

# Occupant Centric Grid- Interactive Buildings

## *5. Introduction to Building Energy Performance Simulation*

CE 397  
Spring 2024

Kingsley Nweye  
Teaching Assistant

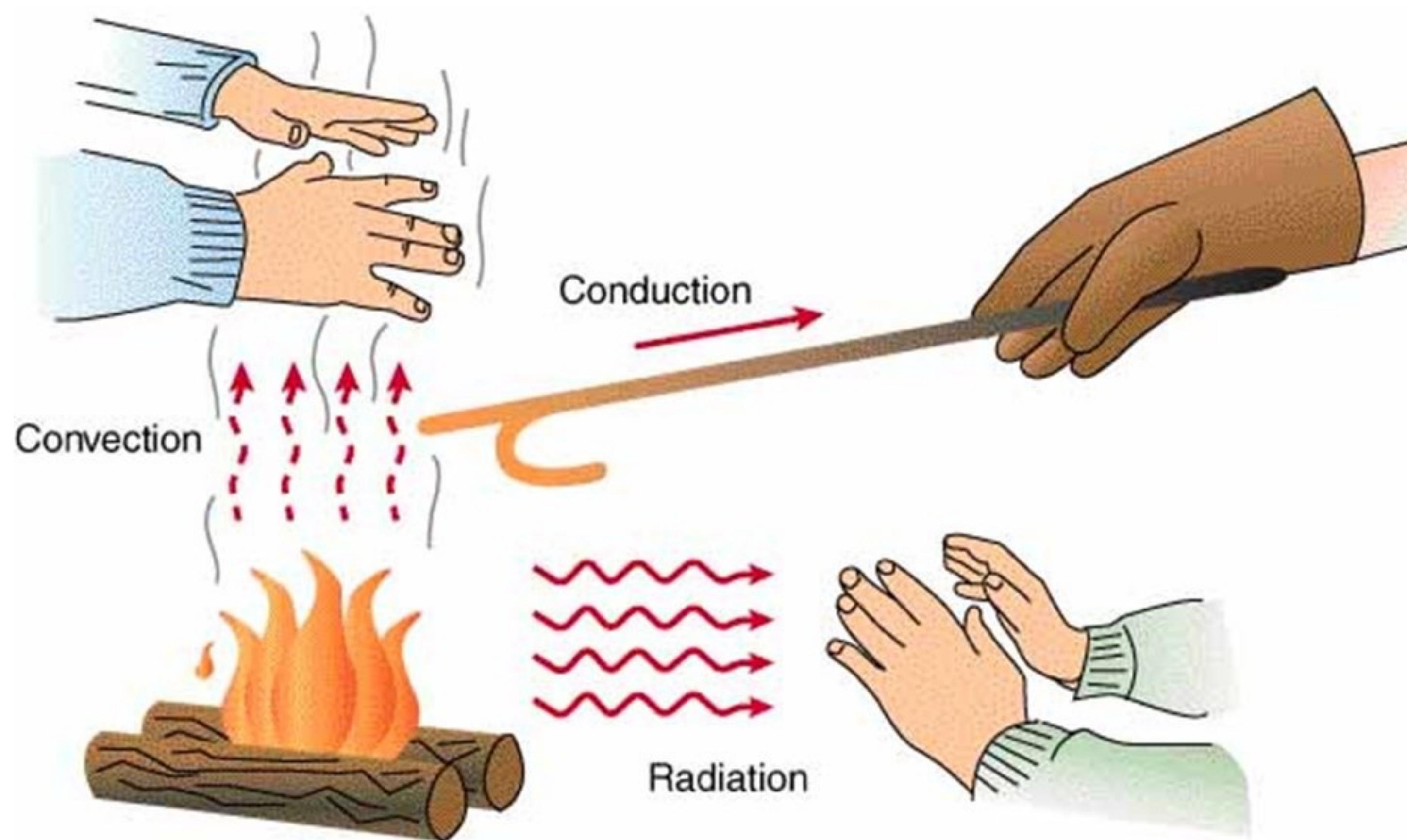
# Tentative course outline/schedule

<b>Week</b>	<b>Class</b>	<b>Topic</b>	<b>Guest Lecture</b>
1	01/17	Introduction / Overview / Python	
2	01/24	Machine Learning I	
3	01/31	Machine Learning II	
4	02/07	Machine Learning III	Justin Hill (Southern)
5	02/14	Occupant Behavior Modeling	
6	02/21	Occupant Behavior Modeling	Tanya Barham (CEL)
7	02/28	Occupant Behavior Modeling	Jessica Granderson (LBNL)
8	03/06	Occupant Behavior Modeling	Hussain Kazmi (KU Leuven)
9	03/13	Spring Break	
10	03/20	Advanced Control & Calibration	Ankush Chakrabarty (MERL)
11	04/27	Calibration	Donghun Kim (LBNL)
12	04/03	Introduction to CityLearn	
13	04/10	Project Work	Siva Sankaranarayanan (EPRI)
14	04/17	Project work	
15	04/24	Project work	

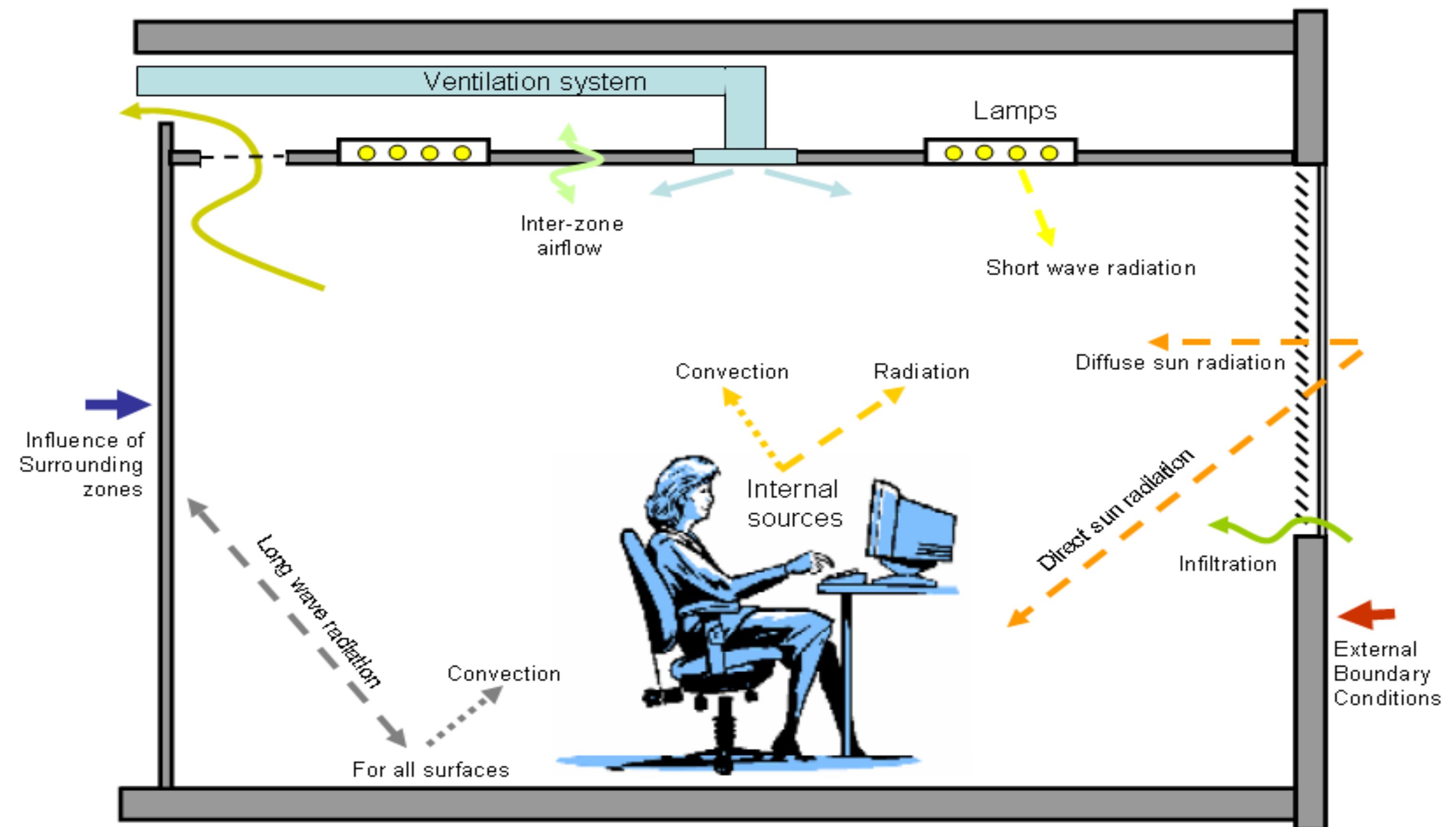
# The Plan for Today

- Lecture
  - Heat transfer modes
  - Heat gains and losses in a building
  - Building energy performance simulation
- Activity
  - Install EnergyPlus in CoLab
  - Run test simulation notebook
- Homework help/troubleshooting

# Interaction between building elements based on heat transfer

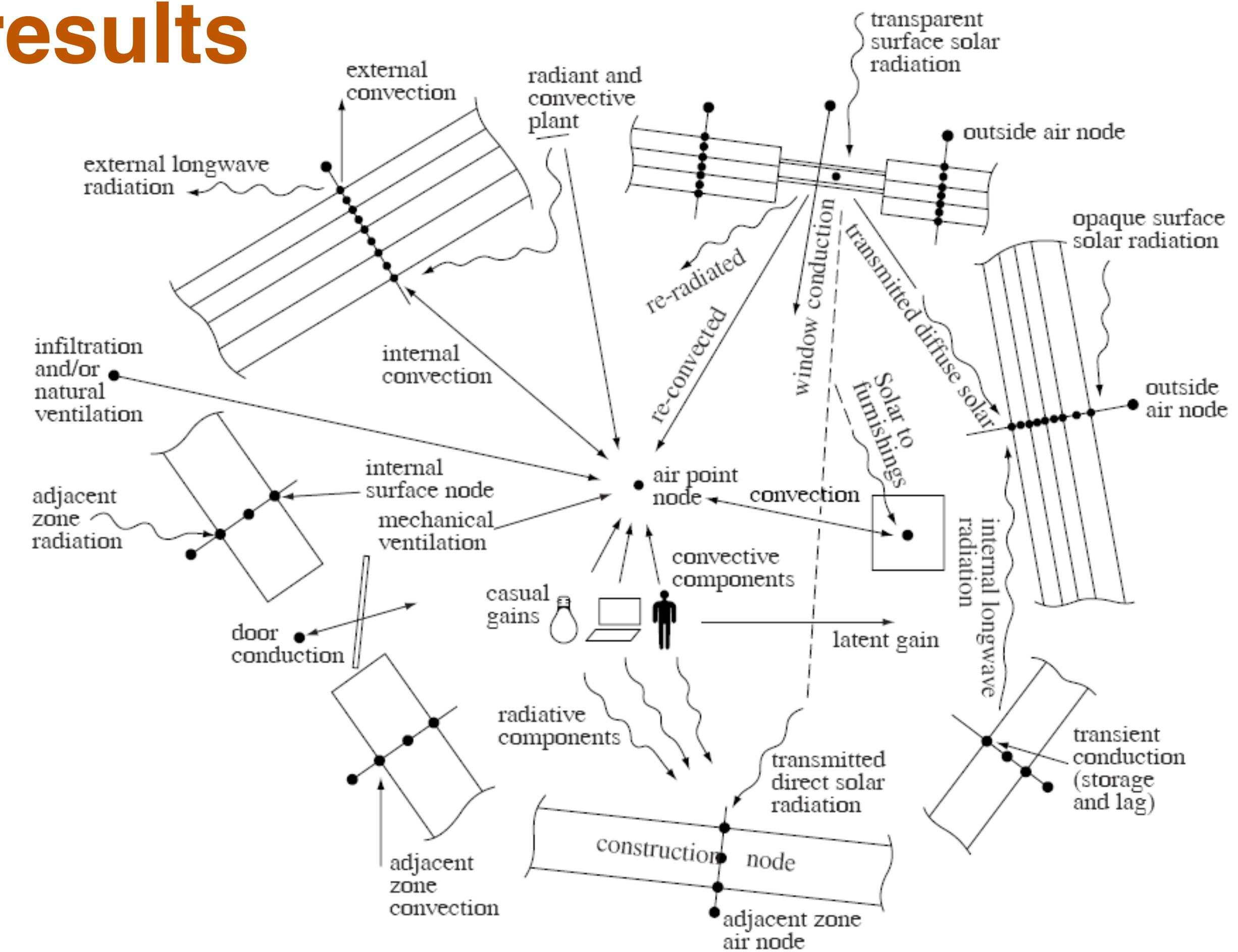


# Heat gains and losses in a thermal zone through all three heat transfer modes



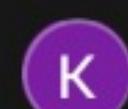
Novoselac, Atila, ARE 371, CE 397 Energy simulation in building design, The University of Texas at Austin, 2019

# Heat transfer is a transient problem: elements are discretized to get accurate results



Novoselac, Atila, ARE 371, CE 397 Energy simulation in building design, The University of Texas at Austin, 2019

# What is building energy performance simulation?



You

What is building energy performance simulation



ChatGPT

Building energy performance simulation is a computational process used to predict and analyze the energy usage of a building over time. It involves the use of computer models to simulate various aspects of a building's energy consumption, such as heating, cooling, lighting, and ventilation systems, as well as the interactions between these systems and the building envelope (walls, windows, roofs, etc.).

