



Research Article

Passive Cooling Retrofit Strategies for Reducing Energy Demand in a Residential Building in Karachi, Pakistan

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Abstract

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Buildings are the biggest electricity consumers and carbon emitters, and space cooling and heating are responsible for a substantial amount of the energy usage. In developing nations, the energy efficiency of existing residential buildings is often poor owing to poor thermal design and the prevalence of energy-intensive cooling systems, which provide immense potential for improvement through retrofitting. This paper describes an Autodesk Ecotect based retrofit analysis of a residential building in Karachi, Pakistan, using passive cooling systems as a case study. A reference building model was created and analyzed from 1 January 2025 to 31 December 2025 to determine the annual heating and cooling demand, solar access, passive heat gain terms, ventilation-related gains, and indoor air temperature. Various retrofitting options were explored, such as argon gas-filled double glazing with solar control film, improved natural ventilation with wind catcher and cross ventilation, green roofs, insulation of building envelopes, exterior reflective coatings with different reflectance values, and indirect nocturnal radiant cooling. The analysis indicates that substitution of single glazing with tinted double glazing resulted in a 12.17% reduction in annual thermal loads with improved indoor comfort conditions. In addition, energy retrofits at the appliance level, using efficient lighting and appliances, decreased the monthly electricity consumption from 539 kWh to 390 kWh, resulting in a monthly savings of 149 kWh. The results show that combining passive envelope and ventilation retrofits with efficient appliances can be an effective way to reduce cooling-driven energy demand and improve thermal comfort in residential buildings in hot climates.

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I. INTRODUCTION

The world has undoubtedly focused on creating more sustainable structures, technology, and systems due to the growing demands on energy consumption, the depletion of resources that are not sustainable, and the threat of climate change [1]. As a result, the utilization of renewable energy sources and the improvement of energy conservation are now the main components of energy regulations and standards for

nations worldwide [2]. In the context of the overall energy problem, buildings are identified as one of the biggest electricity consumers and a source of greenhouse gas emissions. A substantial amount of building energy is linked to the provision of indoor thermal comfort through space cooling and heating [3]. This issue is more pressing in hot climates, where cooling energy consumption is the dominant component of overall electricity consumption and continues to rise due to rising temperatures, urbanization, and

population growth. As a result, improving the construction industry's energy efficiency has been found to be one of the best approaches to solving the energy issue [4]. Although new energy-efficient buildings are increasingly being promoted, the greatest potential for energy efficiency still lies in buildings [5]. Large number of residential buildings in developing nations were erected without proper thermal considerations, leading to high cooling demands, poor indoor thermal conditions during extreme seasons, and a greater dependence on mechanical cooling systems [6], [7]. Retrofitting existing buildings, therefore, provides a viable option for upgrading building performance without the associated costs of demolition and new construction [8].

Pakistan is an extremely relevant context for residential retrofit analysis, given the country's consistent mismatch between energy demand and supply, as well as its heavy reliance on electricity for cooling [9]. Karachi, being the largest metropolitan in Pakistan, has extended warm periods and a high level of humidity, resulting in a significant cooling energy demand in residential buildings [10]. Although the building sector has a significant energy demand, thermal comfort conditions are often not satisfactory, implying that buildings are operating inefficiently [11]. This scenario underlines the need for assessing the effectiveness of retrofit strategies that can minimize heat gain from the building envelope and enhance passive cooling performance [12].

In the last few years, a considerable amount of work has been carried out to explore building retrofitting actions through simulation-based methods and experimental studies [13]. Envelope retrofits, including insulation and glazing upgrades, are some of the most analyzed retrofitting actions, and most of the studies have shown a positive impact in terms of reduced cooling and heating demands [14]. Nevertheless, a common aspect of the existing literature is that the retrofit analysis is often performed for a single action (such as glazing replacement or insulation thickness optimization) and not for a combination of passive strategies as a whole retrofit solution. Moreover, most of the studies have been carried out in temperate or cold climates, and hot-humid climates like Karachi are still less represented [15].

Some recent studies using modeling-based retrofit analysis have shown the benefit of using digital simulation tools for retrofit decision support, especially for the evaluation of insulation materials, façade retrofits, and energy performance under different operating conditions. However, a major part of the retrofit literature is more focused on the development of modeling workflows or cost analysis, without much attention to thermal load breakdown analysis or passive gain interpretation [16]. Similarly, research on cool roof materials and reflective surfaces has provided experimental verification of surface temperature reduction but has not used this information to estimate the annual thermal load effect of the building using a comprehensive building energy simulation workflow. Green roofing research has also shown thermal load reduction benefits through surface temperature reduction and insulation effects, but most of the research has

been conducted at the component level and not at the annual simulation level for residential buildings [17].

Another significant limitation found in the retrofit case studies is the lack of connection between thermal load reductions and household electricity consumption. Although many studies have found cooling load reductions, fewer studies have considered appliance-level electricity calculations or offered a general perspective on the combined impact of envelope retrofits and efficient equipment upgrades on reducing household electricity consumption on a monthly basis. In practice, residential energy consumption in hot and dry conditions is greatly impacted by building envelopes and the effectiveness of large household appliances like air conditioners, lighting, and refrigerator units [18].

In a large factory, the preference for daylighting over electric lighting was investigated. By turning off or lowering the illumination at four different times of the day for the same luminous intensity and then assessing the thermal loads, the simulated findings were compared with actual values. The results showed that the building's cooling load demand decreased by 35%. However, there was a 7% increase in the required heating load [19]. Mohammed and Budaiwi examined the possibility of reducing the energy use. The step-by-step checks provided the necessary data about the technical drawings, electrical power use, etc. A number of passive strategies were used, and the findings indicated that 16% of energy could be saved by using standards, 7% by using energy-efficient lighting, 3% by using appropriate insulation, and 2% by using double-glazed windows [20]. In a different study, the scientists looked into several approaches for upgrading two Iranian educational buildings. Buildings' energy performance was examined, and different retrofitting techniques were graded according to payback timeframes and simulations. The results demonstrated that insulating the roof, switching to double-glazed windows from single-glazed ones, and appropriately tightening the air may save a significant amount of energy [21]. Tomas *et al.* studied a cost-effective passive retrofitting method for retrofitting Swedish single-family houses and found that the most cost-effective retrofitting method was the installation of an air heat pump, while the least cost-effective method was the installation of a window [22].

To address these issues, this research work proposes an energy retrofit analysis of a residential building in Karachi, Pakistan, utilizing Autodesk Ecotect building performance simulation software. The initial building model was created and analyzed from 1 January 2025 to 31 December 2025. The simulation tool was employed to assess the annual heating and cooling demand, solar access, ventilation-related gains, passive gains distribution, and indoor temperature distribution. Various passive retrofits were considered, such as argon gas-filled double glazing with solar control film, enhanced natural ventilation with wind catcher and cross ventilation, green roofs, insulation of building envelopes, reflective exterior paints with varying reflectance values, and indirect nocturnal radiant cooling. Furthermore, appliance-

level retrofits were analyzed through electricity use calculations, taking into account efficient lighting and appliance replacement. The main contribution of this research work is the design of a methodical and replicable retrofitting assessment approach that combines Ecotect-based thermal analysis with electricity load calculations for a residential building in a hot and humid climate. In contrast to other case studies that have focused on the assessment of individual retrofitting solutions or non-residential buildings, this research work offers a comprehensive assessment of various passive design strategies and establishes a connection between thermal performance results and electricity savings for a household in a Karachi-based case study.

