International Journal of Research Publication and Reviews, Vol 5, no 1, pp 387-393 January 2024

WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Case Study of Net Zero Energy Buildings

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ABSTRACT

The concept of Zero Energy Homes (ZEHs) emerges as a promising solution to mitigate emissions from traditional power plants by reducing overall consumption. ZEHs aim to match the total annual energy usage of a building with renewable energy generated onsite.This research presents a combination of case studies showcasing diverse strategies employed in various contexts to achieve Net-Zero Energy Buildings (nZEBs). It emphasizes the integration of Building Information Modeling (BIM), energy analysis, and practical construction methods to optimize design for enhanced energy efficiency. Additionally, the study searching into combining local bio-based construction materials with Photovoltaic (PV) systems for sustainable rural housing solutions in developing nations.The findings underscore the potential of integrating renewable energy sources with locally sourced building materials, showcasing their feasibility in constructing cost-effective, energy-efficient rural homes. These insights provide a comprehensive understanding and offer practical strategies for achieving nZEBs across different environments. Ultimately, these studies cover the way towards a more sustainable and energy-efficient future by promoting innovative solutions and practices in building design and construction.

Keywords: Smart grids, nZEBs, HAVC System, Passive and Active design, Renewable Energy, Photovoltaic Systems.

1. Introduction

As our world faces big changes in the weather, we're getting worried about using too much energy. Net-Zero Energy Buildings (nZEBs) are special buildings designed to use only as much energy as they make. These buildings are essential to help us use less energy and fight climate change.We want nZEBs to be just as good for the environment as they are for people. Regular buildings use a lot of energy and create pollution. But nZEBs are different because they don't rely on things like gas or coal for power.

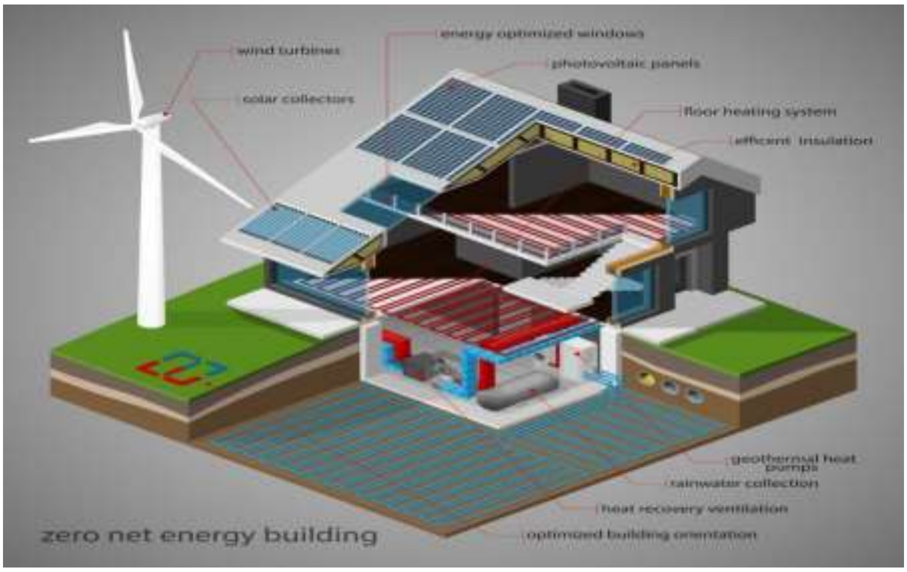

Figure 1:Integrated NetZero Energy Featured Building

They use energy-saving designs and renewable energy sources like sunlight to generate their own power.Building nZEBs isn't easy. It costs more at the beginning, and it needs experts to plan and build. But in the long run, they're worth it. They help save money on energy bills and make us feel more comfortable at home.These special buildings also help our world. They reduce how much pollution we make and can even get support from the government to save money. Plus, they make our power system stronger because they can make their energy, reducing the stress on power plants and cutting pollution even more.

Architects and engineers very carefully consider multiple facets during the design phase, including building orientation, envelope insulation, natural ventilation, and seamless integration of renewable energy systems. Construction practices must be refined to minimize energy loss and ensure the effective installation of energy-efficient technologies. Moreover, occupants' awareness and adherence to energy-saving practices significantly augment the system's efficiency.

