

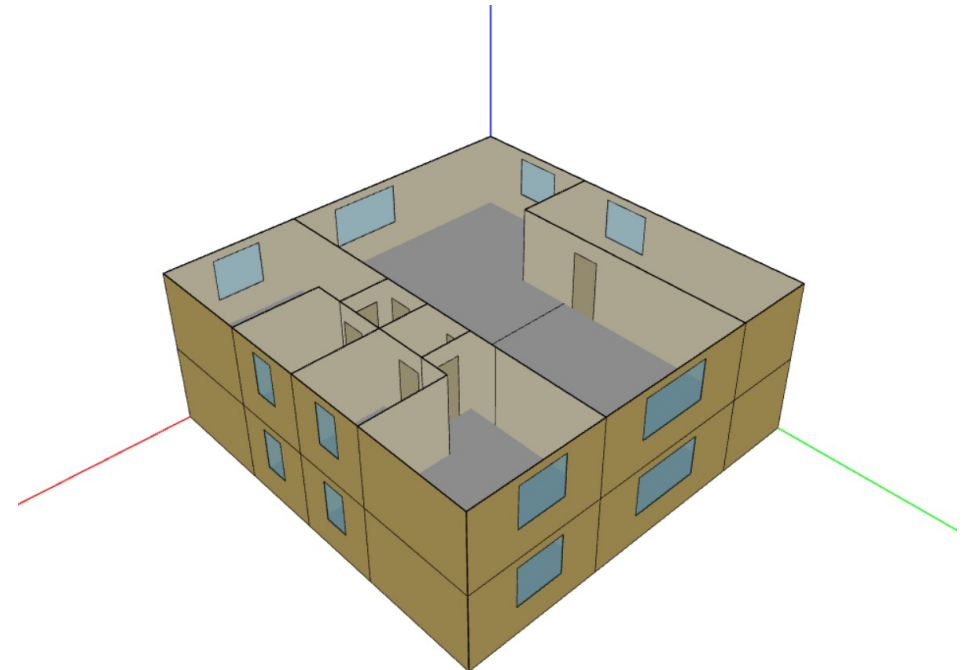
Introduction to building energy modeling

Andrew Sonta & Matteo Favero
ENG-445 Energy and Comfort in Buildings
11 September 2025

Course Project

- Scheduled time: Thursday 12:30-2:00 (see course schedule)
- Energy modeling of a building
- Part 1: individual modeling of a single apartment + energy performance strategies
- Part 2: group work on building modeling + design

Week	Date	Topic	Timing	Teacher	Project (AS, MF, TAs)
1	11/09	Course Introduction	45'	DL	Introduction (BPS) + Start individual project + Import geometry
		Climate change and energy			
		Energy use in buildings			
2	18/09	The value of human-centric buildings	45'	DL	Tutorial creating space types
		Quiz			
		On your own: Quick recall of units, heat transfer, psychometrics			
2	18/09	Thermal comfort, quick overview	45'	DL	Tutorial creating space types
		Overheating of buildings			
		Thermal comfort & energy efficiency			
2	18/09	Exercises	45'	DL	Tutorial creating space types



Learning goals

- Introduce building energy modeling
 - Inputs, outputs
 - Flow and logic
- Understand when energy modeling is appropriate
- Become familiar with EnergyPlus and OpenStudio
- Understand how energy modeling tools are used in practice

