WP3

Learning Material, Training Courses and Joint Proposal Preparation

D3.3
Training Courses and Learning Material on Energy Efficient Building Operation (v1)

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V1.0 (draft)	28/03/2022	NUIG	Luis M. Blanes, Marcus M. Keane
Internal review	29/03/2022	IMP	Valentina Janev
Final version	30/03/2022	NUIG	Luis M. Blanes, Marcus M. Keane

Executive Summary

The main objective of SINERGY work package 3 is to establish collaboration with strategic partners, i.e. AIT and NUIG,and enable expertise and "know-how" exchange in the area of smart grids, distributed energy resources, building optimization and building information modelling.

Task 3.2 focuses on the preparation of training courses on Energy efficient building operation, mainly provided by the partner NUIG National University of Ireland Galway. The report (Deliverable 3.3) summarizes the training courses under elaboration in the first reporting period, from January 2021 to March 2022. Due to COVID-19, in the first reporting period, 2 lectures were delivered online.

The first face-to-face training has been scheduled for the period from 31st of May to 2nd of June 2022.

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Abbreviations and Acronyms

EEBO Energy Efficient Building Operation

1. Introduction

The main scope of work package 3 (Learning Material, Training Courses and Joint Project Proposals Preparation) can be summarized as:

- Task 3.1: Preparation of training courses on Smart Grid technologies (this report)
- Task 3.2: Preparation of training courses on Energy Efficient Building Operation (D3.2)
- Task 3.3: Joint project proposals preparation and management skills upgrade (D3.3)

This report points to the proposed lectures by NUIG (see for instance Figure 1, a screenshot from the SINERGY repository)[1]

The modules developed will consist in a video lecture developed using Kaltura. A link to the video lecture will be provided within the SINERGY portal as an e-course series.

Table 1 gives a summary list of lectures prepared in the first reporting period, from January 2021 until March 2022.

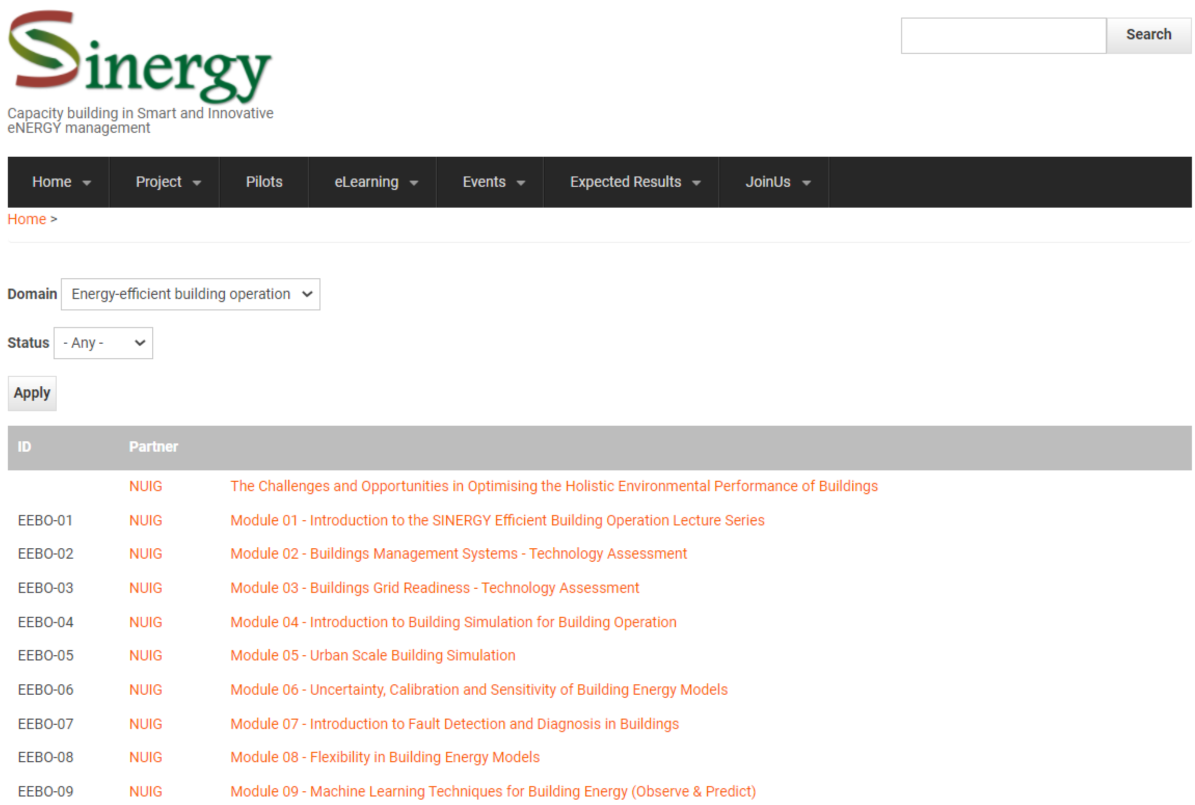


Figure 1. NUIG Lectures in SINERGY repository (example)

