



Module 1 – Climate resilience: Adapting buildings to Climate Change

Table of Contents

1 Introduction.....	3
2 Background and Motivation.....	3
3 Theoretical Framework	3
3.1 Key Concepts and Definitions	3
3.2 Module structure.....	4
4 Practical Applications	5
5 Summary and Take-home learning messages.....	5
6 Further Reading and Resources	6
7 Assignments and Assessments Strategy	6



1 Introduction

The module 'Climate resilience: Adapting buildings to Climate Change' provides an in-depth study of climate change adaptation, covering topics such as climate variation, multiscale climate modeling, extreme weather events, and their impact on building performance. Students will explore real-world examples, policies, and solutions, gaining insights into resilience, flexibility, and the use of climate data to assess building performance under various conditions. Practical assignments and hands-on training will equip students with the skills to navigate and address these challenges effectively. The specific aims are:

- To provide a comprehensive understanding of climate change adaptation in the context of nearly zero-energy buildings (nZEB), focusing on the factors influencing building performance under varying climate conditions and extreme weather events.
- To equip students with the knowledge to utilize climate data and assess the resilience and sustainability of building designs.

2 Background and Motivation

The increasing frequency and intensity of extreme weather events—such as heatwaves, cold spells, and heavy precipitation—underscore the urgent need to adapt buildings and cities to changing climate conditions. While climate mitigation aims to reduce greenhouse gas emissions through energy efficiency and renewable energy, climate adaptation focuses on adjusting building design, materials, and operation to ensure performance and comfort under future climate stress. Closely related but distinct, climate resilience emphasizes a building's ability to withstand and recover from climate extremes and uncertainties, while concepts like robustness, reliability, and flexibility offer additional dimensions for performance-based design.

The traditional reliance on historical weather data is no longer sufficient to inform future-ready building strategies. Future climate assessments must account for variability, nonlinearity, and spatial resolution—from global climate models (GCMs) down to urban and microscale modeling. Many buildings, especially in colder climates like Sweden, are vulnerable due to a lack of cooling systems and design strategies for high-temperature events. In this context, students need to develop a critical understanding of how to integrate multiscale climate data, urban morphology, and simulation methods to evaluate and enhance building performance. This module addresses that need by combining climate science, simulation tools, and adaptation theory into a cohesive, practice-oriented learning experience.

3 Theoretical Framework

3.1 Key Concepts and Definitions

This module builds upon a range of foundational and advanced concepts that are central to climate-resilient building design. Key terms include:

- **Climate scenarios and models:** Global Climate Models (GCMs), Regional Climate Models (RCMs), and downscaling methods to derive usable future climate data.
- **Adaptation, mitigation, and resilience:** Strategies to reduce climate risk, emissions, and improve recovery from extreme events.
- **Urban climate and microclimate:** The influence of urban morphology, materials, and vegetation on local climate conditions, including the Urban Heat Island (UHI) effect.
- **Performance-based design and assessment:** Using high-resolution climate data to evaluate energy use, indoor thermal comfort, and peak demand under future climate conditions.

These concepts provide the theoretical foundation for simulating and designing buildings that remain functional, efficient, and safe under evolving climate extremes.

3.2 Module structure

The module is structured into four interconnected parts, each focusing on a specific topic that builds toward a comprehensive understanding of climate resilience in the built environment. While each part addresses distinct theoretical and practical aspects, they are closely linked through a common focus on climate change adaptation, data-driven assessment, and resilient design strategies. Each session includes real-world case studies, practical tools, and research-informed examples to bridge theory and application.

Part 1 – Climate Change Fundamentals: From Global Drivers to Future Risks:

This session introduces fundamental concepts such as climate change mechanisms, IPCC scenarios (SRES, RCPs, SSPs), and the relevance of these scenarios to building energy performance. Students learn about the impacts of global warming and extreme events on indoor comfort and the importance of spatial and temporal climate data.

Part 2 – Climate Models and Future Climate Data:

Focuses on how climate data is generated, processed, and applied at different scales. Global and regional climate models (GCMs and RCMs) are introduced, along with methods for downscaling and developing weather files suitable for building simulations. Emphasis is placed on the limitations of conventional datasets like TMY and the benefits of high-resolution data.

Part 3 – Climate Adaptation, Resilience, and Mitigation:

The third session ties previous parts together by introducing key design concepts such as resilience, robustness, reliability, and flexibility.

Part 4 – Climate-Resilient Urban Infrastructure:

This session examines how urban morphology, land use, and vegetation affect local climate (urban heat island, canyon effects, wind flow). It introduces microclimate modeling methods (e.g., CFD) and shows how fine-resolution climate data can influence building performance, particularly under extreme climate scenarios.

Together, these four parts lead students through an integrated learning journey—from foundational climate science to advanced simulation techniques and resilient building design. Students gain the skills to critically assess how future climate conditions

impact building performance and explore strategies to enhance resilience. Using climate-informed performance metrics and scenario-based simulations, the module equips students to evaluate future-ready buildings. The course concludes with real-world examples that illustrate the application of adaptation and mitigation strategies in practice.