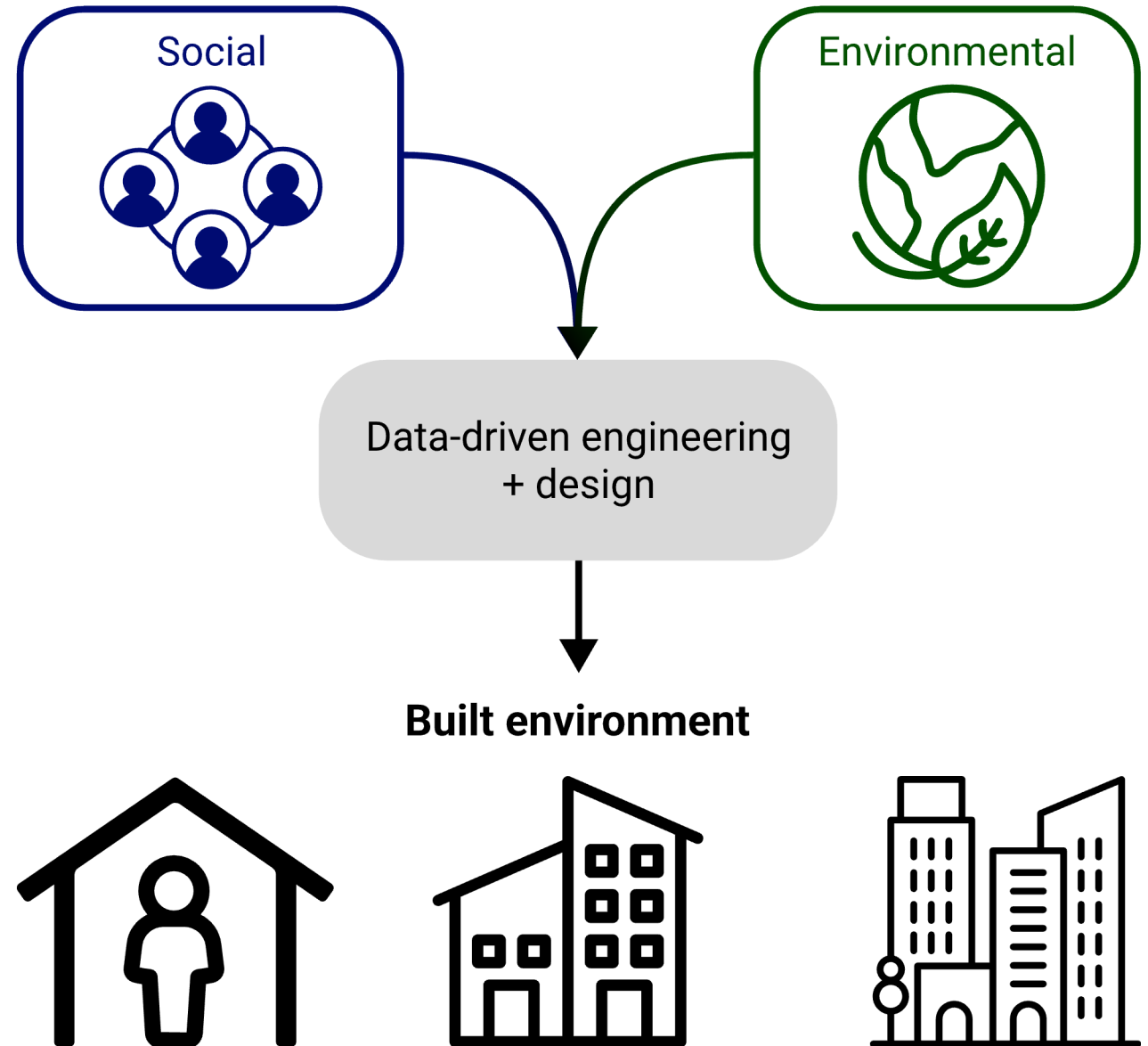
About me

- Academic Background
 1. BS Civil Engineering, Northwestern University
 2. MS/PhD Sustainable Design and Construction, Stanford University
 3. Postdoc, Data Science Institute, Columbia University
- Interdisciplinarity:
civil engineering, architecture,
data science, social science



ETHOS Lab

Engineering and Technology for Human Oriented Sustainability



Master Projects

<https://www.epfl.ch/labs/ethos/ethos-student-projects/>

- Demand flexibility provision in Swiss households (PDM only) ▼
- Large Language Model (LLM) Agent-Based Modeling (ABM) of Residential Energy Behavior under Flexible Load Management Scenarios ▼
- Data-driven inference of complex systems models of equity factors in the built environment using natural language processing ▼
- Data-driven analysis of city scale human-building interaction ▼
- Occupant-centric models for thermal comfort in buildings ▼
- Data-driven personalized comfort modeling in buildings ▼
- Sensing the Smart Living Lab's indoor environment ▼
- Understanding the similarities and differences in occupant behavior around the world based on domestic appliances usage ▼
- Strategies for demand side management based on insights from energy meter disaggregation ▼
- Clustering of urban form ▼

What is building energy modeling?

