Adv. Energy Sci. Technol., 2(1) (2026) 1-25

Advances in Energy Science and Technology

AEST

Amirkabir University of Technology

Integrated passive active design towards Net Zero Energy Building (NZEB): A life cycle and circularity perspective

MohammadReza Mehdizade Marzebali [a], Masoumeh Mohamadian [a, *], Masoumeh Bararzadeh Ledari [b]

[a] Department of Energy Engineering and Physics, Amirkabir University of Technology

[b] Department of Energy Engineering, Sharif University of Technology

Keywords

Net Zero Energy Buildings
Phase Change Materials
Life Cycle Assessment
Photovoltaic
Green Roof
Circularity

Article Info

DOI:10.22060/aest.2026.25901.1007

Received date 22 May 2026

Revised date 19 June 2026

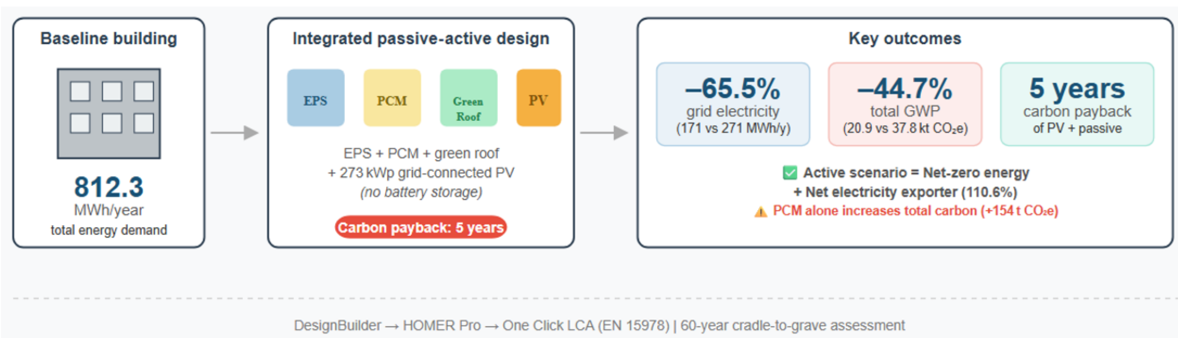
Accepted date 21 June 2026

* **Corresponding author:**
mohamadian@aut.ac.ir

Abstract

This study investigates the life cycle environmental performance of a large office building (11,400 m²) in Tehran's semi arid climate towards NZEB. A sequential simulation framework is developed: DesignBuilder for passive optimization (EPS insulation, PCM, multi layer green roof) and HOMER Pro for a 273 kWp grid connected PV system without battery storage. A cradle to grave LCA (One Click LCA, EN 15978) and circularity assessment are performed over a 60 year service life. The best passive configuration reduces total energy demand by 11.8%. Adding PV cuts annual grid electricity purchase by 65.5% (from 271.1 to 171.2 MWh), making the building a net electricity exporter (110.6% annual penetration). Although the active scenario increases embodied carbon by 16% (from 6,887 to 7,990 t CO_2e), it lowers operational carbon by 58.7% (from 30,871 to 12,755 t CO_2e), resulting in a 44.7% lower total life cycle GWP (20,902 vs. 37,758 t CO_2e). The carbon payback of the full passive active package is only 5 years. A negative trade off for PCM is observed (+154 t total carbon vs. EPS only), and circularity improves from 11.5% to 13% material return to cycle. The proposed battery less passive active framework demonstrates a fast repaying, low carbon NZEB pathway suitable for developing countries with unstable grids. The findings also caution against using PCM in climates where EPS already provides effective insulation.

Graphical Abstract



Journal homepage: https://aest.aut.ac.ir/
E-ISSN: 3115-9117

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

1. Introduction

Reducing energy consumption in buildings plays a central role in achieving sustainability goals and transitioning towards Net Zero Energy Buildings (NZEBs) [1]. Among the various approaches explored, passive and active energy strategies are widely recognized as essential and complementary components of building energy optimization [2]. Passive design strategies aim to reduce energy demand through architectural features and environmental responsiveness [3], whereas active systems contribute to energy generation, distribution, and intelligent control [4]. Passive strategies are often the starting point in designing energy-efficient buildings due to their ability to reduce reliance on mechanical systems [5]. Building orientation and form can be optimized to maximize solar heat gain during winter and minimize it during summer, leading to substantial reductions in heating and cooling demand [2]. Enhanced insulation and high-performance building envelopes help reduce heat transfer, thereby improving thermal comfort and lowering energy consumption [6]. Natural ventilation techniques, including cross ventilation and stack effect, are utilized to improve indoor air quality and minimize the need for mechanical ventilation. Hybrid ventilation systems, combining natural and mechanical methods, have demonstrated the potential to significantly reduce primary energy use, as shown in the study by Abdeen Mustafa Omer [7]. The strategic use of shading devices such as overhangs, louvers, and blinds helps prevent overheating and reduces cooling loads up to 7% [8]. Moreover, passive cooling strategies, including earth-to-air heat exchangers, thermal chimneys, and wind catchers, contribute to maintaining indoor comfort conditions without additional energy input [6]. Eghtedari and Mahravan [9] evaluated a hybrid passive cooling system using simulation tools, showing that fossil fuel consumption and environmental impact can be significantly reduced. Falegari and Shirzadi Javid [10] also highlighted the importance of local climate adaptation in passive strategies, achieving up to 30% energy demand reduction and 28% operational energy savings.

While passive design forms the foundation of building energy performance, active solutions are necessary for addressing remaining energy needs, particularly in dense urban settings and high-performance buildings. The integration of photovoltaic (PV) systems, whether rooftop-mounted or building-integrated, enables buildings to produce renewable electricity on-site [11]. In many cases, such systems can cover between 16-81 % of a building's total energy consumption [12]. Solar thermal collectors contribute to hot water supply and space heating, particularly in residential buildings. Heat pumps, including air-source and ground-source variants, are increasingly adopted due to their high efficiency and alignment with decarbonization goals [13]. Battery energy storage systems (BESS) and thermal energy storage systems (TESS) help balance supply and demand by shifting load from peak to off-peak periods and increasing renewable self-consumption [14]. Kaspar et al. [15] successfully used such systems to reduce peak loads and capture excess renewable energy. Yu [16] proposed advanced sizing and dispatch methods for BESS and TESS in office buildings, resulting in improved energy efficiency and reduced greenhouse gas emissions. Building Energy Management Systems (BEMS) support the coordination and real-time optimization of building operations [14]. The integration of hydrogen storage and fuel cells adds resilience, especially for managing seasonal energy variability, as discussed by Mehrjerdi et al. [17] and Bellos et al. [18].

The combination of passive and active strategies is increasingly viewed as the most effective path to achieving NZEB status. Studies such as those by Ciardiello et al. [19] have applied genetic algorithms and dynamic energy simulations to identify the best combination of retrofit measures. Christopher et al. [20] emphasized the importance of optimized combinations of technologies based on energy generation, emissions reduction, and payback period. Zhang et al. [21]

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

explored the integration of thermal and electrical storage, highlighting the value of phase change materials (PCM) for thermal regulation. Simulation results support that combining building envelope improvements with renewable generation and intelligent control systems leads to enhanced energy performance and reduced environmental impact. An important factor influencing the selection and effectiveness of both passive and active strategies is the building typology, whether the building is residential, office, or commercial. Residential buildings, with their irregular occupancy patterns and relatively low internal loads, benefit significantly from passive design approaches such as insulation, natural ventilation, and orientation-based solar gain. Rooftop photovoltaics are also more feasible in single-family dwellings, enabling higher self-sufficiency. In contrast, commercial buildings often have dense internal loads, consistent occupancy, and significant lighting and equipment use, making active strategies such as energy storage, advanced HVAC control, and BEMS more impactful. Office buildings, with predictable daytime occupancy, represent a hybrid case where both passive measures like dynamic shading and active systems such as PV-battery setups show strong performance. Studies by Guo and Saelens [22], Yu [16], and Tumminia et al. [23] have highlighted how energy optimization approaches must be tailored to the specific usage patterns of different building types to maximize energy savings and cost-effectiveness. Moreover, life cycle environmental impacts and system sizing requirements vary significantly by building typology, suggesting that no one-size-fits-all solution exists. A more typology-sensitive design approach is therefore essential to guide future implementations.

Evaluating the long-term environmental impacts of building energy strategies is increasingly performed through Life Cycle Assessment (LCA). This method accounts for the environmental burdens associated with all phases of a building's life, from material extraction and construction to operation and end-of-life [24]. Palumbo [25] and Hossameldin Kamel [26] emphasized the value of LCA in understanding the full environmental profile of buildings. Research shows that in NZEBs, the operational phase contributes less to overall impacts than embodied emissions, underscoring the importance of material selection and construction processes [27]. Prideaux et al. [28] used LCA to evaluate both operational and embodied impacts, highlighting the trade-offs in sustainable design. Tools like OneClick LCA support early design decision-making with reliable impact estimation. Raugei et al. [29] conducted a comparative LCA on photovoltaic systems, demonstrating environmental benefits over conventional energy supply systems. Nevertheless, studies such as Vuarnoz [30] and Hottenroth et al. [31] show that energy storage technologies (especially lithium-ion batteries) can introduce significant environmental impacts through their manufacturing and end-of-life phases. Li et al. [32] identified that compressed air energy storage (CAES) systems may offer better environmental performance under certain renewable-based scenarios.

The novelty of this study lies in the integrated life cycle assessment of a battery-less net-zero energy building (NZEB) in Tehran's semi-arid climate, where a full combination of three passive strategies (EPS insulation, PCM with a melting point of 23 °C, and a multi-layer green roof) is coupled with a 273 kWp grid-connected photovoltaic system without any battery storage. Unlike previous works that examine EPS, PCM, or green roofs in isolation or focus solely on residential buildings, this research quantifies the synergistic effect of all three passive measures on reducing heating and cooling demand in a large office building (11,400 m²). Moreover, while most NZEB studies rely on battery storage to increase renewable self-consumption, this work deliberately adopts a battery-less strategy to avoid storage-related embodied carbon and energy losses. The study goes beyond conventional energy analysis by providing a full cradle-to-grave LCA (One Click LCA, EN 15978) over 60 years, including a detailed circularity assessment with country-specific recycling rates and material wastage factors. The most striking finding is a carbon payback period of only 5 years for the entire passive plus active package, which is exceptionally short for an NZEB in a developing country context. Additionally, the research reveals a negative

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

trade-off for PCM when added to an already well-insulated building (EPS only), showing that PCM increases total life cycle carbon by 154 t, a critical insight for material selection in similar climates. The sequential simulation approach (DesignBuilder for passive optimization followed by HOMER Pro for grid-interactive PV sizing) provides a practical, replicable methodology that balances energy performance, life cycle carbon, and circularity, making it directly applicable to other office buildings in regions with unstable electricity grids.

