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BUILDING ENERGY SIMULATION MODULE: THE DESIGN, IMPLEMENTATION AND EVALUATION OF A DUAL-ASSESSMENT MASTERS MODULE

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Abstract

Building energy simulation is a key competence in energy systems engineering education. Students are often challenged to appropriately apply core concepts in modelling workflows. This paper presents a novel curriculum design for masters level building energy module delivered through a combined lecture and project format. Cohort evidence includes pre and post comparison of project outcomes. Project outcomes show similar central tendency pre versus post periods, with reduced spread in the post period, consistent with more structured milestone-driven delivery. The paper provides a transferable module structure, workflow, and assessment rubric for building energy education using professional modelling toolchains.

Context and motivation

Energy use in buildings is central to the climate agenda and building professionals are increasingly expected to evaluate retrofit pathways using performance simulation modelling (Sood et al., 2025). Within tertiary education, a key challenge is that students need to need to acquire competence in building energy system concepts, yet they often struggle when these concepts need to be applied in a modelling workflow where outcomes depend on assumptions and controls. This topic directly aligns with five of the seventeen United Nations Sustainable Development Goals (SDGs): 7) Renewable Energy, 8) Good Jobs and Economic Growth, 11) Sustainable Cities and Communities, 12) Responsible Consumption and 13) Climate Action (Kartal et al., 2024). It is therefore of paramount importance that graduate students understand fundamental building physics, as well as building energy simulation know-how, so they are equipped with the required skills and experiences to make informed decisions during their professional careers.

A recurring concern, observed in project-based delivery, is that a subgroup of students engage late or inconsistently and therefore do not reach the workload threshold required for deeper analysis. This pattern aligns with reported observations in similar project-led modules. The curriculum design described here aims to reduce this failure mode through milestone-driven structure and explicit assessment criteria.

The module is delivered to masters level mechanical and energy systems engineering students in the final year of their programme. The module combines theory, worked examples, and a simulation retrofit project. The design intent is that students learn concepts in lectures and then use them in the project to build and defend a building retrofit recommendation. The summative weighting was 40% project and 60% examination prior to 2021, and was changed to 50% project and 50% examination from 2021 onward to strengthen sustained engagement with project-based learning. Module assessment comprises two components: an end of trimester exam (worth 50% of the the overall grade) and a project, an example of which is shown in Figure 1, for groups of two or three students (worth 50% of the overall grade). The same grade is awarded to all group members for the project component.

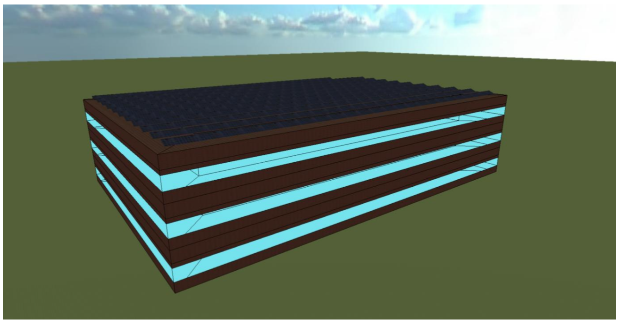

Figure 1: Example building project used for the group retrofit project.

Curriculum design approach

The curriculum design goal is to deliver deep pedagogical outcome through a balanced combination of lectures, problem sets, and project work (Gilchrist, 1999). The project is designed as a top-down building performance analysis and retrofit appraisal of an existing commercial building. The core threshold concept for the module is holistic building performance analysis through systems thinking, where building physics, HVAC systems operation, comfort, and economics are treated as linked rather than isolated topics.