4 Practical Applications

Through a combination of theory, data analysis, and real-world case studies, students will explore how climate change, particularly extreme events, affects buildings, energy systems, and comfort. The module emphasizes climate resilience and the application of global and local climate modeling techniques. Key concepts include climate adaptation, mitigation, resilience, robustness, and the use of multiscale climate data in building performance simulation. By the end of the module, students will be able to:

- Understand the principles of climate change adaptation, mitigation, and resilience in the context of building performance and sustainable design.
- Analyze the impacts of climate change and extreme weather on buildings and energy systems using performance-based assessment methods.
- Apply tools and methods (e.g., EnergyPlus, Elements, Python) to visualize and evaluate climate data and building simulation results.
- Recognize how to use climate data for assessing energy use, comfort, and resilience in buildings.
- Evaluate how buildings and their components respond to climate change risks, with a focus on adaptation and mitigation strategies.
- Become familiar with global and regional climate modeling (GCMs, RCMs), downscaling methods, and the generation of typical and extreme future climate files.
- Critically analyze the climate adaptation of buildings from a holistic and sustainability perspective.

5 Summary and Take-home learning messages

This module will provide students with a strong foundation in understanding the interplay between climate change and building performance, with a particular focus on adaptation, resilience, and the application of climate data in future-ready design. Students will learn how to work with multiscale climate models and simulation tools to assess and enhance the climate resilience of buildings and urban environments.

- Students will understand that climate change will increasingly affect building performance, requiring consideration of both typical and extreme future conditions.
- They will recognize that adaptation and resilience will be essential alongside mitigation in achieving sustainable and robust buildings.

- Students will learn how to work with global and regional climate models (GCMs and RCMs) and understand the importance of downscaling for building-level application.
- They will be able to account for microclimate and urban morphology effects, which will significantly influence comfort and energy demand under future extremes.
- Scenario-based simulations using high-resolution climate data will enable students to develop more reliable and flexible building design strategies.

6 Further Reading and Resources

List of additional resources for students who wish to explore the topic further:

- Oke TR. Urban Climates. 1st ed. Cambridge: Cambridge University Press; 2017.
- Javanroodi K, Perera ATD, Hong T, Nik VM. Designing climate resilient energy systems in complex urban areas considering urban morphology: A technical review. *Advances in Applied Energy* 2023;12:100155.
<https://doi.org/10.1016/j.adapen.2023.100155>.
- Nik VM, Perera ATD, Chen D. Towards climate resilient urban energy systems: a review. *National Science Review* 2021;8:nwaa134.
<https://doi.org/10.1093/nsr/nwaa134>.
- Moazami A, Carlucci S, Nik VM, Geving S. Towards climate robust buildings: An innovative method for designing buildings with robust energy performance under climate change. *Energy and Buildings* 2019;202.
<https://doi.org/10.1016/j.enbuild.2019.109378>.
- Nik VM. Making energy simulation easier for future climate – Synthesizing typical and extreme weather data sets out of regional climate models (RCMs). *Applied Energy* 2016;177:204–26.
<https://doi.org/10.1016/j.apenergy.2016.05.107>.

7 Assignments and Assessments Strategy

To support and reinforce learning, the module includes a combination of quizzes, assignments, and hands-on exercises designed to deepen understanding and apply theoretical knowledge in practical contexts.

Each part of the module is accompanied by online quizzes, combining multiple-choice and open-ended questions to test students' understanding of the core theoretical foundations—such as climate models, scenario frameworks, microclimate concepts, and resilience strategies. These quizzes provide immediate feedback, enabling students to identify areas for improvement and solidify their grasp of complex concepts before moving on to more applied tasks.

Assignment 1: Climate Scenario Comparison (online)

During the online learning phase, students complete two major assignments. The first assignment focuses on analyzing climate variation using nine different future climate

files generated from various GCMs, RCMs, and RCPs for the city of Madrid. Students are introduced to an open-source tool called Elements to open and visualize .epw format weather files, and a Python-based analysis script provided via Google Colab. The task includes:

- Extracting and comparing key climate variables (e.g., temperature, humidity, solar radiation, wind speed).
- Understanding how different climate models and emission pathways influence the predicted weather data.
- Generating visual comparisons and writing a brief report on climate variation trends and their implications.

This exercise demonstrates the real-world variability between climate models and equips students with practical skills in climate data handling and interpretation. It also introduces them to relevant research examples and case studies, helping them understand how model uncertainty and scenario selection can influence the outcomes of energy and resilience assessments for buildings and urban areas.

Assessment for Assignment 1 will be based on a written report that includes the assessment and visualization of a series of future climate datasets derived from different climate scenarios. Students will critically analyze the data to understand variations across GCMs, RCMs, and RCPs. This assignment serves as essential preparation for Assignment 2, completed during the in-person training sessions, where students will use the same climate datasets to conduct building energy simulations and evaluate energy performance and indoor thermal comfort.

Assignment 2: Energy performance and indoor comfort analysis (in-class activity)

Assignment 2 will be introduced in detail during the in-person training sessions, where students will apply their knowledge of climate data to perform building performance simulations. Students are provided with a series of tutorial videos to help them become familiar with the EnergyPlus simulation software (link is provided in Blackboard). These tutorials will cover essential steps such as downloading and installing the software, setting up basic simulation models, and understanding the workflow for input and output handling.

Students are expected to independently review the tutorial material before attending the in-class sessions to ensure they are ready to work with the tool. However, a short overview will be provided during in-class activities.

During the in-person sessions, students will receive a specific simulation task focused on evaluating the energy performance and indoor thermal comfort of a residential building using various future climate scenarios (derived from different GCMs, RCMs, and RCPs). Students will perform simulations in EnergyPlus, and analyze results using tools such as Python, MATLAB, or Excel to:

- Compare heating and cooling energy demands across different climate files.
- Assess thermal comfort metrics (e.g., operative temperature, discomfort hours).

