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Net Zero Energy Buildings

Samyukta Shrestha[1*], Sweta Shrestha[2]
[1]*Dept of Architecture, Kathmandu Engineering College, E-mail: samyuktashrestha103@gmail.com*
[2]*Assoc. Professor, Dept of Architecture, Kathmandu Engineering College, E-mail: sweta.shrestha@kecktm.edu.np*

Abstract — Net Zero Energy Buildings (NZEBs) have emerged as a cornerstone in sustainable development, aiming to balance energy consumption with renewable energy production. This paper explores the principles, technological strategies, and practical implementations of NZEBs. By integrating insights from case studies and theoretical frameworks, the study provides a comprehensive understanding of the challenges and solutions in achieving energy efficiency in buildings. The findings aim to inform architects, engineers, and policymakers about advancing the built environment's sustainability.

Keywords — Zero-energy buildings, Renewable Energy, Energy Efficient Design, Energy Consumption, Smart Building & Technological Advancement

Introduction

Buildings play a pivotal role in global energy consumption, accounting for over 40% of energy use worldwide. As urbanization accelerates, the demand for energy-efficient and environmentally sustainable designs has grown exponentially. Net Zero Energy Buildings (NZEBs) have emerged as a cornerstone in mitigating climate change, reducing greenhouse gas emissions, and promoting energy conservation. NZEBs aim to balance energy consumption with renewable energy generation, achieving net-zero energy usage annually. This paper delves into the principles, methodologies, results, and implications of NZEBs, exploring cutting-edge technologies and sustainable practices that enhance building performance.

The necessity for NZEBs stems from alarming trends in global warming, resource depletion, and rising energy costs. In response, governments, architects, and engineers are advancing innovative solutions to transition towards energy-neutral buildings. This research examines strategies for achieving NZEBs, drawing on practical applications and case examples.

Background and Importance of NZEBs

NZEBs are designed to produce as much energy as they consume over a given period, typically one year. They achieve this through a combination of energy efficiency measures and renewable energy sources. Key drivers for NZEB adoption include:

1. *Rising Energy Costs*: Increasing global energy prices necessitate more efficient energy use in buildings.
2. *Environmental Preservation*: Reducing greenhouse gas emissions and dependency on fossil fuels is critical for mitigating climate change.
3. *Regulatory Mandates*: Governments worldwide are introducing stricter energy efficiency regulations to promote NZEB construction.
4. *Technological Advancements*: Innovations in materials, renewable energy systems, and building automation enhance the feasibility of NZEBs.

Principles and Design Elements of NZEBs

Achieving NZEB status involves adhering to specific principles and incorporating effective design strategies:

A. Building Performance Metrics

Metrics such as net-zero site energy, source energy, cost, and emissions are employed to evaluate a building's energy balance. These metrics ensure that energy efficiency goals align with renewable energy production capabilities.

Sustainable Design Features

1. Passive Design**:** Optimizing building orientation, insulation, and window placement to minimize energy loads.
2. Efficient Systems: Employing energy-efficient HVAC systems, lighting, and appliances.
3. Renewable Energy Integration: Using photovoltaic panels, wind turbines, and geothermal systems to offset energy demand.

** Corresponding Author*

B. Building Envelope Measures

Enhanced insulation, double-skin facades, and low-emissivity glazing minimize heat transfer, reducing energy demands for heating and cooling.

A. Advanced Energy Management

Building automation systems optimize energy use by monitoring and controlling lighting, HVAC systems, and other energy-consuming equipment. [4]

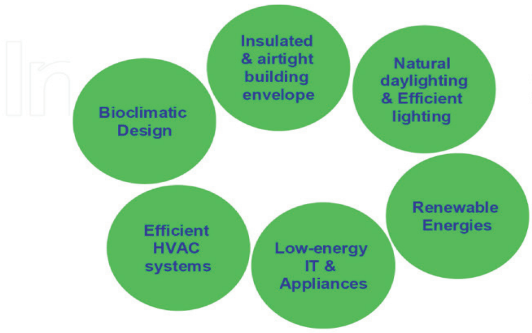


Fig. 1 Various energy efficiency measures

Technological Strategies for NZEBs

A. Renewable Energy Systems

1. Solar Photovoltaic (PV) Panels: Convert sunlight into electricity, providing a sustainable and cost-effective energy source. [13]