The approach follows integrated course design principles, focusing on: learning goals, assessment and feedback, and aligned teaching activities. The design also draws on threshold concept theory (Timmermans and Meyer, 2019) and project based learning principles (Savery, 2006). A practical requirement is that the assessment structure must encourage sustained engagement across the trimester rather than late engagement with the project component. This module has prerequisites and expects a considerable level of prior learning in the areas of thermodynamics and heat transfer. The key issue is that buildings can be viewed rather simplistically as static assets over which occupants have very little control but in reality buildings are dynamic and fulfil a range of functions that vary significantly over time. The lecture material, combined with related problem sets and exercises contribute to much of the formative learning within the module and in turn contribute to the group project that applies, analyses, evaluates and synthesises the course content. The end of trimester summative assessment also examines a deep understanding of course material but in a different way to the group project. Figure 2 is used to frame the design from both teacher and student perspectives.

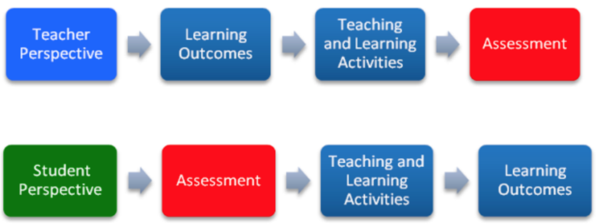

Figure 2: Curriculum design from teacher and student perspectives (adapted from (Biggs, 2003)).

Threshold concepts and learning objectives

The module is organised around a key number of threshold concepts that students must master to progress:

1. Key principles of building physics and heat transfer in buildings.
2. Psychrometrics and understanding of air-conditioning processes.
3. HVAC systems and control.
4. Building economic performance analysis.

The learning objectives and key concept map used to structure lecture content and project tasks are shown in Figure 3. The concept map is used as a reference throughout the trimester to reduce content fragmentation and to make linkages between topics explicit. The map is organised around a central question: how to ensure deep learning throughout the module. Learning objectives branch into four threshold concept areas: fundamental building physics, HVAC systems operation, building energy performance simulation, and the role and nature of occupancy in buildings. Prior learning in fluid mechanics, heat transfer, and thermodynamics is a stated prerequisite. Two summative assessment components emerge from the learning objectives: the end-of-year exam and the EBL group project. Both connect to programme outcomes and professional accreditation. The group project is designed for a variety of learning styles and is enabled by formative learning and in-class tutorials. It is assessed through presentations and links to potential industry and academic employers as external stakeholders. The exam ensures authenticity and transparency of individual learning. Assessment methods collectively facilitate skill development and transparency. The design is grounded in focused problem-based learning exercises and informed by relevant legislation, standards, and guides. Feedback continuously improves the design. Node colours identify type: green for the key question, orange for module-specific content, blue for programme-specific content, and yellow for external nodes.

Table 1 maps each intended learning outcome to the teaching activities through which it is developed and to the assessment component through which it is evaluated. The rubric criteria in Table 2 correspond directly to these outcomes: assumption traceability and plausibility checking map to outcomes 1 and 2; comfort interpretation maps to outcome 2; economic logic maps to outcome 4; and the oral defence maps to outcome 5.

Table 1: Constructive alignment: intended learning outcomes, teaching activities, and assessment methods.

Learning outcome	Teaching activity	Assessment
Building physics and heat transfer	Lectures wks 1–4; problem sets	Exam; baseline model
Psychrometrics and A/C processes	Lectures wks 5–7; chart exercises	Exam; comfort evaluation
HVAC systems and control	Lectures wks 8–10; tutorials 4–6	Exam; retrofit options
Economic performance (NPV)	Lectures wks 10–11; discounting exercise	Exam; economic analysis
Defend modelling decisions holistically	Mid-term gate; reasoning exercise	Oral defence (individual)

Lecture–project integration and milestone staging

The module is delivered through aligned lectures and project sessions over a 12 week teaching trimester. Lectures introduce concepts and methods. Project sessions require students to apply these concepts to the project case study through staged tasks. The staging is intentional. Without milestones, students tend to allocate effort toward software tasks and output generation rather than interpretation and diagnosis.