- Investigate the influence of extreme climate conditions on building performance.
- Interpret results in the context of climate adaptation and resilience strategies.

The final analysis will contribute to the overall assessment of the module, emphasizing critical thinking, data literacy, and the ability to translate climate data into meaningful building performance insights.



Work package n°3 - Course content development

Module 2 Circular economy and symbiosis

(Work package 3 - Course content development: outline for the theoretical part)

Table of Contents

1 Introduction.....	3
2 Background and Motivation.....	3
3 Theoretical Framework	4
3.1 Key Concepts and Definitions	4
3.2 Detailed Explanation	4
3.3 Case Studies and Examples	5
4 Practical Applications	5
5 Summary and Take-home learning messages.....	6
6 Further Reading and Resources	6
7 Assignments and Assessments Strategy	7



1 Introduction

The topic's importance and relevance are quite clear. The linear way of production and consumption has led to mountains of waste, polluted soil, air and fresh water, loss of biodiversity and ocean acidification and of climate change.

We have one planet, but live as if we had five, ending the conditions for the life we live. Four limits of the nine planetary boundaries have already been exceeded, loss of biodiversity, altered land use, altered biogeochemical flows of nitrogen and phosphorus. The First and Second laws of Thermodynamics have been neglected for too long. Extraction from finite layers in the ground must stop and renewable sources should be used to the extent they grow to avoid over-extraction. This is the basis for circular economy as means to possibly mitigate the climate change and to achieve the sustainable development goals (SDG).

The aim of micromodule 2 is making students aware of the basis and the strategies for changing the linear direction to a circular one. Awareness of one's own carbon footprint is a first step. The second step is to be aware of the systemic hierarchy for circularity assessment. Case based learning with examples will be utilized and the mixed/interdisciplinary teams of students will cooperate in finding energy efficient circular solutions and maybe also company symbiosis where one industry's waste becomes another's raw material in the chosen cases.

2 Background and Motivation

In Europe, this existing building stock is responsible for 40% of total energy use and app. 36% of CO₂ emissions. Construction industry is therefore facing increased demands to contribute to a more sustainable future, as global challenges are growing. Awareness of the environmental impact in the construction sector has increased significantly, which has led to an interest in circular solutions, resource efficiency and choice of environmentally friendly materials. Conventional construction methods are being questioned more often, also by the big companies, and development is moving towards new ways of working with focus on sustainability.

Building new energy efficient nearly zero energy buildings (NZEB) is important, but 95% of the built environment we will have in 30 years from now is already built, and most of the building stock is not energy efficient. Hence the need for a holistic view of energy efficient circular solutions in the whole construction sector.

3 Theoretical Framework

3.1 Key Concepts and Definitions

Decreasing our carbon footprint is something we all have to deal with and beginning with our own personal footprint is a first start.

Defining projects using the systemic hierarchy for circularity assessment is the first key concept in micromodule 2.

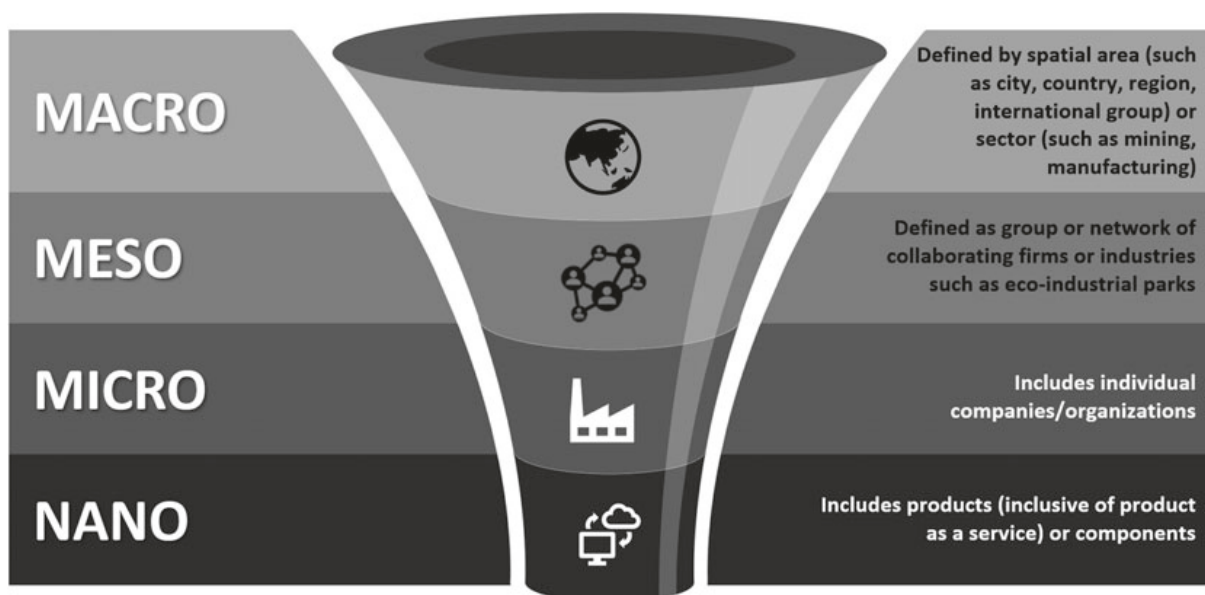
Using the ten Rs within circular economy when working with the existing building stock as well as with new buildings is the second key concept.

Combining circular economy and energy efficiency for every kind of building projects is the third key concept.

Making use of symbiosis with companies in e.g. regenerating construction and indoor building materials is the fourth key concepts.