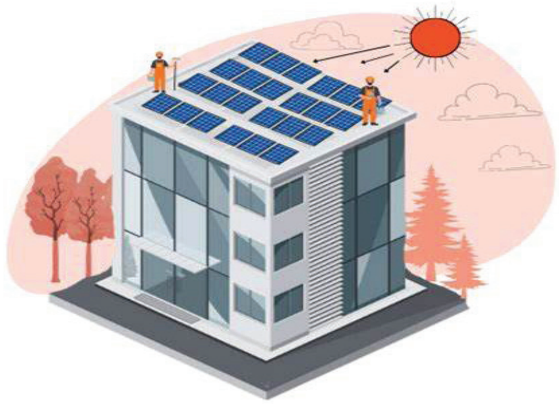


Fig. 2 Solar Panels

2. Geothermal Heat Pumps: Leverage the Earth's stable temperature for heating and cooling. [6]

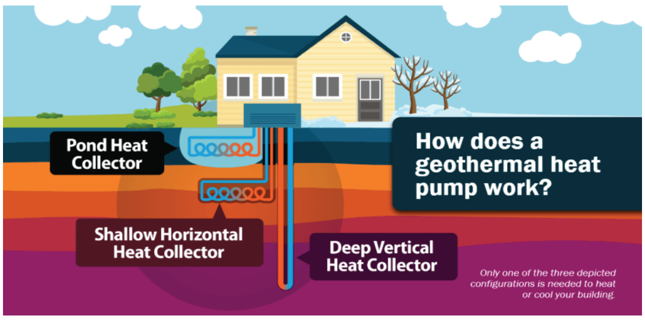


Fig. 3 Geothermal Heat Collector

3. Wind Turbines: Generate electricity in areas with consistent wind conditions.

Energy Efficiency Technologies

1. LED Lighting: Reduces energy consumption by up to 75% compared to traditional lighting.
2. Thermal Storage Systems: Utilize phase-change materials to store and release thermal energy.
3. High-Performance HVAC Systems**:** Optimize energy use with variable capacity chillers and heat recovery systems.

Water Efficiency Measures

1. Rainwater Harvesting: Collects and reuses rainwater for non-potable applications. [16]

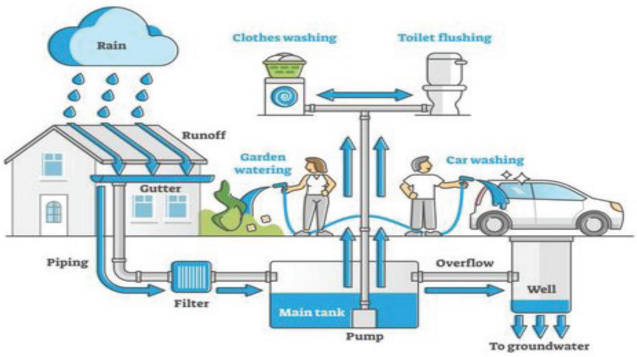


Fig. 4 Rain water harvesting

1. Greywater Systems: Recycle water for irrigation and flushing, reducing overall water demand.

Integration of Artificial Intelligence (AI) in NZEBs

The integration of Artificial Intelligence (AI) into Net Zero Energy Buildings (NZEBs) is revolutionizing energy management and efficiency. AI-powered systems enable smarter decision-making and dynamic optimization of energy use. Key aspects include:

Predictive Energy Management

AI algorithms analyze historical and real-time data to predict energy demand and optimize energy consumption patterns. This helps reduce wastage and ensures efficient use of renewable energy sources.

Advanced Building Automation

AI enhances building automation systems by integrating smart sensors and IoT devices. These systems monitor and adjust lighting, HVAC, and other building functions based on occupancy and environmental conditions.

Fault Detection and Maintenance

AI-powered tools detect inefficiencies or faults in building systems in real-time, enabling proactive maintenance and minimizing energy losses.

Renewable Energy Optimization

AI optimizes the performance of renewable energy systems by analyzing weather patterns and adjusting operations to maximize energy generation and storage.

User-Centric Comfort and Efficiency

AI systems learn occupant behavior and preferences to create personalized comfort settings while minimizing energy use.

Case Studies and Applications

The objective of a case study on Net Zero Energy Buildings (NZEBs) is to study real-world examples to understand how strategies and technologies are practically applied to achieve net zero energy. It aims to identify challenges and solutions, evaluate performance outcomes, and document best practices and lessons learned. This provides valuable insights for improving energy efficiency, overcoming implementation barriers, and guiding future sustainable building projects.

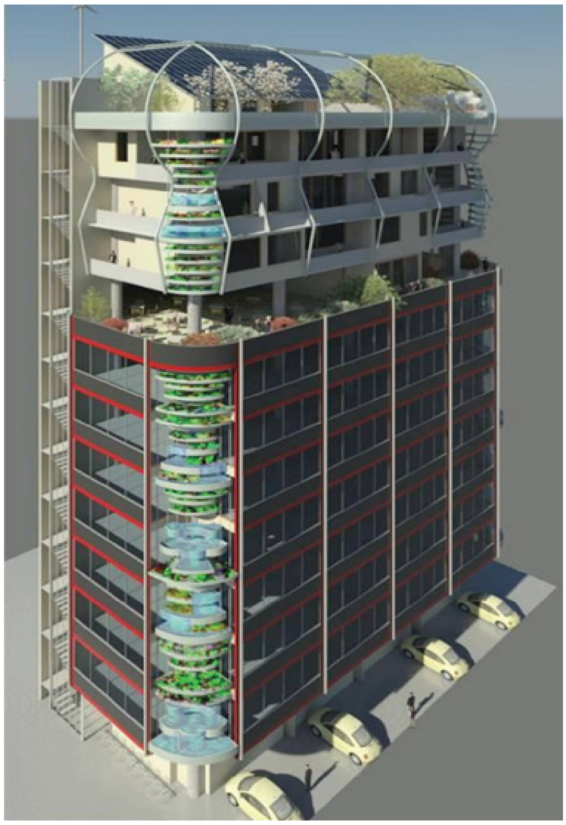


Fig. 5 Hama Iron and Steel Building

The Hama Iron and Steel Building, located in Kamaladi, Kathmandu, Nepal, is a notable industrial facility dedicated to the production and processing of iron and steel products. It serves as a key player in the country's steel industry, contributing to various construction and manufacturing projects. The building is equipped with modern machinery and technology, ensuring high-quality steel production. Its operations support the local economy by providing employment opportunities and fostering industrial growth in the region. [8]

It is a mixed-use structure featuring two basement levels and twelve above-ground stories. The site area spans 633 square meters, with a footprint area of 353 square meters. The total built-up area of the building is 6,405 square meters. [5]