A student-centric overview of the module structure, including lecture content, project tutorials, and assessment milestones, is shown in Figure 8 in Appendix. The figure is intended to communicate what is expected, by when, and why each milestone exists. This covers 12 teaching weeks plus an exam period across six columns: week, topic, lecture topic, reading material, learning milestone, progress milestone, and assessment detail. Weeks 1 and 2 cover buildings and climate, the internal environment, and

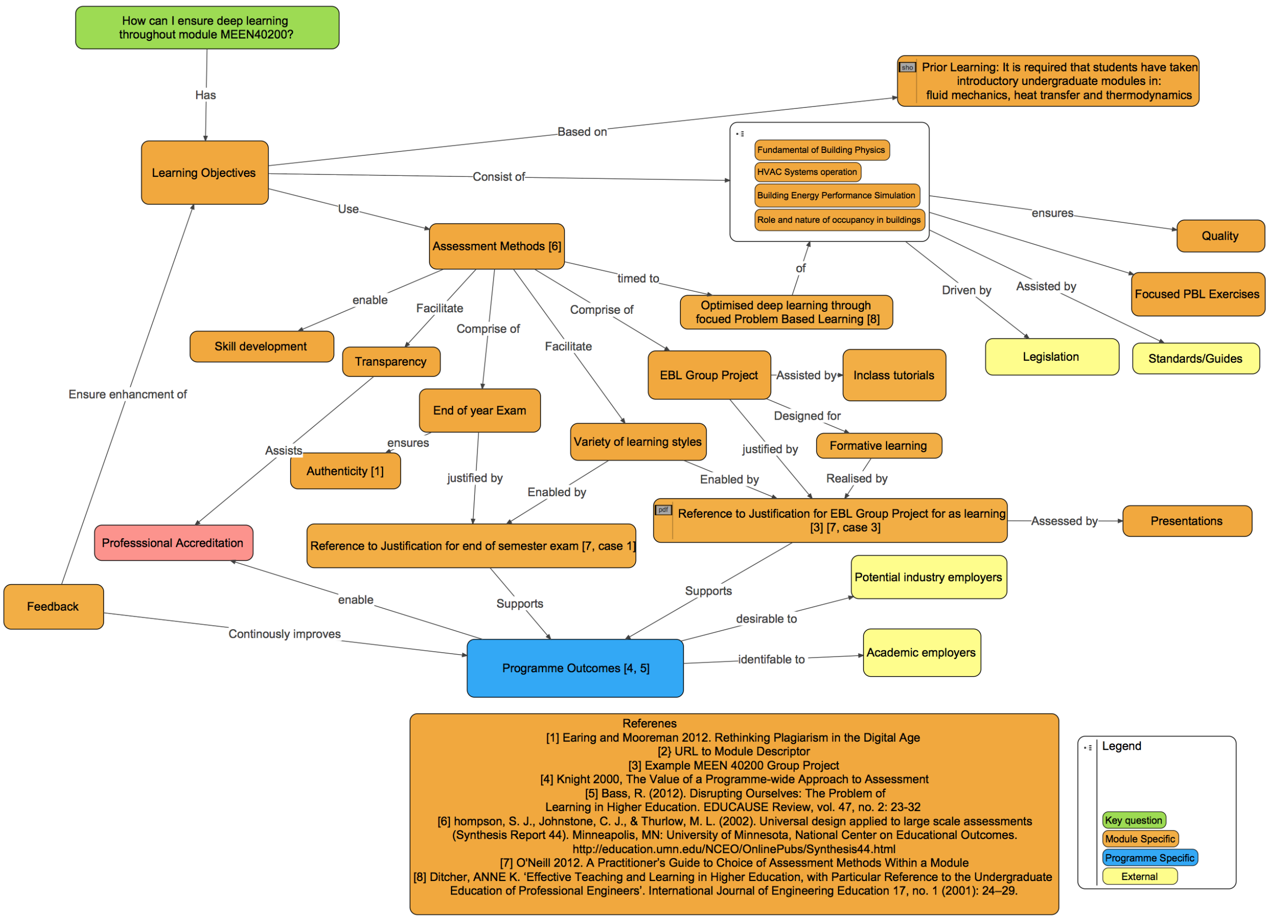

Figure 3: Learning objectives and key concepts used to structure the module.

