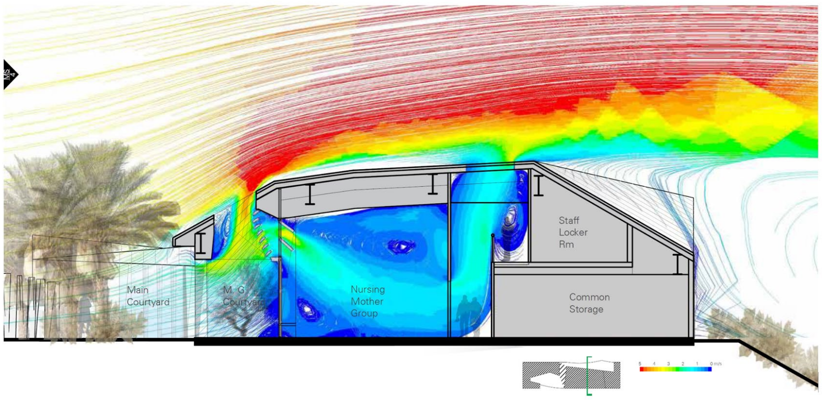
ARCH 754-001 Performance Design Workshop

Reinventing Environmental Systems Design

Instructor: Dr. Jihun Kim <jihun@design.upenn.edu>
Time: Spring 2022, Wednesdays, 8:45~11:45 AM (EST),
Location: Meyerson 321 for in-person meetings
If a remote meeting is scheduled, use https://upenn.zoom.us/j/92844285330
Announcements: https://miro.com/app/board/uXjVPyDbsBg=/?share_link_id=9761473508



ARCH 754 examines the design and assessment of the environmental systems in architecture that have been developed to improve thermal comfort and reduce energy use. With semester-long design research, the focus is on the thermodynamic analyses of the systems for their climatic effects on occupants, for which students learn the necessary technical and analytic skills. The environmental systems of interest may include the Trombe wall, double-skin façade, external thermal mass, integrated shading, stack ventilation, and passive downdraft cooling. For performance assessments, computational fluid dynamics and building energy simulation are incorporated along with physical modeling and energy flow diagrams. The course further provides technical skills that serve the ARCH 709 EBD Research Studio offered in the same semester. Students must have completed ARCH 753 Introduction to Building Performance Simulation as a prerequisite.

METHODS

Class meetings include lectures, workshops, and desk crits. The lecture series provides theoretical backgrounds and concepts in the incorporated computer simulations, while workshops/demonstrations expose students to exercise technical skills in a structured way that is directly applicable to individual assignments. Desk crits scaffold the term project in a group that allows students to explore architectural design ideas for environmental performance while deepening the learnings by applying the lessons to the student's interests. Refer to the weekly schedule for the key lectures, workshops, and assignments.

LOGISTICS

ACADEMIC INTEGRITY

Academic honesty is fundamental to our scholarly community. The Pennbook contains the University Code of Academic Integrity, to which the School of Design strictly adheres. A confirmed violation of that Code in this course will result in a failing grade, and likely in other disciplinary measures. The University of Pennsylvania Code of Academic Integrity is available online at https://catalog.upenn.edu/pennbook/code-of-academic-integrity/

ATTENDANCE

Students are expected to attend all classes for the entire scheduled meeting time and are responsible for completing assignments and knowing the material covered in class. If a student must miss a class due to an excused absence, it is the responsibility of the student to learn the content covered in the lecture, submit the in-class lab assignment for the week, and submit the following week's assignment on time. If the student needs assistance to do so, it is the student's responsibility to arrange any make-up material. Students are requested to alert the instructor by email for the excused absences at least 24 hours in advance of the session.

EVALUATION AND GRADING

Assessment of student performance will be calculated based on the following components:

- 30% : Midterm project
- 30% : Final project
- 20% : Individual assignments
- 20% : Attendance and Participation in class

Grades will be given to your ability to meet the course deadlines, deliverables, and course objectives. Grading of assignments will consider timely submissions in compliance with instructions. Two latenesses are considered one absence. Final grades will be given by the course instructor and the letter grades are understood to mean the following. A: Excellent, B: Good, C: Marginal, F: Fail, where their numerical values are, A+=4.0, A=4.0, A-=3.7, B+=3.3, B=3, B-=2.7, C+=2.3, C=2.0, C-=1.7, F=0. https://www.design.upenn.edu/weitzman-school-academic-performance-and-grading

PROJECT ARCHIVING

At the end of the semester, students are required to submit their work for departmental archiving and potential publications. This includes all presentation files (typically InDesign) and all related WORKING files (Illustrator files, high-resolution image files, Rhino files, and DesignBuilder files). All files shall be named with the course number, project name, drawing title, last name, and your first initial, such as
ARCH753_LightQuality_SectionDiagram_Smith_M+Jane K.pdf.
* This naming convention shall be used for all assignment submissions.
* For the InDesign file, the “Embed” function is recommended, instead of “Package”.
* All vector files, such as Illustrator or CAD, shall be submitted editable.
* Submission location is CANVAS unless instructed otherwise.

