CAE 465/526 Building Energy Conservation Technologies

Fall 2023

September 7, 2023

Intro to building energy modeling

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ANNOUNCEMENTS

Announcement

- Assignment 1 is due tonight (you can submit it by tomorrow if you need more time)

- IPRO students will present their workflow and also a few CAE 526 should plan to briefly talk about their approaches and challenges

Announcement

- Do you have any comments about the training recordings?

Announcement

- Regularly check out the Q&A file:

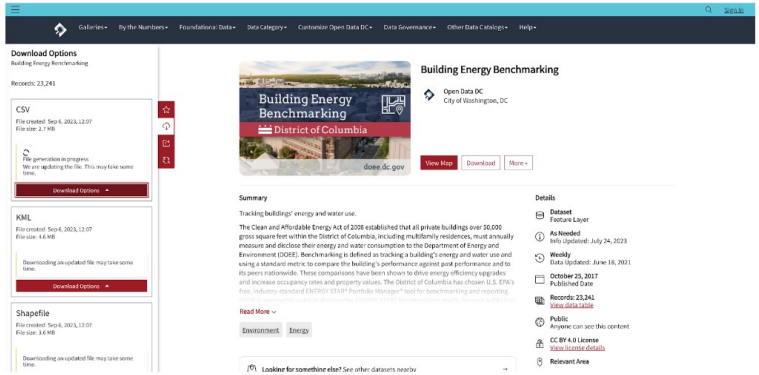
CAE 465/526 Fall 2023 Q&As

Assignment 1

Question: I am trying to do the assignment for 526 Energy conservation Buildings but I can´t find any website that I can download the data from it that it´s not Chicago. I´m looking in the links that you gave us in the statement sheet but I can´t find any.

Response: There are several cities that the data is easily accessible.

DC:



(https://opendata.dc.gov/datasets/DCGIS::building-energy-benchmarking/about)

Click on the Download button and then on the right hand side you can pick the format (it may take a few seconds or up to a minute for data to be generated).

https://docs.google.com/document/d/1Z1gcaVK3XlCq4EuVr9dm-KPQY9ws7rnXbUycBxOQ940/edit#heading=h.7xv0zdhfny5a

Announcement

- Assignment 2 will be posted later today (due next Friday)

INTRO TO THE WHOLE BUILDING ENERGY MODELING

Intro to Building Energy Simulation

- What's building energy modeling?

Intro to Building Energy Simulation

- What's building energy modeling?

Intro to Building Energy Simulation

- What are the benefits of using building energy modeling?
  - Simulate accurate hourly simulation results with load calculations for each thermal zone
  - Enable modification of the energy model to predict future changes in the building
  - …

Intro to Building Energy Simulation

- What are the challenges of using building energy modeling?
  - Require an expert to create energy models
  - Require access to detailed mechanical drawings and detailed information to prepare the energy models
  - Require careful consideration for the campus buildings to meet the building energy use pattern
  - …

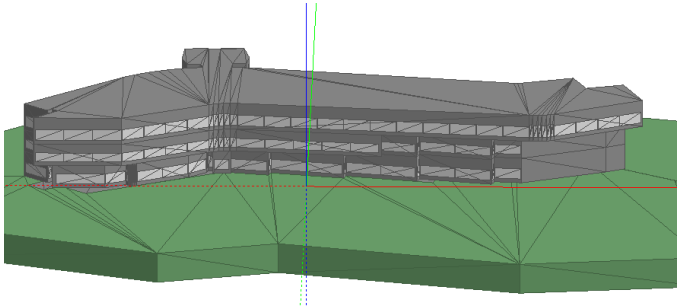
Intro to Building Energy Simulation

- Design requirements based on ASHRAE 90.1 requires a simulation software that is capable of
  - A minimum of 1400 hours per year
  - Hourly variations in occupancy, lighting power, miscellaneous equipment power, thermostat setpoints, and HVAC system operation, defined separately for each day of the week and holidays
  - Thermal mass effects
  - Ten or more thermal zones
  - Part-load performance curves for mechanical equipment Capacity and efficiency correction curves for mechanical heating and cooling equipment
    Air-side and water-side economizers with integrated control
    The budget building design characteristics specified in Section 11.4.5

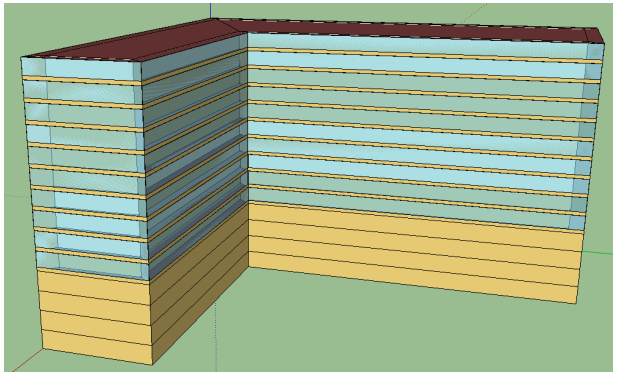
ASHRAE 90.1 2013

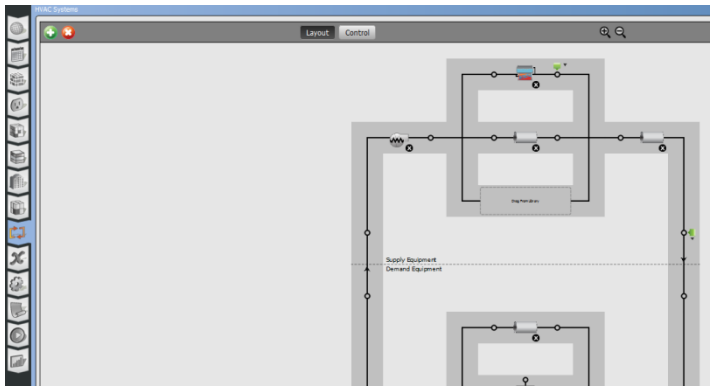
Intro to Building Energy Simulation

- Examples of the energy simulation tools:
  - EnergyPlus (text-based energy simulation tools sponsored with DOE).
  - DesignBuilder (A commercial interface for EnergyPlus):



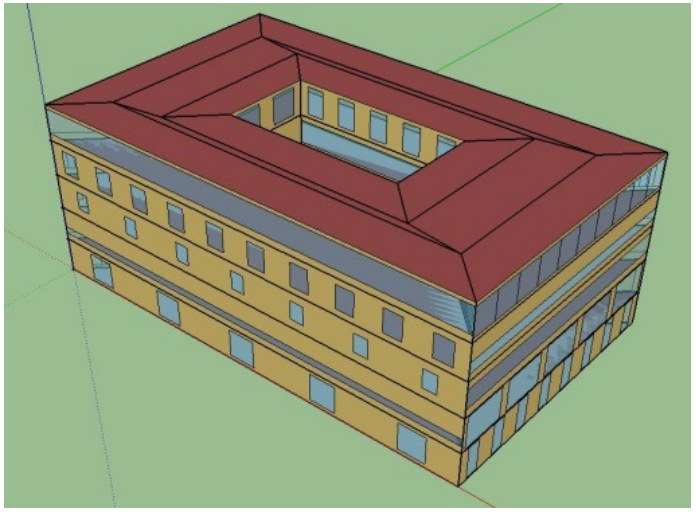
- OpenStudio (middleware of simulation tools including EnergyPlus):

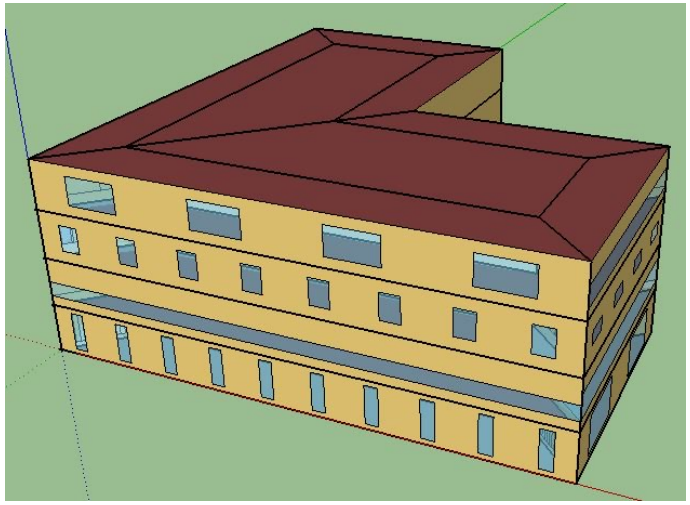


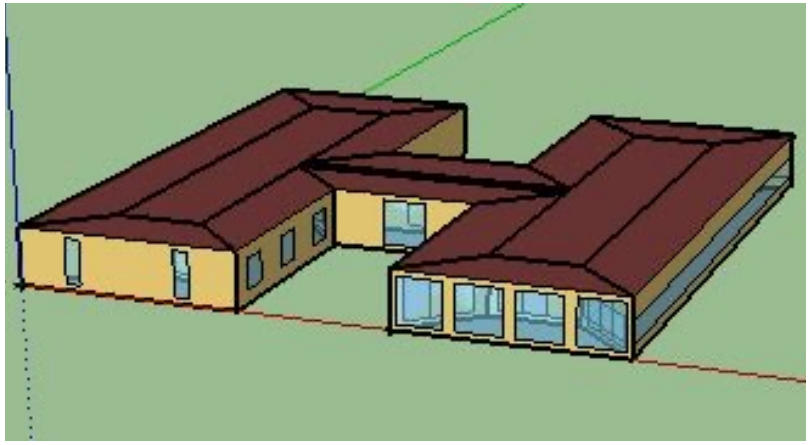


Intro to Building Energy Simulation

- Complex building energy models (geometry)



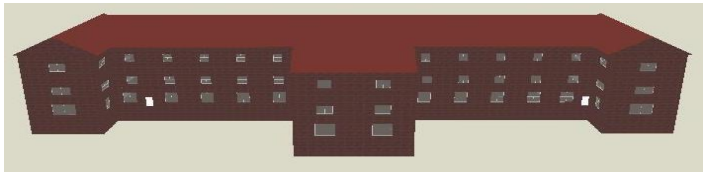




Heidarinejad et al. 2017

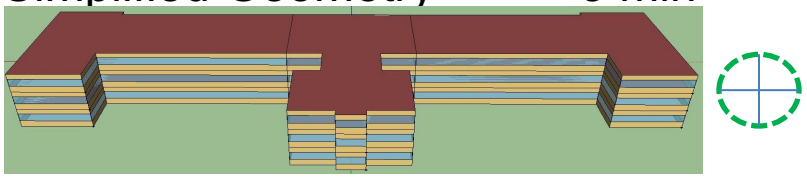
Intro to Building Energy Simulation

Detailed 15 min

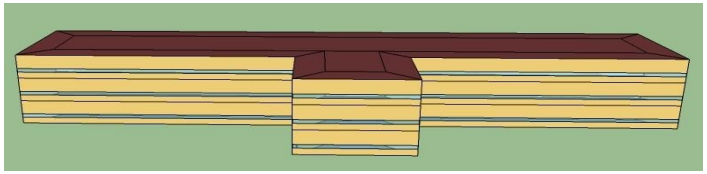


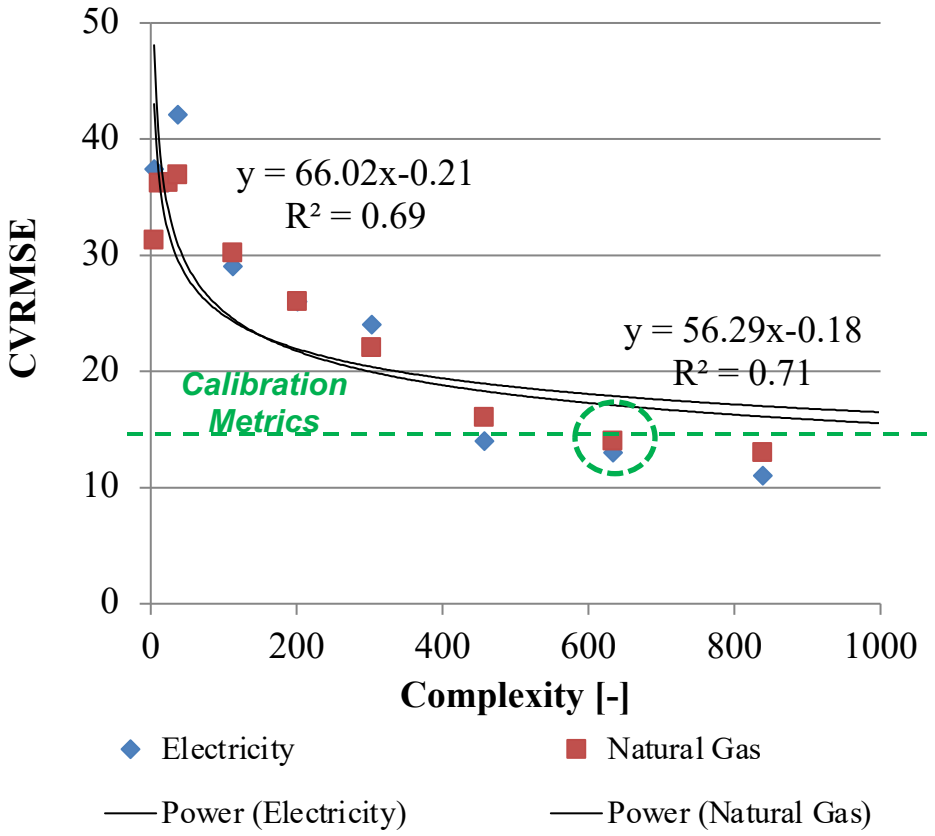
Simplified Thermal 7

Simplified Geometry 5 min



Reduced-Order Model 2 min





CVRSME = Coefficient of Variation Root Mean Square Error

Intro to Building Energy Simulation

- What do we need to create an an accurate building energy model?

Intro to Building Energy Simulation

- Couple of key variables that are needed for a careful energy modeling:
  - **Internal loads & Operation schedules:** Most of the buildings are internally-load dominated or mixed-used buildings (e.g., lab-mixes or classroom/office)

Intro to Building Energy Simulation

- Couple of key variables that are needed for a careful energy modeling:
  - **Occupancy:** Due to the mixed-used space type for a significant number of buildings, the occupancy patterns may not follow the typical occupancy schedules in the energy simulation tools

Intro to Building Energy Simulation

- Couple of key variables that are needed for a careful energy modeling:
  - **HVAC system and associated inputs:** Because buildings may have different HVAC systems, it is important to have the correct HVAC system

Intro to Building Energy Simulation

- Couple of key variables that are needed for a careful energy modeling:
  - **Building Enclosure:** It may require hand calculations before implementing the correct inputs into the energy models

Intro to Building Energy Simulation

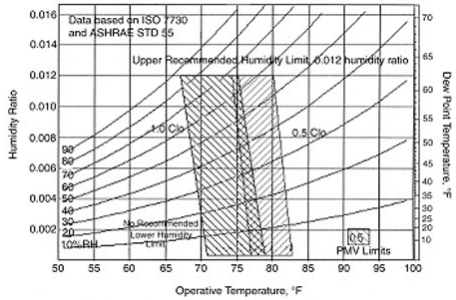
Ease of Collection	Variability	Impact on Energy Use	Variable Type	Examples	Inferable for Simple	Inferable for Advanced	Inferable for Beyond Advanced
Easy	Low	Low	A1	Floor plate type		X	X
Easy	Low	Medium	A1			X	X
Easy	Low	High	A1			X	X
Easy	Medium	Low	A1			X	X
Easy	Medium	Medium	S1	Floor area	X		
Easy	Medium	High	S1	Building vintage	X	X	X
Easy	High	Low	S1	Wall type	X	X	X
Easy	High	Medium	S1	Lighting type	X	X	X
Easy	High	High	S1		X	X	X
Moderate	Low	Medium	A2	Insulation thickness			
Moderate	Low	High	A2	Window solar heat		X	X
Moderate	Medium	Medium	A2	gain coefficient		X	X
Moderate	Medium	High	S2	Shading dimension	X		
Moderate	High	Medium	S2	HVAC efficiency	X	X	X
Moderate	High	High	S2		X	X	X
Moderate	Low	Low	A3	Wall insulation			
Moderate	Medium	Low	A3	thickness		X	X
Moderate	High	Low	A3	Service hot water efficiency		X	X
Difficult	Low	Low	BA1	Fan blade			
Difficult	Low	Medium	BA1	efficiencies			X
Difficult	Low	High	BA1				X
Difficult	Medium	Low	BA1				X
Difficult	High	Low	BA1				X
Difficult	Medium	Medium	BA2	Air infiltration rates			
Difficult	Medium	High	BA2	Wall insulation R-			X
Difficult	High	Medium	BA2	value			X
Difficult	High	High	BA2				X

(a) S = simple level (minimum required set of user inputs).
(b) A = advanced level (minimum required set of user inputs for an advanced score).
(c) BA = beyond advanced level (additional user inputs for more accurate results).