2. Materials and Methods

The pathway to net-zero energy in buildings involves a combination of passive and active strategies to minimize energy demand while utilizing renewable sources. EPS insulation reduces heat transfer, improving thermal efficiency, while PCM stores and releases thermal energy to regulate indoor temperatures. A green roof provides natural insulation and limits heat absorption, enhancing thermal comfort. To fully achieve net-zero energy, solar photovoltaic panels are integrated to generate electricity, ensuring that the remaining energy needs are met through renewable sources, ultimately balancing the building's energy consumption and production (**Fig. 1**). So, the active scenario integrates rooftop PV systems modeled in HOMER Pro, using hourly load data extracted from the final passive configuration. The system is grid-connected without storage, where surplus energy is exported, and deficits are supplemented by grid supply.

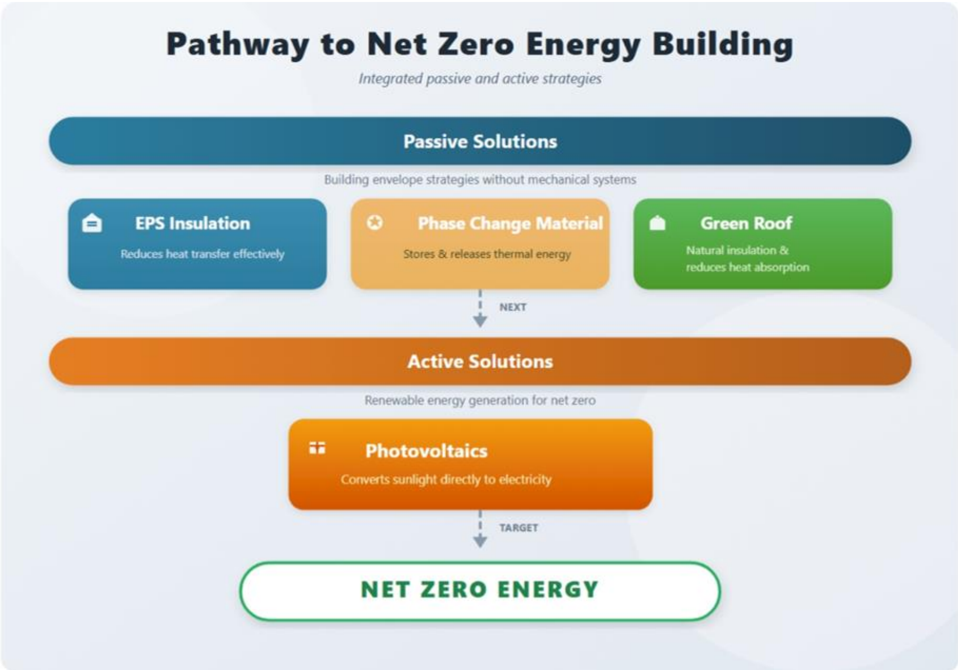


Fig. 1. Net Zero energy pathways in this study.

2.1. Case Study

This research focuses on a large office building located in Tehran's semi-arid climate. The building has a gross floor area of approximately 11,400 m², with two underground and six above-ground floors, totaling nine roofs. Its dimensions are 29.4 m in width, 49.56 m in length, and 31.86 m in height. The building hosts over 500 students and 27 faculty members, though not simultaneously. Given Iran's deepening energy imbalance, there is an urgent need to develop grid-independent buildings [33]. Such buildings reduce reliance on unstable external energy supplies while minimizing carbon emissions. The ultimate goal is to achieve net-zero energy and carbon performance. Therefore, this study examines how optimizing wall and roof thermal conductivity, based on local climate data, can enhance energy efficiency and support sustainable,

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

low-carbon building strategies. **Fig. 2** shows the real building and its architectural Plan. Also, the full details of the materials are shown in the Appendix part (**Table A1**).

(a) **(b)**

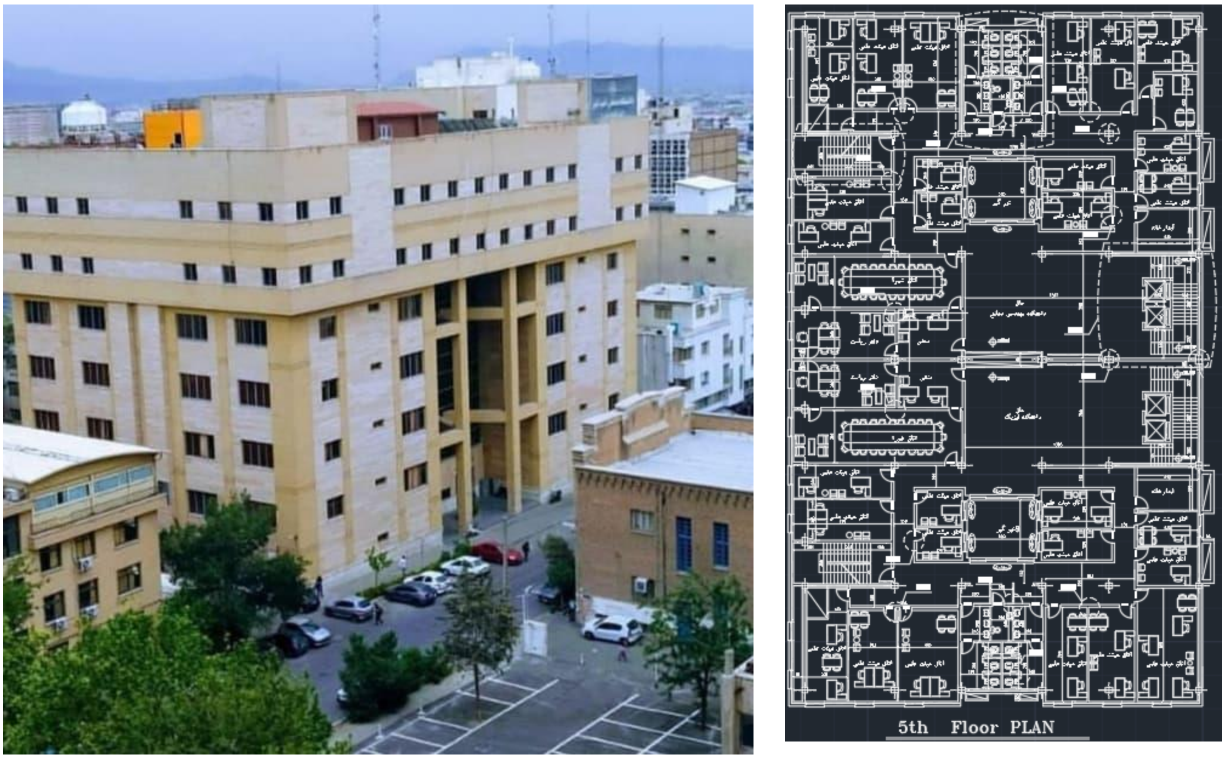
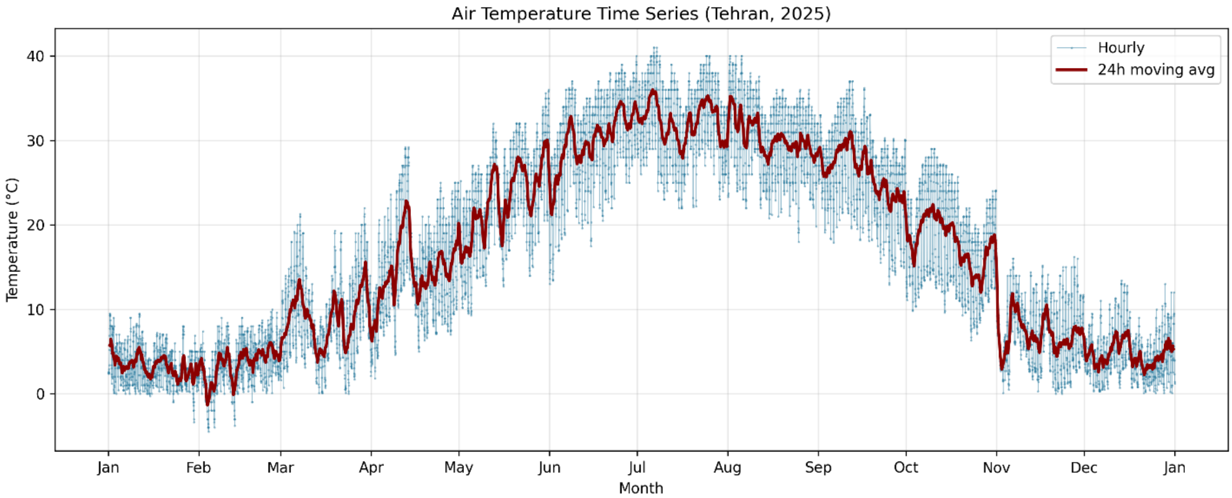


Fig. 2. Department of Industrial and Energy (left) with plan (right).

The model incorporates architectural, thermal, and occupancy parameters, calibrated with local weather data of Tehran to ensure realistic operational profiles. Weather information is a necessary variable that is unique to the building location. The weather data used in this simulation is available on the weather data of this software, which is approved by the producers of this software. **Fig. 3** shows the Temperature, and solar radiation of the Tehran with average of 13.8°C and 202 w/m^2, respectively.

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

(a)



(b)

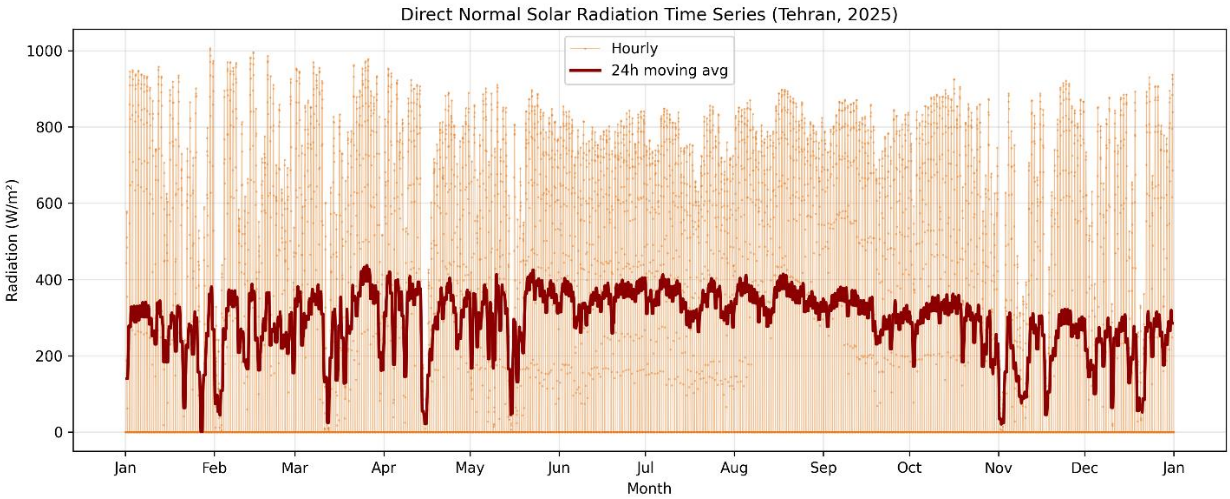


Fig. 3. Different climatic condition in the study area. (a)Temperature, and (b) solar radiation.