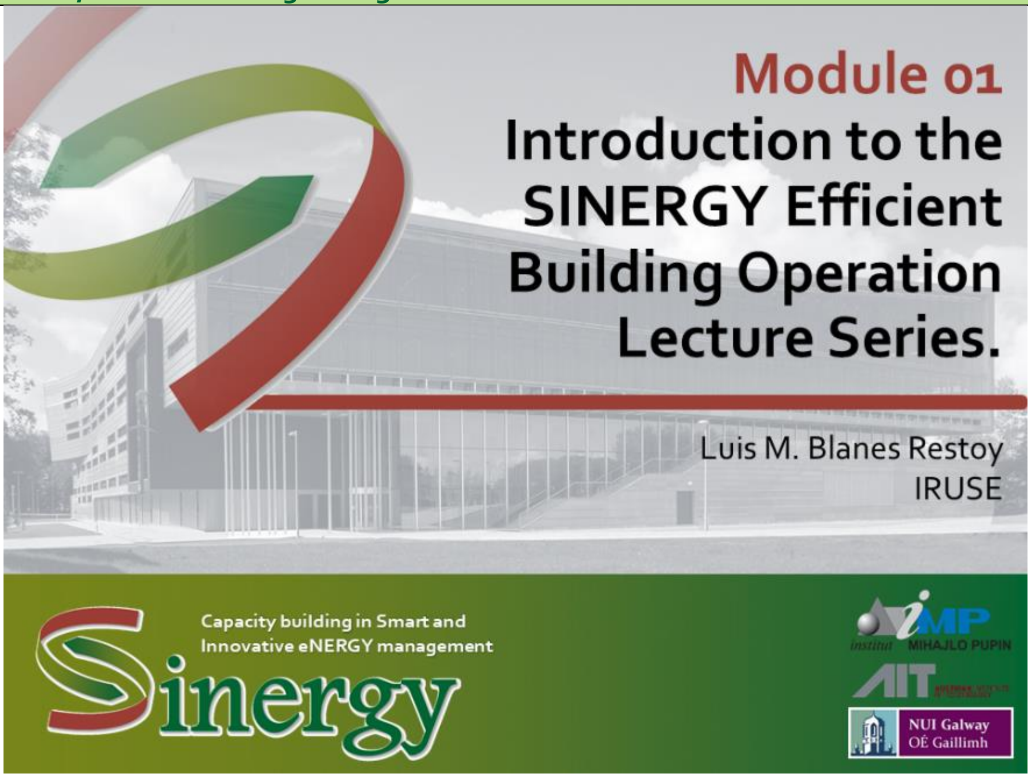
Table 1 gives a list of lectures prepared in the first reporting period, from January 2021 until March 2022.

[1] SINERGY Lectures | Project Sinergy (project-sinergy.org)

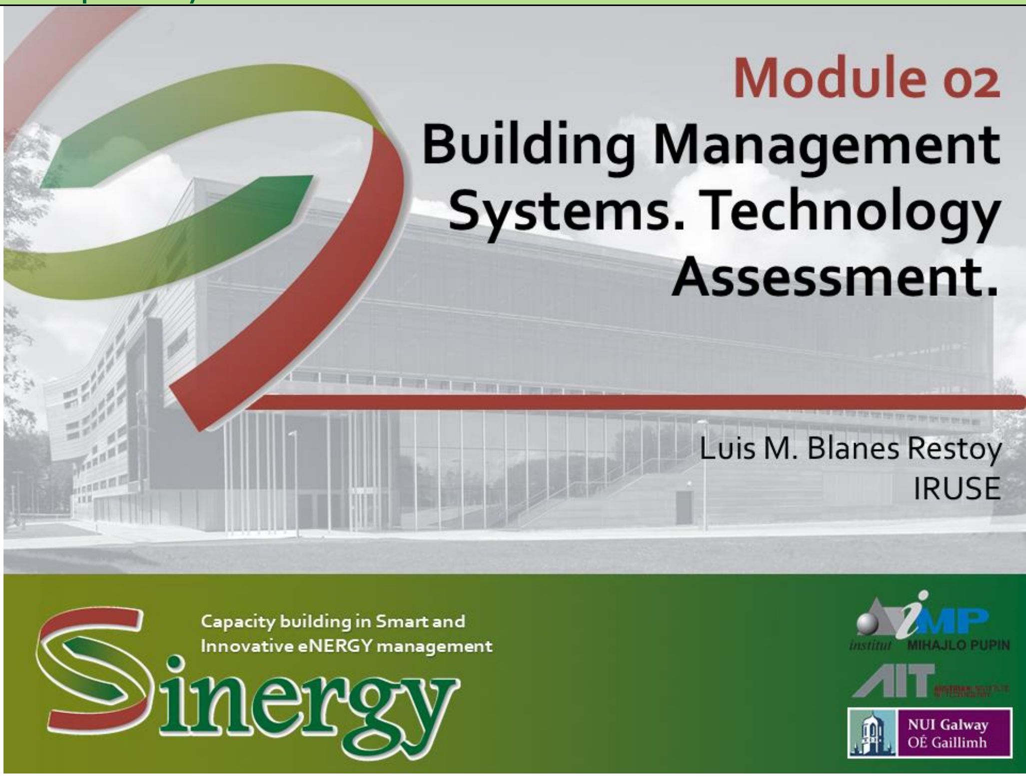
Table 1. Energy Efficient Building Operation (prepared by M15)

	Energy Efficient Building Operation		
ID	Module Title (version 1)	Delivered by:	Status:
EEBO-01	Module 01 - Introduction to the SINERGY Efficient Building Operation Lecture Series	NUIG	done
EEBO-02	Module 02 - Buildings Management Systems - Technology Assessment	NUIG	done
EEBO-03	Module 03 - Buildings Grid Readiness - Technology Assessment	NUIG	done
EEBO-04	Module 04 - Introduction to Building Simulation for Building Operation	NUIG	done
EEBO-05	Module 05 - Urban Scale Building Simulation	NUIG	done
EEBO-06	Module 06 - Uncertainty, Calibration and Sensitivity of Building Energy Models	NUIG	done
EEBO-07	Module 07 - Introduction to Fault Detection and Diagnosis in Buildings	NUIG	done
EEBO-08	Module 08 - Flexibility in Building Energy Models	NUIG	done
EEBO-09	Module 09 - Machine Learning Techniques for Building Energy (Observe & Predict)	NUIG	done
EEBO-10	Module 10 - Machine Learning Techniques for Building Energy (Adjust & Manage & Interact)	NUIG	done

