



Module 4 – Energy Building: Advanced Energy Management and Production

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1 Introduction

Residential buildings are major contributors to global energy consumption and associated greenhouse gas emissions, driven largely by heating, cooling, electricity usage, and traditional reliance on fossil fuels. Recent studies indicate that buildings account for approximately 40% of total global energy consumption and nearly 30% of worldwide CO₂ emissions (IEA, 2024), highlighting their significant environmental footprint. With rapid urbanization and increasing energy demands, transitioning towards sustainable and energy-efficient buildings has become critically important.

This module addresses these sustainability challenges by integrating renewable energy technologies, demand-side management strategies, advanced energy storage solutions, and smart building technologies. Through a structured Problem-Based Learning (PBL) approach, interdisciplinary student teams will explore realistic scenarios involving residential building retrofits aimed at achieving Near-Zero Energy Building (nZEB) standards. Students will actively engage in designing innovative and practical solutions to significantly reduce environmental impacts, lower operational costs, and enhance occupant comfort.

2 Background and Motivation

Environmental challenges associated with energy consumption in residential buildings, including substantial greenhouse gas emissions, energy inefficiency, and high operational costs, highlight the critical need for adopting sustainable and integrated energy practices. The residential sector's significant reliance on fossil fuels underscores its contribution to global climate change and resource depletion. Transitioning towards sustainability requires the widespread adoption of renewable energy technologies, effective demand-side management (DSM) strategies, and intelligent energy storage solutions.

The shift towards sustainable residential buildings necessitates the integration of innovative smart building technologies and optimized energy management practices. These approaches aim to significantly reduce energy consumption, minimize carbon emissions, and enhance grid resilience and occupant comfort. By promoting renewable energy integration, efficient storage systems, and smart management techniques, the module directly addresses these pressing environmental and energy efficiency challenges, positioning students as active contributors towards a sustainable and resilient built environment.

3 Theoretical Framework

3.1 Key Concepts and Definitions

- **Renewable Energy Systems:** Technologies such as Solar Photovoltaics (PV), Wind Energy, and Geothermal Heat Pumps (GHP) used to generate

sustainable and clean energy, reducing dependency on fossil fuels and minimizing greenhouse gas emissions.

- **Building-Integrated Photovoltaics (BIPV):** Photovoltaic modules designed as integral parts of the building structure, simultaneously serving as building envelope materials and energy-generating components.
- **Demand-Side Management (DSM):** Techniques such as peak clipping, load shifting, valley filling, and energy conservation aimed at optimizing energy use patterns, reducing peak loads, and improving overall building energy efficiency.
- **Energy Storage Systems (ESS):** Systems like Battery Energy Storage (Li-ion or Lead-acid) and Thermal Energy Storage, crucial for storing excess renewable energy and ensuring stable and reliable energy supply.
- **Smart Buildings and Near-Zero Energy Buildings (nZEB):** Intelligent building designs integrating automation, IoT sensors, and adaptive control systems to optimize energy usage, occupant comfort, and environmental performance, significantly reducing net energy consumption.

3.2 Project

Students will form interdisciplinary teams employing a Problem-Based Learning (PBL) methodology to explore and optimize the energy performance of a two-floor residential building located in an urban environment. The project will focus on transforming the current fossil-fuel-dependent building into a sustainable, Smart and Near-Zero Energy Building (nZEB).

Teams will select suitable renewable energy technologies, evaluate appropriate demand-side management (DSM) techniques, identify optimal energy storage solutions, and integrate essential smart building technologies. Students will analyze feasibility, system complexity, urban constraints, and anticipated environmental benefits to make informed decisions. The primary objective is to provide practical, innovative, and justified recommendations aimed at significantly reducing greenhouse gas emissions, lowering energy consumption, enhancing occupant comfort, and achieving sustainable energy independence.



4 Practical Applications

After completing this module, students will develop a comprehensive understanding of the components and strategies involved in designing and retrofitting sustainable residential buildings. They will be able to identify, evaluate, and integrate renewable energy systems such as solar PV, wind energy, and geothermal heat pumps based on practical constraints and energy efficiency goals.

Students will gain hands-on knowledge of Demand-Side Management (DSM) strategies including peak clipping, load shifting, and conservation and understand how these techniques contribute to energy optimization and grid stability. They will also become familiar with different energy storage solutions (e.g., lithium-ion and thermal storage) and learn how to select the most suitable options based on application, cost, and safety.

