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Rethinking net zero: A new perspective on achieving net zero energy buildings

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ABSTRACT

"Energy" is an essential component of modern civilization, driving economic growth, technological innovation, and urbanization. However, the desire of the energy contributes to several geopolitical conflicts, emissions, and environmental deterioration. Since the building sector is highly energy-intensive with its construction and operations, addressing its energy requirement is crucial. A solution is provided by The Net Zero Energy Building (NZEB) strategy, applies to buildings whose annual energy consumption is equal to the amount of energy produced from renewable sources. This paper presents a new framework for designing energy-efficient buildings by developing the NZEB approach and integrating BIM. It introduces the Realistic Net-Zero Energy Building (RNZEB) method, that highlights the necessity for buildings to balance not only their operational energy consumes, also the embodied energy of materials utilises renewable resources throughout their whole lifespan. This study uses information collected from a conceptual residential project in London to demonstrate how the RNZEB approach is effective and how different structural systems (steel, reinforced concrete, timber) and building operations impact total energy consumption. The result demonstrates embodied energy of traditional steel house is 308,599.2 kWh, concrete house is 240,247.2 kWh, and timber house is 151,902.7 kWh. Employing low embodied energy materials reduces the energy footprint by 33.90 % for steel, 24.70 % for concrete, and 11.05 % for timber. Additionally, applying cutting-edge technologies results in impressive operational energy savings of up to 84.45 %. The RNZEB method's goal is to reset these reduced energies with renewable resources. Steel house in its 49th year, concrete in its 43rd, and timber in its 32nd year achieve the RNZE target.

1. Introduction

Buildings afford humans a place to live, a sense of security, and a structured environment in which individuals can perform a range of tasks required for daily activities, jobs, and social interactions. On the other hand, buildings take an enormous amount of energy, non-renewable resources, arable land, and materials, as well as generate a quantity of waste, pollute the air, water, and soil, release greenhouse gases into the atmosphere, and ultimately cause global warming (Arenas and Shafique, 2024). Buildings' most significant risk is from their energy consumption, which poses threats.

Firstly, the buildings and construction sector are accountable for about 39 % of the worldwide greenhouse gas emissions connected to energy, with the manufacture of materials contributing 11 % of these emissions in 2018 (GABC, 2019). Emissions cause climate change causes sea level rise, extreme and unstable weather, a rise in the frequency and severity of natural catastrophes, a decrease in crop production, and a

loss of biodiversity (Shivanna, 2022).

Secondly, the building and construction industry is responsible for 32 % of the global energy consumption (Buildings-GSR, 2025). This represents the building sector's extremely high energy demand and emphasises its major impacts on global energy requirement. For a long time, energy security and geopolitics have been important factors in world affairs, many countries consider energy as a vital source of power and wealth, they continue to compete over claiming controls and utilise key supplies (Klare, 2015). Conflicts over offshore oil and natural gas resources in the Arctic Ocean and the East and South China Seas are examples that describes the way the implementation of new technology has led to new disputes of its own (Klare, 2015). The relationship between energy and conflict emphasises the importance of transitioning to more sustainable and decentralized energy systems in the building, where energy is most in demand.

Lastly, the consumption of energy derived from fossil fuels remains a significant problem (Azari, 2019). Buildings desire fossil fuels to

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generate electricity and significant quantities of natural gas for heating. Therefore, nations frequently find themselves reliant on imports for these conventional energy resources, leading to increased foreign dependency. This reliance involves negative consequences, including increased economic vulnerability to fluctuations in the price of energy globally and higher geopolitical risk because of disruptions in the energy supply (Sahu and Mahalik, 2024). The COVID-19 pandemic and the Russia-Ukraine war have raised attention to the weaknesses and disruptions in supply chains (Benton et al., 2022). Those have a significant effect on the availability of critical infrastructure, these interruptions highlight how vulnerable the world's supply chain is and how they might have an important impact on vital buildings.

To mitigate these detrimental consequences of the buildings, this study provides decentralised and sustainable energy systems, such as renewable energy sources and energy-efficient building techniques, which are necessary for the environment to reduce the negative effect of the construction sector.

1.1. Research gap

To address these risks and hazards driven by buildings, the strategy is suggested for Net Zero-Energy Building (NZEB). NZEB is a structure with net zero energy consumption, which means that the building's yearly energy consumption is equal to the amount of renewable energy generated on the site renewable energy sources (US Department of Energy, 2015). In the case that NZEB is applied to eliminate the negative environmental impact of building, this definition avoids a crucial point, which does not take steps to remove the embodied energy of the materials used in the structure. Simply balancing the annual energy consumed by a building is not sufficient for a comprehensive net-zero strategy. Because that occasionally may increase the likelihood of more emissions and negative environmental impact.

Many operational energy-efficiency techniques used in modern buildings, including thicker envelopes, additional insulation, exterior shading devices, multiple-glazed windows, etc., increase embodied energy and can threaten meaningful net life cycle energy savings (Azari and Abbasabadi, 2018). Consequently, even though the building's operational energy consumption is decreased, its total embodied energy may rise, which could lead to increased carbon emissions over the building's lifecycle.

The research recommends RNZEB, a more comprehensive strategy, to deal with this issue. There are several similarities between NZEBs and RNZEBs, including maximum passive energy savings, building insulation, energy-efficient technologies, and the use of on-site renewable energy sources. Their main differences are embodied energy and grid interaction: NZEBs often ignore embodied energy and concentrate on battery integration, whereas RNZEBs prioritise low-carbon materials and are designed not only to integrate battery but also supply energy back to the grid.

1.2. Research questions and present contributions

This paper aims to develop one of the most comprehensive and complete Net-Zero Energy method achievable, as "Realistic Net Zero Energy" is referred to, by utilizing the advantages of the currently used strategies and removing its drawbacks for balancing the energy of the buildings, which is also to provide answers by addressing the following questions:

How would implementing a net-zero energy strategy in buildings, considering aspects including energy use, carbon emissions, and consumption of resources, contribute to benefit the planet and humanity?

In the context of designing and constructing buildings for net-zero energy, what is a currently overlooked perspective that could be incorporated into the process, and how might the application of this new approach be?

How does the net-zero energy building decrease the energy it

requires and its embodied energy as well as integrate renewable energy sources, enabling it to fulfil its energy demands?

The RNZEB approach is enforced in that the building generates sufficient power from renewable sources to meet both the structure's embodied energy and the total energy it will consume over its lifespan. The building will utilise this power for its purposes and feed extra electricity back into the municipal grid. The promises provided by this method; RNZE strategy may therefore be the most important tool in achieving the UK's Net Zero Target by 2050, as it reduces the buildings sector's energy demands and emissions production to zero. The RNZEB approach eliminates emissions from the energy consumed by buildings and reduces a city's emissions by partially meeting its electricity demand through transmitting energy to the grid.

Natural resources have sparked ongoing geopolitical tensions and even battle between the nations that control them and those who seek to capitalise on them. By implementing RNZEB methods in the building sector, where energy consumption is most significant, the necessary energy can be met the utilization of renewable energy source, helping in lowering the need for fossil fuels and the risks they pose. This strategy promotes national energy security and might help reduce global tensions related to energy reliance. RNZEB strategy may help to reduce foreign dependency on energy and raw materials by encouraging recycling and locally sourced using low embodied energy materials and building of energy-resilient structures which reduce reliance on external energy sources as well as it might be a solution to the waste problem and preservation of the natural resources.

To illustrate the benefits of the RNZEB strategy, the study analyses a concept house constructed of three different structure systems (steel, reinforced concrete, and timber) that was constructed using traditional methods. Following that, the performance of each version is contrasted with that of the same house that uses RNZEB techniques.

2. Literature review

2.1. Net zero energy building

The requirement for building has increased due to the population's rapid growth, which has led to an increase in the total energy consumption of the population. The idea of Net Zero Energy Buildings (NZEBS) and green cities has evolved to solve this issue (Ibrahim and Ananthi, 2024). Buildings intended to generate as much energy as buildings use throughout their life cycle through renewable energy sources, and achieve a net-zero energy balance, are known as NZEBs, as mentioned before. Usually, a combination of on-site renewable energy generation and great energy efficiency is used to achieve the target (Abrahamsen et al., 2023). The previous objective of the NZE strategy is to minimise energy use, the building should be designed with features such as a green modern isolation and passive design techniques to decrease energy consumption (Lou and Hsieh, 2024). HVAC (heating, ventilation, and air conditioning) systems are among the largest consumers of energy in buildings, because they are crucial to maintaining the resident comfort so, there is a great opportunity to significantly lower energy usage through performance improvements to conventional HVAC systems (Bhagwat et al., 2015). Finally, ZEBs incorporate renewable energy and other technologies to fulfil their low energy requirements (Li et al., 2013). Future suggestions for promoting NZEB initiatives include implementing standards, policies and offering financial incentives. Therefore, more developers would be encouraged to invest in sustainable building technology and design. As a result, NZEB implementation may be accelerated, which will significantly lower energy use, carbon emissions, and environmental effects in the building industry (Ibrahim and Ananthi, 2024).

2.2. Building energy saving methods

Energy-saving techniques for residential projects can be broadly

divided into two categories: passive and active methods. Passive Energy-Saving Method includes building orientation and design; Optimising building orientation to maximise passive solar advantages is a basic and economical way to design buildings that use less energy (Karimi et al., 2024). Natural ventilation combined with passive cooling is a practical way to reduce reliance on energy-intensive mechanical HVAC systems (Gilvaei et al., 2022). Thermal insulation functions on the principle that insulation should be installed properly using energy-efficient materials to minimise heat gain or loss, which in consequence reduces energy consumption (Aditya et al., 2017). Reducing consumption of energy requires upgrading building envelopes, the primary measurement of envelope performance is thermal resistance (R-value), and enhancing building envelopes' R-value is crucial to achieving energy efficiency (Al-Radhi et al., 2025). The natural insulation of green roofs reduces heat transmission through the roof, which in turn reduces the demand for air cooling in the summer and heating in the winter (Shafique et al., 2018).

A number of techniques have been applied in the active classification, including the use of new refrigerants, ground-source and hybrid heat pumps, and earth-to-air heat exchangers. Active systems involve the use of a fan and heat pumps/boilers to transfer the energy throughout the building (Taherian and Peters, 2023).

2.3. Building energy generating methods

A renewable energy system uses natural resources such as sunshine, wind, water, and geothermal heat to produce energy. Building projects may use these technologies to improve sustainability, minimise carbon emissions, and lessen dependency on fossil fuels (Ma et al., 2023). Solar panel; by transforming sunlight into direct current in solar cells, or PV cells, solar PV technology is one of the best ways for utilising solar power to generate electricity. Devices based on electronic semiconductor materials, namely but not only crystalline silicon (c-Si) or thin-film semiconductor materials, are used for PV energy conversion (Al-Ezzi and Ansari, 2022). The most popular technique is rooftop installations, in which solar panels are put on the top of residential, office complexes, hospitals, and hotels to maximise solar radiation (Ghaleb and Asif, 2022). Another method is called "building-integrated photovoltaics," or BIPV. Modern PV modules called BIPVs are incorporated into the envelope of the building which can also be included into the facade; these devices often take the place of the traditional roofing system. Additionally, compared to non-integrated systems, integrated photovoltaics construction eliminates the need for stand-alone systems and land allocation (Polcovicu et al., 2022).