2. Summary of Lectures

<table>
<tr><th colspan="2">Module 01 - Introduction to the SINERGY Efficient Building Operation Lecture Series (EEBO-01)</th></tr>
<tr><td>Keywords</td><td>Sinergy, Energy Efficiency, Building Performance Simulation, Building Lifecycle, EPBD, Holistic Building Management</td></tr>
<tr><td>Summary</td><td>


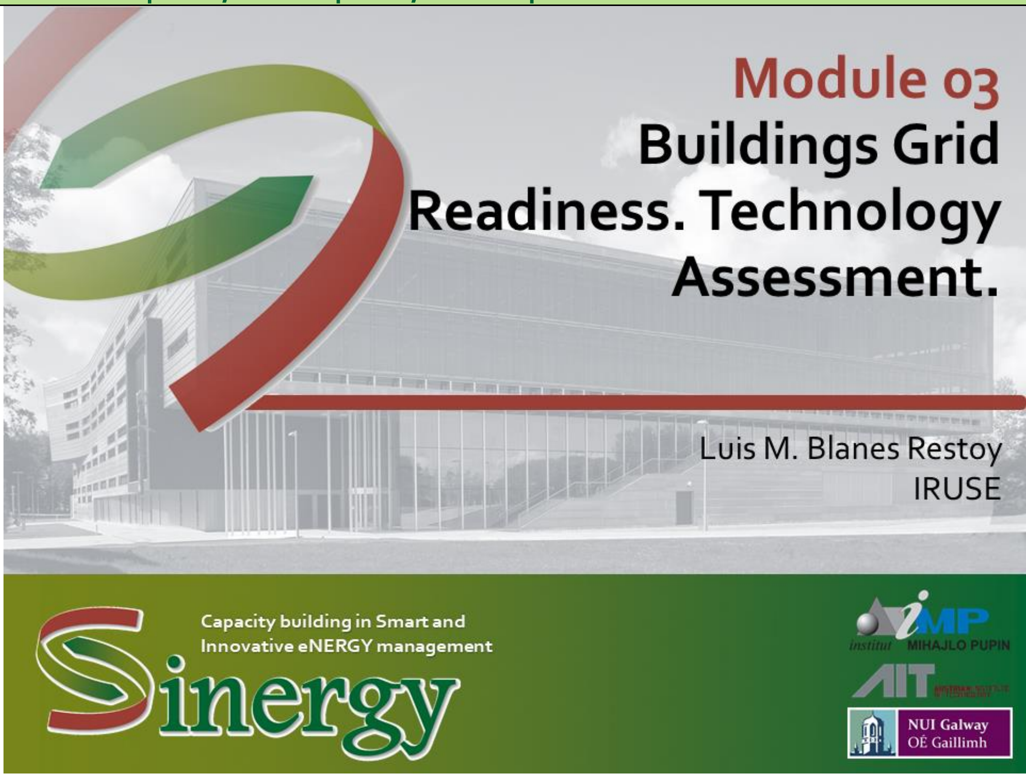
This is an introductory module of the lectures corresponding to the Efficient Building Operation discipline of the SINERGY project and will provide an overview of the landscape around the subject of Building Efficient Operation and supporting disciplines. Buildings represent a significant sector in the future low-carbon economy, with nearly one third of the final energy use in developed countries. Policy responses to the efficiency challenge have put pressure in the design and operation of buildings. They emphasise the adoption of renewable energy sources, the integration of recent smart technologies and enhancement of thermal and operational efficiency. Lately, user behaviour and improved levels of quality have also become a part of the overall pursuit of more efficient buildings. It is therefore paramount to understand the complex interactions of several influencing factors: buildings physics and thermodynamics, the ever-changing technologies supporting building operation, the user interactions (feedback and comfort), and make them compatible with the decarbonisation agenda.
</td></tr>
<tr><th colspan="2">Reference Material</th></tr>
<tr><td colspan="2">
https://doi.org/10.1016/j.buildenv.2020.106908
https://eur-lex.europa.eu/eli/dir/2010/31
https://doi.org/10.1016/j.enbuild.2020.110322
https://doi.org/10.1016/j.spc.2021.10.013
https://doi.org/10.1016/j.jclepro.2021.126665
</td></tr>
</table>

Module 02 - Buildings Management Systems. Technology Assessment. (EEBO-02)	
Keywords	Smart Readiness Indicator, Interoperability, Building Management Systems, Interoperability
Summary	 Building Management Systems (BMS) control a range of sensors and devices within a building passive and active facilities. They use a combination of hardware devices (sensors, actuators, communication networks, controllers (PLC, DDC) and software modules such as control algorithms, communication protocols, supervisory software and graphical and or machine interfaces. We provide a topology and classification of the BMS systems according to the level of sophistication (the tasks and information BMS can handle) and smartness. BMS are fundamental mediators to implement energy efficient measures, monitor energy performance and ultimately progress towards an advanced level of automation, predictability, interoperability with the users and with the future distributed energy production, storage and consumption.
Reference Material	
http://hdl.handle.net/10379/5263 https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/smart-readiness-indicator_en EN 15232 Standard https://doi.org/10.1016/j.jobe.2021.102222 https://doi.org/10.1016/j.jclepro.2021.126665 http://hdl.handle.net/10379/16562	

Module 03 - Buildings Grid Readiness. Technology Assessment (EEBO-03)

Keywords: Smart Readiness Indicator, Smart retrofitting, Smart grid, Smart buildings, Climate response, Grid response, User response