This simulation process typically involves creating a digital representation of the building, known as a building energy model, which includes information about its geometry, construction materials, occupancy patterns, and equipment specifications. This model is then subjected to various scenarios, such as different weather conditions, occupancy schedules, and energy management strategies, to assess its energy performance under different conditions.

# What is building energy performance simulation?

Building energy performance simulation can be used for a variety of purposes, including:

1. Design optimization: Architects and engineers can use simulation tools to evaluate different building designs and systems options to optimize energy efficiency and performance before construction begins.
2. Compliance with energy codes and standards: Building energy simulation is often used to demonstrate compliance with energy codes and standards, such as LEED (Leadership in Energy and Environmental Design) or ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) standards.
3. Retrofit analysis: Building owners and facility managers can use simulation tools to assess the potential energy savings and return on investment of retrofitting existing buildings with energy-efficient technologies or upgrades.
4. Performance verification: Building energy simulation can be used to compare predicted energy performance with actual energy usage data to verify that a building is operating as intended and identify opportunities for further optimization.

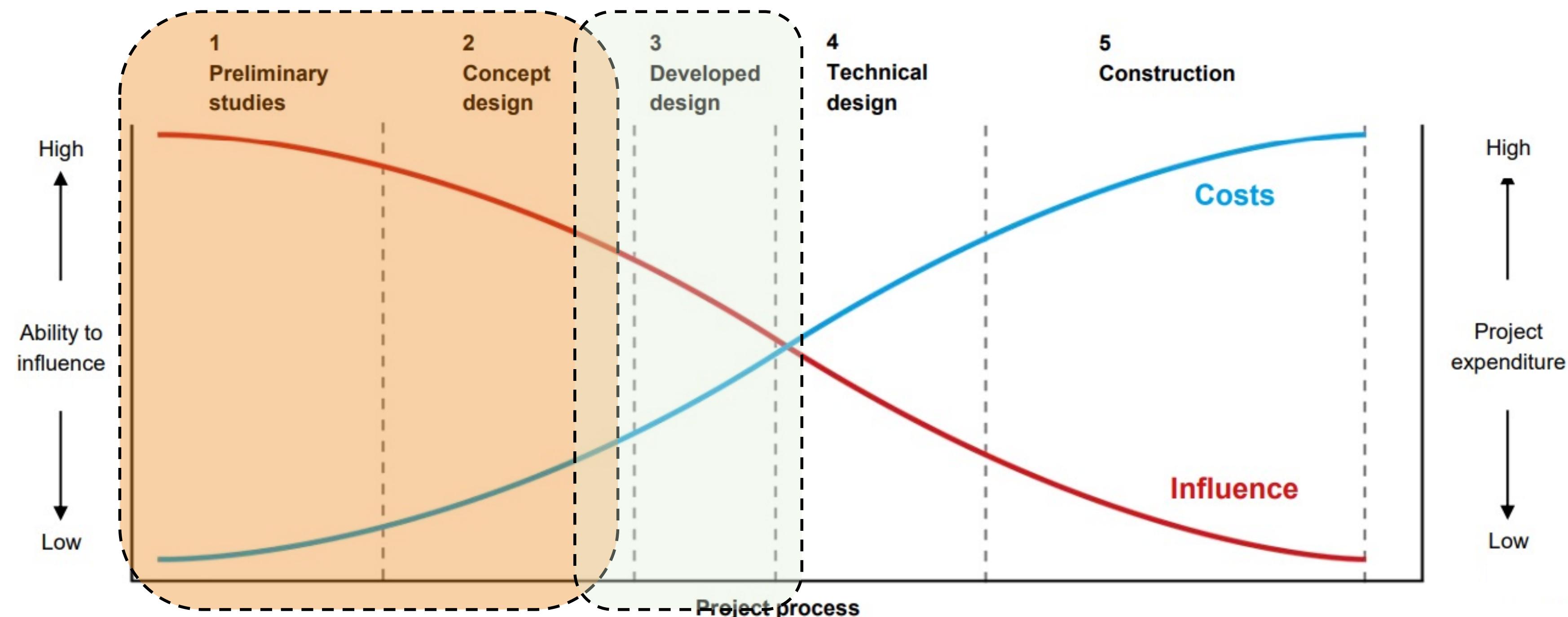
Overall, building energy performance simulation plays a crucial role in helping stakeholders make informed decisions about the design, operation, and retrofitting of buildings to improve energy efficiency, reduce environmental impact, and save costs.



# Why is building energy performance simulation important?

Wilson, Eric JH, et al. *End-use load profiles for the US building stock: Methodology and results of model calibration, validation, and uncertainty quantification*. No. NREL/TP-5500-80889. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2022

THIS IS  
IMPORTANT!



Miller, Clayton, BPS5223 Passive System Course – Simulation Tools, National University of Singapore, 2023

# Simulation lifecycle

## Identify business or research problem

- How is my bill affected if I use double pane tinted windows? (energy problem solved by retrofit)
- How does my ECJ's energy use change if temperatures are setback at night? (energy use problem solved by scheduling)
- How is the thermal comfort in my bedroom affected if I turn off the fan at night? (comfort inquiry through scheduling)
- What is the best control strategy for my battery to maximize PV generation and reduce bill (control problem through parametric study of different strategies)

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## Design energy model

- Define boundary condition
- Abstraction of real-world entity (**assumptions, lots of them!**)
- Define weather file
- Collect envelope property data
- Collect scheduling and occupant behavior data
- Use collected data to define energy model using system of equations or schema that defines surfaces, their properties, interactions with other surfaces and mechanical systems.

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## Baseline simulation

- **1-year** long simulation to capture seasonal effects
- Run simulation and collect results

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## Design energy model

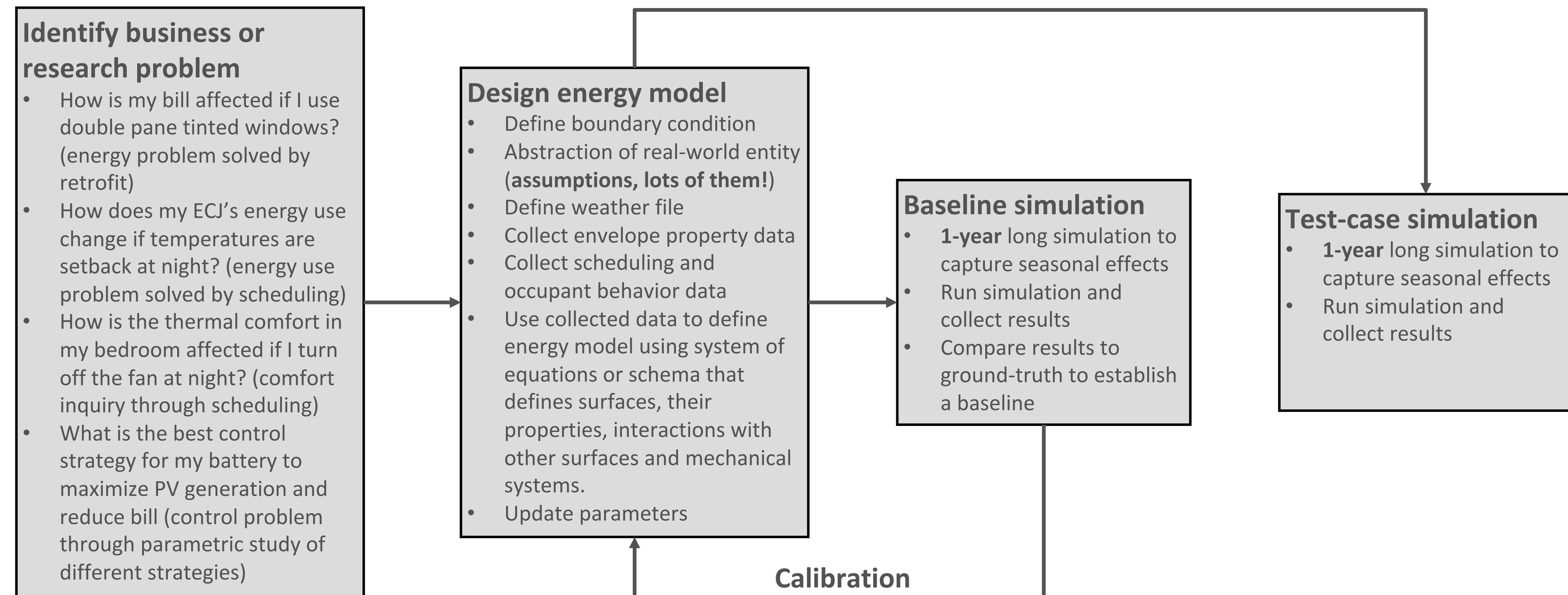
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- Update parameters

## Baseline simulation

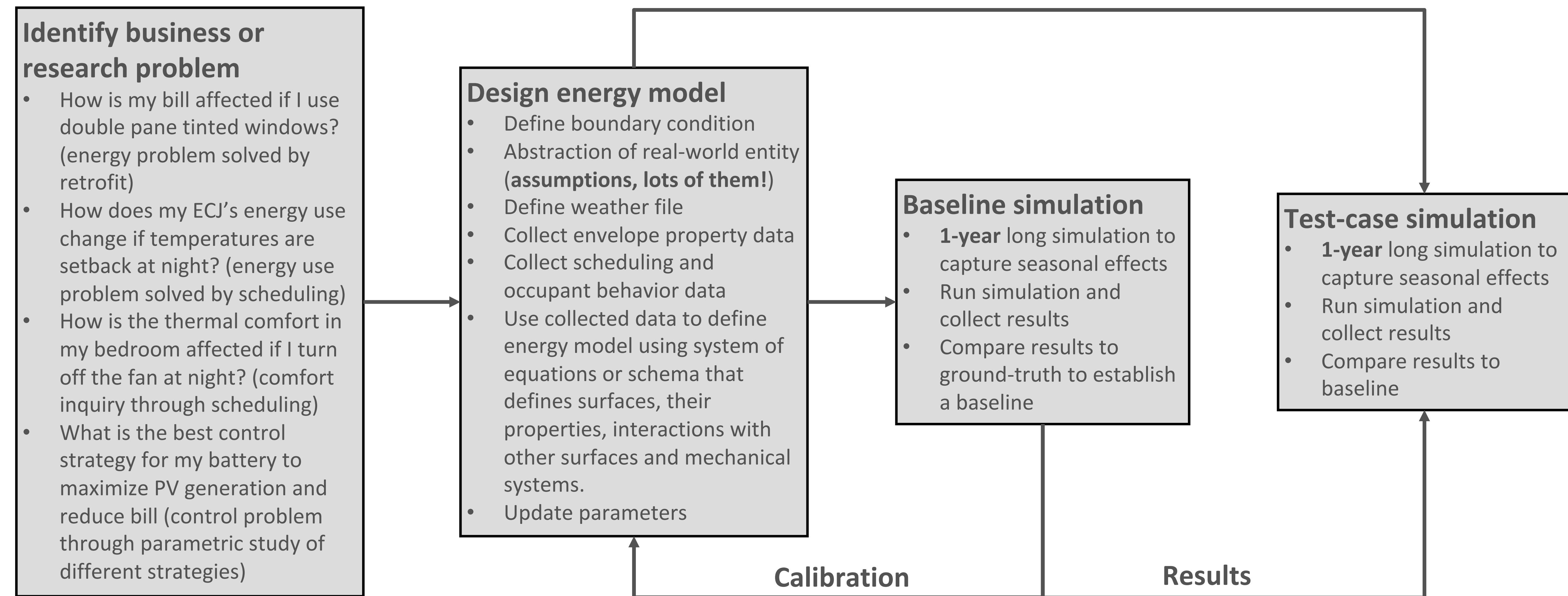
- **1-year** long simulation to capture seasonal effects
- Run simulation and collect results
- Compare results to ground-truth to establish a baseline