3.2 Detailed Explanation

Circular economy is implemented on four levels; macro, meso, micro and nano levels.



Schematic representation of the four levels of systemic hierarchy considered for circularity assessment—(top-down) macro, meso, micro, and nano. (Right) The scope of each level of the systemic hierarchy is defined (Patil & Ramakrishna Eds. 2023).

The Rs are usually explained as being five or seven, but there are actually ten Rs used within circular economy.

1. Refuse – prevent raw materials' use
2. Reduce – decrease raw materials' use
3. Redesign – reshape product with a view to circularity principles
4. Reuse – use product again (as second hand)
5. Repair – maintain and repair products
6. Refurbish – Revive product
7. Remanufacture – make new from second-hand product
8. Re-purpose – reuse product but with other function
9. Recycle – salvage material streams with highest possible value
10. Recover – incinerate waste with energy recovery

A rough categorising of the Rs could be as follows. The first and second R is defined at a macro level, and at a meso level we have R number 2, 3, 4 and 9. R number 4, 5, 6, 7, 8 and 9 can be found on the micro level. R number 4 and 10 can be categorised as both macro and nano depending on how electricity and heat are defined and the size of the energy generating plant. Company symbiosis can be found on macro, meso as well as on micro levels within the systemic hierarchy. This rough categorising should be discussed by the interdisciplinary teams.

3.3 Case Studies and Examples

One of the cases from the real world is a study of a multi-family building in Gothenburg where circular economy and the Rs have been used by an architect. The aim for the housing company was to regenerate the building using as few new materials and components as possible. This exemplary study will form the basis for the interdisciplinary teams' understanding how circular economy can be used and on what level of the systemic hierarchy it was performed.

All lectures and literature studies digitally available in micromodule 2 is aimed at enhancing and deepen the understanding of the three subtopics; four levels of systemic hierarchy, the use of the Rs in circular economy, and companies' symbiosis.

4 Practical Applications

In the final case during the last week of the nZEBRA testing period the interdisciplinary teams will have a lecture and then, by themselves, design energy efficient and circular solutions. The exact case is not yet decided on. It can be analysing and suggesting energy efficient circular solutions for an office building, or it can be solutions for companies' symbiosis where one industry's waste becomes another's raw material.

(Discuss how the theoretical knowledge can be applied in practical situations. Provide examples of practical applications and explain how they relate to the theoretical concepts discussed earlier.)

5 Summary and Take-home learning messages

The students will be given the possibility to read and discuss the learning material by working in interdisciplinary teams forming an awareness of circular economy and company symbiosis and their necessary contribution to the SDGs.

Learning objectives

1. Understand the systemic hierarchy levels for assessment of circularity
2. Understand the basic concept of circular economy
3. Define the major components of circular economy and how they can be used
4. Understand the process of symbiosis

(Summarize the key points covered in the topic. Highlight the most important concepts and takeaways for the students.)

6 Further Reading and Resources

Books

- McDonough W. & Braungart M. (2002) *Cradle to cradle: Remaking the way we make things*. New York: North Point Press.
- Anoop Patil R. and Ramakrishna S. (2023) *Circularity assessment: Macro to Nano. Accountability towards sustainability*. Singapore: Springer Nature Singapore Pte Ltd. <https://doi.org/10.1007/978-981-19-9700-6>
- Jonansson G., Sundin E., Wiktorsson M. (2019) *Sustainable Manufacturing*. Lund: Studentlitteratur AB.

Thesis

- Kunic N. (2024) *Transforming a Building by Implementing Circular Economy Principles*. Master Thesis. Halmstad: Halmstad University.

Articles

- Dokter G., Thuvander L., and Rahe U. (2021) How circular is current design practice? Investigating perspectives across industrial design and architecture in the transition towards a circular economy. *Sustainable Production and consumption* 26 (2021) 692-708. <https://doi.org/10.1016/j.spc.2020.12.032>
- Nußholz J., Çetin S., Eberhardt L., De Wolf C., Bocken N. (2023) From circular strategies to actions: 65 European circular building cases and their decarbonisation potential. *Resources, Conservation & Recycling Advances*. 17 (2023) 200130. <https://doi.org/10.1016/j.rcradv.2023.200130>



- Nyström K. and Murata M. (2024) Regenerative businesses' role in industrial symbiosis realisation. *Sustainable Development*. 2024;1–14. DOI: 10.1002/sd.3246
- Cardoso Chrispima M., Mattsson M., Ulvenblad P. (2023) The underrepresented key elements of Circular Economy: A critical review of assessment tools and a guide for action. *Sustainable Production and Consumption*. 35 (2023) 539-558.
<https://doi.org/10.1016/j.spc.2022.11.019>

Websites

- www.ellenmacarthurfoundation.org
- https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en

7 Assignments and Assessments Strategy

- o Each student should be able to do two digital tests based on the digital lectures and the literature in micromodule 2 on the Blackboard with 80% right answers.
This will equal 25 points.
- o Each interdisciplinary team will discuss the three subtopics; the four levels of systemic hierarchy, the use of the Rs in circular economy, and companies' symbiosis, and hand in a written assignment of minimum 3-pages.
This will equal 35 points.
- o Each interdisciplinary team will in an IRL workshop/seminar analyse, discuss and suggest energy efficient circular solutions for a case.
This will equal 40 points.

(Outline the assignments and assessments related to this topic. Describe the tasks, expectations, and criteria for evaluation.)