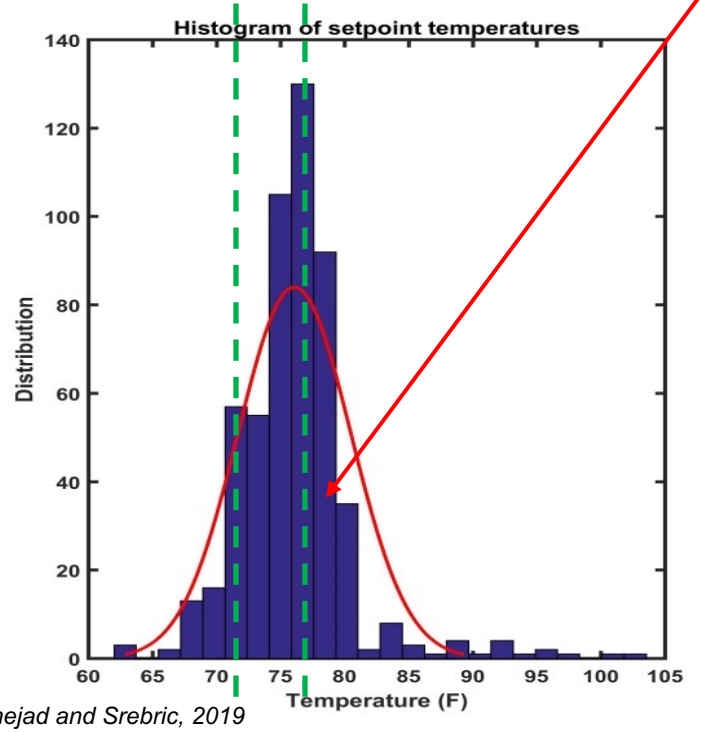
Intro to Building Energy Simulation

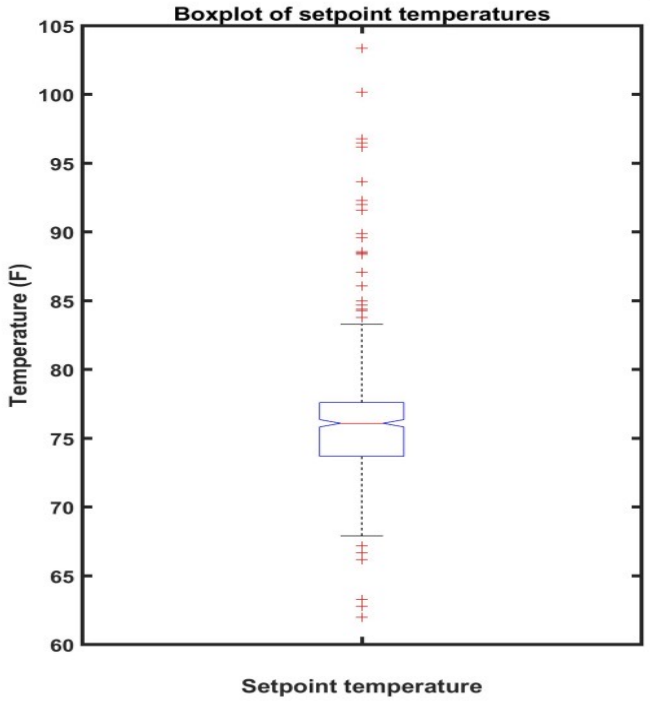
- Internal loads & Operation schedules:

Thermal comfort range



Address complaints

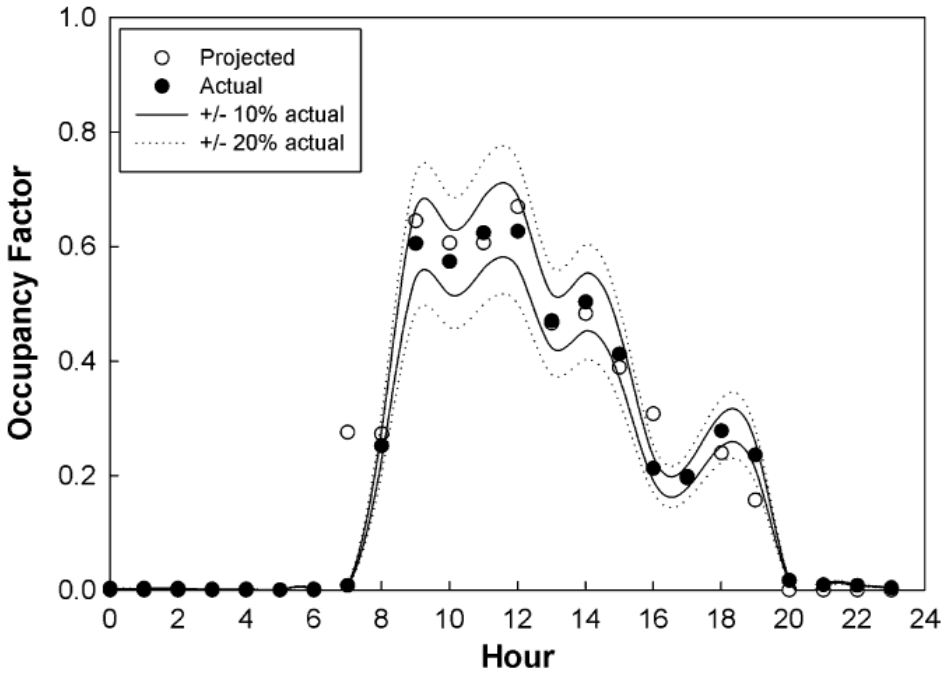




Heidarinejad and Srebric, 2019

Intro to Building Energy Simulation

- Occupancy schedules
  - Careful consideration for are needed to provide occupancy rate of the buildings:
    - Combination of different space types, rendering the campus buildings unique in terms of the occupancy rate
    - Does not follow the typical occupancy rates recommended in the energy simulation programs

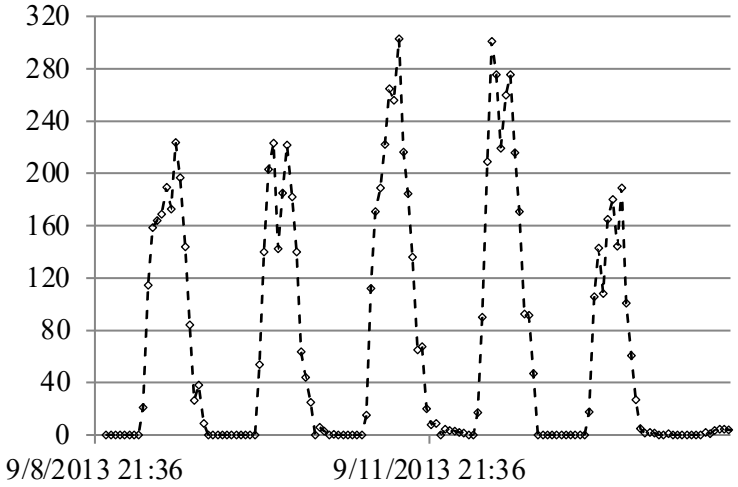


Davis III, J.A. and Nutter D.W. 2010

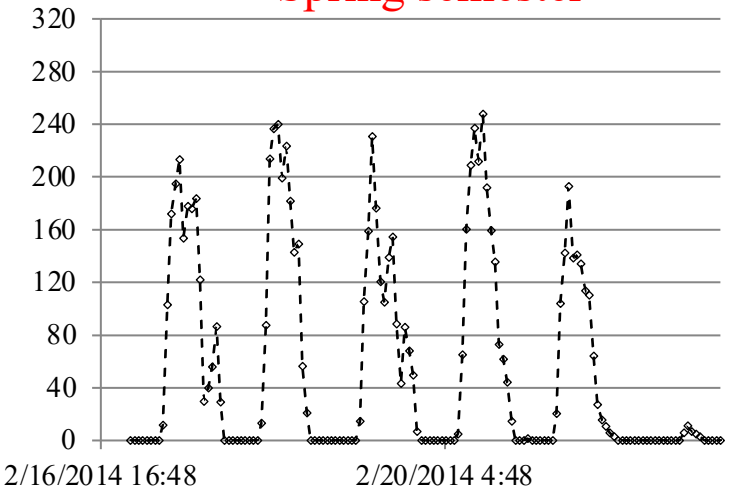
Intro to Building Energy Simulation

- Occupancy schedules

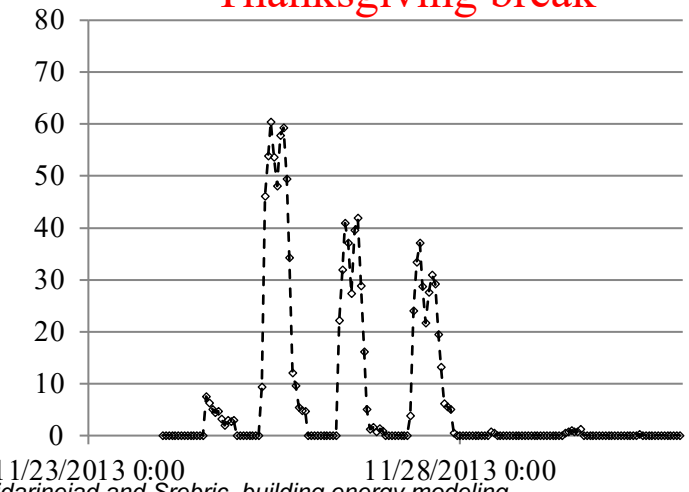
Fall semester



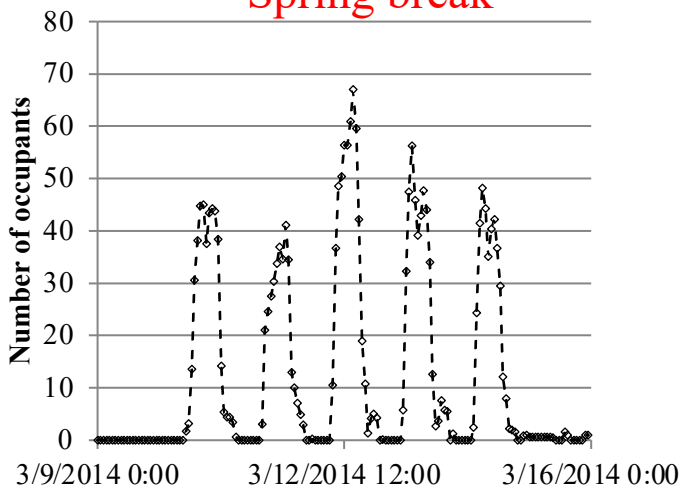
Spring semester



Thanksgiving break



Spring break



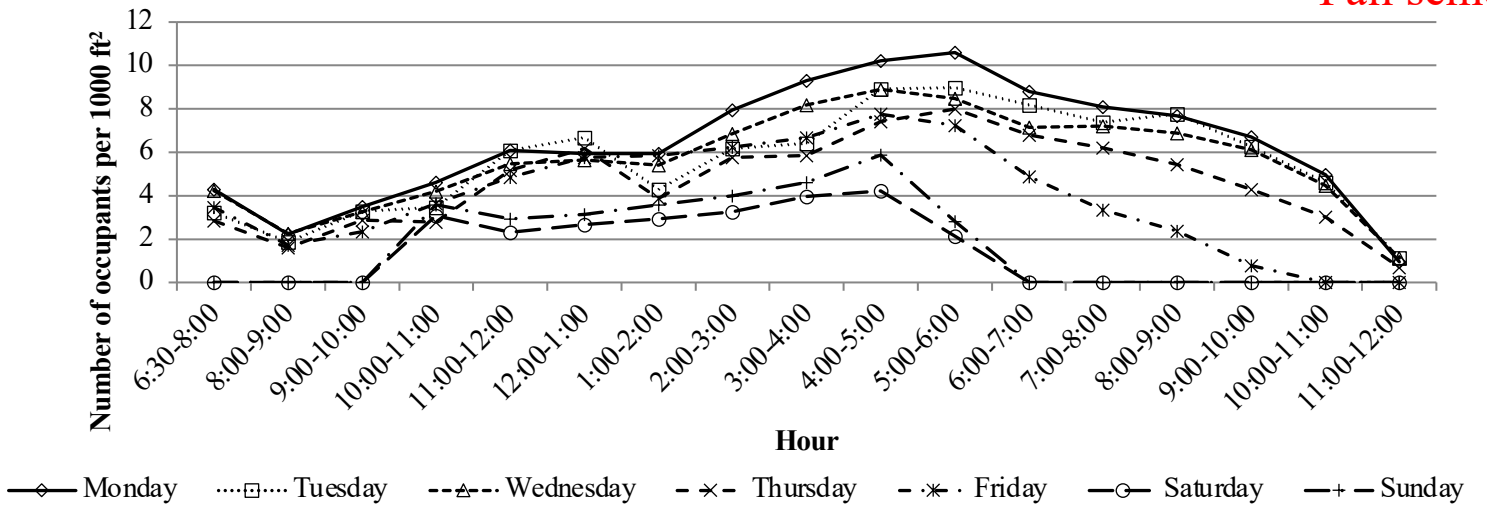
Intro to Building Energy Simulation

- Occupancy schedules
  - Beyond installation of fairly expensive occupancy sensors at the entrance and exit of buildings is to benefit from the existing infrastructures at the buildings:
    - Appliance using WiFi or desktop computers connect to the network through their IP address
    - Swipe access card readers for a building or space
    - Class schedules and FTE operation hours
    - CO_2 sensors for the demand control systems

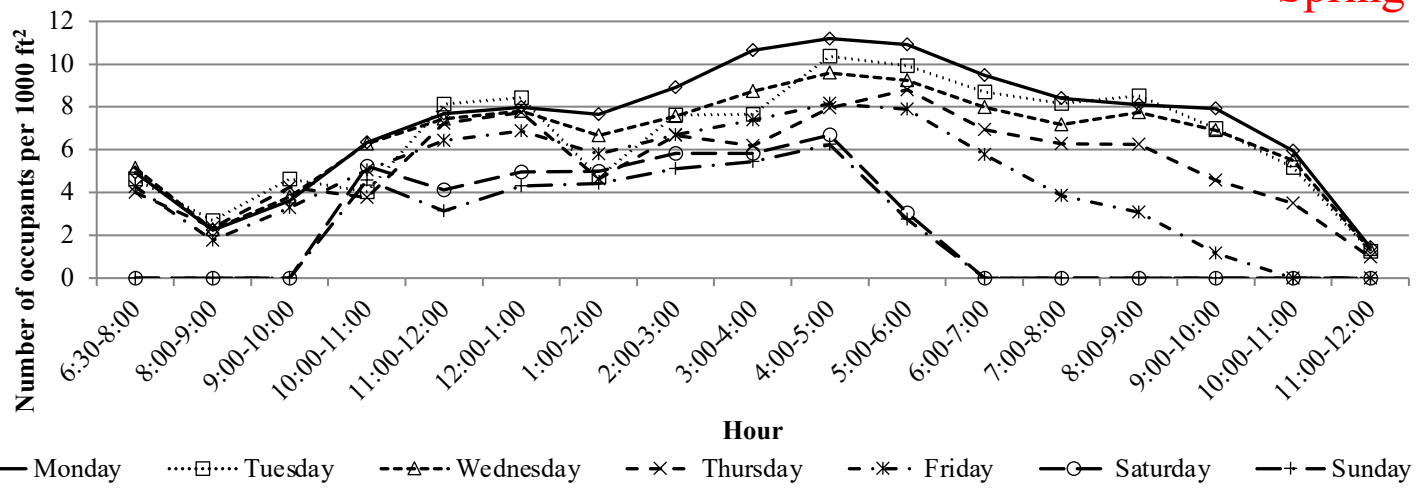
Intro to Building Energy Simulation

- Occupancy schedules

Fall semester



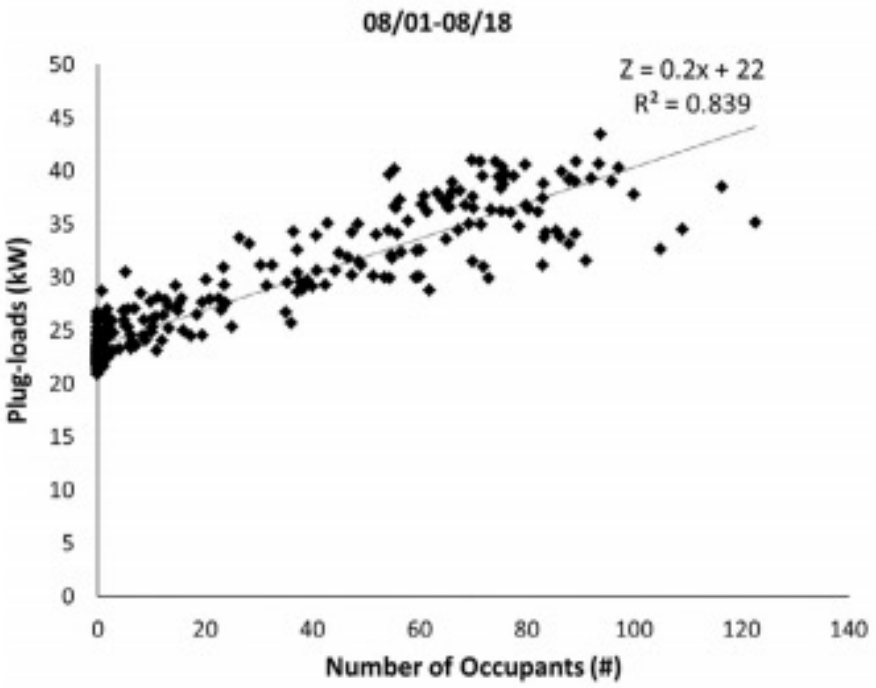
Spring semester

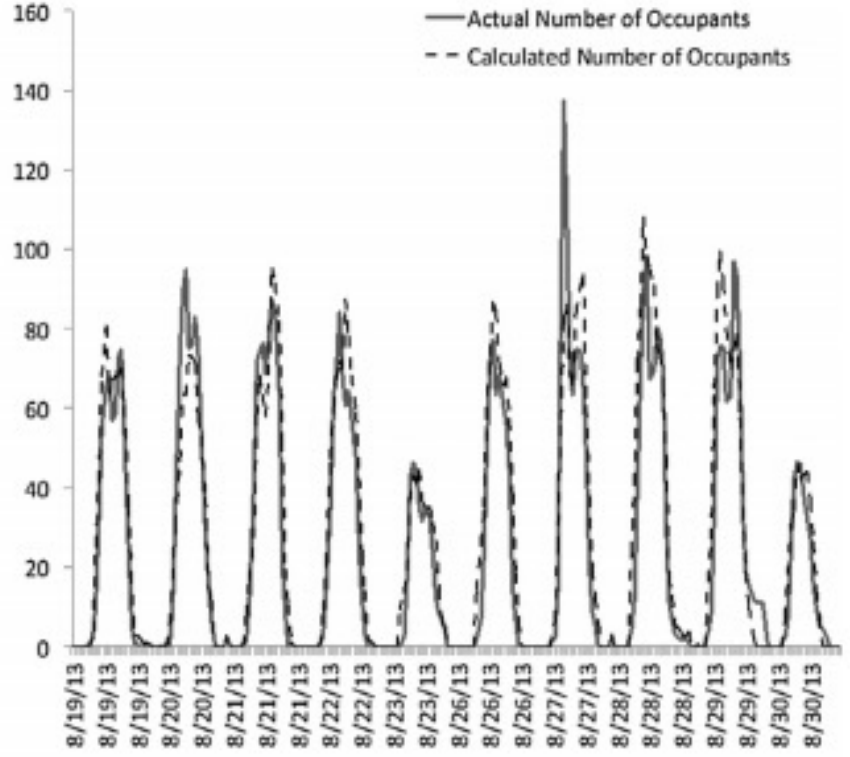


Heidarinejad and Srebric, building energy modeling

Intro to Building Energy Simulation

- Internal loads & Operation schedules:
  - ❑ Plug load and electricity is linearly correlated with the building occupancy