Certification

The Hama Iron and Steel Building in Kathmandu, Nepal, has been registered for LEED certification under the LEED NC 2009 system. However, as of now, it has not been certified and remains in the registered status. This means that the building has completed the necessary steps to be considered for LEED certification but has not yet achieved a specific certification level such as Certified, Silver, Gold, or Platinum. [2] [12]

The Hama Iron and Steel Building in Kathmandu, Nepal, has earned a total of 48 points. This includes:

- Sustainable Sites: 15 points
- Water Efficiency: 4 points
- Energy and Atmosphere: 11 points
- Materials and Resources: 2 points
- Indoor Environmental Quality: 9 points
- Innovation in Design: 4 points
- Regional Priority: 3 points

This places the building at the LEED Certified level, which requires a minimum of 40 points. [9]

1. Design Development and Construction

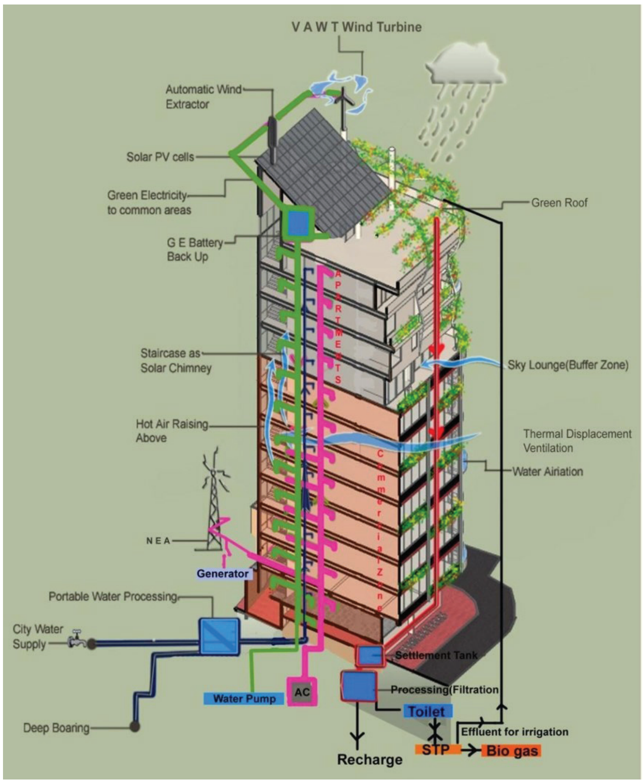


Fig. 6 Resource Efficiency of the Hama Iron & Steel Building

The Hama Iron and Steel Building has been designed as a sustainable building in terms of both construction and operations. Special efforts have been put into energy and water efficiency, waste reduction and landscape integration. User wellness has been embedded within the design of the Hama Iron and Steel Building from day one, to offer a quality environment: natural daylight, air quality and temperature control.

Energy models project that the Hama Iron and Steel Building will use approximately 30 per cent less energy than a conventional new construction. The building will be mostly powered by renewable energy, part of which will be produced on site thanks to photovoltaic solar panels and rain water harvesting. [5]

Material & Resources

Fig. 7 Materials used in construction

The intent of the project is to reuse building materials and products to reduce the demand for new materials and minimize waste. This involves using salvaged, refurbished, or reused materials that constitute at least 5% or 10% of the total material cost for the project. Specifically, iron and steel waste from reinforcement bars are repurposed to create structures for hydroponics, trusses, troughs, and decorative rain chains. This approach supports sustainability and efficient resource management.

The building employs various materials and techniques for different criteria such as the following:

- Double Grid ACP panel with thermocol sheet at back for both sound and thermal insulation
- Double Glazed Glass used
- High reflective stainless steel used on exterior
- Expanded polystyrene (EPS) used for interior partition insulation (4-inch thickness)
- Cement fibre board used for wall partition
- Use of metal and steel in staircase, structural purpose
- Use of Sustainable Material

i. Recycled Content

ii. Rapidly Renewable

iii. Certified Wood (FSC)

iv. Low VOC Content Material

Fig. 8 Slope provided for solar panels.

The project features wind turbine & solar panel installation on the roof, which will generate approximately 180 kWh of electricity per year. It is 21 percent efficient and reduces the cost by 20 percent. The energy produced by these solar panels will partially cover the building's electricity needs, including lighting, HVAC systems, heat pumps, and other operational requirements. This significant renewable energy contribution highlights the project's dedication to sustainability and reducing reliance on non-renewable energy sources.

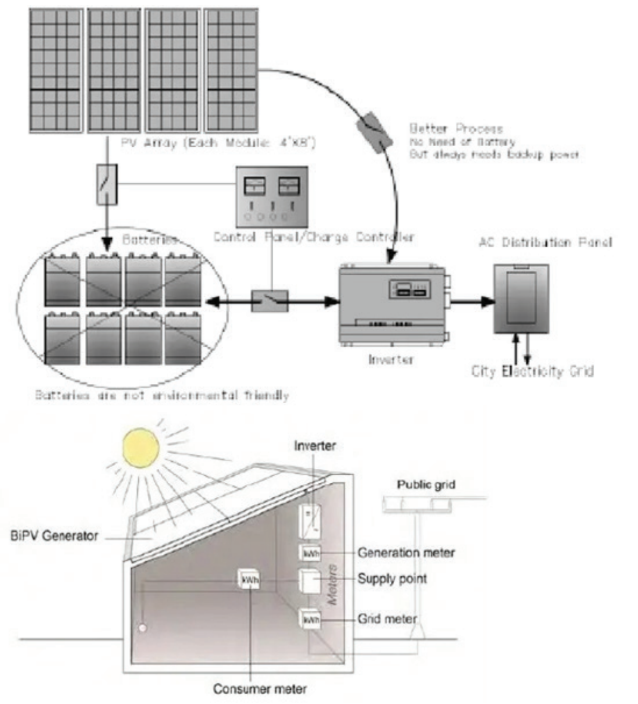


Fig. 9 Grid-tied battery system

Grid tied battery-less system of solar photovoltaic used so that the power they generate can be fed directly into the utility grid. Whenever the systems are active, the electricity produced is not stored; instead, it is delivered directly to the loads in building or to the local electric company.

