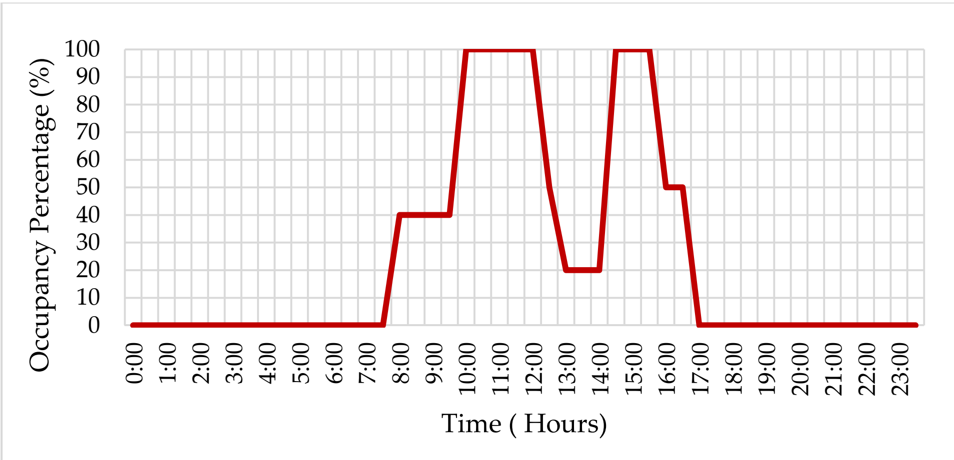


Figure A4. Computer lab occupancy schedule.

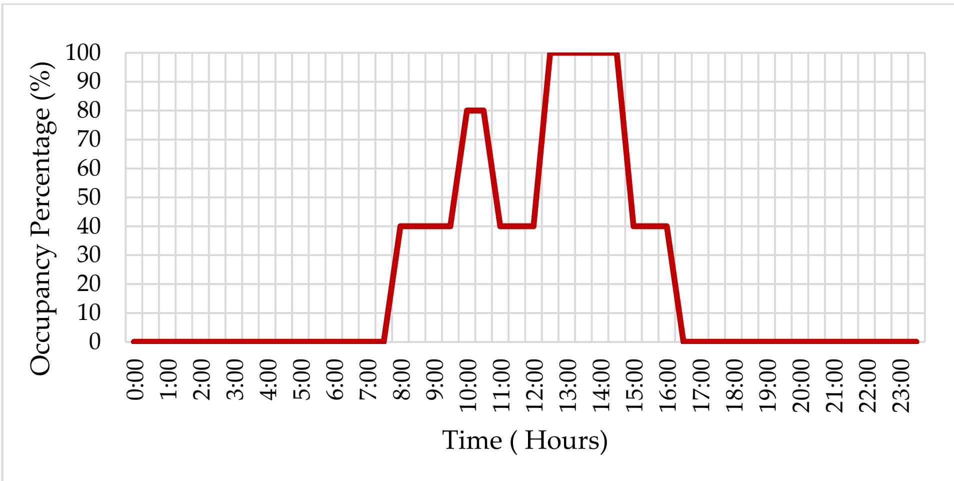


Figure A5. Common room and canteen occupancy schedule.

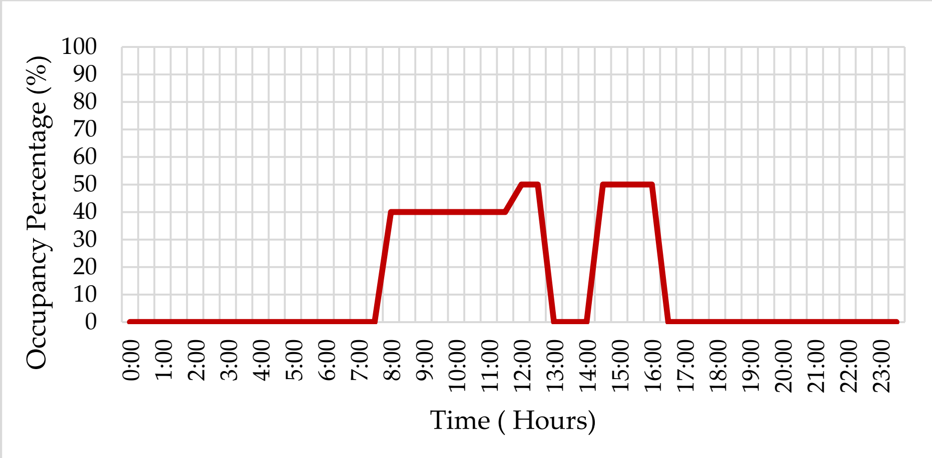


Figure A6. Laboratory occupancy schedule.

