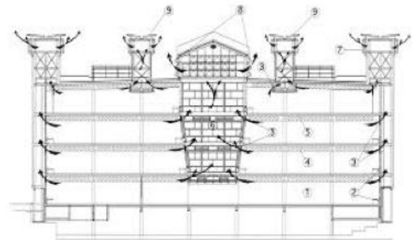
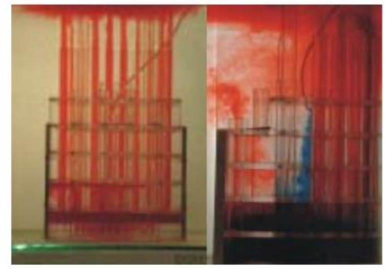
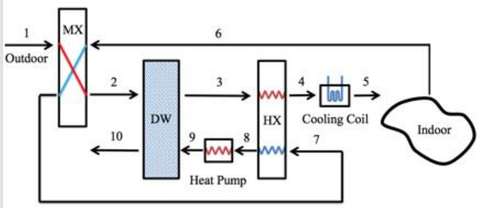
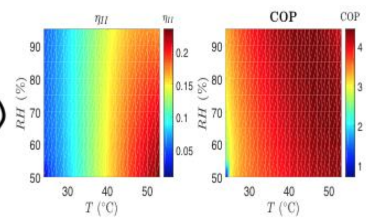
Heating, Cooling and Ventilating Systems for Low-Carbon Buildings
4.s46 Department of Architecture Spring 2018



Images: UCL, BPI Cambridge, MIT and NUS

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Monday and Wednesday, 9:30-11, Room 4-146; Lab Friday 9:30-11, Room 5-415
Units: 3-2-7; 3-2-4 available

Consensus understanding of climate change identifies a need to drastically reduce anthropogenic emissions of greenhouse gases in coming decades, including those associated with buildings. In this course, we seek a thermofluids understanding of the basics of natural and mechanical systems for conditioning high-performance buildings and will develop and assess systems based on this understanding.

We will investigate natural ventilation in detail. Topics include the thermal and fluid dynamics of airflow in buildings, application to multi-zone wind- and buoyancy-driven airflows, and adjustments in urban areas to account for reduced wind speeds. Performance assessments will be based on first-principles analyses and simulations that couple airflow and energy analysis programs. Building cooling strategies will be motivated by mapping conventional and innovative cooling systems on the psychrometric chart. First-principles analysis and simulations with an equation-based language, Modelica, and with EnergyPlus will be used to quantify the performance of energy recovery systems, membrane- and desiccant-based dehumidification, evaporative cooling (direct, indirect and dew-point), thermal storage at diurnal (building materials) and annual (ground-coupled heat pumps) scales and radiant cooling and heat-rejection systems. System design in leading commercial practice will be presented and critiqued. Through a group project, climate- and building-specific systems will be assessed on the basis of energy consumption, carbon emissions and resilience to climate change.

The class is open to all members of the MIT community and to cross-registered students.

Learning objectives

The objectives of the course are to help students:

- Understand the societal and environmental context of building energy consumption;
- Understand and apply the scientific principles underlying the thermal and fluid dynamic characteristics of buildings and building conditioning systems, and apply these fundamentals to practical design problems;
- Recognize design opportunities to use natural ventilation;
- Develop an ability to use contemporary component and whole-building simulation programs to analyze building performance;
- Learn to evaluate a range of technologies for creating comfortable indoor environments and
- Demonstrate an ability to critically discuss and present the environmental concept of low-energy and low-carbon building systems integrated into a building.

Requirements

This course requires the following:

- Attendance of bi-weekly lectures;
- Timely completion of assignments that involve analytic and computational assessment of system performance;
- Completion of a group course project;
- Active participation in class discussions.

Course Grading

50% homework assignments
15% interim design project presentation
25% design project final presentation and report
10% class participation

Please familiarize yourself with MIT's Academic Integrity Expectations at
http://web.mit.edu/academicintegrity/.