2.2. Simulation

DesignBuilder is a user-friendly simulation program that helps analyze a building's energy use [34]. Its visual interface makes it easy to create and view complex building models (**Fig. 4**) [34]. The software uses the EnergyPlus engine to accurately calculate heating, cooling, and overall energy needs [35]. It allows detailed modeling and improvement of HVAC systems [36]. A large materials database helps users assign correct thermal properties [37]. The tool also supports adding solar panels to test renewable energy performance [34]. It compares different design options to find the most efficient one [35] and helps meet standards like LEED and ASHRAE [36]. That is why researchers and professionals use it for sustainable building design.

Advances in Energy Science and Technology

AEST

Amirkabir University of Technology

(a) (b)

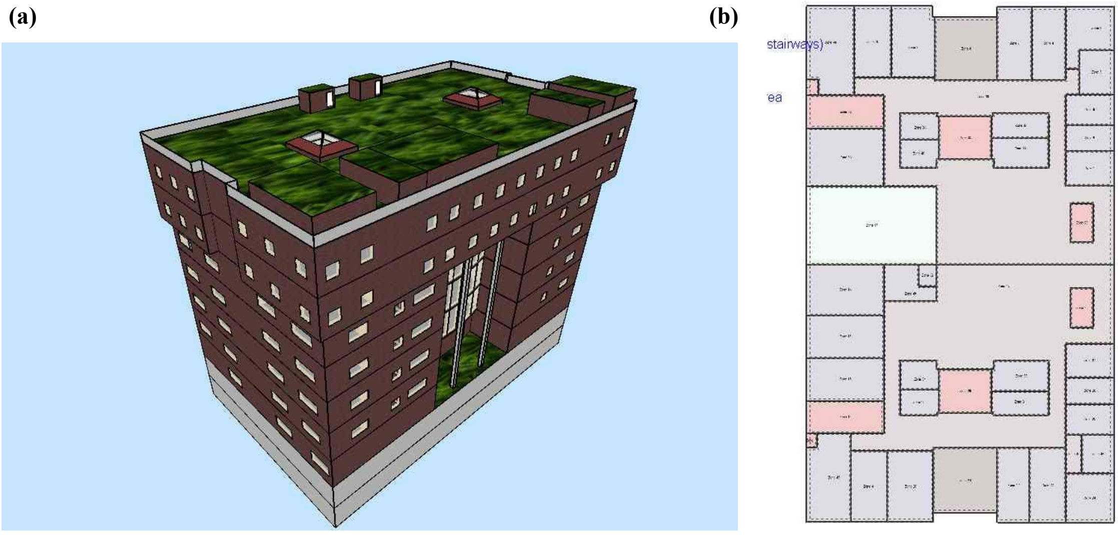


Fig. 4. (a) Green roof schematic in DesignBuilder. (b) Plan of the office buidling.

2.2.1. Validity of the DesignBuilder Simulation

To provide credence to our modelling approach we use the rigorous validation of the DesignBuilder-EnergyPlus platform performed by Fathalian & Kargarsharifabad [38] for an office building in Semnan, Iran that shares a similar semi-arid climate to Tehran. In their actual validation study the authors simulated the annual energy consumption of a 651.34 m² office building and compared it directly against monthly electricity and natural gas billing records. Their simulation yielded an annual energy intensity of 152.4 kWh/m² against an actually measured intensity of 155.73 kWh/m², resulting in an annual discrepancy of less than 1.6% well within the acceptable margin for building performance simulation according to ASHRAE Guideline 14. More importantly for our work, they conducted a supplementary re-validation by physically replacing the single-glazed windows with low-emission double-glazed ones and then comparing the simulated predictions against the actual utility bills after one full year of operation. In that second validation stage the annual difference between the simulated model and the billing values was slightly more than 2.1%, confirming the software's predictive capability for both baseline and retrofit scenarios. Following their exact input protocols, specifically the detailed thermophysical material properties (**Table 1** of their work), the hourly occupancy schedules (7:00 to 16:00 with peak percentages, as per their Table 3) and the natural ventilation assumptions, we are confident that our DesignBuilder model provides a physically sound and sufficiently accurate representation of our larger 11,400 m² case study. We also cross checked our monthly load trends against Tehran's long-term degree-day data, and the seasonal variation pattern closely mirrors the consumption trends reported in their Figure 2, further substantiating the reliability of our baseline model.

2.3. Passive Design

2.3.1. EPS

Expanded Polystyrene (EPS) has significantly improved the structural integrity and design of buildings. Since its establishment as a standard insulating material in the 1950s, EPS has found numerous innovative applications. Presently, it is widely used in various construction projects due to its environmental sustainability, enhanced energy efficiency, durability, and improved indoor air quality [39]. To manage energy consumption effectively, a layer of polystyrene sheet can be installed on the exterior wall of the building under examination. Polystyrene's low thermal conductivity (approximately 0.033 W/m K) allows for considerable annual energy savings when a thin layer of this insulator is applied

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

[38]. **Table 1** shows the characteristic of the selected EPS insulate. Also, the **Table A2** (Appendix) implies this passive strategy between the building envelope layer.

Table 1. Characteristics of EPS.

EPS	Expanded Poly Styrene (Heavy weight)
Conductivity (W/M-K)	0.035
Specific Heat (J/Kg-K)	1400
Density (Kg/M^3)	25

2.3.2. PCM

PCMs are materials that can change phase from liquid to solid and vice versa without changing the temperature. When PCM receives energy in the solid phase, it uses this energy to loosen the intermolecular bonds, and until this energy is equal to the latent energy required for phase change, its solid phase does not turn into a liquid. If the temperature of the environment around the material decreases, PCM, like all other materials, tries to release the energy that it has hidden in itself [40]. PCMs have higher thermal conductivity than other materials, which makes them have a faster energy absorption and release process by creating a lower temperature gradient [41]. A group of phase change materials includes organic compounds that are divided into paraffins and non-paraffins subgroups. These materials are able to change phase again without destroying or separating their phases [40]. They have high chemical stability, no supercooling problem, they are not corrosive, they can be recycled, but they have low thermal conductivity, and they also have high flammability and volume change [42]. This research uses paraffin wax as main material of the PCM. **Table 2** shows the PCM specifications used in the external walls and roof. Also, the **Table A2** implies this passive strategy between the building envelope layer.

Table 2. PCM specifications used.

Type	BioPCM@M182/Q21
Melting Point (°C)	23
Conductivity (W/M-K)	0.2
Specific Heat (J/Kg-K)	1970
Density (Kg/M^3)	235
Number of points on the curve	16

2.3.3. Green Roof

Green roof reduces energy consumption in educational buildings for heating and cooling. Also, reducing the amount of energy consumption in these buildings is done by controlling and reducing heat transfer through energy storage [43]. Due to the fact that heat transfer always takes place from spaces with higher temperature to spaces with lower temperature, therefore, in educational buildings, heat transfer is done through roofs from inside to outside in winter and from outside to inside in summer [43]. The green roof increases the thermal capacity of the roof layers (**Table 3**) and acts as a thermal insulation for the roof of the building. Also, vegetation in the green roof system can reduce the heat transfer through the roof of the building during the summer by evaporation and transpiration, maintaining humidity and shading on the roof [44]. In winter, the green roof performs its positive thermal function. Table shows the green roof layer in our study. Also, the **Table A2** implies this passive strategy between the building envelope layer.

Plants constantly keep some air in their roots, which acts as a thermal insulation layer. Of course, the effectiveness of this thermal insulation layer in the green roof depends on the amount of moisture it holds [45]. **Table 4** shows the plants characteristics and the layers of the green- roof details equipped in the building external roof.

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

Table 3. Green roof layers.

Materials	Thickness (mm)	U-Value (W/(m^2-K))	Function
Plants	200	-	Vegetation layer
Soil	304.8	2.77	Growing layer
Polypropylene-geotextile	20	4.331	Filtration layer
Gravel	50	3.586	Drainage layer
Polyethylene / Polythene	10	5.872	Root barrier layer
Ethylene propylene diene monomer (EPDM)	2	6.757	Water proofing layer

Table 4. Plants characteristic.

Plants	dark green long blades of leaves
Height of plants (m)	0.2
Leaf area index (LAI)	5
Leaf reflectivity	0.15
Leaf emissivity	0.8

2.4. Active Energy System Design

This hybrid renewable energy system is designed to efficiently integrate various energy sources to meet different energy demands, including electricity, heating, and cooling. By combining renewable sources like solar with traditional fossil resources such as national grid, the system ensures a reliable and sustainable energy supply [33]. The system utilizes solar panels to capture renewable energy from the sun. The electricity generated from this source is managed through selling the excess electricity to the grid and purchase electricity when there is electricity reduction from renewable source. Due to the transfer of load to the storage system during peak load and its consumption during off-peak periods, the battery undergoes charging and discharging. This transfer of load results in significant energy loss, and the battery does not achieve full efficiency, losing part of the load during storage. Additionally, in terms of materials, technology, and construction, there is a high level of embodied carbon that is harmful to the environment and negatively impacts it. Therefore, it is preferable for it (produced power) to be sold. The system does not require a battery; in case of electricity shortage, power will be purchased from the grid, and if production exceeds the building's load, excess power will be sold back to the grid. The system also includes an electrical chiller to meet cooling demands using the generated electricity. Additionally, natural gas is used to meet heating demands through a boiler and heating system. **Fig. 5** depicts the overall configuration of the hybrid renewable energy system, illustrating how the different components interact to provide a stable and flexible energy supply.

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

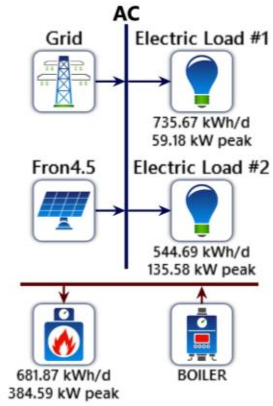


Fig. 5. Configuration of the hybrid renewable energy system.

2.4.1. PV System

PV systems utilize solar radiation to generate electricity. The output power of a PV module depends on the cell temperature and the module's characteristics. The following equation represents the PV module's output power [46]:

$$P_{PV} = P_{PV}\,rated * f_{Dpv} * G/1000 * [1 + \alpha(T_{cell} - 25)] \tag{1}$$

Where, $P_{PVrated}$ is the PV rated power, T_{cell} is the temperature of the cell, α with 0.49 (%/°C) is the temperature coefficient of power, f_{dPV} is the derating factor with 3% per year and module efficiency is 15.3%, and G is solar radiation (w/m^2).

2.4.2. HOMER

HOMER Pro software is a versatile tool that enables users to simulate and evaluate different energy systems by combining various energy sources, storage solutions, and load scenarios. This analysis helps identify the most economical and reliable configurations. The software considers factors such as solar radiation, wind patterns, and other relevant environmental parameters to create realistic simulations [46]. Its optimization process focuses on minimizing costs or emissions while meeting predetermined reliability standards. This software proves particularly valuable for assessing renewable energy integration, standalone microgrids, and grid-connected systems in different kind of locations. It also accounts for a range of variables, including the performance efficiency of system components, environmental influences on renewable energy availability, and technical and economic factors vital to decision-making processes [47].