REFERENCES

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Stott, R. (2015). This Innovative Brick Sucks Pollution from the Air Like a Vacuum Cleaner.
AD Editorial Team (2019). This Innovative Cooling Installation Fights Soaring Temperatures in New Delhi.

WEEKLY SCHEDULE

Class #	Mon	Day	Topic	Workshop	Assignments (Individual)	Term Project
1	Jan	18	CFD Concepts – Spatial Discretization + Thermodynamic Abstraction	SE3D Mesh	Abstract a Bull	Form a group
2		25	CFD Initialization (I/O Spacetime)- Energy Source/Sink, Interaction in Spacetime, Transient, Relaxation	DC2D Envelope	CO2 Displacement (+VOC)	Existing System Research Typology Build-up
3	Feb	1	CFD Arch Applications (Thermal Zones/Flow Continuitiy/Dimension : ZC9D) + Special Objects	DC2D Roof	Extreme Heat - Roof	Existing System Type - EFD Future System Design - Proposal + EFD
		8	**Cancel for studio travel**			
4		15	Term project development: Design	SI3D Descrits	Smoke Control	CFD of Existing Systems + Future System + Bare Base Case
5		22	Term project development: Technical	Descrits		
6	Mar	1	Term project development: Representation	Descrits		Physical Simulation w/ Datalogger + IR + Stand Light (Key elements in full scale)
		8	**Cancel for spring break (3/3 Studio Midterm)**			
7		15	**Miterm Review - Term Project**			
8		22	BES basics – Concepts, Key Settings	DesignBuilder Building	Greenhouse Game - Two zones (vertical), Opening, Shading, Materials	Future System Design - Revised
9		29	BES intermediate – Shading, Window, Material,	DesignBuilder Shoebox	Façade Game - Two Skins, Adiabatic/Shoebox, PCM, Schedule/Operation	
10	Apr	5	BES advanced – Schedule, Operation, Airflow	DesignBuilder Façade	Courtyard - Outdoor, Nodal Network	BES Existing & Future System
11		12	Term project development: Design	Descrits		
12		19	Term project development: Technical	Descrits		
13		26	Term project development: Representation	Descrits		
14	May	3	**Final - Term Project – Final Presentation**			

*The schedule is subject to change by the instructor.
*Any individual assignment is due before the following class.

ARCH 754 Term Research Description

The term research aims to understand an existing environmental system qualitatively and quantitatively while advancing it with the criteria and technologies of the old and new. For this noble goal, semester-long design research is launched with two major parts as follows.

OVERARCHING PROCESS

The first part of the design research begins with analyzing an existing passive/architectural system for environmental performance. By reviewing existing building examples, a system is analyzed for its history, purposes, and applications. Advantages and disadvantages must be identified, especially regarding thermal comfort, sensory experiences, and energy savings. The commonalities in geometry and material from the examples provide the base information to develop an existing system type that represents not only the thermodynamic role of the individual components but also the system formation as a whole. A developed typology must allow demonstrating the systems' dynamic operations to respond to the changes in climatic variables and occupant needs.

The second part of the design research is to develop a new environmental system, evolving from the existing one. The new system must deal with impending global issues (hyper-environmental criteria) as well as the existing design criteria. To stay effective in climate change, both global warming and weather extremities, the building's carbon footprint shall be more rigorously accounted, for while providing satisfactory environments for occupants, beyond the normalized standards. Special attention is given to mitigating the spread of COVID-19 with passive and active strategies. It must also be mindful of the construction trends, such as buildings' supersizing for urban densification and unitization for economical constructions. Emerging technologies must be investigated for their potential in fostering the effectiveness and efficiency of the system.

The 6 major requirements are listed below in the recommended sequence, but your group can decide to rearrange them to your needs. By the midterm, your group must demonstrate all except the BES. Refer to the weekly schedule in the syllabus.