2. Literature Review

McBee, Masa Noguchi1, Andreas Athienitis2, Véronique Delisle3, Josef Ayoub3& Bradley Berneche4 "Net Zero Energy Homes of the Future:A Case Study of the ÉcoTerraTM House in Canada"Integrated photovoltaic systems in the ÉcoTerra house offer advantages over standalone PV arrays or solar thermal collectors. The house utilizes a two-stage geothermal heat pump for heating or cooling, employing an eco-friendly refrigerant. Hydro-Québec, for the ÉcoTerra project, demonstrated 'net metering' for residential development, while the RETScreen Version tool enables users to model building energy efficiency and cost savings by specifying envelope properties, heating systems, and electrical loads [1].

*Rati Khandelwal, Ravindra Kumar Jain, Mukesh Kumar Gupta "*Case Study: India's First Net-Zero Energy Building- Indira Paryavaran Bhavan " Indira Paryavaran Bhawan in Delhi, situated in a composite zone, employs passive design strategies for self-sustainability. Integrated photovoltaic (BIPV) handles lighting load, while a geothermal system addresses cooling needs. The HVAC system incorporates a chilled beam system to fulfill conditioning load, emphasizing energy-efficient and self-sustaining features [2].

*Liping Wang *, Julie Gwilliam, Phil Jones"*Case study of zero energy house design in UK" EnergyPlus simulations focus on building envelope design, while TRANSYS is employed for building and renewable energy systems design. The parametric study explores U values, window ratios, and orientations. Heating is provided from January to March and October to December, with cooling from April to September. Increased thermal insulation reduces total energy consumption. The study includes hot water, space heating, and lighting electricity systems, and simulates a grid-connected renewable energy system in Cardiff using a 50-degree photovoltaic array slope, Type 194, Type 90 wind turbine, and Type 48 DC/AC inverter[3].

Yuanming Kwan, Lisa Guana,"*Design a Zero Energy House in Brisbane, Australia" EnergyPlus 8.1 software was used for simulating house energy performance, modeling heating, cooling, lighting, ventilation, and other energy flows. The model includes a unitary heat pump representing typical home air conditioning. The design emphasizes an energy-efficient building envelope, lighting, and appliances, incorporating three-in-one technology for hot water, cooling, and heating using solar energy. A 5kW crystalline silicone photovoltaic panel system faces north at a 26° tilt to meet the annual energy demand of the house [4].

Chatchawan Chaichanaa , Panida Thararakb , Yuttana Monaa,⁎"Towards net-zero energy school: A case study in Thailand "The study by Wongsapai et al. also employed the Long-Range Energy Alternatives Planning (LEAP) software to assess energy demand and greenhouse gas emissions' impact on energy efficiency. The integrated power supply system's electricity generation was simulated using spreadsheet software, incorporating hourly weather data (solar radiation, ambient temperature, and wind speed) from Metronorm software[5].

*Hikmat H. Ali1 *, Fahmi A. Abu Al-Rub2 , Bashar Shboul3 , Hind Al Moumani1*"Evaluation of Near-net-zero-energy Building Strategies: A Case

Study on Residential Buildings in Jordan" This study aimed to assess the cost-optimal nearly Zero Energy Building (nNZEB) among two options using life cycle cost analysis and exploring various design strategies. The process involved a survey in Irbid to evaluate current residential buildings, selecting a representative base case for analysis, and applying passive and active design strategies. Different energy efficiency measures were then implemented to achieve nNZEB[6].

*Ase Lekang Sørensena *, Anne Gerd Imenesb,c, Steinar Grynninga , Tor Helge Dokkad* "Energy measurements at Skarpnes zero energy homes in Southern Norway: Do the loads match up with the on-site energy production?" This paper introduces an energy monitoring method and reports one year of measurements from five homes starting in June 2015. The houses feature a concrete slab with EPS insulation for the ground and cellar walls made of core-insulated lightweight aggregate blocks. AMS meters track total energy purchase and sale, while SMA inverters monitor solar energy production. The Elspec G4400 power quality analyzer measures net power and grid parameters (frequency, voltage, phase), and ABB power meters are installed on different electrical circuits to monitor load patterns[7].

Simi Hoque1 "NET ZERO ENERGY HOMES: An Evaluation of Two Homes in the Northeastern United States" In this study, three areas are categorized based on (a) architectural organization, (b) building envelope, and (c) electromechanical systems. The H-1 house maximizes passive solar gain and utilizes photovoltaic panels. It features an open floor plan to optimize sunlight, reducing the need for direct gain passive solar heating. The building envelope incorporates an exterior air retarder with two layers of foil-faced rigid urethane insulation to minimize air infiltration and thermal bridging[8].