building energy balance; the first project overview session establishes teams and the initial site. Week 3 introduces energy simulation and heat transfer; building fabric investigations are expected to be complete by its end. Week 4 covers internal gains, thermal mass, and thermal bridges; a formative self-assessment checkpoint occurs here, shown in orange. Week 5 covers daylighting and introduces psychrometrics; the key learning milestone is to understand the key principles of building physics. Week 6 covers natural ventilation and a formative problem set is released to students. Week 7 completes psychrometrics in practice; the base case model must be finished and the initial mid-term report submitted by the end of this week, which is the quality gate. After two study weeks, weeks 8–10 cover demand-side equipment, plant heating, heat pumps, and cooling; HVAC design alternatives are progressively completed during this period. Weeks 11 and 12 are reserved for make-up sessions and final project submission and presentation. The summative exam falls in the exam period. Row colours identify content type: white for lectures, blue for project tutorials, green for prerecorded lectures, light grey for reading material, yellow for key learning outcomes, purple for progress milestones, and orange for assessment components.

A week-by-week schedule is provided to students to support planning and to reduce drift in the project. An example is shown in Table **??** in Appendix.

Assessment design and feedback

Assessment components

The assessment model combines two summative components:

- An individual written examination to assess conceptual understanding and analytical competence under time constraints.
- A group retrofit project to assess applied modelling judgement and decision justification through a report and oral defence.

Formative feedback and quality gates

The project includes structured feedback loops. A mid-term formative deliverable requires groups to present baseline model behaviour, identify key drivers of performance, and propose retrofit pathways for the second half of the module. The deliverable is returned quickly to support iteration and project progression. This mid term checkpoint functions as a quality gate. It reduces late rework by identifying issues in schedules, internal gains, controls, and zoning logic before option comparisons are finalised.

Oral defence

The final presentation includes technical assessment across individual group members. The questioning targets: assumption selection, plausibility checks, interpretation of comfort outputs, and the causal link between retrofit measures and changes in energy, comfort, and cost. Questioning is directed at each group member individually in turn. A student who has not engaged with the project in depth will most likely answer incomplete or vague to these questions at the required level, and the responses inform the overall project assessment alongside the written report. This is the primary mechanism through which individual competence is differentiated within the group grade.

Project workflow and evidence of operationalisation

Workflow overview

The project workflow follows five staged steps. In the first stage, baseline model establishment, the group configures and validates the building model against reference benchmarks to confirm that model behaviour is physically reasonable before any retrofit analysis begins. In the second stage, baseline diagnosis, energy drivers, comfort conditions, and operating patterns are identified and documented alongside the assumptions that underpin them. In the third stage, option definition, retrofit measures are selected and their technical feasibility assessed under the constraints of the building and its occupancy. In the fourth stage, option comparison, the selected measures are evaluated against the baseline on energy, comfort, and economic criteria using net present value analysis. In the fifth stage, final justification, the group defends the chosen retrofit pathway and explains the reasoning behind the assumptions, results, and conclusions. The workflow is designed so that lecture content is operationalised at each stage. For example, psychrometrics and HVAC concepts appear in control intent and comfort interpretation, and discounting appears in NPV-based comparison rather than as a stand-alone calculation.

The simulation software used for the project is IES Virtual Environment (IES VE) (IES, 2026). Prior to IES VE, Simergy was used. The module design is not dependent on either tool specifically. Any professional-grade building energy simulation environment that supports multi-zone thermal and HVAC modelling would support the same workflow.

The module structure is transferable to other institutional contexts. Three factors are relevant when adapting the design. The first is class size, which affects how group supervision and oral defence logistics are managed. Larger cohorts may require more structured oral defence scheduling and more explicit supervision records to support individual contribution monitoring. The second is software availability; the workflow does not depend on IES VE specifically. The third is curriculum prerequisites: the module assumes prior learning in thermodynamics and heat transfer.