Wind turbine; building projects may utilise wind turbines to collect wind kinetic energy and produce power. To optimise the use of wind resources, these turbines can be erected on nearby land, integrated into building structures, or positioned on rooftops (Bošnjaković et al., 2025). Wind turbines are classified into two basic types: horizontal-axis wind turbines (HAWTs), which rotate their blades around a horizontal axis, and wind turbines with vertical axis rotation (VAWTs), which include blades rotating in a vertical direction, each is appropriate for a particular set of wind circumstances and uses (Wang et al., 2024).

2.4. Embodied energy

Many different types of materials are used in building construction, embodied energy refers these building materials of energy in manufacture, on-site delivery, construction, maintenance, refurbishment, and final destruction (Dixit et al., 2012). Embodied energy, which considers the hidden energy included in construction goods, is a crucial component in evaluating the overall environmental effect of building materials. Embodied energy can be reduced by using recycled material, material efficiency, energy saving manufacturing procedures (Almusaed et al., 2024). ICE (The Inventory of Carbon and Energy) is a comprehensive database created specially to measure the embodied energy

connected to different building materials, it is a cradle-to-gate and is open access (Hammond and Jones, 2008). The University of Bath created ICE, which offers crucial information for evaluating the environmental effects of construction materials at every stage of their life cycles, from extraction to disposal (Hammond and Jones, 2008).

2.5. Building information modelling (BIM)

Building Information Modelling (BIM) is a "methodology to manage the essential building design and project data in digital format throughout the building's life-cycle" that is generated by a combination of related regulations, procedures, and technology which is a broad field of project in the AECO (Architecture, Engineering, Construction, and Operations) sector (Succar, 2009). BIM may offer an integrated platform for planning, visualisation, and analysis, which may be a major help in the design and construction of NZEBs (Myint and Shafique, 2024). BIM improves sustainability results for multi-family residential buildings by facilitating an integrated and methodical approach to green building design that follows LEED requirements (Ur Rehman et al., 2022). The early design phase can be used to optimise the building's energy performance through simulation by architects and engineers thanks to this thorough digital illustration (Myint and Shafique, 2024). BIM can evaluate several design options and determine the most energy-efficient lighting, ventilation, heating, and cooling systems by incorporating energy analysis tools. To make sure that the building's energy output can equal or surpass its consumption, it also assesses energy generation systems less challenging (An et al., 2024). Promoting a modern approach to sustainable design through the adaptable application of BIM technologies involves incorporating eco-friendly practices. Additionally, assessing a variety of results in order to receive eco-friendly rating credits (Siddhartha and Ananthi, 2024).

Project teams may monitor and control the embodied energy of building materials and carbon emissions with the aid of BIM to assess LCA (Hussain et al., 2023). The BIM can ensure every aspect of the building's design, construction, and operation contributes to reaching net zero energy and emissions objectives by providing accurate documentation and real-time changes. The Fig. 1 represents a process for comfort optimization and building energy modelling with BIM.

The process begins with a physical model (using the BIM), followed by an energy model derived from the physical model, and finally an energy simulation to demonstrate the building's performance, as shown in Fig. 1. Seven steps were involved in the implementation of this procedure: designing the physical model, defining the location, developing the energy model, creating the first energy simulation, adjusting comfort in accordance with current standards, processing the data using experimental planning, and developing a statistical analysis of the revised model confirming the results.

3. Theory and methodology

The purpose of this study is to introduce the significance of including the energy required to produce materials that are not included in the existing definition of net zero energy into the equation with the Realistic Net Zero Energy Strategy it developed. It quantifies the total energy consumption associated with the materials and operations of buildings as well as demonstrates how this energy demand can be offset by utilizing renewable energy sources. Using information from one of the BIM systems, Revit, the total embodied energy of the structure is computed, and encouraged to select low-energy materials. Then, Buildings are required to fulfil their operating energy requirements as well as produce an amount of energy from renewable resources equal to the total embodied energy. When this excess produced energy is transmitted to the city grid during the building's lifespan, it will achieve the RNZEB target.

The goal of the paper is to demonstrate the significance of the Realistic Net-Zero Energy strategy in the globe and the reasons it is more

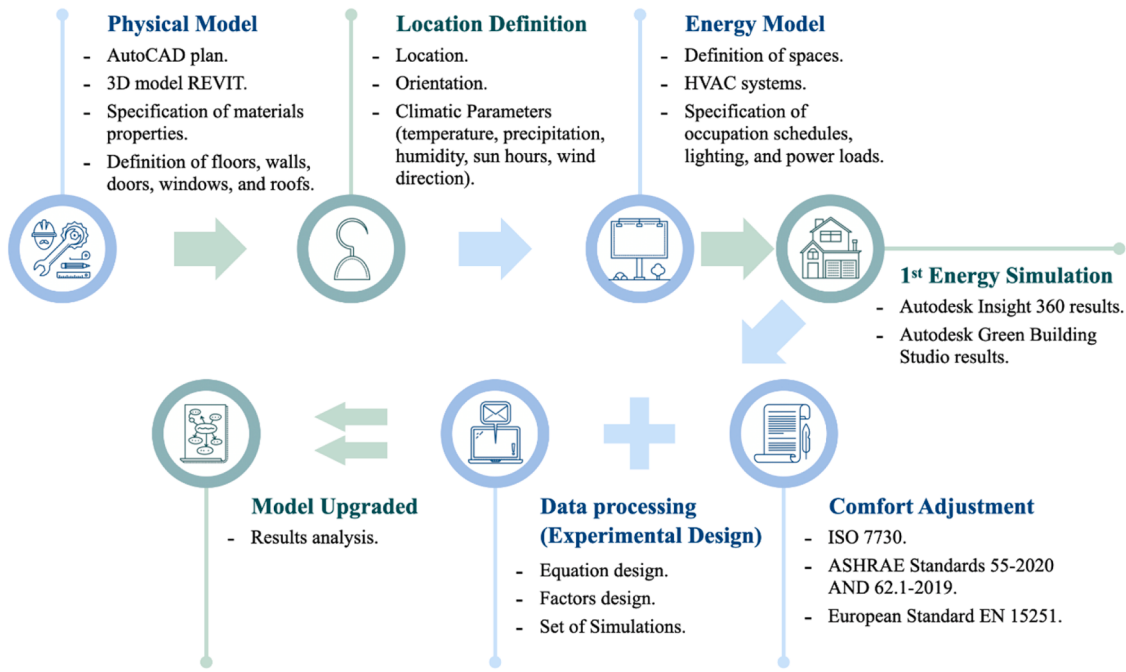


Fig. 1. BIM workflow (González et al., 2021).

effective and complete than other methods. To accomplish this, a conceptual two-story house is planned in London. The house will be constructed with steel, reinforced concrete, timber structure using conventional construction techniques and calculating additional measurements, including each building's overall embodied energy and energy use for operations. Then, will apply cutting-edge technology, eco-friendly design techniques, and low-energy embodied materials to these buildings, and will recalculate the same measurements. These different data will be analysed to demonstrate the efficacy and effectiveness of the RNZEB Method. The functional unit utilised in this study is the "total house," which was conceptualised in London. The energy required for construction material manufacturing and the house's energy usage over its 50-year life cycle are included in the system boundaries.

3.1. Equation of realistic net zero energy buildings

The equation suggested by the study is:

$$0 \geq E_1 + E_2 - E_3 \quad (1)$$

E_1 = The amount of the total energy required for the building's material. E_2 = The amount of total energy required by the building's operation in its 50-year lifespan. E_3 = The amount of total energy generated from renewable resources in its 50 years. The unit is in Kilowatt-hour (kWh).

3.1.1. Embodied energy (E_1)

The total amount of energy required for building material extraction, manufacture, transportation, and assembly, as well as for building construction, building maintenance, and end-of-life operations (Kamazani et al., 2025).

$$E_1 = \sum_{n=1}^{k=0} E_{1i} = \sum_{n=1}^{i=1} (a_i \times b_i) \quad (2)$$

E_1 = the total energy from material production; E_{1i} = the energy from the production of material i , a_i = the coefficient of energy from the production of material i , b_i = the quantity of material i , $i = 1, 2, \dots, n$, are the types of materials considered. The unit of a_i is kWh/kg, and the unit

of b_i is kg. The energy factor a_i depends on the material type.

3.1.2. Operational energy (E_2)

The term "building operational energy" describes the energy used for equipment and appliance use, lighting, heating, and cooling all over a building's operating phase (Pérez-Lombard et al., 2008).

$$E_2 = \sum_{n=1}^{k=0} E_{2i} = \sum_{n=1}^{c_i \times d_i} (c_i \times d_i) + \sum_{n=1}^{k_i \times l_i} (k_i \times l_i) + \sum_{n=1}^{m_i \times p_i} (m_i \times p_i) + \sum_{n=1}^{r_i \times s_i} (r_i \times s_i) \quad (3)$$

E_2 = the total energy from operation; E_{2i} = the energy from the operation i . c_i = Energy consumed per hour for heating i , d_i = hour used i , $i = 1, 2, \dots, n$, are the number of equipment considered. The unit of c_i is kW, and the unit of d_i is hour. k_i = Energy consumed per hour for cooling i , l_i = hour used i , $i = 1, 2, \dots, n$, are the number of equipment considered. The unit of k_i is kW, and the unit of l_i is hour. m_i = Energy consumed per hour for lighting i , p_i = hour used i , $i = 1, 2, \dots, n$, are the number of equipment considered. The unit of m_i is kW, and the unit of p_i is hour. r_i = Energy consumed per hour for appliance i , s_i = hour used i , $i = 1, 2, \dots, n$, are the number of equipment considered. The unit of r_i is kW, and the unit of s_i is hour.

3.1.3. Generation energy (E_3)

Biofuels, biomass, micro-hydro, hydroelectricity, wind power, solar power, and hydroelectricity are varieties of renewable energy technology (Chel and Kaushik, 2018). Energy was generated from solar and wind sources in this paper.

$$E_3 = \sum_{n=1}^{k=0} E_{3i} = \sum_{n=1}^{t_i \times u_i} (t_i \times u_i) + \sum_{n=1}^{v_i \times y_i} (v_i \times y_i) \quad (4)$$

E_3 = the total generation energy from renewable resources; E_{3i} = the energy from the renewable resource i , t_i = Energy generation per square metre from solar panel i , u_i = square metre i , $i = 1, 2, \dots, n$, are the number of equipment considered. The unit of t_i is kWh/m², and the unit of u_i is m². v_i = Energy generation per metre from wind turbine i , y_i = metre i , $i = 1, 2, \dots, n$, are the number of equipment considered. The unit

of v_i is kWh/m, and the unit of y_i is m.

3.2. Research flow

This research aims to demonstrate the importance of a Realistic Net Zero strategy by comparing data from concept housing projects built using traditional methods in London with data from their RNZE versions. The research also investigates the condition of these houses when they are constructed with steel, reinforced concrete, and timber, demonstrating the impact of the energy from materials and structure

systems selection. These buildings are obligated to conform to a set of clearly defined phases as shown in Fig. 2 to achieve the RNZE target.

Design Phase: designing the preliminary project by adding the design of additional energy-saving methods with building codes, customer demands, and architectural knowledge. Factors such as orientation, and integration of natural lighting and ventilation are all considered throughout the design process.

Phase 1 (E_1); the structure system is determined, and the application project is drawn with Revit 2024 based on the preliminary project.