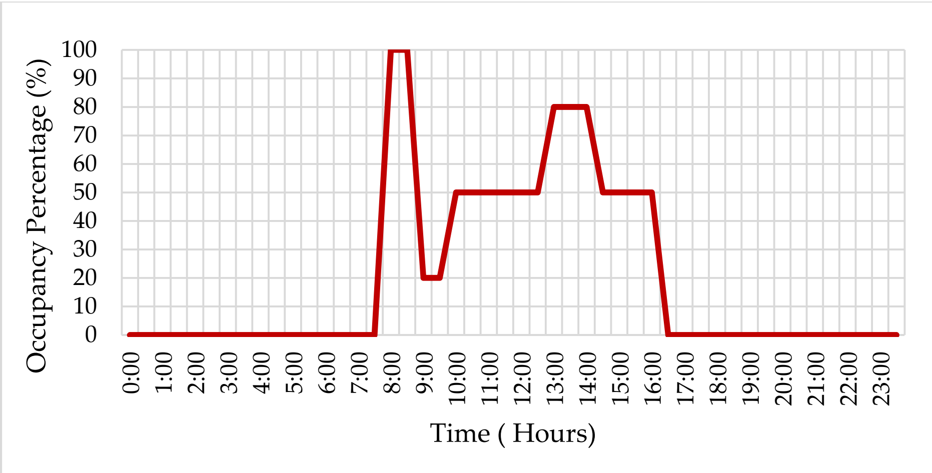


Figure A7. Toilet occupancy schedule.

Appendix B. Breakdown of Monthly Electricity Demand

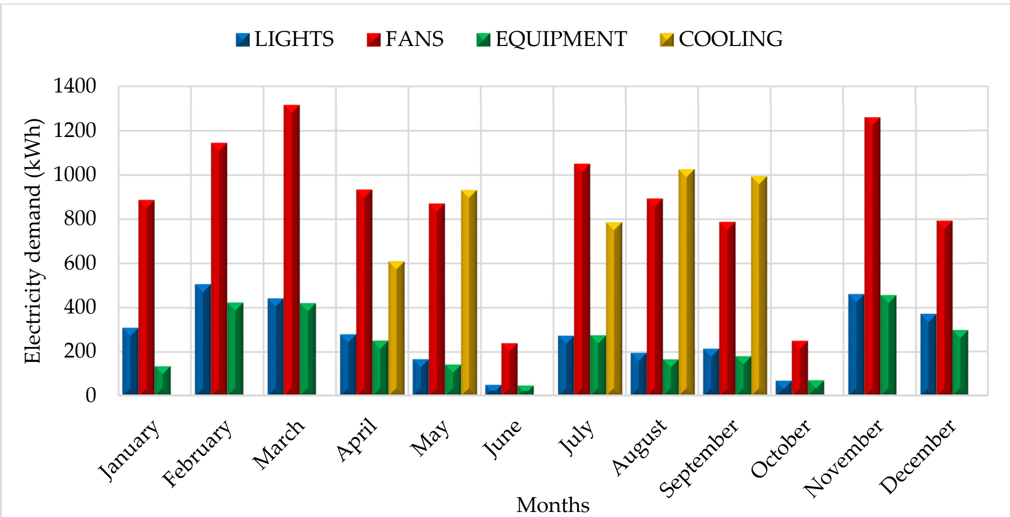
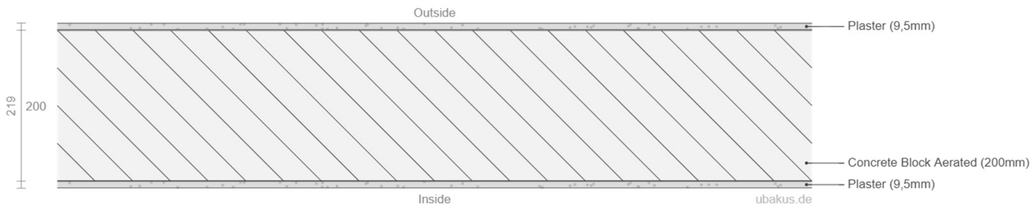


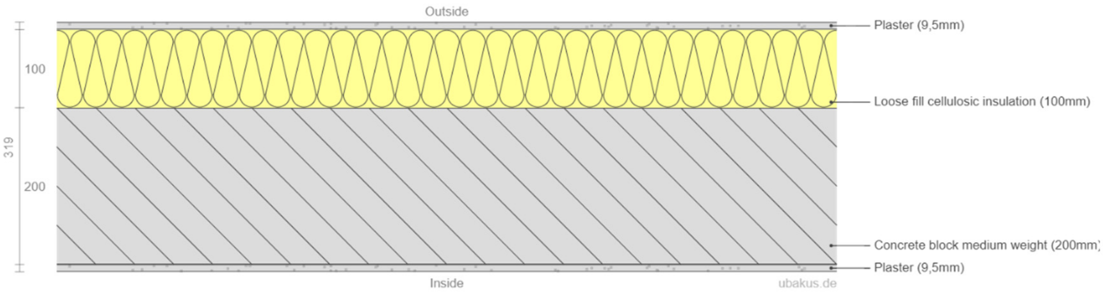
Figure A8. Breakdown of monthly electricity demand.