Simi Hoque1 "NET ZERO ENERGY HOMES: An Evaluation of Two Homes in the Northeastern United States" The P-1 home features a thermal envelope constructed with closed-cell urethane foam insulation sprayed into stud cavities. It incorporates a heat recovery system transferring waste heat from exhaust to incoming fresh air. The renewable energy production system is wind-powered, and the passive solar system prioritizes providing natural daylight rather than serving as a primary heat source. The P-1 house demonstrates detailed envelope design, construction, and enhanced electromechanical systems compared to the H-1 house[9].

*Shady Attia * and Camille Gobin* “Climate Change Effects on Belgian Households: A Case Study of a Nearly Zero Energy Building “This paper seeks to assess the influence of climate change on overheating hours using both static and adaptive comfort models. General Circulation Models (GCMs) are employed to simulate the global climate system's response to rising greenhouse gas concentrations. The triple glazing used comprises three panes of 4 mm each, separated by 12 mm of an Argon-Krypton mixture. The house is constructed with timber, featuring a timber truss frame. The simulation is conducted using the dynamic energy simulation program Energy Plus v9.0[10].

Sara El Hassani a, , Mouatassim Charai a,b,* , Mohammed Amine Moussaoui a , Ahmed Mezrhab a* ”Towards rural net-zero energy buildings through integration of photovoltaic systems within bio-based earth houses: Case study in Eastern Morocco “Integrated This paper deals with Energy Plus software was employed to evaluate the energy-saving capabilities of bio-based building envelopes, while HOMER Pro, a specialized tool, was used for analyzing and optimizing renewable energy systems. The study focused on creating innovative bio-based earth blocks using locally sourced materials. TRNSYS was utilized to assess the energy consumption of a residence. The research included the development and thermophysical characterization of locally sourced adobe for building, and 3D building modeling was performed using the Open Studio plug-in for Sketch-Up[11].

Sunil Sharma1 , Dr. Ashwani Kumar2 , Dr. Nand Kumar2 , Sobhagyawati Gupta “DEVELOPING A NET ZERO ENERGY BUILDING: A CASE STUDY OF AN INSTITUTIONAL LIBRARY ” This paper focused on PVsyst software which was employed to simulate the library building, assessing the feasibility of integrating solar photovoltaic panels. The library model was constructed using eQUEST. The Central Library design incorporates traditional wisdom, featuring thick walls, fewer west-facing windows, and ample floor-to-floor height. The simulation revealed that a 431-square meter PV installation covering 500 sq. meters of the roof could generate 94.42 MWhr./annum electricity.[12].

Nader. A. Nader1 † --- Rami S. Alsayed2 “NET-ZERO ENERGY BUILDING – CASE STUDY AL KHOBAR CITY, SAUDI ARABIA” The primary contribution of the paper lies in identifying an effective energy-saving system, specifically the hybrid system involving Phase-Change Materials (PCM). PCM undergo a phase change from solid to liquid within the temperature range of 23-26°C when used in construction. In the proposed system, standard wall materials include a 20mm brick wall with 2mm polyurethane insulation containing PCM. The PCM stabilizes room temperature by melting as it absorbs heat during the day and returns to its solid state during ventilation at night. The application of PCM is recommended in various construction elements, including walls, ceiling tiles, air conditioners, thermal heating, and more[13].

Hussein Abaza , Amaal Al Shenawa* “Towards Net-Zero Energy Consumption with Near Net Zero Initial Cost: A Case Study from Georgia, USA”This paper concentrates on BIM (Building Information Modeling) software, specifically Revit, was employed for the design and construction phases of this home. The software generated annual energy consumption data for each design alternative. A building simulation model was created using the Energy Plus simulation engine within the BIM environment. The decision was made to use dual-stage seasonal energy efficiency factor (SEER)-16 units, providing approximately 23% greater energy efficiency compared to single-stage SEER-13 units. Additionally, single-hung windows were chosen due to the absence of natural ventilation consideration in the house design and their superior air tightness compared to double-hung windows. [14].

Bongwirnso Umaru Mohammed a, , Yufenyuy Severine Wiysahnyuy b , Noman Ashraf a , Blaise Mempouo c , Ghislain Mengounou Mengata b,d*

“Pathways for efficient transition into net zero energy buildings (nZEB) in Sub-Sahara Africa. Case study: Cameroon, Senegal, and Cˆoted’Ivoire” This article emphasizes guidelines for a smooth transition to net-zero energy buildings in Cameroon, Senegal, and Côte d'Ivoire, focusing on passive design strategies such as building orientation, insulation, air tightness, natural ventilation, shading, thermal mass, and day lighting. It advocates for the use of energy-efficient appliances, including LED and CFL bulbs and 'A' or 'B' rated appliances. Smart building technology, utilizing the Internet of Things, is recommended for controlling temperature, lighting, and security systems. The exploitation of renewable energy sources like hydro power, biomass, geothermal, solar (both direct and indirect), and wind is also highlighted.[15].