II. METHODOLOGY

In this research, the potential benefits of thermal retrofitting are quantified for an existing residential building in Karachi, Pakistan. The building is analyzed in its existing state as the baseline scenario and compared with a series of retrofit options applied through passive cooling techniques. A simulation analysis was performed to determine the annual thermal loads and comfort-related parameters for the building using Autodesk Ecotect Analysis software. Ecotect Analysis

software was chosen for this research because of its ability to carry out a comprehensive building performance analysis, which includes the calculation of thermal loads, solar access and solar radiation mapping, ventilation-related gain calculation, and passive gains breakdown. The method used in this research enables a comparison of the baseline and retrofit scenarios under the same climatic conditions, which enables the evaluation of the individual passive techniques for residential buildings in hot climates.

A. Building Description

The building chosen for this study is a double-storeys (G+1) residential building located in Karachi, Pakistan. The building was chosen because it is a typical residential structure developed without any performance-driven thermal design considerations and hence provides a good baseline for analysis. The building has been modeled using Autodesk Ecotect based on the architectural design geometry, and the annual thermal performance of the building has been analyzed from 1 January 2025 to 31 December 2025. The important building parameters used for the baseline model are presented in Table I.

TABLE I BUILDING DESCRIPTION

S. No.	Parameter	Value / Description
1	Orientation	Long axis facing North–South
2	Number of storeys	2 (G+1)
3	Total Area	240 m ²
4	Total Volume	720 m ³
5	Total Area of Exposed Walls	320 m ²
6	Total Windows Area	48 m ²
7	Window to Wall Ratio	0.20
8	Floor Height	3.0 m
9	Indoor Design Temp.	24°C
10	Operating Schedule	Residential occupancy
11	Occupancies	7 persons
12	Infiltration Rate	0.50 ACH
13	Lighting Level	200 lux
14	Appliances	Residential appliance set

B. Modelling of the Building

1. Baseline Design: Baseline building is a representation of the existing residential structure commonly found in Karachi. The external walls were assumed to be brick masonry with cement plastering, and the roof was assumed to be a reinforced concrete slab with a conventional finishing layer. The windows in the baseline building were assumed to be single-glazed with aluminum frames, which are commonly found in residential structures and are known to make a significant contribution to solar heat gains and cooling loads. The doors were assumed to be conventional solid-core wooden doors. The baseline building was analyzed to determine the thermal performance of the existing structure.

To evaluate baseline performance, the following analyses were performed using Autodesk Ecotect:

- Thermal load analysis
- Solar access and incident radiation analysis
- Passive gains breakdown analysis
- Ventilation gain analysis

For the glazing retrofit scenario, baseline single-glazed aluminium windows were replaced with tinted argon-filled double glazing with solar control film. The thermal transmittance (U-value) of glazing was reduced from 5.80 W/m²·K (single glazing) to 2.00 W/m²·K (double glazing), and all other building parameters were kept constant to isolate the impact of glazing improvement.

TABLE II GLAZING PROPERTIES USED IN SIMULATION

Window type	U-value ($\text{W/m}^2\cdot\text{K}$)
Single glazing (baseline)	5.80
Double glazing (retrofit)	2.00

The baseline envelope thermal properties and window-to-wall ratio used in the simulation are summarized in Table III. The baseline envelope U-values were adopted from standard construction thermal properties and typical residential material layers used in Pakistan.

TABLE III U-VALUES OF BASELINE DESIGN

Component	Baseline Construction	Description	U-value ($\text{W/m}^2\cdot\text{K}$)
Wall	Brick masonry + cement plaster	Typical external brick wall with internal and external plaster	1.80
Roof	RCC slab + finish	Reinforced concrete slab with conventional roof finishing	2.50
Window	Single glazing (aluminum frame)	Clear single-glazed window	5.80
Door	Solid wood	Standard residential door	2.50
Window-to-Wall Ratio	—	WWR	0.20

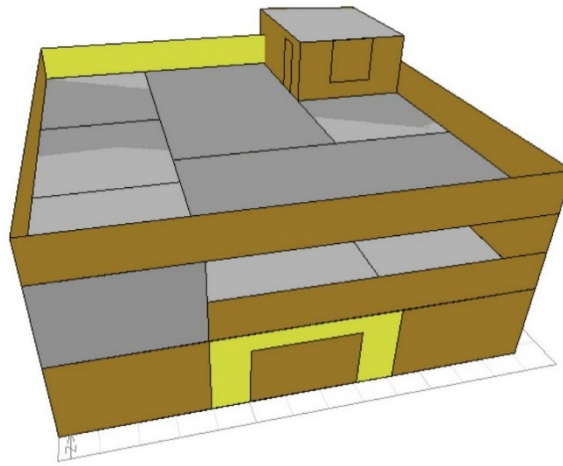


Fig.1 3D Model of Residential Building

2. Applying Retrofitting Techniques: After determining the baseline performance of the existing building, a set of passive cooling retrofit measures was applied to lower the annual thermal loads. The retrofit measures were determined based on their feasibility in Karachi residential buildings and their ability to mitigate the dominant heat gain paths identified in the baseline analysis. The retrofit measures included increasing the thermal resistance of the building envelope, minimizing solar heat gain through glazing, and optimizing passive ventilation and roof cooling. The following retrofitting techniques were evaluated in this study:

- Replacement of single glazing with double glazing and solar control film
- Natural ventilation enhancement (wind catcher and cross ventilation)
- Application of green roof
- Envelope insulation improvement
- Application of reflective exterior coatings (multiple reflectance levels)
- Indirect nocturnal radiant cooling
- Appliance-level energy efficiency retrofitting

All retrofitting options were simulated with the same climatic boundary conditions and operating assumptions as in the baseline simulation. Individual retrofit measures were initially assessed by keeping all other parameters unchanged to determine the individual effect of each retrofitting measure. Thereafter, combined retrofit simulations were carried out to evaluate the cumulative effect of integrated passive cooling measures. The retrofitted solutions were compared to the baseline design to determine the annual thermal load reduction and changes in indoor temperature behavior.

3. Reflective Coating Retrofit: The reflective coating retrofits were assessed by varying the external surface solar reflectance of the building envelope. Three values of coating reflectance (32%, 42%, and 61%) were simulated with the same boundary conditions to determine the effect of surface reflectance on heat gain due to cooling. The surface reflectance values considered in the simulations (0.20–0.61) were selected based on reported ranges for metallic and ceramic reflective coatings in recent studies on radiative and thermal coatings.

TABLE IV REFLECTIVE COATING CASES USED IN SIMULATION

Case	Surface reflectance	Reference
Baseline	0.20	[25]
Coating-1	0.32	[26]
Coating-2	0.42	[27]
Coating-3	0.61	[28]

4. *Indirect Radiant Cooling Retrofit:* Indirect radiant cooling was considered as a passive approach to improve the ability to reject heat during night-time. The retrofit approach was simulated by adding an indirect radiant cooling system at roof level to facilitate long-wave radiative cooling during night-time. The same internal gains, schedules, and boundary conditions were retained.

5. *Green Roof Retrofit:* The green roof retrofit was analyzed by substituting the default roof surface finish with a green roof assembly to lower the roof's solar heat absorption and

increase roof-level thermal resistance. All other variables were held constant.