Calibration

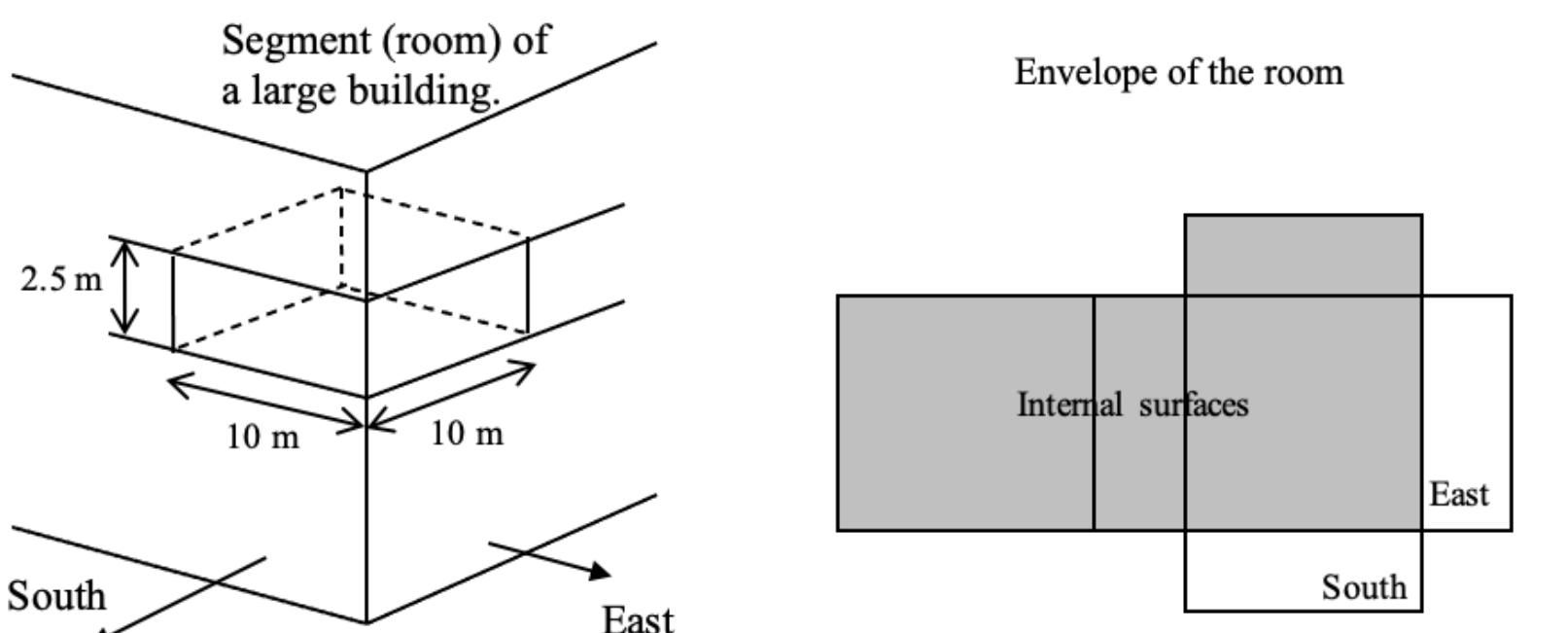
# Simulation lifecycle



# Simulation lifecycle

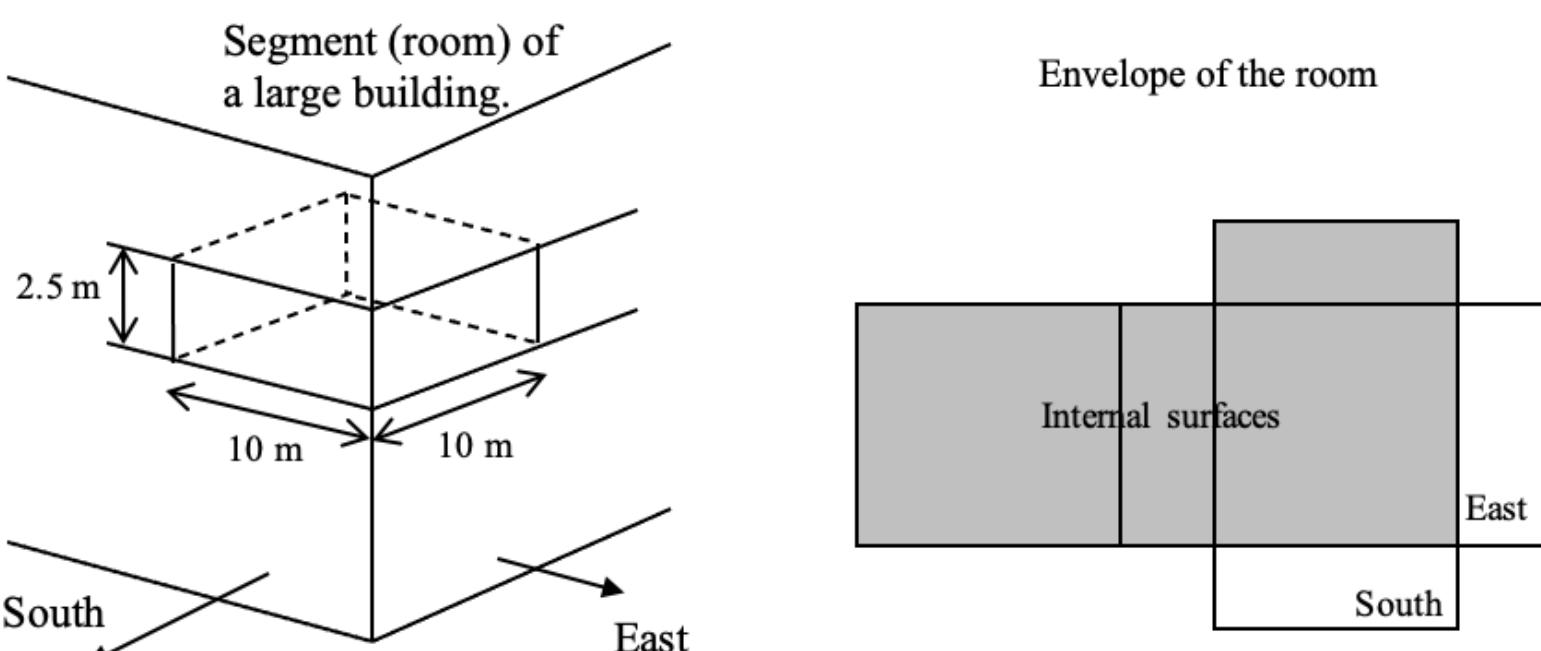


# In its simplest form, an energy model is a solvable system of linear & non-linear equations



- Shoebox model of corner room
- Given a weather file and for different surface properties, occupancy and infiltration calculate:
  - the wall temperatures
  - air temperature
  - HVAC energy needed to maintain setpoint.

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- Given a weather file and for different surface properties, occupancy and infiltration calculate:
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```

%% Iterations
disp('Solving system of equations...')
for i=2:(timesteps+1)
    disp(i)
    %% Node equations
    %% South Wall
    % 1.1
    q_condtosurf1_1 = 0;

    q_swrlsolto1_1 =...
        n1_1.therm_mass.area...
        * (n1_1.therm_mass.sol_dir_rad(i) + n1_1.therm_mass.sol_dif_tot_rad(i))...
        * n1_1.therm_mass.material.abs_swr;

    q_lwr_skyto1_1 =... % Linearized
        n1_1.therm_mass.area * f1_sky * n1_1.therm_mass.material.emm_lwr...
        * n_sky.therm_mass.material.emm_lwr * sb_const...
        * (n_sky.temp(i-1)^2 + n1_1.temp(i-1)^2)...
        * (n_sky.temp(i-1) + n1_1.temp(i-1)) * (n_sky.temp(i) - n1_1_temp_new);

    q_lwr_groundto1_1 =... % Linearized
        n1_1.therm_mass.area * f1_g * n1_1.therm_mass.material.emm_lwr...
        * n_ground.therm_mass.material.emm_lwr * sb_const...
        * (n_ground.temp(i-1)^2 + n1_1.temp(i-1)^2)...
        * (n_ground.temp(i-1) + n1_1.temp(i-1)) * (n_ground.temp(i) - n1_1_temp_new);

    q_conv_eato1_1 =...
        n1_1.therm_mass.area * n1_1.h(i) * (n_ea.temp(i) - n1_1_temp_new);

    q_cond_1_2to1_1 =...
        n1_1.therm_mass.area * n1_1.therm_mass.material.cond/(n1_1.therm_mass.delta_x/2)...
        * (n1_2_temp_new - n1_1_temp_new);

    eq1_1 =...
        q_condtosurf1_1...
        - (q_swrlsolto1_1 + q_lwr_skyto1_1 + q_lwr_groundto1_1 + q_conv_eato1_1 + q_cond_1_2to1_1);