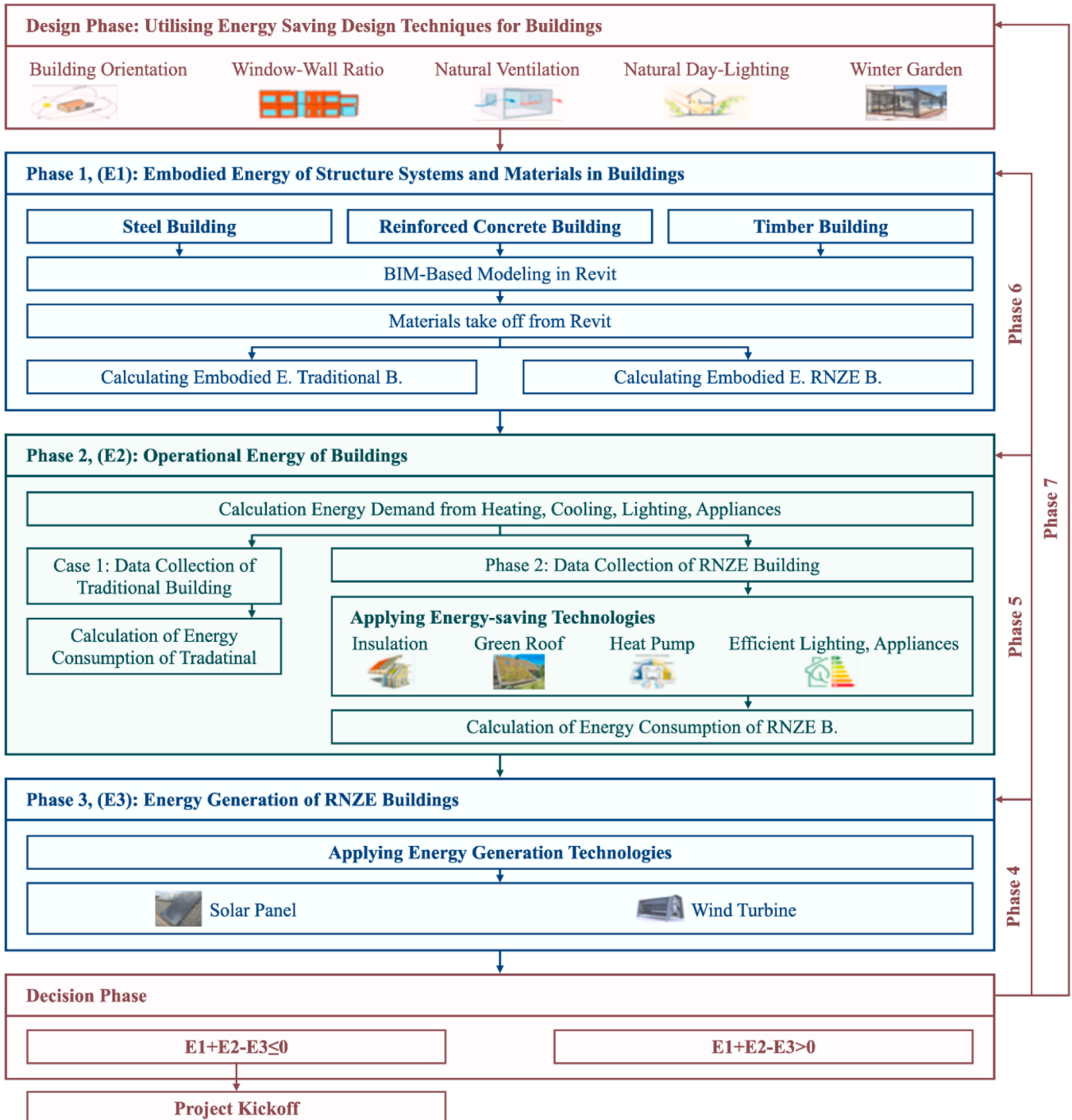


Fig. 2. Flowchart of the study's methodology.

The total embodied energy of the building is calculated using two options: Traditional and realistic net zero energy.

Phase 2 (E_2); the energy required for appliances, lighting, heating, and cooling in a traditional building is calculated at this point to compare operating energies. The energy consumption that results from implementing energy-efficient techniques common to the RNZE version is then calculated.

Phase 3 (E_3); technologies can generate energy from renewable sources that can be applied to the RNZE building are decided and the energy produced from these sources is calculated.

Decision Phase: The project is considered feasible if the energy generated in the RNZE building is equal to or greater than the total of the building's operational and embodied energy. But in the event that the energy generated is less than this amount, further actions are taken:

Phase 4; return to Phase 3 and investigate additional methods to produce renewable energy. The goal is to balance the energy output such that it equals or surpasses the total energy used by the building for both operations and embodied energy.

Phase 5; if phase 4 is not sufficient, it is returned to phase 2, and new energy-saving methods for decreasing operational then ways to produce more energy from renewable resources are sought for ensuring energy balance.

Phase 6; if phase 5's actions appear to be insufficient, the process goes back to Phase 1, during which lower-carbon structural systems or materials are chosen to minimise embodied energy. To achieve energy balance, new energy-saving techniques and different approaches to generating renewable energy are also investigated. Phase 7; if none of these phases can satisfy the RNZEB standards, the process goes back to the design phase for an extensive review and radical adjustments, reevaluating every phase from this stage forward to attain energy balance.

3.3. Case study

For this study, a 2-storey detached house project was designed as a concept in London as a case study. It consists of 4 bedrooms, 3 bathrooms, a kitchen, a living room, a winter garden, a storage area and an attic as shown in Fig. 3.

The first floor is 98 m², the second floor is 82 m² and the attic is 90 m². The total is 270 m². The energy demands of a traditionally constructed steel, reinforced concrete, and timber house with these plans

and design principles are compared with the energy demands of the RNZE versions of these houses. This case study consists of 6 scenarios. Fig. 4 shows the schematic and artistic visualisation of these various scenarios, while Table 1 illustrates the key building characteristics of these scenarios.

3.3.1. Design phase of the concept project

To achieve Realistic Net Zero Energy in building design, passive energy-saving techniques can be efficiently included in the preliminary design phase to help achieve this target. The main areas where the household spends most of its time (the living room, kitchen, and winter garden) are orientated to face south in this project. By positioning these places to take advantage of maximum solar heat gain and natural light, the amount of artificial lighting and heating required in these often-utilised areas is reduced. In contrast, areas that are less important for natural light and warmth, such as bathrooms, storage, and staircases, are orientated towards the north. To maximise sun, gain and improve energy savings during the winter, wider windows and the winter garden were added to the building's south side. This passive solar heating method lessens artificial heating system requirements by capturing sunshine. The quantity and size of windows on the north side of the building have been restricted to reduce this thermal inefficiency. While all of the project's rooms are constructed with windows, energy saving is accomplished through the strategic use of sunshine. By employing this method, the building's total energy efficiency is increased and its reliance on artificial illumination is reduced, which lowers power usage.

3.3.2. Embodied energy

The proper structural system is carefully selected, and the building materials are also picked precisely in this phase. Following the selections, Revit 2024 (a highly advanced software program that makes creating complex application project designs easier) is used to meticulously application projects. The material bills of quantities are carefully taken out of Revit 2024. The Inventory of Carbon and Energy (ICE) database, developed by the University of Bath, is used in the paper to measure and evaluate the embodied energy of the suggested construction materials (Hammond and Jones, 2008).

3.3.2.1. Calculation embodied energy of the traditional houses.

a. Traditional Steel House

The embodied energy of the house according to the study would be

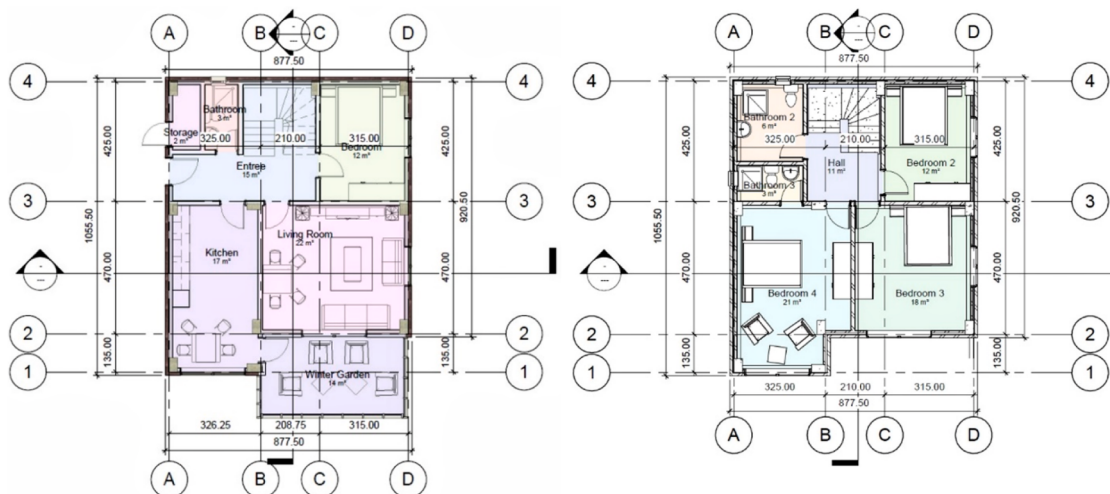


Fig. 3. Floor plans of a conceptual house.

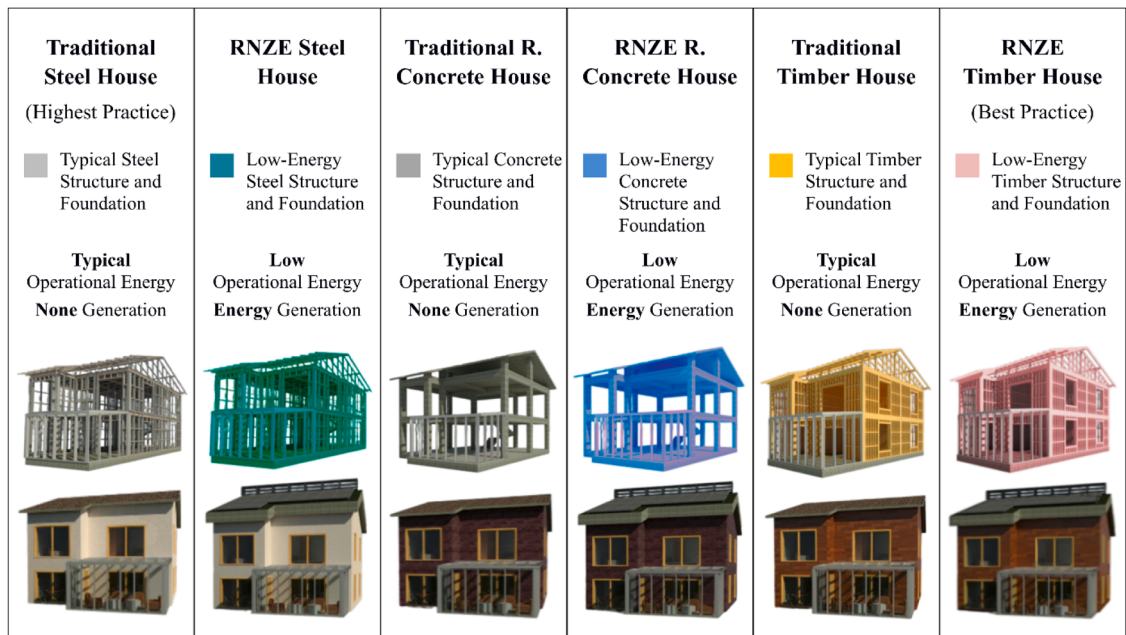


Fig. 4. Schematic and artistic visualisation of the traditional and RNZE houses scenarios.