TABLE V ROOF U-VALUES USED FOR GREEN ROOF RETROFIT

Roof case	Roof U-value (W/m ² ·K)
Baseline RCC roof	2.50
Green roof	0.60

6. *Envelope Insulation Retrofit:* For the insulation retrofit, the U-values of the exterior walls and roof were changed to reflect insulated construction. The base case and insulated scenarios were solved with the same climatic boundary conditions, internal loads, and operating schedules. The envelope U-values for the insulation retrofit are given in Table VI.

$$Q = U \times A \times \Delta T \dots \dots \dots (1)$$

TABLE VI ENVELOPE U-VALUES USED FOR INSULATION RETROFIT

Component	Baseline U-value (W/m ² ·K)	Insulated U-value (W/m ² ·K)
External wall	1.80	0.80
Roof	2.50	1.00

7. *Appliance Electricity Load Estimation:* For the estimation of the baseline electricity demand of the household, an appliance-level load calculation was carried out. The calculation was done by using the rated power of the appliances, the number of appliances, and their average operating hours. The monthly electricity demand was estimated by converting the connected load to kWh and then multiplying it by the total operating hours in a month. The baseline appliance stock and the associated monthly energy demand are presented in Table VII. By using this approach, the baseline electricity demand of the case study house was estimated to be 539.24 kWh/month.

The load can be found by the formula given below

$$E_{month} = \sum_{i=1}^n \left(\frac{P_i \times N_i \times h_i \times D}{1000} \right) \dots \dots \dots (2)$$

Where,

P_i = kWh per hour (or kW) of appliance i

N_i = number of appliances

h_i = hours/day

D = days/month

TABLE VII LOAD CALCULATION PER MONTH

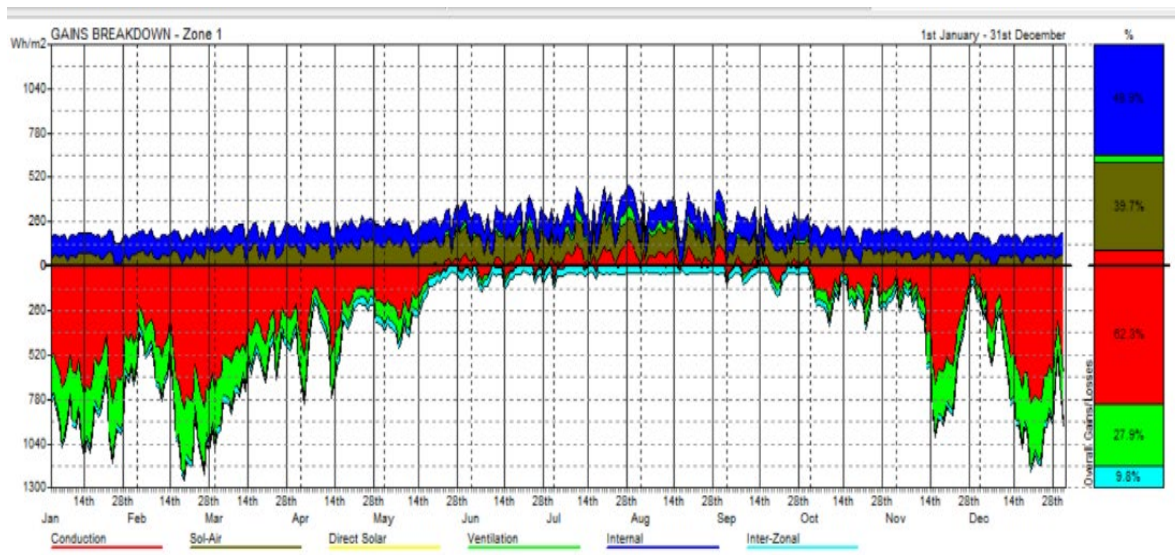
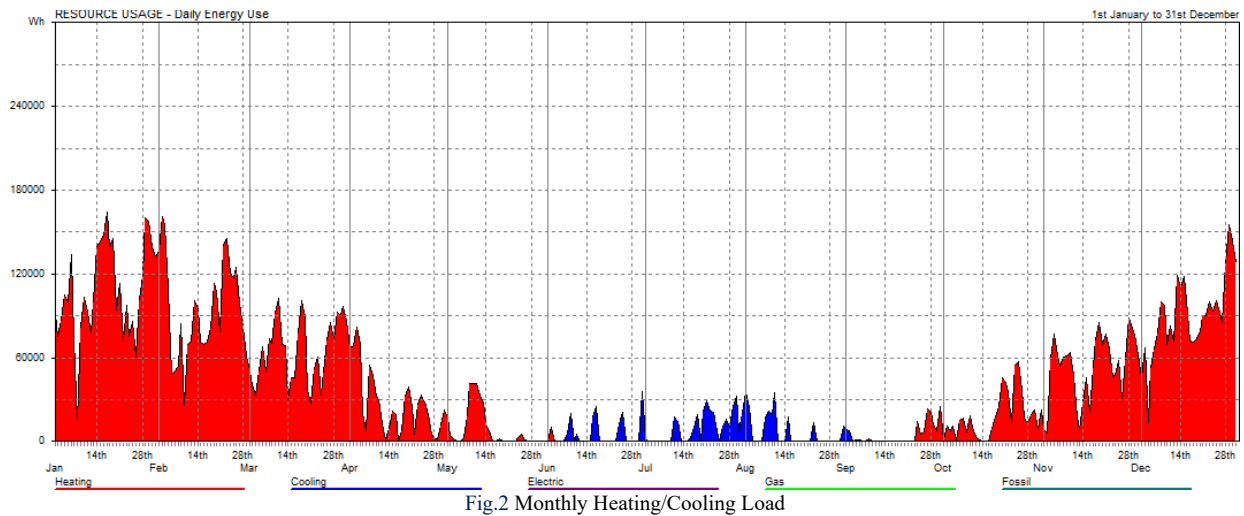
Equipment	No. of equipment	Unit per(kWh)	Numbers of hours per day	Total units (kWh)	Total units per month
Fans	4	0.3	8	2.4	74.4
Bulb	8	0.288	4	1.152	34.56
Pump	1	0.9	2	1.8	55.8
Ac (1.5) ton	1	2	5	10	310
Fridge	1	0.26	8	2.08	64.48
Total	13	3.748	29	27.8	539.24

III. RESULTS AND DISCUSSION

A. Baseline Thermal Performance

The baseline simulation was carried out to assess the annual thermal performance of the residential case study building. The outcome of the simulation reveals that the building is cooling-dominated, with a substantial increase in cooling

demand during the warm season, while the heating demand is negligible. Analysis of solar access and solar radiation indicates that the roof and solar-facing sides receive the highest amount of solar radiation throughout the year, which indicates that envelope heat gain is a significant factor in cooling demand in the baseline case. This is an important aspect that shows the need for retrofits that can minimize roof heat gain.



Breakdown of passive gains: This further verifies that solar gains from glazing and conduction from the building envelope are significant contributors to indoor heat accumulation. Indoor temperature mapping also reveals that the baseline indoor condition regularly surpasses comfort thresholds during hot periods, thus establishing that conventional residential construction in Karachi is not capable of sustaining thermal comfort without the use of mechanical cooling.