Required text

None. Readings will be assigned from multiple sources.

Software

- CONTAM with FMU interface to EnergyPlus. CONTAM (https://www.nist.gov/services-resources/software/contam) is a freely available program developed by the National Institute of Standards and Technology (NIST) to simulate multi-zone airflows and contaminant transport. A link will be provided to a version that includes Functional Mockup Unit (FMU) real-time interface with EnergyPlus, in which CONTAM provides zonal airflows to EnergyPlus, which affect zonal energy balances, and EnergyPlus provides zonal temperatures to CONTAM, which affect buoyancy-driven airflows.
- EnergyPlus (https://energyplus.net) is the whole-building energy simulation program we will use to generate heating and cooling loads that must be met by space-conditioning equipment we will define and represent by seasonal efficiency metrics.
- Rhino 5 (http://Rhino3d.com) is the 3D modeler associated with Grasshopper and UMI.
- Archsim (http://archsim.com) will be used to define building templates and create first-cut EnergyPlus input data files (IDFs) that we will modify with provided Python scripts to represent internal loads (peak values and schedules) appropriate for energy-efficient buildings.
- Grasshopper and Ladybug (http://www.grasshopper3d.com, http://www.grasshopper3d.com/group/ladybug) are freely downloadable programs, the former familiar to Rhino users. Ladybug can be added as a set of functions (not exe files) that can be dragged onto the Grasshopper canvas. Ladybug can perform user-defined climate analyses, such as 3-D plots of temperature as a function of date and time and wind roses limited to specific outdoor temperatures.
- CoolVent is a freely downloadable tool (http://coolvent.mit.edu) developed at MIT for analyzing airflows and indoor temperatures associated with naturally ventilated buildings.
- ASHRAE or other psychrometric chart software (HDPsyChart or comparable) that will plot condition lines and cooling paths

Schedule – subject to minor revision

W1	2/7	L1	Climate change, urban heat island, ecodistricts, buildings (LN)
	2/9	Lab	Assign teams and overview project (MIT's redevelopment of the Volpe Center near Kendall Square); review of natural ventilation toolkit
		R	Toolkit pdf, expanded to include more on discharge coefficients
		A1	National carbon emissions, with end-use disaggregation
W2	2/12	L2	Climate-control systems and considerations for design integration (PR)
	2/14	L3	Buoyancy- and wind-driven airflow; two-way airflows through single openings; mass and energy balances (LN)
	2/16	Lab	Overview of EnergyPlus, its interfaces, and low-carbon building templates
		R	excerpts from Spindler thesis and Li paper
		A	none: project work to define building and loads in EnergyPlus
W3	2/20	L4	Note President's Day shift! Thermal comfort and energy balance, the heart of all passive and active design considerations (PR)
	2/21	L5	Mass and energy balances for multiple zones in series, for wind and buoyancy flows (LN)
	2/23	Lab	continued use of EnergyPlus and interfaces to define building loads;
		R	none
		A2	Multizone airflow calculations and application to solar chimneys
W4	2/26	L6	Advanced analytic flows (Li, Linden, Woods) (LN)
	2/28	L7	Urban airflows, with quantitative emphasis on reduced airspeed and wind-pressure coefficients; introduction to CoolVent (LN)
	3/2	Lab	analytic solutions for mass and energy balances; CoolVent for multizone flow and temperature calculations, with emphasis on chimneys
		R	wind-pressure coefficient literature
		A3	Assessment of UCL School of East European and Slavic Studies (SEESS) building
W5	3/5	L8	CONTAM math, templates, wind-pressure coefficient libraries, demo and tutorial (LN)
	3/7	L9	Coupling CONTAM to EnergyPlus through FMUs through series of well-documented single- and multi-zone cases. (LN, using Apisada Chulakadabba's work)
	3/9	Lab	CONTAM FMU demos with CONTAM and EP-Launch
		R	CONTAM manual and tutorials, including use of FMUs, overview of EnergyPlus
		A4	CONTAM, stand-alone and with FMUs, for natural ventilation assessment
W6	3/12	L10	Critique of naturally ventilated buildings in practice (LN+PR?, can you join even remotely?)
	3/14	L11	Heat storage at diurnal and longer time scales: thermal mass, PCM, earth tubes, ground-coupled heat pumps. Ground-temperature plots. (PR+LN)