2.4.3. Alternative Energy Sources

While grid-connected PV was selected as the most mature and practical active solution for this specific office building, we briefly examined other renewable alternatives that a designer might consider (according to Mehdizade Marzebali and Mohamadian [33]). The first alternative is onsite wind energy. Tehran's average wind speed at 10 m height is modest (~3.5 m/s). Based on the building's available roof area and typical small-scale vertical axis wind turbine (VAWT) performance curves, we estimated a maximum annual generation of only 12–18 MWh/year, which is insufficient to cover the building's remaining electricity demand (467.3 MWh/year after passive optimization). The second alternative is purchasing certified green electricity from the national grid. While this would theoretically offset operational carbon, Iran's grid currently relies heavily on fossil fuels with a negligible renewable penetration (<1% at the time of this study), making a green power purchase agreement practically unavailable and economically unviable. A third alternative is combined heat and power (CHP); however, this requires a continuous fuel supply chain and emits combustion pollutants, which contradicts the net-zero carbon objective of this study. Therefore, we concluded that grid-connected solar PV remains the most technically feasible and environmentally sound active choice for this case.

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

2.5. Environmental and Circularity Assessment in One Click LCA

Life Cycle Assessment (LCA) is a globally recognized method for evaluating the environmental impacts of materials, systems, and processes over their entire lifespan, from resource extraction to end-of-life disposal [48]. It supports decision-makers in identifying strategies with minimal environmental burden by revealing how impacts shift across life cycle stages [49]. Moreover, it provides useful insights for cost analysis, environmental comparisons, and the development of sustainable policies [50]. In this research, One Click LCA software was used to carry out the environmental assessment. This tool complies with EN 15978 and ISO 14040/44 standards and allows for comprehensive evaluation of embodied and operational carbon emissions [51]. Integrated with Building Information Modeling (BIM) and linked to verified Environmental Product Declarations (EPDs), it facilitates the rapid comparison of design options and material alternatives [52]. One Click LCA enables real-time scenario analysis and supports strategies aimed at reducing emissions across the building life cycle [53]. **Fig. 6** illustrates the system boundary, which includes stages A1-A3 (materials), A4-A5 (transport and construction), B4-B5 (replacement), B6 (operational energy), B7 (water), C2-C4 (waste transport, processing, disposal), and module D (circularity). Operational energy was taken from DesignBuilder and HOMER simulations. Five scenarios were assessed: Base, EPS, EPS + PCM, EPS + PCM + Green Roof, and Active (best passive + 273 kWp PV without battery).

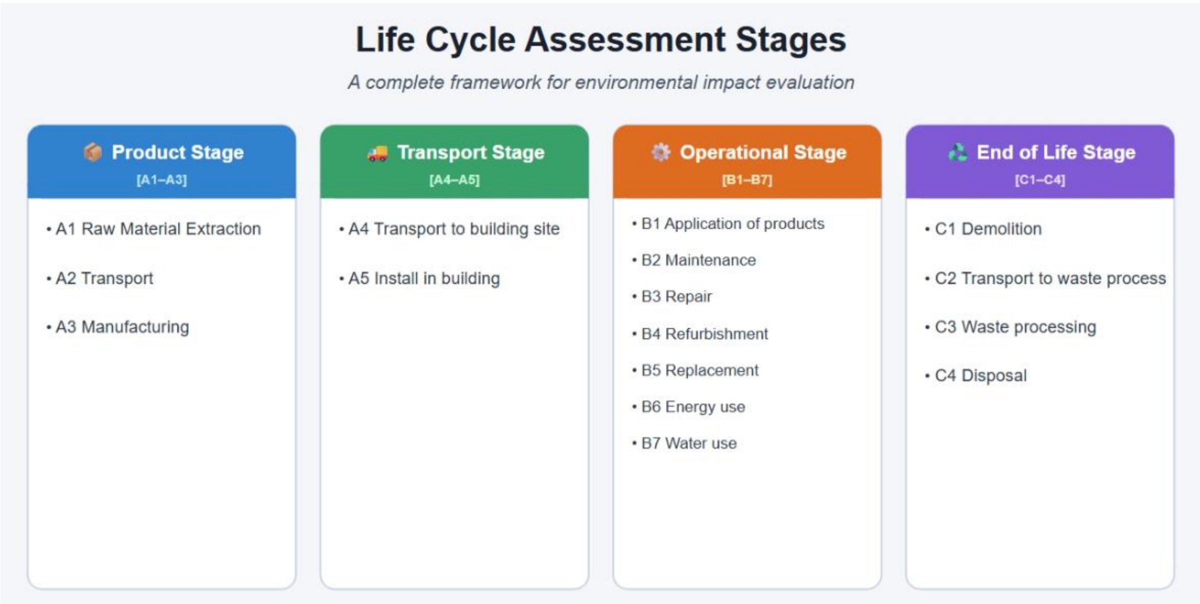


Fig. 6. LCA environmental impact stages.

3. Results and Discussion

3.1. Reference building energy demand

The total energy consumption in the base building, which represents the weakest state of the building envelope and the highest energy demand, is 812.25 MWh per year. Of this, electricity consumption accounts for 271.12 MWh per year (33.38%), primarily used for lighting and equipment. Thermal energy consumption is 316.76 MWh (38.99%), utilized for space heating and domestic hot water. The cooling system requires 224.38 MWh (27.62%) to maintain indoor comfort. The highest energy consumption occurs in January, reaching 108.70 MWh, due to increased heating demand based on the building's usage schedule. The lowest consumption is observed in April, with 43.34 MWh, attributed to the holiday schedule

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

and mild weather conditions that reduce heating and cooling requirements. **Fig. 7** shows the triple energy consumption of the building.

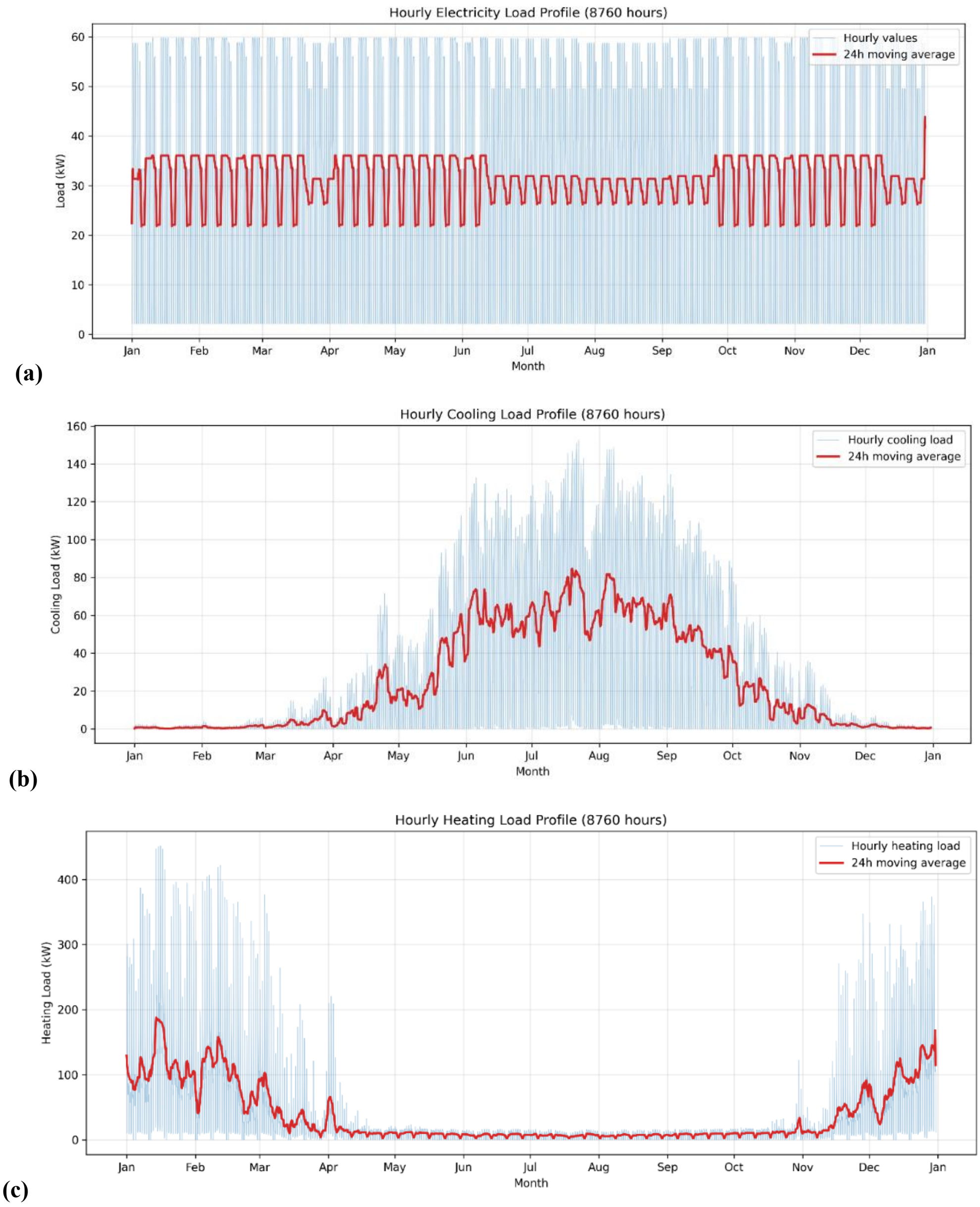


Fig. 7. (a) Electricity, (b) cooling, and (c) heating Consumption of the building.

3.2. Individual Passive Strategies

Applying a single passive measure affects heating and cooling differently (**Fig. 8**). The green roof alone cuts heating by 8.55% (from 254.5 to 232.2 MWh) and cooling by 4.82% (to 640.8 MWh). PCM on the roof follows closely, reducing heating by 8.02% and cooling by 3.82%. EPS on the wall delivers moderate savings: 4.33% for heating and 2.23% for cooling. Clearly, interventions on the roof (green roof or PCM) are more effective than wall insulation, because the roof receives the highest solar radiation in summer.

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

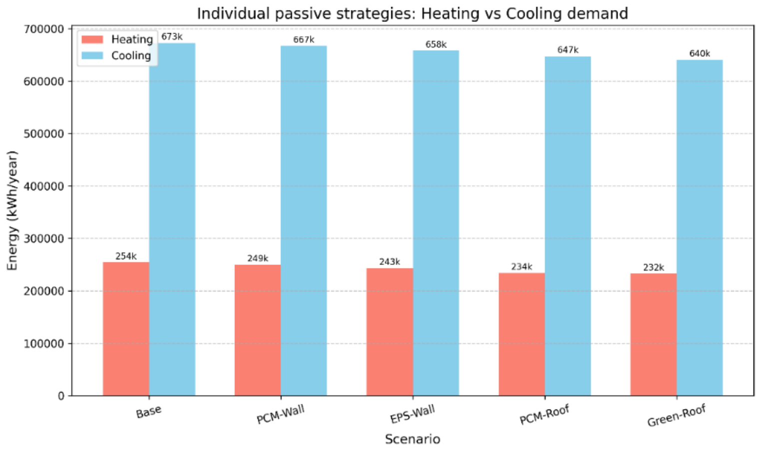


Fig. 8. Grouped bar chart – individual passive strategies.

