The course aims at providing the fundamental knowledge of the physics related to buildings, with a focus on heat and mass transfer, moisture and the energy consumed in buildings to guarantee the comfort of their occupants.

At the end of the course, students will be able to:

- Describe the environmental parameters and the building components features that affect the energy consumption of a building
- Describe the heat and mass transfer through building assemblies
- Calculate the peak load of an enclosed space
- Calculate the annual energy consumption of a building
- Describe sustainable solutions for energy-efficient and comfortable design

Instructor

Dr. Giorgia Chinazzo
Office: Tech A330
Office hours: Virtual meetings by appointment (email to coordinate)
E-mail: giorgia.chinazzo@northwestern.edu

Class times
2-3:20 Tuesday and Thursday

Location
Online – Zoom link provided

Suggested textbook

Pre-requisites
Familiarity with the fundamental concepts of thermodynamics

Course Assessment
Attendance, participation to discussion (in class), and homework (exercises and Canvas posting about readings) – 30%
Weekly exercises and readings.

Midterm – 15%
Exercises, multiple choices and open questions on the content presented in the first half of the course.

Group project – 35%
Poster + final presentation of a sustainable design for an outdoor dining space for the city of Chicago, to be presented in the last week of the course.

Final exam – 20%
Exercises, multiple choices and open questions on the content presented in the second half of the course.

Deliverables
Exercises, Canvas Discussions about Readings, Project Poster and Presentation.
Evaluations and expectations

Attendance

Students must attend the Zoom meetings for lectures and student presentations. They will earn 5 points per class for a total of 100 points (20 classes). Students are allowed one "freebie" absence that will not deduct points from the attendance grade. However, students cannot skip the classes in which they are supposed to present their project to the class.

Homework

These are exercises related to the topic discussed during the lectures. They can be exercises similar to those analyzed during the lectures or exercises that can be solved with the material provided. Each homework is composed of different exercises with various levels of complexity, each associated with a maximum number of points (for a total of 150 for each homework). Some of the homework might include multiple choices and open questions on the content presented in the lectures.

Participation

Participation is evaluated through Discussion Boards Posts on Canvas and participation to discussion during classes regarding the assigned Readings. The discussion threads are a critical connection among students, hence it's important that these posts are substantive, insightful and useful. Students are supposed to share their thoughts on the readings assigned and/or to provide further examples and/or share their own experiences linked to the topic. Students will be able to see their peers' posts once they will submit theirs. They are then encouraged to comment on some of the posts of their classmates, to enrich the discussion.

The quality of posts is much more important than quantity. Posts should be richly developed and take the discussion deeper into the topic or in a new, but related and relevant direction.

Posts should average 100 - 150 words each (as a general guideline) and must be well-written, with no spelling, grammatical or punctuation errors.

Based on this, an "average" post will be assigned a maximum of 40 points. To reach the maximum number of points for each Discussion Thread (i.e., 50 points) a student can:

- Build on a colleague’s post - provide an example, pose a question for elaboration, develop the point in more detail, apply the point to another situation or personal experiences, etc.
- Consider adding an article or outside reference source (e.g., a video) related to the same issue.

Additional 50 points can be gained during the discussion in class. Prior to it, students are invited to read the Discussion Boards Posts on Canvas.

Midterm and final exams

They comprise of exercises (as those assigned in the homework), multiple choices and open questions on the content presented in the first and second half of the course (for the midterm and final exam, respectively), including the readings. Examples of multiple-choice questions will be
shown through the use of the polling tool on Zoom at the beginning of some lectures (to which students will be asked to reply - the responses do not account for the final grade).

Exercises and questions are associated with points according to their complexity, for a total of 1000 points per exam.

The exams will last 80 minutes each and students will be allowed to use a calculator. The exams will take place through Canvas Quizzes, but students will need a pen and paper to develop some exercises. Only the final result will be written as a response on Canvas Quiz (possibility to submit the exercise procedure via email immediately after the exam).

**Group project**

Students are requested to work in a group to develop a sustainable design for an outdoor dining space for the city of Chicago. The project will be presented in the second lecture/week of the course.

Two mid-term (ungraded) revisions of the project development are scheduled during the course.

Deliverables:

- Final presentation
- Poster

The project is evaluated for a maximum of 1000 points.