Water Efficiency

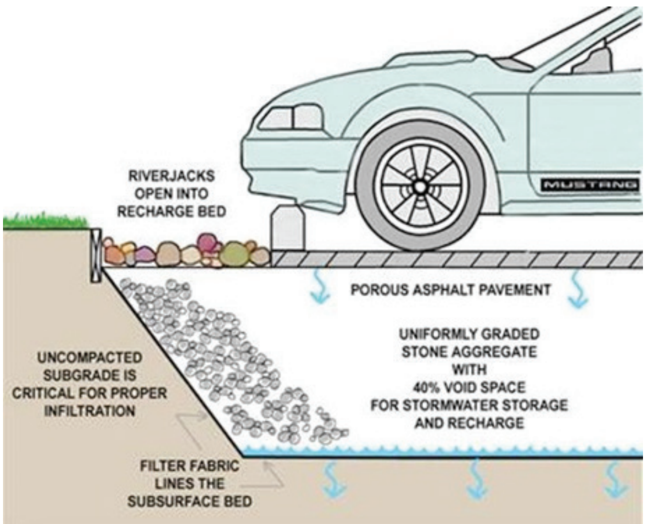


Fig. 10 Provision used for site run-off

The Hama Iron and Steel Building is able to harvest and reuse rainwater and recharging ground water table (20,000-50,000-gallon water tank capacity). Rainwater will be harvested and stored for reuse in toilet flushing, car washing and plant watering. Water-saving features mean that the Hama Iron and Steel Building's consumption of the municipal supply should be 60 per cent less than a conventional building.

The Hama Iron and Steel Building has implemented effective stormwater management techniques to significantly reduce site run-off. Before development, the quantity of site run-off was measured at 265.84 cubic feet per storm. Following development, this quantity was reduced to 171.08 cubic feet per storm, achieving a 35.65% reduction. This reduction is indicative of the building's efficient water management practices, contributing to sustainability and environmental conservation by mitigating the impact of stormwater on the surrounding ecosystem.

Additionally, water consumption was lowered by 50%, reflecting the implementation of advanced energy-efficient technologies. The integration of on-site renewable energy sources, such as solar panels and heat pumps, further underscores the project's commitment to sustainability and reducing its environmental impact.

Vegetation

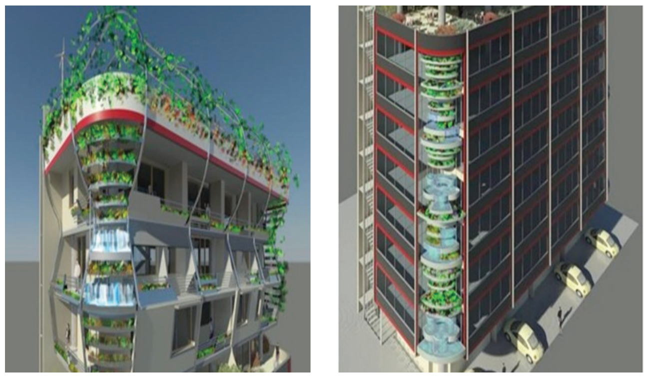


Fig. 11 Vertical Garden using hydroponics

The Hama Iron and Steel Building incorporates vertical gardens and hydroponics as part of its sustainable design features. The vertical garden is strategically placed on the exterior and interior walls, enhancing aesthetics and improving air quality by filtering pollutants and providing natural insulation.

Hydroponics, a soil-less method of growing plants, is utilized within the building, allowing for efficient water usage and space optimization. These systems are supported by reused materials, such as repurposed iron and steel, reinforcing the building's commitment to sustainability and resource efficiency.