Table 1

Key building characteristics of traditional and realistic net zero energy house case study scenarios.

Building Characteristics	Traditional Steel	RNZE Steel	Traditional R. Concrete	RNZE R. Concrete	Traditional Steel	RNZE Timber
Design						
Total construction area	270 m ²	270 m ²	270 m ²	270 m ²	270 m ²	270 m ²
Orientation	Optimum	Optimum	Optimum	Optimum	Optimum	Optimum
Natural Ventilation	Optimum	Optimum	Optimum	Optimum	Optimum	Optimum
Window-Wall Ratio	85 %	85 %	85 %	85 %	85 %	85 %
Natural Day-Lighting	Optimum	Optimum	Optimum	Optimum	Optimum	Optimum
Winter Garden	Yes	Yes	Yes	Yes	Yes	Yes
Structure system						
Beam and Column	Steel	L. Steel	Concrete	L. Concrete	Timber	L. Timber
Foundation	Concrete	L. Concrete	Concrete	L. Concrete	Concrete	L. Concrete
Winter Garden, window	Aluminium	L. Aluminium	Aluminium	L. Aluminium	Aluminium	L. Aluminium
Insulation						
Rock wool	No	Yes	No	Yes	No	Yes
Green Roof	No	Yes	No	Yes	No	Yes
Windows Glazing	Single	Double	Single	Double	Single	Double
Operational Energy						
Lighting	Incandescent	LED	Incandescent	LED	Incandescent	LED
Heating	Natural Gas	Heat Pump	Natural Gas	Heat Pump	Natural Gas	Heat Pump
Cooling	Air-Conditioner	Heat Pump	Air-Conditioner	Heat Pump	Air-Conditioner	Heat Pump
Appliances	Typical	A+++	Typical	A+++	Typical	A+++
Generation Energy						
Solar Panel	No	Yes	No	Yes	No	Yes
Wind Turbine	No	Yes	No	Yes	No	Yes



(a) Architectural 3D View



(b) Structural 3D View

Fig. 5. Revit models of the house design in steel.

approximately 1110,957.7 megajoules (MJ), or roughly 308,599.2 kWh, provided it was built using traditional steel building techniques, as detailed in supplementary 1.2.a (Fig. 5).

b. Traditional Reinforced Concrete House

The embodied energy of the house according to the study would be approximately 864,890.2 megajoules (MJ), or roughly 240,247.2 kWh, provided it was built using traditional reinforced concrete building techniques, as shown in supplementary 1.2.b (Fig. 6).

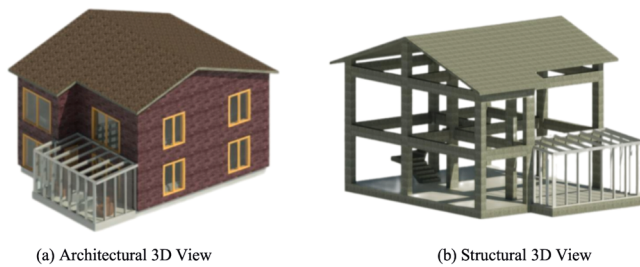


Fig. 6. Revit models of the house design in reinforced concrete.

c. Traditional Timber House

The embodied energy of the house according to the study would be approximately 546,854.6 megajoules (MJ), or roughly 151,902.7 kWh, provided it was built using traditional timber building techniques, as illustrated in supplementary 1.2.c (Fig. 7).

3.3.2.2. Reduction of embodied energy of materials. There have been several attempts to reduce the embodied energy of building materials. These initiatives include, for example, the development of new bio-based natural materials (like hempcrete and geopolymers), the use of complex construction techniques (such as robotic construction and large-scale 3D printing), the utilisation of locally sourced, long-lasting, low-maintenance materials, and the incorporation of renewable energy into the production and shipping industries (Dixit et al., 2025). Applying these methods to C25 concrete often results in a drop in this value of embodied energy to 0.75 MJ/kg, reinforced concrete steel decreases to 8.8 MJ/kg, reduce the embodied energy of aluminium to 28.8 MJ/kg, the embodied energy of the timber decreases to 8 MJ/kg (ICE, 2019).

The implementation of the aforementioned energy reduction techniques in the London conceptual house projects have led to notable enhancements in the embodied energy of buildings. The total embodied energy of the RNZE steel house decreased to 734,792.6 MJ (204,108.8 kWh), the total embodied energy of the RNZE reinforced concrete house decreased to 651,460.4 MJ (180,961.1 kWh), and the total embodied energy of the RNZE timber house decreased to 481,641.1 MJ (133,789.1 kWh). Supplementary 1.2.2 provides information on the ways the embodied energy of materials has been reduced, and supplementary 1.2.3 presents the process utilised to calculate the embodied energy of RNZE Houses.

3.3.3. Operational energy

The energy used for activities including heating, cooling, lighting, and operation of various appliances and systems required to maintain daily functionality is referred to as operational energy (Pérez-Lombard et al., 2008), and it is an essential part of a building's energy profile.

3.3.3.1. Calculation operational energy of traditional house.

a. Lighting

In this study traditional houses use incandescent type bulb, which usually around 10 lm per watt. Lighting energy consumption can be calculated by multiplying the installed lighting power by a quantity called equivalent operating time (Rosemann and Suvagau, 2008). Annual energy requirement for lighting is 4793.00 kWh, as shown in supplementary 1.3.1.a.

b. Cooling

In the paper, air conditioning is used to cool traditional houses. Providing thermal comfort and a suitable level of indoor air quality for

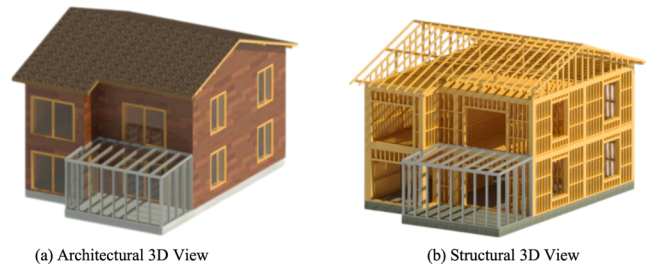


Fig. 7. Revit models of the house design in timber.

residents is the aim of the systems (Yu et al., 2009). The energy required for one year's cooling is 4350.00 kWh, as shown in supplementary 1.3.1. b.

c. Heating

Heating is crucial for preserving comfort, health, and the structural integrity of houses. One of the most popular methods for providing the energy required for space heating in residential buildings is still gas-fired heating boiler units (Simic et al., 2021). Following equation is a basic formula for calculating heating energy requirements (University of Strathclyde, 2020).

Annual Heating Energy Requirement

$$= \text{Peak Heating Load} \times \text{Full Load Hours} \quad (5)$$

- Heating Load = 26.45 kW (the necessary amount of heat).
- The average heating operating duration in the UK is between 1691 and 1890 h per year, according to research by Delta Energy & Environment Ltd. (BEIS, 2017).
- Considering such uncertainty margins and changes in the usage period, assume that 1800 h of heating are needed annually in the study.

$$\begin{aligned} \text{Annual Energy Requirement} &: 26.45 \text{ kW} \times 1800 \text{ h} \\ &\approx 47,610.00 \text{ kWh/year} \end{aligned}$$

- The efficiency of the boiler selected for this paper is 92 %.

$$\begin{aligned} \text{Adjusted Annual Energy Requirement} &= \frac{47,610 \text{ kWh/year}}{0.92} \\ &\approx 51,749.00 \text{ kWh/year} \end{aligned} \quad (6)$$

A more detailed calculation is present in supplementary 1.3.1.c.

d. Appliances

Appliances for the home are necessary tools made to simplify, accelerate, and enhance the convenience of daily tasks. The annual energy consumption of the appliances used in a traditional home designed as a concept in London is 5125.00 kWh, as indicated in supplementary 1.3.1.d.

3.3.3.2. Calculation operational energy of realistic net zero energy house. The variety of methods and tools used to combine energy-efficient technology, renewable energy sources, and advanced building techniques to accomplish the realistic net zero energy objective is depicted in Fig. 8.



Fig. 8. Features of the realistic net zero energy house.

a. Energy Efficient Lighting

Energy-efficient lighting involves the use of lighting technologies that, in comparison with traditional lighting solutions, utilise less power while offering the same or better levels of illumination. LED (Light Emitting Diode) and CFL (Compact Fluorescent Lamp) bulbs are the most widely used energy-saving lighting options. The fast growth of solid-state lighting based on high-brightness visible LEDs can possibly be attributed to several important features, including high efficiency, durability, low power consumption, rugged construction, and reliability (Yam and Hassan, 2005). Since LEDs have a luminous efficacy rate of 70 lumens per watt (much higher than that of CFLs and conventional incandescent bulbs) LEDs are used in this study for energy-saving lighting. The annual energy requirement of a RNZE house that uses LED for lighting is 702.40 kWh, as detailed in supplementary 1.3.2.a.

b. Energy Efficient Heating and Cooling

To achieve energy-efficient heating and cooling in a RNZE home, minimising heat loss and capacity is an essential priority. Envelope Insulation assists this project in achieving Net Zero Energy Targets. The Energy Performance of Buildings Directive recommends designers to incorporate insulating materials into the building envelope to lower the energy consumption during operation in order to preserve the structure's intended temperature and provide thermal comfort for its residents (Braulio-Gonzalo and Bovea, 2017). In RNZE houses, double-glazed aluminium-framed windows is used to improve the insulation of the building envelope, and rock wool and green roof are employed for thermal insulation in the walls and floors as shown in Fig. 8. The energy required to maintain thermal comfort in the RNZE house is shown below, using a more efficient heat pump for heating and cooling, as provided in supplementary 1.3.2.b.

b.i. Calculating Annual Energy Requirement for Heating with a Heat Pump

- The heating load is 8.98 kW.
- The total number of Heating Degree Days (HDD) in the UK is affected by external temperatures and environmental factors, which also affect the amount of heating hours each year (range between 1691–1890 h per year). The study assumes that the heating time is 1800 h to account for this variability.

- The COP of the air-air heat pump varies between 3.4 and 3.54 (Wang et al., 2021).
- Considering such uncertainty margins and changes in the usage period, a COP is assumed of 3.5 on average to provide sensitivity in the paper.

Annual Heating Energy Requirement

$$= \frac{\text{Heating Load} \times \text{Heating Hours}}{\text{COP}} \quad (7)$$

$$\text{Annual Heating Energy Requirement} = \frac{8.98 \text{ kW} \times 1800 \text{ hours}}{3.5} \approx 4,618.00 \text{ kWh/year}$$

b.ii. Calculating the Annual Energy Requirement of Cooling with a Heat Pump

By transporting heat from the inside of the house to the outside, a heat pump can be used to cool a building and reduce its interior temperature. The Coefficient of Performance (COP), a measure of how well the pump uses electrical energy to remove heat, is used to quantify the efficiency of the system. The COP for contemporary air to air heat pumps usually falls between 3.4 and 3.54 (Wang et al., 2021). This means that for every 1 kW of electrical energy used, the heat pump can remove 3.4 to 3.54 kW of heat from the conditioned area.