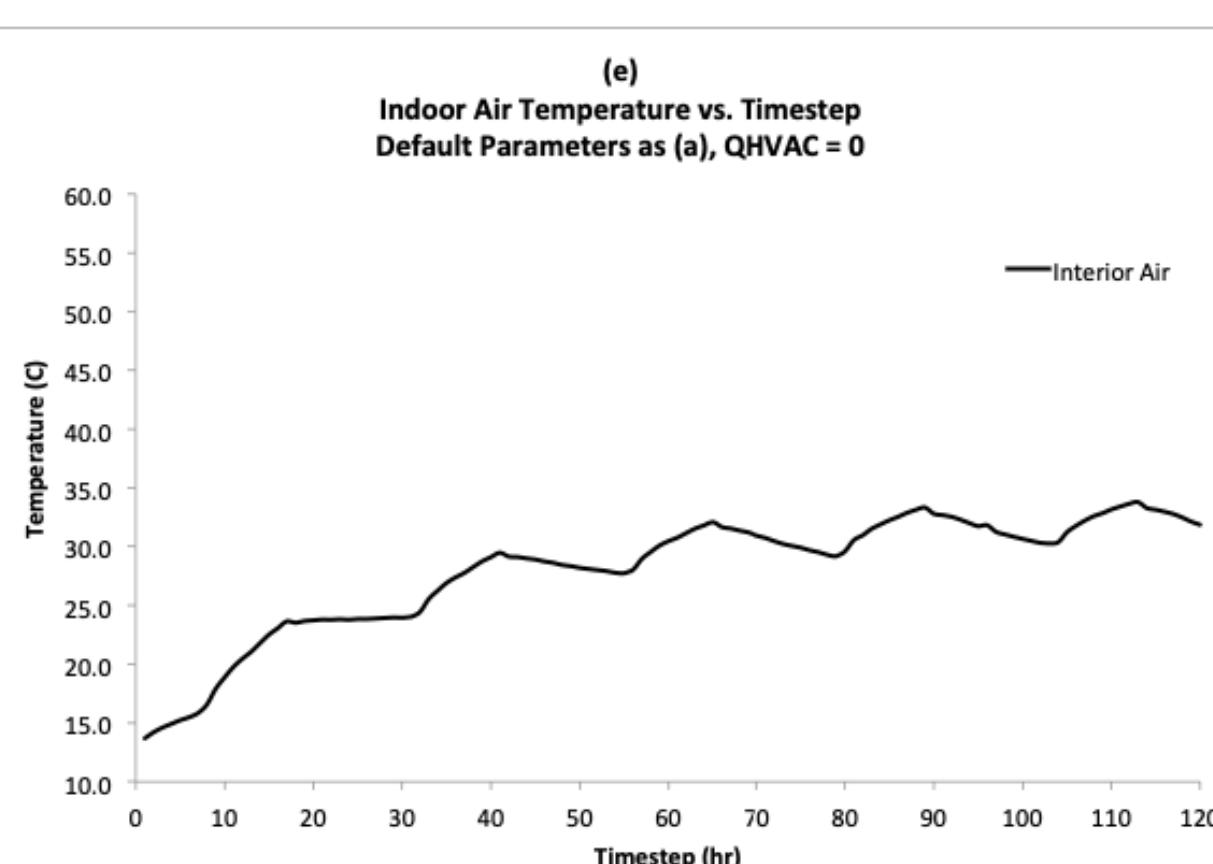
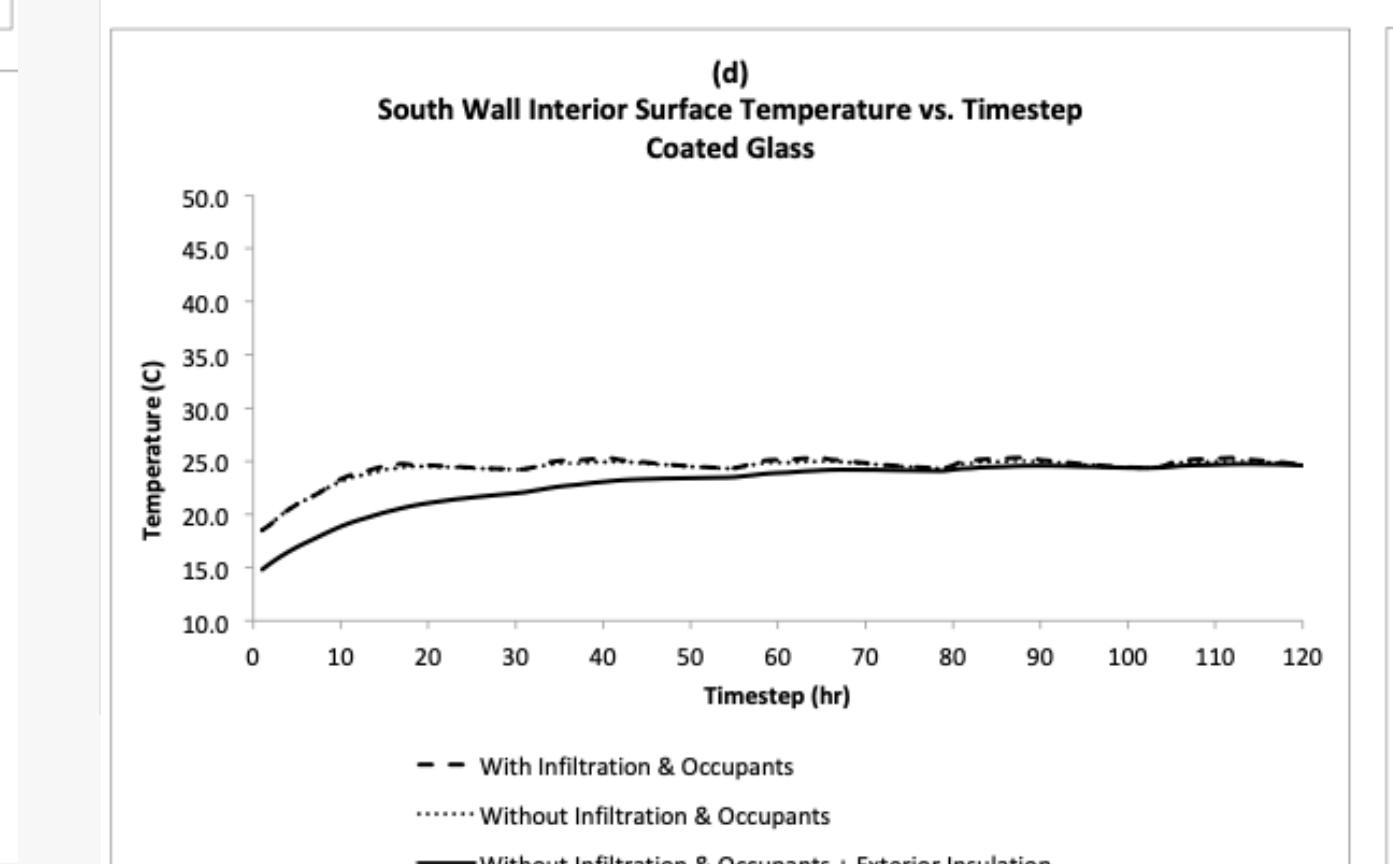
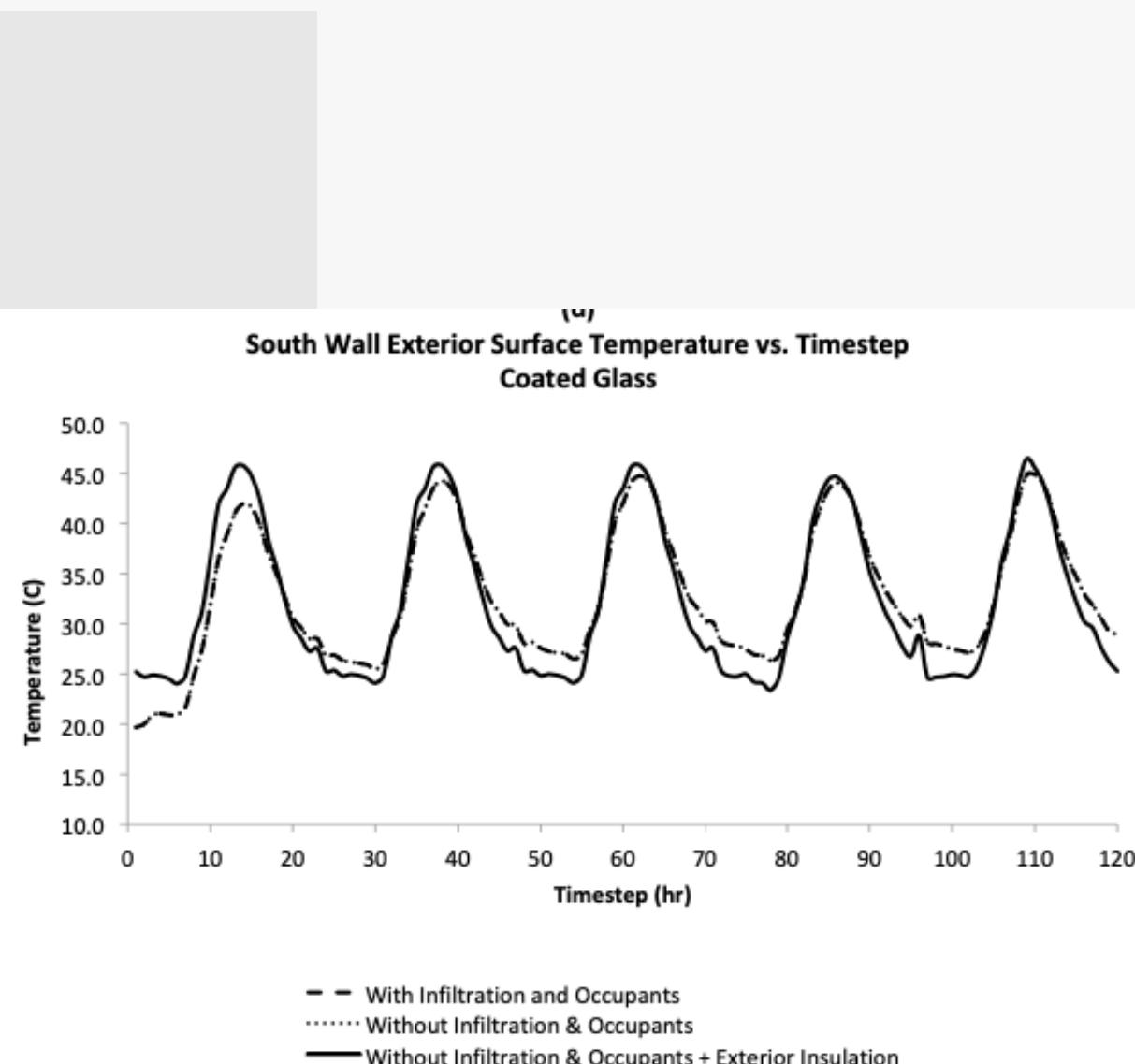
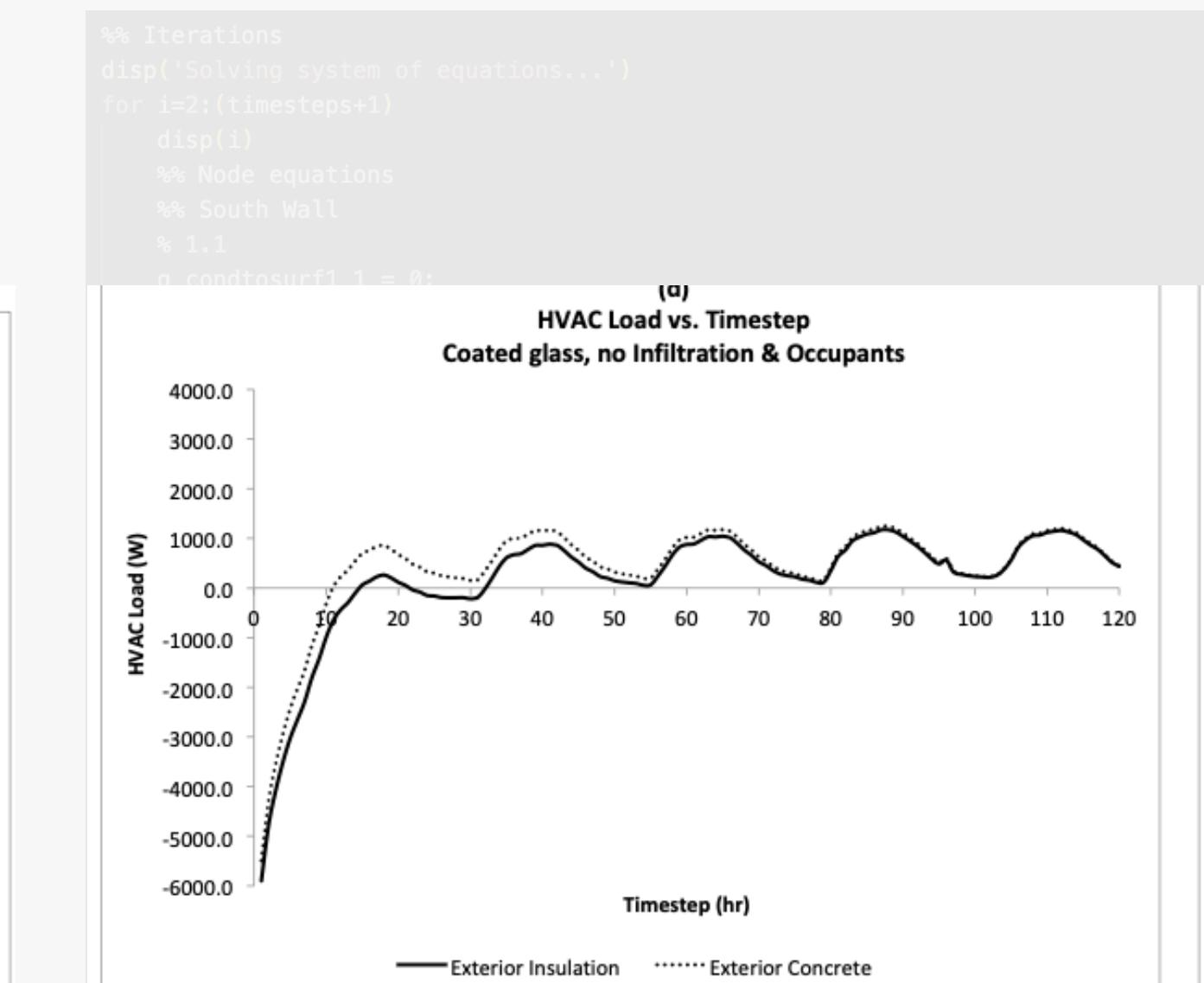
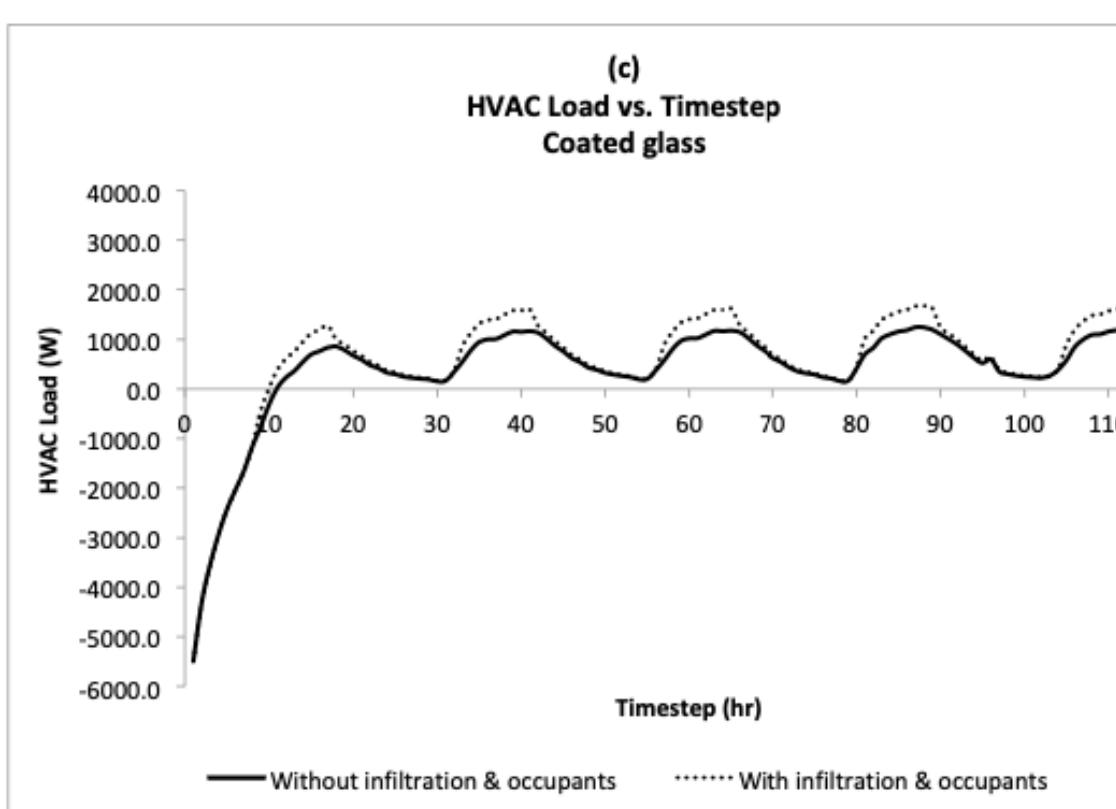
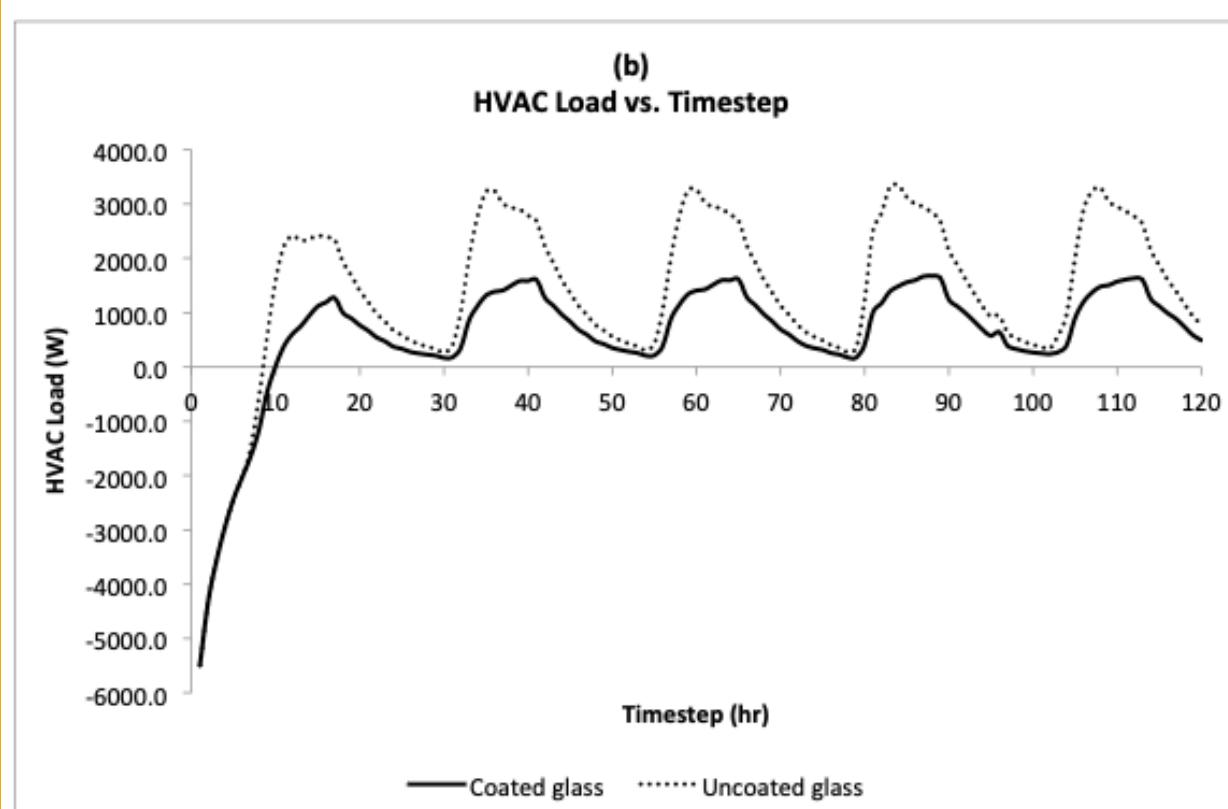
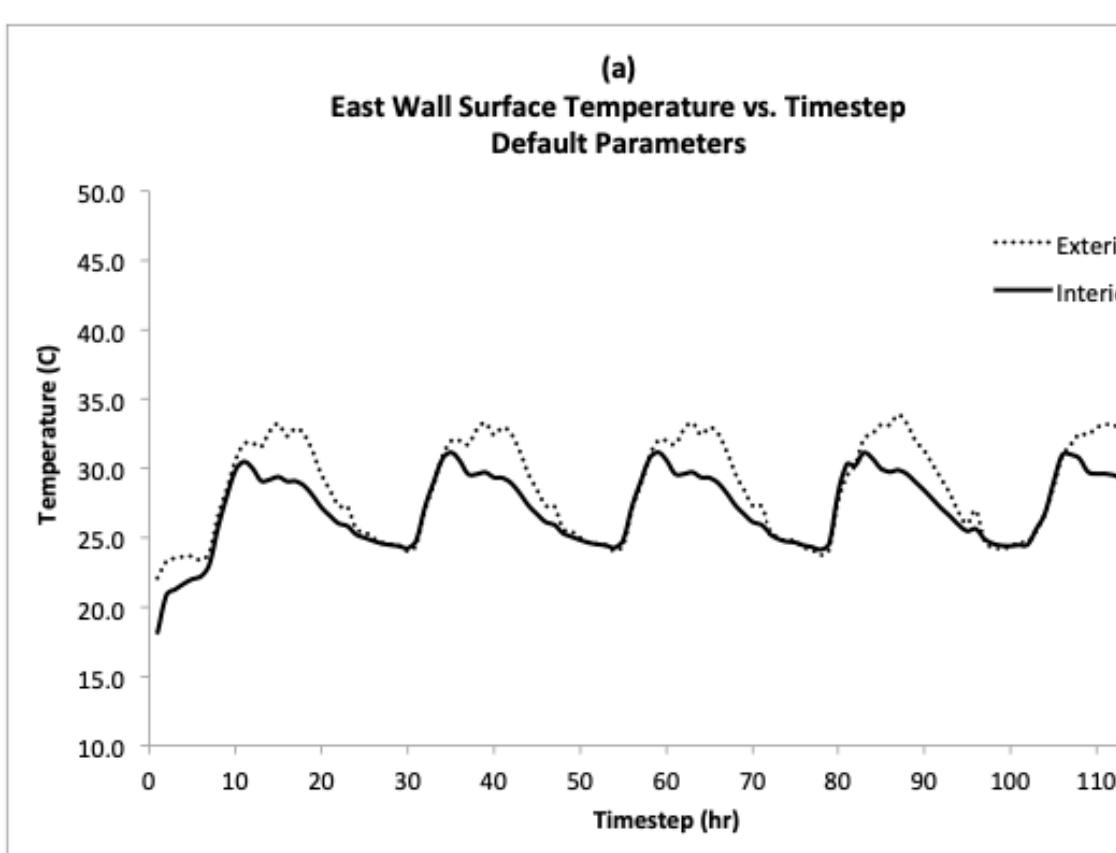
