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Units: 2-4-6 (Institute Lab)

Prerequisites: 8.01, 18.01

Schedule: Lecture  Wednesday, 9:30-11:00 a.m., 1-132
Description

This term the course focuses on the improved design and technical analysis of a primary school in Singapore, as an exemplar of schools in similar Southeast Asia climates. The goal is to improve thermal comfort of the students and teachers and provide a healthy learning environment while attempting to meet a goal of providing all necessary energy from on-site, renewable sources. The focus on the physical environment for education builds on previous work within the Building Technology Program and the D-Lab Schools: Building Technology Lab course for schools in Cambodia, Haiti, Nepal, Pakistan, Sierra Leone and South Africa.

Our institutional partners in Singapore include the Building and Construction Authority (BCA) and Ministry of Education (MOE). We have a good working relationship with the Vice Principal of Punggol Primary School, Mr. Meng Hong YAP and with BCA staff members. Our investigation builds on research proposed and initiated by Singapore-based groups from MIT, UC Berkeley and ETH Zurich and from the National University of Singapore (NUS) will study climate and thermal comfort; daylighting, ventilation and thermal conditions inside simulated and or physically modeled classrooms; building materials and construction methods that improve current practice; and electrical power and water systems. We will also design an innovative canopy over an existing courtyard to provide a scaffolding for photovoltaic and other energy systems.

The course is set up as a series of short studies and lab-based projects, to be performed in teams formed to take best advantage of the skill sets of class participants. Necessary in-class instruction in simulation software will be supplemented by online tutorials. Results of these investigations will be compiled in a report, prepared in stages and submitted in final version at the end of the term.

Software we anticipate using includes Rhino and the associated Grasshopper visual scripting program, which will allow us to perform climate, thermal comfort, airflow analyses and energy analyses within a design framework that easily obtains necessary geometrical information from a CAD model. We will also employ stand-alone software for structural design and pollutant transport.

Course objectives:

- Develop an understanding of culture, education systems, climate and construction methods and materials in the country and local region of the school under consideration
- Develop an ability to analyze climate, its impact on the thermal comfort of school occupants and its influence on building design.
- Through experiments, application of engineering fundamentals and simulations, learn to quantify key aspects of building performance, including daylighting, moderation of indoor temperature, natural ventilation, and structural integrity and efficiency.
- Improve written and oral communication skills, including an ability to present design concepts and building performance to a non-technical audience.

Evaluation criteria:
The course grade will be based on participation in class and lab reports. Weekly assignments will require work that will be incorporated into the reports and may be presented orally in labs for discussion and feedback but will not be graded.

Participation is crucial to the success of the course. Attendance in lab and lecture will be noted. Poor attendance, particularly in lab, will result in a reduced grade.

You will typically be encouraged to work in groups of 2-3, depending on the lab and available resources. Lab reports are prepared on a group basis: one report per group. Groups may be changed during the term, as a function of the needs of students and the discretion of the instructor.

Course work will be weighted as follows:

<table>
<thead>
<tr>
<th>Report Type</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Interim report #1</td>
<td>25%</td>
</tr>
<tr>
<td>Interim report #2</td>
<td>25%</td>
</tr>
<tr>
<td>Final report</td>
<td>40%</td>
</tr>
<tr>
<td>Attendance and participation</td>
<td>10%</td>
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Interim reports must be submitted on time, subject only to extraordinary circumstances beyond academic workload. Late interim lab reports will be penalized 10% of full credit; reports more than one late will receive no credit. The final report may be submitted as late as 5 p.m. on Monday, December 18 with no grading penalty; submittals after this date and time will receive no credit. Lab reports will be returned within one week of submittal. Schedule adjustments will be considered as necessary to accommodate major studio reviews, other significant deadlines, or the impact of local weather on experimental work.

There is no final exam in this course and there will be no quizzes.
### Tentative Schedule