3.3. Two-strategy combinations

Combining two passive measures brings larger savings. **Fig. 9** ranks the eight best two-strategy combinations by total energy reduction. PCM Wall + EPS Roof is the best pair, cutting overall energy by 9.36% (heating -16.76%, cooling -9.0%). The next best is EPS-PCM Roof (8.43% saving) and EPS-Green-Roof (8.28%). Interestingly, EPS Wall + Green Roof (7.07% saving) outperforms PCM Wall + Green Roof (6.0% saving). This suggests that EPS and green roof work better together than PCM and green roof in this climate.

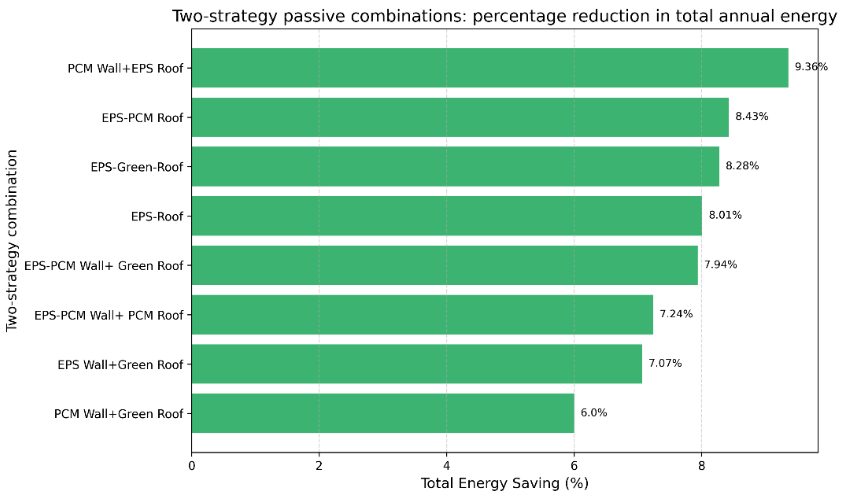


Fig. 9. Horizontal bar chart – two-strategy combinations.

3.4. Three-strategy and full combinations

Adding a third strategy pushes savings further, but the incremental gain diminishes. **Fig. 10** presents a heatmap that shows how different wall configurations (rows) and roof configurations (columns) affect total energy reduction. The highest saving (11.83%) is obtained with an EPS-PCM wall and a roof that combines PCM, EPS and green roof. The heatmap clearly shows that multi-layer roofs (PCM + EPS + green) consistently deliver savings above 11%, regardless of the wall type.

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

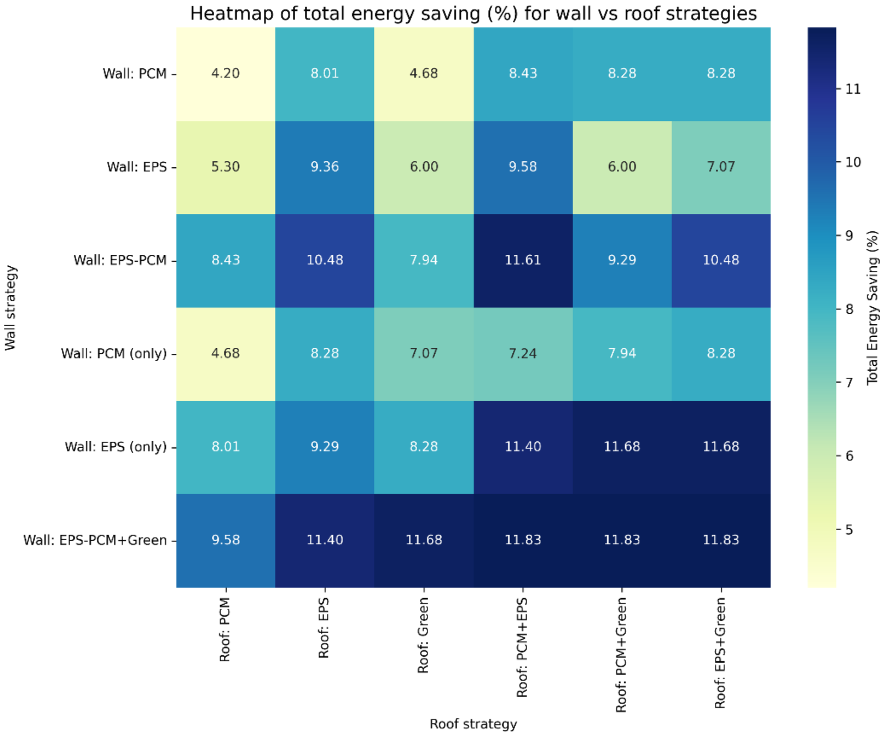


Fig. 10. Heatmap – wall vs roof strategies.

3.5. Best Passive Scenario and Key Findings

The overall best passive configuration is EPS-PCM Wall + PCM-EPS-Green Roof, which lowers total energy consumption by 11.83%, from 812.3 MWh to 716.2 MWh per year. Heating drops by 21.35% and cooling by 11.39% (see **Fig. 11**). The top five scenarios all share a common pattern: a wall that includes both EPS and PCM, and a roof with at least two layers (usually PCM + EPS, PCM + green, or all three). This tells us that for Tehran's cooling-dominated climate, the most effective passive strategy is multi-layer roof insulation combined with an EPS-PCM hybrid wall. The annual saving of over 96 MWh directly reduces the PV capacity needed to reach net-zero.

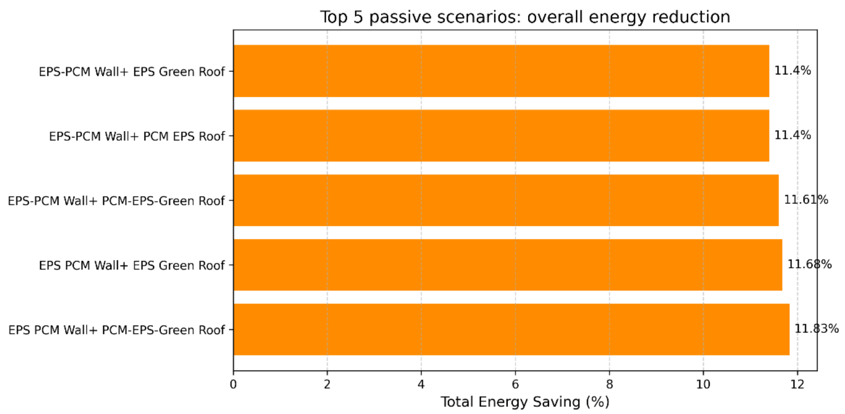


Fig. 11. Five best passive scenarios in terms of overall annual energy reduction.

3.6. Active Scenario: Grid-Connected PV without Storage

After applying the best passive configuration, the building's hourly electricity demand is taken as the AC Primary Load from the HOMER simulation. A 273 kWp PV system (Fronius Symo 4.5-3-S) is added, connected to the grid without

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

batteries. The system exports surplus electricity and imports deficits. **Fig. 12** summaries the annual energy balance. The building consumes 467.3 MWh, the PV array generates 517.0 MWh, of which 220.9 MWh is exported. Grid purchases are 171.2 MWh, resulting in a net export of 49.7 MWh and an annual renewable penetration (generation/load) of 110.6%. Consequently, the building achieves net-zero energy status and acts as a net electricity producer.

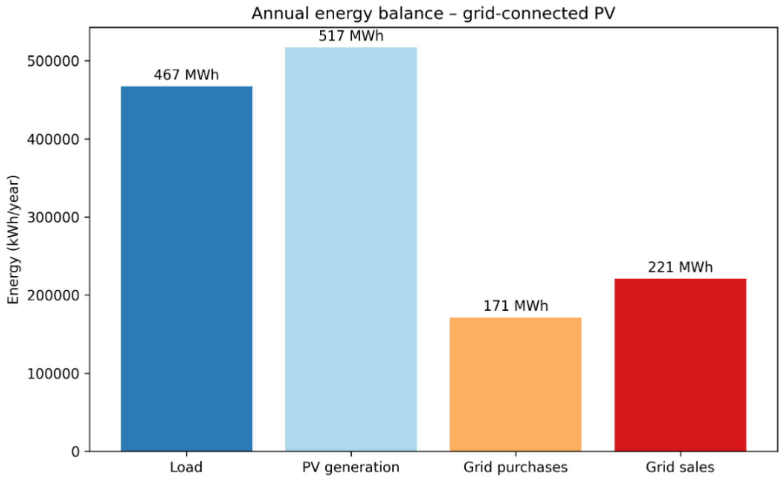


Fig. 12. Annual energy balance: load, PV generation, grid purchases and sales.

Furthermore, **Fig. 13** presents the daily averages of grid purchases, grid sales, and total power for a representative summer week (days 180–186, corresponding to June 15–22). Grid purchases range from 20.5 kW/day to 51.5 kW/day, with the highest purchase occurring on June 17 (51.5 kW/day). Grid sales vary between 0 kW/day and 20.3 kW/day; on June 17 and 18, sales are nearly zero (0.0 and 0.2 kW/day, respectively), indicating that the PV generation was fully consumed on site or was insufficient. Over the entire week, total purchases (251 kW) exceed total sales (70 kW) by a factor of more than three, meaning that the building acts as a net importer even during summer. This suggests that the 273 kWp PV system, while reducing grid dependence, does not fully offset the building's consumption on a daily basis, a finding that aligns with the annual balance, where net export is only achieved through the accumulation of small daily surpluses over the whole year.

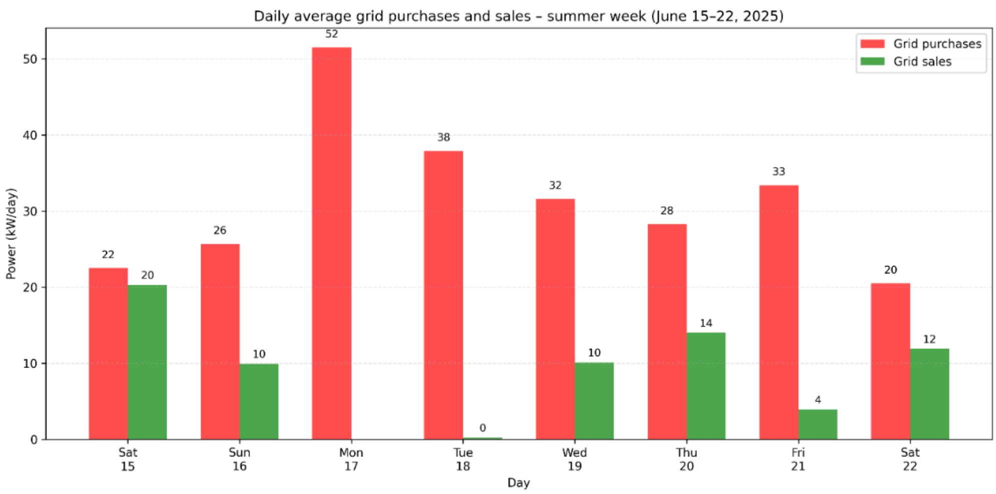


Fig. 13. Weekly daily averages.

Also, **Fig. 14** presents histograms of hourly grid purchases and sales over the entire year. Purchases are concentrated at low power values (median 2.17 kW), indicating that for most hours the building draws little from the grid, but a heavy tail

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

extends to 149.5 kW (99th percentile 105 kW). Sales, in contrast, are zero for more than half the hours (median = 0), yet they can reach 277.3 kW in favorable conditions. The mean sales value (26.3 kW) is pulled upward by these rare high-export events, which occur mainly on clear summer days with low load. This distribution confirms that the battery-less PV system effectively reduces grid purchases during most hours, while occasional large exports compensate for the remaining imports.