Building energy estimation
using a computer program
that simulates energy flows
and processes

Typically hour-by-hour for 1
year

Loads

- Cooling and heating loads

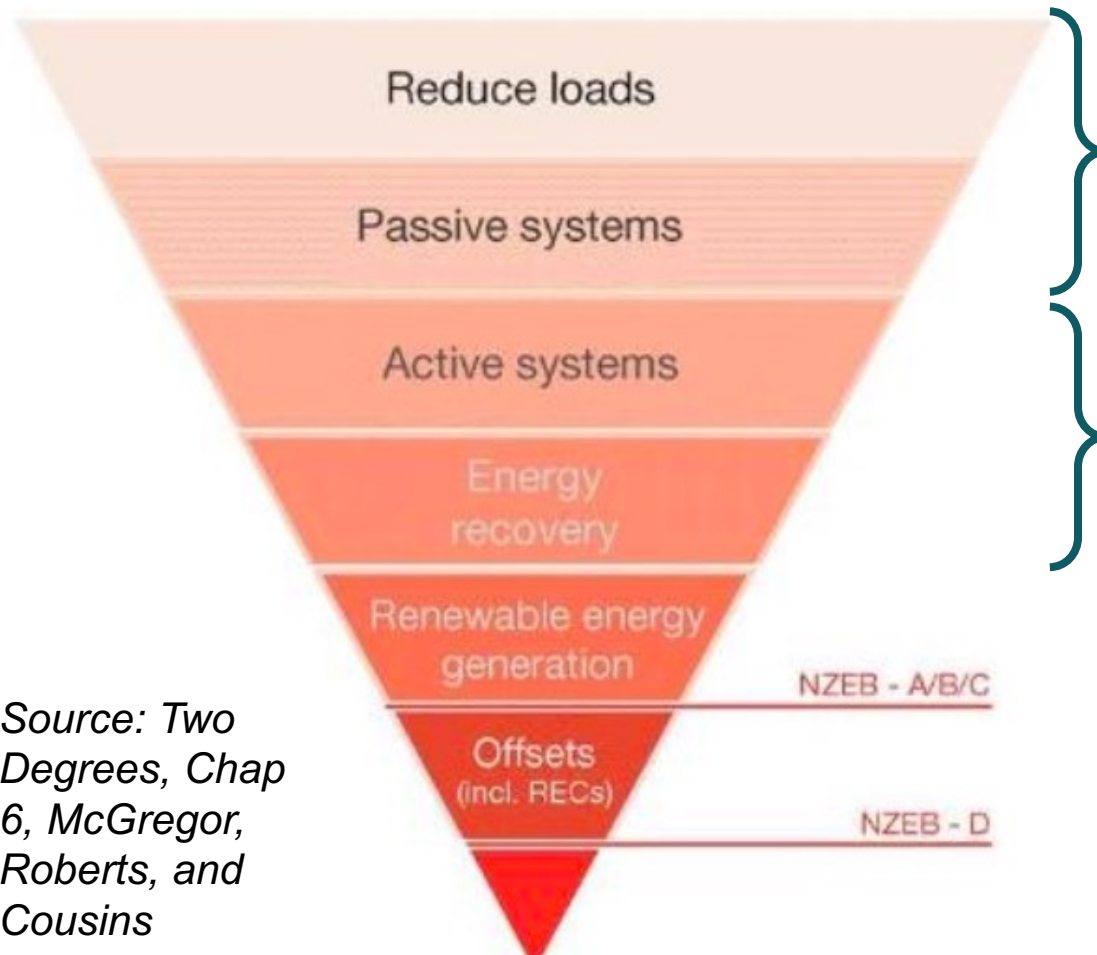
Energy

- Energy use of systems in response to loads

Cost

- Operating costs using energy data

Why perform simulation?