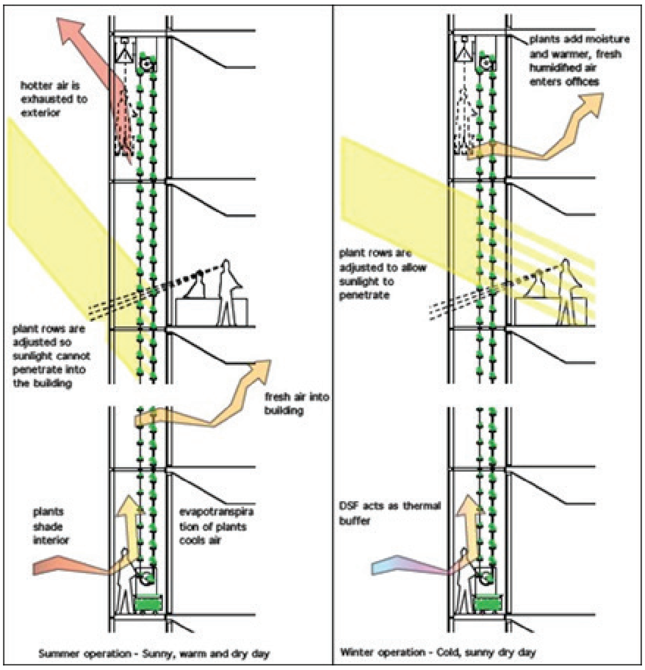


Fig. 12 Hydroponics

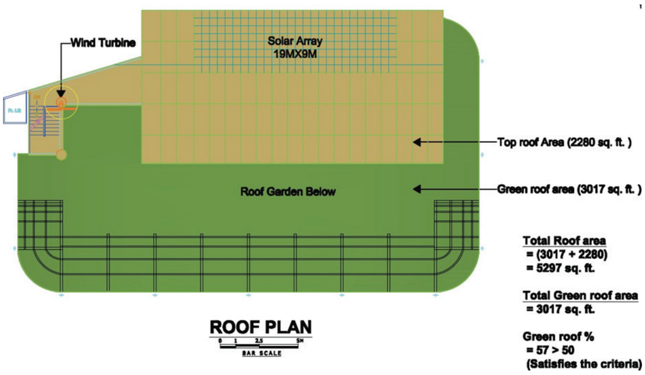


Fig. 13 Install a vegetated roof that covers at least 50% of the roof area.

Transport

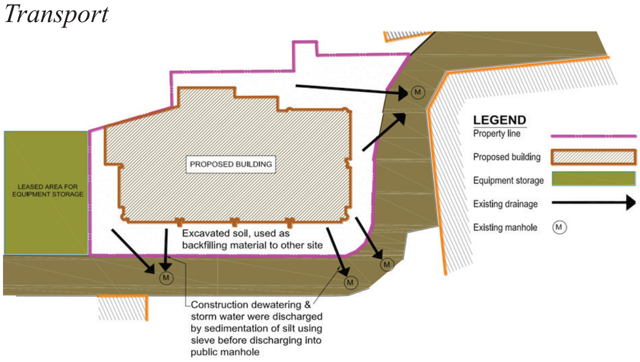


Fig. 14 Site plan of Hama Steel building

The project actively promotes ecological and sustainable mobility options. It includes 25 bicycle spaces and provides employee subsidies for sustainable transportation methods, encouraging a shift away from conventional car use. To support the adoption of green vehicles, the building is equipped with chargers for 2 electric cars. These initiatives highlight the project's commitment to fostering active and environmentally friendly commuting practices among its occupants.

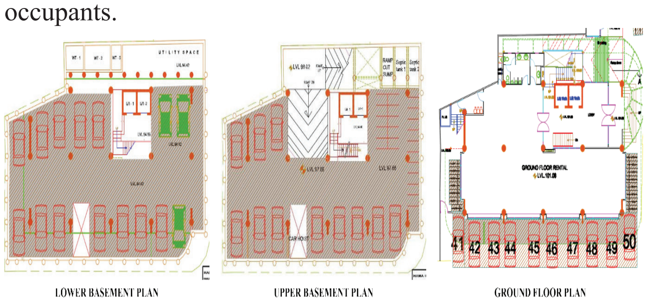


Fig. 15 Floor plans of Hama Steel Building

The Edge, Amsterdam, Netherlands

Fig. 16 The Edge, Amsterdam.

The Edge, located in Amsterdam, is a pioneering office building celebrated for its integration of smart technologies and the Internet of Things (IoT). Completed in November 2014, its design does not follow traditional Building Information Modelling (BIM) methods but achieves many BIM-like benefits such as automated energy performance visualization, building usage monitoring, and energy analysis. Recognized globally as one of the smartest buildings, The Edge is often referred to as "a computer with a roof." Its success stems from the effective communication among key drivers, including Deloitte, OVG, and PLP Architects, who collaborated on the project with a focus on innovative solutions for workplace design.

Design Concept

The concept of The Edge emerged after Deloitte conducted surveys revealing underutilization of desk spaces. Deloitte predicted a 78% increase in employees by 2020 but sought to reduce desk space by creating a more flexible, activity-based assignment system. This led to the 2007 competition, which PLP Architects won, and the design for The Edge was created with the goal of supporting flexible working and social collaboration.

Design Development and Construction

The development of The Edge was shaped by clear communication between Deloitte, the developer, and the architect, fostering a shared vision. The design emphasized a balance of sustainability, flexible working, and technological integration. The atrium, a central feature of the building, played a critical role in providing both social and visual benefits. Despite the financial downturn in 2008, the design team-maintained focus on these principles, adapting the design for potential changes in tenancy while retaining the core elements of sustainability and flexibility.

Fig. 17 The atrium stretches 15 stories

The atrium at The Edge is a central design element, stretching 15 stories and designed to maximize natural light while minimizing direct sunlight. Its north-facing orientation, along with solar path and massing studies, helped shape the building's footprint to ensure diffused natural light reached deep into the workspaces. The atrium also connects the building's levels through skybridges, enhancing its social and visual appeal.

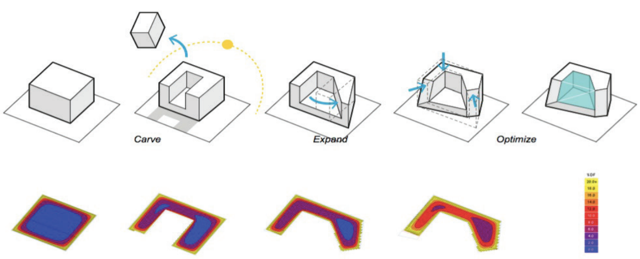


Fig. 18 Solar and massing studies by the architects for determining the ideal

Passive and Active Design Features

Several passive and active design features contribute to The Edge's sustainability. These include extensive bicycle parking, electric car charging units, and a south façade with thermal mass to regulate temperature. To achieve zero-energy status, additional solar panels were installed on neighbouring rooftops, supplementing the building's own 1,920 square meters of panels. The building also incorporates geothermal energy through an aquifer for heating in winter, while ventilation systems circulate air efficiently, and rainwater is recycled for non-potable uses. These features are estimated to reduce CO_2 emissions by 42 million kg over a decade.

