4.441 From the Solar House to Net Zero Buildings

Department	School of Architecture and Planning (Course 4)
Time / Location	TR 11:00 – 12:30 lecture in 1-150 Remote lab 1 hour per week (time TBD with participants)
Instructor	Christoph Reinhart, Professor, Architecture (tito@mit.edu)
Teaching Assistant	Ali Irani, PhD Candidate, Architecture (airani@mit.edu)
Prerequisites	4.401/4.464 or Permission of instructors Access to a new Windows computer

Figure 1: Howard Sloan House I by Fred and William Keck, 1940, Glenview, IL (Photograph by Hedrich-Blessing)

Context

Current global warming has already led to politically destabilizing droughts, heartbreaking human migration due to sea-level rise and irreversible devastation of biodiversity. It we want to avert even greater tragedy, we need to keep global temperature rise below 2.0°C, an ambition which translates into a global carbon budget for buildings of 340GtCO_2e until 2050. To remain within this budget, the global renovation rate must increase from the current 1% to 5% per year and all new construction must be carbon neutral by 2030 in terms of both operational and embodied energy use (Figure 2). What may have sounded like a fantasy just a decade ago, is becoming today's societal imperative.

To reach carbon neutrality, all energy uses in a building need to be electrified while the electric grid is decarbonized via expanded use of renewables and energy storage. For government agencies, utilities and home owners, a net zero building has become synonymous with the adoption of four technologies: Heat pumps, rooftop photovoltaics, weatherization and added insulation. Traditional hallmarks of sustainable design such as daylighting, natural ventilation, sun spaces and the use of thermal mass are conspicuously absent from that list. They have disappeared from the public's imagination of how buildings should deal with climate change. What has happened?

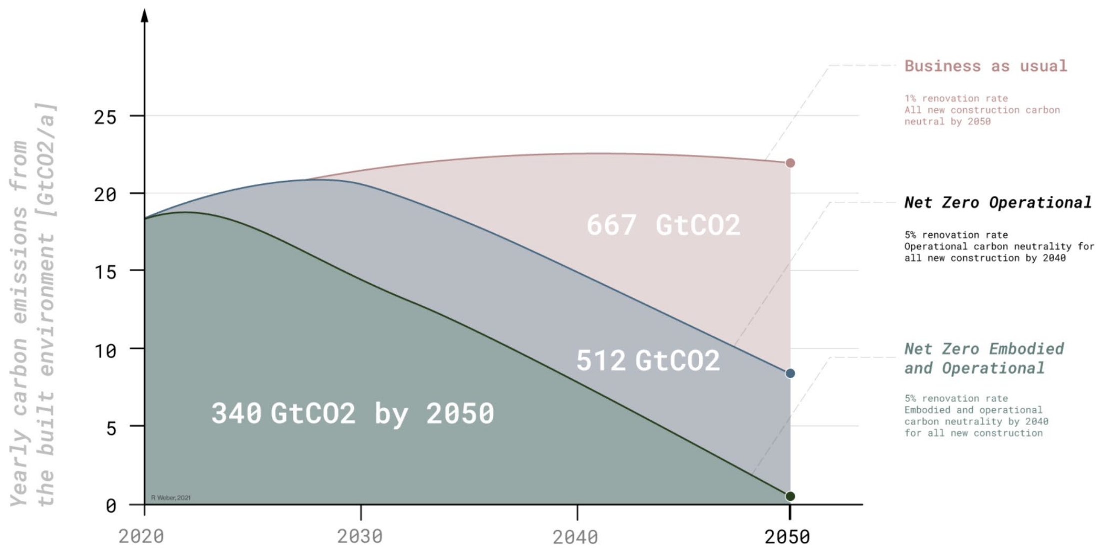

Figure 2: To keep carbon emissions of the global building stock below 340GtCO2 by 2050, the annual global renovation rate has to increase to 5% and all new construction has to be carbon neutral by 2030[1]

Course Description

This class provides students with the historic awareness and technical skills needed to become agents of change for a carbon neutral building sector by merging the fields of architectural design and environmental performance analysis. Over the past decade, building performance simulation tools for energy, daylighting and solar design have made their way into mandatory building technology classes for architects such as MIT's 4.401/4.464. In those classes, students learn how to start off with a "typical" building and explore various interventions from envelope improvements to reduced internal lighting and equipment loads, ventilation and HVAC upgrades as well as onsite deployment of photovoltaics. In combination, these measures can lead to net zero ready building concepts. The benefit of this pedagogical approach is that students learn what energy flows to pay attention to for different building types and how to productively work with the local microclimate. This knowledge should later promote elevated discussions between architect and environmental consultant.