3. Reduction of consumption

The consumption of nZEBs can be reduced by implementing the following strategies.They are

- Passive design strategies
- Active design strategies
- HVAC systems improvement
- Energy efficient appliances
- Smart building technology

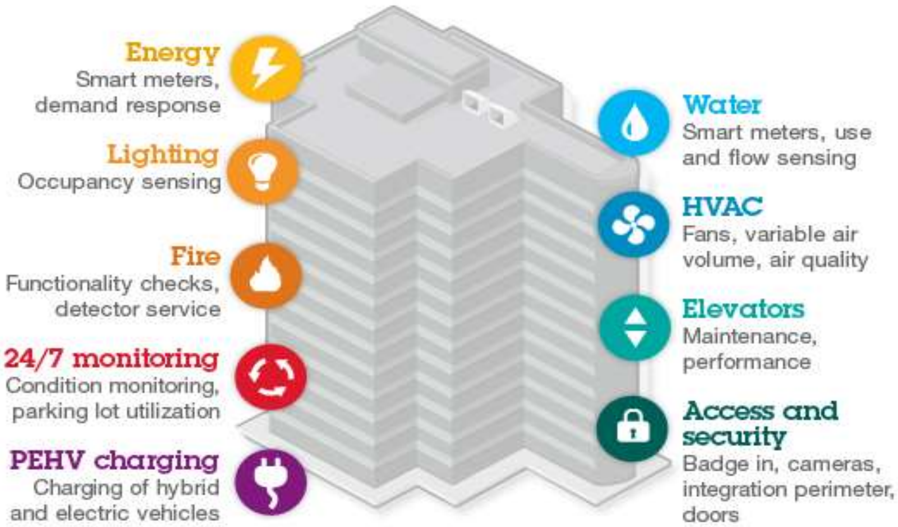

Figure 2:Integration of smart Technology in homes

Passive Design Strategies:

Emphasizes climate-oriented passive design strategies, including building orientation, insulation, air tightness, natural ventilation, shading, thermal mass, and day lighting.Highlights the use of environmentally friendly materials, such as rock wool insulation and high-efficiency double-glazed glass.Incorporates landscaping with native plants for over 50% coverage outside the building to reduce water consumption.Implements skylights for indoor natural sunlight and provides 75% of the building floor space with adequate daylight.

Active Design Strategies:

Utilizes energy-efficient lighting with lux level sensors, achieving a total lighting power density much below Energy Conservation Building Code benchmarks.Installs integrated photovoltaic (BIPV) systems to provide energy for lighting.Incorporates a chilled beam system, reducing energy consumption by approximately 50% compared to conventional systems.Implements water-cooled chillers, double skin air handling units with variable frequency drives (VFD), and VFDs for various components to enhance energy efficiency.

HVAC Systems Improvement:

Recognizes HVAC systems as a significant contributor to building energy consumption.Emphasizes regular maintenance checks to ensure the system operates efficiently.Installs proper thermal insulation to minimize heat loss or gain.Implements energy recovery wheels to pre-cool fresh supply air from toilet exhaust air, maintaining room temperature at an energy-efficient 26 ±1 °C.

Energy-Efficient Appliances:

Encourages the use of energy-efficient light bulbs and fixtures to reduce electricity consumption.Incorporates small wind turbines for domestic usage in the 3–7 m/s band for zero-energy buildings.Measures total energy purchase and sale using AMS-meters , facilitating the calculation of total electricity use in each building.

Smart Building Technology:

Deploys Internet of Things technology to control temperature, lighting, and security systems.Addresses human forgetfulness by automating lighting, HVAC settings, and other appliances.Integrates smart devices and sensors with a central building management system for optimal performance, sustainability, and cost reduction.

4. Renewable Energy Sources

Various renewable energies are used to generate energy in zero energy building. They are:

- Hydro power
- Bio Energy
- Geothermal Energy

- Solar Energy
- Wind Energy

Hydro power

Hydroelectricity is generated when water flows from a higher to lower elevation, turning turbines to generate power. Generally large dam projects with reservoirs are just one type of hydro power project; smaller run-of river and in-stream projects are also possible so, this application is used to generate power in nZEBs. Hydroelectricity uses well established technology, and its projects make advantage of a dynamic resource.