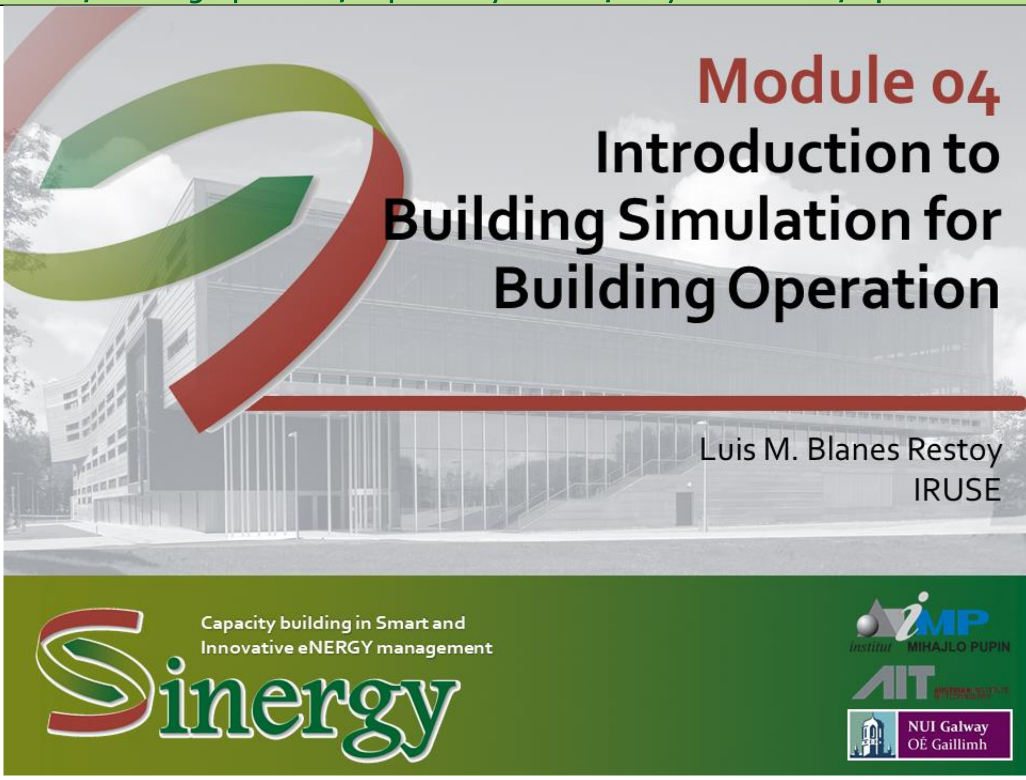
Summary



The concept of Smart Readiness Indicator (SRI) has been proposed by the Energy Performance Building Directive (EPBD). This refers to the degree of responsiveness a building possesses in order to interact with data, machines, and operational requirements in the context of the smart grid. In general terms, a smart building is able to effectively facilitate: (1) adaptation due to the users, (2) enhanced operations and maintenance and (3) adaptation to respond to the grid conditions. We explore a range of definitions and indicators developed by the different definitions, indicators and methodologies to measure smartness in the built environment.

Reference Material

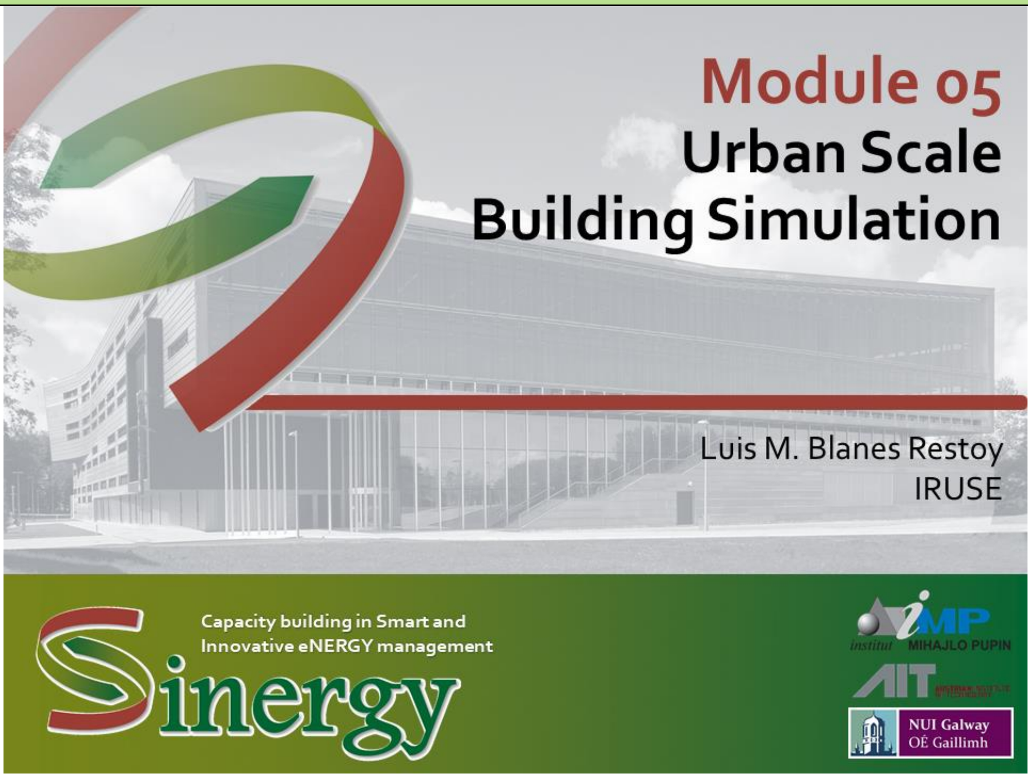
https://doi.org/10.1016/j.scs.2020.102328
https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/smart-readiness-indicator_en
http://hdl.handle.net/10379/16562