Predict energy demand

Understand the operation of buildings

Required by building standards for new constructions and renovations

Source: *Two Degrees, Chap 6, McGregor, Roberts, and Cousins*

What are the tools?



For our class



TRNSYS



DesignBuilder
SOFTWARE



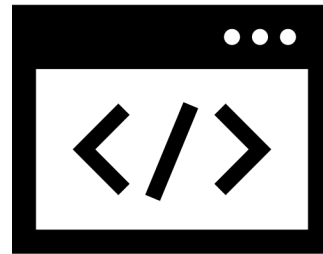
IDA ICE

Energy simulation flow

Inputs



Solver



Outputs



- Building characteristics
- System type
- Operation schedules
- (more on next slide...)

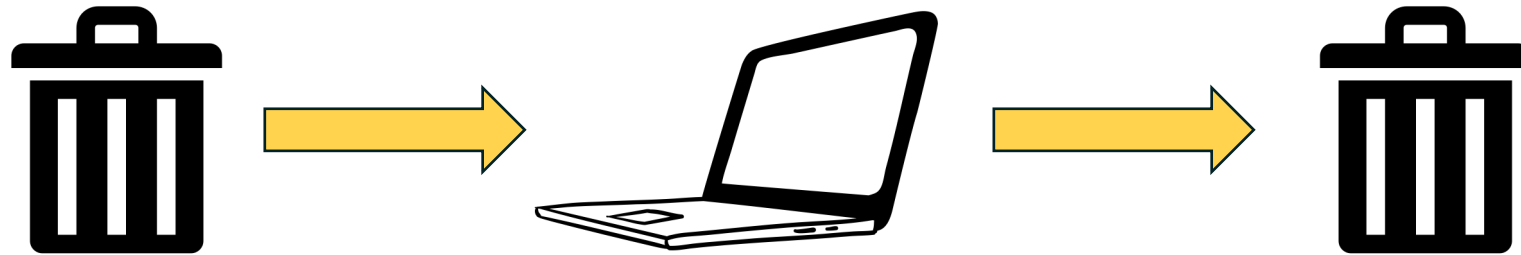
- Thermal balancing equations

- Energy demand and consumption
- Indoor environmental conditions
- Graphs/comparisons

Energy simulation inputs

- Weather data
- Building geometry
- Thermal zones
- Construction characteristics
 - Walls, roof, windows, floors
- Air infiltration rate
- Internal heat gains
 - Occupants
 - Lights
 - Equipment
 - Usage schedules
- HVAC type / usage
 - System type
 - Component performance
 - Ventilation rate
 - Controls, thermostat schedules
- Utility Rates
(for cost analysis)