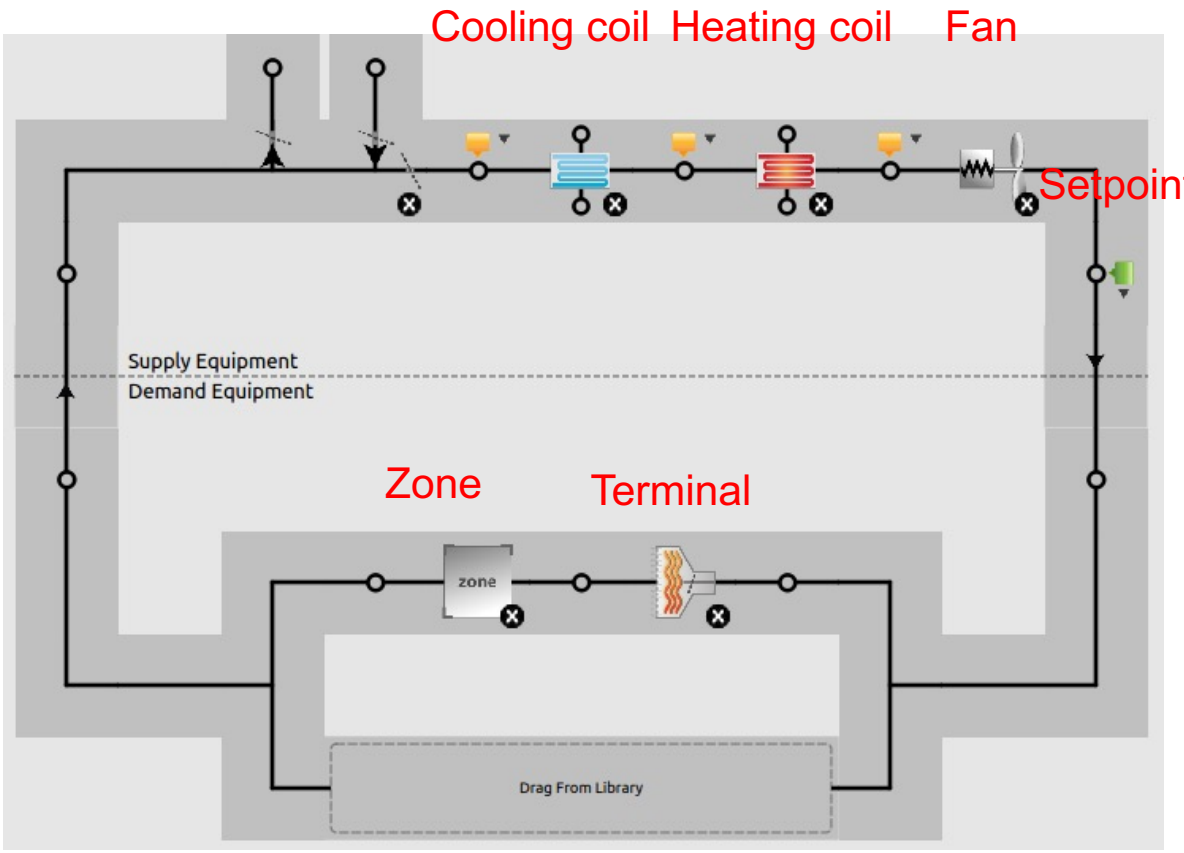




Kim et al. 2017

Intro to Building Energy Simulation

- HVAC system and associated inputs (e.g., an air loop)
  - Cooling coil
  - Heating coil
  - Fan
  - Setpoint manager
  - Zone
  - Terminal



Intro to Building Energy Simulation

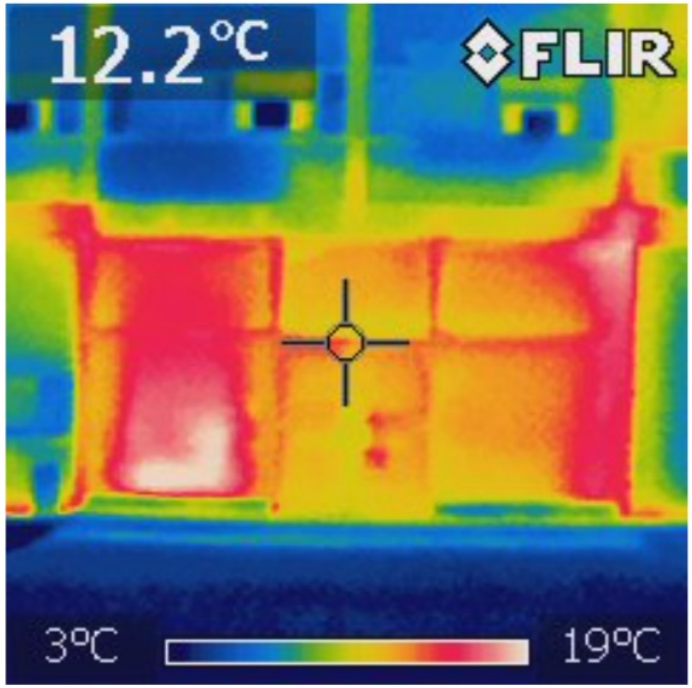
- HVAC system and associated inputs (e.g., an air loop)

Intro to Building Energy Simulation

- HVAC system and associated inputs (e.g., an air loop)

Intro to Building Energy Simulation

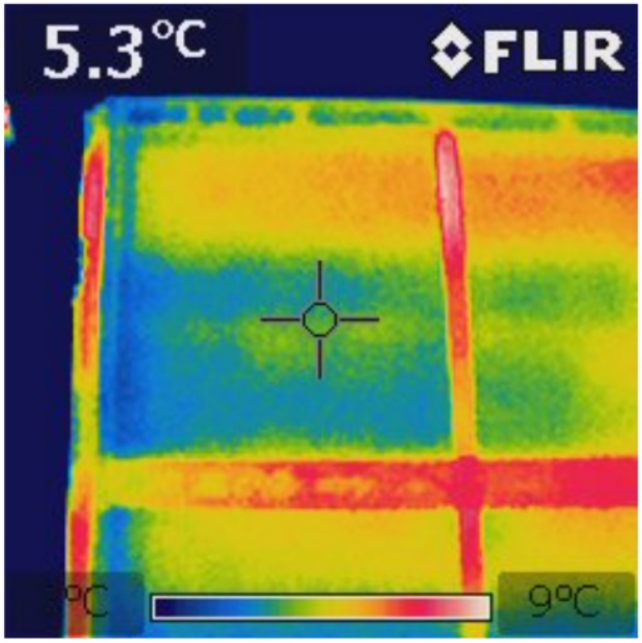
- Building Enclosure



Intro to Building Energy Simulation

- Building Enclosure

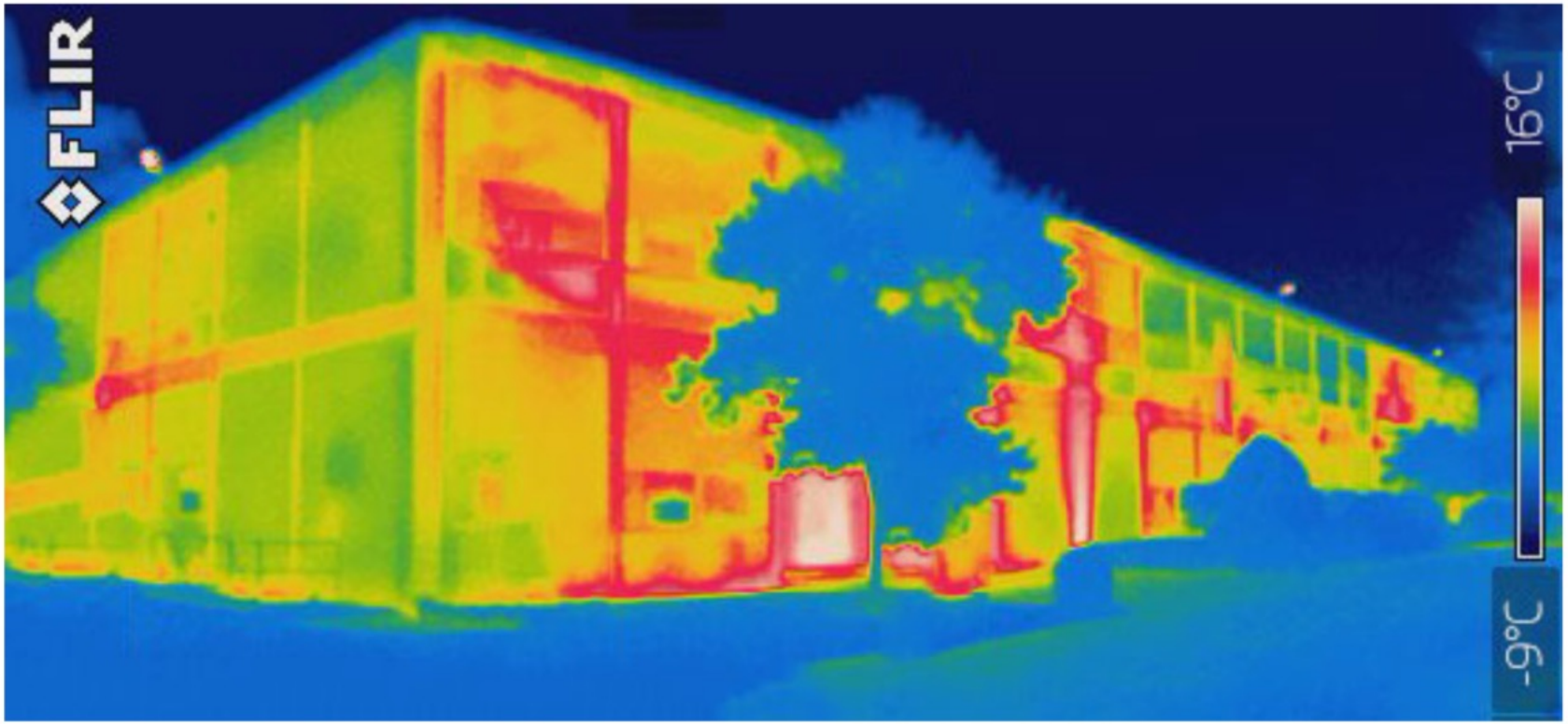
41.5 F



Intro to Building Energy Simulation

- Building Enclosure

60.8 F



15.8 F

Intro to Building Energy Simulation

- Building Enclosure (e.g., insulating the enclosure)

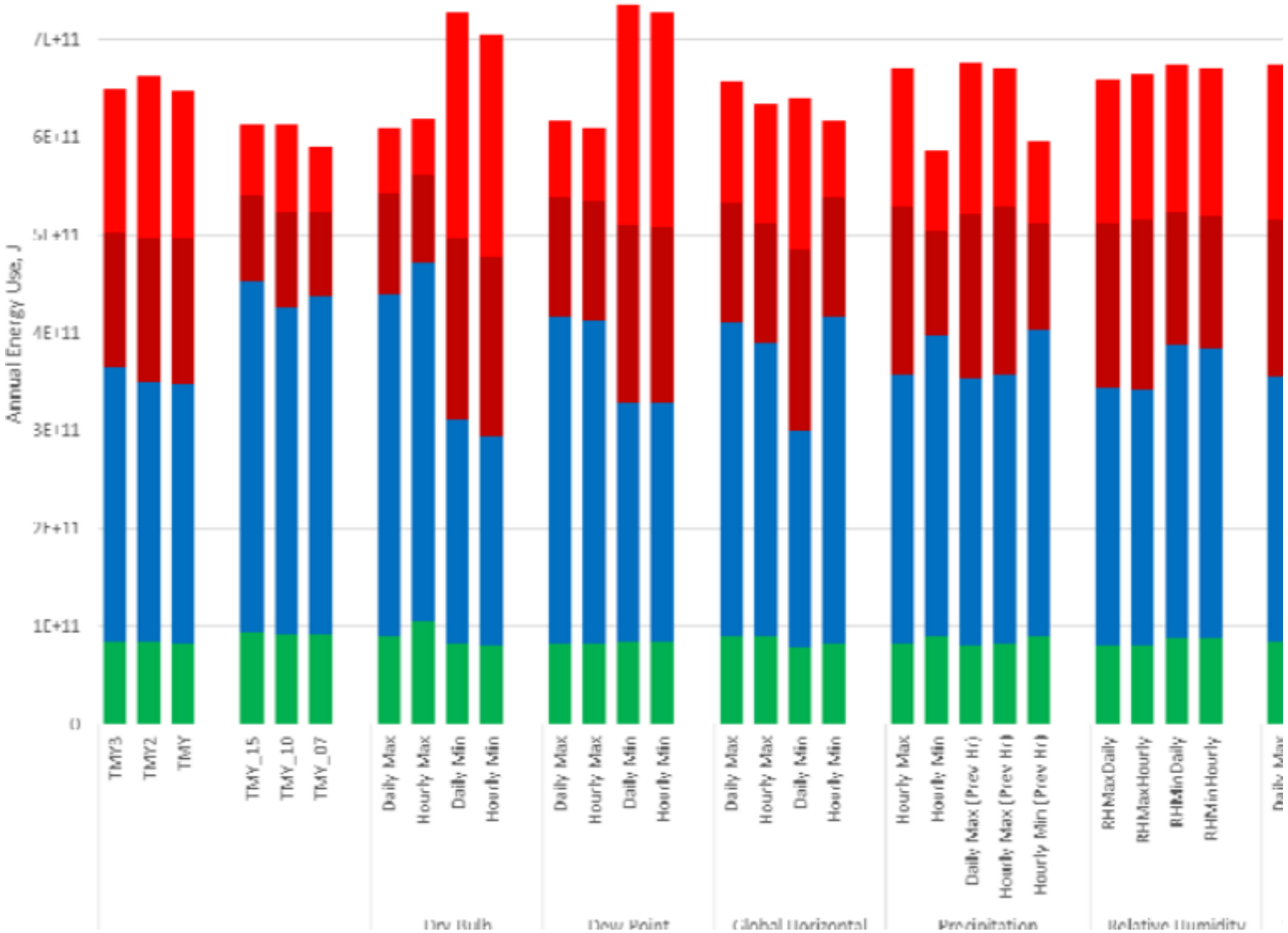
Brick layer: 4” thick, R-0.6 (IP)
Fiberglass insulation and studs: 6” thick, R-21.3 (IP)
Wood studs: 6” thick, R-6.5 (IP)
Gypsum board: 0.5” thick, R-0.4 (IP)