Digital Competence and Development of IoT concepts

In terms of digital competence, the building was designed with future-proof IoT capabilities. The technology to gather data for predictive maintenance and occupancy monitoring was not available at the time, prompting collaboration between Deloitte, OVG, and Philips. They developed a new, internet-connected light fixture with embedded sensors for monitoring various environmental factors. These fixtures, now part of Philips' standard catalogue, are equipped with LEDs powered via Ethernet cables and can be remotely monitored, further enhancing the building's smart capabilities.

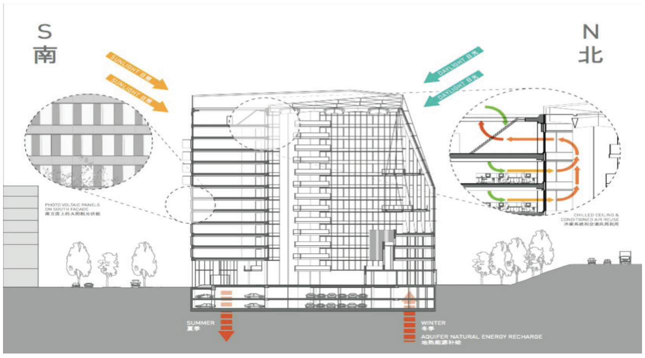


Fig. 19 A host of sustainable design solutions and technologies make The Edge a success.

Olympic House, Lausanne, Switzerland

Fig. 20 Olympic House

Olympic House, the new headquarters of the International Olympic Committee (IOC), was inaugurated on Olympic Day in Lausanne, Switzerland. Designed by the Danish architecture firm 3XN, the building aims to consolidate the IOC staff, currently spread across four locations in Lausanne, into one unified space. The project embodies the IOC's commitment to international cooperation, transparency, and sustainability.

The IOC initiated the move in 2014 and selected 3XN through a multi-stage, international architecture competition. 3XN partnered with Swiss firm IttenBrechbühl to oversee construction. The design of Olympic House revolves around five key principles: movement, transparency, flexibility, sustainability, and collaboration. These principles reflect the core values of Olympism and the role of the IOC in fostering collaboration, all expressed through the building's iconic design. [3]

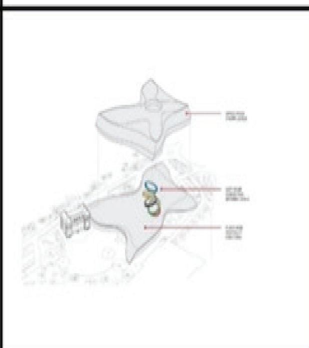
	**Integration:** The green base of Olympic House blends in with the natural setting of the park.		**Peace:** The solar panels on the roof of Olympic House represent the shape of a dove landing in the park.
	**Athletes at the heart**: The shape of Olympic House is inspired by the movement of athletes performing their sport. The curved facades help to minimise the visual impact of the building in the landscape and bring a maximum amount of light into the interior spaces.		**Unity:** Olympic House will be the meeting place for the Olympic Movement, and its central staircase, which echoes the Olympic rings, will link the various floors. The design of the staircase is in line with the concept of "active architecture" that encourages the movement of building users.

Fig. 21 Design Concept

Olympic House has been designed around the four concepts of Integration (into the natural landscape), Athletes at the heart (shape inspired by movement), Peace (solar panels on the roof representing a dove), and Unity (five-ring central staircase). [11]

Certification

Fig. 22 Awards received by the building.

Olympic House in Lausanne has achieved remarkable sustainability milestones with three prestigious certifications. It received the highest level of LEED certification, LEED Platinum, for its environmentally conscious design, earning 93 points, the most ever for any LEED v4-certified new construction project. In addition, Olympic House is the first international headquarters to obtain the Platinum level of the Swiss Sustainable Construction Standard (SNBS) and the second building overall to do so. The building also holds the Minergie P standard, which recognizes energy-efficient buildings. These certifications make Olympic House the first building in Switzerland to achieve LEED v4 Platinum and the first to receive all three certifications. [10]