Additionally, students will explore the role of smart building technologies, such as IoT sensors, smart thermostats, and automated lighting/HVAC systems. They will learn how to design systems that enhance occupant comfort, reduce operational costs, and support intelligent energy management.

Overall, the module provides students with foundational knowledge and practical skills that prepare them to contribute meaningfully to the design and implementation of energy-efficient, smart, and sustainable buildings in their future academic or professional endeavors.

5 Summary and Take-home learning messages

This module introduced students to practical strategies for optimizing the energy performance of residential buildings using a combination of renewable energy technologies, energy storage systems, demand-side management techniques, and smart building solutions. By engaging in a structured Problem-Based Learning (PBL) approach, students applied technical knowledge to solve a realistic energy transition challenge and design solutions that support the transformation of a conventional building into a Smart and Near-Zero Energy Building (nZEB).

The module emphasized the role of photovoltaic systems, wind and geothermal technologies, battery and thermal storage solutions, and intelligent control systems in creating energy-efficient, low-emission buildings. Students also learned how to apply DSM strategies to manage load profiles effectively and integrate smart technologies that enable automation, real-time monitoring, and adaptive energy control.

Take-Home Learning Messages:

- Sustainable residential buildings require integrated solutions that combine renewable energy production, efficient storage, smart control, and behavioral energy use.

- Demand-side management techniques are crucial in shaping energy consumption to align with generation and grid requirements.
- Smart building technologies, including IoT-based systems and intelligent automation, significantly improve energy efficiency, user comfort, and building resilience.
- Transitioning to nZEBs is a multidimensional process that involves technical, environmental, and practical decision-making.
- The skills gained in this module offer a strong foundation for future roles in sustainable building design, smart energy systems, and environmental consultancy.

6 Further Reading and Resources

Books:

- **Kalogirou, S. A. (2022).** *Solar Energy Engineering: Processes and Systems* (2nd ed.). Academic Press.
– A comprehensive guide on solar technologies including PV systems, BIPV, and thermal storage.
- **Clarke, J. A. (2019).** *Energy Simulation in Building Design*. Routledge.
– Covers modeling techniques and simulation tools used in evaluating energy performance in buildings.
- **Schnieders, J. & Feist, W. (2020).** *Passive Houses and Net Zero Energy Buildings*. PHI Publications.
– Practical insights into achieving nZEB standards with smart building strategies.

Articles & Papers:

- **IEA (2023).** *Tracking Buildings 2023 – International Energy Agency*.
– Analysis of global building energy use trends and progress toward net-zero goals.
<https://www.iea.org/reports/tracking-buildings-2023>
- **Zhao, Y. et al. (2023).** *Battery Energy Storage Systems in Smart Buildings: Design and Applications*. *Renewable & Sustainable Energy Reviews*, 173.
– Discusses current trends in integrating batteries with smart grids and residential energy systems.
- **Pérez-Lombard, L., Ortiz, J., & Pout, C. (2021).** *A Review on Buildings' Energy Consumption Information*. *Energy and Buildings*, 43(3).
– Overview of energy consumption patterns and efficiency strategies in residential buildings.



Web Resources:

- **Smart Readiness Indicator (EU):**
<https://smartreadinessindicator.eu>
– Official EU site explaining the SRI framework and smart technology integration in buildings.
- **International Renewable Energy Agency (IRENA):**
<https://www.irena.org>
– Resources on global trends in solar, wind, and geothermal energy.
- **Open Energy Information (OpenEI):**
<https://openei.org>
– Tools and data sets related to DSM, energy efficiency, and renewable technologies.
- **U.S. Department of Energy – Building Technologies Office:**
<https://www.energy.gov/eere/buildings>
– Educational materials and case studies on smart and energy-efficient buildings.

7 Assignments and Assessments Strategy

This module adopts a hands-on Problem-Based Learning (PBL) approach where students will work in interdisciplinary teams to develop practical, sustainable solutions for optimizing energy use in a residential building. The primary assignment involves proposing a well-justified strategy for retrofitting a two-floor residential building using renewable energy, smart technologies, energy storage, and demand-side management concepts introduced during the module.

Students will be guided during online sessions, where further instructions, templates, and intermediate tasks will be provided. These sessions aim to prepare students for the final project and help them engage with the course content progressively.

Grading Rubric and Evaluation Criteria

The evaluation will follow a weighted rubric with a maximum of **20 points**, broken down as follows:

Criteria	Points
Clarity and feasibility of renewable energy choice	5
Practical implementation of DSM technique	5
Justification for selected energy storage	4
Smart technologies selection and justification	4
Overall clarity, presentation, and teamwork	2