Example of holistic building performance analysis

The module leverages the concept of Problem Based Learning (PBL) and this requires three key elements (Lloyd-Jones et al., 1998): the students must be presented with a problem or initiating trigger at the start of the process, learning takes place through the research of issues identified in the initial tutorial, and knowledge is used to further the understanding of the trigger situation. This approach is used within individual concepts but overarching threshold concept of holistic building performance analysis through systems of systems thinking is achieved through a **project** based learning approach for the group project.

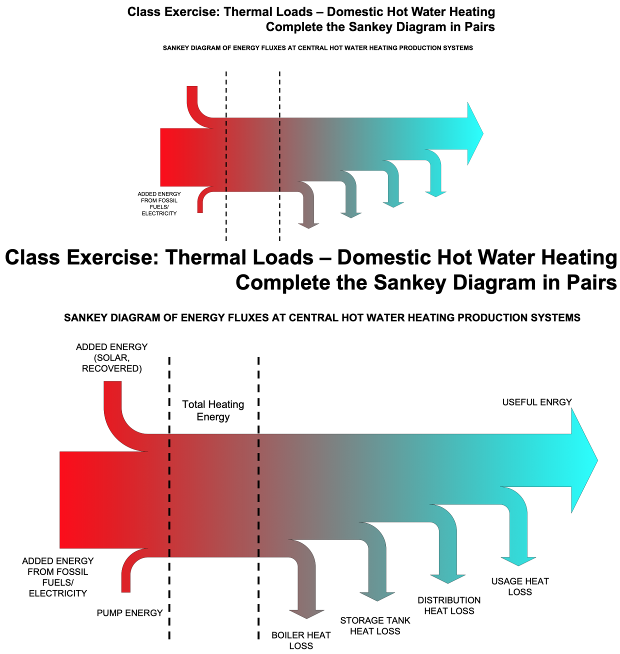

Figure 4: Example exercise used to develop holistic performance reasoning: (top) student attempt, (bottom) reference solution.

Figure 4 illustrates an in-class exercise used to develop the threshold concept of holistic building performance analysis. Students begin with an incomplete reasoning chain and must account for direct and indirect changes to energy flows and building physics under a trigger event. The exercise is used to prepare students to interpret simulation results as a system response rather than as isolated outputs.

Transferable rubric structure for the project

To make expectations explicit and to support consistent grading, the project assessment can be structured around decision-quality criteria. Table 2 provides a compact rubric structure consistent with the milestone design and the intended learning outcomes. The intent is to reward assumption transparency, diagnosis, and interpretation rather than output volume.

Table 2: Rubric structure for the retrofit project report and defence.

Criterion (evidence in report, model, and defence)	Weight (%)
Baseline model definition and traceable assumptions	20
Plausibility checks and diagnosis (benchmarks and drivers)	20
Retrofit option definition and feasibility under constraints	15
Comfort evaluation and interpretation against stated criteria	15
Economic analysis (NPV structure and consistency checks)	15
Communication and oral defence (technical justification)	15

Supporting cohort evidence

Data sources and methodology

The evaluation draws on two data sources: project grade records spanning eleven years and institutional module feedback surveys covering four delivery years. The analysis is descriptive. The intent is to characterise outcome patterns across the pre-change and post-change periods. Two summary measures are reported: central tendency, represented by the median of the midpoint-proxy distribution within each period, and spread, represented by the interquartile range. These measures are appropriate for ordinal data and are robust to the unequal band widths in the institutional grade scale. No parametric tests are applied because the pre-period data consist of grade-frequency counts rather than individual records, and because the comparison is across cohorts of different sizes rather than matched individuals. The comparison is therefore descriptive and is intended to characterise whether the pattern of outcomes changed between periods in a way that is consistent with the intended effects of the module redesign. The evaluation is a design-led case study. It covers one module at one institution over one programme. No control group is available because the module redesign was applied to the full cohort in each year. The pre-post comparison conflates the effect of the assessment redesign with other changes over the same period, including changes in cohort composition, programme structure, and the shift to online delivery during 2020/21. These confounds are acknowledged and the cohort evidence is presented as supporting rather than confirmatory.