Module 04 - Introduction to Building Simulation for Building Operation (EEBO-04)	
Keywords	IBPSA, Building Operation, Supervisory Control, Grey-Box Models, Optimization
Summary	 In this module, an overview of the field of building performance simulation applied to the operational phase of the building lifecycle is provided. Firstly, the different approaches to constructing building energy models is described (white box, grey box, black box) with their pros and cons. The role of the International Building Performance Simulation Association is introduced with an evolution of the evolving focus of building simulation through the different conference topics. Different options and experiences for the use of simulation addressing operation and HVAC systems are reviewed with an emphasis on the simulation tools used and the integration in current BMS systems and smart grid. Finally, we introduce the future of building performance models through co-simulation and model exchange using the Modelica language and the Functional Mockup Interface.
Reference Material	
https://doi.org/10.1201/9780429402296 http://www.ibpsa.org/papers-online/ https://doi.org/10.1016/j.rser.2021.111174 http://www.ibpsa.org/proceedings/BS2013/p_2525.pdf https://doi.org/10.1088/1755-1315/323/1/012114 https://ibpsa.github.io/project1/pubs/pdf/LuHinkelmanEtAl_2019_1.pdf https://doi.org/10.1016/j.rser.2021.111174 https://doi.org/10.1016/S0360-1323(02)00041-0	

Module 05 - Urban Scale Building Simulation (EEBO-05)

Keywords: Urban Scale Building Energy Modelling, Interoperability, CityGML, GIS, GML, INSPIRE.

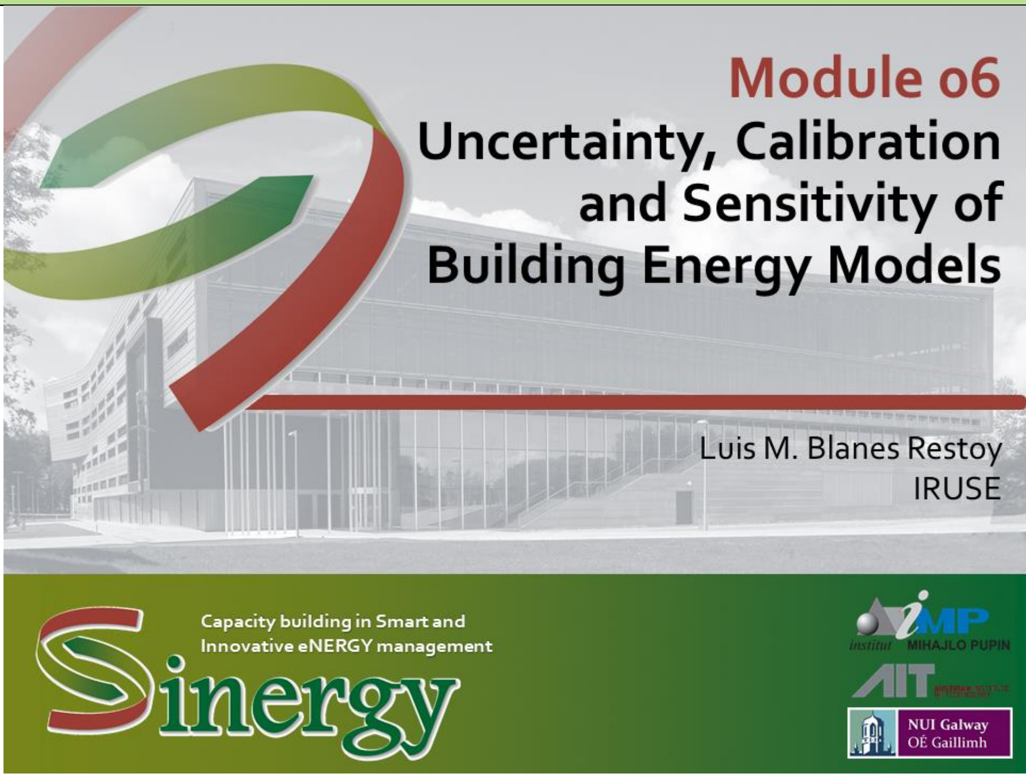
Summary



Urban scale building simulation refers to the extension of building energy modelling to the urban scale. This can be seen as an aggregated city model, built upon aggregated building models. Another interpretation is to build city-wide models from top information at a country level. Simulation at a district scale and city scale is still in its infancy, therefore a review of different urban simulation workflows is illustrated with a focus on bottom-up approaches and identification of the major obstacles to building model accuracy and reliability.