Appendix C. Cross Sections of Alternative Wall and Roof Compositions

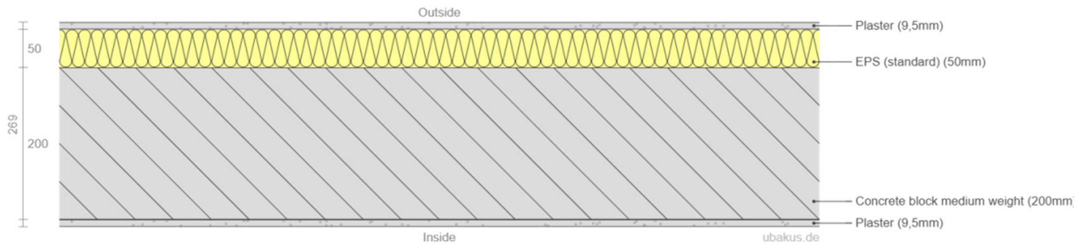
W1



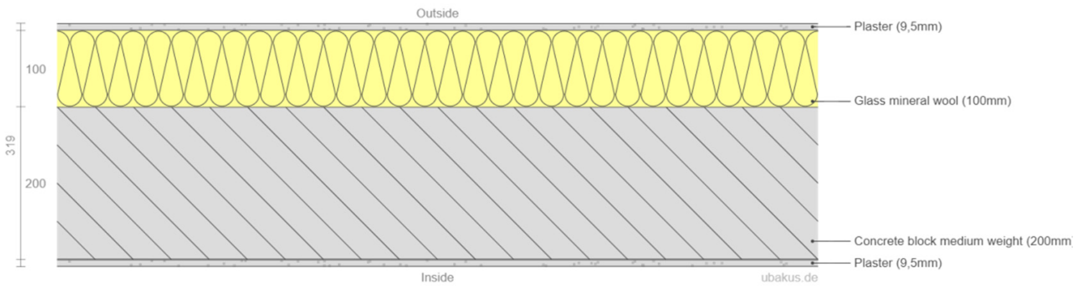
W2



W3



W4



W5

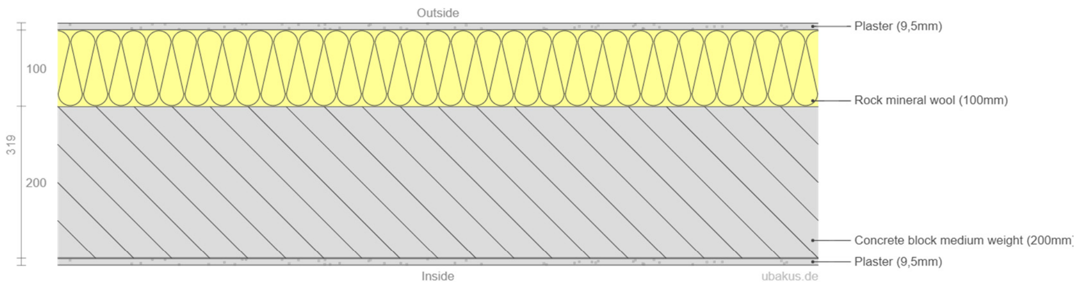


Figure A9. *Cont.*