B. Envelope Retrofit Performance

Envelope retrofit options were assessed to mitigate solar-driven heat gains and conductive heat transfer by means of the building envelope. The retrofit options considered were

glazing upgrades, roof retrofits, and exterior reflective coatings. The retrofit efficiency was determined by comparing the annual and monthly thermal loads, passive gains contribution, and solar exposure factors to the baseline scenario.

The baseline solar analysis shows that the roof and solar-facing walls receive a large amount of incident radiation, thus verifying that the building envelope is a major contributor to the increase in cooling load. This is shown in Figure 4, where the surfaces of the building envelope that receive the maximum amount of solar radiation are prominently identified. This result justifies the use of roof retrofit strategies like insulation improvement, green roofs, and cool roofs.

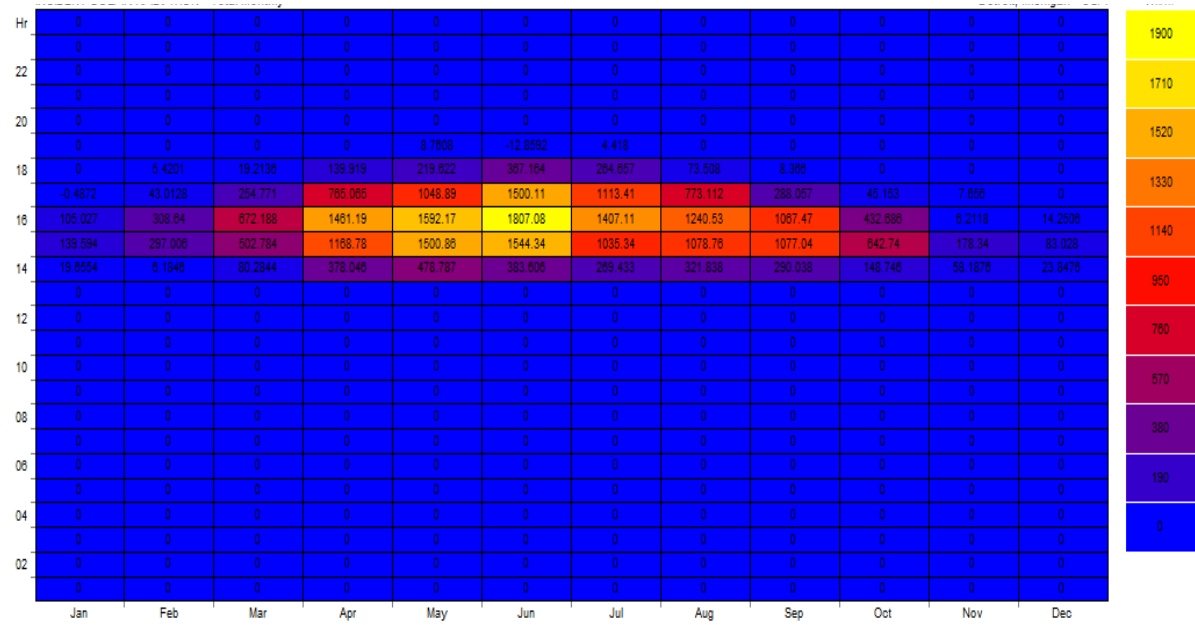


Fig.4 Annual Incident Solar Radiation Distribution

1. Double Glazing: The glazing replacement action had the most straightforward impact out of all the envelope actions. This is because the baseline single glazing was replaced with the tinted argon double glazing with solar control film, thus reducing the solar transmission factor of windows and the overall thermal load. The monthly heating and cooling load difference before and after the glazing retrofit action is shown in Figure 5, which clearly shows the reduction in cooling loads during the warmer months. The glazing retrofit action showed a 12.17% reduction in the annual thermal loads. To

understand the implications of this thermal enhancement, the analysis of passive gains breakdown was carried out for the modified envelope scenario. Figure 6 illustrates the impact of the retrofit action on the distribution of heat gain, which reveals a decrease in the solar and conduction gains. This verifies that the main effect of envelope modifications is to decrease cooling loads by reducing the solar gain through glazing and conduction gain through the roof and external walls.

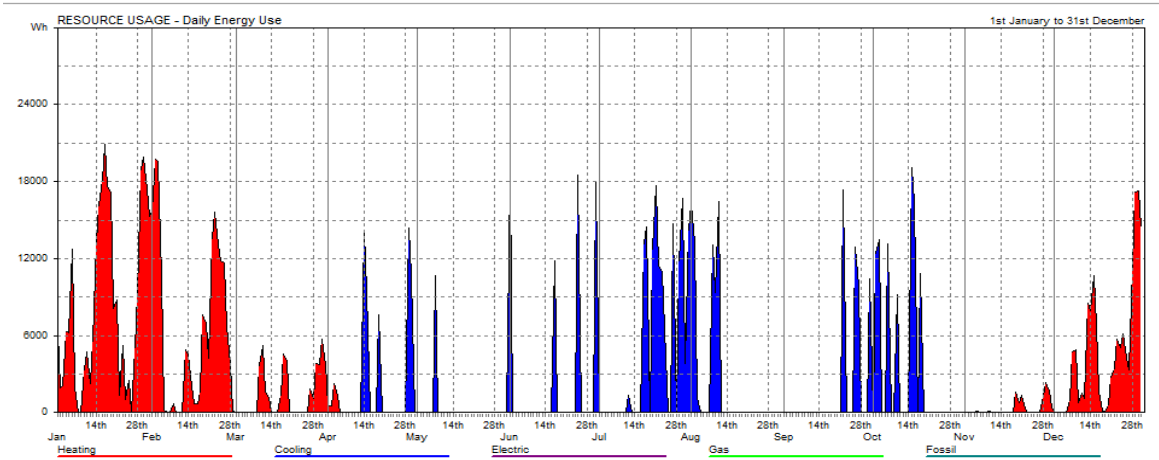


Fig.5 Reduction in Monthly Heating/Cooling Load Requirements After Modification

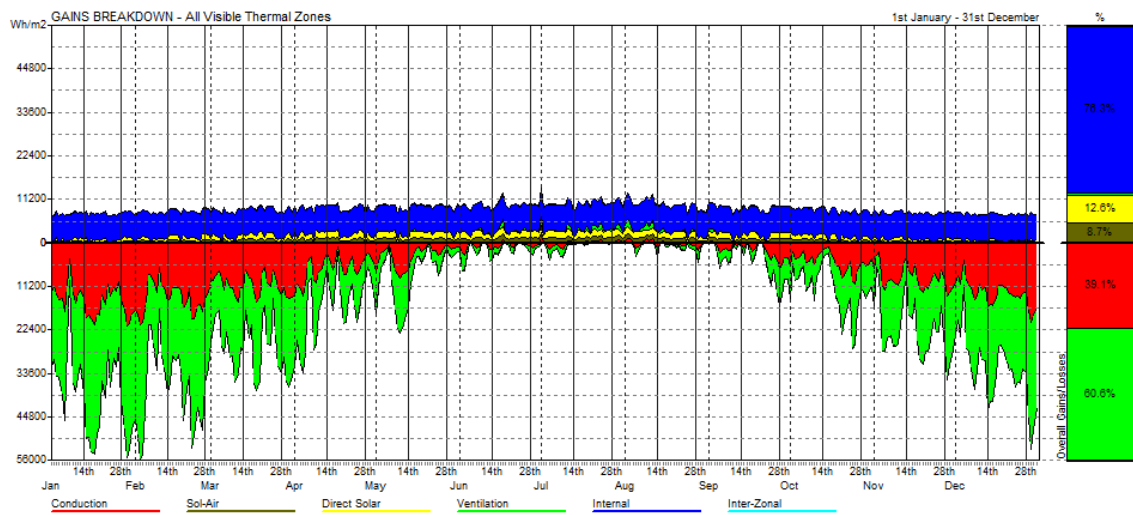


Fig.6 Passive Gains Breakdown Analysis After Modification

2. *Reflective Coating Retrofit Performance:* Figure 7 compares the rate of normalized cooling for the baseline scenario and the reflective coating retrofit scenarios. The data indicates that as the reflectance value increases, the cooling intensity decreases, with the highest cooling intensity reduction realized during the peak summer months. Among the scenarios considered, the greatest reduction was realized in the 61% reflectance coating, thus validating the effectiveness of reflective coatings as a low-cost retrofit measure for Karachi’s climate.