Project outcomes

To provide supporting evidence for the assessment redesign, project outcomes were compared across two periods: 2014–2021 (pre-change) and 2022–2025 (post-change). The pre-period records were available as grade-frequency counts from archived spreadsheets, while post-period records include numeric project marks for 2022–2024 and letter grades for 2025. Where numeric marks were available, they were converted to letter grades using the institutional grading scheme. To enable a single visual comparison across the full cohort history, each letter grade was then assigned the midpoint of its numeric band as a 0–100 proxy (UCD, 2026). The resulting scale is ordinal and descriptive: the midpoint values are used only to characterise the distribution shape and spread and are not used to make proportional claims about performance differences between grade levels. The comparison is therefore descriptive and is intended to characterise outcome patterns rather than to estimate causal learning effects.

Figure 5 shows that the central tendency of project outcomes is similar across periods, while the spread is lower in the post period. The reduced spread is consistent with a more structured project delivery and milestone-driven pacing, where most groups reach an expected standard of analysis and reporting (Figure 6).

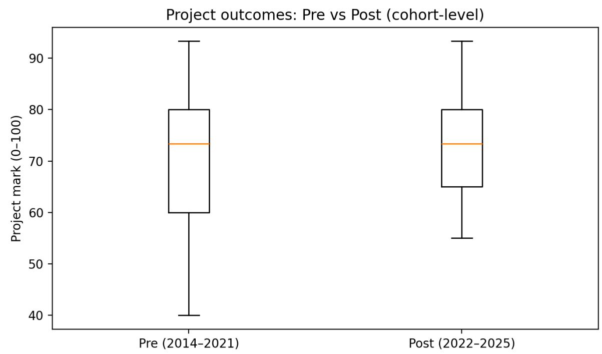

Figure 5: Project outcomes pre (2014–2021) versus post (2022–2025). Pre-period values are derived from grade-frequency records mapped to a 0–100 proxy for visual comparability.

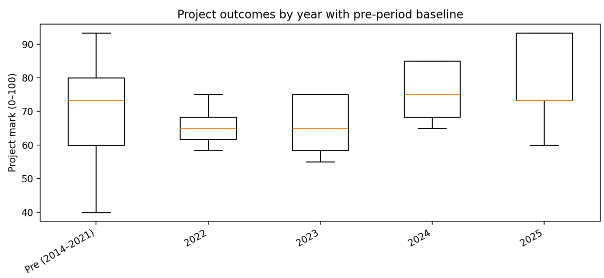

Figure 6: Project outcomes by year for 2022–2025 shown against the aggregated pre-period baseline (2014–2021).

Student module feedback

Module feedback surveys were administered to students across all delivery years using the institutional survey instrument. The survey covers five core questions on a Likert scale from one to five: Q1 subject understanding, Q2 assessment relevance, Q3 learning outcomes achieved, Q4 teaching supported learning, and Q5 overall satisfaction. Table 3 reports the mean scores for MEEN40200 across four trimester cohorts alongside the school-level MEEN benchmark for comparison. Figure 7 shows the year-by-year trend.

Table 3: Mean Likert scores (1–5) for MEEN40200 across four delivery years and MEEN school benchmark (mean of Q1–Q5 per year).

Year	Q1	Q2	Q3	Q4	Q5	n
2020/21	4.50	4.00	3.75	4.00	3.50	4
2021/22	5.00	5.00	5.00	5.00	5.00	2
2022/23	4.67	4.33	4.33	5.00	4.33	3
2023/24	5.00	5.00	4.00	4.00	4.00	1
MEEN avg	4.07	4.07	3.86	3.83	3.73	–

Across all four years, module scores on Q1 to Q5 are at or above the MEEN school average. Q4 (teaching supported learning) and Q1 (improved subject understanding) are consistently the strongest results. Response rates were lowacross all years, ranging from 4% to 17%, which is a known limitation of voluntary institutional survey systems. The feedback data are therefore treated as corroborating evidence rather than a rigorous evaluation of student experience or learning outcomes.