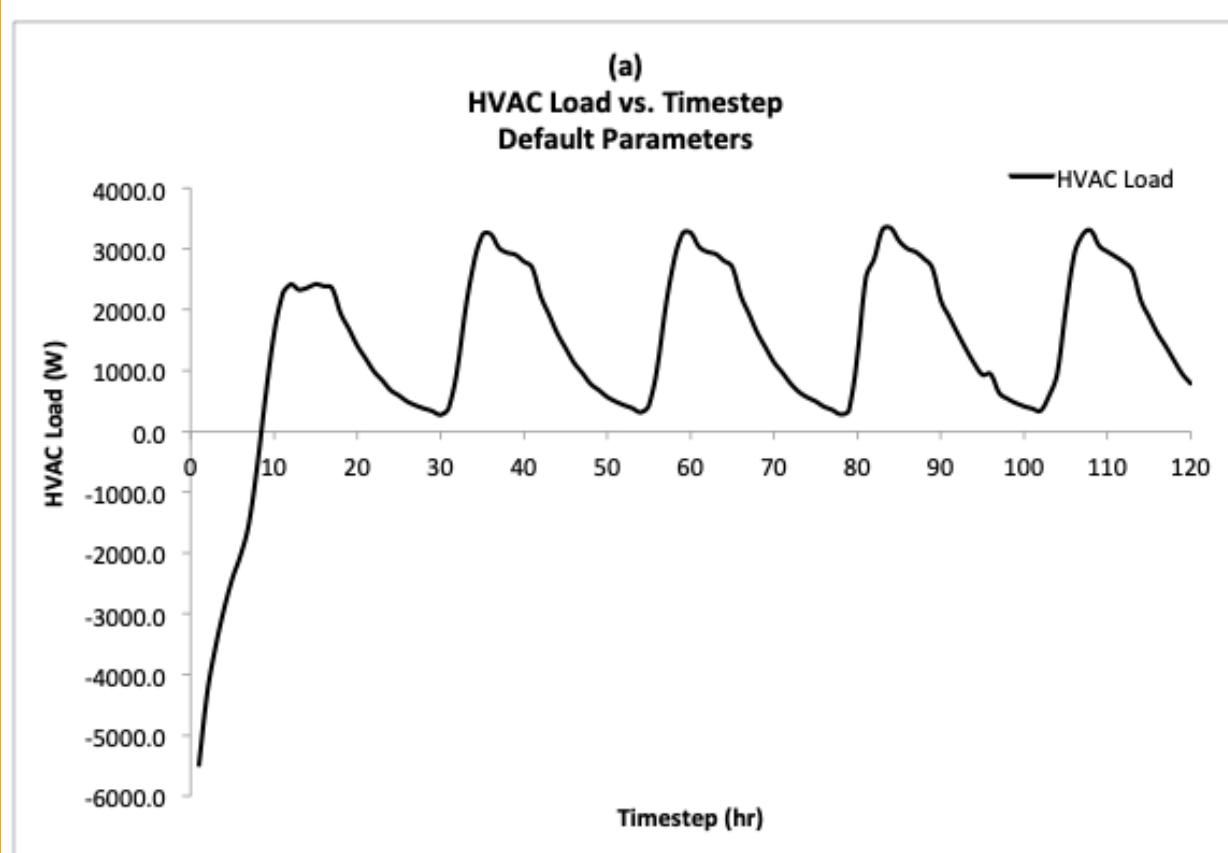
    % 1.2
    q_condtosurf1_2 =...
        n1_2.therm_mass.material.density * n1_2.therm_mass.area...
        * n1_2.therm_mass.delta_x * n1_2.therm_mass.material.spec_cap...
        * (n1_2_temp_new - n1_2.temp(i-1))/delta_time;