A. Existing System Research (Cataloging + Stereotyping)

B. Existing System Typology

C. Performance Evaluation (EFD + CFD + BES) of Existing System

D. Future System Design

E. Future System Typology

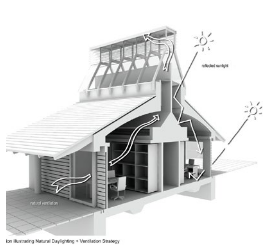
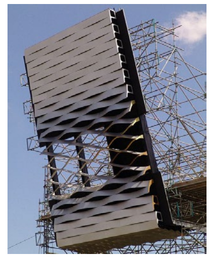
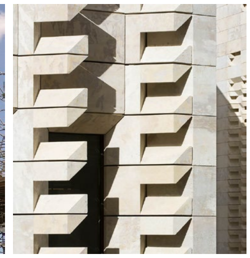
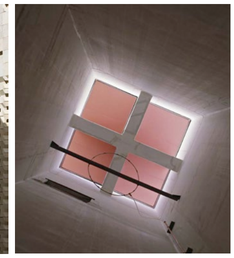
F. Performance Evaluation (Physical Model + EFD + CFD + BES) of Future System

By the final review, your group must have conducted BES, in addition to revamping the midterm presentation (Design + Technical + Representation) and the write-up of the team's transcriptions and reviewers' comments

PART 1 – ANALYZING AN EXISTING SYSTEM TYPE

A. EXISTING SYSTEM RESEARCH



The architectural environmental system has been developed and sophisticated to sustain comfortable and productive microclimatic conditions, such as Trombe wall, stack ventilation, and double skin facades. In this assignment, a system must be chosen from Table 1 below, find three buildings outside the table, and investigated the system's thermodynamic capacities and other human-centered goals with the criteria below.

- General information: Summarize the system's purpose, history, and application in writings and images.
- Thermodynamics: Summarize the system's advantages and disadvantages in writings and images, especially regarding thermal comforts, sensory experiences, and energy savings; Use section (and other types of) drawings of the system in ALL selected buildings.

Table 1 Examples of the environmental systems of interest in buildings

ENVIRONMENTAL SYSTEM	PRECEDENT BUILDINGS
TROMBE WALL	Zion National Park Visitor Center, Utah, US, National Park Service
	Hostel for Youth Education Institute, Germany, Thomas Herzog
	Hábitat 5 (H5) / Estudio Borrachia Arquitectos
	Nature & Environment Learning Centre, Amsterdam, Netherlands / Bureau SLA
	Kelbaugh Solar House, Princeton, US / Douglas K. Kelbaugh
DOUBLE SKIN FAÇADE	Cambridge Public Library, MA, US, William Rawn Architects
	KfW Bank Headquarters, Frankfurt, Germany, Sauerbruch Hutton
	Intesa Sanpaolo Office Building, Italy, Renzo Piano Building Workshop
	Manhattan Beach Public Library, CA, US / HED Architects
STACK VENTILATION	British High Commission, Siri Lanka, Richard Murphy Architects
	BRE Environmental Building, UK, Feilden Clegg Architect
	The Eastgate Centre, Harare, Zimbabwe, Mick Pearce Architect
INTEGRATED SHADING	Messe Basel New Hall, Switzerland, Herzog DeMuron
	Shanghai Tower, China, Kengo Kuma
EXTERNAL THERMAL MASS	Lycée Schorge, Koudougou, Burkina Faso (West Africa), Kéré Architecture
	Valletta City Gate, Malta, Renzo Piano Building Workshop
	The Broad Museum, CA, US, Diller Scofidio + Renfro
PASSIVE DOWNDRAFT COOLING[1]	The Carnegie Center for Global Ecology in Stanford, US, EHDD Architects
	The Pavilion in the Dolat Abad Garden, Yazd, Iran

Note that an alternative research subject/scope could be chosen upon consultation and approval with the instructor. An example would be to analyze the living condition of a typical apartment unit that brought more pollutant sources from work equipment in the pandemic era. This example focuses on the room-to-room and/or area-to-area flow phenomena that better be analyzed in a whole occupancy unit, instead of isolated scope in the passive systems above. Another example would be to analyze the computer lab (M321) or a similar one in that you can identify and field-measure environmental concerns.

[1] Passive downdraft cooling is not fully integrated in E+ as of now, hence, there must be research how to simulate.

B. EXISTING SYSTEM TYPOLOGY

Create a unit system typology in a set of section diagrams of a shoebox to represent the system for its dynamic workings for thermodynamics. The typology must synthetically represent the system selected per group, not per building. Consider the following.

- Commonalities: Both common and unique elements among the buildings shall be shown on the diagrams.
- Operation: Moving parts shall be included either for seasonal or hourly operations, most likely resulting in **multiple sections** for various needs.
- Room: Add a floor, a roof, and a back wall to the façade system to create a section of a hypothetical shoebox building.
- Dimension: 12 ft floor-to-floor height and 18 ft depth of the space for the section of the shoebox. The thickness of all walls and floors shall be 10 inches.