- The total cooling (Q) load is 4350 kW.
- Considering such uncertainty margins and changes in the usage period, a COP is assumed of 3.5 on average to provide sensitivity.

$$\text{Annual Cooling Energy Requirement} = \frac{Q}{\text{COP}}$$

$$\text{Annual Cooling Energy Requirement} = \frac{4,350}{3.5} \approx 1,243.00 \text{ kWh/year}$$

c. Energy Efficient Appliances

Residential energy use is now responsible for a significant portion of overall energy use and associated emissions. Furthermore, there is an extensive amount of potential growth in this consumption in both

developed and developing nations as average earnings and the quantity of household appliances rise (Kelly, 2012). Through conservation efforts as well as more efficient use, this energy consumption can be decreased. Energy-efficient appliances are capable of performing the same duties as their less efficient equivalents with less energy or gas usage. In this paper, A+++ appliances are used for energy saving. The energy consumed by these energy efficiency devices in a year is 3720.00 kWh, as illustrated in supplementary 1.3.2.c.

3.3.4. Generation of energy in realistic net zero energy houses

The purpose of realistic net zero energy is to ensure that a building produces sufficient renewable power to fulfil its operating requirements and offset the embodied energy, hence ending reliance on outside energy sources. In this project, wind turbines and solar panels were utilised to deal with that requirement.

a. Solar Panel

Due to their greater efficiency and superior performance in a range of light situations, monocrystalline solar panels were chosen in this study in light of London's relatively high solar irradiation and constrained roof area. This kind is the best option for this project as it maximises energy output from the given roof surface. Therefore, the monocrystalline solar type with 21.5 % efficiency is installed on a net area of 39.88 square meters at an angle of approximately 30 degrees as shown in Fig. 8. The following equation is for the yearly energy production (Sarniak, 2021)

$$\text{Annual Energy Generation from PV} = A \times I \times \eta \quad (8)$$

- The solar panel's effective area, measured in m^2 , is A. The average solar irradiance, expressed as $\text{kWh}/\text{m}^2/\text{year}$, is I. The solar panels' efficiency is represented by η .
- The European Commission Joint Research Centre estimates that the UK receives between 750 and 1100 kWh/m^2 of total sun irradiation annually (Dhimish et al., 2018).
- Considering such uncertainty margins and changes in the usage period, the value is assumed of 980 $\text{kWh}/\text{m}^2/\text{year}$ on average to provide sensitivity.
- The efficiency of the selected solar panels is 0.215.
- Generation Energy: $39.90 \text{ m}^2 \times 980 \text{ kWh}/\text{m}^2/\text{year} \times 0.215 \approx 8406.50 \text{ kWh}/\text{year}$, as shown in supplementary 1.3.3.a.

b. Wind Turbine

A wind turbine is a machine that generates electricity from wind energy (Manwell et al., 2010). London's moderate wind conditions allow small-scale home wind turbines to provide energy equivalent to the total energy of the entire household and embodied energy, particularly when combined with solar panels. Therefore, Ridge Blade's RB1 Residential model, one of the most efficient wind turbines ever produced, was chosen for this project as shown in Fig. 8.

- Generation Energy: 6 rotors / 7.2 m ridge length / 1.0 m width were used in this project. This system occupies approximately 7.2 m^2 of roof space.
- Capacity per five-rotor system: 2 kW continuous, 2.7 kW peak (RidgeBlade, 2024).
- Considering London's average wind speed, the wind's continuity (capacity factor, generally 15–40 %), and slope of house, this wind turbine is expected to produce 6025.40 kWh of energy per year, as presented in supplementary 1.3.3.b.

Combining wind turbines and solar panels enables the production of sustainable more energy while utilising the benefits of both technologies. Solar energy systems by themselves are unable to provide a steady supply of energy because of their limited availability in the winter and

during the no-sun period. Also, considering wind speeds vary from hour to hour, wind systems themselves lack the ability to provide stable load requirements (Ozdamar et al., 2005). In this study, it is collaborated to produce energy in situations where both systems are disadvantageous. The ability of the RB1 wind turbine to continually produce power offers a notable benefit by taking advantage of higher wind speeds during the night when solar panels are inactive. During the day, especially in the summer, solar panels usually generate more energy; however, during the winter, their production decreases. However, because of the greater wind throughout winter, the RB1 turbine performs better and makes up for the lower solar production (RidgeBlade, 2024). Because of their complementing interaction, solar panels and RB1 provide more steady and balanced energy output throughout the day and in all seasons.

To summarise, the integration of solar panels with wind turbines maximises energy production throughout the year and at different times of the day. These houses are designed as a practical NZE model, produces 14,431.9 kWh of renewable energy per year, of which 6025.4 kWh are generated by wind turbines and 8406.5 kWh from solar panels. The house requires 10,283.4 kWh of energy per year for operations, providing a surplus of 4148.5 kWh annually. The additional electricity is fed into the municipal grid, contributing to balance out the energy that is embodied in buildings. In the paper, the embodied energy of a steel building is 204,108.8 kWh, that of a reinforced concrete structure is 180,961.1 kWh, and that of a timber house is 133,789.1 kWh.

3.4. Feasibility

One of the significant aspects of the methodology adopted for this study is the viability of the Realistic Net Zero Energy Building (RNZEB) approach. Using Revit 2024, an effective BIM software, this project was developed and illustrated at the application level. The structural, mechanical, and electrical (MEP) project components were detailed and designed in compliance with real-world application standards, complementing the architectural model. The calculations of embodied energy (E_1) and operational energy (E_2) were obtained directly from the performance parameters and material quantities produced in the BIM environment or determined by the technical calculations. So, energy demand estimates are assured to represent actual building situations rather than theoretical models.

In addition, the building's design took into account London's climate conditions, including regional weather patterns and seasonal fluctuations. Real-world environmental circumstances were taken into consideration when selecting the site, room orientation, spatial arrangement, and passive design components. This assures that the energy performance results are indicative of a real implementation scenario in the cities London configuration, especially with regard to heating, cooling, and lighting. Additionally, technologically feasible and commercially accessible components were utilised to decide on and integrate renewable energy systems (such as heat pump, wind turbines, solar panels, LED), and statistically proven coefficients were performed to calculate their energy generating capacity.

A RNZEB performance is highly sensitive to both design and environmental factors, especially the building's geographic location. Climate conditions such as temperature, solar irradiation, and wind availability affect both the operational energy demand and the potential for on-site renewable energy generation. Their orientation and the local climate significantly influence the insulation materials and their thickness to be used in RNZEBs, as well as the type of window material and the number of glass layers. RNZEBs' embodied energy is greatly affected by those parameters. By utilize accurate climatic data, this research specifically focuses on London as the project location, ensuring that all calculations and assumptions are based on real-world circumstances.

4. Results analysis

This research offers the idea of a realistic net zero energy building,

which transmit the city grid with the additional electricity it generates as well as provides its operating energy requirements and offsets the embodied energy of the building's construction materials. The result section proves the effectiveness of the RNZE strategy, which is assessed based on the three structure systems are often used in the world (steel, reinforced concrete, timber).

4.1. Comparison of embodied energy in traditional and RNZE house

The same houses in this study, designed in accordance with the RNZE strategy, were constructed using low-energy materials. The embodied energies of the materials used in RNZE houses and traditional houses are compared based on their structure system systems.

4.1.1. Embodied energy of steel house materials

The embodied energy of the materials used in the traditional steel house and the realistic net zero energy steel house are contrasted in the chart shown in Fig. 9. Compared to the typical structure, which consumes 574,910.30 MJ of embodied energy for low-energy structural steel, the RNZE house uses 226,194.20 MJ, or around 60.7 % less. In the same way, the RNZE home's low energy reinforced concrete steel has an embodied energy of 20,075.00 MJ, which is around 59.3 % less than the 49,275.00 MJ of the traditional house. The reductions indicate that the RNZE home could utilise more energy-efficient substitutes, resulting in a structural component system with a lower total energy footprint. The RNZE home uses extra thick glass for insulation, doubling the amount utilised from 10,400.40 MJ in the standard house to 20,800.80 MJ. Furthermore, the RNZE home adds rock wool, a substance absent from the traditional house, which adds 51,975.00 MJ to the total embodied energy. Although these options raise the initial embodied energy, they may indicate an emphasis on enhancing insulation, to boost energy efficiency throughout the building's operating phase. The embodied energy values of both houses are the same for a large number of additional materials, including plasterboard, fibre cement boards, deck sheets, and ceramics.

4.1.2. Reinforced concrete houses

The embodied energy of the materials used in the traditional reinforced concrete house and the RNZE reinforced concrete house are contrasted in the chart shown in Fig. 10. The RNZE home dramatically lowers the embodied energy of reinforced concrete steel to 64,235.80 MJ, a reduction of about 59.3 %, as opposed to 157,670.20 MJ in the standard house. The RNZE home utilises 172,513.60 MJ of bricks, which is approximately 33.3 % less embodied energy than the typical home's 258,770.40 MJ. Significant changes are also visible in the RNZE home concerning aluminium and glass. In contrast, with improved insulation, the energy for glass doubles in the RNZE home to 20,800.80 MJ from

10,400.40 MJ in a normal house. Furthermore, a material not included in the typical home, rock wool, with an embodied energy of 28,446.20 MJ, is included in the RNZE house. Even though the building has more glass and Rock wool, these changes suggest an alteration in material selections, to improve insulation and energy efficiency during the project's operating period. The RNZE concrete house improves insulation and lowers energy consumption in critical structural components.

4.1.3. Timber houses

The embodied energy of the materials used in the traditional timber house and the realistic net zero energy timber house are contrasted in the chart shown in Fig. 11. The embodied energy for structural timber in the RNZE home is significantly lower than in the typical building, using 75,529.50 MJ as opposed to 113,294.30 MJ, or a drop of around 33.3 %. Comparably, the RNZE home uses concrete and reinforced concrete steel more efficiently than a normal house does. Furthermore, the embodied energy required by the RNZE house for aluminium is 7525.40 MJ, which is almost 81.4 % less than that of the typical house, which consumes 40,501.50 MJ. These decreases, especially in important structural components, show that the RNZE house is made to choose more energy-efficient substitutes, assisting in reducing the total embodied energy footprint. Conversely, the RNZE home raises some materials' embodied energy. For example, the RNZE home uses 20,800.80 MJ of glass for insulation, compared to 10,400.40 MJ in the traditional house. Moreover, a material not included in the typical home, Rock wool, provides 51,975.00 MJ of embodied energy to the RNZE house. Despite the greater initial embodied energy in these materials, this reflects an intentional choice to increase insulation potentially in the RNZE house, which will minimise operational energy usage during the building's lifetime.

4.1.4. Comparison of houses' total embodied energies

A comparison of the total embodied energy of traditional and RNZE houses constructed from steel, reinforced concrete, and timber is presented in the bar chart in Fig. 12. The embodied energy of these buildings is substantially lower in their RNZE versions than in their traditional. The RNZE steel building, for example, would solely need 734,792.6 megajoules (MJ), a savings of >33 % from the 1110,957.7 MJ of embodied energy in the traditional steel house. All kinds exhibit this reduction in energy consumption: Traditional reinforced concrete and timber buildings utilise 864,890.2 MJ and 546,854.6 MJ, respectively, whereas their RNZE versions consume 651,460.4 MJ and 481,641.1 MJ, respectively, decreasing by about 24 % and 11 %. The selection of materials with reduced embodied energy is the main reason for the net-zero-energy homes' reduction in embodied energy.

In addition, these structures make significant use of rock wool, a very effective thermal insulation material, to improve energy efficiency



Fig. 9. Comparison of materials embodied energy in steel houses.