    q_cond_1_1to1_2 =...
        n1_2.therm_mass.area * n1_2.therm_mass.material.cond/(n1_2.therm_mass.delta_x/2)...
        * (n1_1_temp_new - n1_2_temp_new);
    
```

- Reduced to a system of 14 linear equations and 14 unknowns
- Solved deterministically using *hand calculation*?, numerical solver e.g. in MATLAB, Python or any preferred language that supports numerical analysis



## In its simplest form an energy model is a solvable system of



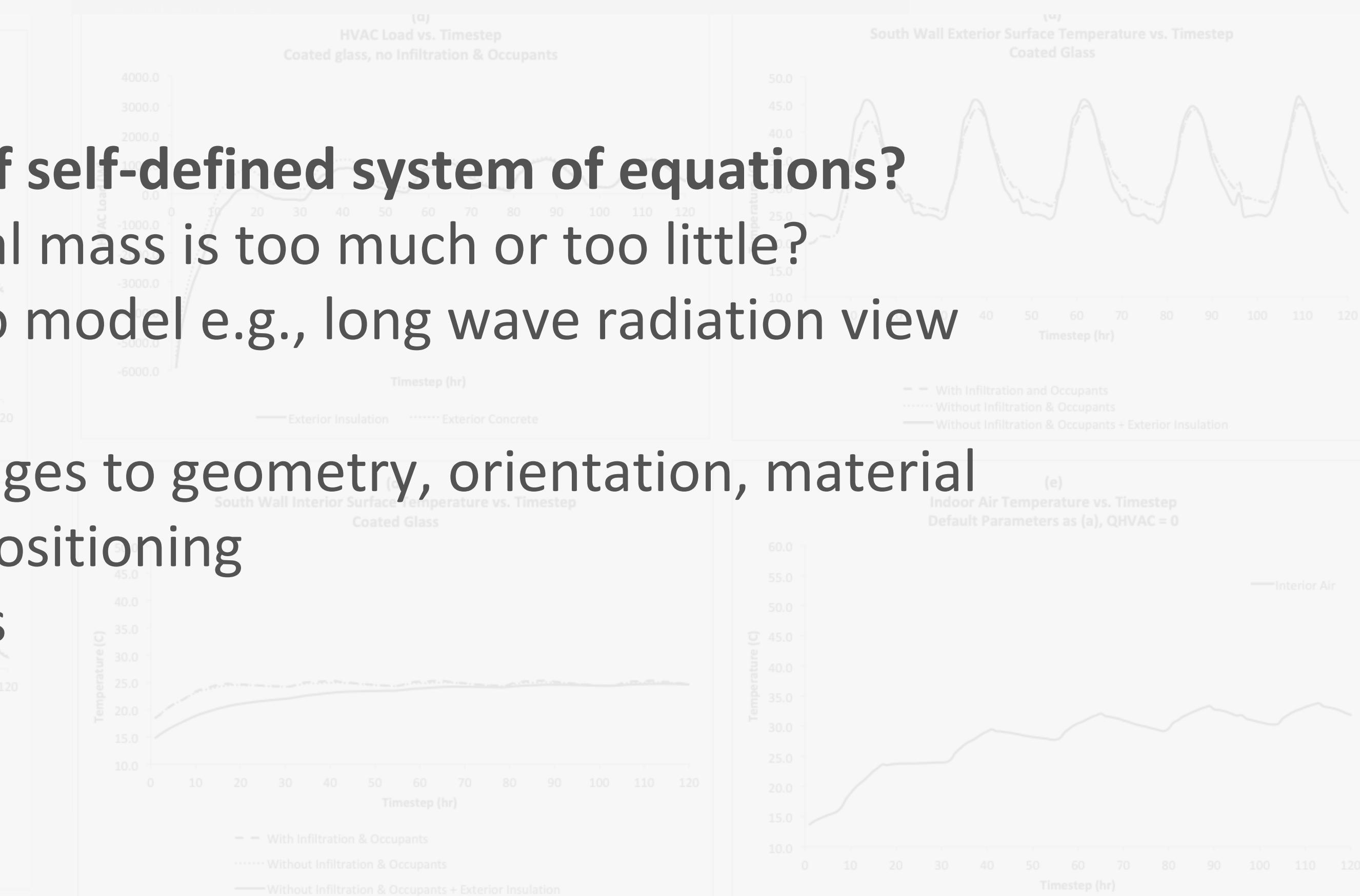
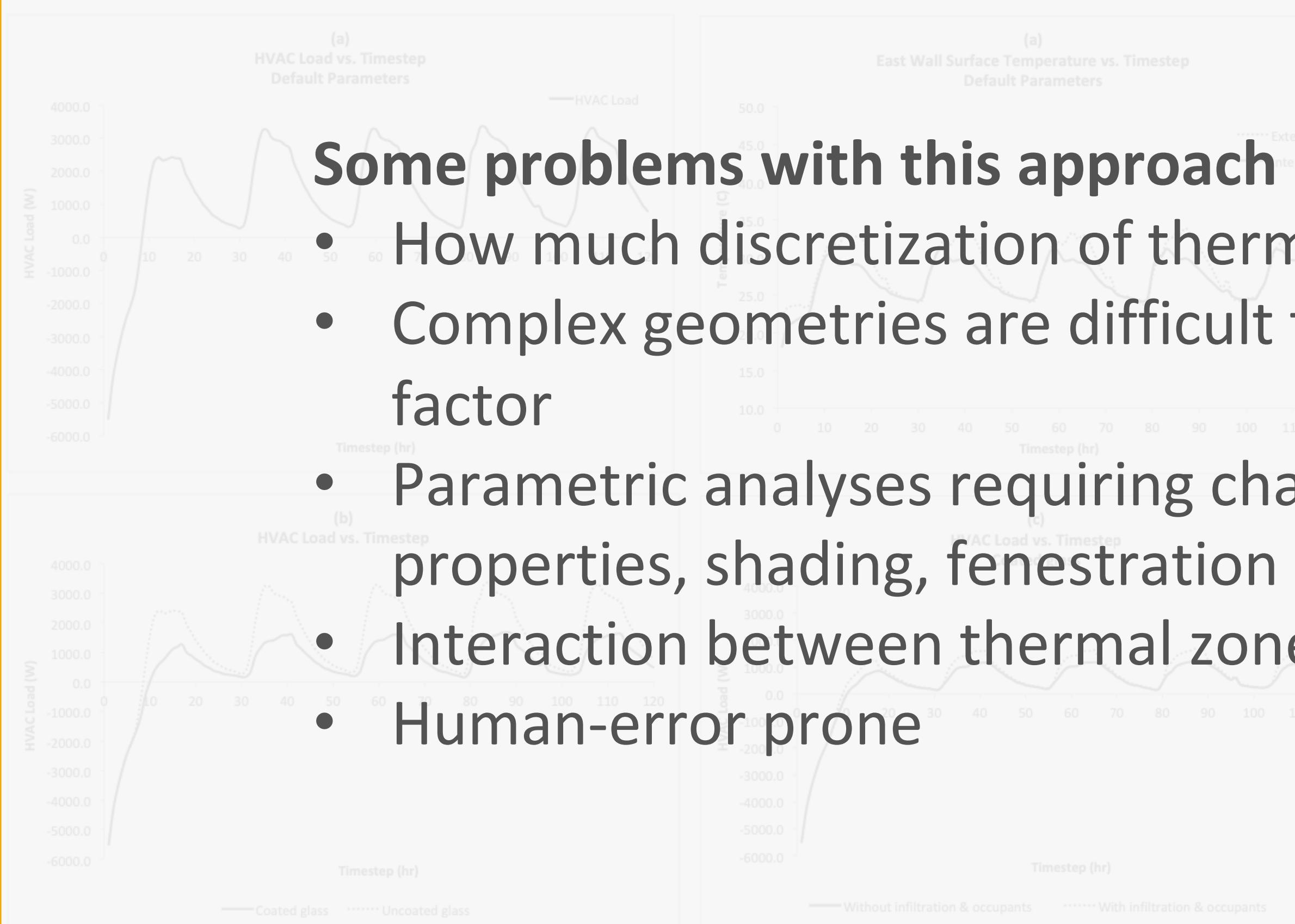
- air temperature
- HVAC energy needed to maintain setpoint.

## Results after 5 days of simulation

- Solved deterministically using *hand calculation*?  
• numerically in MATLAB, Python or any preferred language that supports numerical analysis

## Some problems with this approach of self-defined system of equations?

- How much discretization of thermal mass is too much or too little?
- Complex geometries are difficult to model e.g., long wave radiation view factor
- Parametric analyses requiring changes to geometry, orientation, material properties, shading, fenestration positioning
- Interaction between thermal zones
- Human-error prone



• All temperature  
 HVAC energy needed to maintain  
 setpoint

• Solved deterministically using hand calculation?  
 MATLAB, Python or any  
 preferred language that supports numerical

# Simulation engines and their applications

- Some factors affecting choice of engine and GUI:
  - Experience entry level and learning curve
  - Cost
  - Available HVAC systems
  - Desired model Level of Detail
  - Documentation
  - Customer support
  - Modularity and developer support for full control e.g. SDK
  - General ease of use in terms of UI/UX

Simulation engine	Developer	first Release	Technology	Modeling Language	License	latest Version	Modeler applications and GUI
ApacheSim <sup>[45]</sup>	Integrated Environmental Solutions Ltd., UK				Commercial	6.0	VE 2018 <sup>[46]</sup>