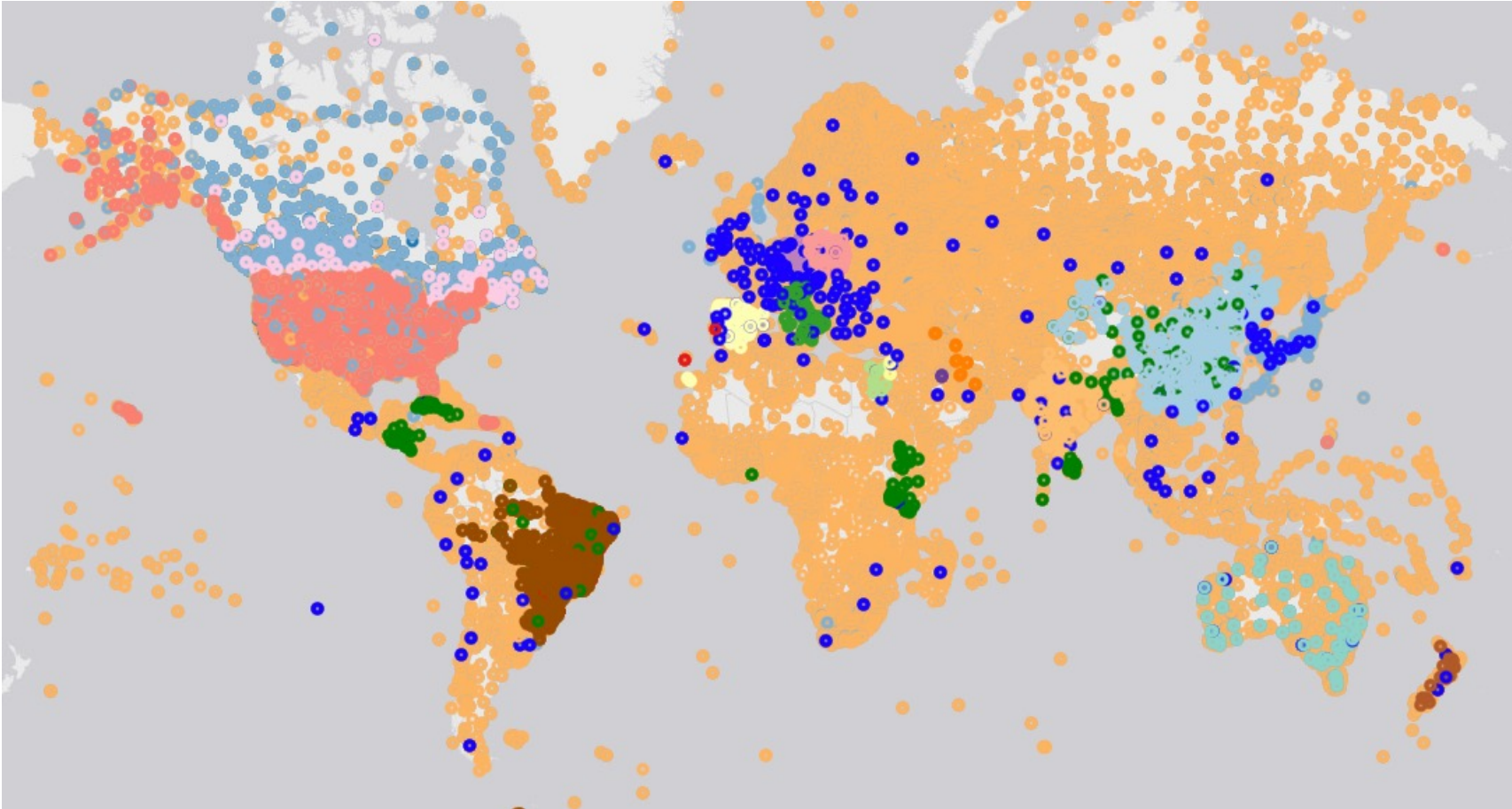
Important rule of modeling...



All models are wrong but some are useful.