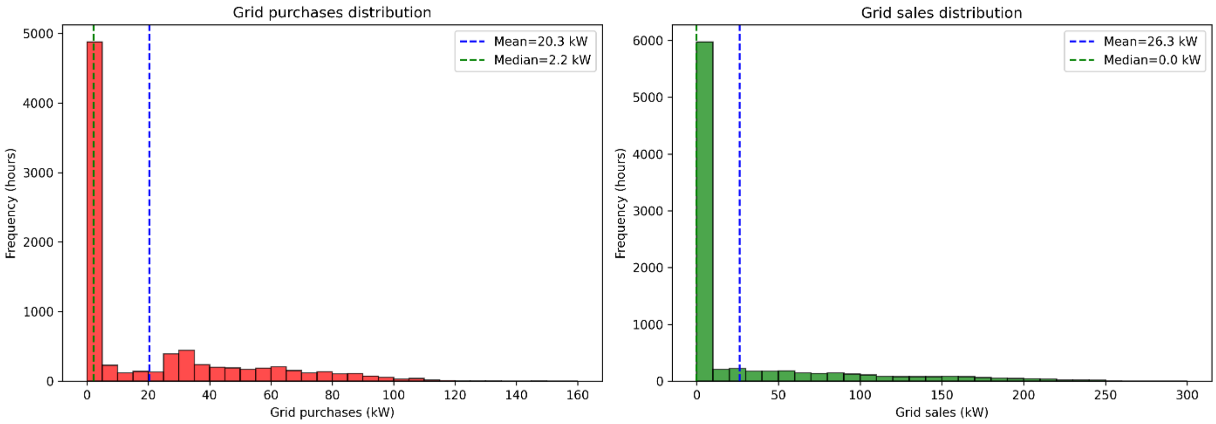


Fig. 14. Distribution of hourly grid purchases (left) and sales (right).

Fig. 15 shows the monthly average renewable penetration. Values range from 35.9% in December to 48.9% in May. Spring months (April–May) have the highest penetration, while winter months (December–January) are the lowest. The annual average of these hourly-capped values is 42.5%, but the annual energy-based penetration reaches 110.6%, confirming net-zero status.

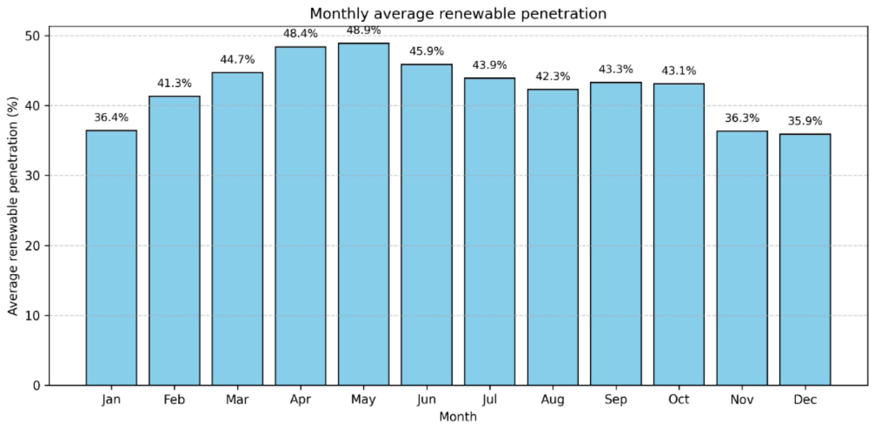


Fig. 15. Monthly average renewable penetration.

3.7. Environmental Analysis

To understand the trade-off between material production and building operation, **Fig. 16** compares the embodied carbon (stages A1-A5, B4-B5, and C) with the operational carbon (stage B6) for all five scenarios over the 60-year service life. As shown in **Fig. 16**, the baseline building has 6,887 t of embodied carbon and 30,871 t of operational carbon. The full passive-active scenario (EPS-PCM-Green roof + 273 kWp PV) increases embodied carbon to 7,990 t due to the PV system and its replacements, but reduces operational carbon to 12,755 t, a 58.7% reduction. Consequently, the total life cycle GWP drops by 44.7% compared to the baseline, confirming that the upfront carbon investment in PV is quickly repaid by operational savings.

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

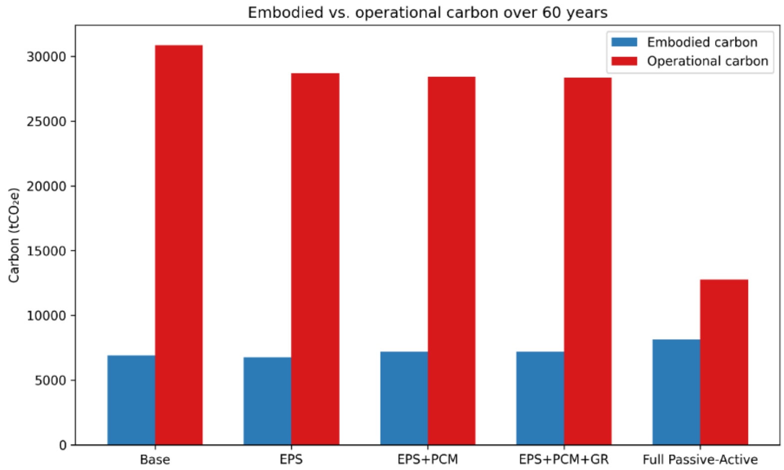


Fig. 16. Embodied vs. operational carbon (t $CO_2 \sim$ e) for the five scenarios over 60 years.

To further investigate the contribution of each design change, **Fig. 17** presents a waterfall chart showing the cumulative change in total life cycle GWP when moving stepwise from the baseline to the active NZEB scenario. The changes correspond to adding material layers as defined in Appendix **Table A2**. First, adding EPS insulation layers to both walls and roof reduces total carbon by 2,298 t. Next, adding a layer of PCM (7.42 cm) to both the walls and the roof, while keeping the EPS layers, increases total carbon by 154 t relative to the EPS-only case. The reason is that the operational saving from PCM (-291 t) is too small to offset the extra embodied carbon from its production and installation (+445 t). In other words, in Tehran's semi-arid climate, the moderate thermal regulation provided by PCM does not justify its material footprint. Adding the green roof layers gives a negligible further reduction of 46 t. Finally, integrating the 273 kWp PV system cuts total carbon by 14,666 t, which is by far the largest single saving. This chart leads to two critical conclusions for designers: (1) PCM should be avoided in this climate and building type, and (2) grid-connected PV without battery is the most impactful measure for achieving NZEB, far surpassing any passive strategy alone.

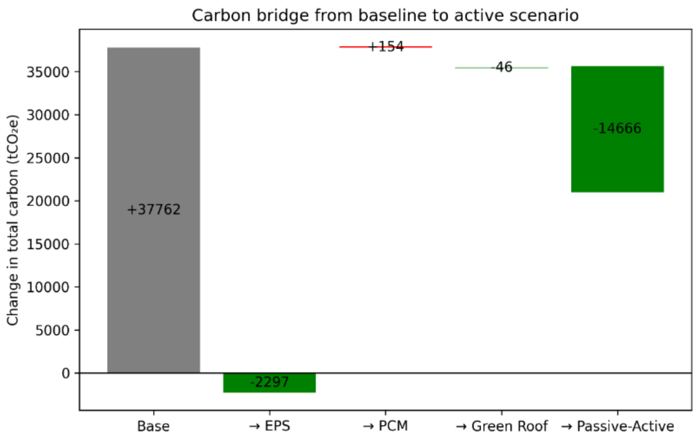


Fig. 17. Waterfall chart of total carbon changes from baseline to active scenario.

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

Fig. 18 compares the cumulative carbon emissions over 60 years for the baseline and the full-featured Active scenario. This active scenario includes all passive strategies together (EPS + PCM on walls, and EPS + PCM + green roof on the roof) plus the 273 kWp grid-connected PV system without battery storage (as defined in Appendix **Table A2** and Section 2.4). The active building starts with a higher initial carbon (8,146 t) than the baseline (6,886 t). This increase comes from two sources: (1) the added embodied carbon of EPS, PCM and the green roof layers, and (2) the embodied and replacement emissions of the PV system. However, the annual operational carbon of the active scenario is only 212.6 t/year, compared to 514.5 t/year for the baseline, thanks to the combination of improved insulation, thermal regulation (PCM), passive cooling (green roof), and on-site solar generation. As a result, the cumulative carbon curve of the active scenario crosses below that of the baseline in year 5 (after 5 full years of operation). This means the carbon payback period of the full package (all passive strategies + PV) is only 5 years. For the remaining 55 years of the building's life, this integrated design provides a continuous climate benefit, with a total saving of approximately 16,600 t over 60 years.

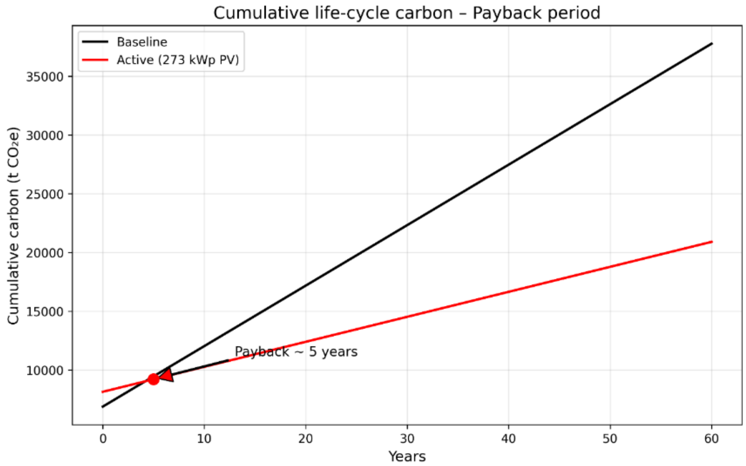


Fig. 18. Cumulative carbon emissions over 60 years.

Fig. 19. Normalized radar chart comparing the contribution of five major building parts across four LCA stages (A1-A3, A4, C2, C4). Values are normalized per stage; closer to the center indicates lower carbon. The foundation and floor slabs dominate in A1-A3 (production), while external walls show a more balanced profile. This visualization helps identify which building parts drive embodied carbon and which stages require priority intervention. The radar chart in **Fig. 19** demonstrates that the foundation and floor slabs have the highest relative carbon in the production stage (A1-A3), while their share in transport (A4) and end-of-life (C2, C4) is comparatively lower. External walls and internal walls show a more even distribution across stages. This pattern confirms that reducing the embodied carbon of concrete-dominated parts (foundation, slabs) should be the first priority for material substitution or low-carbon alternatives.