**Grade breakdown**

For each group of assignments, a total of 1000 points can be earned, according to the following breakdown:

<table>
<thead>
<tr>
<th>Group</th>
<th>Assignment</th>
<th>Points</th>
<th>Percentage of the final grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-term exam</td>
<td>Various exercises and quizzes</td>
<td>1000 points</td>
<td>15%</td>
</tr>
<tr>
<td>Final exam</td>
<td>Various exercises and quizzes</td>
<td>1000 points</td>
<td>20%</td>
</tr>
<tr>
<td>Attendance, Participation and Homework</td>
<td>Discussion Posts and class participation regarding Readings</td>
<td>3 x 100 = 300 points</td>
<td>30%</td>
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<tr>
<td></td>
<td>Exercises</td>
<td>4 x 150 = 600 points</td>
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</tbody>
</table>
Attendance  
20 x 5 = 100 points

Poster  
600 points

Group Project  
35%

Presentation  
400 points

Late submissions grades will be reduced by 5% for each day of delay following the due date. Late assignments will not be accepted after one full week has passed since the original due date and will receive a grade of zero.

Grading Scheme

Undergraduate students will be graded with a Pass/No-Pass note, whereas graduate students will receive A, B or C, No-Pass grades. Grades are assigned according to the points for each type of evaluation and the weight for each type of assignment, following this scheme:

A = 93%–100% (Pass)
A- = 90%–92% (Pass)
B+ = 87%–89% (Pass)
B = 83%–86% (Pass)
B- = 80%–82% (Pass)
C+ = 77%–79% (Pass)
C = 73%–76% (Pass)
C- = 70%–72% (Pass)
F < 69% (No-Pass)
Sustainability Statement: Kellogg School of Management, Northwestern University

The Kellogg Global Hub, on target to achieve LEED Platinum, embodies Northwestern's commitment to green power, sustainable design and community responsibility. The integrated systems concept shaped the building to reduce energy consumption. The plan is organized to maximize natural daylight through a series of atria, light walls, and views on all sides. The energy reduction (46% savings) strategy is synonymous with the creation of a healthy learning and research environment filled with 100% fresh air. Thermal comfort is enhanced through automated shading systems, a geothermal exchange, and high-performance triple glazed curtain-wall to minimize heat loss. Occupants are empowered to control their environment, and motivated through smart behavior to participate in the cumulative reductions of the carbon footprint. The curvilinear form is modeled to define a series of generous outdoor terraces – harbors – that extend outdoor use and activity through shoulder seasons.

1. Fresh outside air is conditioned then ducted through the core shafts.
2. Light court air rises and exhausts at top into penthouse heat recovery unit.
3. Light courts have air delivered from lower level duct work.
4. Supply Air from corridor ceiling ducts from the main core shafts.
5. Displacement ventilation from the ceiling is used to condition typical office spaces.
6. Office spaces exhaust air into atrium via the adjacent corridor.
7. Radiant heating and cooling is delivered through ceiling panels in offices and classrooms.
8. Exhaust air from classrooms transfers to the atrium via the adjacent corridor.
9. Radiant heating and cooling in the floor slab of the atrium provide local comfort in high-ceiling spaces.
10. Undulation building form and projecting canopies provide a variety of sheltered zones for an expanded use of outdoor spaces.
11. Pre-conditions incoming air in the recovery units before being expelled through the clerestory glazing level.
12. Heat recovery units collect sensible and latent heat energy.
13. Clerestory glazing diffuses light through internal layers of frosted plastic cellular plastic, and allows access to natural light.
14. Two and three story light courts bring daylight down into interior offices and meeting rooms.
15. Automated roller shades control solar heat gain for an internal spaces.
16. Vertical glass fins with ceramic frit pattern provide some solar shading to office level facades.
17. Radiant heating and cooling in floor slab and formed metal cooling panels provide thermal comfort for auditorium space.
18. Lower level exterior court brings light down into below grade spaces.
19. Geothermal Field utilizes consistent ground temperature to passively supply low/high temperature heating/cooling energy.
20. Left space transfers exhaust air to the atrium.