C. PERFORMANCE EVALUATION OF EXISTING SYSTEM

The existing system must be analyzed with Energy Flow Diagrams, CFD simulation, and Building Energy Simulation.

PART 2 – DESIGN A FUTURE SYSTEM

D. FUTURE SYSTEM DESIGN

Develop a forward-looking environmental system, evolving from the Existing System Type, while incorporating other environmental criteria. The future system shall aim to create a thermally comfortable and enjoyable environment as thermal factors while reducing the carbon footprint, Hyper-environmental criteria must be considered for it affects the built environment on a global scale. Choose one (or more) from each category below.

Category A. **Thermal Factors**: thermal comfort (normal and asymmetric), thermal pleasure, tactile and other sensory experiences.

Category B. **Hyper-Environmental Criteria**: COVID-19, air pollution, global warming, weather extremities.

You should be mindful of the construction trends, such as supersizing for urban densification and unitization for economical constructions. Emerging technologies can be investigated for their potential in fostering the effectiveness and efficiency of the system.

Category C. Construction trend: buildings' supersizing, construction unitization (scalability/stack-ability to varying sizes), digital design/complexity, adaptability to another climate, adaptive reuse. This interesting article talks about the façade design trend.

Category D. Emerging technology: emerging materials, sensor integration, active energy harvesting potential

Category E. As the design variable, considering passive systems is a must while introducing low-energy active systems can be considered.

E. FUTURE SYSTEM TYPOLOGY

Create a unit system typology in a set of section diagrams to represent the system for its dynamic workings for thermodynamics. The typology can be in either a shoebox or a whole living (or working) unit.

F. PERFORMANCE EVALUATION OF FUTURE SYSTEM

The new system must be analyzed with Physical Modelling/Testing along with Energy Flow Diagrams, CFD simulation, and Building Energy Simulation.

PERFORMANCE EVALUATION

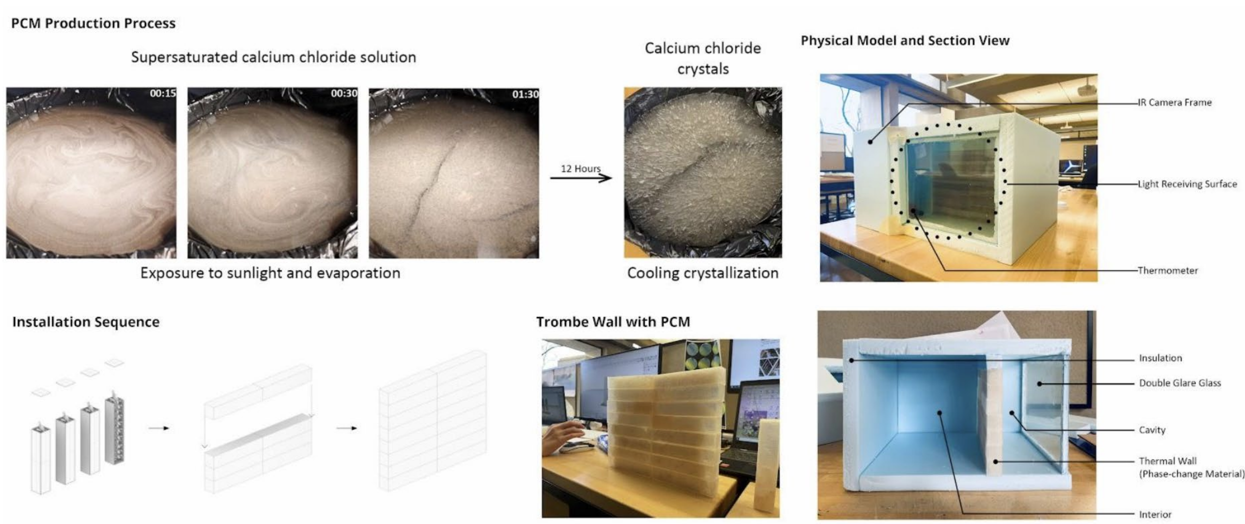
PHYSICAL MODELLING/TESTING

Physical models play significant roles in the research, including understanding the system, strategizing computer simulation, and cross-validating simulation models. As a part of the environmental system research, the student shall build a model in 3 stages: (1) Building a digital 3D model, (2) Constructing a physical 3D model, and (3) Creating a photo essay with supporting numeric data to demonstrate how the geometry and material of the system manipulate the climatic influxes in a dynamic range of sun location. Note that dissecting the environmental system from the whole building allows concentrating on its climatic effect on the associated indoor space.