Module 3: Green Construction- LCA of Building

By TUHH

Table of Contents

1 Introduction.....	3
2 Background and Motivation.....	3
3 Theoretical Framework	4
3.1 Key Concepts and Definitions	4
3.2 Project	4
4 Practical Applications	5
5 Summary and Take-home learning messages.....	6
6 Further Reading and Resources	6
7 Assignments and Assessments Strategy	7



1 Introduction

The construction industry significantly contributes to global environmental degradation by consuming extensive natural resources and energy, producing substantial waste, and emitting large volumes of greenhouse gases. Recent studies indicate that cement production alone accounts for approximately 8% of global CO₂ emissions (IEA, 2023), emphasizing the industry's substantial carbon footprint. Moreover, construction and demolition (C&D) waste remains problematic, with only around 30% being recycled or reused (Eurostat, 2022). With ongoing urbanization and increasing demands for infrastructure, sustainable construction practices have become imperative. This micromodule employs Life Cycle Assessment (LCA)—an analytical method to evaluate the environmental impacts of buildings and materials across their entire lifecycle. Challenge-Based Learning (CBL) is utilized to engage students in practical, real-world sustainability challenges, enabling interdisciplinary teams to collaborate with stakeholders and innovate sustainable solutions.

2 Background and Motivation

Environmental challenges within the construction sector, such as CO₂ emissions, resource depletion, and waste generation, underline the urgent need for adopting sustainable practices. The sector's shift towards sustainability necessitates incorporating circular economy principles, encouraging material reuse, recycling, and prolonged retention within economic systems (Ellen MacArthur Foundation, 2023). Circular economy concepts thus play a crucial role in addressing these environmental challenges.

3 Theoretical Framework

3.1 Key Concepts and Definitions

- Circular Economy in Construction: Promotes material reuse, recycling, and recovery to minimize waste and prolong resource lifecycles. Pre-demolition audits (PDAs) help identify reusable materials, reducing waste.
- Life Cycle Assessment (LCA): A systematic analysis of environmental impacts associated with all stages of a product's lifecycle, from extraction to disposal, guided by international standards (ISO 14040, 2022).
- Life Cycle Thinking (LCT): A comprehensive approach that assesses environmental impacts throughout a product's lifecycle, highlighting opportunities for improvement (Hauschild et al., 2020).
- Challenge-Based Learning (CBL): An educational methodology involving interdisciplinary teamwork to tackle real-world sustainability challenges, promoting innovative solutions in the construction sector.

3.2 Project

Students will form interdisciplinary teams employing CBL methodology to investigate improving the environmental performance of residential buildings through material selection. Utilizing OpenLCA software, they will evaluate various building materials' environmental impacts, assisting decision-making processes. The project site is located in Harburg, Hamburg, used by the Technische Universität Hamburg (TUHH) for laboratory and office spaces. It comprises several buildings, including a two-floor building facing the street, a single-floor building, and a four-floor brick structure. To avoid too much complexity, students will focus on two-floor building facing the street.





Figure 1A view from the entrance and external view of the building



Figure 2A view from the backside of the building

4 Practical Applications

This module extends beyond academic exercises by directly addressing pressing sustainability challenges in real-world contexts. The construction sector significantly impacts environmental degradation, responsible for approximately 37% of global CO₂ emissions, 33% of global resource consumption, and substantial waste generation



Co-funded by
the European Union

(UN Environment Programme, 2023). Consequently, adopting sustainable practices is vital to mitigate these impacts. Digital tools, such as OpenLCA, enhance the accuracy of environmental assessments, optimize resource management, and facilitate efficient building design. Students in this module actively participate as agents of change, applying LCA principles and Challenge-Based Learning to foster practical sustainability solutions. By engaging directly with stakeholders and employing interdisciplinary approaches, students cultivate essential skills and mindsets necessary for advancing sustainable construction practices.

5 Summary and Take-home learning messages

In this module, students explored:

- The critical environmental impacts of the construction industry, particularly regarding resource consumption, emissions, and waste.
- The fundamental principles and benefits of applying LCA to construction, emphasizing informed decision-making in material selection.
- The importance of integrating circular economy principles to enhance sustainability in construction practices.
- Practical application of Challenge-Based Learning (CBL), enabling effective teamwork, collaboration, and real-world problem-solving skills.

6 Further Reading and Resources

Books:

- Hauschild, M.Z., Rosenbaum, R.K., & Olsen, S.I. (Eds.). (2020). Life Cycle Assessment: Theory and Practice. Springer International Publishing.
- Cheshire, D., & Morris, M. (2021). Building Revolutions: Applying the Circular Economy to the Built Environment. Routledge.



Articles:

- Ellen MacArthur Foundation. (2023). Circular economy in the built environment. Retrieved from <https://ellenmacarthurfoundation.org>
- UN Environment Programme. (2023). Global Status Report for Buildings and Construction. Retrieved from <https://globalabc.org>

Websites:

- OpenLCA official website: <https://www.openlca.org>
- European Commission on Circular Economy: https://environment.ec.europa.eu/topics/circular-economy_en
- International Energy Agency (IEA) on Cement Sustainability: <https://www.iea.org/reports/cement>

7 Assignments and Assessments Strategy

Students will engage in small, practical assignments designed to familiarize them with LCA modeling and interpretation using OpenLCA. These tasks will involve assessing individual building materials, comparing environmental impacts, and extrapolating findings to building-scale scenarios. Such activities will build foundational knowledge and skills, preparing students for the comprehensive project outlined in section 3.2.