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

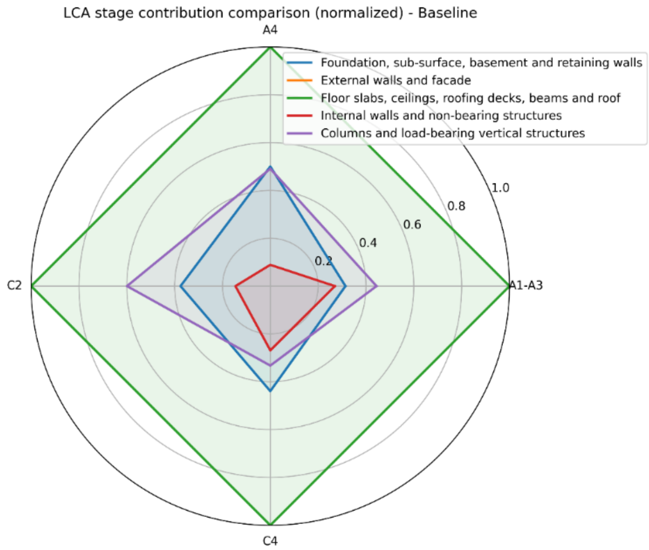


Fig. 19. Normalized radar chart of major building parts across LCA stages.

Fig. 20 presents a heatmap of carbon intensity (kg CO_2e per m² of gross floor area) for each LCA stage and scenario. The baseline building has high operational intensity (B6: 2.71 kg/m²) and moderate embodied intensity. The active scenario shows a dramatic drop in operational intensity (1.12 kg/m²) but higher values in A1-A3 (0.56 kg/m²) and B4-B5 (0.095 kg/m²) due to the PV system. This visualization confirms that the operational carbon reduction far outweighs the embodied increase, and highlights that PCM and green roof have minimal effect on intensity compared to PV.

Fig. 20. Carbon intensity heatmap (kg CO_2e/m^2).

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

3.8 Circularity Assessment

Beyond the life cycle carbon footprint, the circularity of building materials, their potential to be reused, recycled, or returned to the production cycle, was evaluated using One Click LCA. Circularity helps reduce the extraction of virgin resources and the generation of construction waste. For this assessment, we adopted assumptions that reflect current Iranian market conditions. The recyclability rate was set to 30% for steel and concrete (the typical value for Iran) [54], 9% for autoclaved aerated concrete (AAC) blocks (which contain about 30% cement), and 6% for stone cladding (which contains about 20% cement) [54]. A renewable energy content of 5% was applied to all materials, in line with the national mandate that factories source at least 5% of their electricity from renewables. In addition, material wastage during construction was taken from the literature and is summarized in **Table 6**. For the green roof, the soil was assumed to be 100% recyclable with 7% wastage; EPS blocks were given 9% recyclability and 5.25% wastage; and PV panels were assigned high recyclability rates (95% for glass, 90% for silicon).

Table 6. Material wastage rates assumed in the LCA model.

Material	Wastage (%)	Reference
Paint	5.83	[55]
Timber	5.5	[56]
Concrete	5.0	[56]
Glass	4.0	[57]
Mortar (plastering)	3.32	[58]
Steel	2.97	[55]
Tiles	2.7	[58]
Brick	2.27	[58]
Blocks	2.01	[59]
Mortar (general)	1.58	[59]

Fig. 21 shows the circularity profile of the baseline building (without any passive or active measures). Only 13% of the materials are able to return to the consumption cycle at the end of the building's life. Virgin materials account for 64.7% of the total, recycled content for 20.3 %, and materials produced with renewable energy for 3.4%. In other words, the baseline building is strongly dependent on virgin resources and has a low circularity.

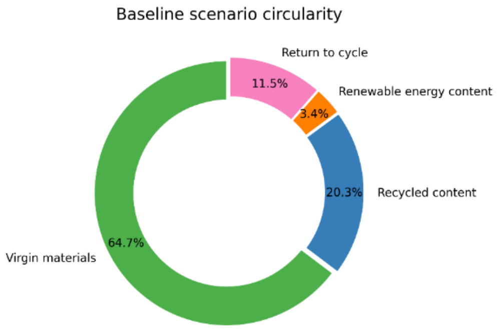


Fig. 21. Circularity profile of the baseline building.

Fig. 22 presents the circularity profile after implementing the full passive-plus-active scenario (EPS + PCM + green roof + PV). Here, the share of materials that can return to the cycle increases to 15%, virgin material use drops to 61.2%, and the recycled content rises to 22.3%. Although the total mass of materials is higher in this scenario, the improved recyclability of the added components (especially the green roof soil, EPS insulation, and PV panels) leads to a net gain in circularity.

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

This demonstrates that well-designed passive and active strategies not only reduce operational and embodied carbon but also contribute to a more circular material economy.

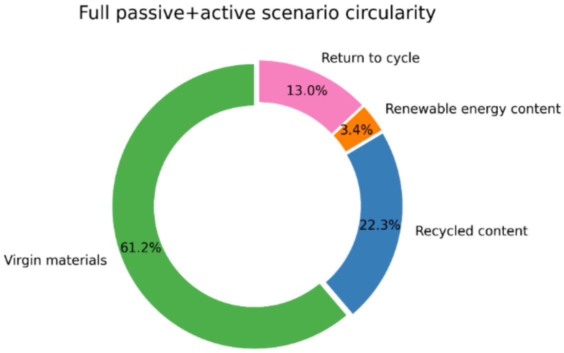


Fig. 22. Circularity profile after implementing all passive and active strategies.

4. Conclusion

This study presented a sequential passive-active design framework for a large office building in Tehran, integrating EPS insulation, PCM, green roof, and grid-connected PV. A detailed LCA (EN 15978) and circularity assessment were performed over a 60-year service life. The main conclusions are:

- The active scenario (EPS + PCM + green roof + PV) achieves NZEB status with a 65.5% reduction in grid electricity purchase and a net annual renewable penetration of 110.6%. Total life cycle GWP drops by 44.7% compared to the baseline, despite a 16% increase in embodied carbon from the PV system.
- The carbon payback period of the full passive-active package is only 5 years. After this short period, the active building provides a continuous climate benefit for the remaining 55 years.
- PCM proves counterproductive in this climate. Adding PCM to an already EPS-insulated building increases total life cycle carbon by 154 t because the operational saving (-291 t) does not outweigh its additional embodied carbon (+445 t).
- The green roof has a negligible effect on total carbon but improves circularity. The full scenario increases the share of materials returning to the cycle from 11.5% (baseline) to 13%.
- The proposed battery-less grid-connected PV strategy is environmentally effective and avoids storage-related embodied carbon and energy losses, offering a replicable model for NZEB design in developing countries with unstable electricity grids.

For future work, the authors recommend: (a) economic analysis (LCC) of the proposed scenarios, (b) investigation of battery storage with dynamic LCA, (c) generalization of the framework to other climate zones and building typologies, (d) using more region-specific EPDs to increase LCA accuracy, (e) Climate-zoned decision matrix - applying the same passive-active framework to at least three additional climate types (cold, hot-humid, and Mediterranean) to generate a prescriptive guide on when to include battery storage, thermal storage, or seasonal hydrogen storage., and (f) Hourly NZEB compliance indicator - developing a simple index (e.g., the fraction of hours per year with net-zero or net-export status) to complement the annual penetration metric, making NZEB standards more rigorous and practically enforceable for 24/7 operation across different latitudes and weather patterns.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

Data Availability

No data is used in this article.

Appendix

Table A1. Materials of the building [**Source**: department architectural plans list].

Materials	Thickness (mm)	Conductivity (W/m-k)	Specific Heat (J/kg-k)	Density (kg/m³)
Roof				
Stone Granite	20	2.5	790	2610
Mortar	30	0.88	896	2800
Bitumen	5	0.23	1000	1100
Mortar	2	0.88	896	2800
cast concrete (lightweight)	50	0.38	1000	1200
Concrete (%2 steel)	180	2.5	1000	2400
External Wall				
Brickwork	50	0.84	800	1700
Mortar	20	0.88	896	2800
AAC Block*	150	0.11	896	2800
Air layer Gap	50	-	-	-
AAC Block	100	0.11	896	2800
Cement/plaster/mortar-plaster	20	0.35	840	950
Gypsum Plastering	5	0.4	1000	1000

* AAC = Autoclaved Aerated Concrete.

Table A2. Passive strategies materials.

Passive Solutions	Layers of Wall	Layers of Roof
EPS	Brickwork outer	Stone Granite Chocolate
	Mortar	Mortar
	EPS	Bitumen
	Air gap	Cast Concrete(lightweight)
	EPS	EPS (Heavy weight) (8 cm)
	Cement/Plaster/Mortar-Plaster	Concrete (%2 Steel)
	Gypsum Plastering	Simple roofing panel (Dampa)
EPS + PCM	Brickwork outer	Stone Granite Chocolate
	Mortar	Mortar
	PCM (7.42 cm)	PCM (7.42 cm)
	EPS	Bitumen
	Air gap	Cast Concrete(lightweight)
	EPS	EPS (Heavy weight) (8 cm)
	Cement/Plaster/Mortar-Plaster	Concrete (%2 Steel)
	Gypsum Plastering	Simple roofing panel (Dampa)
EPS + PCM + Green Roof	Brickwork outer	Green roof layers (mentioned)
	Mortar	Stone Granite Chocolate
	PCM (7.42 cm)	Mortar
	EPS	PCM (7.42 cm)
	Air gap	Bitumen
	EPS	Cast Concrete(lightweight)
	Cement/Plaster/Mortar-Plaster	EPS (Heavy weight) (8 cm)
	Gypsum Plastering	Concrete (%2 Steel)
		Simple roofing panel (Dampa)

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

References

[1] M. Roberts, S. Allen, E. Marsh, J. Clarke, and D. Coley, Consequential impacts of a net-zero carbon design: life cycle assessment of an active building. IOP Conf. Ser. Earth Environ. Sci. 1078 (2022) 12091.

[2] H. Taherian and R. W. Peters, Advanced active and passive methods in residential energy efficiency. Energies 16 (2023) 3905.

[3] S. Lahmar, M. Maalmi, and R. Idchabani, Multiobjective building design optimization using an efficient adaptive Kriging metamodel. Simulation (2023) 00375497231168630.

[4] S. Wang, X. Chen, L. Bu, B. Wang, K. Yu, and D. He, A DQN-based coordination method of HVAC and energy storage for building energy management. in: 2023 IEEE 7th Conference on Energy Internet and Energy System Integration (EI2), IEEE, 2023, pp. 4891–4896.

[5] G. P. L. Teixeira, A. S. Guimarães, and J. M. P. Q. Delgado, Active and passive solutions for an energy efficient building. Diffus. Found. Mater. Appl. 30 (2022) 125–157.

[6] J. Gargasas, K. Bazienė, and P. Dzienis, Low energy buildings: multifunctional strategies and solutions. Entrep. Sustain. Issues 11 (2023) 314–330.

[7] A. M. Omer, Built environment: relating the benefits of renewable energy technologies. Int. J. Automot. Mech. Eng. 5 (2022) 561–575.

[8] S. Rahmouni and A. S. Mohammed, Impact of shading devices on cooling load in educational buildings. J. Green Build. 19 (2024) 223–238.

[9] M. Eghtedari and A. Mahravan, Evaluation a hybrid passive cooling system for a building using experimental and commercial software (Design Builder). J. Renew. Energy Environ. 8 (2021) 74–80.

[10] S. Falegari and A. A. Shirzadi Javid, Integrating building information modeling and life cycle assessment to analyze the role of climate and passive design parameters in energy consumption. Energy Environ. 35 (2022) 2087–2106.