Carrier HAP <sup>[47]</sup>	United Technologies, US				Commercial	5.11	Carrier HAP
COMFIE <sup>[48]</sup>	Mines ParisTech, then IZUBA énergies, FR	1994			Commercial	5.21.3.0	Pleiades
DOE-2 <sup>[49]</sup>	James J. Hirsch & Associates, US	1978			Freeware	2.2	eQuest, <sup>[50]</sup> RIUSKA, <sup>[51]</sup> EnergyPro, [52] GBS <sup>[53]</sup>
EnergyPlus <sup>[54]</sup>	Lawrence Berkeley National Laboratory, US	2001			Freeware	9.4.0	DesignBuilder, <sup>[55]</sup> OpenStudio, <sup>[56]</sup> cove.tool, <sup>[57][58]</sup> Many other <sup>[59]</sup>
ESP-r <sup>[60]</sup>	University of Strathclyde, UK	1974			Freeware	11.11	ESP-r
IDA <sup>[39]</sup>	EQUA Simulation AB, SE	1998	DAE	NMF, Modelica	Commercial	4.8	ICE, <sup>[39]</sup> ESBO <sup>[61]</sup>
SPARK <sup>[62]</sup>	Lawrence Berkeley National Laboratory, US	1986	DAE		Freeware	2.01	VisualSPARK
TAS <sup>[63]</sup>	Environmental Design Solutions Limited, UK				Commercial	9.5.0	TAS 3D Modeler
TRNSYS <sup>[64]</sup>	University of Wisconsin-Madison, US	1975		FORTRAN, C/C++	Commercial	18.0	Simulation Studio, <sup>[65]</sup> TRNBuild

[https://en.wikipedia.org/wiki/Building\\_performance\\_simulation](https://en.wikipedia.org/wiki/Building_performance_simulation)



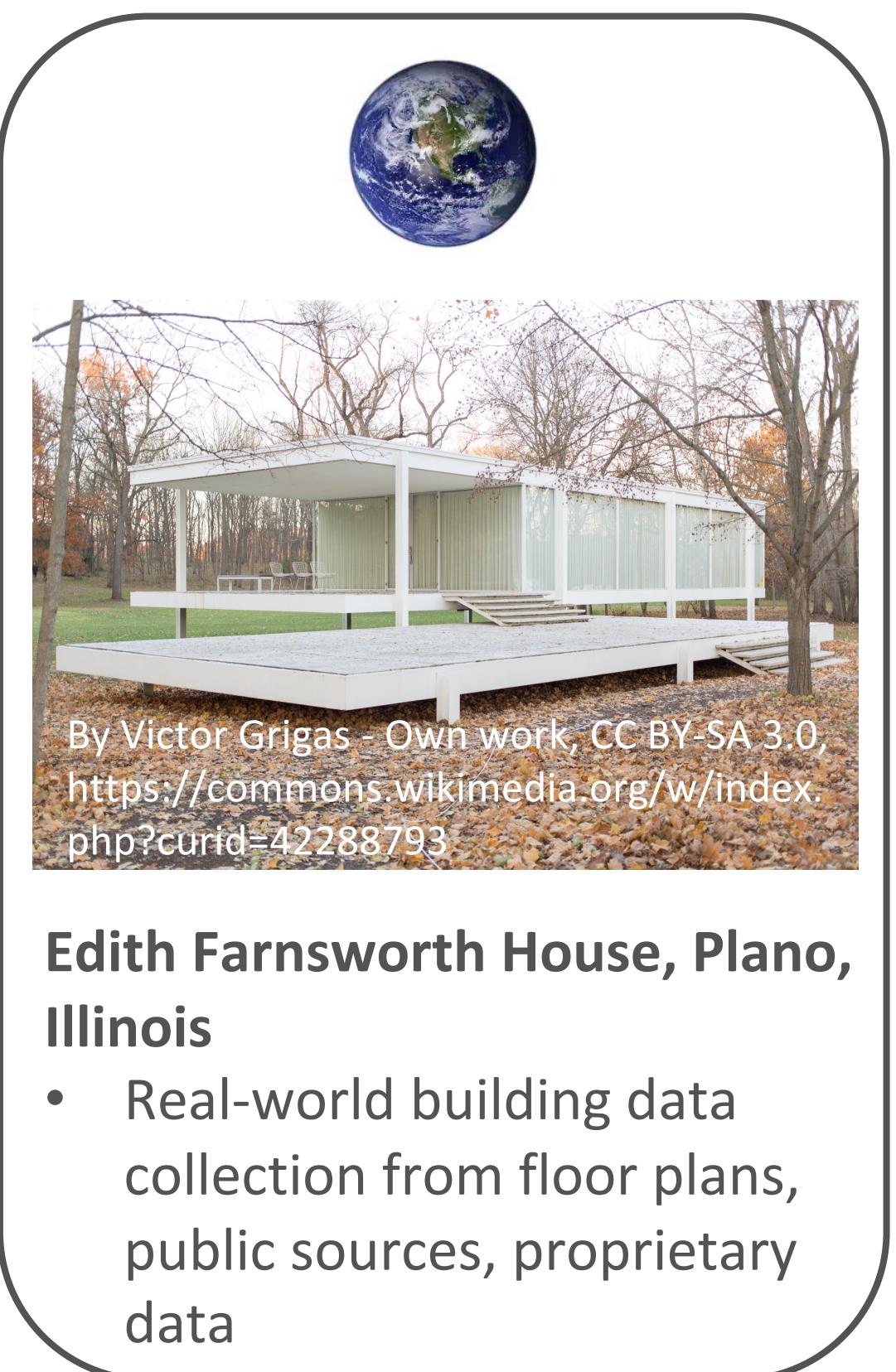
# EnergyPlus for this class

- Advantages**
  - Open source
  - Lots of applications in academia, research and industry
  - Large community support
  - Regular updates
  - Highly documented
  - Comprehensive library of mechanical systems
  - Ready-to-use representative energy models
  - Cross-platform
  - Python SDK

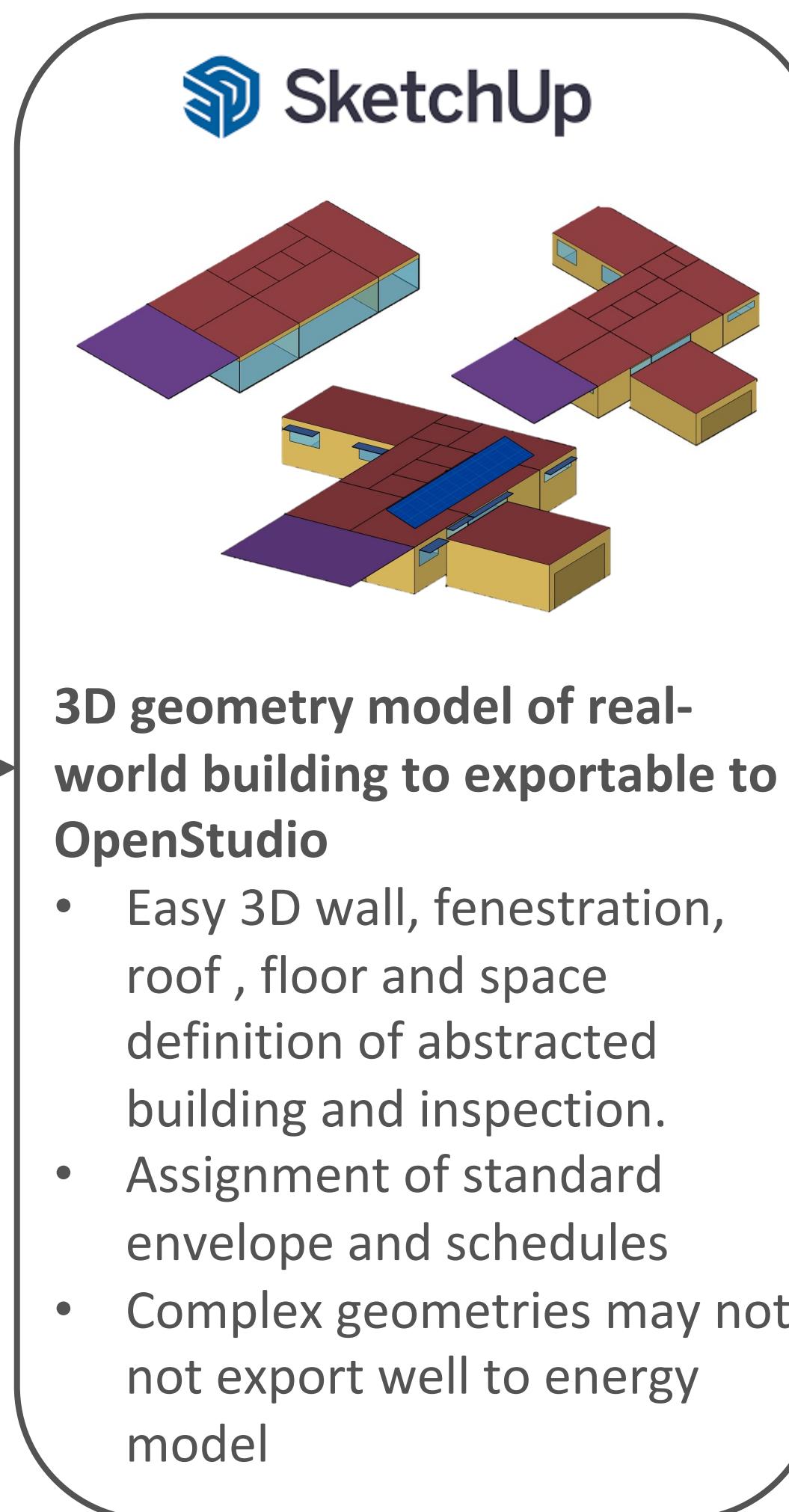
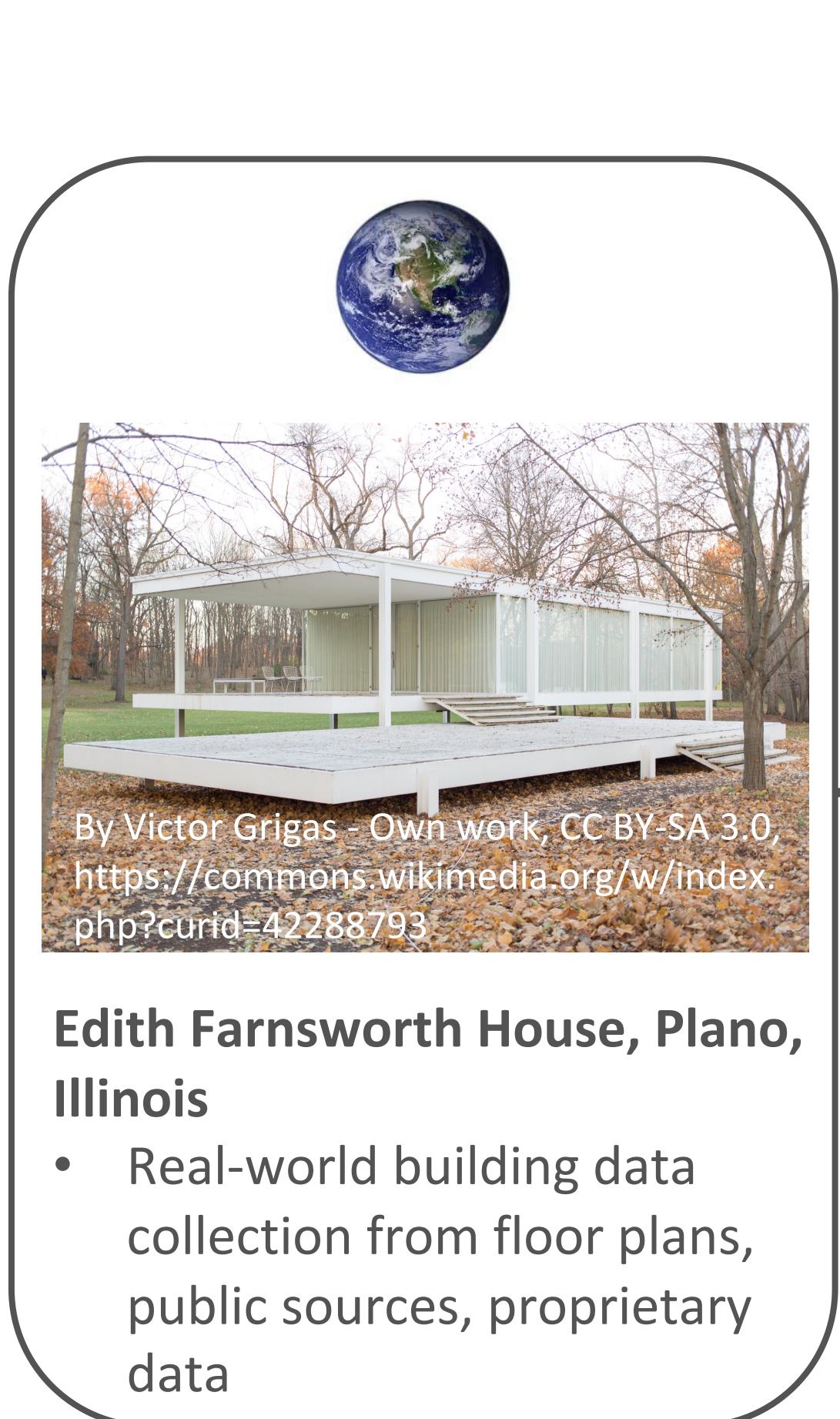
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# e+ Typical EnergyPlus workflow



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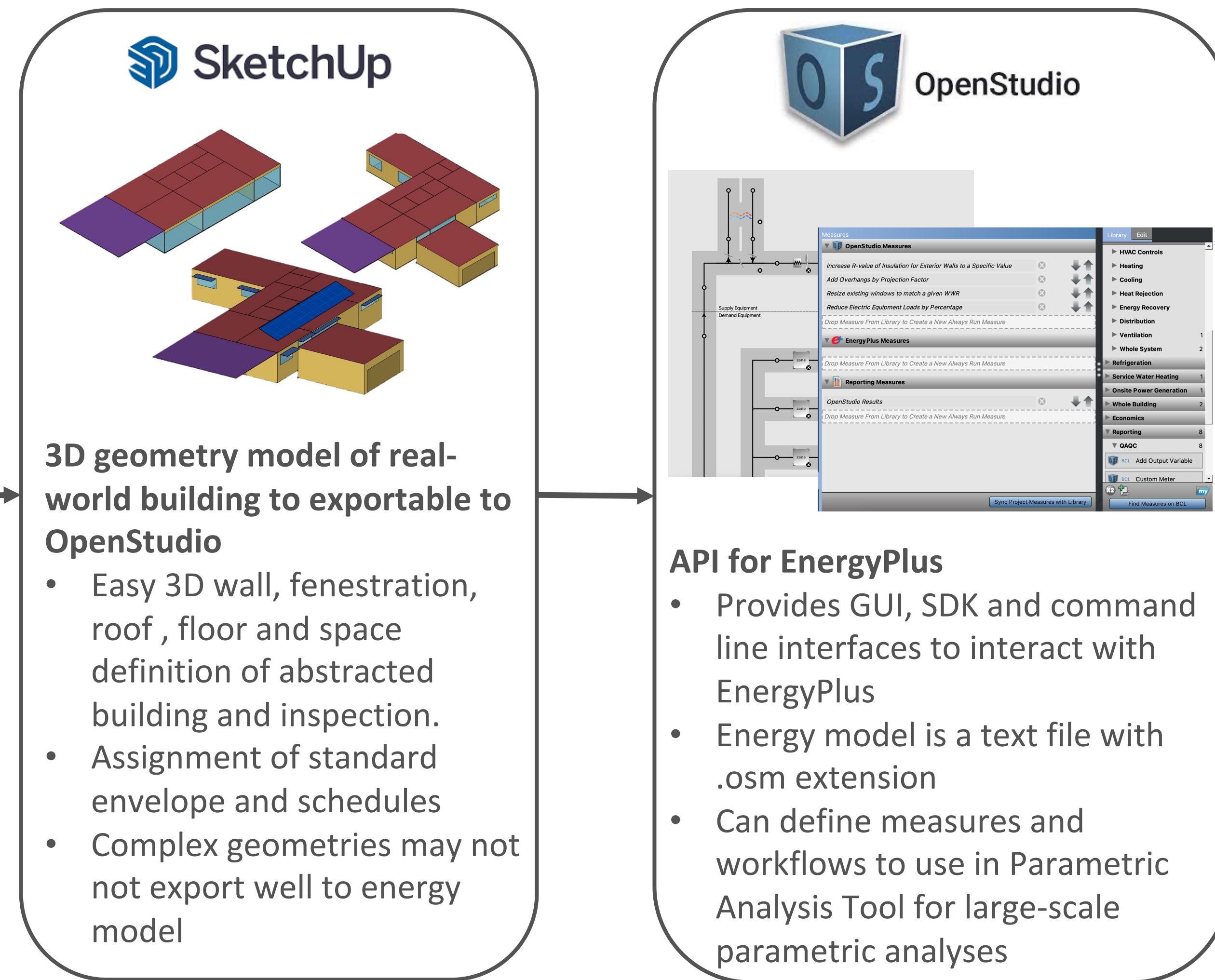


# e+ Typical EnergyPlus workflow



## Edith Farnsworth House, Plano, Illinois

- Real-world building data collection from floor plans, public sources, proprietary data