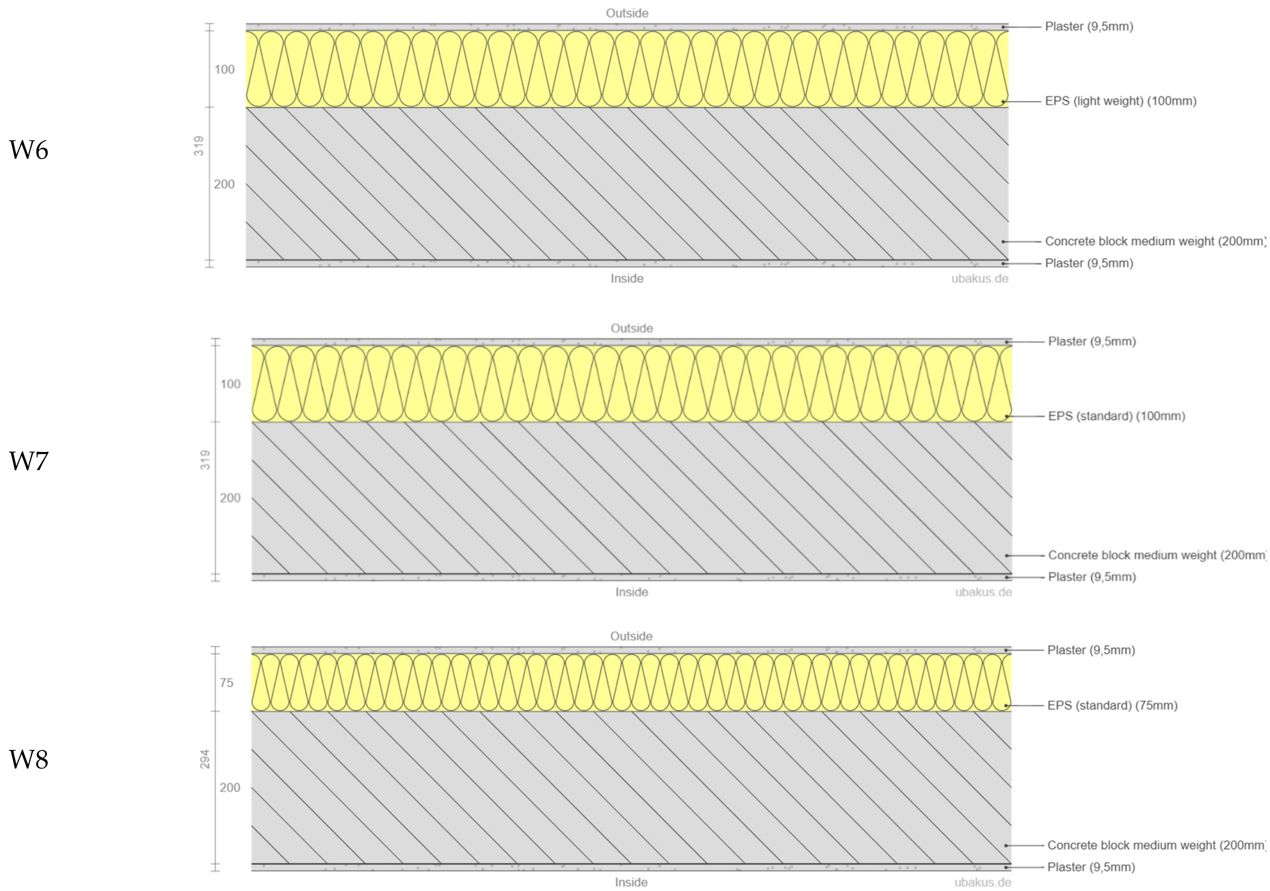


Figure A9. Cross sections of alternative wall compositions.

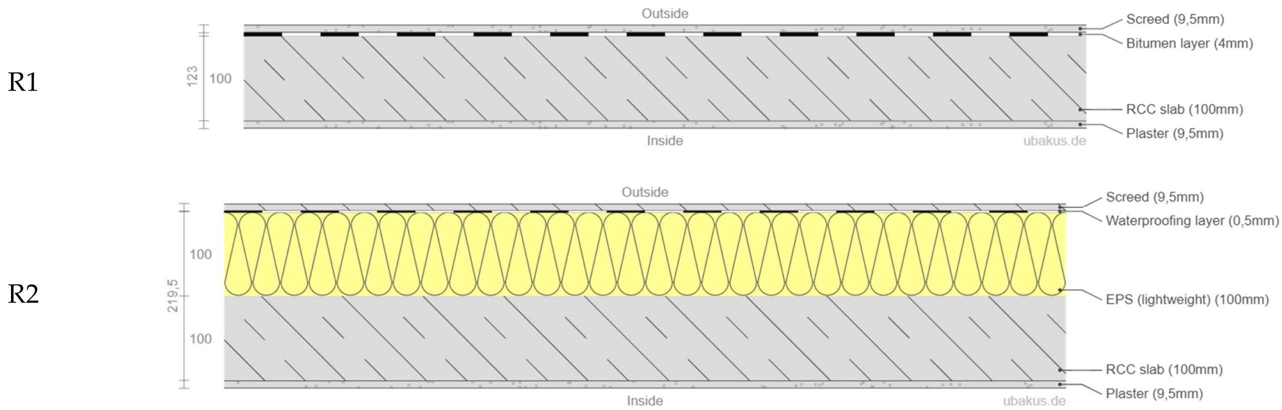
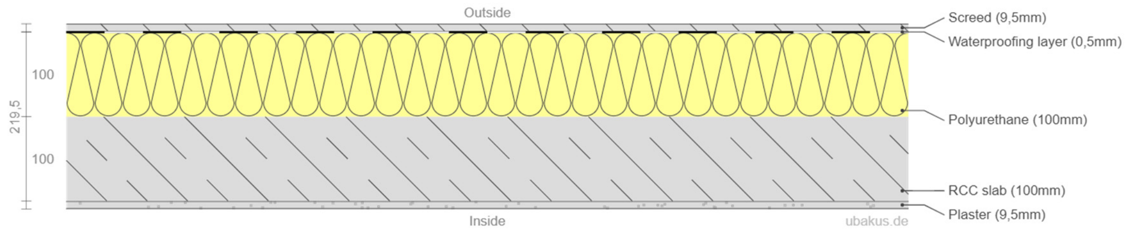
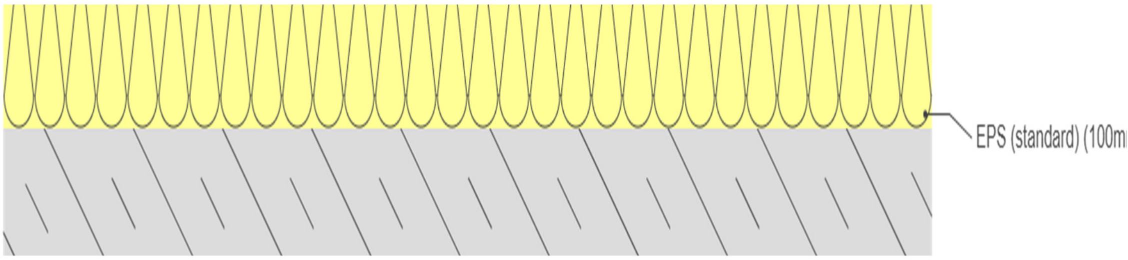