WEATHER DATA

Weather Data

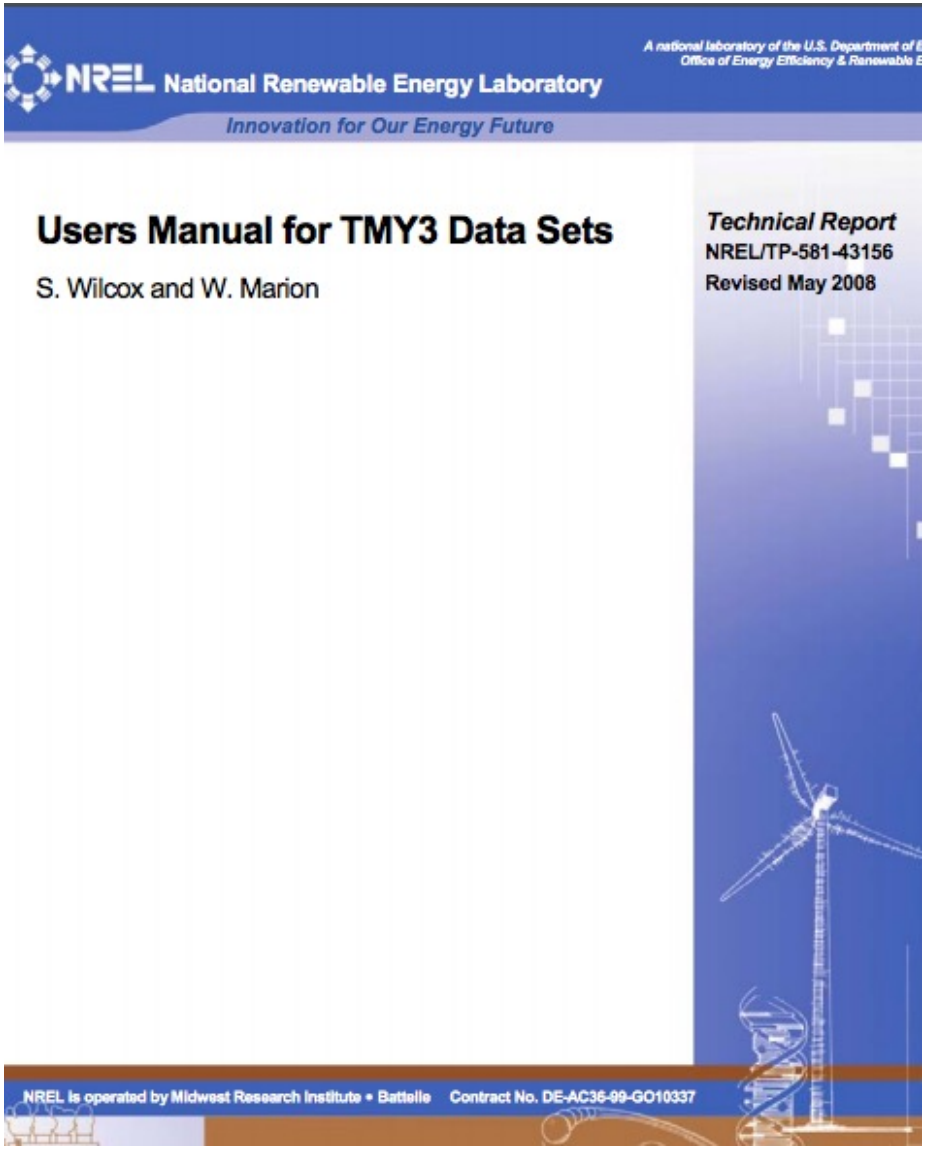
- What is the best option for the selection of a weather data type?
  - ❑ Actual Meteorological Year (AMY)
  - ❑ Typical Meteorological Year (TMY)
  - ❑ eXtreme Meteorological Year (XMY)
  - ❑ Future Typical Meteorological Year (fTMY)

Weather Data



http://www.ibpsa.org/proceedings/BS2015/p2707.pdf

Weather Data



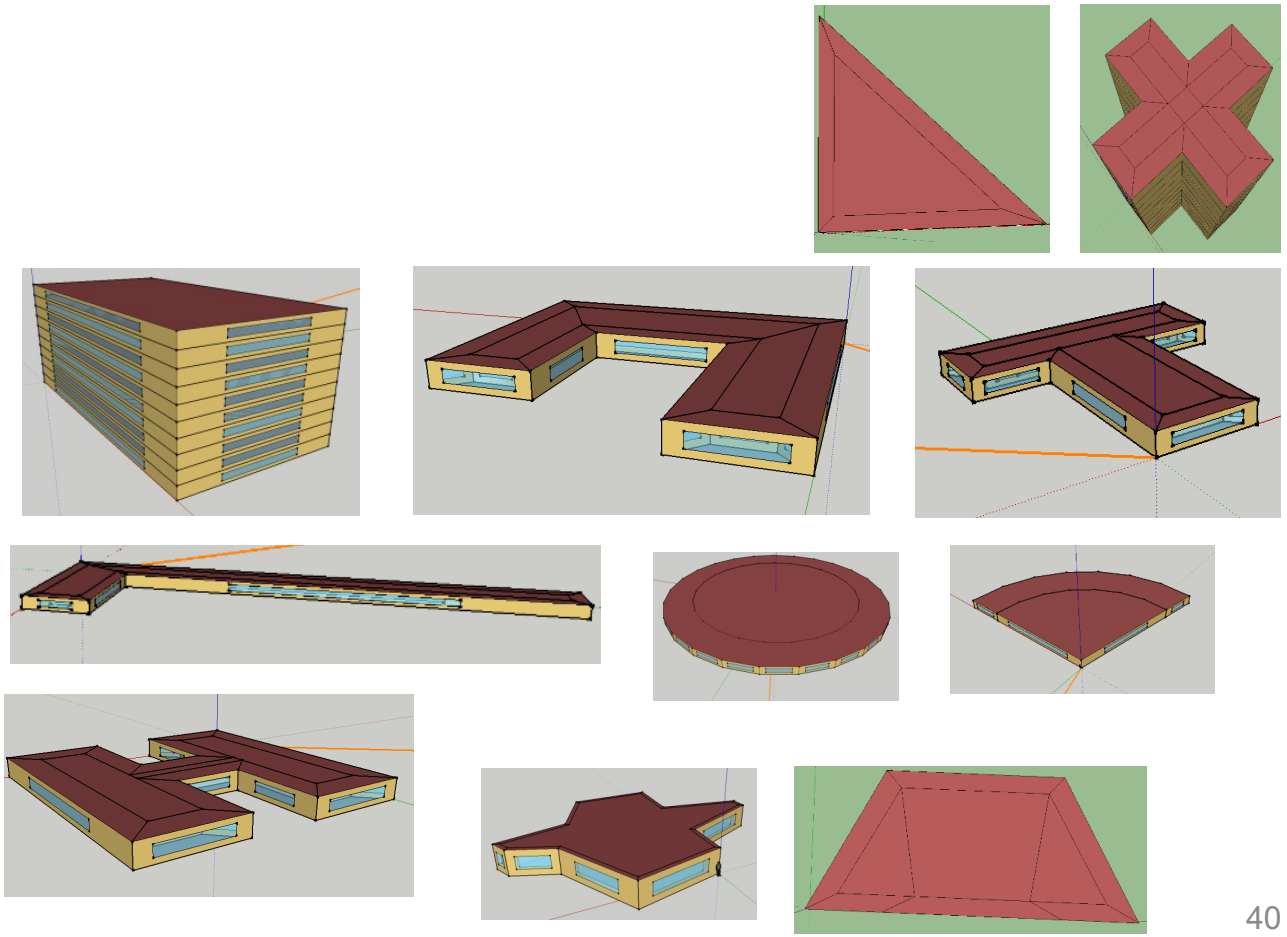
https://www.nrel.gov/docs/fy08osti/43156.pdf

BUILDING SHAPES

Building Shapes

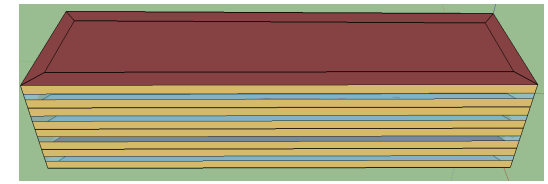
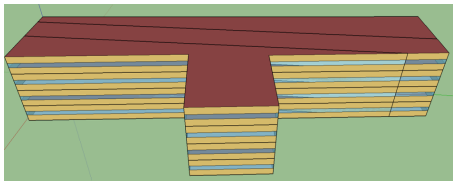
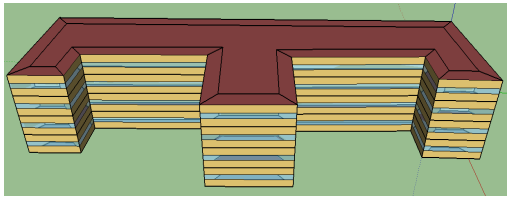
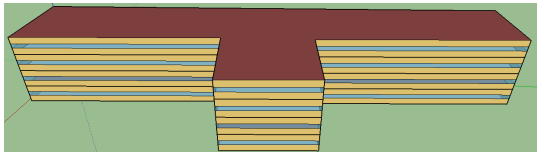
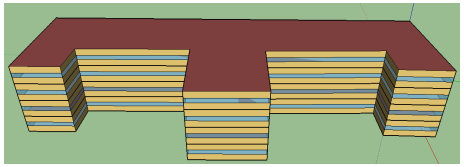
- Building geometry is an important part of the building energy modeling that may take a large portion of the building energy modeler's time. Typical building shapes are:

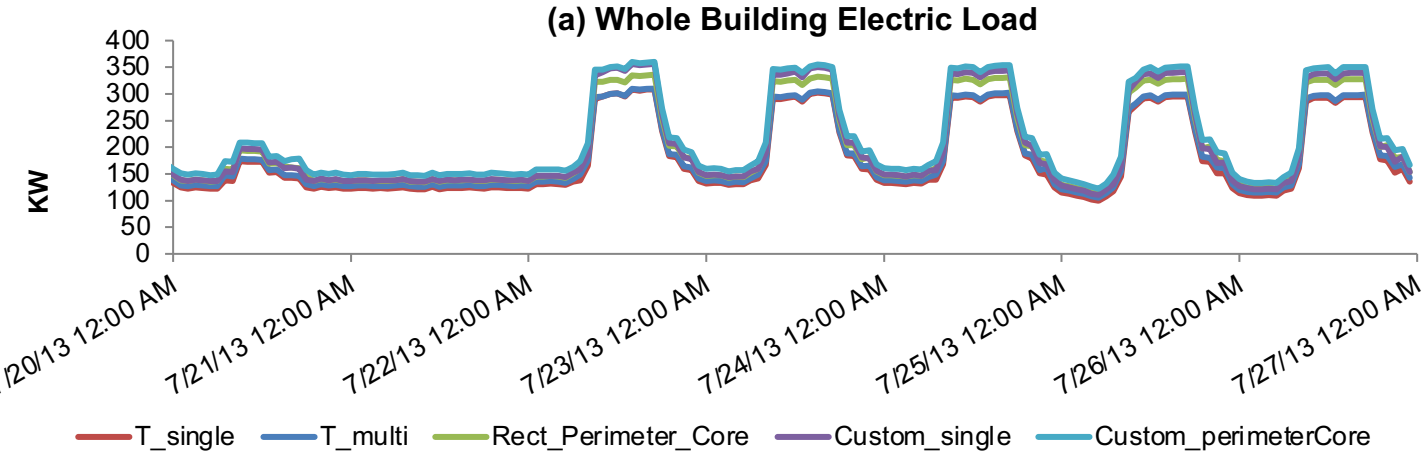
  - Courtyard
  - Cross
  - Pie
  - Convex polygon
  - Rectangle
  - Trapezoid
  - Triangle
  - Square cutout
  - H
  - L
  - S
  - T
  - U
  - M



Heidarinejad et al. 2017

Building Shapes

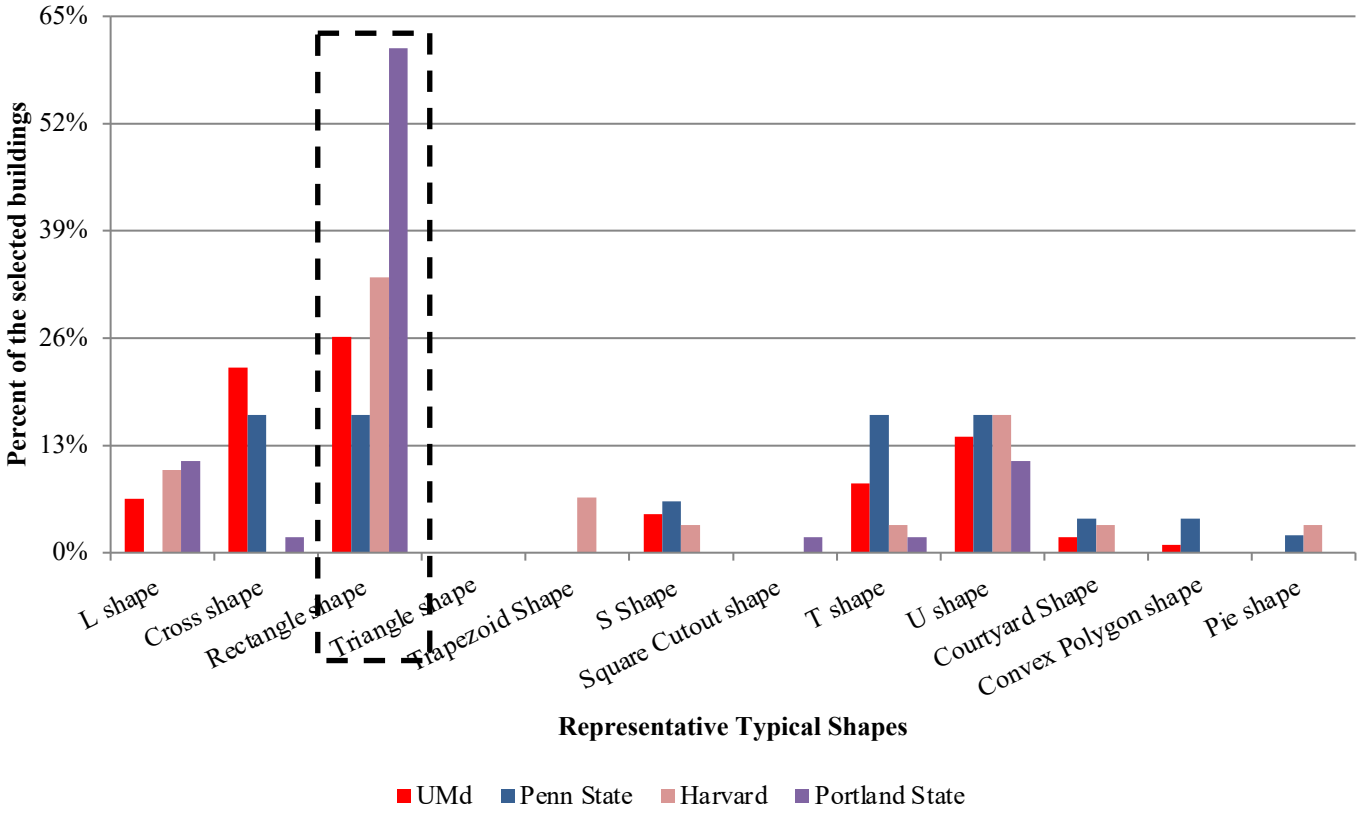


Heidarinejad et al. 2017

Building Shapes

- # of buildings:
  - UMd = 108
  - Penn State = 48
  - Harvard = 30
  - Portland State = 52

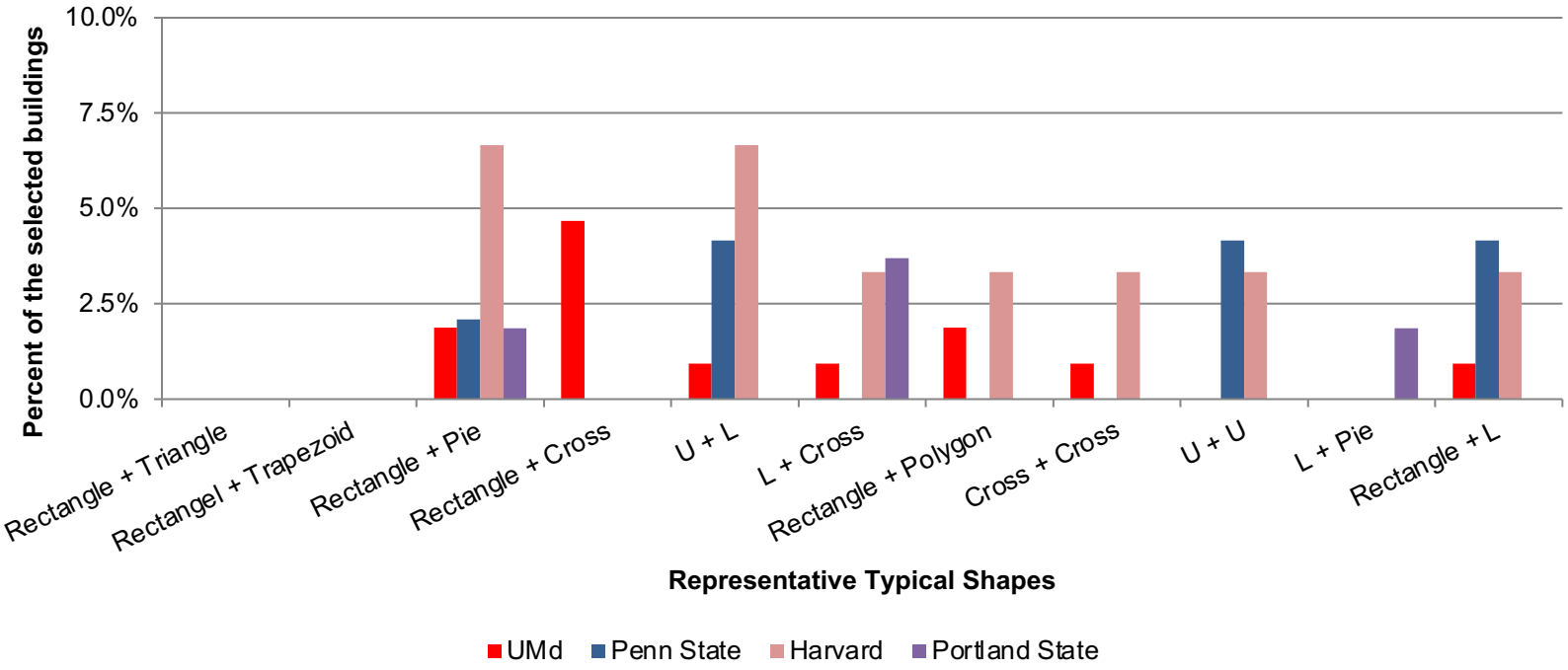
- The results of (CBECS) also confirm buildings could be modeled with typical shapes.