Grading Rubric and Evaluation Criteria:

- Research and Analysis (30%): Quality, depth, and analytical skills in addressing sustainability challenges.
- Collaboration and Participation (20%): Team effectiveness, communication, and individual contributions.
- Solution Design (30%): Creativity, innovation, and practicality of proposed sustainability solutions.
- Presentation and Defense (20%): Clarity, professionalism, and persuasiveness during presentations.





Module 4 – Energy Building: Advanced Energy Management and Production

Table of Contents

1 Introduction.....	3
2 Background and Motivation.....	3
3 Theoretical Framework	3
4 Practical Applications	5
5 Summary and Take-home learning messages.....	5
6 Further Reading and Resources	6
7 Assignments and Assessments Strategy	7



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



Module 5 – Energy and Buildings: Indoor Climate; Heating, Cooling, and Ventilation System

Table of Contents

1 Introduction.....	3
2 Background and Motivation.....	3
3 Theoretical Framework	3
3.1 Key Concepts and Definitions	3
3.2 Project	3
4 Practical Applications	4
5 Summary and Take-home learning messages.....	4
6 Further Reading and Resources	5
7 Assignments and Assessments Strategy	5



1 Introduction

This module introduces the fundamentals of heating and cooling in buildings, emphasizing their role in maintaining thermal comfort and reducing energy use. The focus is on designing an energy-efficient and moisture-safe building.

2 Background and Motivation

The heating and cooling of buildings account for a significant portion of global energy consumption and greenhouse gas emissions. Improving energy efficiency and indoor climate control is essential for meeting environmental targets and enhancing occupant well-being.

3 Theoretical Framework

3.1 Key Concepts and Definitions

Key terms include thermal comfort, HVAC (Heating, Ventilation, and Air Conditioning), energy- and moisture calculations, energy efficiency, passive and active heating/cooling systems, and indoor air quality (IAQ). Understanding these concepts is essential for designing systems that meet user needs while minimizing energy use.

3.2 Project

This project aims to design a building to meet low energy use demands and high moisture safety based on building physics-related performance criteria. The building is a one-family detached house with a wooden structure (timber-framed), a slab on ground, and an outdoor air-ventilated attic, also known as a cold attic.

The project contains the following parts:

- **U-value:** calculate the U-value for different parts of the building envelope and the mean U-value for the whole building. A U-value of $1 \text{ W}/(\text{m}^2 \cdot \text{K})$ can be used for windows and doors. Thermal bridges for the entire building can be assumed to be equal to 15 % of the total UA value.
- **Wall:** choose an external wall with a wooden structure from literature, the internet, etc. Calculate temperature and moisture content distribution in the external walls during steady-state conditions. The outdoor temperature is -10°C , and the relative humidity is 90 %. The indoor temperature is $+21^\circ\text{C}$, and the relative humidity is 65 %. Calculate the relative humidity at the interfaces between the different layers and compare the results to the critical moisture level for mold growth on building materials. If condensation occurs anywhere within the wall construction, calculate the least required vapor resistance, s_d , to avoid condensation.
- **Cold attic:** calculate the temperature and the relative humidity in the outdoor ventilated attic using heat and moisture balances. For the calculation of this



part, DWOT for the location in question must be used. Consideration must be taken to long-wavelength radiation in the sky. Sky temperature can be assumed to be equal to $-30\text{ }^{\circ}\text{C}$. Air exchange of outdoor air with the attic can be considered equal to 4 1/h. Leakage from inside the house to the attic, mainly due to the slot around the hatch on the ceiling, must be calculated and considered in the calculations.

- **Energy:** Calculate design heat power and annual energy consumption for space heating. Calculate the primary energy number, PEN, according to BBR. Does your building meet BBR requirements? Input data can be chosen from the site energiberakningar.se.
- **Analyze and discuss the results.**

4 Practical Applications

The module will empower students with cutting-edge knowledge and technologies regarding energy efficiency in buildings. State-of-the-art research on energy-efficient buildings will be raised and discussed. The keywords of this module are HVAC, energy balance calculations, energy-efficient buildings, and indoor climate. Learning objectives include:

- Develop in-depth knowledge of energy-smart solutions in the built environment.
- Design heating, cooling, and ventilation systems for various kinds of buildings.
- Calculate and account for energy in buildings and energy efficiency measures without negative impacts on the indoor climate. Perform energy balances and carry out energy and moisture calculations using different software.
- Account for the relationship between a building's indoor climate and the dweller's well-being.
- Critically analyze the energy efficiency from a holistic and sustainability perspective.

5 Summary and Take-home learning messages

Students will learn to assess and design heating and cooling systems that optimise indoor climate and minimise energy use. Applications include system sizing, selection of efficient equipment, and implementation of control strategies for various building types. The expected outcomes are:

- Demonstrate understanding of basic principles of HVAC
- Understand energy use in buildings from a sustainability and holistic point of view
- Showing the ability of performing advanced calculation for energy in buildings and assess the impact on sustainability
- Demonstrate ability of designing HVAC-system

6 Further Reading and Resources

List of additional resources for students who wish to explore the topic further:

- Linden V., Gaalen K-V., Zeegers A. (2024). *Building Physics*. TU Delft, Faculty of Architecture and the Built Environment, Architectural Engineering and Technology, Group Building Physics and Building Services.
- Pinteric, M. (2021). *Building Physics, From physical principles to international standards*, Springer.
- Abel E., Elmroth A. (2007). *Buildings and Energy - a systematic approach*, Formas.
- Hall F., Greeno R., *Building Services Handbook*, Routledge.
- Energy calculations: <https://www.energiberakning.se/default.aspx>

7 Assignments and Assessments Strategy

In this module, students will be given 1 assignment. Assignment involve analyzing the heating and cooling strategy of a hypothetical building. Students will evaluate energy performance, indoor climate quality, and propose improvements based on smart and efficient technologies. Group discussions will foster comparison between different building types and usage scenarios.