For the term project, build a 1:1 scale part-of-whole key component that measures accurately the thermodynamic phenomenon. While thermography can show visual inspection, the measured numerical data must be used to validate the computer simulation.

- Choose model materials for their thermal and spectral properties.
- Borrow infrared cameras (thermography*) from the library, thermocouple/dataloggers (continuous spot measurements), and a heat lamp from the center or find them in the studio space
- Avoid unintended heat leaks by adding insulation material to openings
- Consider the kit-of-parts approach to test with and without the system of interest

*A set of thermography images in a time series must be used with a data range for visual inspection as a whole. Refer to the instruction: https://www.dropbox.com/s/6hce2ozmbi3rx9x/Instruction%20to%20change%20the%20data%20range%20through%20FLIR%20Thermal%20Studio.pdf?dl=0



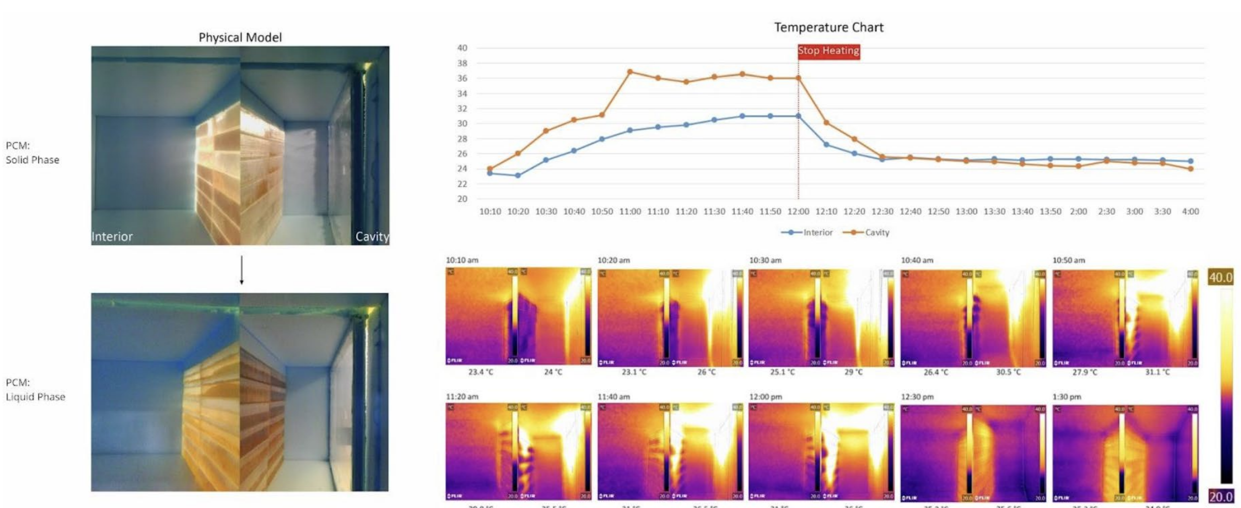


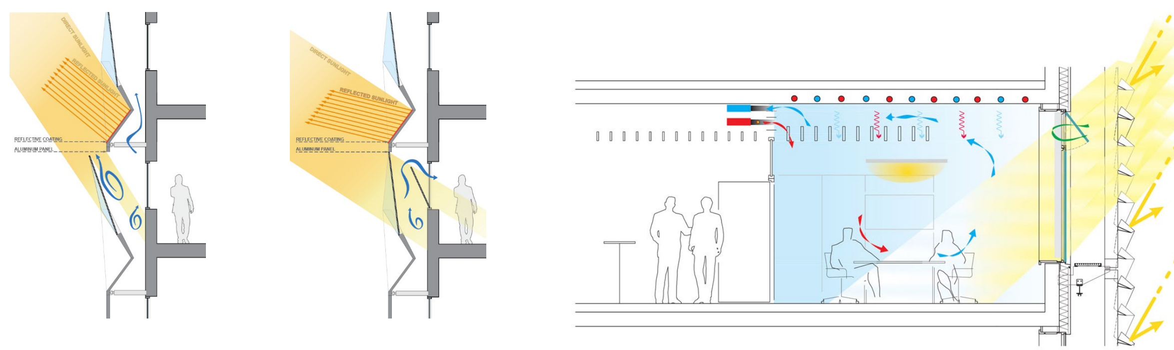
Figure 1 Phase Change Double-Skin Facade by Xiaowen Yu + Yuan Le + Yun Gao (2022 Spring)

ENERGY FLOW DIAGRAM (EFD)

The energy flow diagram (EFD) is used to quickly approximate the microclimate that a system may generate. With the solar angles for the building site, an EFD primarily shows the trajectory light travels, considering the system's geometry and material. Tracing the incident light and its reflection is the first step for energy influx on the façade moving into interior space. The second step is to approximate the absorption and transmission of light until its energy is used up and dissipates. The third step is to add ambient information, such as temperature and humidity. The collected information in an EFD allows for projecting heat transfer and airflow in the system. EFD can be useful to illustrate the various modes of system operation for the seasonal changes/occupants' needs, which also may help to strategize computer simulations.