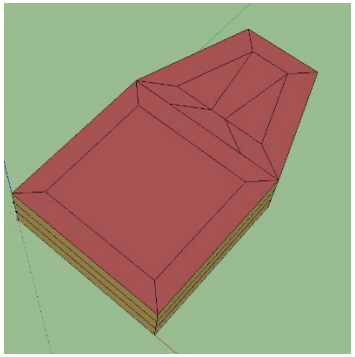


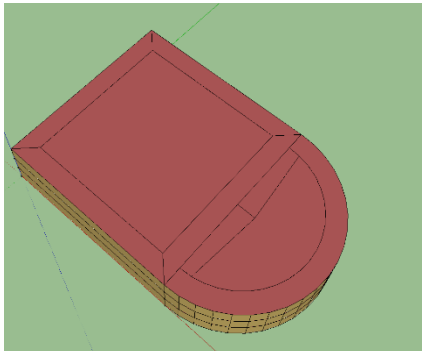
Heidarinejad et al. 2017

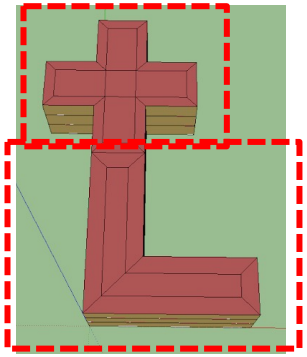
Building Shapes

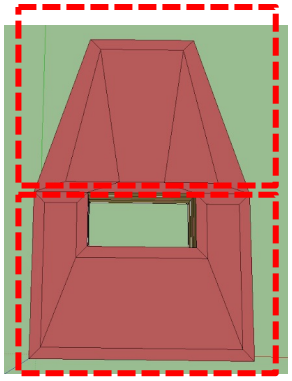
- Combination of the shapes can cover most of the remaining buildings





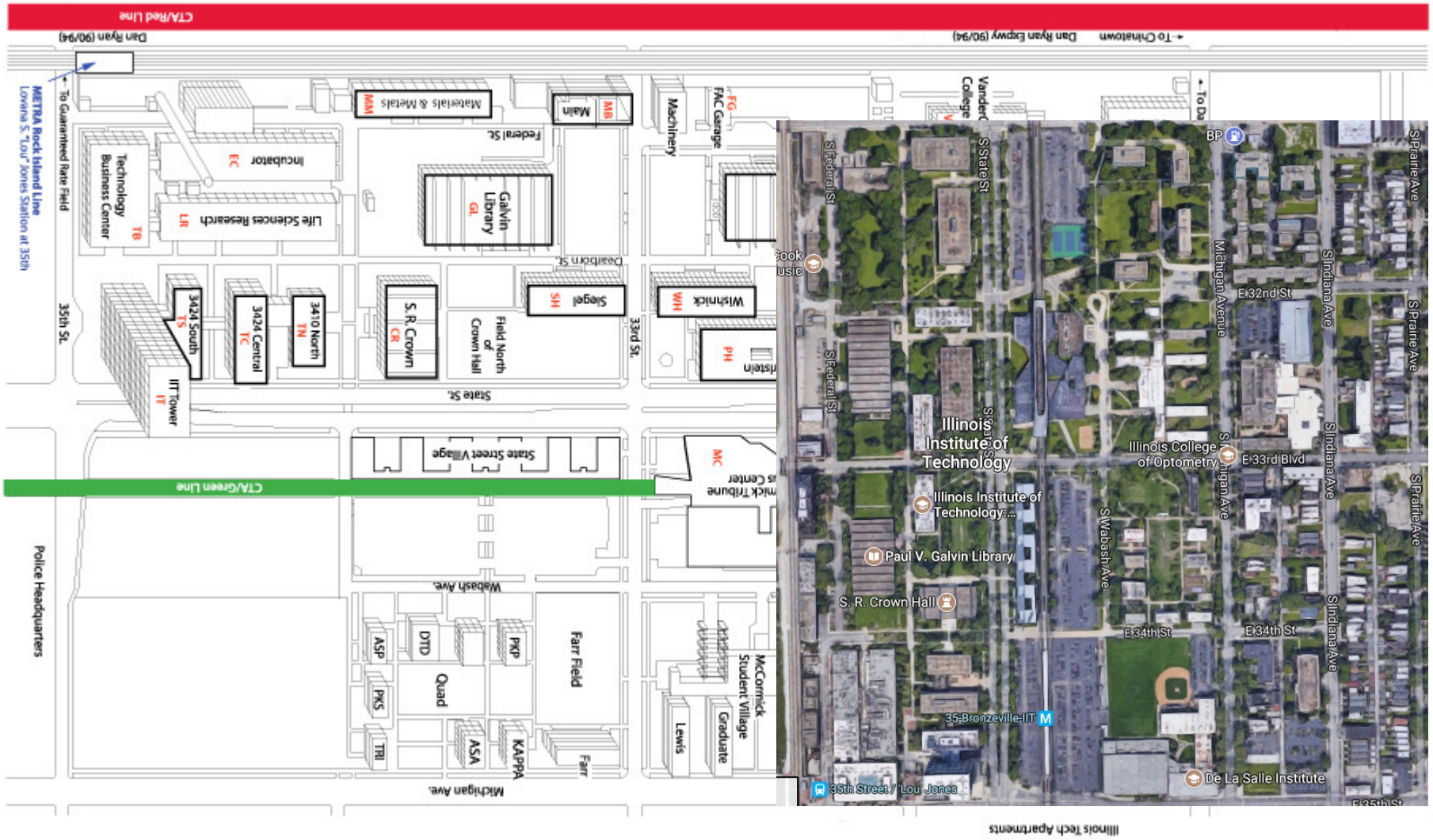






Heidarinejad et al. 2017

Building Shapes



What is the percentage for our campus?

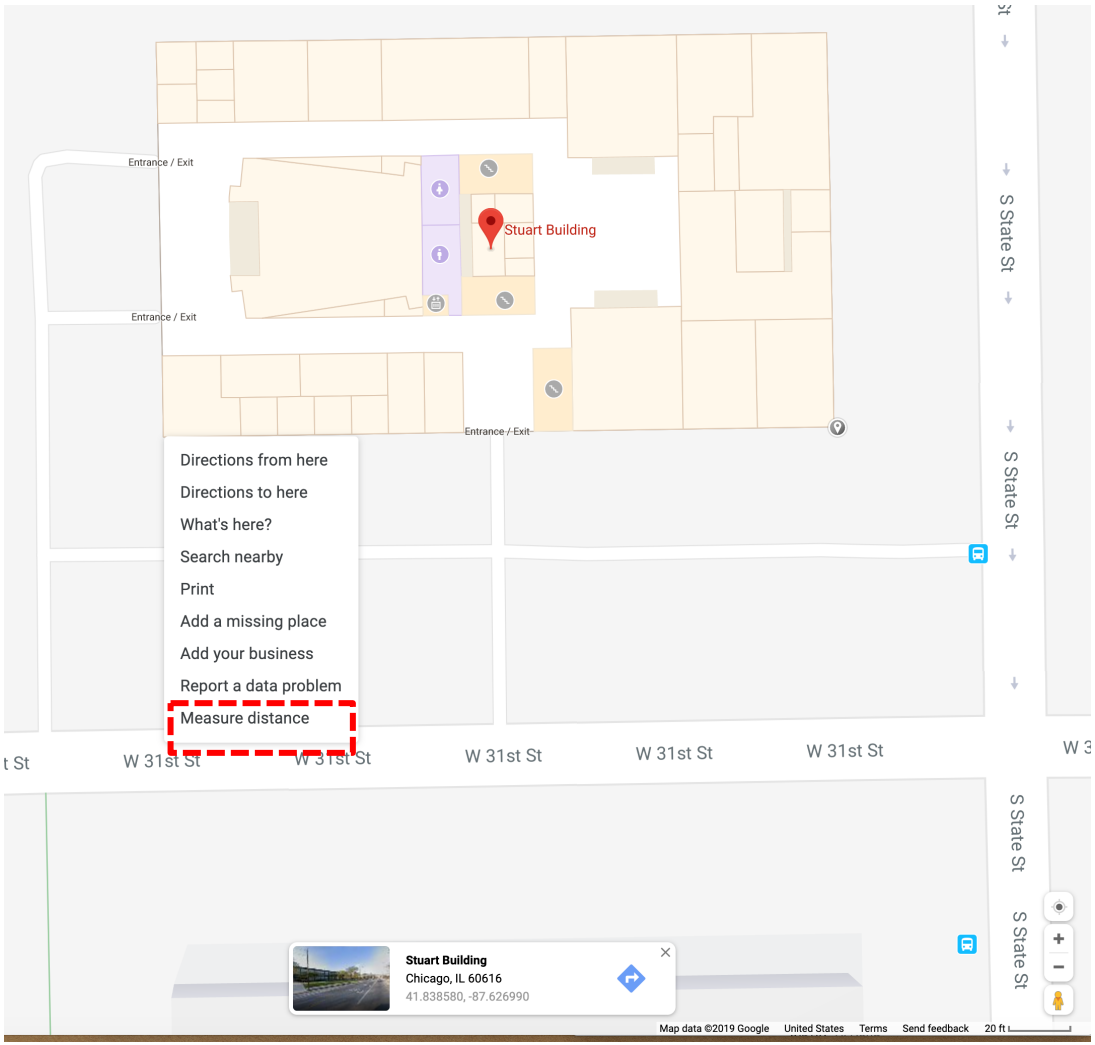
FLOOR PLAN

Floor Plan

- Consider Stuart building
- How do we calculate this in absence of the floorplans?

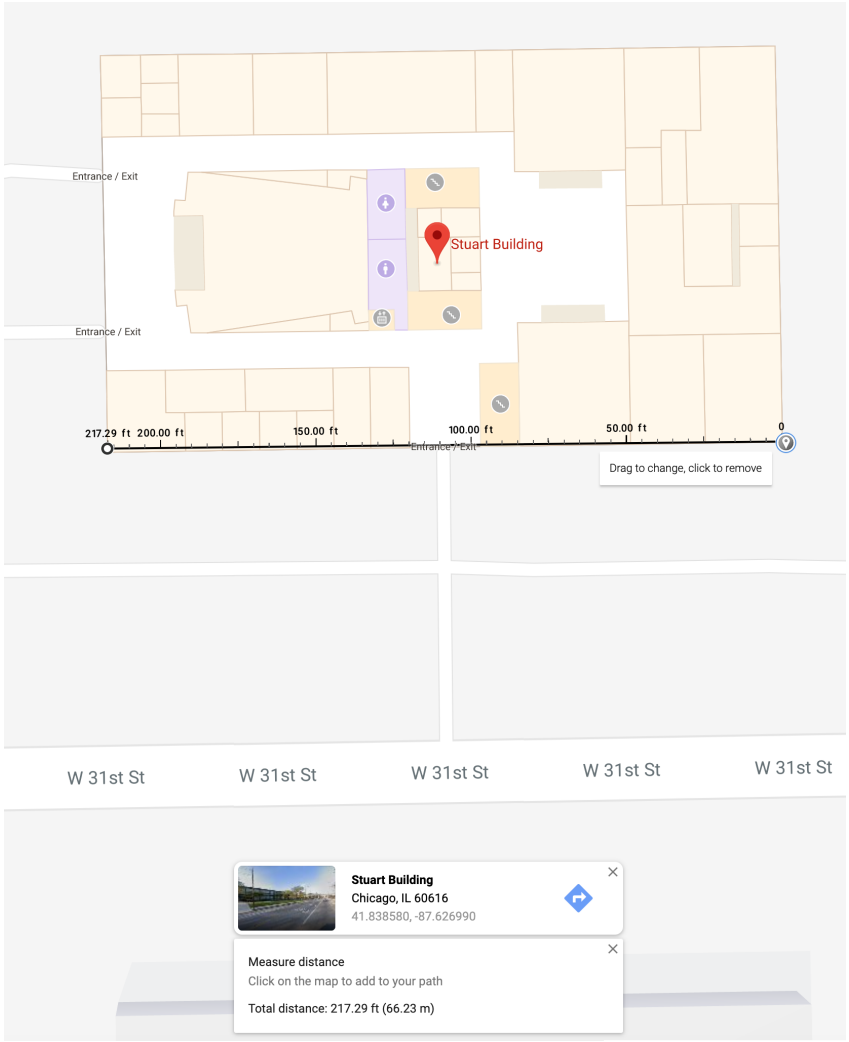
Floor Plan

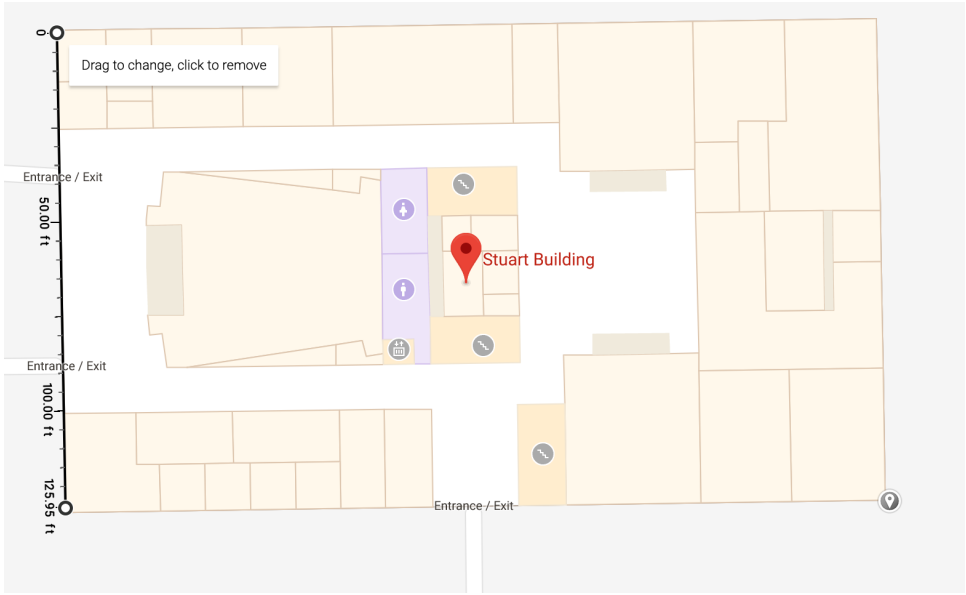
- One of the easiest options:



Floor Plan

- One of the easiest options:



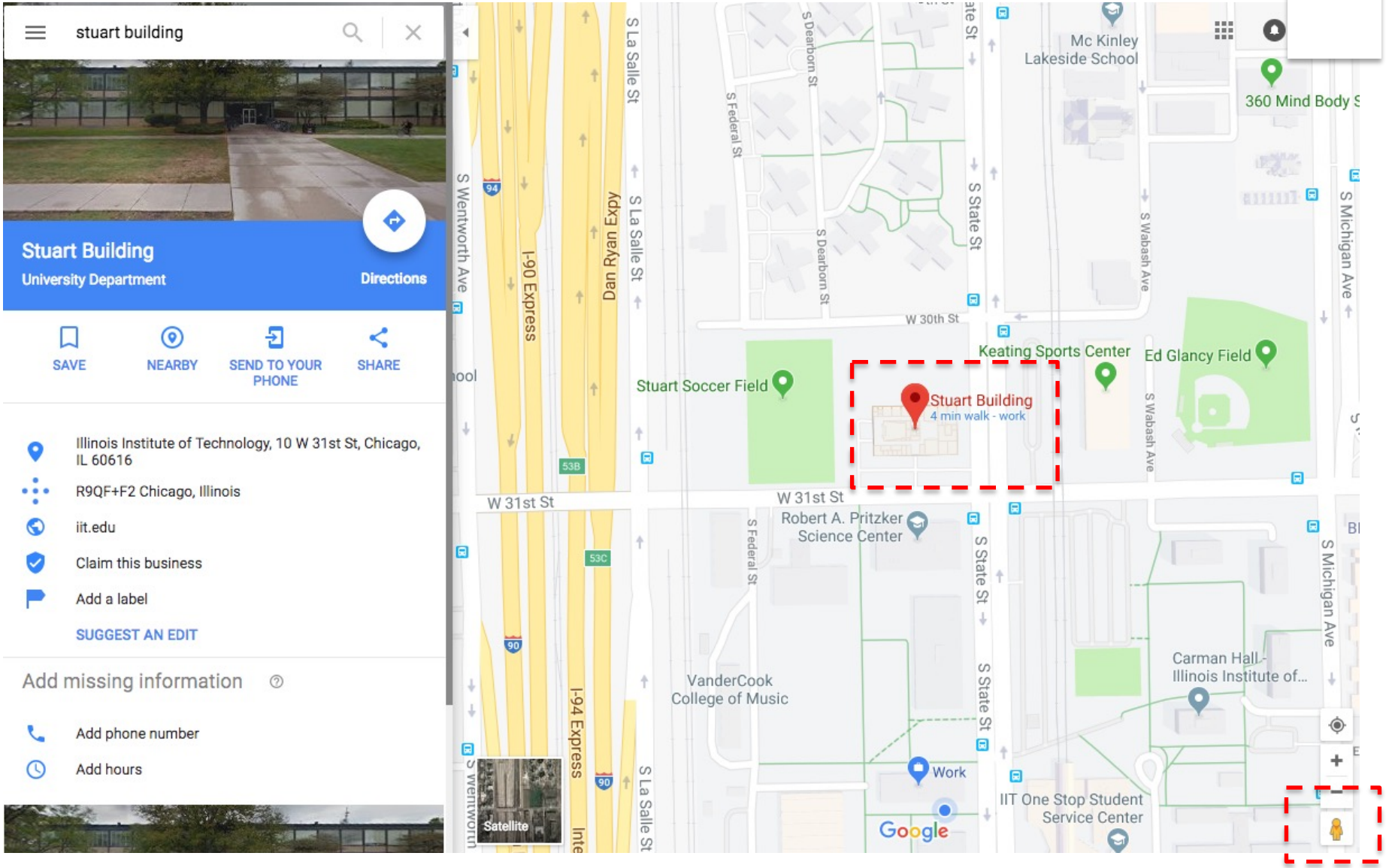


WINDOW-TO-WALL RATIO

Window-to-Wall Ratio

- A simple calculation of Window-to-Wall (WWR) ratio benefit from the following steps:
  - Identify the building on the search engine maps
  - View the building facades
  - Scale the sides and measure the distances