Figure A10. *Cont.*

R3



R4



R5

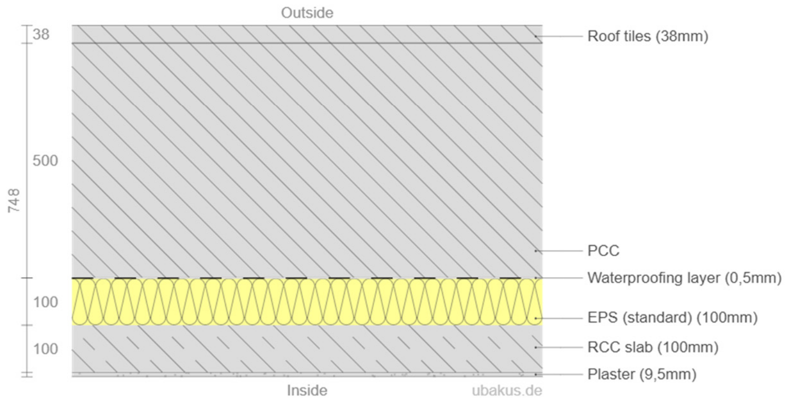
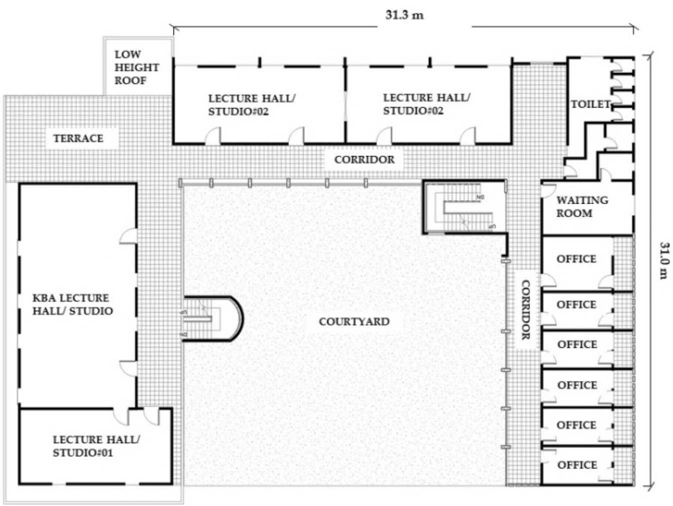


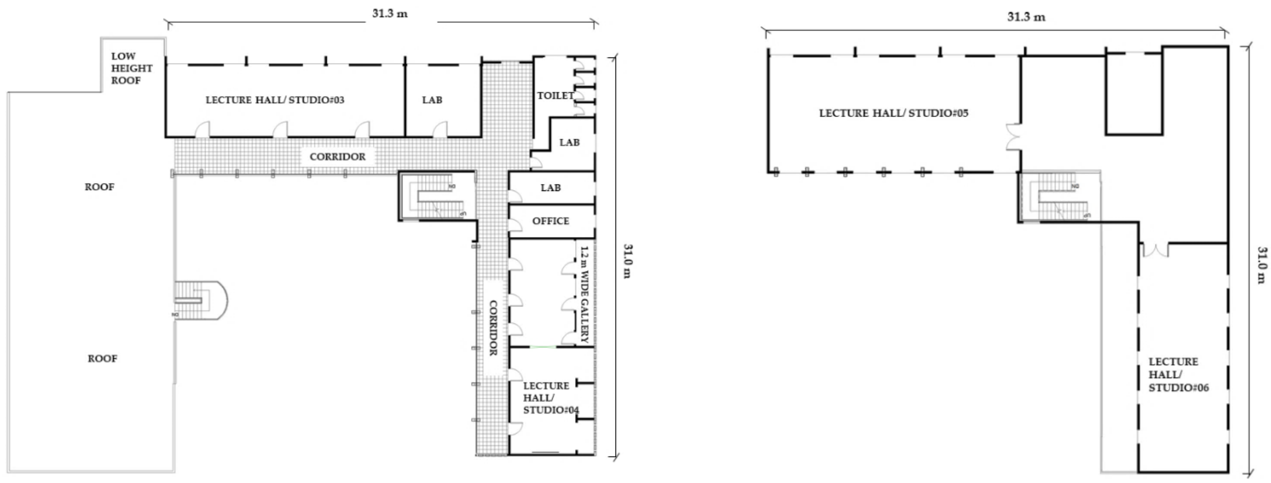
Figure A10. Cross sections of alternative roof compositions.

Appendix D. Floor Plans of the ACB



(**a**)

Figure A11. *Cont.*



(**b**) (**c**)

Figure A11. Floor plans of the ACB: (**a**) first floor, (**b**) second floor, and (**c**) third floor.