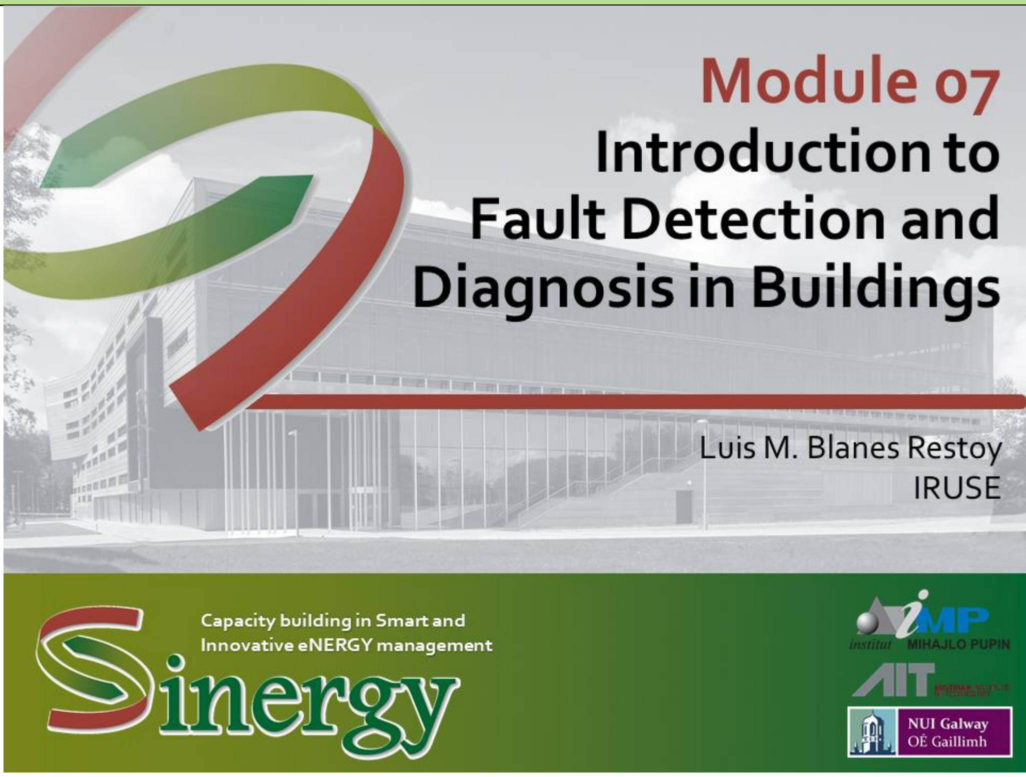
Reference Material

https://doi.org/10.1016/j.enbuild.2021.111073
https://doi.org/10.1016/j.apenergy.2020.114861
https://doi.org/10.1016/j.apenergy.2020.115834
https://doi.org/10.1016/j.scs.2020.102408
https://doi.org/10.1016/j.rser.2020.109902

Module 06 - Uncertainty, Calibration and Sensitivity of Building Energy Models (EEBO-06)	
Keywords	Building Performance Simulation, Calibration, Reproducibility, Optimization, Uncertainty, Sensitivity, Bayesian Calibration
Summary	 In this module we will review tools and methods to match building energy simulation results to measured real data. Firstly, we will analyse the main causes for discrepancy between building energy models and measured results. Secondly, we will differentiate between different terms such as: validation, calibration, verification, replicability, uncertainty and sensitivity, uncertainty propagations. Workflows for different calibration techniques and tools (brute force, Bayesian calibration, etc.) are reviewed.

Reference Material

- https://doi.org/10.1016/j.rser.2014.05.007
- https://doi.org/10.1111/j.1751-5823.2008.00062_17.x
- https://doi.org/10.1016/j.enbuild.2021.111533
- https://strathprints.strath.ac.uk/62081/
- https://doi.org/10.1016/j.enbuild.2011.12.029
- https://doi.org/10.1016/S0378-7788(02)00070-1
- https://doi.org/10.1016/j.enbuild.2016.04.025
- https://doi.org/10.1016/j.apenergy.2020.115141
- https://doi.org/10.1016/j.rser.2018.05.029

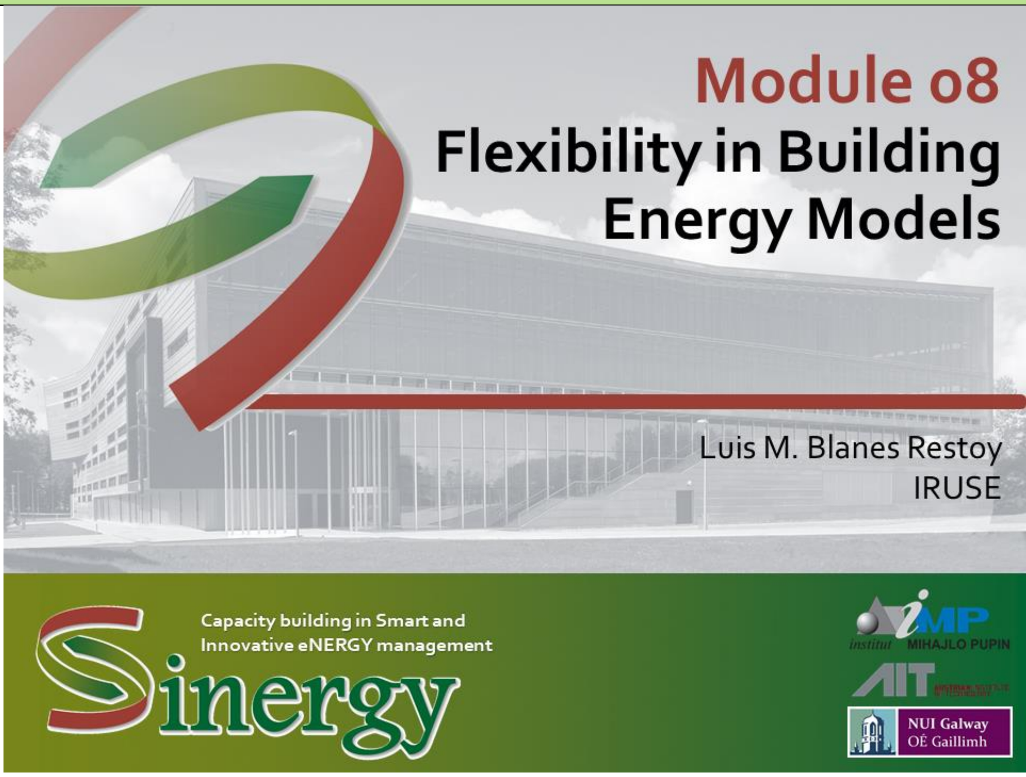
<table>
<tr><th colspan="2">Introduction to Fault Detection and Diagnosis in Buildings (EEBO-07)</th></tr>
<tr><td>Keywords</td><td>APAR rules, Model-Based Fault Detection, First Principles, Artificial Neural Networks, Expert Systems, Qualitative Modelling FDD</td></tr>
<tr><td>Summary</td><td>