Window-to-Wall Ratio



Window-to-Wall Ratio

Window-to-Wall Ratio

Window-to-Wall Ratio

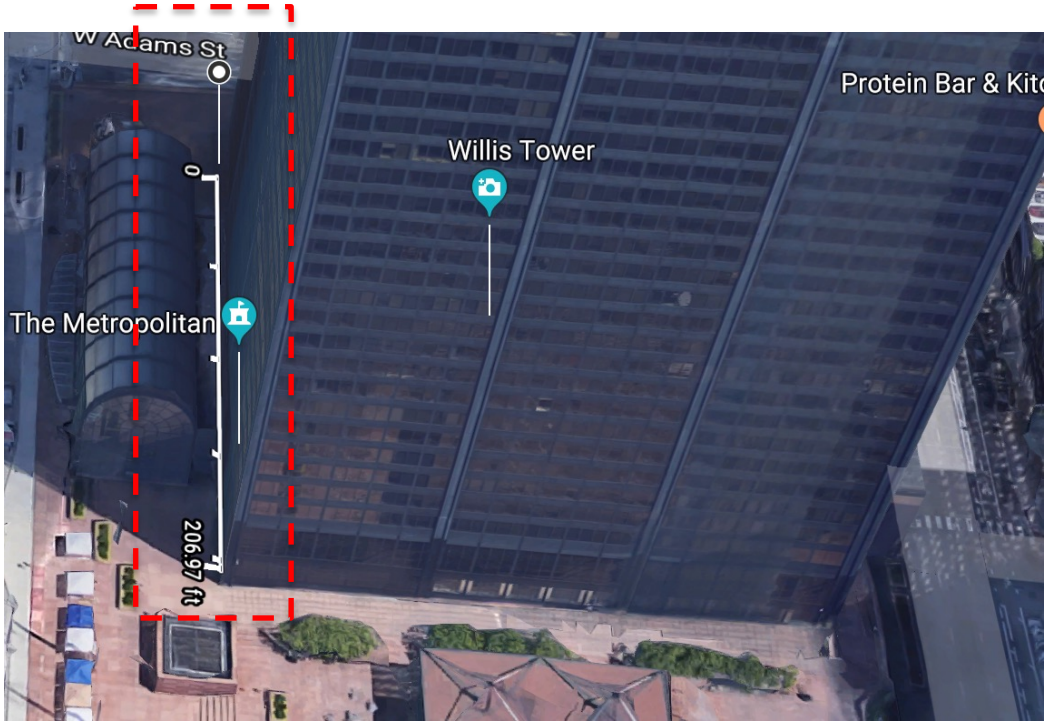
CLASS ACTIVITY

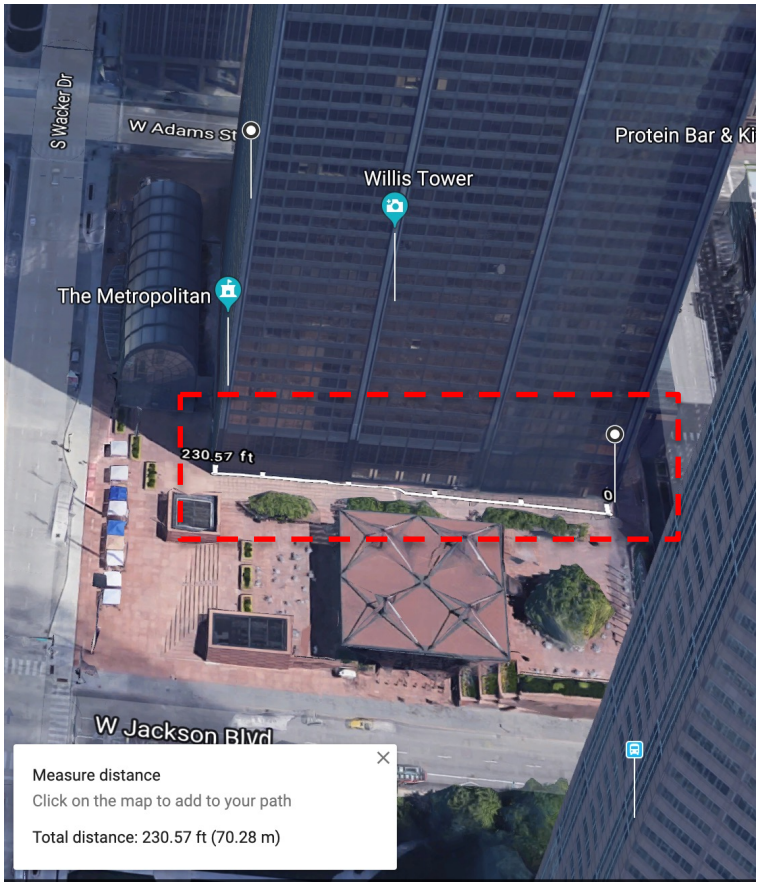
Class Activity

- Calculate WWR, building floor area, and height for the Willis Tower (or a similar commercial building in downtown)

Class Activity

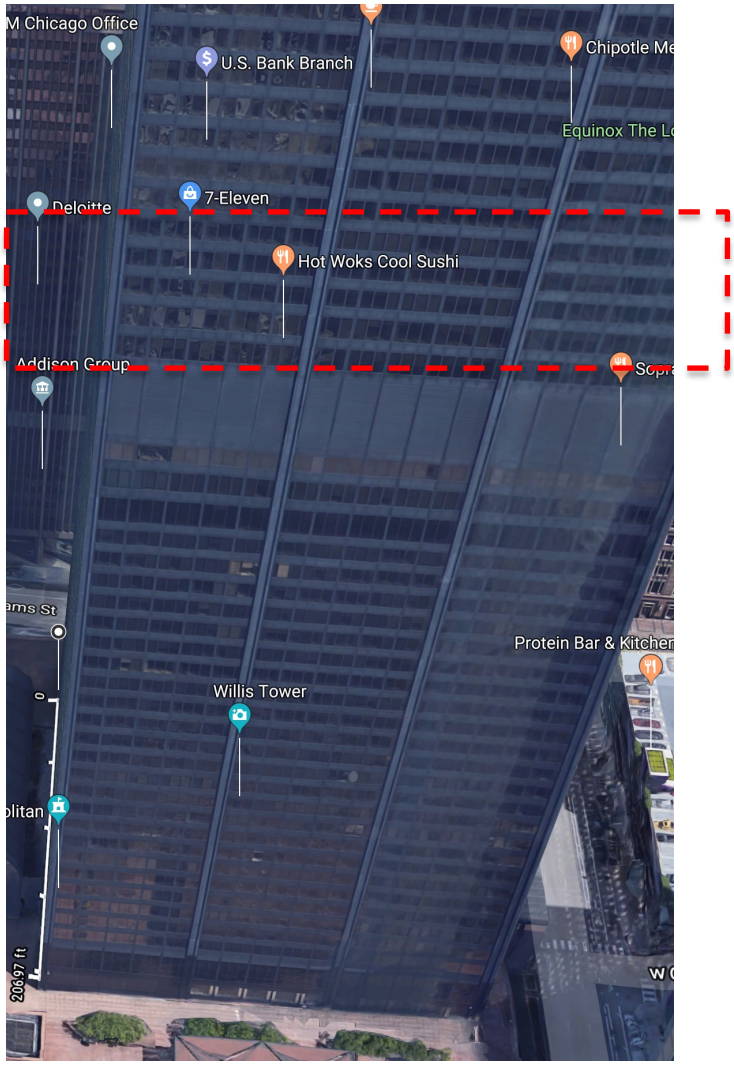
- Building floor area for Willis Tower





Class Activity

- In calculation of WWR, consider windows



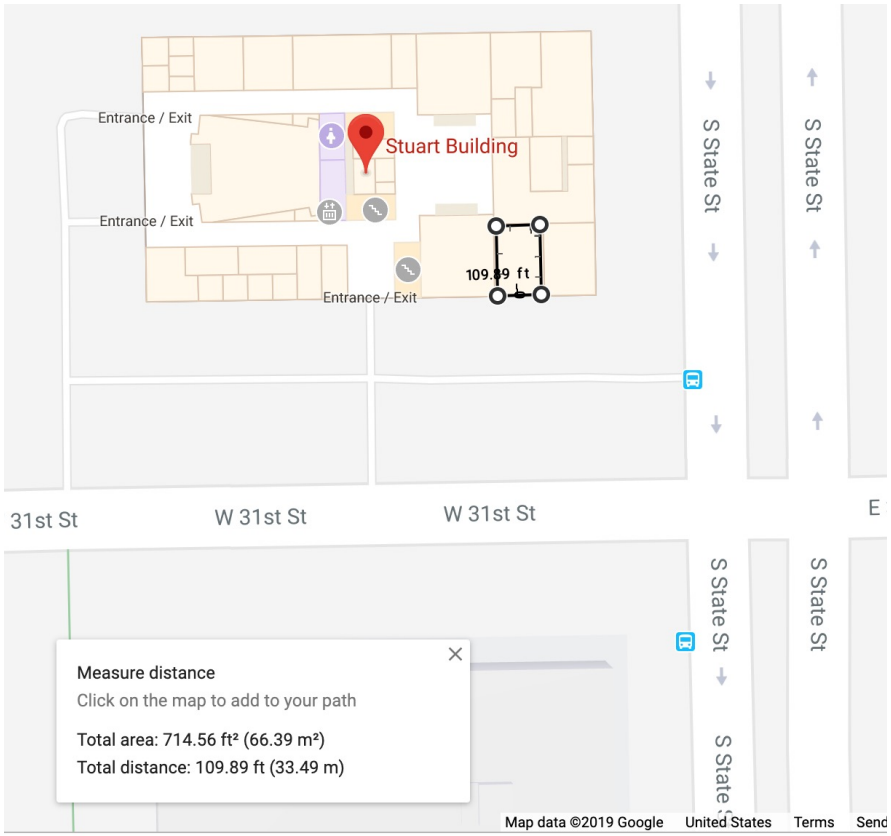
SPACES

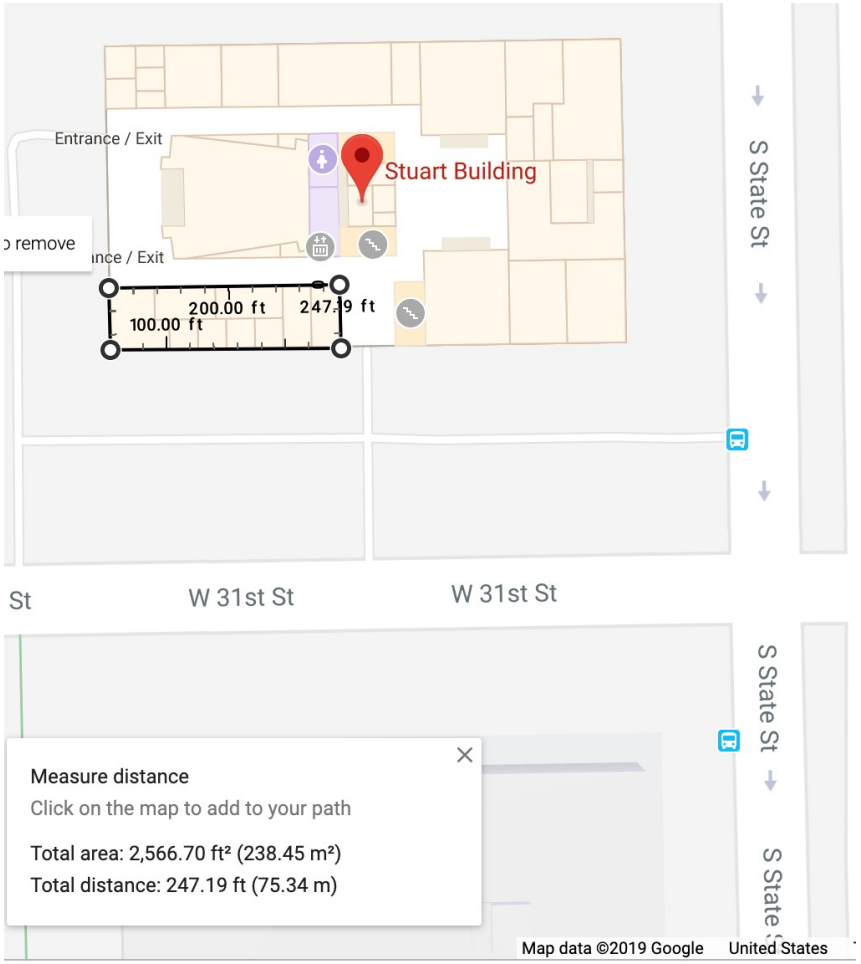
Spaces

- How to find out about the spaces in a building?
  - Use architectural and mechanical drawings
  - Utilize online resources (if possible)

Spaces

- How to find out about the spaces in a building?





THERMAL ZONING

Thermal Zoning

- What's a thermal zone?

ASHRAE Standard 90.1: "HVAC Zones or Thermal Zone is space or group of spaces within a building with heating and cooling requirements that are sufficiently similar so that desired conditions (e.g., temperature) can be maintained throughout using a single sensor (e.g., thermostat or temperature sensor)"

Spaces that are being served by one thermostat

Thermal Zoning

- Where do we find the standards?

https://www.ashrae.org/technical-resources/standards-and-guidelines

Preview ASHRAE Standards and Guidelines

You may preview the following ASHRAE Standards & Guidelines with the links be selection with the option to purchase your copy with the buy button. If you need t ashrae@iengineering.com.

Errata to guidelines and standards can be found here.

Guideline 1.4-2019

Guideline 11-2021

Guideline 12-2020

Guideline 28-2021

Guideline 29-2019

Guideline 36-2021

Standard 15-2019

Standard 34-2019

Standard 52.2-2017

Standard 55-2020

Standard 62.1-2019

Standard 62.2-2019

Standard 84-2020

Standard 90.1-2019 (I-P)

Thermal Zoning

- ASHRAE 90.1-2019:

7. *Thermal Blocks—HVAC Zones* Designed	
Where *HVAC zones* are defined on HVAC design drawings, each *HVAC zone* shall be modeled as a separate *thermal block*. **Exceptions:** Different *HVAC zones* may be combined to create a single *thermal block* or identical *thermal blocks* to which multipliers are applied, provided that all of the following conditions are met: 1. The *space* use classification is the same throughout the *thermal block,* or all of the zones have peak internal loads that differ by less than 10 Btu/h·ft^2 from the average. 2. All *HVAC zones* in the *thermal block* that are adjacent to glazed *exterior walls* and glazed *semiexterior walls* face the same *orientation* or their orientations vary by less than 45 degrees. 3. All of the zones are served by the same *HVAC system* or by the same kind of *HVAC system*. 4. All of the zones have schedules that differ by 40 or less equivalent full-load hours per week.	Same as *proposed design*.