References

1. Shoubi, M.V.; Bagchi, A.; Barough, A.S. Reducing the operational energy demand in reducing the operational energy demand in buildings using building information modeling tools and sustainability approaches. *Ain Shams Eng. J.* **2015**, *6*, 41–55. [CrossRef]
2. Yılmaz, Z. Evaluation of energy efficient design strategies for different climatic zones: Comparison of thermal performance of buildings in temperate-humid and hot-dry climate. *Energy Build.* **2007**, *39*, 306–316. [CrossRef]
3. International Energy Agency. Global Status Report for Buildings and Construction. Available online: https://www.iea.org/reports/global-status-report-for-buildings-and-construction-2019 (accessed on 12 February 2021).
4. Ahsan, M.M.; Zulqernain, M.; Ahmad, H.; Wajid, B.A.; Shahzad, S.; Hussain, M. Reducing the operational energy consump-tion in buildings by passive cooling techniques using building information modelling tools. *Int. J. Renew. Energy Res.* **2019**, *9*, 343–353.
5. Ministry of Planning Development and Reform; Government of Pakistan. *National Action Plan*; Government of Pakistan: Islamabad, Pakistan, 2019.
6. Ministry of Energy (Petroleum Division). *Pakistan Energy Yearbook*; Ministry of Energy: Islamabad, Pakistan, 2018.
7. HIMA Verte. Energy Saving in Pakistan. 2016. Available online: https://img1.wsimg.com/blobby/go/a53308c6-148c-4dca-b8b1-d0227fe8ea99/downloads/1bp8e88mo_374945.pdf?ver=1616937863780 (accessed on 15 February 2021).
8. Mahar, W.A.; Verbeeck, G.; Singh, M.K.; Attia, S. An Investigation of Thermal Comfort of Houses in Dry and Semi-Arid Climates of Quetta, Pakistan. *Sustainability* **2019**, *11*, 5203. [CrossRef]
9. Khalid, A. Design Strategies and Guidelines for Tropical Coast of Pakistan, Using Climate Consultant. *Eur. J. Sustain. Dev.* **2015**, *5*, 505–512. [CrossRef]
10. Sadineni, S.B.; Madala, S.; Boehm, R.F. Passive building energy savings: A review of building envelope components. *Renew. Sustain. Energy Rev.* **2011**, *15*, 3617–3631. [CrossRef]
11. Okba, E.M. Building envelope design as a passive cooling technique. In Proceedings of the International Conference on Passive Low Energy Cooling for the Built Environment, Santorini, Greece, 19–21 May 2005; pp. 467–473.
12. Iwaro, J.; Mwasha, A. The impact of sustainable building envelope design on building sustainability using Integrated Performance Model. *Int. J. Sustain. Built Environ.* **2013**, *2*, 153–171. [CrossRef]
13. Sait, H.H. Auditing and analysis of energy consumption of an educational building in hot and humid area. *Energy Convers. Manag.* **2013**, *66*, 143–152. [CrossRef]
14. Iqbal, I.; Al-Homoud, M.S. Parametric analysis of alternative energy conservation measures in an office building in hot and humid climate. *Build. Environ.* **2007**, *42*, 2166–2177. [CrossRef]
15. Perez, Y.V.; Capeluto, I.G. Climatic considerations in school building design in the hot–humid climate for reducing energy consumption. *Appl. Energy* **2009**, *86*, 340–348. [CrossRef]
16. Cheng, V.; Ng, E.; Givoni, B. Effect of envelope colour and thermal mass on indoor temperatures in hot humid climate. *Sol. Energy* **2005**, *78*, 528–534. [CrossRef]
17. Mirrahimi, S.; Mohamed, M.F.; Haw, L.C.; Ibrahim, N.L.N.; Yusoff, W.F.M.; Aflaki, A. The effect of building envelope on the thermal comfort and energy saving for high-rise buildings in hot–humid climate. *Renew. Sustain. Energy Rev.* **2016**, *53*, 1508–1519. [CrossRef]
18. Cheung, C.; Fuller, R.; Luther, M. Energy-efficient envelope design for high-rise apartments. *Energy Build.* **2005**, *37*, 37–48. [CrossRef]
19. Hassan, A.S.; Al-Ashwal, N.T. Impact of Building Envelope Modification on Energy Performance of High-Rise Apartments in Kuala Lumpur, Malaysia. *Int. Trans. J. Eng. Manag. Appl. Sci. Technol.* **2015**, *6*, 91–105.