Bio Energy

Bio energy refers to renewable energy that is derived from living organisms. Bio energy is a favourable renewable resource that might power vehicles, power electrical grids, provide heat for homes, and even heat water. Forest by-products like wood wastes, agricultural wastes like sugar cane waste, and animal husbandry residues like cow dung are also potential fuels for bio energy plants. It is used to pre-heating water in the tank.

Geothermal Energy

Geothermal energy, sometimes known as “ground heat,” is a clean and sustainable source of thermal energy that is produced by the earth’s internal heat and pressure. To extract heat from geothermal reservoirs, wells and other methods of extraction are used. Different fluids with varying temperatures can be used to generate electricity and for other heat-related purposes like water heating ,room heating,after they are drawn to the surface.

Solar Energy

Photovoltaic systems are a must for net-zero Energy homes. With solar panels installed on the roof or on the ground, you can convert sunlight to electricity – and even store it for the winter. This works best if during the hottest days of the year, only the roof is exposed to direct sunlight. Maximum net zero energy homes are depend on solar energy because it will generate easily and continuously throught the year except cloudy and rainy day.

Wind Energy

It refers to the energy generated by the flow of air in the atmosphere. The blow of wind rotates the turbine which converts the kinetic energy into electric energy which can be stored and use at any time.It is more useful when the solar is not sufficient due to insufficient radiation of sun during cloudy days. These are mainly used in high wind blowing areas where the turbines can generate power efficiently and effectively.

5. Software Tools For Analysis

Ret Screen

PV potential annual electricity production was assessed using NRCan's RETScreen tool, allowing modeling of building attributes, evaluating energy/cost savings, greenhouse gas emissions, and financial viability of energy efficiency measures[1].

Figure 3: Details of Ret screen software tool

Energy Plus

Energy Plus simulations, a building performance tool by the U.S. Department of Energy, enable facade design studies and house energy performance evaluation. This software models heating, cooling, lighting, ventilation, and more, making it ideal for assessing the energy-saving potential of bio-based building envelopes.

Transys

TRNSYS is employed for designing building and renewable energy systems, particularly for assessing the feasibility of zero-energy houses in Cardiff. The study compares various design methods, focusing on renewable electricity, solar hot water, and energy-efficient heating systems. TRNSYS 16.0 models a domestic solar hot water system, emphasizing its potential in the UK to reduce conventional energy consumption.

Spread Sheet

Electricity generated from the integrated power supply system is simulated using spreadsheet software, considering hourly load curves, energy auditing data, and weather information (solar radiation, ambient temperature, wind speed) from Metronorm software. The simulation accounts for specifications of PV modules, inverters, and chargers to assess system performance[5].

Engineering Equation Solver

A computational study employed energy simulation tools for design decision-making, optimizing energy efficiency, and reducing operating costs. Building simulation, facilitated by the Engineering Equation Solver (EES), provided detailed analysis during early design phases, predicting energy use, cost, system sizing, and performance. The approach integrated modeling and simulation to enhance energy efficiency and address architectural questions upfront, emphasizing lighting control, ventilation, and system efficiencies for an effective design[6].

Conclusion:

Homes that produce as much energy as they consume, using technologies like solar panels and smart heating/cooling systems, represent a sustainable future in architecture. Tools like EnergyPlus simulations and wind turbines play important roles in making this happen. Designing homes that naturally use sunlight and other resources is crucial for efficiency. The European Union's push for nearly zero energy buildings sets an example for the world to follow, showing a strong commitment to eco-friendly construction. However, there are challenges, like making these solutions affordable and ensuring people understand their benefits. To overcome these challenges, it's important for governments, researchers, and industries to work together. This teamwork will drive the widespread adoption of sustainable housing, making it a reality for many. In simple terms, building homes that use renewable energy and smart designs is not just a technological trend but a way for us all to contribute to a greener and better future.

Future Scope:

Continous research and synthesis in renewable energy technologies, energy storage systems, and smart home solutions will increase the efficiency and affordability of net zero energy homes. Reduction of prodution and processing cost of different material involved in nZEBs can make the all homes to be nZEHomes. Growing awareness among consumers about environmental sustainability and the long-term cost benefits of net zero energy homes will drive a demand for eco-friendly living habitats. Increasing global commitments to sustainability, including initiatives like the United Nations Sustainable Development Goals and paris Agreement, will encourage countries and communities to adopt net zero energy practices in their residential construction.

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