From an architectural design standpoint, a limitation of the above-mentioned technology upgrades is that they are largely independent of the form of the building. This makes them inherently less interesting for studio and architectural thesis projects which tend to favor more dramatic, highly visible passive design solutions from burying a structure underground to using solar chimneys. Unfortunately (and somewhat ironically) such systems are more difficult to simulate than their active counterparts using the current generation of environmental performance tools that are embedded in design software. This leads to a situation where the architect presents a sustainable design concept via iconic renderings and sections in lieu of rather than in combination with careful quantitative evaluations. Thermal comfort analysis becomes an exercise in wishful thinking. This class is aimed at students who want to study simulation techniques in sufficient detail to overcome this disconnect.

[1] R. Weber, C. Mueller and C. Reinhart, Building for Zero, The Grand Challenge of Architecture without Carbon (October 8, 2021). Available at SSRN: http://dx.doi.org/10.2139/ssrn.3939009

Figure 3: Powerhouse Telemark by Snohetta, 2020, Porsgrunn, Norway (Source: https://snohetta.com/projects/523-powerhouse-telemark-a-sustainable-model-for-the-future-of-workspaces)

This hands-on survey course deals with building-level sustainable design concepts and technologies and their evolution in high performance buildings over time. Throughout the term, we will discuss a series of path breaking buildings from the first solar buildings of the 1940s to the creative activists' buildings of the 1960s, the Passivhaus movement of the 1990s, the LEED and BREEAM buildings in the early 2000s and (finally) today's net zero energy buildings. Along with each era, we will discuss the technologies that were favored by design teams at the time, evolving attitudes towards occupant comfort and introduce advanced simulation approaches that allow designers to experiment with these concepts in their own projects.

Specific topics that we will cover are modeling sun spaces, solar chimneys, double skin facades, two-dimensional heat flow and moisture management, onsite energy storage and solar hot water systems. Via a series of assignments, student will apply these technologies to a semester long project of their choice. This may be a current or former studio project, an idea for thesis, an analysis of an existing building or a more fundamental building science exploration. Students may work individually or in groups. The class is open to all members of the MIT community with a preference for individuals who previously took 4.401/4.464 or otherwise have a foundation in building energy modeling (BEM).

Learning Objectives

At the end of this course, students will:

- Appreciate the evolution of high-performance buildings from the 1940s until today,
- Learn how to apply a series of advanced passive and active design measures to their own projects and
- Be prepared to design realistic net zero building concepts.

Course Format

The class format will consist of two weekly 90-minute in person lectures and a remote 60-minute lab session. The time for the lab session will be based on the availability of all class participants. Work for the class will be divided into a series of homework assignments that successively build up to a semester-long project.

Fig 4: New School of Design & Environment NUS by Serie Architects, 2016, Singapore (Source: https://divisare.com/projects/332055-serie-architects-new-school-of-design-environment-national-university-of-singapore)

Course Requirements

Attendance and active participation in all lectures and labs session is mandatory. Timely completion of all assignments is also required. Assignment types, due dates and grading weights are listed below. Presentations for the semester long project will be graded based on the clarity of the project's objectives, originality and inner logic of the presentation and sophistication of analysis techniques used.

Assignment/Requirement	Due Date	Grade Weight
Active participation in class	-	15%
Ass 1 In search of a thermal nugget	Mar 2	5%
Ass 2 Project idea	Mar 2	5%
Ass 3 Create a thermal baseline model	Mar 9	5%
Ass 4 Create a multizone/program optimized model	Mar 16	5%
Ass 5 Design a sun room/ atrium/ solar chimney	Apr 6	10%
Ass 6 Design a Passivhaus compliant envelope	Apr 13	10%
Ass 7 Build a heliodon model	Apr 20	10%
Ass 8 Skeleton project presentation	Apr 27	5%
Ass 9 Battery storage + hourly building load curves	May 4	5%
Final presentations	May 11	25%

Software and Tools

Throughout the course, we will be using a Rhinoceros/Grasshopper-based daylighting and energy analysis software called ClimateStudio as a starting point for further analysis in EnergyPlus. Some of the assignments will be conducted in other software packages such as HTflux or via the EnergyPlus IDF editor. Instructions in these tools will be provided during weekly lab sessions.