20. Al-Tamimi, N.; Fadzil, S.F.S. Energy-efficient envelope design for high-rise residential buildings in Malaysia. *Arch. Sci. Rev.* **2012**, *55*, 119–127. [CrossRef]
21. Sang, X.; Pan, W.; Kumaraswamy, M. Informing Energy-efficient Building Envelope Design Decisions for Hong Kong. *Energy Procedia* **2014**, *62*, 123–131. [CrossRef]
22. Mahar, W.A.; Anwar, N.U.R.; Attia, S. Building Energy Efficiency Policies and Practices in Pakistan: A Literature Review. In Proceedings of the 5th International Conference on Energy, Environment and Sustainable Development (EESD-2018), Jamshoro, Pakistan, 14–16 November 2018.
23. Rehman, A.; Deyuan, Z. Pakistan's energy scenario: A forecast of commercial energy consumption and supply from different sources through. *Energy Sustain. Soc.* **2018**, *8*, 26. [CrossRef]
24. Anwar, N.U.R.; Mahar, W.A.; Khan, J.F. Renewable energy technologies in Balochistan: Practice, prospects and challenges. In Proceedings of the 5th International Conference on Energy, Environment and Sustainable Development (EESD-2018), Jamshoro, Pakistan, 14–16 November 2018.
25. Ministry of Finance of Pakistan. Energy. In *Pakistan Economic Survey 2019–2020*; Ministry of Finance of Pakistan: Islamabad, Pakistan, 2020.
26. Xie, Y.; Fang, C.; Lin, G.C.; Gong, H.; Qiao, B. Tempo-Spatial Patterns of Land Use Changes and Urban Development in Globalizing China: A Study of Beijing. *Sensors* **2007**, *7*, 2881–2906. [CrossRef]
27. The Nation News. Unscheduled Load-Shedding Continues in Karachi Despite Government Claims. 2020. Available online: https://nation.com.pk/15-Jul-2020/unscheduled-load-shedding-continues-in-karachi-despite-govt-claims (accessed on 16 March 2021).
28. Poel, B.; van Cruchten, G.; Balaras, C.A. Energy performance assessment of existing dwellings. *Energy Build.* **2007**, *39*, 393–403. [CrossRef]
29. Saleem, F. Investigation of Energy Efficiency Opportunities and Assessment of Renewable Energy technologies for a College in the Rural Area of Pakistan: A Case Study of Namal College. Master's Thesis, Murdoch University, Perth, Australia, 2016.
30. Kazmi, N.A.; Anjum, N.; Iftikhar, N.; Qureshi, S. User comfort and energy efficiency in public buildings of hot composite climate of Multan, Pakistan. *J. Res. Archit. Plan.* **2011**, *10*, 76–95.
31. Mahar, W.A.; Attia, S. *Indoor Thermal Comfort in Residential Building Stock: A Study of RCC Houses in Quetta, Pakistan*; Techninal Report; Sustainable Building Design SBD Lab/University of Liege: Liege, Belgium, 2018.
32. Mahar, W.A.; Amer, M.; Attia, S. Indoor thermal comfort assessment of residential building stock in Quetta, Pakistan. In Proceedings of the European Network for Housing Research (ENHR) Annual Conference 2018, Uppsala, Sweden, 12–14 September 2018; pp. 1–12.
33. Mahar, W.A.; Verbeeck, G.; Reiter, S.; Attia, S. Sensitivity Analysis of Passive Design Strategies for Residential Buildings in Cold Semi-Arid Climates. *Sustainability* **2020**, *12*, 1091. [CrossRef]
34. Shaheen, N.; Arif, S.; Khan, A. Thermal Performance of Typical Residential Building in Karachi with Different Materials for Construction. *Mehran Univ. Res. J. Eng. Technol.* **2015**, *35*, 189–198. Available online: http://publications.muet.edu.pk/research_papers/pdf/pdf1275.pdf (accessed on 3 March 2021).
35. Mahar, W.A. Methodology for the Design of Climate-Responsive Houses for Improved Thermal Comfort in Cold Semi-Arid Climates. Ph.D. Thesis, University of Liège, Liege, Belgium, 2021.
36. Naeem, A.; Rafeeqi, S.F.A. NED city campus restoration- setting benchmarks for conservation practices. *J. Res. Archit. Plan.* **2012**, *12*, 1–12.
37. Bughio, M.; Schuetze, T.; Mahar, W.A. Comparative Analysis of Indoor Environmental Quality of Architectural Campus Buildings' Lecture Halls and its Perception by Building Users in Karachi, Pakistan. *Sustainability* **2020**, *12*, 2995. [CrossRef]
38. Autodesk Revit. Understanding Revit 2020. Available online: https://help.autodesk.com/view/RVT/2019/ENU/ (accessed on 15 July 2020).
39. Khan, M.S.; Adil, M.; Khalil, F.; Jamil, I. BIM Based Energy Simulation for Assessment of Buildings: Energy Wastage for Pakistan. In Proceedings of the 4th Conference on Sustainability in Process Industry (SPI-2018), Peshawar, Pakistan, 24–25 October 2018; pp. 44–49.
40. Khan, M.S.; Adil, M.; Khan, A. Assessment of structural design capability of building information modeling (BIM) tools in building industry of Pakistan. *J. Mech. Contin. Math. Sci.* **2019**, *14*, 385–401. [CrossRef]
41. Khan, M.S.; Khan, A.; Adil, M.; Khalil, F. Role of Building Information Modeling (BIM) in Building Design Industry. In Proceedings of the INUMDC 2018: "Iqra National University Multi-Disciplinary conference", Peshawar, Pakistan, 7–8 November 2018; pp. 119–123.
42. DesignBuilder. DesignBuilder Revit—gbXML Tutorial 2018. Available online: http://www.batisim.net/telechargement/documentation-logiciel/444-designbuilder-revit-gbxml-tutorial-v2/file.html (accessed on 5 March 2021).
43. Kamel, E.; Memari, A.M. Review of BIM's application in energy simulation: Tools, issues, and solutions. *Autom. Constr.* **2019**, *97*, 164–180. [CrossRef]
44. DesignBuilder. Software DesignBuilder Simulation + CFD Training Guide. 2008. Available online: http://www.designbuilder.co.uk/downloadsv1/doc/DesignBuilder-Simulation-Training-Manual.pdf (accessed on 5 March 2021).