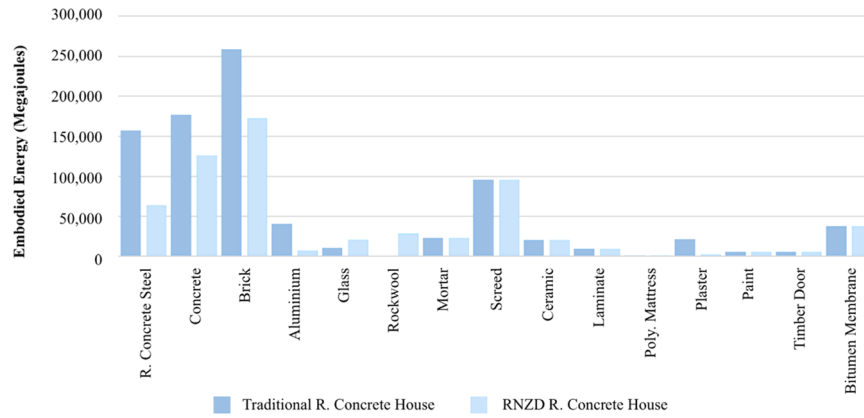


Fig. 10. Comparison of materials embodied energy in reinforced concrete houses.

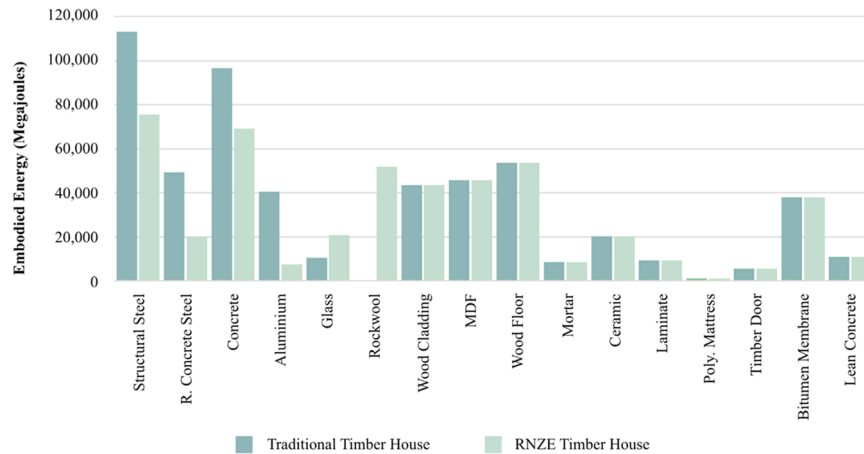


Fig. 11. Comparison of materials embodied energy in timber houses.

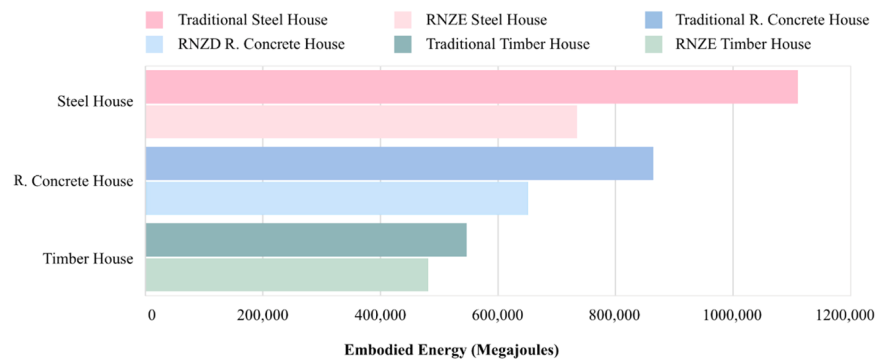


Fig. 12. Comparison of total embodied energy of traditional houses and RNZE houses.

throughout the operating period. In this study, 2-layer glass and rock wool were used for thermal insulation. The extra glass layer and additional rock wool increase the embodied energy of RNZE steel houses and RNZE timber houses by 62,375.4 MJ (equivalent to 17,326 kWh), and in reinforced concrete houses by 38,846.7 MJ (equivalent to 10,790 kWh). On the other hand, their use lowers the net energy need by substantially reducing the energy that would otherwise be consumed during the building's lifetime.

Overall, the data shows that traditional and net-zero energy versions of timber buildings have the lowest embodied energy, followed by reinforced concrete and steel homes in that order. The Conceptual House's embodied energy varies greatly, ranging from 1110,957.7 MJ

(308,599.2 kWh) to 481,641.1 MJ (133,789.1 kWh), depending on the structural systems and materials chosen. This variation demonstrates how using optimised structural systems can result in the construction of more than two dwellings with the same amount of energy.

4.2. Operational energy of houses

The Fig. 13 assesses the operational energy performance of the houses designed traditionally compared to those designed using RNZE principles. A considerable difference in efficiency can be observed when comparing the energy use of a traditional house with a RNZE home over a year. The RNZE home uses just 4618 kWh per year, or around 91.08 %

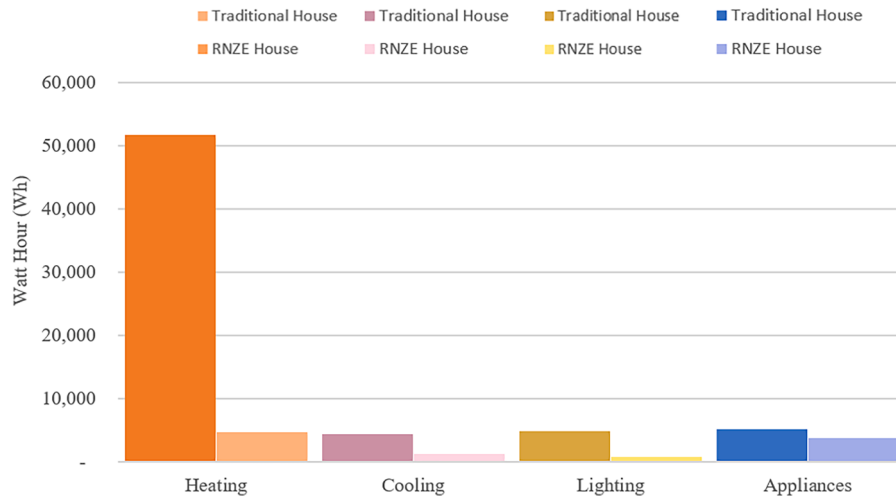


Fig. 13. Operational energy of traditional houses and RNZE houses.

less energy, to maintain a suitable indoor temperature than the standard house, which takes 51,749 kWh. The cutting-edge design techniques and contemporary materials used in the RNZE house significantly lower both heat capacity and heat loss, which is primarily responsible for this substantial drop. In addition to the natural gas combi boiler in the traditional home, the RNZE house uses a highly efficient heat pump for heating, which adds to the dramatic energy savings and makes the RNZE house far more sustainable and energy efficient.

The annual consumption of a traditional house with an electric air conditioner is 4350 kWh. By using a heat pump in conjunction with contemporary building techniques and insulation, the RNZE house significantly lowers its yearly energy usage to just 1243 kWh. This amounts to a considerable 3107 kWh, or 71.4 %, decrease. The performance of the heat pump and the improved insulation in the RNZE house demonstrate the possibility of significant energy savings. The lighting in a traditional house consumes 4793 kWh per year, which is a substantial energy burden mainly because it uses inefficient incandescent bulbs. By comparison, the RNZE House, which prioritises sustainability, uses a mere 702.4 kWh annually for lighting as shown in Fig. 13. This indicates a remarkable 85.3 % decrease in energy usage. The introduction of energy-efficient LED lighting, which is not only more effective than conventional incandescent bulbs but also more durable and eco-friendlier, has caused a significant drop.

The RNZE house, which makes use of A+++ energy-efficient equipment, drastically lowers its annual consumption to 3720 kWh from 5125 kWh for a typical house as shown in Fig. 13. The RNZE home uses around 27.4 % less energy as a result of this 1405-kWh decrease. This significant drop in energy usage highlights how efficient high-

efficiency appliances is in lowering total energy requirements.

4.3. Comparison of embodied energy and operational energy in houses

Achieving the total environmental effect and lifetime energy efficiency of buildings requires evaluating the operational and embodied energy of homes. 70–90 % of a building's total energy usage throughout its lifetime is usually accounted for by operational energy; but, in high-performance or passive homes, where operational energy needs are minimised by cutting-edge design and technology, this percentage may drop. The embodied energy of typical steel, reinforced concrete, and timber houses constructed according to the traditional methods designed in this research are 308,599.20, 240,247.20, and 151,902.70 kWh, respectively. Embodied energy accounts for around 10 % of the total energy used in traditional houses. Nevertheless, because of the substantial reduction in operating energy, this percentage rises noticeably in RNZE homes. The accompanying pie charts in Fig. 14 demonstrate the significance of embodied energy and operational energy in the overall energy consumption of realistic net zero energy houses by contrasting it with operational energy across the three primary structural systems (steel, reinforced concrete, and timber).

The RNZE steel house uses 514,170 kWh of energy overall, or 72 % of its total energy usage, for operational purposes as shown in Fig. 14a. In contrast, 28 % of the overall energy profile, or 204,108.8 kWh, is made up of embodied energy. Operational energy makes up 74 % of the total energy consumed in the RNZE reinforced concrete house (514,170 kWh), while embodied energy makes up 26 % (180,961.1 kWh) as seen in Fig. 14b. Fig. 14c demonstrates that the operational energy consumed

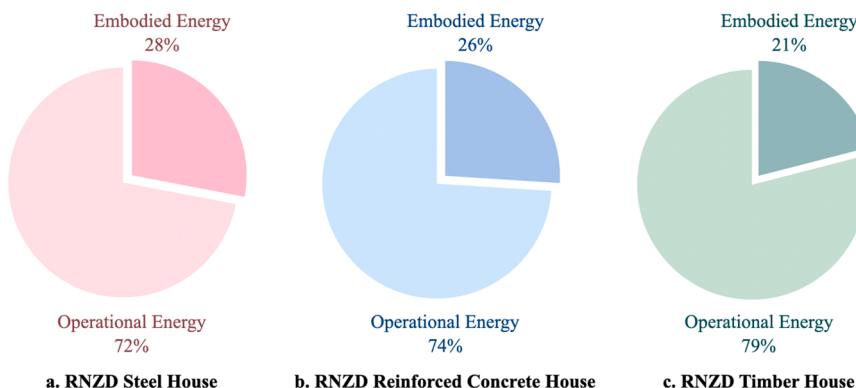


Fig. 14. Comparison of embodied and operational energy within RNZE houses.

in the RNZE House is 514,170 kWh, which is 79 % of the total energy. For the remaining 21 %, or 133,789.1 kWh, embodied energy is responsible. Although the timber house has the lowest embodied energy percentage, embodied energy still plays a significant role in the building's overall energy requirements.

As a result, the pie charts illustrate that, across different building systems, embodied energy varies from 21 % to 28 % of the operating energy. Over the course of a building's lifetime, the embodied energy can equal or even surpass the operational energy, especially in buildings made of energy-intensive materials. Because of its enormous volume, this embodied energy is a significant aspect of the building's total energy profile and shouldn't be ignored when talking about energy efficiency.

4.4. Energy generation of realistic net zero energy house

In this research, solar and wind energy were utilised to meet the power requirements of the realistic net-zero energy house. A pie chart depicting the house's annual energy output is shown in Fig. 15, with a focus on the contributions of solar and wind energy sources.