Design Development and Construction

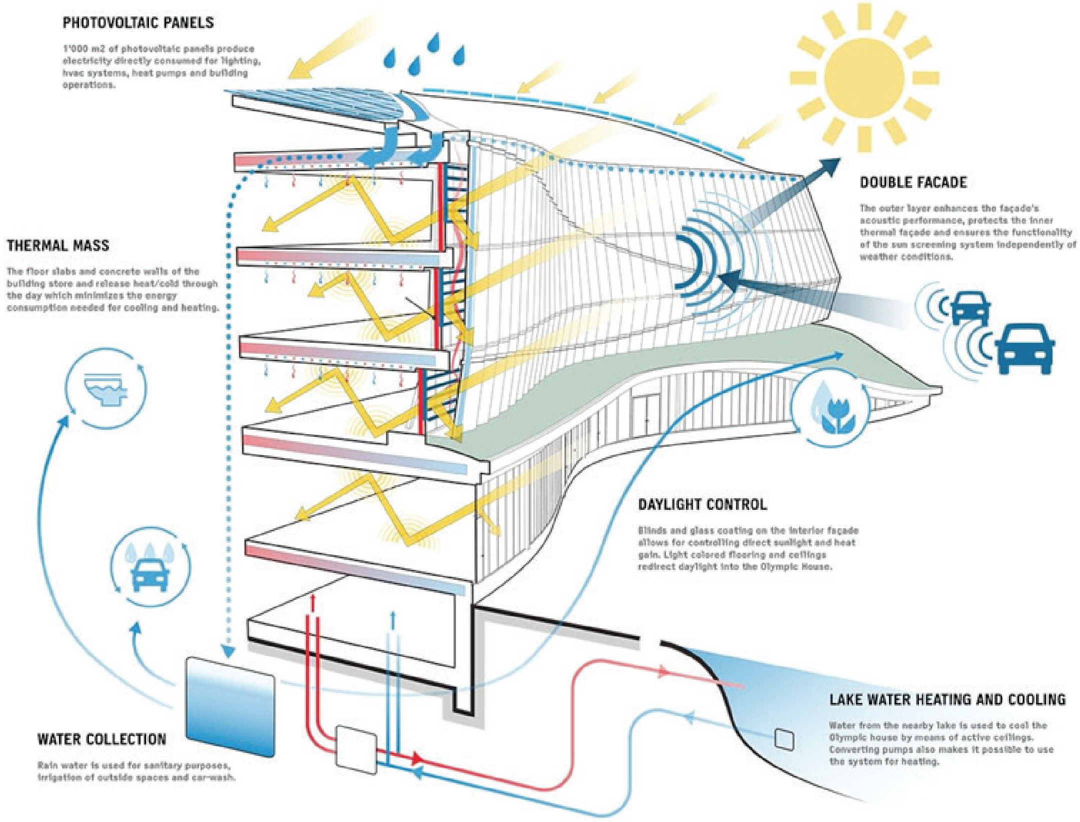


Fig. 23 Resource Efficiency of the Olympic House

Olympic House is designed with a strong emphasis on sustainability in both its construction and operations. The building incorporates energy and water efficiency, waste reduction, and landscape integration. User wellness is central to the design, offering features like access to outdoor views, natural daylight, air quality control, and temperature regulation. Carbon emissions from the building will be fully compensated through the IOC-Dow carbon partnership.

Despite being three times larger than the previous headquarters, Olympic House will not consume more energy. This is achieved through energy-saving measures such as enhanced insulation, smart building technology, and LED lighting. Energy models predict that the building will use approximately 35% less energy than a typical new construction. It will primarily be powered by renewable energy, with some energy generated on-site through photovoltaic solar panels and heat pumps that use lake water. [10]

Fig. 24 Recycling of the material from former building & construction waste

Right from the start of the project, sustainable development has been one of the five key success factors of the programme to enlarge the IOC headquarters. Over 95 per cent of the materials from the former administrative buildings have been re-used or recycled and can be regrouped in three categories:

- Iconic: Repositioning of the marble arch
- Value added: Donation of electronical boards and bathroom fittings to local associations.
- Volume: Recycling of concrete

The project achieved significant sustainability milestones, with 80% of construction costs being allocated to local contractors. This approach not only supported the local economy but also minimized transportation emissions. Additionally, 95% of the construction waste generated during the project was successfully recycled. The use of local designers, materials, and labour further contributed to reducing the project's carbon footprint, reinforcing the environmental and community benefits of localized sourcing and expertise.

Fig. 25 Solar panels on the roof of the building

The project features a 1,000 square meter solar panel installation on the roof, which will generate approximately 200 MWh of electricity per year. This amount is equivalent to the annual electricity consumption of 60 Swiss households. The energy produced by these solar panels will partially cover the building's electricity needs, including lighting, HVAC systems, heat pumps, and other operational requirements. This significant renewable energy contribution highlights the project's dedication to sustainability and reducing reliance on non-renewable energy sources.

Water Efficiency

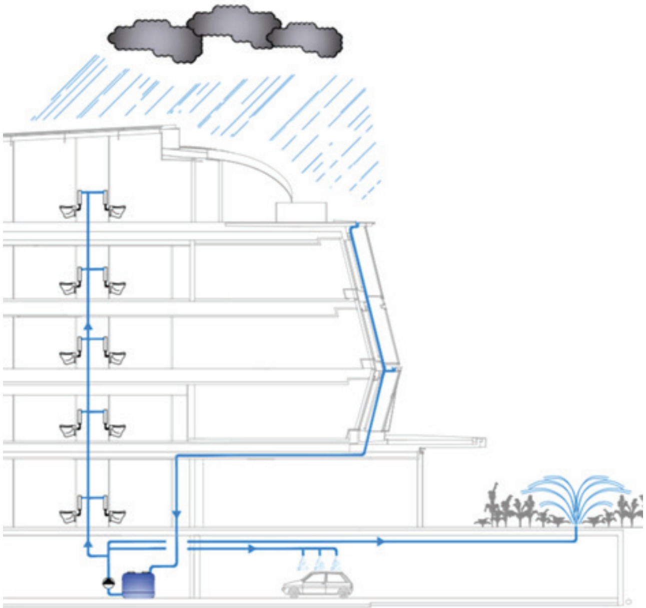


Fig. 26 Rain water harvesting

The Olympic House is able to harvest and reuse rainwater, thanks to a 300 m3 water tank. Rainwater will be harvested and stored for reuse in toilet flushing, car washing and plant watering. Water-saving features mean that the Olympic House's consumption of the municipal supply should be 60 per cent less than a conventional building.