ANSI/ASHRAE/IES Standard 90.1-2019 (I-P) 305

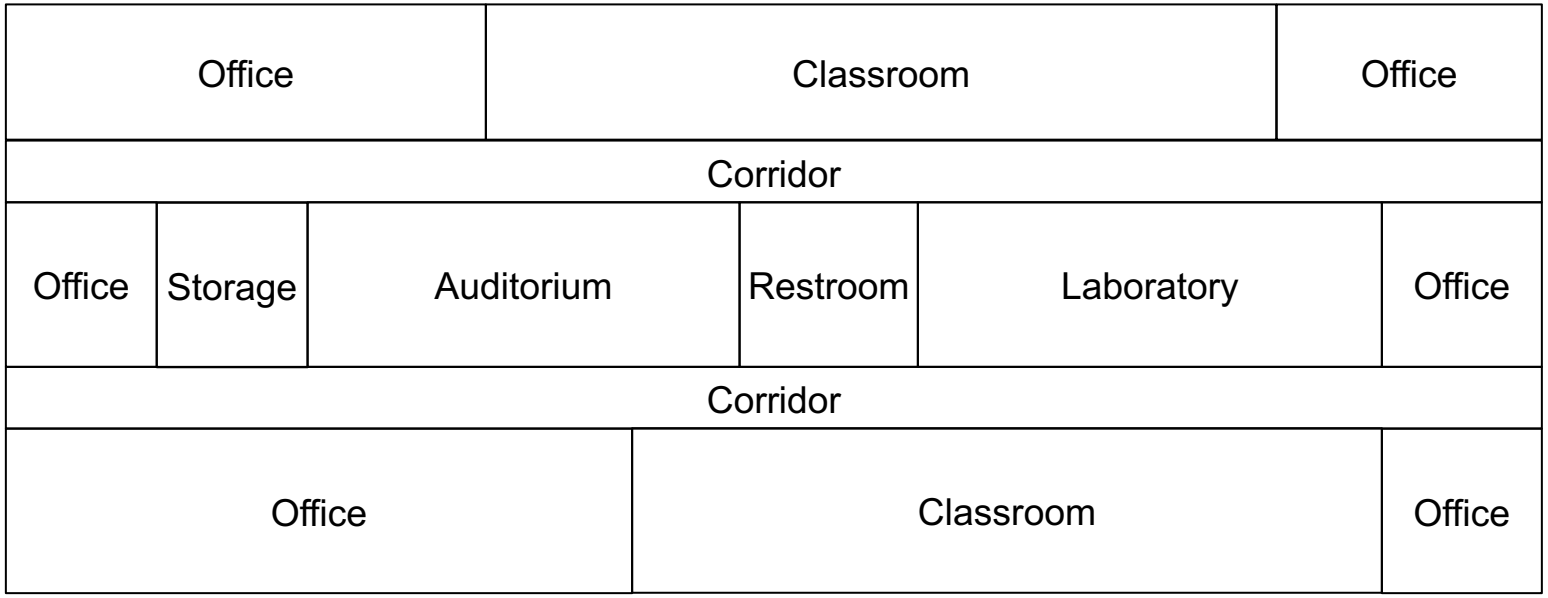
Thermal Zoning

- ASHRAE 90.1-2019:

No.	*Proposed Building Performance*	*Baseline Building Performance*
8. *Thermal Blocks—HVAC Zones* Not Designed		
	Where the *HVAC zones* and *systems* have not yet been designed, *thermal blocks* shall be defined based on similar internal load densities, occupancy, lighting, thermal and *space* temperature schedules, and in combination with the following guidelines: a. Separate *thermal blocks* shall be assumed for interior and perimeter *spaces*. Interior *spaces* shall be those located greater than 15 ft from an *exterior wall* or *semiexterior wall*. Perimeter *spaces* shall be those located within 15 ft of an *exterior wall* or *semiexterior wall*. A separate thermal zone does not need to be modeled for areas adjacent to *semiexterior walls* that separate *semiheated space* from *conditioned space*. b. Separate *thermal blocks* shall be assumed for *spaces* adjacent to glazed *exterior walls* or glazed *semiexterior walls*; a separate zone shall be provided for each *orientation*, except that orientations that differ by less than 45 degrees may be considered to be the same *orientation*. Each zone shall include all *floor* area that is 15 ft or less from a glazed perimeter *wall*, except that *floor* area within 15 ft of glazed perimeter *walls* having more than one *orientation* shall be divided proportionately between zones. c. Separate *thermal blocks* shall be assumed for *spaces* having *floors* that are in contact with the ground or exposed to ambient conditions from zones that do not share these features. d. Separate *thermal blocks* shall be assumed for *spaces* having exterior ceiling or *roof* assemblies from zones that do not share these features.	Same as *proposed design*.
9. *Thermal Blocks*—Multifamily *Residential Buildings*		
	Residential spaces shall be modeled using at least one *thermal block* per *dwelling unit*, except that those units facing the same orientations may be combined into one *thermal block*. Corner units and units with *roof* or *floor* loads shall only be combined with units sharing these features.	Same as *proposed design*.

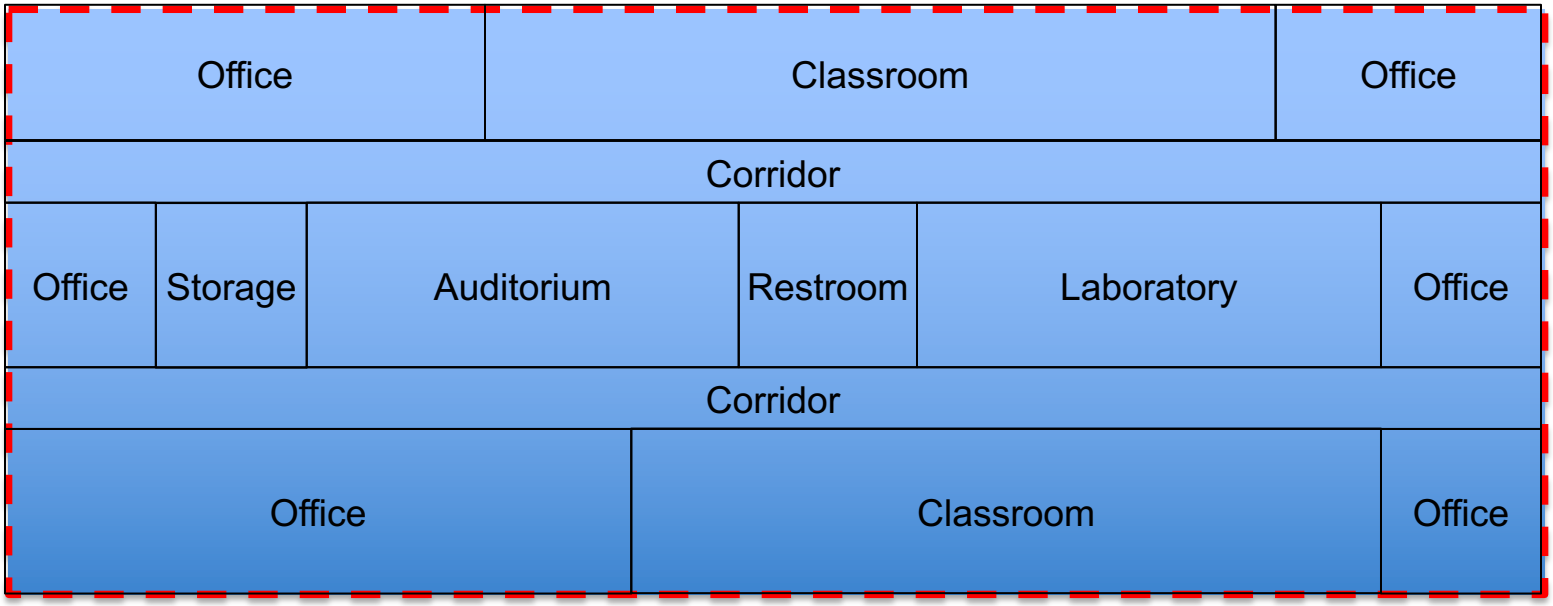
Thermal Zoning

- Always consider looking at the mechanical drawings first:



Thermal Zoning

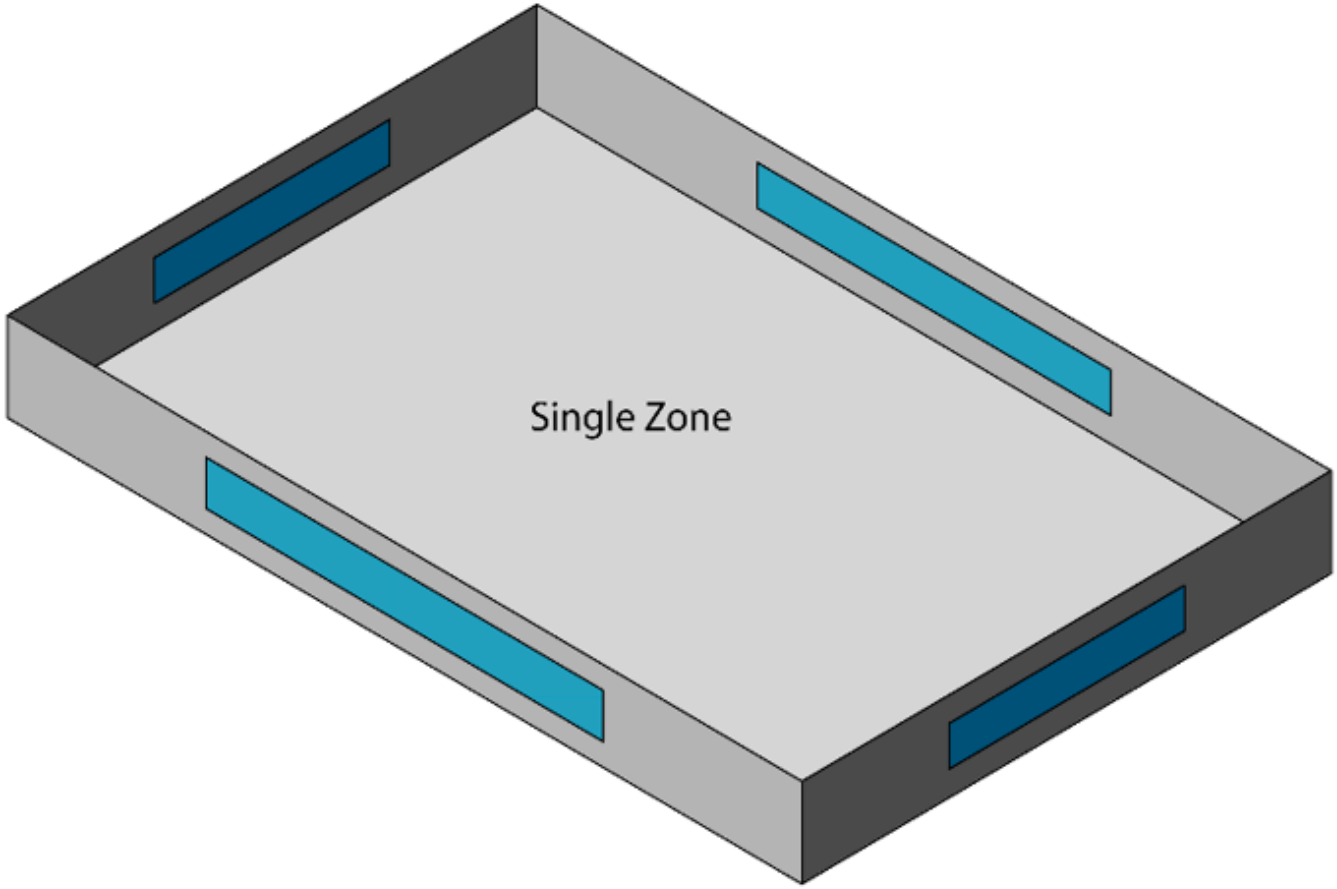
- What's the simplest form of a thermal zone?



"Single Zone"

Thermal Zoning

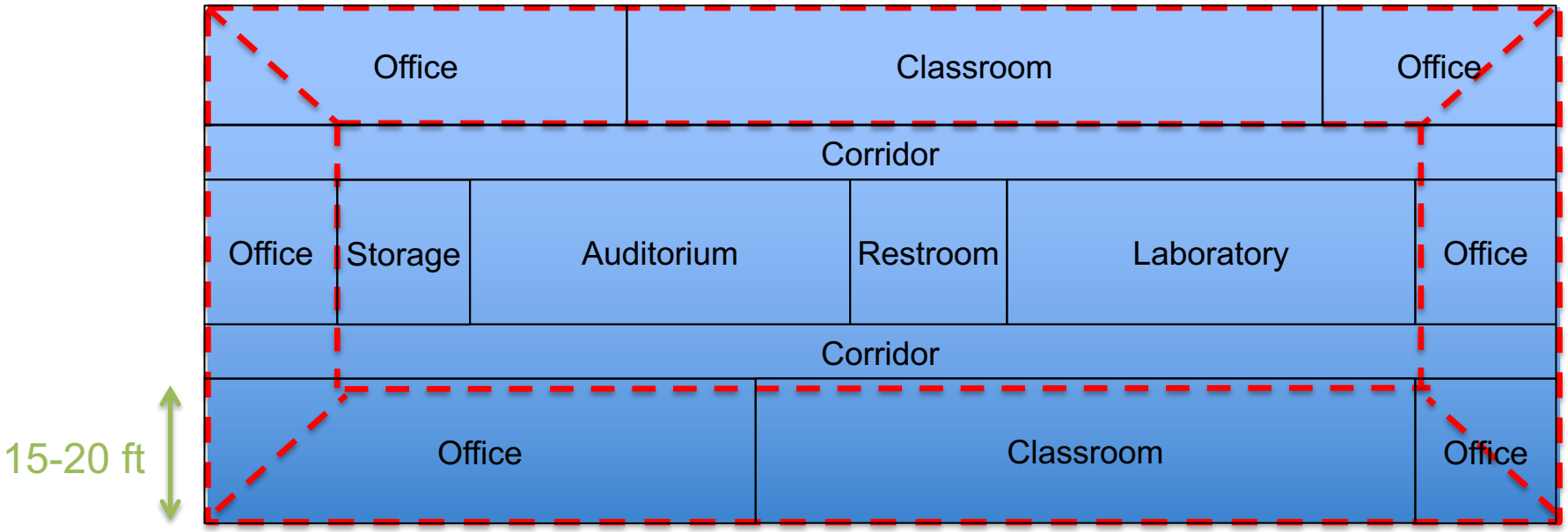
- Single zone



https://www.covetool.com/2019/05/2864/

Thermal Zoning

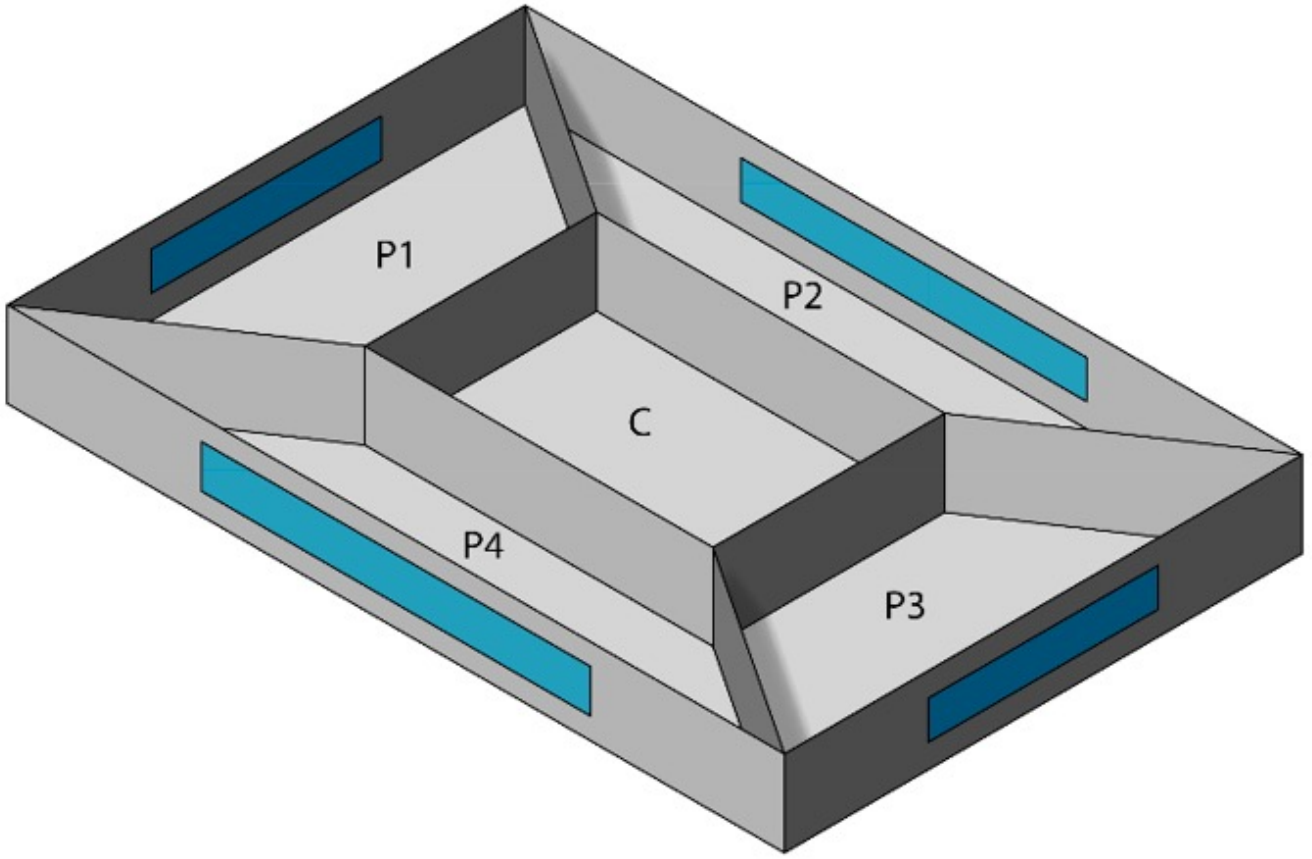
- What's the simplest form of a thermal zone after a single zone mode?