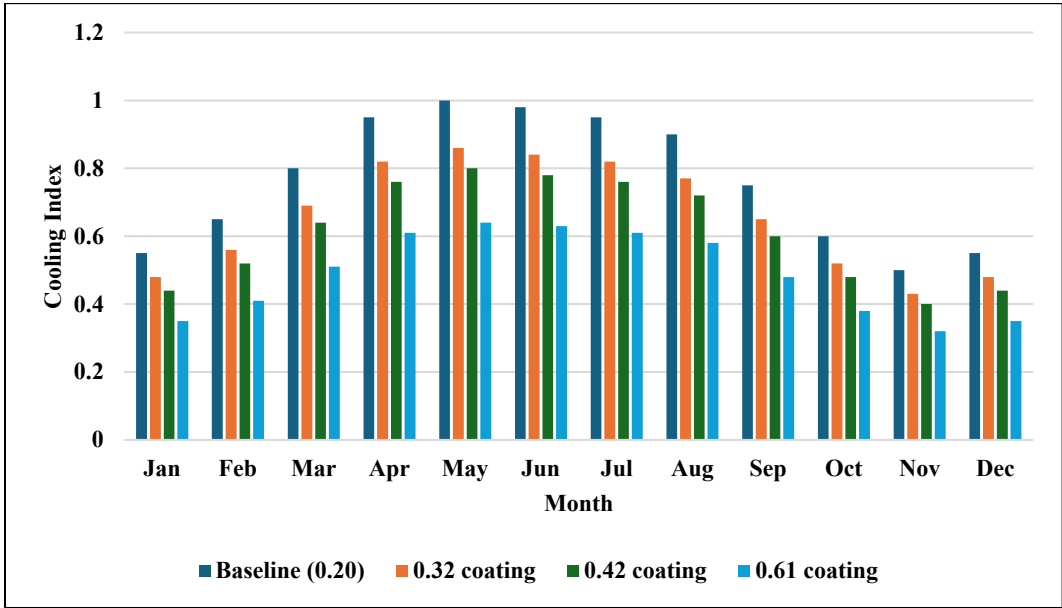


Fig.7 Monthly Normalized Cooling Index for Reflective Coating Retrofit Cases

3. *Indirect Radiant Cooling Performance:* Figure 8 shows the indoor temperature pattern after the indirect radiant cooling retrofit. The results show enhanced cooling at night and lower indoor temperatures during hot periods. This is an indication that the indirect radiant cooling technique is effective in passive cooling strategies, especially when combined with envelope retrofits that minimize solar gains during hot periods.

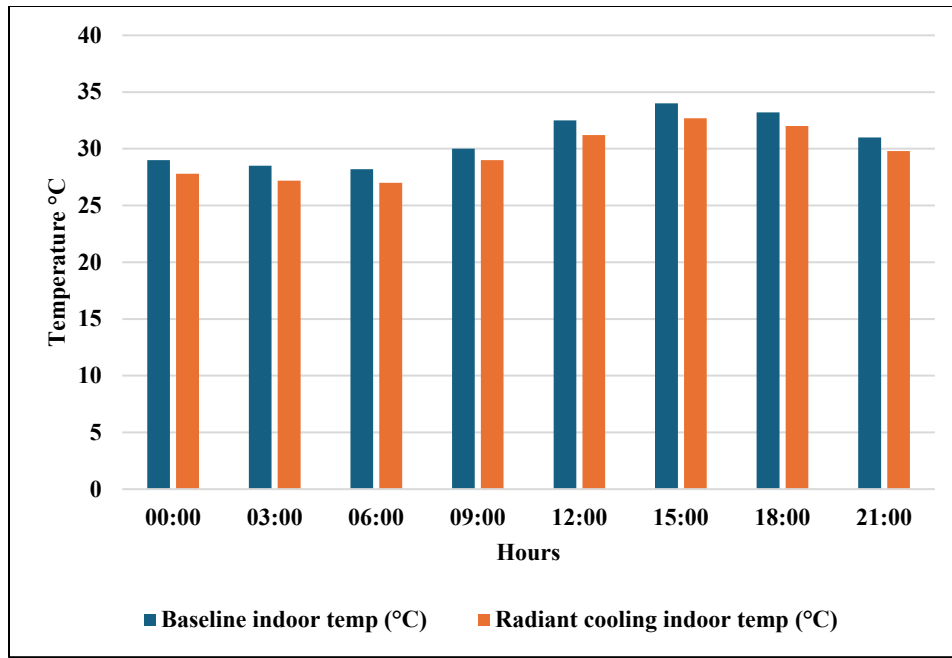


Fig.8 Indoor Temperature Profile Comparison for Baseline and Indirect Radiant Cooling

4. *Green Roof Retrofit Performance:* Table VIII illustrates the roof conduction heat gain for the baseline roof and the green roof retrofit scenario. The outcome indicates that the green roof significantly reduces roof-driven heat gain. In the baseline scenario, roof conduction heat gain was 6000 W,

which reduced to 1440 W, indicating a reduction of 76.0% after the implementation of the green roof retrofit. This verifies that roof-level measures are very effective in Karachi because of the high roof solar exposure and summer overheating periods.

TABLE VIII ROOF CONDUCTION HEAT GAIN COMPARISON FOR BASELINE AND GREEN ROOF RETROFIT CASES

Case	Roof area (m ²)	Roof U-value (W/m ² ·K)	Roof conduction gain (W)
Baseline roof	240	2.50	6000
Green roof	240	0.60	1440

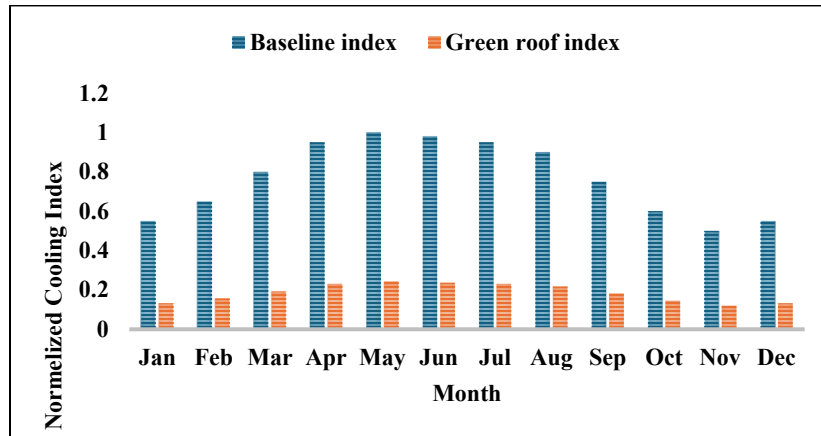


Fig.9 Monthly Normalized Cooling Trend for Baseline and Green Roof Cases

$$\text{Green Roof Ratio} = \left(\frac{1440}{6000} \right) = 0.24$$

Figure 9 shows the normalized cooling trend for the baseline roof and the green roof retrofit scenario. The baseline roof has a higher cooling intensity during the warm season, with the highest intensity ranging from April to August. However, after the green roof retrofit, the cooling intensity is reduced

in all months, with the highest reduction during the peak summer months. This verifies that green roofs are most effective in the Karachi climate, as they can reduce roof-generated heat gain by suppressing solar absorption and enhancing roof thermal resistance during the peak summer months.