Assessment is based on a written report including:

- Description of the building and cross-section drawings on the external wall, slab on the ground, and attic, including material data.
- Calculations, the results of all calculations, analysis, discussion, and conclusions

Calculations must be done thoroughly, correctly, and as accurately as possible. All assumptions must be justified. All solution steps and input data must be clearly presented.



Module 6 – Smart Buildings – Modern Technologies and Systems Integration

Table of Contents

1 Introduction.....	3
2 Background and Motivation.....	3
3 Theoretical Framework	3
3.1 Key Concepts and Definitions	3
3.2 Smart Readiness, Energy Management and technologies	3
3.3 Case Studies and Examples	5
4 Practical Applications	5
5 Summary and Take-home learning messages.....	5
6 Further Reading and Resources	6
7 Assignments and Assessments Strategy	7



1 Introduction

Smart Buildings module introduces the concept of smart buildings and their significance in modern urban development. It covers integrated technologies that enhance building performance and sustainability. Key topics include smart readiness indicators, energy management, new technologies, and the human factor.

2 Background and Motivation

The development of smart buildings is crucial in the context of modern urban development and sustainability. Integrated technologies enhance building performance, reduce energy consumption, and improve user comfort. This module explores the systems that make buildings intelligent and the broader implications of these technologies in the context of digital transformation. The goal is to provide a foundational understanding of smart buildings, their readiness indicators, energy management, new technologies, and the human factor, along with examples that illustrate these concepts. By the end, the students will understand the essential aspects of smart buildings and the importance of smart readiness indicators in the context of smart buildings.

3 Theoretical Framework

3.1 Key Concepts and Definitions

A smart building uses automated processes and advanced technology to efficiently manage and control its systems, such as heating, ventilation, air conditioning (HVAC), lighting, security, and other essential functions. These buildings integrate Internet of Things (IoT) devices, sensors, artificial intelligence (AI), and data analytics to optimize performance.

Challenges of Smart Buildings involve high initial costs, cybersecurity risks, complex integration, reliability of internet and power, and scalability challenges. Advantages, such as energy efficiency, cost reduction, occupant comfort and productivity, and enhanced safety and security, outweigh these challenges.

Future Trends in Smart Buildings include integration with smart cities, 5G connectivity, AI-driven adaptation, digital twins, and simulation. Sustainability is a core principle, with smart buildings integrating renewable energy sources like solar panels and wind turbines to reduce environmental impact. Comfort-driven systems that improve air quality and lighting are crucial for enhancing occupant well-being.

3.2 Smart Readiness, Energy Management and technologies

The Smart Readiness Indicator (SRI) is a standardized EU framework designed to evaluate a building's capability to effectively use smart technologies, such as building automation, energy management, and integration with the energy grid. The primary objectives of the SRI are to enhance energy efficiency, reduce carbon emissions, and

improve occupant comfort. There are two methods for calculating the SRI: Method A: A simplified approach suitable for smaller or less complex buildings, evaluating 27 smart functionalities. Method B: A more detailed assessment for larger or more complex buildings, evaluating 54 smart functionalities.

The SRI evaluation focuses on three key functionalities: optimizing energy efficiency and overall building performance, enhancing user comfort and convenience, increasing energy flexibility and interaction with the grid

Each smart functionality is assessed using seven impact criteria, including energy efficiency, fault detection and diagnostics, comfort, convenience, health and well-being, user information, and energy flexibility. Different building types have unique operational profiles and needs, influencing how smart technologies are applied. Climate is also a critical factor, with the European SRI framework dividing Europe into five climate zones, each assigning different importance to technical domains such as heating and cooling.

The SRI framework ensures a consistent and transparent assessment of a building's smart capabilities, supporting the EU's goals for energy efficiency and sustainability.

Energy management in buildings involves a structured approach to using energy efficiently across all systems and zones. The five pillars of energy management are monitoring, analysis, optimization, user engagement, and implementation. Main Goals of Energy Management include cost savings, reducing environmental impact, enhancing comfort, improving control and data visibility, and ensuring regulatory compliance. Legislation such as the Energy Performance of Buildings Directive (EPBD), ISO 50001, and the Smart Readiness Indicator (SRI) drives energy management practices.

Nearly Zero Energy Buildings (nZEB) are designed to use significantly less energy than traditional buildings, often integrating renewable energy sources and smart controls. Zero Emission Buildings (ZEB) aim for zero net emissions during operation, combining energy efficiency, on-site generation, and digital intelligence.

Building Management Systems (BMS) act as the digital brain of a building, monitoring and controlling systems like HVAC, lighting, and security. Future BMS will be AI-driven, cloud-based, and capable of real-time adaptation. While BMS offers centralized control and high-energy savings, challenges include high upfront costs, complexity, and the need for skilled personnel. Smart Meters enhance energy efficiency by providing detailed, real-time data on electricity, gas, water, and heat usage.

Measurement and Verification (M&V) of energy savings is tailored to different building types and behaviours, providing feedback for continuous improvement. M&V validates energy savings, supports compliance, and enhances transparency.

Future-ready buildings must address both operational and embedded carbon to meet 2050 climate targets. This requires faster renovation, increased digitalization, educated professionals, and supportive policies. Ultimately, energy management is

about designing buildings that respect environmental limits while enhancing quality of life.