"Core and Perimeter Zone"

Thermal Zoning

- Core zone and perimeter



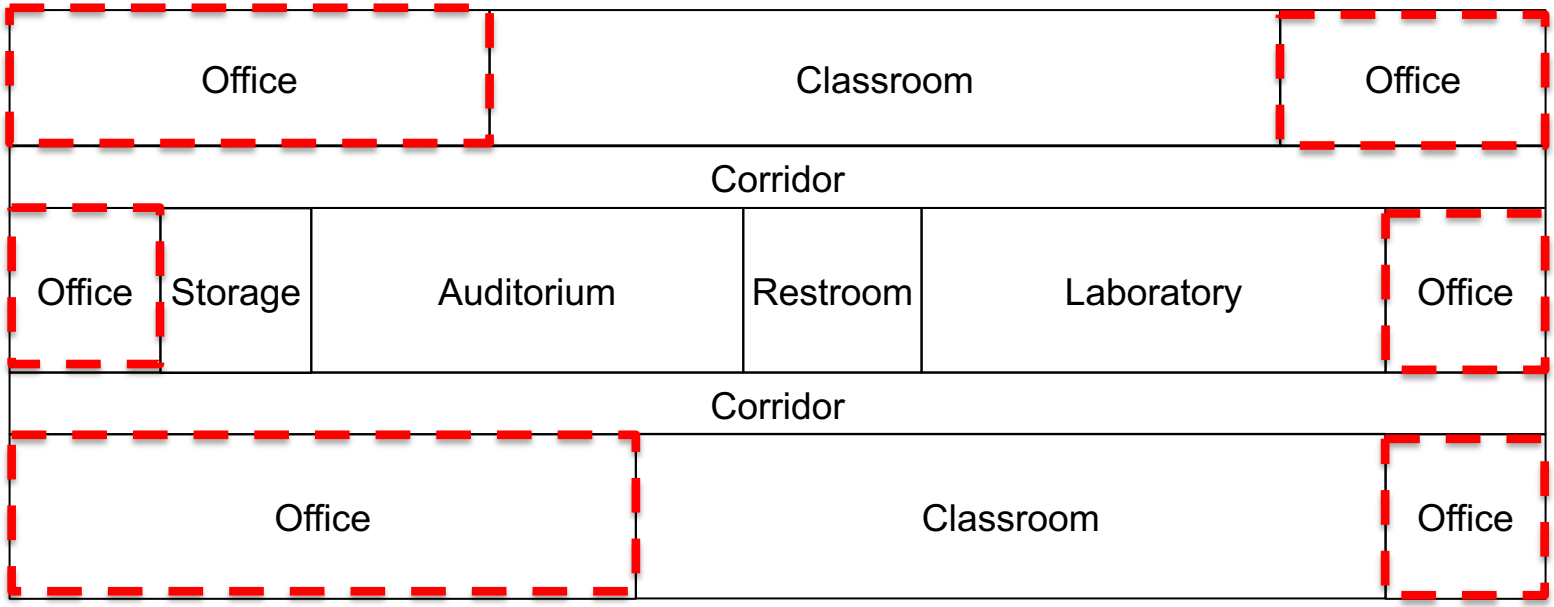
https://www.covetool.com/2019/05/2864/

Thermal Zoning

- What are the most important consideration for a detailed thermal zone modeling:
  - Orientation (e.g., East, West)
    - Daylight
    - Heat gain
  - Areas
    - Similar areas
  - Functionality
    - Similar internal loads and ventilation requirements
  - Proximity
    - Same floor
    - Same location in a floor but at different floors

Thermal Zoning

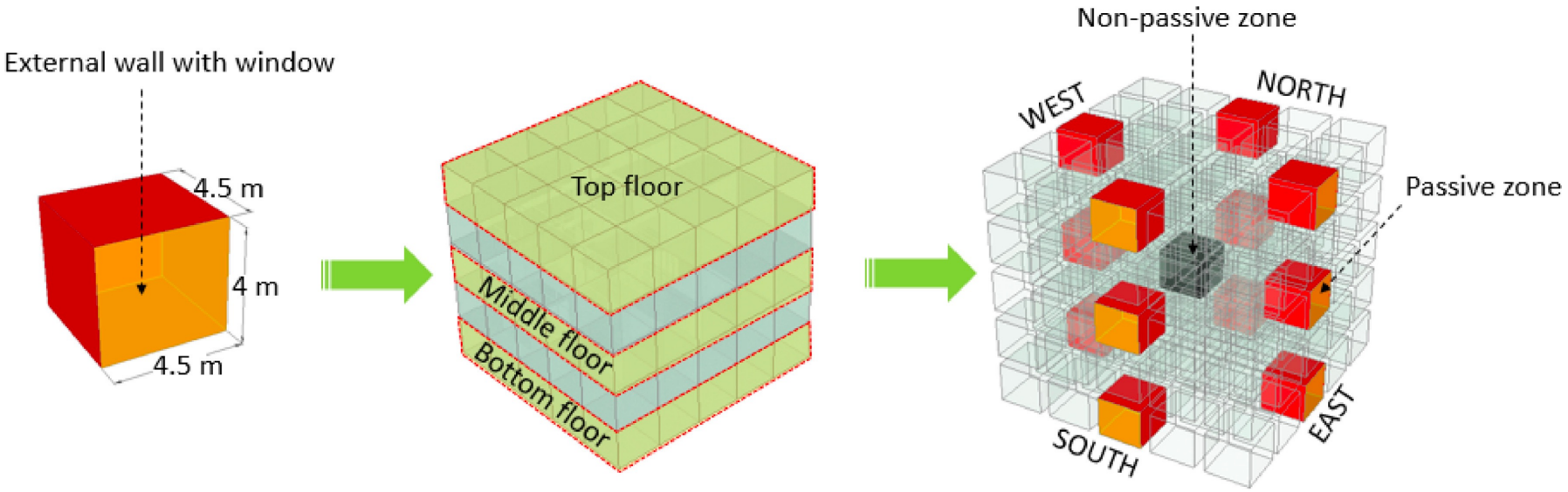
- Consider adding thermal zone for this floor plan.



Do you think the following thermal zone is a good strategy?

Thermal Zoning

- Let's look at different thermal zone modeling in the literature



Thermal Zoning

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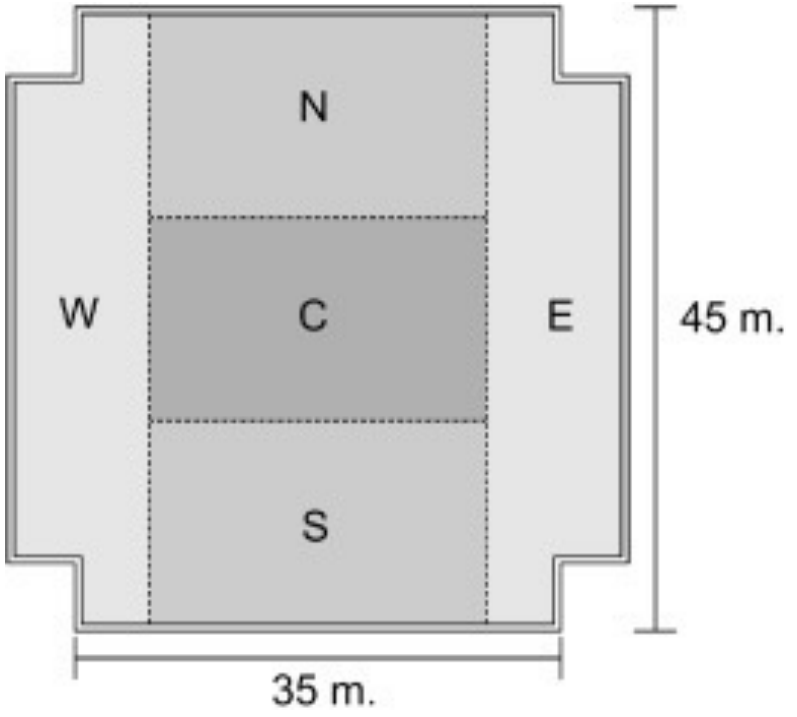
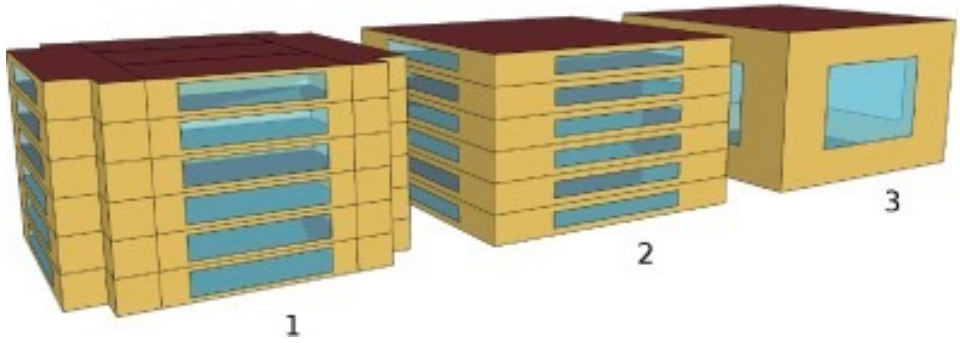
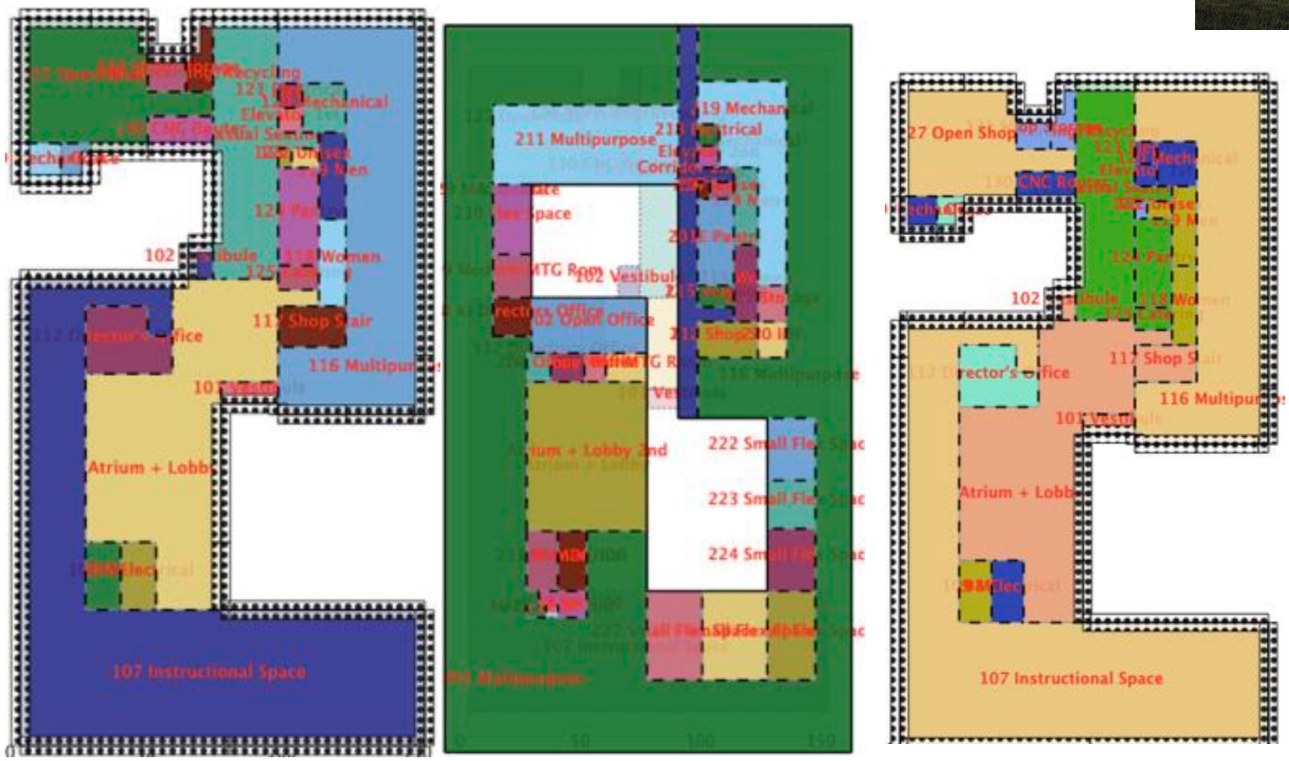




Comparison between simplified and detailed EnergyPlus models coupled with an urban canopy model

Thermal Zoning

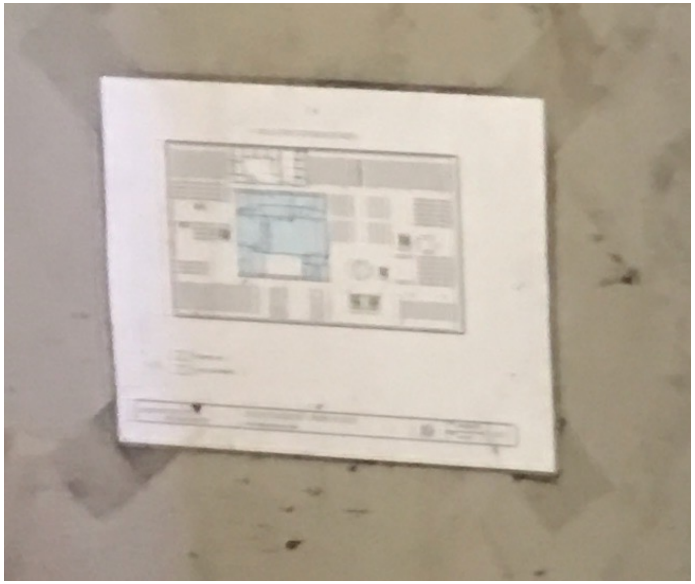
- Our campus models



Maristany, 2019

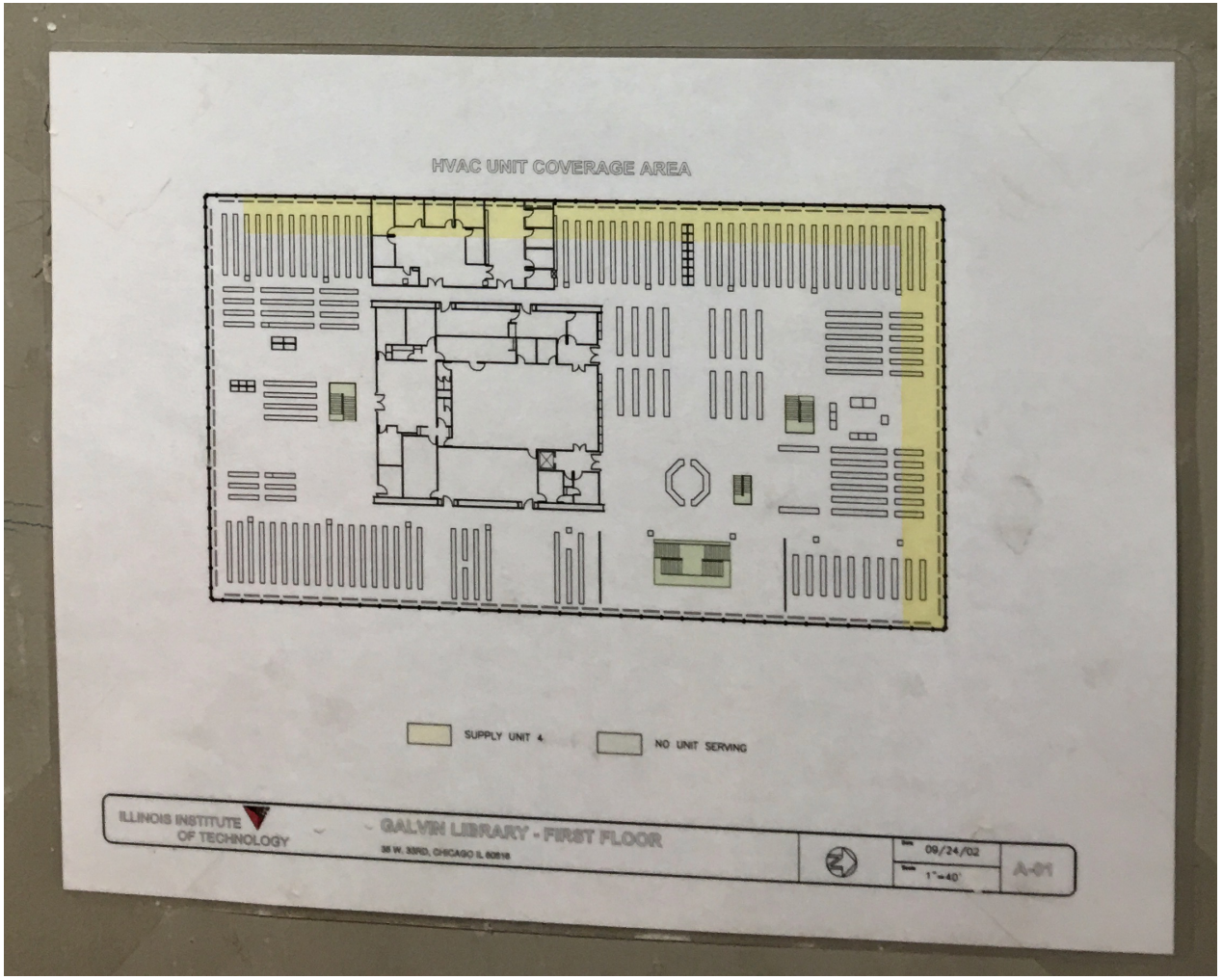
Thermal Zoning

- In a real building, this is also visualized



Thermal Zoning

- In a real building, this is also visualized



CLASS ACTIVITY

Class Activity

- A floor plan is posted on Blackboard:
  - ❑ Let's try to understand the floor plan
  - ❑ Let's work on the thermal zoning
  - ❑ Let's try to understand the dimensions