The study analyses the concept design of a RNZE house constructed in London, utilising renewable energy sources such as solar panels and wind turbines to offset the building's minimised energy usage. The wind turbines provide 6025.40 kWh of electricity annually, compared to 8406.50 kWh from the solar panels. These numbers show how much energy is produced annually by each renewable source and how much that source contributes to the building's balanced energy profile. When solar panels and wind turbines are compared, solar panels produce around 39.5 % more electricity. To be more precise, the wind turbines provide 41.8 % and the solar panels around 58.2 % of the total renewable energy produced. The distribution highlights the significance of including solar and wind energy systems in order to adequately satisfy the energy requirements of a net zero energy building. This is particularly relevant in a city like London, where fluctuating weather patterns can impact the production of both renewable energy sources.

4.5. The houses' annual energy flow

A bar chart comparing the traditional houses and realistic net zero energy houses under study's annual energy use is shown in Fig. 16a. Additionally, a bar chart in Fig. 16b demonstrates another comparison made between the amount of energy generated by the RNZE version as well as the energy consumption of these RNZE houses. In comparison,

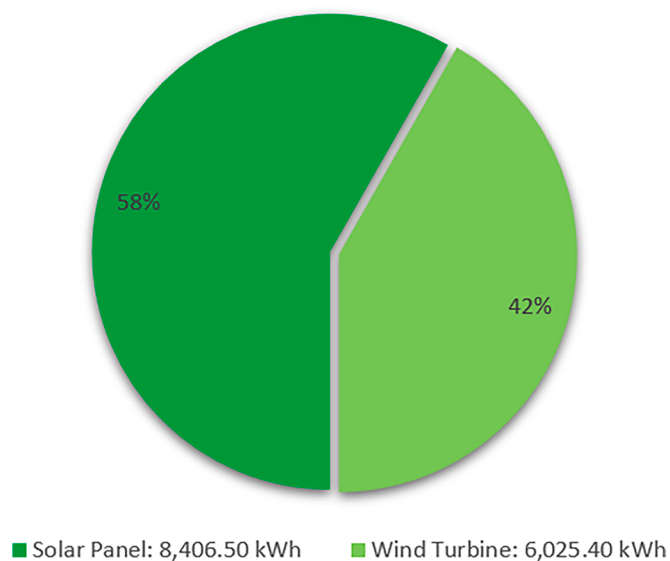


Fig. 15. Distribution of generated annually energy by solar panel, wind turbine in RNZE house.

the RNZE house uses just 10,283.4 kWh yearly, whereas the standard house uses 66,017 kWh. This works out to an 84.4 % reduction in energy demand, or a reduction of around 55,733.6 kWh.

Realistic net zero energy desires to completely eliminate a building's yearly energy usage by producing an equivalent quantity of energy from renewable sources. The house under investigation generates 14,431.90 kWh a year from solar panels and wind turbines in this study. This proves unequivocally that renewable energy sources are insufficient to cover the energy demands of a traditional house, which has an annual energy demand of 66,000 kWh. Because of this, it is essential that a RNZE home first drastically cut its energy use by putting cutting-edge strategies and tactics into practice. Therefore, the yearly energy consumption of the RNZE house was effectively lowered to 10,283.4 kWh in this project, meeting this objective.

Over the course of the structure's existence, this embodied energy must be made up for by producing and returning an equivalent quantity of energy to the municipal grid. The yearly energy generation in the housing project under analysis in this study is 14,431.90 kWh, whereas the annual energy demand is 10,283.4 kWh. The additional electricity generated (4148.5 kWh) will be used to eliminate the building energy footprint and achieve the RNZE goal.

4.6. Houses reaching the realistic net zero target by year

The line graph in Fig. 17 illustrates the number of years needed for the energy used in the manufacturing of steel, concrete, and timber houses materials that were produced by the realistic net zero energy approach that was analysed in this study to be balanced by the energy these homes produce from renewable sources.

For the RNZE steel house, this energy consumption is estimated to be 204,108.8 kWh. By the 49th year of its 50-year lifespan, the house will have successfully balanced its energy footprint by transmitting an amount of energy equal to its total embodied energy back to the city grid, having generated 4148.5 kWh more energy annually from renewable sources than its annual consumption of 10,283.4 kWh. The RNZE timber home has an embodied energy of 133,789.1 kWh, whereas the RNZE reinforced concrete house has an embodied energy of 180,961.1 kWh, as assessed in this research. The reinforced concrete house will fully balance the embodied energy in 43 years, and the timber house will fully balance in 32 years, both well before the end of their 50-year lifespans, if the annual excess of 4148.5 kWh of energy generated by these houses is used to offset their energy footprints. The study demonstrates that the selection of building materials and structural systems has a major effect on how much energy housing uses, especially when it comes to embodied energy. With the lowest embodied energy, the RNZE timber home balances its energy footprint in 32 years, compared to 43 years for the reinforced concrete house and 49 years for the steel house. This illustrates how using materials with lower embodied energy, such as timber, can reduce the time required to make up for the energy consumed during construction and eventually promote more energy-saving building techniques.

4.7. Energy flow of houses' 50-year lifespan

A bar chart showing the embodied energy and the energy usage throughout a 50-year lifespan of the steel, reinforced concrete, and timber houses designed in this research is shown in Fig. 18. The graph also compares how much energy the RNZE versions of these homes produce and require for the same purpose.

308,599.20 kWh is the embodied energy of the traditional steel house, whereas 204,108.80 kWh is needed for the RNZE steel house. This is a decrease of almost 33.87 %. The typical version of the reinforced concrete home demands 240,247.20 kWh, whereas the RNZE variant needs 180,961.10 kWh. This equates to savings of over 24.68 %. The RNZE timber house required 133,789.10 kWh, while traditional version's embodied energy was 151,902.70 kWh. This is a reduction of

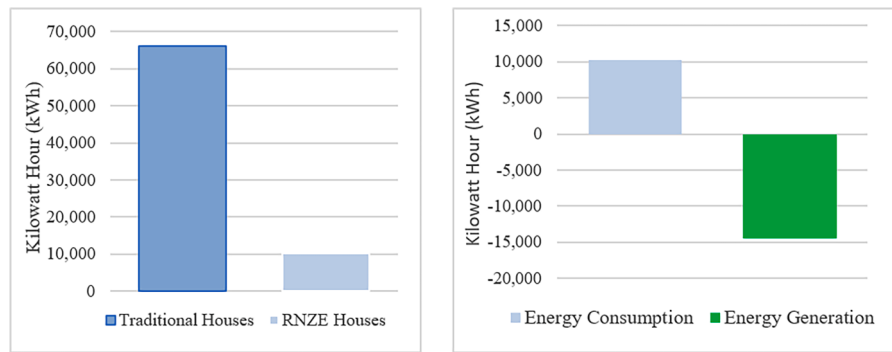


Fig. 16. (a). Comparison annual operational energy and (b) comparison of annual energy in RNZE house.

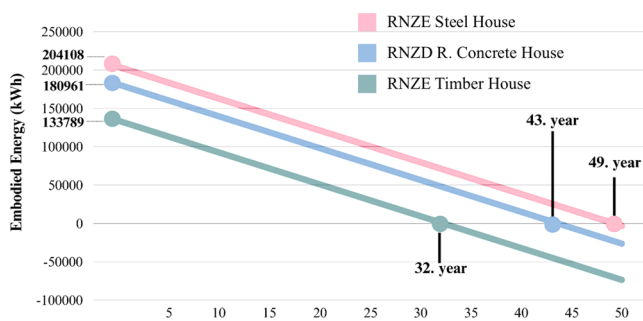


Fig. 17. Houses reaching the realistic net zero energy target by year.

approximately 11.92 %. The traditional timber house, such as the steel and reinforced concrete house, requires 3300,850.00 kWh of operating energy, while the RNZE version, like the others, only uses 514,150.00 kWh. This is a significant reduction of approximately 84.45 %. Operational energy is divided into four categories: heating, cooling, lighting, and appliances. Regarding heating and cooling, the net-zero energy house consumes 91 % less energy for heating and 71 % less energy for cooling. Energy usage is down 27 % for appliances and down 85 % for lighting. These percentages demonstrate the net-zero energy house's significant overall energy efficiency.

The objective of the RNZE Strategy is to use energy from renewable sources during the building's lifespan to balance off the entire amount of embodied and operational energy. The overall energy usage for the three

types of homes considered in this study is 3609,449.2 kWh for traditional steel, 3541,097.2 kWh for traditional reinforced concrete, and 3452,752.7 kWh for traditional timber. However, a net-zero energy balance is unachievable since these houses can only generate 721,595 kWh of energy from renewable sources. On the other hand, in a year, these households' overall energy usage drops dramatically to 718,258 kWh, 695,111 kWh, and 647,939 kWh, respectively, when RNZE techniques are applied into practice. This decrease makes it possible for the energy generated to equal or more the total energy used, reaching the targeted realistic NZE target.

4.8. Realistic net zero energy

The Sankey diagrams depict the 50-year energy flows for houses made of steel, reinforced concrete, and timber used in this study. The energy produced by wind turbines and solar panels, the energy used for operations, and the energy added to the municipal grid are all shown in these diagrams as flows that are proportionate to the corresponding amounts.

In the Fig. 19a, steel home produces 721,565 kWh of energy in total, with 301,270 kWh (42 %) coming from wind turbines and 420,325 kWh (52 %) from solar panels. 514,170 kWh (71.2 %) of the total energy produced is required for operating energy requirements. This operating energy is further broken down into the following categories: appliances (26,700 kWh; 25.7 %), lighting (35,120 kWh; 4.8 %), cooling (62,150 kWh); and heating (230,900 kWh). In addition, 204,108.8 kWh, or around 28.8 % of the total energy produced, is attributed to the energy required for the extraction, transportation, and manufacturing of

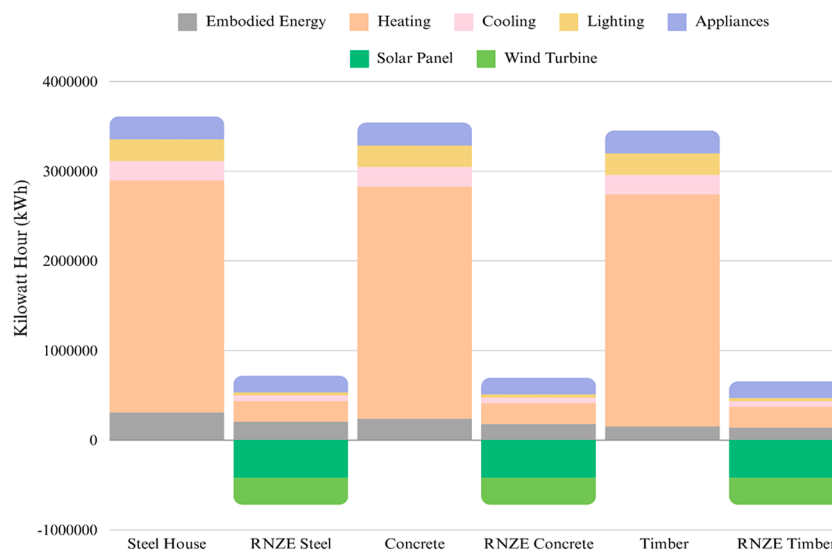


Fig. 18. Energy flow of all houses' 50-year lifespan (kWh).