- Rhinoceros 7.0 (http://www.rhino3d.com/)
- ClimateStudio (http://solemma.com) – MIT educational license on course web site
- HTflux (https://www.htflux.com/en/) – MIT educational license TBD

Academic Integrity

As in any other MIT course and especially in a research context, plagiarism and cheating are not acceptable. Never turn in an assignment that is not your own work, or products that do not include your own work as part of team assignment. If required, please re familiarize yourself with the MIT Academic Integrity Handbook that can be downloaded from http://web.mit.edu/academicintegrity/.

References

Weekly reading material will be provided to course participants via the course web site.

Historic Review | Thermal Comfort | Advanced Analysis Methods | Panel discussion and field visit

	Tuesday Lecture for 4.s43 11:00 – 12.30	Thursday Lecture for 4.s43 11:00 – 12.30	Lab TBD	Reading	Assignment/Submission (due date)*
1	**Feb 7** L01 Course introduction	**Feb 9** L02 The first solar houses	Software installation and review of ClimateStudio	o CDD 1 Introduction o CDD 2 Energy use in buildings	
2	**Feb 14** L03 Thermal comfort I: Balance calculations	**Feb 16** L04 Thermal comfort II: Measuring comfort	Mapping comfort	o CDD 4 Thermal Comfort o Thermal Comfort (Fanger)	**Ass 1** In search of a thermal nugget (Mar 2)
3	**Feb 21** No class (Monday class schedule instead)	**Feb 23** L05 Review Building Energy Modeling (A Irani)	Drop-in lab		**Ass 2** Project idea (Mar 2)
4	**Feb 28** L06 MIT Solar Energy Program + Creative Activists	**Mar 2** L07 Building Energy Modeling: Transient methods	Drop-in lab	o Hottel paper o Living in a passive solar home	**Ass 3** Create a thermal baseline model (Mar 9)
5	**Mar 7** No class (instructor traveling)	**Mar 9** L08 Panel on programming (C Cerezo (KPF), S Quinn (HOK), Gensler TBD)	Optimizing program	o CDD 5 Internal loads	**Ass 4** Create a multizone/program optimized model (Mar 16)
6	**Mar 14** L09 High performance envelopes: Sun spaces, atria and solar chimneys	**Mar 16** L10 High performance envelopes: Material characterization	Sun spaces, atria and solar chimneys		
7	**Mar 21** L11 High performance envelopes: Dynamic shading & trees	**Mar 23** L12 High performance envelopes: Modeling Solar gains	Windows & Optics; shading factor schedules		**Ass 5** Design a sun room/ atrium/ solar chimney (Apr 6)
8	Spring break				
9	**Apr 4** L13 Passivhaus + Green Building Rating Systems	**Apr 6** L14 High performance envelopes: Thermal bridges & heat flow through the ground	2D heat flow in HTflux, KIVA		**Ass 6** Design a Passivhaus compliant envelope (Apr 13)
10	**Apr 11** L15 High performance envelopes: Moisture Management In Walls (J Geisinger (Utile))	**Apr 13** L16 High performance envelopes: Physical model building	WUFI (A Irani)		**Ass 7** Build a heliodon model (Apr 20)
11	**Apr 18** CPS Break	**Apr 20** Lab: High performance envelopes: Helidon day (Dept photos)	Heliodon movies		**Ass 8** Skeleton project presentation (Apr 27)
12	**Apr 25** L17 Net Zero Energy Buildings + grid integration + storage in E+	**Apr 27** L18 Dynamic HVAC (A Irani)	Modeling batteries		**Ass 9** Battery storage + hourly building load curves (May 4)
13	**May 2** L19 Domestic hot water	**May 4** Dry run presentations	Drop-in lab		
14	**May 9** Field visit Divinity school (A10 TBC)	**May 11** Final Presentations (Reviewers TBD)			
15	**May 16** Visit: Harvard John A. Paulson School Of Engineering And Applied Science (Noblett, Behnisch Architekten				

*) Unless otherwise noted, assignments have to be submitted to CANVAS by 11:00AM on the due date