<table>
<thead>
<tr>
<th>Type</th>
<th>Date</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture</td>
<td>9/6</td>
<td>Course overview and review of building technology studies of schools in developing (and recently developed) countries; Singapore schools as a model for urban SE Asia; formation of project teams; thermal comfort and climate fundamentals</td>
</tr>
<tr>
<td>Lab</td>
<td>9/11</td>
<td>Investigation of education and local and regional construction materials in Singapore and Southeast Asia; Climate investigation with Ladybug and UC Berkeley Center for Built Environment (CBE) thermal comfort tool</td>
</tr>
<tr>
<td>Lecture</td>
<td>9/13</td>
<td>Materials and construction: meeting multiple objectives and preview of formwork for reinforced concrete beam</td>
</tr>
<tr>
<td>Lab</td>
<td>9/18</td>
<td>Fabrication of formwork</td>
</tr>
<tr>
<td>Lecture</td>
<td>9/20</td>
<td>Outdoor and indoor thermal comfort metrics; prediction of satisfactory classroom conditions</td>
</tr>
<tr>
<td>Lab</td>
<td>9/25</td>
<td>Assessment of indoor and outdoor temperature and humidity measurements relative to thermal comfort metrics</td>
</tr>
<tr>
<td>Lecture</td>
<td>9/27</td>
<td>Lighting fundamentals; luminous efficacy of light sources; inverse square law and applications; zonal-cavity method for lighting and daylight design; daylight factors and daylight availability; daylight measurements in MIT classrooms to establish/confirm illuminance target;</td>
</tr>
<tr>
<td>Lab</td>
<td>10/2</td>
<td>Mixing and pouring concrete; daylight autonomy simulation with DIVA for Rhino; estimation of lighting electricity consumption in Singapore classrooms; estimation of fan energy use; guidelines for interim report #1</td>
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<tr>
<td></td>
<td>10/6</td>
<td><strong>Add Date</strong></td>
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<tr>
<td></td>
<td>10/9-10</td>
<td><strong>Columbus Day holiday</strong></td>
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<tr>
<td>Lecture</td>
<td>10/11</td>
<td>Fundamentals of natural ventilation: hydrostatic equation, ideal gas law, Bernoulli’s equation, orifice equation;</td>
</tr>
<tr>
<td>Lab</td>
<td>10/16</td>
<td>Available PV electricity from roof and wall surfaces, using Ladybug; comparison of available energy with electricity demand</td>
</tr>
<tr>
<td>Lecture</td>
<td>10/18</td>
<td><strong>interim report #1 due</strong></td>
</tr>
<tr>
<td>Lab</td>
<td>10/23</td>
<td>Fabrication of appropriate airflow model of the classroom block and surroundings</td>
</tr>
<tr>
<td>Lecture</td>
<td>10/25</td>
<td>Buoyancy- and wind-driven airflows; airflow mass and energy balances</td>
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<tr>
<td>Lab</td>
<td>10/30</td>
<td>Testing reinforced concrete beams</td>
</tr>
<tr>
<td>Lecture</td>
<td>11/1</td>
<td>Interpreting results of beam testing; airflow in urban areas</td>
</tr>
</tbody>
</table>
WBWT visualization of airflows through classroom block

Indoor air quality, including particulates and CO$_2$; guidelines for interim report #2

Quantitative assessment of wind-driven airflows with outdoor obstruction using CoolVent or a computational fluid dynamics program; haze and filtering technologies

Dehumidification with desiccants and membranes; heat exchangers for sensible and latent cooling

Design, sizing and performance evaluation of dehumidification and sensible cooling systems

rooftop energy systems; interim report #2 due

Thanksgiving holidays

Courtyard canopy structure: possible uses and simulation-based design

thermal and airflow characteristics of canopy structure; estimates of annual thermal performance and energy consumption

Performance of classroom block, including demand for energy for two space-conditioning strategies

Life-cycle cost assessments

final presentation; completion of final report

Adaptation of school to Southeast Asia; Final report due

Last day of classes

Library texts

*Illumination Engineering From Edison’s Lamp to the Laser Second Edition*
Joseph B. Murdoch
2003, Vision Communications
ISBN 1-885750-05-6

*Daylighting handbook I: Fundamentals, designing with the Sun*
Christoph Reinhart
2014
ISBN 9780692203637

Stellar

This course will have a Stellar site, where homework assignments and instructions will be posted and where lab reports can be submitted electronically. [http://stellar.mit.edu/S/course/4/fa15/4.411/](http://stellar.mit.edu/S/course/4/fa15/4.411/)
Academic integrity + honesty

Academic integrity is a serious issue. Data sources must include attribution. Lab reports must reflect the thoughts and efforts of team members, unless noted. Please familiarize yourself with MIT’s Academic Integrity expectations at http://web.mit.edu/academicintegrity/.

Software

At appropriate times in the course you will be asked to install the following software, for which (near) current download links are provided.

**Rhino 5.0** - [http://www.rhino3d.com/download](http://www.rhino3d.com/download) - need Windows version to work with grasshopper


**GHPython** - [http://www.food4rhino.com/project/ghpython?utfh](http://www.food4rhino.com/project/ghpython?utfh) – follow installation instructions on website

**Ladybug and Honeybee (and other insects!)** – [http://www.grasshopper3d.com/group/ladybug](http://www.grasshopper3d.com/group/ladybug) – install by dragging all of the objects contained in the folder onto the Grasshopper canvas.

**CoolVent** - [http://coolvent.mit.edu/download/](http://coolvent.mit.edu/download/)


**scSTREAM** – computational fluid dynamics program. Download and installation instructions will be provided at the appropriate time.

There are additional programs that we may use, individually or collectively:

**Climate Consultant** ([http://www.energy-design-tools.aud.ucla.edu](http://www.energy-design-tools.aud.ucla.edu)) is a freely downloadable tool that runs under Windows or Mac OS and provides a relatively comprehensive set of non-customizable graphical presentations of data from standard weather files. We prefer Ladybug and the CBE thermal comfort tool but acknowledge that Climate Consultant is easy to use for standard climate information.