With the section diagrams of the system typology, a set of energy flow diagrams must demonstrate seasonal energy variations.

1. Each EFD must illustrate a mode of system operation and the microclimate that it would generate for each season: summer, fall/spring, and winter.
2. The thermodynamic role of individual components shall be indicated as well as the system formation as a whole, together affecting the indoor microclimate in light, air, and heat
3. Assume the site was in Philadelphia which has a mixed climate.
4. See the instruction for energy flow diagrams at https://www.dropbox.com/s/4uaybdghiam9ok2/Energy%20flow%20diagram%20instruction.pdf?dl=0



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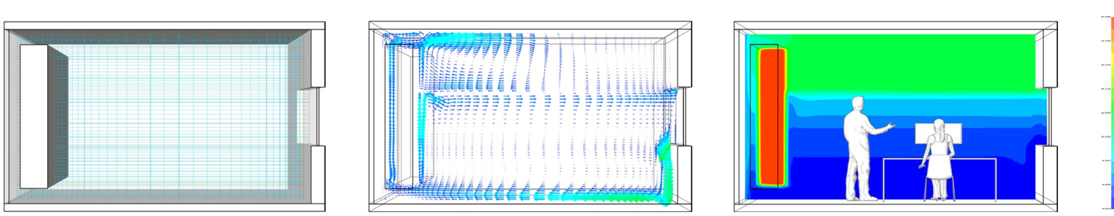
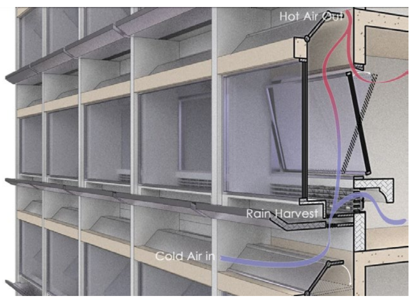
COMPUTATIONAL FLUID DYNAMICS (CFD)

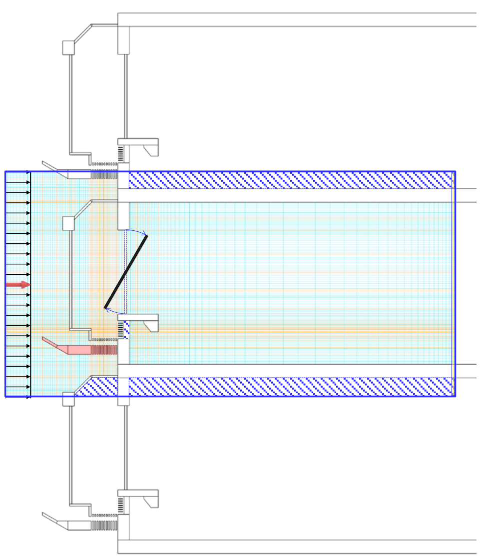
To assess the effectiveness of an environmental system, computational fluid dynamics (CFD) is adopted for its analytic capacities in a wide range of thermodynamic problems. The intensity and distribution of heat and airflow are the main elements of interest to analyze inhomogeneous thermal environments and their asymmetrical impacts on thermal comfort. The simulation results are used to test design ideas and to make informed decisions in design development. Apart from providing proper boundary conditions, a key to successful CFD simulation is to establish a computational grid and relaxation strategy that would be suitable for a specific problem. Resources: 1) General, 2) RhinoCFD