This module introduces the concept of Fault Detection and Diagnosis in buildings (FDD) and HVAC systems. A significant amount of energy is wasted in buildings due to unnoticed faults. This could be addressed by embedding FDD in BMS systems (condition-based maintenance). FDD techniques (FDIDP, also including Fault Identification and Fault Prognosis) are a mature field in industries such as automotive and aeronautics. We focus on the developments of FDD science to Heating, Ventilation, Air Conditioning and Refrigeration (HVAC-R) in Buildings. A classical taxonomy proposed by Srinivas Katipamula & Michael R. Brambley is described. Examples of FDD
</td></tr>
<tr><th colspan="2">Reference Material</th></tr>
<tr><td colspan="2">https://www.tandfonline.com/doi/abs/10.1080/10789669.2005.10391123
https://www.tandfonline.com/doi/abs/10.1080/10789669.2005.10391133
https://doi.org/10.1080/23744731.2017.1318008
https://doi.org/10.1016/j.egypro.2014.12.432
https://core.ac.uk/download/pdf/147238038.pdf</td></tr>
</table>

Module 08 - Flexibility in Building Energy Models (EEBO-08)

Keywords: Demand Response, Distributed Energy Sources, Flexibility, Smart Grid, Battery Energy Storage System, EnergyPlus, Modelica, Functional Mockup Interface, Co-Simulation, Model Exchange

Summary



In this module, we will consider the building as part of the new smart grid. Distributed renewable energy technologies pose a challenge The building itself need to be reconsidered to adapt to this new variable grid with innovative interfaces to the grid and control capabilities that exploit the flexibility aspect with adapting strategies to optimize the variable and discontinuous condition of the smart grid. Concepts related with flexibility are analysed such as load shifting, loads covering, and time responsiveness of building controls, energy systems and occupant interaction with a focus on how to translate this into building energy models.

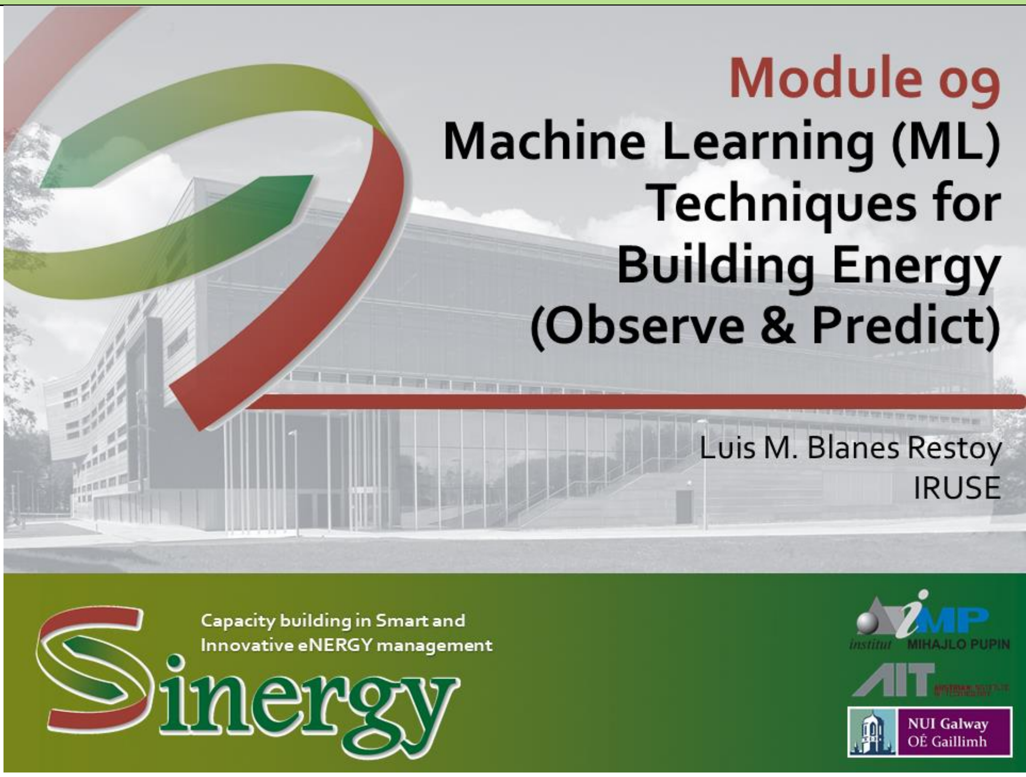
Reference Material

https://doi.org/10.1016/j.apenergy.2021.118445
https://doi.org/10.1016/j.energy.2020.119598
https://doi.org/10.1016/j.egypro.2016.06.274
https://doi.org/10.1016/j.apenergy.2021.117836
https://doi.org/10.1016/j.enbuild.2021.111263
http://www.ibpsa.org/proceedings/BS2017/BS2017_441.pdf

Module 09 - Machine Learning Techniques for Building Energy (Observe & Predict) (EEBO-09)

Keywords: Linear Regression, Decision Forest Regression, Boosted Decision Tree Regression, Neural Network