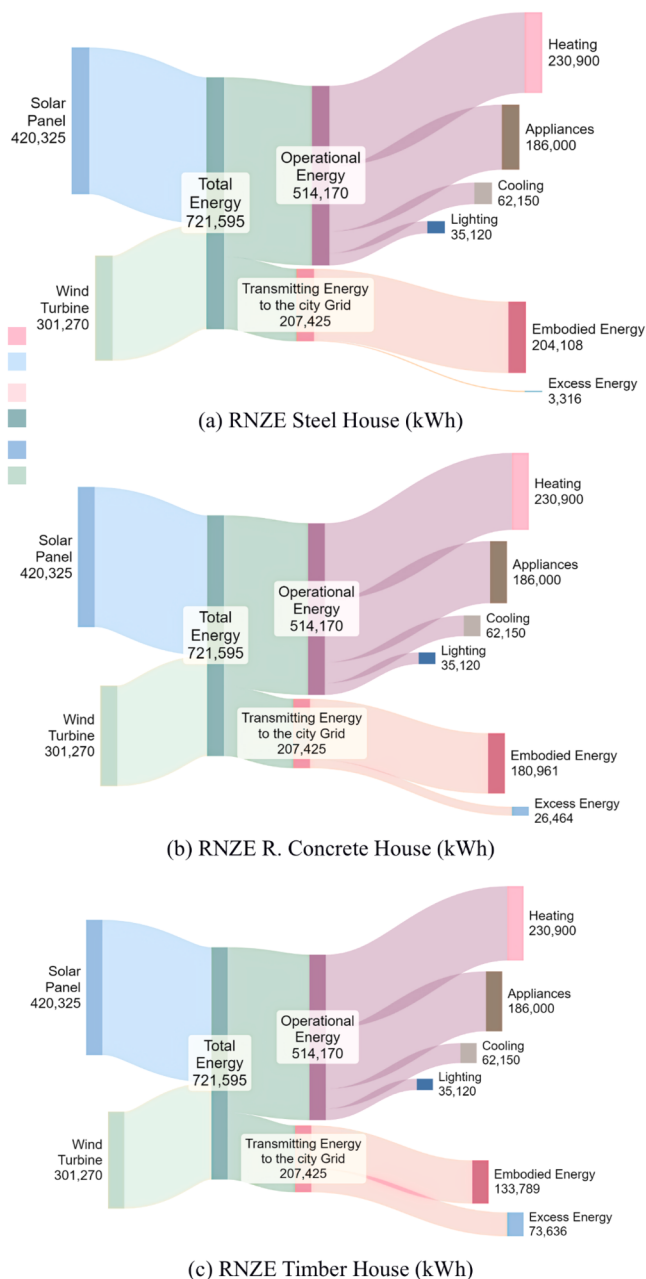


Fig. 19. Sankey diagram of realistic net zero houses.

materials required for the structure of the building. After production, this energy should be sent into the public grid. RNZE steel houses are able to create an extra 3316 kWh of energy after considering all energy required before and throughout the building's operating period.

The reinforced concrete house produces 721,350 kWh of energy in total, much like the RNZE steel house. The residence uses 521,530 kWh for its activities. In Fig. 19b, the reinforced concrete home's requirement to export 180,961.1 kWh of energy to the grid (which represents the house's energy footprint) distinguishes it from the RNZE steel house. This amounts to around 13 % less than the energy exported by the steel house in RNZE. The RNZE reinforced concrete home has the capacity to generate an extra 26,500 kWh of energy after the elimination of all operating and embodied energy. Similarly, the reinforced concrete and steel RNZE buildings, the timber house produces 721,350 kWh of energy in total. Of this, 521,530 kWh (71.2 %) are used for daily operations.

In the Fig. 19c, the timber house's energy footprint, or 133,789.1 kWh, must be sent to the grid in order to meet the RNZE objective. This

export requirement is lower than the RNZE reinforced concrete houses and the steel houses by 26 % and 35 %, respectively. The RNZE timber home may produce an extra 73,636 kWh of surplus energy after eliminating all embodied and operating energy. This extra energy is 22 times more than steel houses and 8 times greater than reinforced concrete houses. It is clear that the production procedures for the materials utilised to build the structure required an enormous amount of energy.

5. Discussion

Developing an innovative method to improve on current the Net Zero Energy (NZE) building approaches is the main goal of this research project. Similar to previous NZE methods, the Realistic Net Zero Energy (RNZE) strategy put forward in this study aims to reduce the operational energy consumed by buildings while ensuring that the energy required is produced from renewable sources. Its thorough examination of both operational and embodied energy is what distinguishes the RNZE approach from traditional NZE approaches. This study investigates the energy needs for building a conceptually planned home in London with three commonly used building structural systems: steel, reinforced concrete, and timber. The purpose of the analysis is to determine how the use of the RNZE method in these various building systems affects energy consumption. Through this analysis, the study clarifies the important part that embodied energy performs in a building's overall energy demand and demonstrates how this component varies based on the building system and materials employed.

The embodied energy of a typical steel house in the study's planned homes is 308,599.2 kWh, which is 51 % more energy than the 204,108.8-kWh needed for a practical net-zero steel energy house. The potential for energy savings through the adoption of cutting-edge, energy-efficient technologies is demonstrated by this significant reduction. Comparably, the 180,961.1 kWh of embodied energy in net-zero reinforced concrete homes is 33 % less than that of typical reinforced concrete homes, which utilise 240,247.2 kWh. This tendency is also shown in the construction of timber houses, where net-zero timber houses require 133,789.1 kWh, but typical timber houses require 151,902.7 kWh, a 12 % rise. The results demonstrate that the embodied energy varies significantly depending on the building systems and materials chosen. Adopting more energy-efficient systems and materials is naturally encouraged by the RNZE strategy, which requires balancing the building's embodied energy with equal energy output. Following that, this study evaluated the operational energy consumption of homes built with conventional techniques, including energy used for appliances, lighting, heating, and cooling. Then, using energy-saving techniques and instruments made available by the RNZE framework, this energy demand was minimised. The RNZE home, designed conceptually in London, uses 91 % less energy for heating than the standard homes, requiring just 230,900 kWh instead of 2587,450 kWh. In the same way, lighting energy consumption drops by 85 %, from 239,650 kWh to 35,100 kWh, while cooling energy demand drops by 71 %, from 217,500 kWh to 62,150 kWh. Furthermore, appliances utilise 27 % less energy, going from 256,250 kWh to 186,000 kWh. Lastly, according to the RNZE model, buildings produce energy equal to the sum of their operational and embodied energy from renewable resources. By providing the grid with a quantity of energy equal to the embodied energy of the building, this method not only removes residences' reliance on outside energy sources but also helps to satisfy the city's overall energy demands. Based on the information provided in this research, the RNZE houses, designed in the study, can produce 721,595.00 kWh of electricity per year from solar panels and wind turbines combined. It is ensured that the overall energy production effectively fulfils the RNZE objective and achieves a sustainable energy balance by matching it with the operational and embodied energy minimised by the house.

The 'Climate Change Act 2008', 'Energy White Paper 2020' and 'Future Homes and Buildings Standards' represent the foundations of the UK's journey towards net zero buildings. These policies low-carbon

heating, high insulation standards, and renewable generating in new building projects. The significance of this study highlights the necessity to include a requirement the materials used in newly constructed buildings be low-energy. Retrofitting is important and crucial because four-fifths of the buildings that will be in use in 2050 are already constructed. The United Kingdom implemented retrofit measures into its national policy for reaching net-zero emissions target. Insulation, improved airtightness, smart controls, heat pumps, and solar photovoltaics are examples of deep retrofit techniques that may reduce operating energy consumption in the regulation. In addition, based on findings of this paper, selecting low-energy materials during the retrofitting can provide significant reductions in total energy requirements of buildings. However, the feasibility of achieving the net zero target is threatened by a number of factors, including substantial initial expenditures, fragmented policy delivery, a lack of skilled labour, and sourcing low-carbon materials. To overcome these constraints and ensure that Net Zero targets are fulfilled throughout the building industry, a coordinated policy approach, strong financial sources, and alignment with the RNZEB strategy are required.

6. Conclusion

A revolutionary viewpoint on energy-sustainable building design is provided by the RNZEB method, which emphasises the vital importance of taking operational and embodied energy into account simultaneously. Through the integration of cutting-edge technology, environmentally friendly materials, and renewable energy systems, the RNZEB strategy offers the construction sector a means of substantially reducing its environmental footprint. The results of this study, it required 32 years for the timber house concept, 43 years for the reinforced concrete house, and 49 years for the steel house to reach energy demand balance under the RNZEB strategy. The RNZEB strategy has proven that buildings can meet both operational and embodied energy needs, from renewable sources over a 50-year life cycle. However, achieving true net-zero energy in buildings requires a thorough strategy that goes beyond just balancing embodied and operational energy with renewable sources.

A more comprehensive framework that considers every energy-consuming stage of a building's lifespan should be proposed by this method, which may develop by the name of True Net Zero Energy Building (TNZEB). This covers not only the operational and embedded energy that is usually taken into account, but also the energy requirements related to the transportation of materials, construction activities, appliance embodied energy, continuous maintenance, and final destruction. One significant source of energy consumption can be found in the delivery operations involved in moving supplies to the building site. The TNZEB strategy promotes the production of equal amounts of renewable energy in addition to encouraging the use of locally produced materials and low-energy modes of transportation like electric or rail systems that are powered by renewable energy sources to counteract this. Comparably, the energy requirements of construction activities (from excavation to building component assembly) must also be met by the production of renewable energy. This demand may be greatly decreased by putting prefabrication processes into practice and minimising on-site energy usage. The TNZEB approach highlights the necessity of considering not only the energy consumed during the building phase but also the energy contained in appliances and the continuous energy requirements for building maintenance. The energy required in manufacturing, shipping, and installation is included in the embodied energy of wind turbines, solar panels, lights, and HVAC systems. To attain a net-zero energy balance, buildings must select energy-efficient equipment and produce enough renewable energy throughout their operation to offset this embodied energy. Furthermore, the net-zero calculation must take ongoing maintenance activities such as replacements, repairs, and system upkeep into consideration. Important first steps in this strategy include emphasising long-lasting, low-maintenance materials and incorporating renewable energy into

maintenance tasks.

Finally, the TNZEB strategy tackles the energy usage related to the building's end-of-life phase, particularly with regard to destruction and waste disposal. Reducing the energy requirements of demolition can also be accomplished by designing structures using easy-to-demolish materials that can be recycled or repurposed. The TNZEB strategy offers a comprehensive approach by incorporating these factors into a lifecycle assessment. This not only lessens the environmental impact of buildings but also promotes innovation in sustainable design, material choice, and energy generation techniques, ultimately advancing the objective of a built environment that is truly net zero.

The UK's 2050 net-zero target can be fulfilled directly by the RNZEB approach described in this study and the proposed TNZEB framework. Designers and policymakers have a crucial role to play in promoting adoption by;

- RNZEB and TNZEB approach should be required in building regulation.
- To reduce embodied energy of building offer specific incentives for locally sourced, recycled, and low-energy materials.
- Provide target tax benefits and support to corporations developing renewable energy technologies.

To ensure that the built environment fully contributes to the UK's net-zero commitments, the RNZEB and TNZEB frameworks should be piloted in commercial and public sector developments, including government offices, hospitals, and schools. This is because of their repeatability, scale, and visibility, which can accelerate industry-wide adoption.

CRedit authorship contribution statement

Orhan Ercal: Writing – original draft, Validation, Supervision, Software, Methodology, Investigation, Data curation, Conceptualization. **Muhammad Shafique:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Formal analysis, Conceptualization, Investigation, Validation.

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.

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Supplementary materials

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