5. Insulation Retrofit Performance: The insulation retrofit resulted in a reduction in conductive heat gain in the building envelope. From the envelope heat transfer comparison, the total conduction heat gain in the walls and roof was reduced from 11,760 W in the baseline case to 4,960 W after the insulation retrofit. This is an approximate reduction of 57.8%, thus verifying that insulation is an effective passive retrofit technique for residential buildings in Karachi, especially during the peak summer months.

$$\eta = \left(\frac{Q_{base} - Q_{ins}}{Q_{base}} \right) \times 100 \quad (3)$$

Figure 10 illustrates the comparison of envelope conduction heat gain for the baseline scenario and the insulation retrofit scenario. The outcome indicates that a reduction in the envelope U-values is effective in minimizing heat gain due to conduction in walls and roofs. In the baseline scenario, the total heat gain due to conduction in walls and roofs was 11,760 W, with values of 5760 W and 6000 W, respectively. However, after the insulation retrofit, the heat gain due to conduction in walls and roofs was reduced to 4960 W, with values of 2560 W and 2400 W, respectively. This indicates a reduction of approximately 57.8%, thus verifying that insulation is an effective retrofit measure for minimizing envelope cooling loads in Karachi.

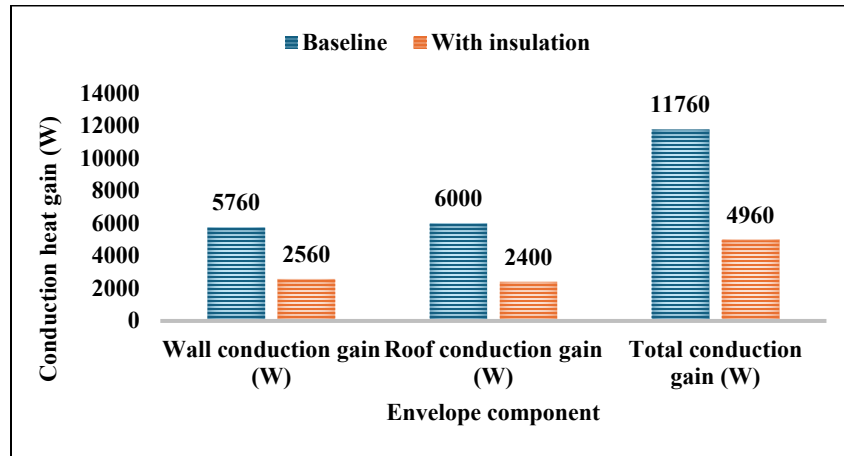


Fig.10 Comparison of Envelope Conduction Heat Gain for Baseline and Insulated Cases

Figure 11 below shows the monthly normalized cooling trend for the baseline and insulation retrofit scenarios. It is evident that the baseline cooling trend has a higher cooling intensity during the warm season, with maximum cooling intensity between April and August, which matches the climatic conditions of Karachi. After the insulation retrofit, the

normalized cooling index reduces in all months, with the most significant reduction during the peak summer months when the envelope heat gain is at its maximum. This indicates that the insulation retrofit mainly reduces the conduction heat transfer through the roof and external walls.

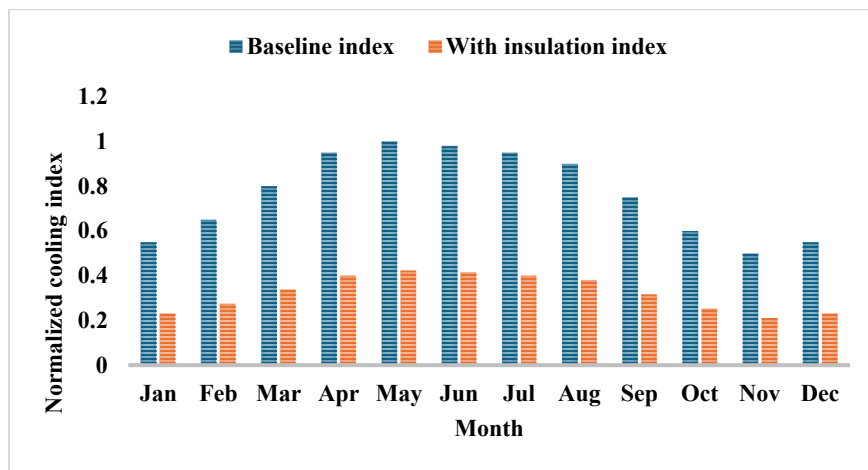


Fig.11 Monthly Normalized Cooling Trend for Baseline and Insulated Cases

C. Passive Cooling Performance

Passive cooling strategies were considered to minimize the increase in indoor temperature and enhance thermal comfort

without increasing the demand for mechanical cooling. The strategies considered aimed at optimizing natural ventilation performance and night-time heat rejection, which is important for residential buildings in Karachi, where the

cooling demand is influenced by both high outdoor temperatures and solar gains. Natural ventilation optimization was considered through the integration of wind catchers and optimization of cross ventilation. The strategies were considered to enhance air movement within the occupied space and minimize indoor temperature during periods when outdoor conditions are favorable. The initial analysis of ventilation gain revealed that ventilation has a positive effect on the building thermal balance and can either increase or decrease indoor heat depending on outdoor temperature conditions.

Apart from the strategies that utilize ventilation, the concept of indirect nocturnal radiant cooling was also proposed as a passive means of rejecting stored heat during night-time. This technique is expected to cool the air cavity at roof level by means of long-wave radiative cooling to the sky and to transfer the cooling potential to the indoor space. The efficacy of this technique is indicated by the results of indoor temperature profile simulation, which show decreased indoor temperature peaks and enhanced night-time cooling performance following the application of passive cooling modifications.