<table>
<thead>
<tr>
<th>Week</th>
<th>Date</th>
<th>Lecture</th>
<th>Topic(s)</th>
<th>Assignment(s)</th>
<th>Assignment due</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>04/01</td>
<td>Course Introduction</td>
<td>Presentation of the course. Building science definition, buildings and greenhouse gas emissions, climate change, approaches to zero energy and carbon. References to climate and architecture, climate analysis, vernacular architecture, passive and active strategies</td>
<td>Group project: Group creation</td>
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<tr>
<td>2</td>
<td>04/06</td>
<td>Practical session: Project presentation</td>
<td>Project presentation</td>
<td>Group project: site, passive strategies and examples analysis</td>
<td>Final definition of group members</td>
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<td></td>
<td>04/08</td>
<td>Theoretical session: Heat transfer principles</td>
<td>Conduction, convection, radiation</td>
<td>Reading 1: Walgreens net zero energy store</td>
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<td>3</td>
<td>04/13</td>
<td>Theoretical session: Heat transfer in buildings</td>
<td>Energy performances of the building envelope components, temperature progression in constructions</td>
<td>Exercise 1: U value walls, temperature of walls and internal layers</td>
<td>Thoughts on Reading 1 (upload on Canvas discussions by 9 am)</td>
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<td></td>
<td>04/15</td>
<td>Theoretical session: Thermal bridges</td>
<td>Thermal bridges Discussion about Reading 1</td>
<td>Group project: shape, structure, materials, seating solution</td>
<td>Presentation of site, passive strategies and examples analysis</td>
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<td>4</td>
<td>04/20</td>
<td>Practical session: Project revision</td>
<td>First project revision <em>individual group revision + time to work on the project for each group</em></td>
<td>Group project:</td>
<td>Presentation of site, passive strategies and examples analysis</td>
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<td></td>
<td>04/22</td>
<td>Theoretical session: Thermal mass</td>
<td>Thermal mass Correction/discussion Exercise 1</td>
<td>Exercise 2: thermal mass</td>
<td>Exercise 1 <em>(uploaded on Canvas by 9 am)</em></td>
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<tr>
<td>Week</td>
<td>Date</td>
<td>Session</td>
<td>Description</td>
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<td>5</td>
<td>04/27</td>
<td>Theoretical session: Moisture in buildings – Part 1</td>
<td>Air and water vapor, relative humidity, surface condensation, internal condensation and moisture prevention</td>
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<tr>
<td></td>
<td>04/29</td>
<td>Theoretical session: Moisture in buildings – Part 2</td>
<td>Air and water vapor, relative humidity, surface condensation, internal condensation and moisture prevention</td>
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<td>(Correction/discussion Exercise 2, if time allows)</td>
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<td>Exercise 3: superficial and interstitial condensation</td>
<td>Exercise 2 (uploaded on Canvas by 9 am)</td>
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<td>6</td>
<td>05/04</td>
<td>Evaluation: Mid-term exam</td>
<td>Exercises, multiple choices and open questions on the content presented in the first half of the course</td>
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<td></td>
<td>05/06</td>
<td>Theoretical session: Ventilation and infiltration</td>
<td>Mass transfer in buildings, building airtightness, natural ventilation, mechanical ventilation, ventilation rate, indoor air quality</td>
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<td>Reading 2: Air quality disparity</td>
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<td>7</td>
<td>05/11</td>
<td>Theoretical session: Solar geometry</td>
<td>Sun energy and position, solar charts</td>
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<td>(Correction/discussion Exercise 3, if time allows)</td>
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<td></td>
<td>05/13</td>
<td>Theoretical session: Solar radiation in buildings</td>
<td>Shading systems, window properties, radiation on surfaces and through glazing</td>
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<td>Discussion about Reading 2</td>
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<td>Reading 3: Rethinking the All-Glass Building</td>
<td>Thoughts on Reading 2 (upload on Canvas discussions by 9 am)</td>
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<td>8</td>
<td>05/18</td>
<td>Practical session: Project revision</td>
<td>Second project revision (individual group revision + time to work on the project for each group)</td>
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<td>Group project: final project presentation and poster</td>
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<td>05/20</td>
<td>Theoretical session: Building energy balance - part I</td>
<td>Thermal losses of the building, heat balance equation, heat balance for load calculations (peak load calculation)</td>
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<td>05/25</td>
<td>Theoretical session: Building energy balance - part II</td>
<td>Exercises on peak load calculation</td>
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<td>Discussion about Reading 3</td>
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<td>Exercise 4: peak load calculation</td>
<td>Thoughts on Reading 3 (upload on Canvas discussions by 9 am)</td>
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<tr>
<td>Date</td>
<td>Event Description</td>
<td>Details</td>
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<tr>
<td>05/27</td>
<td>Theoretical session: Annual energy consumption</td>
<td>Annual energy consumption calculation, efficiency, heating systems, cost of energy</td>
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<tr>
<td>06/01</td>
<td>Theoretical session: Standards, codes and certifications (recorded/asynchronous)</td>
<td>U.S. standards and codes, LEED and other certification systems</td>
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<td>Exercise 4 (uploaded on Canvas by the end of the day)</td>
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<td>06/03</td>
<td>Evaluation: Group presentation</td>
<td>Presentation by students – group project + active participation by other groups (Q&amp;A)</td>
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<td>Upload poster and presentation on Canvas (by 9 am)</td>
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<tr>
<td>TBD</td>
<td>Evaluation: Final exam</td>
<td>Exercises, multiple choices and open questions on the content presented in the second half of the course</td>
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</table>

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