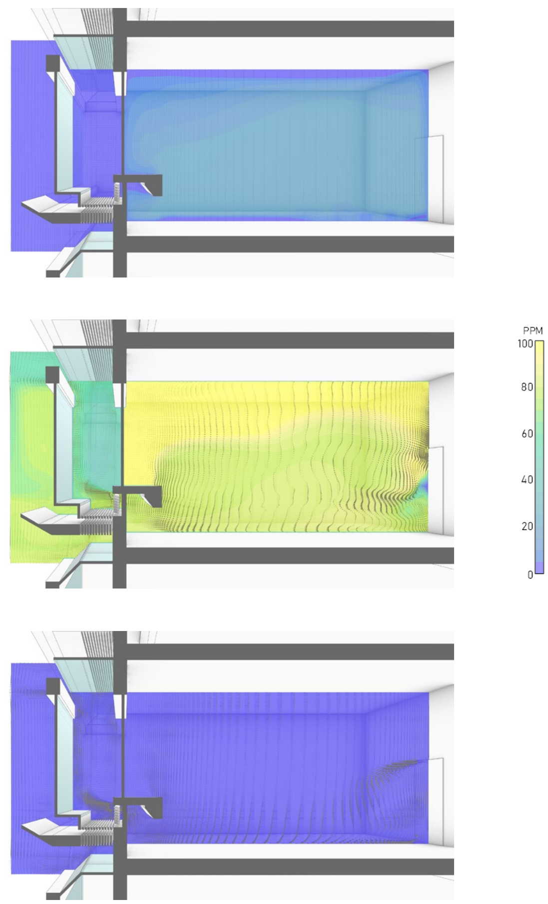


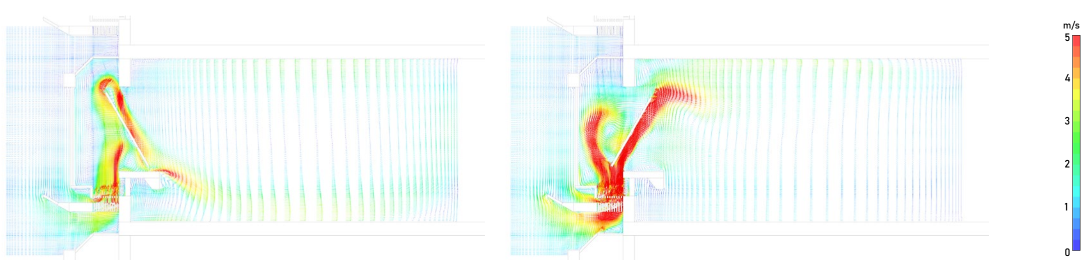
In the term project, the technical focus is to create a simulation environment to effectively assess the energy flow of the system of interest. Before you proceed to create CFD models, confirm that you had created 1) diverse configurations of the system to meet seasonal and/or hourly needs, conforming to the EFDs; 2) performance goals with the **thermal factors** and **hyper-environmental criteria.** CFD settings must be created based on the prior learnings of the course while deciding

1. the number of thermal zones
2. the extent of the domain
3. the selection of heat sources and sinks for ambient and focus areas
4. the proper boundary conditions for the weather
5. to preheat objects, especially thermal mass objects in winter.
6. the proper level of abstraction of the objects in the model
7. the mesh resolution, and the time setting for effective and economic assessment









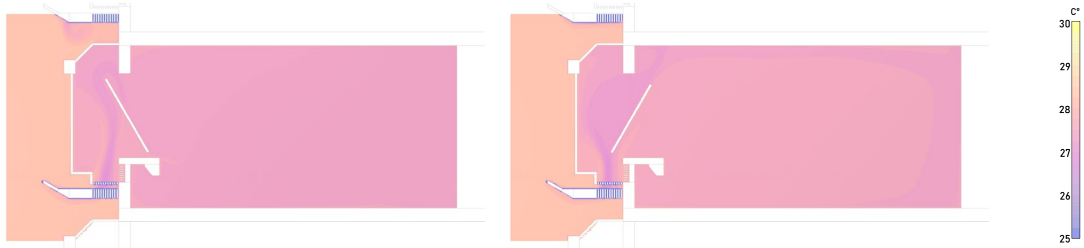
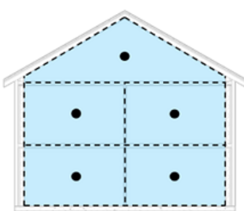


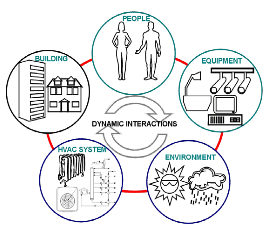
Figure 2 Dual-Zone Continuous 2-Dimensional (DC2D) CFD was applied to a façade system of a building with the ambient air temperature of 28 C° and 1 m/s headwind in 24 C°; CO as pollutants were modeled at the entire room for the first 10 minutes, testing the effectiveness of the natural ventilation over 1 hour period © Jun Xiao, Summer 2021 in ARCH 754 Performance Design Workshop at UPenn