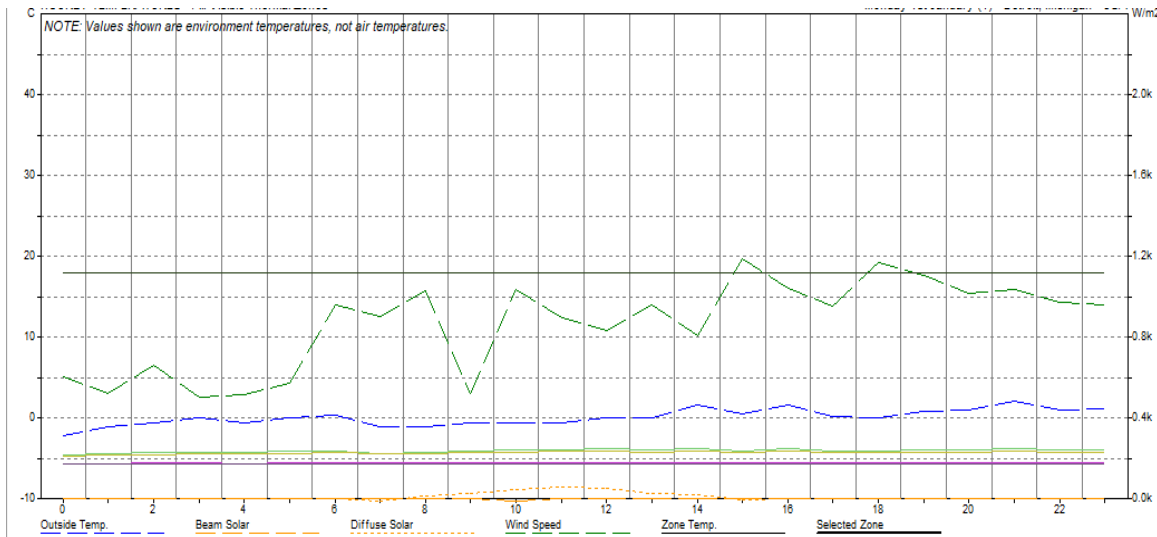


Fig.12 Indoor Temperature Profile Comparison

Regarding the results of passive cooling, it is found that ventilation augmentation and night cooling techniques are complementary to envelope retrofits in terms of enhancing comfort conditions indoors, which can be achieved by insulation and glazing retrofits only to a certain extent. Such techniques are very useful in the case of residential buildings, where low-cost solutions can be effectively utilized for improving comfort conditions in combination with envelope heat gain reduction techniques.

D. Appliance Electricity Savings

Apart from envelope and passive cooling retrofits, appliance-level efficiency enhancement was also considered for the evaluation of operational electricity savings at the household scale. The baseline electricity consumption was determined using the appliance load estimation technique outlined in Section 2, yielding a monthly electricity demand of 539.24 kWh/month. The baseline outcome shows that air-conditioning is the major contributor to monthly electricity demand, followed by lighting, fans, refrigeration, and water pumping.

TABLE IX ENERGY CONSUMPTION PER MONTH AFTER IMPROVEMENT

Equipment's	No. of equipment	Unit/(kWh)	Numbers of hours per day	Total units (kWh)	Total units per month
Fans	4	0.3	6	2.4	65
LED	8	0.288	4	1.152	20
Pump	1	0.9	2	1.8	40
AC (1.5 ton)	1	2	5	10	210
Fridge	1	0.26	8	2.08	55
Total	13	3.748	29	27.8	390

Appliance retrofits were carried out by replacing existing appliances with energy-efficient models of the same comfort and service level. The retrofits included the replacement of

existing tube lights with LED lighting, the replacement of an existing conventional 1.5-ton air conditioner with a DC inverter model, the replacement of an old refrigerator with a

more efficient star-rated model, and the replacement of an existing AC pump with a DC pump. Following the implementation of these retrofits, the monthly electricity demand was lowered to 390 kWh/month. This indicates a net

savings of approximately 149 kWh/month, or a decrease of about 27.6% in household electricity demand.

$$\Delta E = 539.24 - 390 \approx 149 \text{ kWh/month}$$

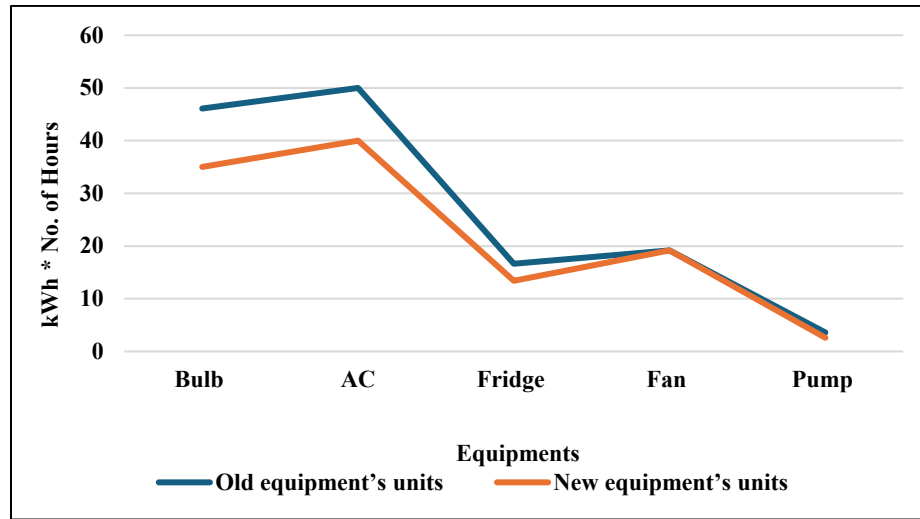


Fig.13 Comparison of Old and New Equipment

E. Solar and Ventilation Gain Analysis

To gain a better insight into the major mechanisms that contribute to cooling demand in the case study building, solar gain and ventilation gain analyses were carried out using Autodesk Ecotect. These analyses help to explain the physical reasons for choosing the proposed retrofit solutions by identifying the main sources of heat gain in the Karachi climate. The results of solar access and incident radiation analyses reveal that the roof and solar-facing façades receive

the maximum amount of solar exposure throughout the year, thereby validating the fact that solar-driven envelope heat gain is a significant factor in indoor temperature increase and cooling loads. This is evident from Figure 14, which clearly indicates the envelope areas that receive the maximum amount of solar exposure. The results reveal that roof-based retrofit measures, including insulation improvement, green roofs, and reflective coatings, are expected to offer substantial cooling load benefits.

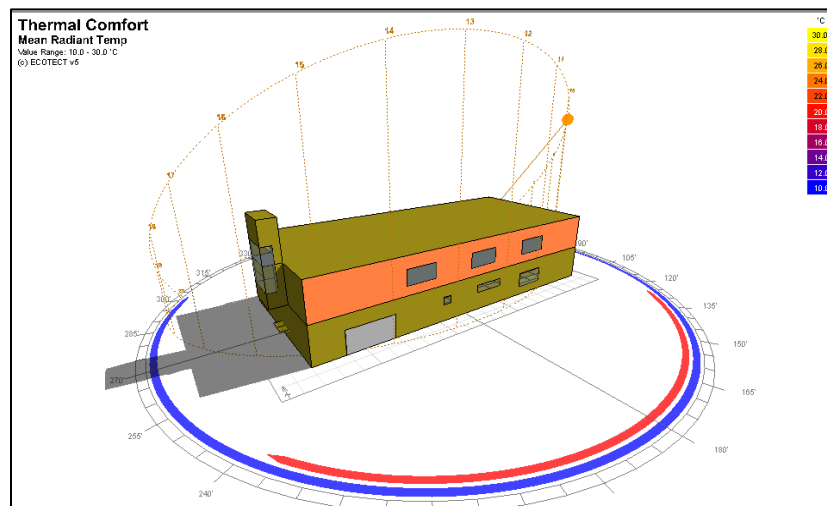


Fig.14 Building Solar Access Analysis

Apart from external envelope exposure, an indirect solar radiation gain analysis was also carried out to assess solar heat gain through glazing. The results reveal that windows do contribute substantially to indoor heat gain, especially during

summer periods when solar intensity is high. This validates the effectiveness of glazing retrofits discussed in Section III, which indicated that double glazing with solar control film resulted in a 12.17% reduction in annual thermal loads.