Additionally, energy consumption was lowered by 35%, reflecting the implementation of advanced energy-efficient technologies. The integration of on-site renewable energy sources, such as solar panels and heat pumps, further underscores the project's commitment to sustainability and reducing its environmental impact.

Lake Water

Fig. 27 Water used from Lake Geneva

Olympic House will be cooled and heated via a pumping station that uses water from Lake Geneva. A pipe collects the water at a constant temperature (approximately 5 degrees Celsius) at a depth of more than 60 metres, and takes it to the pumping station close to the shore. This enormous tube, 50cm in diameter and 1.2km long, was assembled in the large Noville canal, then transported through the lake to Vidy, where it was attached to the pumping station and lowered by force of gravity.

This cutting-edge system, which is already in use by local institutions such as IMD, Nestlé, EPFL, and the Bellerive pool, eliminates the need for traditional air conditioning. The adoption of this technology underscores the project's commitment to sustainable building practices and energy efficiency.

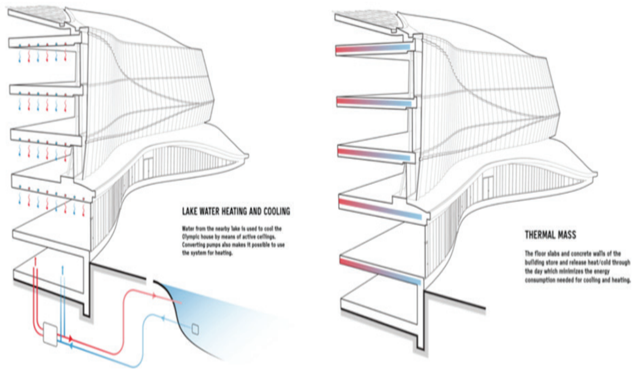


Fig. 28 Lake water used for Thermal Comfort

Vegetation

Fig. 29 Roof Garden

More than 60 per cent of the site area is open space and half of it is vegetated, with 50 trees added since before development. Only indigenous plant species are being used, with meadow areas that include pollinating plants and require lower maintenance than lawns. There will be 2,500 square metres of vegetated roof; and outdoor lighting will be optimised to minimise light pollution.

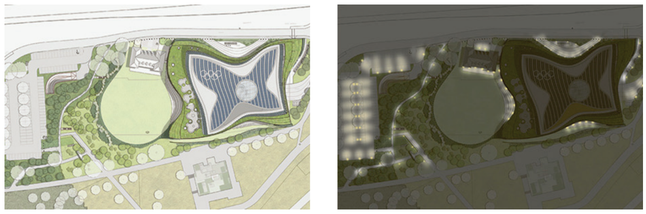


Fig. 30 Vegetated roof & optimized outdoor lighting

Material

Fig. 31 Material used in Olympic House

Significant efforts were deployed to screen all construction materials, equipment items, finishing materials and furniture items so that they comply with strict environmental standards, such as low contents of potentially harmful substances, in order to guarantee very good indoor air quality.

All wooden products will be FSC-certified, meaning that they come from responsibly managed forests. More specifically, it means that the wood is legally harvested, the forest is managed in a way that maintains the quality of forest ecosystems over the long term and that protects the social and economic well-being of workers and local communities. Preference was given to materials and furniture that have a lower-than-average environmental footprint over their life cycle.

Fig. 32 Access to quality views

The building design emphasizes flexibility and occupant well-being. It provides adaptable spaces, ensuring 90% of regularly occupied areas have access to quality views. Additionally, there are no static elements within 8 meters of the façade, enhancing spatial dynamics and usability. The building also boasts high indoor air quality, achieved through the selection of low-emission materials and the implementation of a highly efficient ventilation system. These features collectively contribute to a healthier and more productive environment for occupants.

Transport

The project actively promotes ecological and sustainable mobility options. It includes 135 bicycle spaces and provides employee subsidies for sustainable transportation methods, encouraging a shift away from conventional car use. To support the adoption of green vehicles, the building is equipped with chargers for electric cars and features a hydrogen station. These initiatives highlight the project's commitment to fostering active and environmentally friendly commuting practices among its occupants.

Challenges in NZEB Implementation

A. High Initial Costs

The capital investment required for renewable energy systems and advanced materials can be prohibitive, especially in developing regions.

Technical Barriers

Integrating diverse technologies and ensuring their seamless operation requires expertise and sophisticated tools.

Policy and Regulatory

Issues Lack of uniform regulations and incentives often hampers NZEB adoption.

Maintenance and Operational Challenges

Long-term performance depends on proper maintenance, which may involve additional costs and specialized knowledge.

Recommendations for Advancing NZEB Adoption

Government Incentives

Subsidies and tax breaks can offset initial costs.

Public Awareness Campaigns

Educating stakeholders about the benefits of NZEBs can drive demand.

Standardization of Policies

Unified global standards can streamline implementation and promote best practices.

Research and Development

Continued innovation in materials, renewable energy systems, and smart technologies is essential.

Conclusion

Net Zero Energy Buildings represent a pivotal step toward a sustainable future. By combining energy efficiency, renewable energy, and intelligent design, NZEBs reduce environmental impact while enhancing occupant comfort. Although challenges exist, targeted efforts in policy, technology, and education can accelerate their adoption. This paper underscores the potential of NZEBs to transform the built environment, offering a blueprint for architects, engineers, and policymakers to lead the transition to a low-carbon future.

Acknowledgement

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