3.3 Case Studies and Examples

Two real-life examples of smart buildings are shortly described below. More examples can be found in the Module 6 Booklet on smart buildings.

Luxembourg, NeoBuild Office

Technical Description: Integrates advanced energy management systems, utilizes solar panels, and is equipped with smart sensors for monitoring and optimizing energy usage.

Potential for Improvement: Enhance IoT integration for better data collection, implement advanced AI algorithms for energy management, and upgrade insulation and window technologies.

Luxembourg, The Elmen Social Housing Project

Technical Description: Features a comprehensive energy management system, incorporates solar panels and geothermal energy, and has smart lighting and HVAC systems that adjust based on occupancy and external conditions.

Potential for Improvement: Further integrate IoT devices for real-time monitoring, implement AI-driven analytics for optimization and maintenance prediction, and upgrade building materials for better thermal insulation.

4 Practical Applications

After completing module 6, students will have better understanding of implications related to smart building concept and significance, smart readiness indicators and methodologies that yet have to be adopted at the EU level and legal framework concerning smart buildings. They will be able to recognize relevant technical systems in buildings and their levels of smartness. They will also understand the importance of energy management, smart metering and data collection in smart buildings and will be able to select and apply an adequate methodology to verify the savings that are achieved through these technologies.

Generally speaking, the students will acquire basic knowledge on smart buildings, which will serve as a solid basis to build upon, depending on the future requirements, i.e. from their employers.

5 Summary and Take-home learning messages

Smart buildings use integrated technologies to enhance performance and sustainability. They feature automated systems for HVAC, lighting, security, and more, offering benefits like energy savings, cost reduction, comfort, and safety.

The Smart Readiness Indicator (SRI) is an EU framework that evaluates smart technologies in buildings, focusing on energy efficiency, comfort, and flexibility across nine domains.

Efficient energy management in smart buildings aims for cost savings, reduced environmental impact, and enhanced comfort, incorporating concepts like nZEB, ZEB, BMS, smart meters, and M&V.

Take-home Learning Messages: Smart buildings use IoT, AI, and data analytics to optimize performance and sustainability, significantly reducing energy consumption and operational costs. Automated systems enhance occupant comfort and productivity. Despite high initial costs and cybersecurity risks, the benefits outweigh the challenges. Future trends include deeper integration with smart cities, advanced connectivity, AI, and sustainable practices. Applying SRI methodologies improves smart readiness evaluation, requiring ongoing assessment and adaptation.

6 Further Reading and Resources

List of additional resources for students who wish to explore the topic further, Smart Buildings:

1. **Smart readiness indicator (SRI) Commission initiative**
https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/smart-readiness-indicator_en
2. **Training package for SRI assessors**
<https://ec.europa.eu/smart-readiness-indicator>
<https://ec.europa.eu/eusurvey/runner/SRI-assessment-package>
3. **SRI assessment tool**
<https://sri2market.eu/sri/>
4. **SRI2MARKET e-learning lessons on the SRI and its assessment methodology**
<https://learning.sri2market.eu/moodle/course/view.php?id=3>
5. **EVO organization (IPMVP)**
<https://www.evo-world.org/en/>
6. **Directive 2010/31/EU on the Energy Performance of Buildings (EPBD)**
<https://eur-lex.europa.eu/eli/dir/2010/31/oj>
7. **Directive (EU) 2018/844 (Amending the EPBD and EED)**
<https://eur-lex.europa.eu/eli/dir/2018/844/oj>
8. **Commission Delegated Regulation (EU) 2020/2155 (Smart Readiness Indicator – SRI definition & methodology)**
https://eur-lex.europa.eu/eli/reg_del/2020/2155/oj
9. **Commission Implementing Regulation (EU) 2020/2156 (SRI implementation procedures)**
https://eur-lex.europa.eu/eli/reg_impl/2020/2156/oj
10. **Directive 2012/27/EU on Energy Efficiency (EED)**
<https://eur-lex.europa.eu/eli/dir/2012/27/oj>
11. **Directive (EU) 2024/1275 on the Energy Performance of Buildings**
<https://eur-lex.europa.eu/eli/dir/2024/1275/oj>



12. General Union Environment Action Programme to 2030

<http://data.europa.eu/eli/dec/2022/591/oj>

13. 2023 revision of Energy Performance of Buildings Directive

[https://eur-lex.europa.eu/legal-](https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202401275&pk_keyword=Energy&pk_content=Directive)

[content/EN/TXT/?uri=OJ:L_202401275&pk_keyword=Energy&pk_content=Directive](https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202401275&pk_keyword=Energy&pk_content=Directive)

7 Assignments and Assessments Strategy

In this module students will be given 2 assignments.

First assignment will be communicated during online learning. It will prepare students for the group work in Hamburg. The assignment will be divided into two parts, to be completed by two separate groups:

Group 1 – students who live in Single-Family Homes

Task: Students will be asked to reflect on your home environment and daily interactions with systems like heating, lighting, or ventilation. Students will be asked to note any smart features and how your home responds to occupancy, time of day, or weather conditions and prepare notes for your group's discussion.

Group 2 – Students who live in Multi-Family Buildings

Task: Students will be asked to observe shared and private systems in your building. Identify smart features in central heating, hallways, or common. They will also be asked to reflect on their control over these systems (centrally managed or user-adjustable) and prepare notes for your group's discussion.

Connection to Final Assignment

The group structure continues into the final assignment in Hamburg, which will be communicated to students in person.