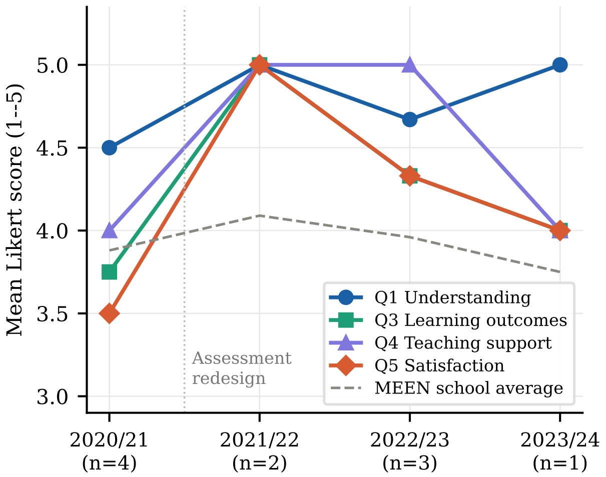

Figure 7: Mean student Likert responses for MEEN40200 across four delivery years compared against the MEEN school average. Response counts range from $n = 1$ to $n = 4$; results should be interpreted as corroborating evidence only.

Open-ended responses from 2020/21 provide qualitative context for one of the key design decisions described in this paper. Students identified the building energy simulation software as a source of significant friction, reporting that a large amount of time in the first weeks was spent on model construction rather than on analysis. This feedback informed the decision to provide a pre-built working model from the outset of the project and to shift early milestone tasks toward diagnosis and interpretation, as noted in the Workflow overview section above.

Implementation considerations

Three implementation considerations have shaped the module design. First, students can spend time on low-value tasks that do not improve the validity of conclusions, particularly when early modelling tasks are overly open-ended. This has been addressed by providing a working base model and by using milestones that prioritise baseline behaviour, diagnosis, and interpretation. Second, software issues can shift attention away from learning objectives. This has been mitigated by reducing the amount of custom model construction required early in the trimester and by placing emphasis on analysis and justification in assessment criteria. Third, students differ in study patterns. The milestone design and mid-term checkpoint reduce the risk that project work is deferred until late in the semester.

Implications for education and assessment

The lecture - project structure supports an explicit pathway from theory to application. The design makes key concepts reappear as modelling decisions and report arguments, and uses milestones to support iteration. For competency assurance, the dual assessment structure provides two complementary views: conceptual reasoning under time constraints and applied modelling judgement evidenced through a report and oral defence. If minimum competence is required in both domains, a practical policy option is to require a minimum pass standard in both components. If improved grading resolution is required within the project, the rubric weight can be shifted further toward assumption traceability, plausibility checking, and interpretation. Another option could be the application of peer review within each project group.

Conclusions

This paper presented a curriculum design for a masters level building energy systems module delivered through a coupled lecture-project format and assessed through an individual written examination and a group retrofit simulation project. The design is organised around threshold concepts and staged milestones, including a mid-term feedback and a final oral defence and reporting. The intent is that lecture content is not treated as separate theory, but is applied in the project through explicit assumptions, plausibility checks, and reporting that links model outputs to energy, comfort, and economic reasoning.

The contribution to the teaching domain is an explicit, transferable design pattern for simulation-based building energy education. The paper specifies how a lecture sequence can be aligned to a project workflow from the start of the semester, how milestones can be used to stabilise baseline models before retrofit comparison, and how questioning can be used to assess the reasoning behind modelling choices and interpretation. This addresses a recurring difficulty in simulation teaching: students may be able to generate outputs, yet struggle to explain why results change, whether outputs are plausible, and how conclusions follow from assumptions and controls.

The cohort evidence provides practical insight into assessment behaviour under this design. A pre and post comparison of project outcomes indicates similar central tendency across periods, with reduced spread in the post period. This is consistent with a more structured, milestone-driven delivery in which most groups reach the expected standard of analysis and understanding. At the same time, examination outcomes provide a stronger basis for individual differentiation, which supports the rationale for dual assessment when programme requirements include both conceptual mastery and applied modelling judgement. The implication is that project and examination components should be treated as complementary measures rather than substitutes, and that overall grades alone are not sufficient to infer competence because weighting policies and component dispersion affect how final outcomes are formed.