45. National Energy Conservation Centre (ENERCON); Pakistan Engineering Council (PEC); Ministry of Housing and Works. Building Code of Pakistan Energy Provisions (2011). Available online: https://www.iea.org/policies/2539-building-code-of-pakistan-energy-provisions-2011 (accessed on 18 February 2021).
46. Trachte, S.; de Herde, A. Sustainable refurbishment—School buildings. In Proceedings of the IEA Solar Heating and Cooling Programme, Istanbul, Turkey, 2–4 December 2015.
47. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). *Measurement of Energy, Demand, and Water Savings*; ASHRAE Guideline 14-2014; ASHRAE: Peachtree Corners, GA, USA, 2014. Available online: https://upgreengrade.ir/admin_panel/assets/images/books/ASHRAE%20Guideline%2014-2014.pdf (accessed on 5 March 2021).
48. Garwood, T.L.; Hughes, B.R.; O'Connor, D.; Calautit, J.K.; Oates, M.R.; Hodgson, T. A framework for producing gbXML building geometry from Point Clouds for accurate and efficient Building Energy Modelling. *Appl. Energy* **2018**, *224*, 527–537. [CrossRef]
49. Semahi, S.; Benbouras, M.; Mahar, W.; Zemmouri, N.; Attia, S. Development of Spatial Distribution Maps for Energy Demand and Thermal Comfort Estimation in Algeria. *Sustainability* **2020**, *12*, 6066. [CrossRef]
50. Lotfabadi, P.; Hançer, P. A Comparative Study of Traditional and Contemporary Building Envelope Construction Techniques in terms of Thermal Comfort and Energy Efficiency in Hot and Humid Climates. *Sustainability* **2019**, *11*, 3582. [CrossRef]
51. Bano, F.; Kamal, M.A. Examining the Role of Building Envelope for Energy Efficiency in Office Buildings in India. *Archit. Res.* **2016**, *6*, 107–115. [CrossRef]
52. Mcilvaine, J.; Sutherland, K.; Martin, E. *Energy Retrofit Field Study and Best Practices in a Hot-Humid Climate*; U.S. Department of Energy: Oak Ridge, TN, USA, 2013.
53. Boostani, H.; Hancer, P. A Model for External Walls Selection in Hot and Humid Climates. *Sustainability* **2018**, *11*, 100. [CrossRef]
54. National Renewable Energy Laboratory. Energy Design Guidelines for High Performance Schools. 2002. Available online: https://www.nrel.gov/docs/fy02osti/29105.pdf (accessed on 18 February 2021).
55. Baderia, N. The Role of Thermal Mass in Humid Subtropical Climate: Thermal Performance and EnergyDemand of CSET Building Ningbo. 2014. Available online: http://www.plea2014.in/wpcontent/uploads/2014/12/Paper_5E_2747_PR.pdf (accessed on 18 February 2021).
56. Long, L.; Ye, H. The roles of thermal insulation and heat storage in the energy performance of the wall materials: A simulation study. *Sci. Rep.* **2016**, *6*, 24181. [CrossRef]
57. Ren, J.; Liu, J.; Cao, X.; Hou, Y. Influencing factors and energy-saving control strategies for indoor fine particles in commercial office buildings in six Chinese cities. *Energy Build.* **2017**, *149*, 171–179. [CrossRef]
58. Shaeri, J.; Habibi, A.; Yaghoubi, M.; Chokhachian, A. The Optimum Window-to-Wall Ratio in Office Buildings for Hot-Humid, Hot-Dry, and Cold Climates in Iran. *Environments* **2019**, *6*, 45. [CrossRef]
59. Lee, J.; Jung, H.; Park, J.; Yoon, Y. Optimization of building window system in Asian regions by analyzing solar heat gain and daylighting elements. *Renew. Energy* **2013**, *50*, 522–531. [CrossRef]
60. Gut, P.; Ackerknecht, D. *Climate Responsive Building: Appropriate Building Construction in Tropical and Subtropical Regions*; SKAT Publications: St. Gallen, Switzerland, 1993.
61. Nicol, J.F.; Raja, I.A.; Allaudin, A.; Jamy, G.N. Climatic variations in comfortable temperatures: The Pakistan projects. *Energy Build.* **1999**, *30*, 261–279. [CrossRef]
62. Chen, Y.; Mae, M.; Taniguchi, K.; Kojima, T.; Mori, H.; Trihamdani, A.R.; Morita, K.; Sasajima, Y. Performance of passive design strategies in hot and humid regions. Case study: Tangerang, Indonesia. *J. Asian Arch. Build. Eng.* **2020**, 1–19. [CrossRef]
63. Passivhaus Institut. The Passivhaus Estandar in European Warm Climates: Design Guidelines for Comfrotable Low Energy Homes: Part Comfort, Climate and Passive Strategies. 2007. Available online: http://www.eerg.it/passive-on.org/CD/TechnicalGuidelines/Part3/Part3.pdf (accessed on 8 March 2021).
64. Amecke, H.; Deason, J. *Buildings Energy Efficiency in China, Germany and the United States: Climate Policy Initiative*; CPI Report; Climate Policy Initiative (CPI): San Francisco, CA, USA, 2013.
65. Szokolay, S.V. Dilemmas of warm-humid climate house design: Heavy vs. lightweight + cooling effect of air movement. In Proceedings of the Passive and Low Energy Architecture conference, Cambridge, UK, 2–5 July 2000.
66. Soebarto, V.I. A 'New' Approach to Passive Design for Residential Buildings in a Tropical Climate. In Proceedings of the PLEA '99 "Sustaining the Future—Energy, Ecology, Architecture", Brisbane, Australia, 22–24 September 1999.