	3/16	Lab	Assessment of building thermal mass and night flush (simulation and/analytics in spreadsheet)
		R	Strand's earth tube model for E+; source of ground temperature models, Carrilho de Graca's summary of night flush
		A	none; preparation for project presentation
W7	3/19	L12	Boundaries of energy use (zone, site, source); difference between energy use and carbon emission; Low-energy building standards, practices and examples: Passive House, LEED, Living Building Challenge, etc. (PR)
	3/21	L13	moist-air processes, static and interactive psychrometric chart: condition line, mixing, sensible load factor; vapor compression system, direct and indirect evaporative cooling, argument for splitting sensible and latent heat removal: eliminated reheat, warmer water, opportunities for free sensible cooling, including radiation
	3/23	Lab	First project presentation: loads, opportunities for specific approaches to natural ventilation (LN, PR?, students)
		R	HdPsyChart manual; McQPS chapter3
		A5	Use of interactive psychrometric chart

Spring break!!

W8	4/2	L14	Vapor-compression system in detail: property tables and phase diagrams; refrigerant cycle and GWP/ODP of refrigerants; efficiency metrics: second law of thermodynamics, rated and seasonal COP and EER, IPLV (LN).
	4/4	L15	Gordon-Ng, EnergyPlus and Zakula models, efficiency metrics (EER, COP). Goals: part-load performance as function of understandable parameters. Assess low-lift options. (LN)
	4/6	Lab	Consideration of ground-coupled heat pumps
		R	McQPS chapter 14; Gordon-Ng (available online through MIT libraries)
		A6	Application of GN or other models. Analytic or computational means to calculate seasonal COP or COP as a function of load. Use of Thu's paper to establish break-even dehumidification COP for different ambient conditions.
W9	4/9	L16	All-air system (VAV), DOAS, heat and enthalpy recovery; membranes and desiccants for dehumidification; desiccant wheels and desiccant regeneration (PR)
	4/11	L17	Modelica for system evaluation and building performance (LN, TC)
	4/13	Lab	Dymola/Modelica set up and examples
		R	Modelica-based Buildings Library
		A7	Desiccant and membrane models in Modelica
W10	4/16		Patriots Day!
	4/18	L18	Absorption, adsorption and liquid desiccant cooling, with attention to source of energy – electricity or solar cooling (LN)
	4/20	Lab	Continued Modelica modeling

		R	liquid desiccant cooling (Muslmani et al.)
		A8	Modeling radiant cooling systems, E+ or Modelica
W11	4/23	L19	Hydronic and radiant cooling systems: active and passive chilled beams, TABS (PR)
	4/25	L18	Radiant heat rejection (LN)
	4/27	Lab	Application of models for chilled beams
		R	Models of chilled beams and TABS (from Zakula and Blum), radiant heat rejection (Stanford, UC Boulder, PNNL)
		A9	Simulation of radiant cooling
W12	4/30	L21	Water use for cooling and production of electricity: direct and indirect evaporative cooling and Maitsosenko dew-point indirect evaporative cooler; desiccant or membrane front ends (LN)
	5/2	L22	Critique of Transsolar projects (PR)
	5/4	Lab	Modelica and buildings library
		R	M-cycle and papers by Chua and Palmer
		A10	Modeling DEC, IEC, and dew-point IEC using the psychrometric chart, combining IEC with dehumidification front end (Chua)
W13	5/7	L23	Low-carbon system design (PR)
	5/8	MITEI lecture: Katrin Klingenberg, Passive House Institute, U.S. 5 pm, room TBA	
	5/9	L24	Heat and water recovery at building and district scale. Stanford vs. MIT: heat recovery, co- and tri-generation. Can we make a climate-specific argument for our choice? (LN)
	5/11	Lab	MA Dept of Transportation building or campus central plant tour
		R	none
		A	preparation for project presentations
W14	5/14	L25	project preparation
	5/16	L26	project presentations (no final exam) (LN, PR, students)