Summary

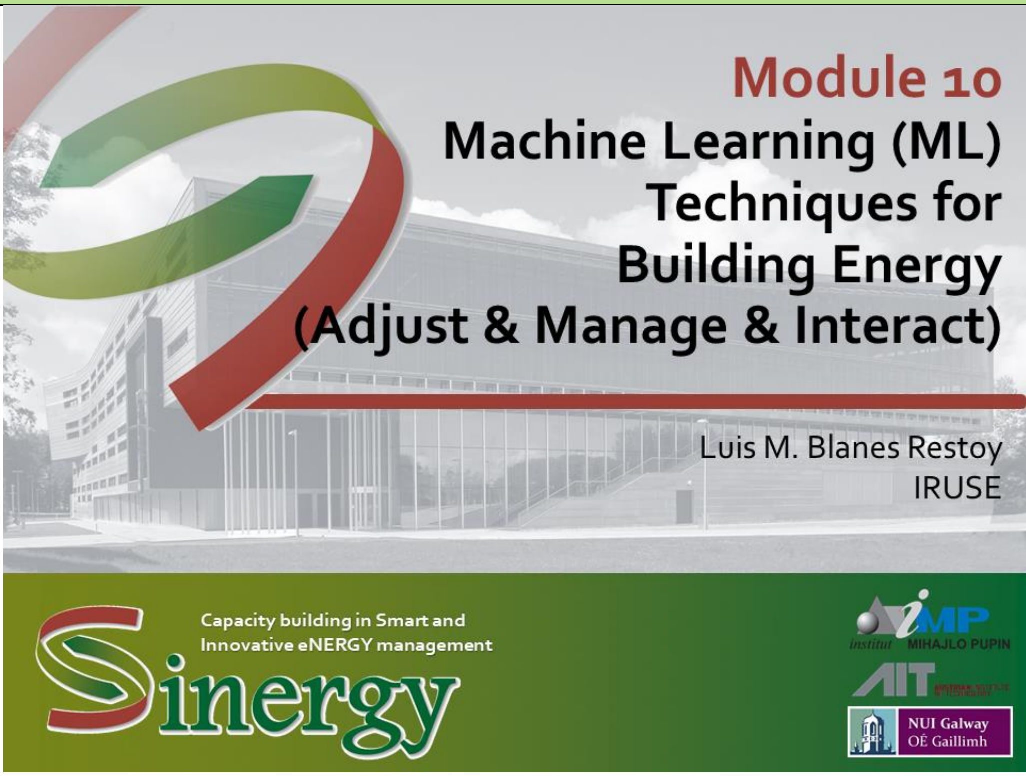


In this first module we focus on the Artificial Intelligence (AI) methods used to analyse large quantities of data in order to perform two main tasks: (1) to observe anomalies, trends and errors in variables and, (2) use this AI methods to predict and forecast different variables such as building energy consumption thus preventing abnormal settings or faults in energy production. Machine Learning techniques are a relevant predictions tools for demand-response applications in the context of the smart grid e.g.: to avoid matching of peak loads over small periods.

Reference Material

https://doi.org/10.1016/j.scs.2021.103445
http://ceur-ws.org/Vol-2563/aics_23.pdf
https://doi.org/10.1016/j.rser.2020.110287
https://doi.org/10.1016/j.egypro.2014.12.417

<table>
<tr><th colspan="2">Module 10 - Machine Learning Techniques for Building Energy (Adjust & Manage & Interact) (EEBO-10)</th></tr>
<tr><td>Keywords</td><td>Reinforcement Learning, Anomaly Detection</td></tr>
<tr><td>Summary</td><td>



In this second module the practical application of Machine Learning (ML) techniques to adjust system behaviour in the occurrence of anomalies and faults is reviewed. This means a ML system is able to detect and adjust HVAC settings or trigger alarm events when a condition is not met. Typical examples are: (1) the use of reinforcement learning applied to monitoring of occupancy patterns and the interaction with thermostats or lighting, (2) use of weather forecast or weather anomalies to predict energy demand and adjust operational settings accordingly.

</td></tr>
<tr><th colspan="2">Reference Material</th></tr>
<tr><td colspan="2">

https://doi.org/10.1016/j.scs.2021.103445
https://doi.org/10.1016/j.egyai.2020.100043
https://doi.org/10.1016/j.jobe.2020.101692
https://doi.org/10.1016/j.rser.2021.111530

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</table>

3. Conclusion

In the first reporting period, 10 lectures were developed.

Because of COVID-19, 2 lectures were presented online (as part of the SINERGY session at the Big Data Analytics Summer School), while the rest will be presented in face-to-face settings at NUIG premises on 1st and 2nd of June 2022.

In this 10 first lectures we have covered introductory modules addressing the main concepts and methodologies regarding Efficient Building Operation. The intention is to provide to the audience with an overview of different disciplines applied to the specific building energy problems, and more specifically to the operational stage of the building life cycle (BLC).

These 10 first modules cover all relevant topics related to building performance simulation and building operation.

Table 2 points to additional lectures that are under development and will be delivered by M30. We plan to add more lectures tailored to IMP PhD students as a result of the proposed itineraries for cross collaboration, the pilot availability and potential for publications and the mentoring activities between NUIG-AIT-IMP.

Table 2. Additional lectures to be prepared by M30

	Smart Grid Technologies	
ID	Title	Keywords
EEBO-11	Module 11 - Building Information Models (BIM) applications for Building Operation.	Interoperability, Architecture Engineering and Construction Industry, IFC,
EEBO-12	Module 12 - Modelling of District Heating and Cooling Systems	District Heating and Cooling, Thermal Energy Networks,
EEBO-13	Module 13 - Model Predictive Control applications for Building Energy Efficiency.	Model Predictive Control, Thermal Inertia, Multi-Obective Optimization,
EEBO-14	Module 14 - Urban Scale Building Simulation Tools and Methods.	IES-VE, Energy Plus, CityGML
EEBO-19	Module 19 - Financial Feasibility of Building Renovation.	Bankability, Building Lifecycle Analysis, Lifecycle Cost,
EEBO-20	Module 20 - Resilience in Building Energy Models	Climate Adaptation, Risk Modelling, Threat Modelling, Disaster Preparedness