[11] C. Liu, B. Luo, W. Wang, H. Gao, Z. Wang, and H. Ding, Energy management and capacity optimization of photovoltaic, energy storage system, flexible building power system considering combined benefit. Energy Eng. (2023).

[12] J. Liu, M. Wang, J. Peng, X. Chen, S. Cao, and H. Yang, Techno-economic design optimization of hybrid renewable energy applications for high-rise residential buildings. Energy Convers. Manag. 213 (2020) 112868.

[13] A. Sternberg and A. Bardow, Power-to-What? – environmental assessment of energy storage systems. Energy Environ. Sci. 8 (2015) 389–400.

[14] P. Trairat and D. Banjerdpongchai, Multi-objective optimal operation of building energy management systems with thermal and battery energy storage in the presence of load uncertainty. Sustainability 14 (2022) 12717.

[15] K. Kaspar, M. Ouf, and U. Eicker, A critical review of control schemes for demand-side energy management of building clusters. Energy Build. 257 (2022) 111731.

[16] M. G. Yu, X. Ma, B. Huang, K. Devaprasad, F. Brown, and D. Wu, Enhancing building energy efficiency through advanced sizing and dispatch methods for energy storage. in: ASHRAE Transactions, 2024, pp. 512–519.

[17] H. Mehrjerdi, A. Iqbal, E. Rakhshani, and J. R. Torres, Daily-seasonal operation in net-zero energy building powered by hybrid renewable energies and hydrogen storage systems. Energy Convers. Manag. 201 (2019) 112156.

[18] E. Bellos, P. Lykas, and C. Tzivanidis, Performance analysis of a zero-energy building using photovoltaics and hydrogen storage. Appl. Syst. Innov. 6 (2023) 43.

[19] A. Ciardiello, J. Dell'Olmo, M. Ferrero, L. M. Pastore, F. Rosso, and F. Salata, Energy retrofit optimization by means of genetic algorithms as an answer to fuel poverty mitigation in social housing buildings. Atmosphere 14 (2023) 1.

[20] S. Christopher, M. P. Vikram, C. Bakli, A. K. Thakur, Y. Ma, Z. Ma, H. Xu, P. M. Cuce, E. Cuce, and P. Singh, Renewable energy potential towards attainment of net-zero energy buildings status – a critical review. J. Clean. Prod. 405 (2023) 136942.

[21] S. Zhang, P. Ocłoń, J. J. Klemeš, P. Michorczyk, K. Pielichowska, and K. Pielichowski, Renewable energy systems for building heating, cooling and electricity production with thermal energy storage. Renew. Sustain. Energy Rev. 165 (2022) 112560.

[22] R. Guo and D. Saelens, Application of model predictive control to building design optimisation. E3S Web Conf. 396 (2023) 03020.

[23] G. Tumminia, F. Sergi, D. Aloisio, S. Longo, M. A. Cusenza, F. Guarino, S. Cellura, and M. Ferraro, Towards an integrated design of renewable electricity generation and storage systems for NZEB use: a parametric analysis. J. Build. Eng. 44 (2021) 103288.

[24] M. Paleari, M. Lavagna, and A. Campioli, The assessment of the relevance of building components and life phases for the environmental profile of nearly zero-energy buildings: life cycle assessment of a multifamily building in Italy. Int. J. Life Cycle Assess. 21 (2016) 1667–1690.

[25] E. Palumbo, Effect of LCA data sources on GBRS reference values: the envelope of an Italian passive house. Energies 14 (2021) 1883.

[26] N. Hossameldin Kamel, Life cycle assessment for healthier built environments. Arch. Art J. (2023).

[27] F. Asdrubali and G. Grazieschi, Life cycle assessment of energy efficient buildings. Energy Rep. 6 (2020) 270–285.

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

[28] F. Prideaux, K. Allacker, R. H. Crawford, and A. Stephan, Integrating life cycle assessment into the building design process—a review. Environ. Res. Infrastruct. Sustain. 4 (2024) 22001.

[29] M. Raugei, N. Keena, N. Novelli, M. Aly Etman, and A. Dyson, Life cycle assessment of an ecological living module equipped with conventional rooftop or integrated concentrating photovoltaics. J. Ind. Ecol. 25 (2021) 1207–1221.

[30] D. Vuarnoz, Assessing the required life-cycle characteristics of electricity storage for ensuring sustainability in buildings. Archit. Sci. Rev. 64 (2021) 28–36.

[31] H. Hottenroth, J. Peters, M. Baumann, T. Viere, and I. Tietze, Life-cycle analysis for assessing environmental impact. in: Energy Storage Options and Their Environmental Impact, R. E. Hester and R. M. Harrison, Eds., The Royal Society of Chemistry, 2018, p. 261.

[32] Y. Li, X. Han, L. Nie, Y. Deng, J. Yan, T. C. Roumpedakis, D. S. Kourkoumpas, and S. Karellas, Life cycle environmental hotspots analysis of typical electrochemical, mechanical and electrical energy storage technologies for different application scenarios: case study in China. J. Clean. Prod. 466 (2024) 142862.

[33] M. R. Mehdizade Marzebali and M. Mohamadian, Techno-environmental and economic assessment of off-grid hybrid energy systems for combined cooling, heating, power, and battery-hydrogen storage. Adv. Energy Sci. Technol. 1 (2025) 28–51.

[34] G. Miracco, F. Nicoletti, V. Ferraro, M. Muzzupappa, V. M. Mattanò, and F. Alberti, Achieving nZEB goal through prefabricated buildings: case study in Italy. Energy Build. 329 (2025) 115301.

[35] N. Soussi, M. Ammar, A. Mokni, and H. Mhiri, Efficiency of a recycled composite material for building insulation. Constr. Build. Mater. 467 (2025) 140358.

[36] A. Aldawoud, L. A. Husein, and E. S. Mushtaha, Electrochromic glazing with nanocoating integration impact on building energy efficiency: bibliometric analysis (1983–2023). Energy Build. 330 (2025) 115300.

[37] A. Albatayneh, R. Albadaineh, A. Juaidi, and R. Abdallah, Trade-off lighting to minimize the cooling loads in semi-arid climate zone. Energy Build. 328 (2025) 115100.

[38] A. Fathalian and H. Kargarsharifabad, Actual validation of energy simulation and investigation of energy management strategies (case study: an office building in Semnan, Iran). Case Stud. Therm. Eng. 12 (2018) 510–516.

[39] N. H. Ramli Sulong, S. A. S. Mustapa, and M. K. Abdul Rashid, Application of expanded polystyrene (EPS) in buildings and constructions: a review. J. Appl. Polym. Sci. 136 (2019) 47529.

[40] M. Mehdizade Marzebali and M. Mohamadian, Performance evaluation of PCM infiniteR29 and its impact on a single-family residential building: a case study in Jinan, China. Adv. Energy Sci. Technol. 1 (2025) 196–214.

[41] F. Agyenim, N. Hewitt, P. Eames, and M. Smyth, A review of materials, heat transfer and phase change problem formulation for latent heat thermal energy storage systems (LHTESS). Renew. Sustain. Energy Rev. 14 (2010) 615–628.

[42] A. K. Pandey, M. S. Hossain, V. V. Tyagi, N. Abd Rahim, J. A. L. Selvaraj, and A. Sari, Novel approaches and recent developments on potential applications of phase change materials in solar energy. Renew. Sustain. Energy Rev. 82 (2018) 281–323.

[43] E. Oberndorfer, J. Lundholm, B. Bass, R. R. Coffman, H. Doshi, N. Dunnett, S. Gaffin, M. Köhler, K. K. Liu, and B. Rowe, Green roofs as urban ecosystems: ecological structures, functions, and services. Bioscience 57 (2007) 823–833.

[44] Z. Tian, Y. Lei, and X. Gu, Building energy impacts of simple green roofs in the hot summer and cold winter climate zone: Suzhou as a study case. Procedia Eng. 205 (2017) 2918–2924.

[45] M. Zhao and J. Srebric, Assessment of green roof performance for sustainable buildings under winter weather conditions. J. Cent. South Univ. 19 (2012) 639–644.

[46] M. Mehdizade and M. Mohamadian, Techno-economic-environmental evaluation of a hybrid energy system in a residential building integrated renewable energies and comparison of different climate conditions. Adv. Energy Sci. Technol. 1 (2026) 349–368.

[47] B. Hüner, Feasibility and environmental analysis of biogas-based hybrid energy system using HOMER pro software: a case study for Hatay. Energy Convers. Manag. 326 (2025) 119480.

[48] J. B. Guinee, Handbook on life cycle assessment operational guide to the ISO standards. Int. J. Life Cycle Assess. 7 (2002) 311–313.

[49] D. Pant, A. Singh, G. Van Bogaert, Y. A. Gallego, L. Diels, and K. Vanbroekhoven, An introduction to the life cycle assessment (LCA) of bioelectrochemical systems (BES) for sustainable energy and product generation: relevance and key aspects. Renew. Sustain. Energy Rev. 15 (2011) 1305–1313.

[50] M. O. de Eicker, R. Hischier, L. A. Kulay, M. Lehmann, R. Zah, and H. Hurni, The applicability of non-local LCI data for LCA. Environ. Impact Assess. Rev. 30 (2010) 192–199.

Advances in Energy Science and Technology
AEST
Amirkabir University of Technology

[51] R. Kurian, K. S. Kulkarni, P. V. Ramani, C. S. Meena, A. Kumar, and R. Cozzolino, Estimation of carbon footprint of residential building in warm humid climate of India through BIM. Energies 14 (2021) 4237.

[52] J. Veselka, M. Nehasilová, K. Dvořáková, P. Ryklová, M. Volf, J. Růžička, and A. Lupíšek, Recommendations for developing a BIM for the purpose of LCA in green building certifications. Sustainability 12 (2020) 6151.

[53] B. Petrovic, J. A. Myhren, X. Zhang, M. Wallhagen, and O. Eriksson, Life cycle assessment of building materials for a single-family house in Sweden. Energy Procedia 158 (2019) 3547–3552.

[54] M. Ghanbari, Dynamic analysis of construction and demolition waste management system (a case study of Tehran, Iran). Adv. Civ. Eng. 2022 (2022) 9348027.

[55] S. Bavuno, C. Ahuma-Smith, G. O. Dokyi, and E. E. Ablordeppey, The perspective of tradesmen on material wastage in the construction industry. Int. J. Eng. Res. Technol. 9 (2020) 174–179.

[56] S. Ugochukwu, L. Abazuonu, and C. Author, An on-site quantification of building material wastage on construction projects in Anambra State, Nigeria: a comparison with the literature. Quest J. J. Archit. Civ. Eng. 3 (2017) 1–9.

[57] P. Tihomirovs, P. Kara De Maeijer, and A. Korjakins, Demolition waste glass usage in the construction industry. Infrastructures 8 (2023) 182.

[58] A. O. John and D. E. Itodo, Professionals' views of material wastage on construction sites and cost overruns. Organ. Technol. Manag. Constr. An Int. J. 5 (2013) 747–757.

[59] G. Wokjira Fayisa and S. Garoma Wayessa, Cause of construction material wastage on public building project in Western Oromia. Am. J. Civ. Eng. 9 (2021) 55.