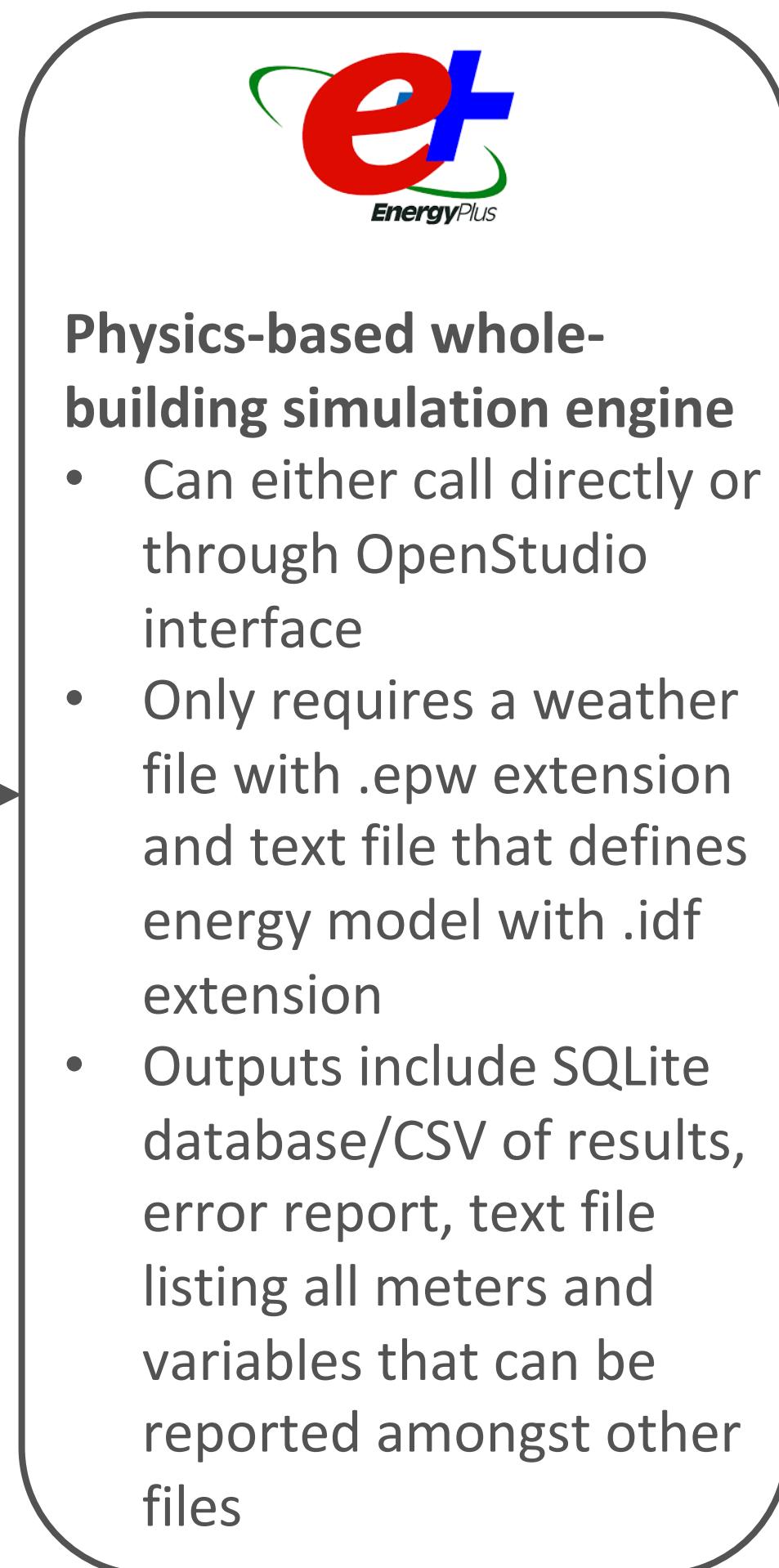
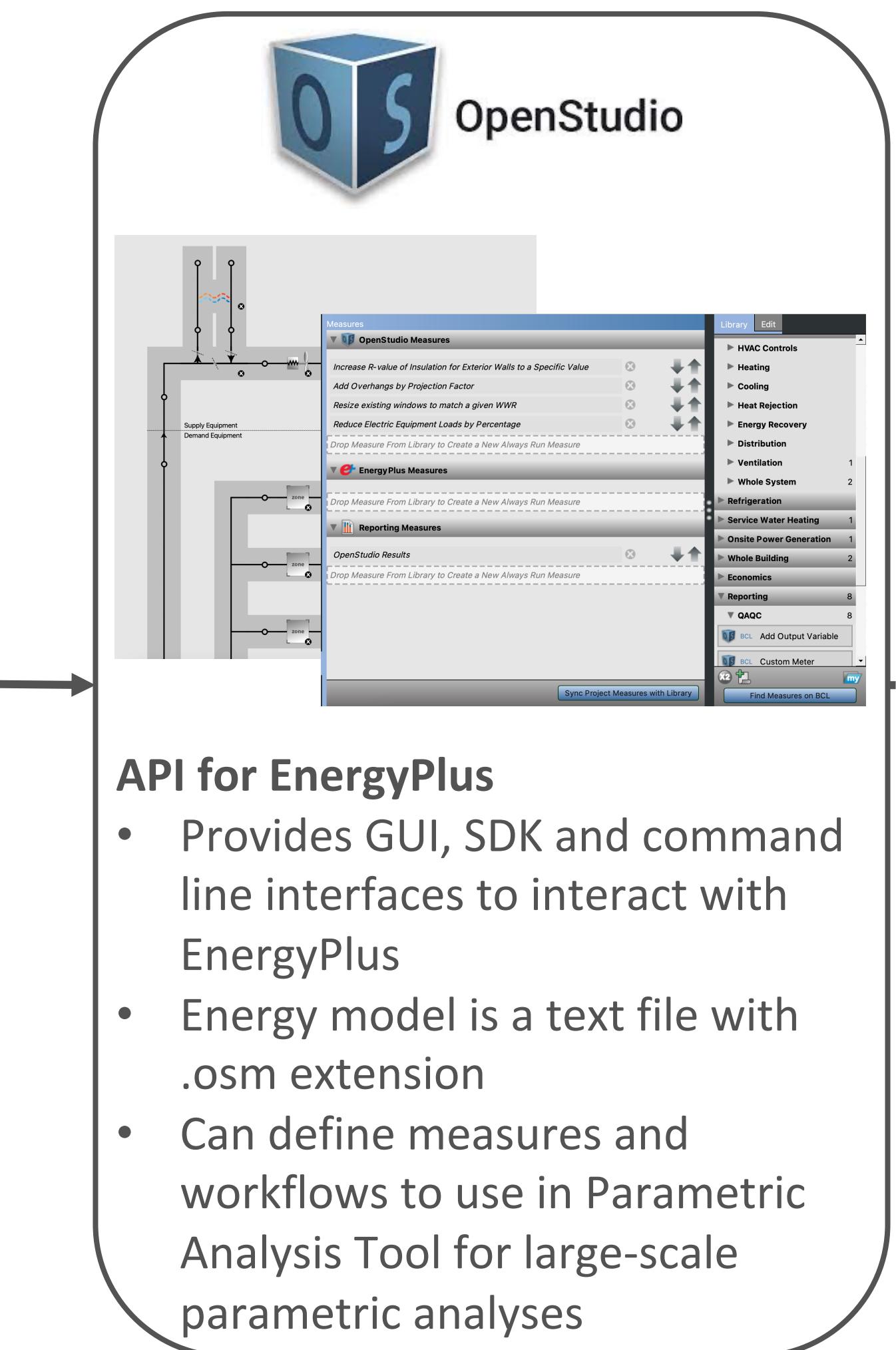
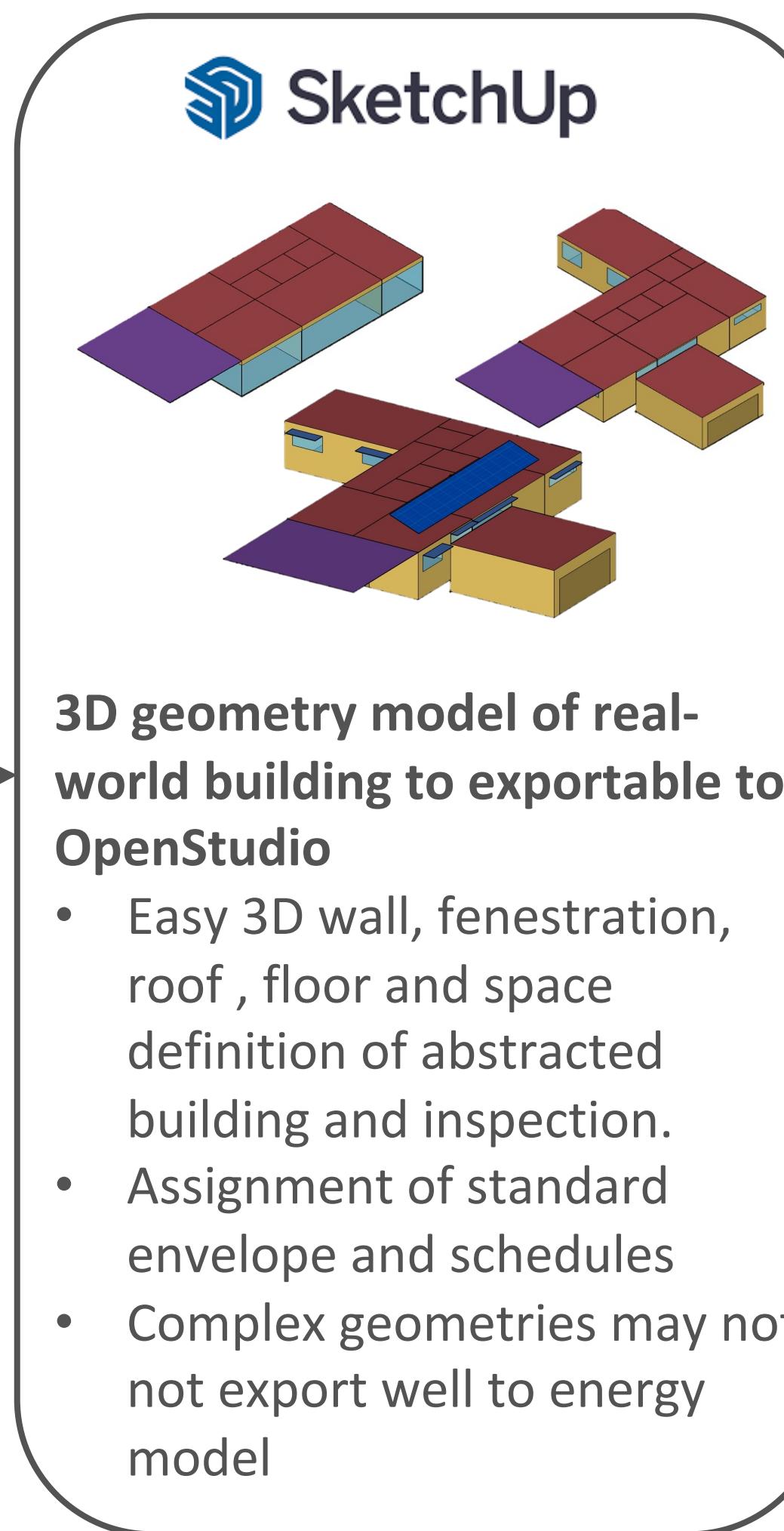


# e+ Typical EnergyPlus workflow



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# EnergyPlus workflow challenges

- Steep learning curve
- High modeling cost time and experience wise
- Garbage in, garbage out
- Geometry generation software e.g., SketchUp not free
- OpenStudio model not backwards compatible with SketchUp
- Many properties to select from and set
- Real-world building properties are not always readily available and require A LOT of assumptions starting out the modeling process
- IDF, though comprehensive, not very readable as it is not clear instantly how objects are connected and can build up to be many lines of text

# e+ Stock building energy models

- 900k energy models representing 58 billion ft<sup>2</sup> commercial and 133 million residential units
- Save modeling time
- Fewer assumptions to be made
- Developed by experts
- QC/QA by national labs
- Representative of U.S. building stock circa 2018
- **We will use the residential stock in EULP for this class**

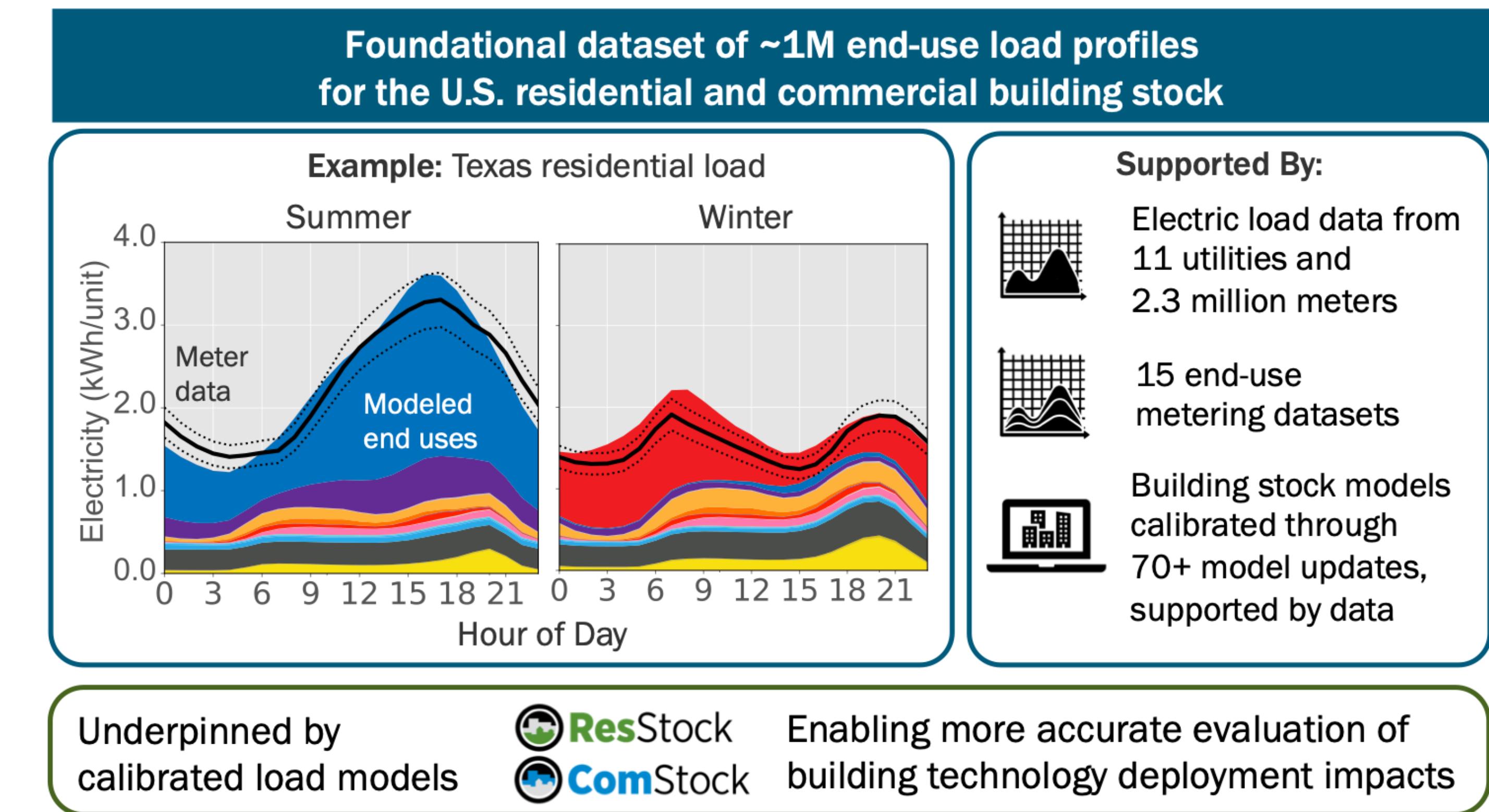


Figure ES-1. Graphical summary of the *End-Use Load Profiles* project

Wilson, Eric JH, et al. *End-use load profiles for the US building stock: Methodology and results of model calibration, validation, and uncertainty quantification*. No. NREL/TP-5500-80889. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2022

# Questions?

# Break

# Activity: Install EnergyPlus and run test simulations

- Install EnergyPlus v9.6.0
  - Option 1: Local installation using instructions in EnergyPlus documentation
  - Install temporarily in Colab environment
- Use provided activity notebook to modify EnergyPlus IDF file, run simulations and visualize results

# Homework help

Ask me questions about homeworks 1 (SQLite & AMI) and 2 (Clustering) ☺