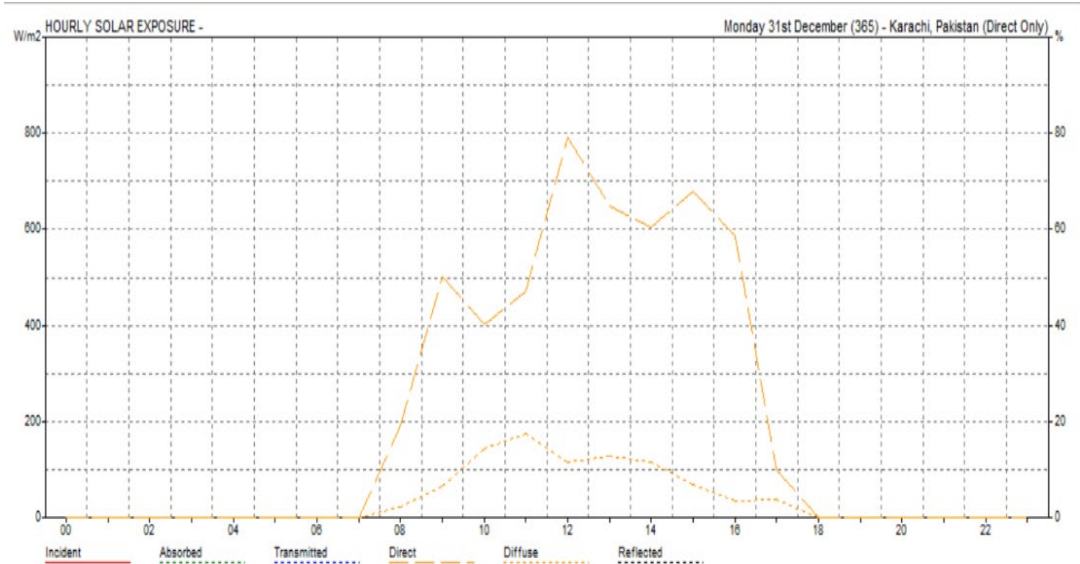


Fig.15 Monthly Solar Radiation Access

Analysis of ventilation gain was also performed to understand the effect of air exchange on indoor conditions. The analysis results show that ventilation results in indoor heat gain when the outdoor temperature is higher than the indoor temperature, and ventilation can be a cooling source when the outdoor conditions are favorable, such as in the evening or during transition periods. This further supports the use of passive strategies such as wind catchers and cross ventilation to reduce indoor temperatures without the use of air conditioning.

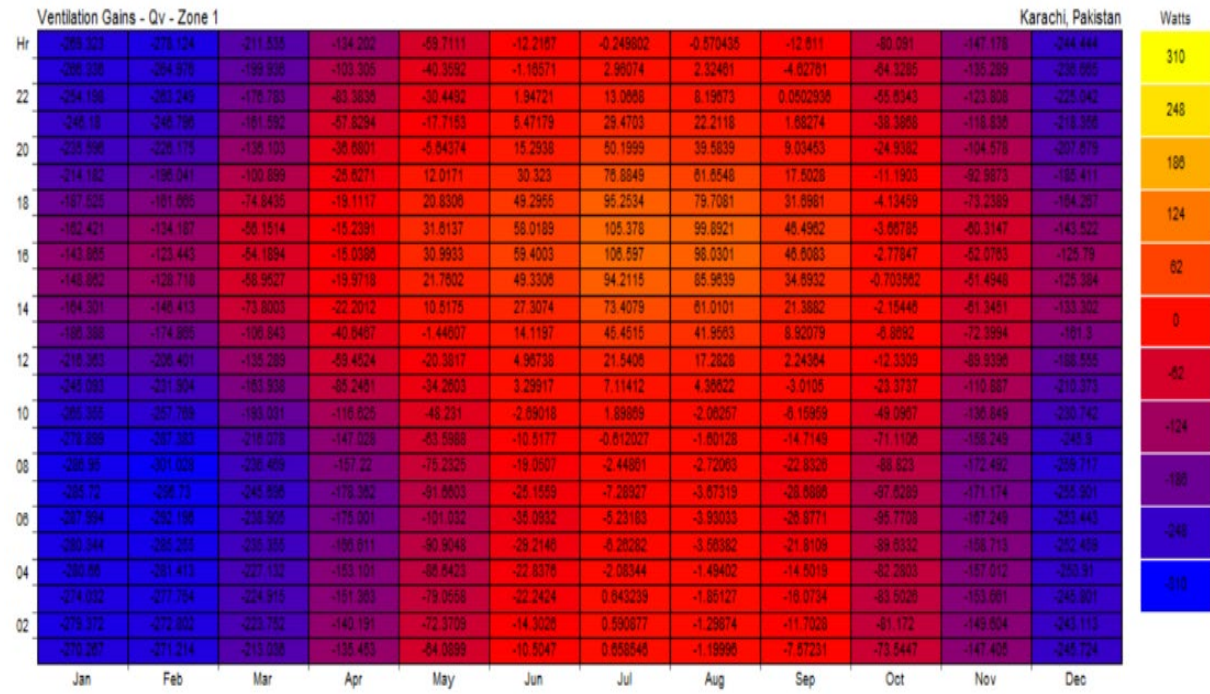


Fig.16 Ventilation Gain Analysis Chart

IV. CONCLUSION

The simulation-based energy retrofit analysis of the double-storey residential building in Karachi, Pakistan, carried out using Autodesk Ecotect, for the period of 1 January 2025 to 31 December 2025, has been presented in this study. The baseline analysis has validated that the existing building structure, designed without the aid of performance-driven thermal design, has high cooling-driven heat gains due to

high solar exposure, inefficient glazing, and conduction through the roof and external walls. The solar and ventilation gain analysis has also shown that solar heat gain on the roof and ventilation gains are major contributors to indoor overheating. A number of passive retrofit options were considered to lower thermal loads and enhance indoor comfort. Glazing retrofit with tinted argon-filled double glazing with solar control film showed a noticeable effect, which lowered annual thermal loads by 12.17% as compared

to the base case. Envelope insulation retrofitting showed a substantial reduction in conduction heat transfer, lowering total envelope conduction heat gain from 11,760 W in the base case to 4,960 W, which is an overall reduction of approximately 57.8%. Green roof retrofitting also lowered roof conduction heat gain from 6,000 W to 1,440 W, which is a reduction of 76.0%, thus proving that roof-level measures are highly effective in the Karachi climate because of the prolonged solar exposure. Apart from the envelope and passive cooling techniques, the appliance-level retrofits also resulted in significant electricity savings. The baseline residential electricity demand was estimated to be 539.24 kWh/month, whereas after the replacement of conventional appliances with efficient ones, the monthly electricity demand reduced to 390 kWh/month. This indicates a reduction of 149 kWh/month, which is approximately 27.6% of the residential electricity demand. The findings from the study clearly indicate that a combination of envelope retrofits (glazing, insulation, and roof retrofits) with passive cooling techniques and appliance retrofits can form a viable retrofit strategy for the reduction of cooling-related electricity demand in residential buildings in Pakistan.

Declaration of Conflicting Interests

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Use of Artificial Intelligence (AI)-Assisted Technology for Manuscript Preparation

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