For future teaching practices, the results support three specific recommendations. First, define project marking around decision quality criteria. Second, retain an early quality gate with timely feedback to reduce late-stage rework and protect time for interpretation and justification. Third, where minimum competence is required in both domains, consider minimum thresholds for each component to avoid systematic compensation. Together, these recommendations frame building energy simulation education as a professional reasoning task supported by a structured project workflow and an assessment model that makes competence observable.

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Appendix

Week	Topic	Lecture Topic	Reading Material	Learning Milestone	Project Progress Milestone	Assessment Details
1	1	Introductory Lecture	The Science Behind Green Building Rating Systems		Initial Meeting, team formation, chose location	
1	2	Buildings and Climate		The Importance of Buildings		
1		Project overview 1	An integrated appraoch to the design and engineering of intelligent buildings			
2	3	Internal Environment	Guide to Setting Thermal Comfort Criteria and Minimizing Energy Use in Delivering Thermal Comfort		Model running, energy loads determined	
2	4	Building Energy Balance				
2		Project tutorial 2				
3	5	Energy Simulation	Summary of Computerised Building Energy Simulation Handbook		Building fabric investigations	
3	6	1-D Heat Transfer Intro				
3	7	1-D Heat Transfer Examples				
3	8	1-D Heat Transfer Detailed Examples				
3	9	Building Envelope Opaque	The perfect Wall			
3	10	Building Envelope Transparent				
4	11	Internal Heat Gains			Inclusion of building loads	
4	12a	Building Envelope Thermal Mass				
4	12b	Building Envelope Thermal Bridges	How "green" are the green roofs? Lifecycle analysis of green roof materials			
4		Project tutorial 3				Formative self assessment of project progress
5	13	Daylighting and Glare	The building performance gap: Are modellers literate?	Understand key principles of building physics (TC)	Inclusion of shading elements	
5	16	Psychrometric Charts Introduction 1				
5	17	Psychrometric Charts Introduction 2				
5	18	Psychrometric Charts Introduction 3				
6	14	Natural Ventilation	The teeny tiny scientific screwup tha helped covid kill		Consideration of natural ventilation	
6	15	Natural Ventilation Examples				Formative problem set available to students
6		Project Tutorial 4 Hands on feedback				
7	19	Psychrometric Charts In Practice 1			Base case model complete, retrofit design alternatives considered.	
7	20	Psychrometric Charts In Practice 2		Understand and Use a Psychometric Chart (TC)		
7		Project Tutorial 5 Hands on feedback				Initial Report submitted (Brightspace)
Study Week 1					Investigation of design alternatives	
Study Week 2						
8	21	Demand Side Equipment 1			initial end-to-end design alternatives including life cycle costs	
8	22	Plant Equipment Heating	Embodied Energy Article from CIBSE			
8	27	Project Tutorial 6				
9	23	Heat Pumps 1			Initial detailed HVAC alternatives	
9	23	Heat Pumps 2				
9		Project Tutorial 7				Formative self assessment of project progress
10	24	Plant Equipment Cooling 1			Completion of all design alternatives with detailed HVAC	
10	25	Plant Equipment Cooling 2		Low Energy HVAC Systems (TC)		
10		Project Tutorial 8 Hands on feedback				
11		Project Tutorial 8 Hands on feedback			Report complete and presentation delivered	
11		Make up lecture if needed				
11		Project Tutorial 8 Hands on feedback		System of Systems thinking applied to a Retrofit Design Project (TC)		Submission of Final Project Report (Bspace)
12		Make up lecture if needed		Presentation of Design Project Results		Presentation of Final Project Report (B.space)
12		Make up lecture if needed				
12		Make up lecture if needed				
Exam Period						Final Summative Exam
LEGEND						
Lecture	Tutorial	Prerecorded lecture	Reading Material	Key Learning Outcome	Progress milestone	Assessment Component

Figure 8: Student-centric view of module structure including lecture content, project tutorials, milestones, and assessments.