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Notes

1. Energy balance, solving for temperature and flow; use analytic approach and numerical solver (EES, Modelica, python or Matlab) to consider chimneys and solar chimneys.
2. Urban airflows: theory, wind speed profiles, pressures, computation with LBWFM (domain, etc.) or scSTREAM; incorporation of airflow calculations into LBWFM? Wind-pressure coefficients in urban areas (refer to Chetan's thesis: there's a lot of information); For Ju, how does CONTAM coupled to E+ handle wind-pressure coefficients?
3. Modeling heat and moisture flows, modeling fins and scoops
4. Intro
    a. building energy, options for meeting loads (categories and/or illustrations of building systems) – tweaked version of Dave's 4.464 HVAC introduction; air, water and refrigerant systems
    b. Tour of MIT campus buildings, including Sloan for enthalpy wheel; system types (air, water, refrigerant) (project/lab class)
6. desiccants: equipment and systems; be careful to distinguish heat recovery wheel (explain in depth) from a desiccant that requires regeneration. Refer to UWCSEA. What's the metric? Absorption isotherms. EES or Modelica models, sensible and latent heat recovery efficiency (effectiveness?)
7. Membranes: equipment and systems; sieves vs. surface reactions. Can Tianyi and Omar's EES code be extended and used?
8. Absorption, adsorption and liquid desiccant cooling, with extended argument about source of energy – electricity or solar cooling
9. Building loads, heat balance model
10. Performance standards, PHI and PHIUS, with quantified loads
    a. Climate-specific (3-4, like Omar and Tianyi's paper) systems for very low energy buildings. Residential and small commercial, PHIUS, RMI Basalt building. What's in use now, what's possible. 3for2 in UWCSEA, breathable wall (perhaps), Singapore zero-energy schools (or leave that to 4.411), Coolerado with and without desiccant or membrane front end
    b. Coolerado with and without desiccant or membrane front end
11. System design to meet diurnal and season loads, including thermal or electricity storage.
    a. MA Dept of Transportation building (tour?)
12. District systems
    a. Tour of MIT cogeneration plant; is there an all-electric counterpoint? How much electricity should MIT buy versus produce? (Project class)
13. Refrigerants: just a little
14. Stratification or horizontal variations in temperature
15. Leon for the Hulic building?

Punch list

- Why CFD? Visual way of checking airflows and pressures around buildings, quantitative way of estimating surface pressures. Indoor flows, with fins or buoyancy effects. Could use LBWFM rather than scSTREAM for outdoor flows. Does it provide enough value? For OTC, yes. Ask Alpha about Butterfly, which is good for OTC. What about NV? Any real need? Probably avoid it.
- If Chetan can import urban-appropriate wind-pressure coefficients, make more use of CoolVent. Could set wind-pressure coefficients in CONTAM-FMU-E+.
- Project: emphasize very low energy system. Expanded version of BT Lab, for Singapore school or NUS SDE Building 4? Or urban U.S. building? HVAC assessment for building of choice, accounting for changing wind direction, buoyancy and wind forces, mixed modes (fans and A/C?), possibly CO_2. One project is better than two, because it integrates NV and mechanical equipment.
- Ask Dave for his Modelica model and Tianyi for EES models, with comments. Convert Tianyi's code to Modelica. Check on Dave's HB .gh files (if we use HB).
- Text? McQuiston et al.? Awbi?
- E+ Access such features as evaporative cooling through HB or Archsim? What interface to run E+: EPlaunch? Ask Chris Mackey. What about DesignBuilder with CFD?
- Hayden Taylor Matlab code for breathing façade