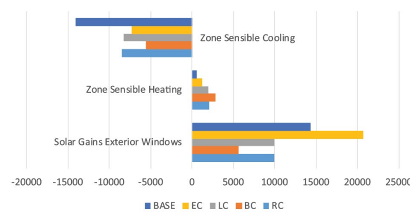
BUILDING ENERGY SIMULATION (BES)

The carbon footprint of an environmental system is evaluated with building energy simulation (BES). Both the adjacent indoor spaces and the whole building can be analyzed under the thermodynamics of the system. In a BES model, a comprehensive set of building information is considered, such as construction systems, occupancy, equipment, and HVAC system. Using a wide range of climate variables, the system is evaluated for light, heat, and airflow for the entire year, acquiring its energy use, thermal comfort, and emission of greenhouse gasses.

Resources: 1) General 2) DesignBuilder







Evaluate the existing system, future system, and bare base case without the adopted system by using DesignBuilder for the following: a) Annual source EUI; b) Yearly fuel breakdown; c) The operative temperature of the summer and winter typical week; d) Other data types if helpful to explain the performance of the system of simulation results. Include EUI benchmark data for the ballpark accuracy of the base case option, such as Building Performance Database, EnergyStar, or similar; e) a summary of the design variables of your choices and their impact on the metrics, especially with the solar heat gain and its interaction with the design elements toward the greenhouse effect; f) Model view: Add a Render View with shadows for each design variant.

BES Checklist!

Modeling assumptions:

- What are the differences among the variants that can be quantified with BES?
- What is the plan to model the dynamic operations of the system in each variant?
- Is your model simple enough to get the answer economically, especially considering a shoebox as opposed to a whole building?
- How would you set the assumptions above in the simulation program (DesignBuilder)?

Setting up a model:

- Is the adjacency setting properly respond to your modeling assumption if you are using a shoebox?
- Do the schedules for openings (windows and vents) coincide with the thermal strategies for different seasons, such as closing windows to stop heat loss in the winter while opening them to bring in comfortable spring wind?

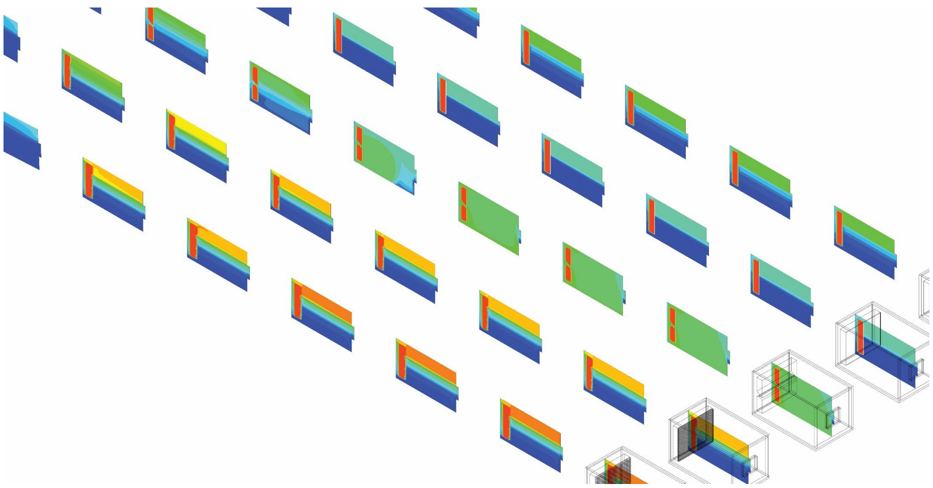
Simulation result analyses:

- Are the EUIs from simulation results within the ballpark accuracy compared to the existing data?

- Are the differences between the two results reasonable to the initial guesses and simulation settings?
- How would you visualize and analyze effectively by using charts and model views?

PERFORMANCE REPRESENTATION

The workshop's research deals with the subjects of time, space, and thermodynamics. Climatic variables change over time, as they are subject to human needs, architectural conditions, and technology. Such complex information makes communication challenging and students must define a coherent strategy for representational graphics. The type of representation may include exploded diagrams, a set of evolutionary/time-lapse images, and videos, among other methods. The example below shows the design studies with temperature changes over time (time-lapse) in an exploded axonometric diagram.



With CFD simulation results, consider

1. choosing the most appropriate visualization techniques, such as animation, series of images in sequence, vector, and color map.
2. using different color schemes for different climatic variables, such as a rainbow for airflow, a heat map for temperature, and blue/yellow for pollutants.
3. the hierarch of information to be evident in the visualization
4. all information on a page must be legible without having to zoom in.
5. writing the summary and adding graphic objects to highlight the key learning points.