- George E. P. Box

Weather data



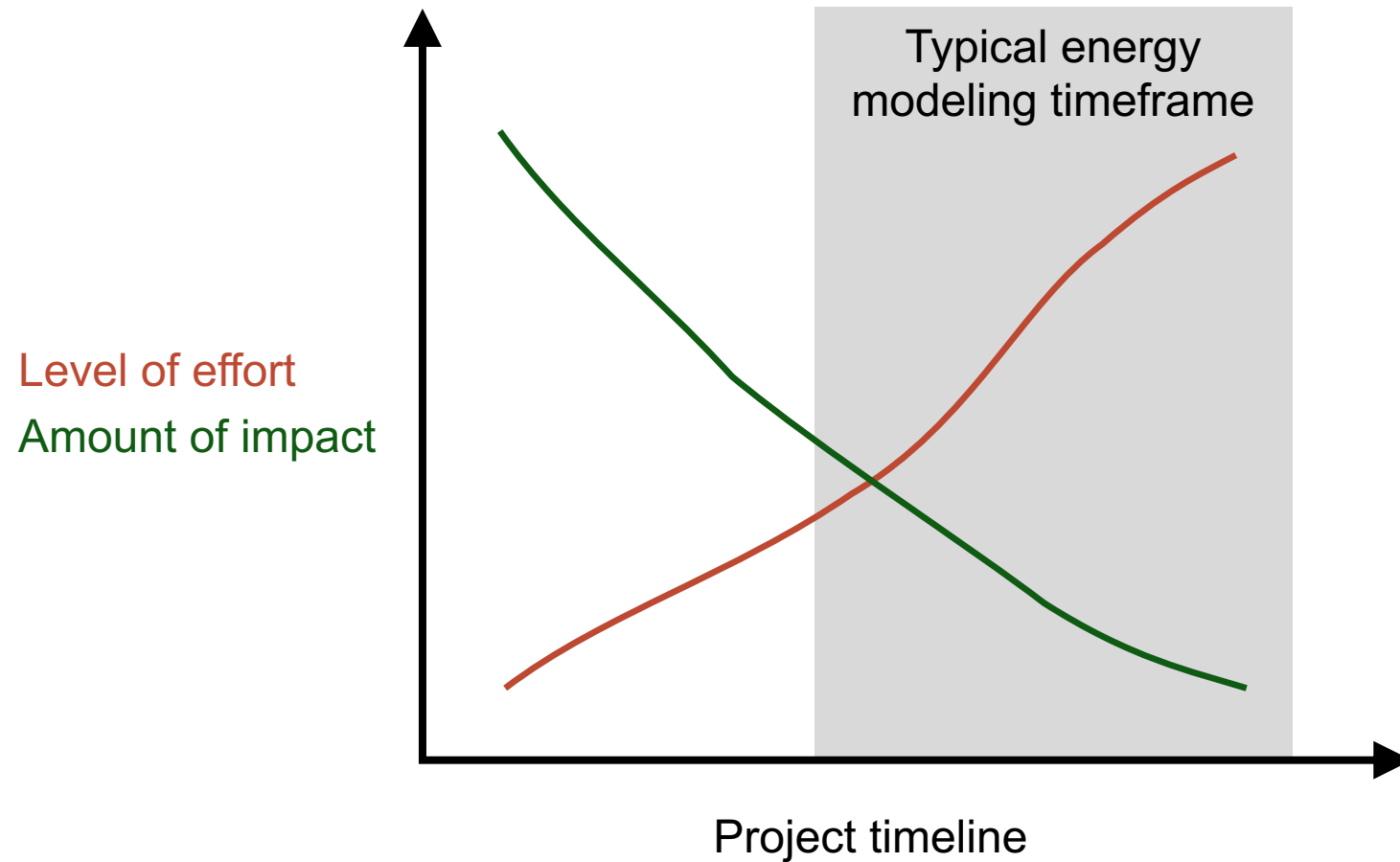
- Provide weather data for a typical year
- Multiple formats
- EnergyPlus Weather File: EPW

Source: Lady Bug Tools

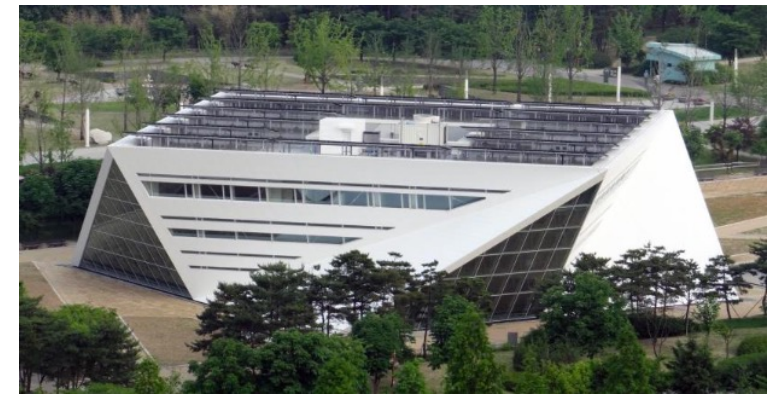
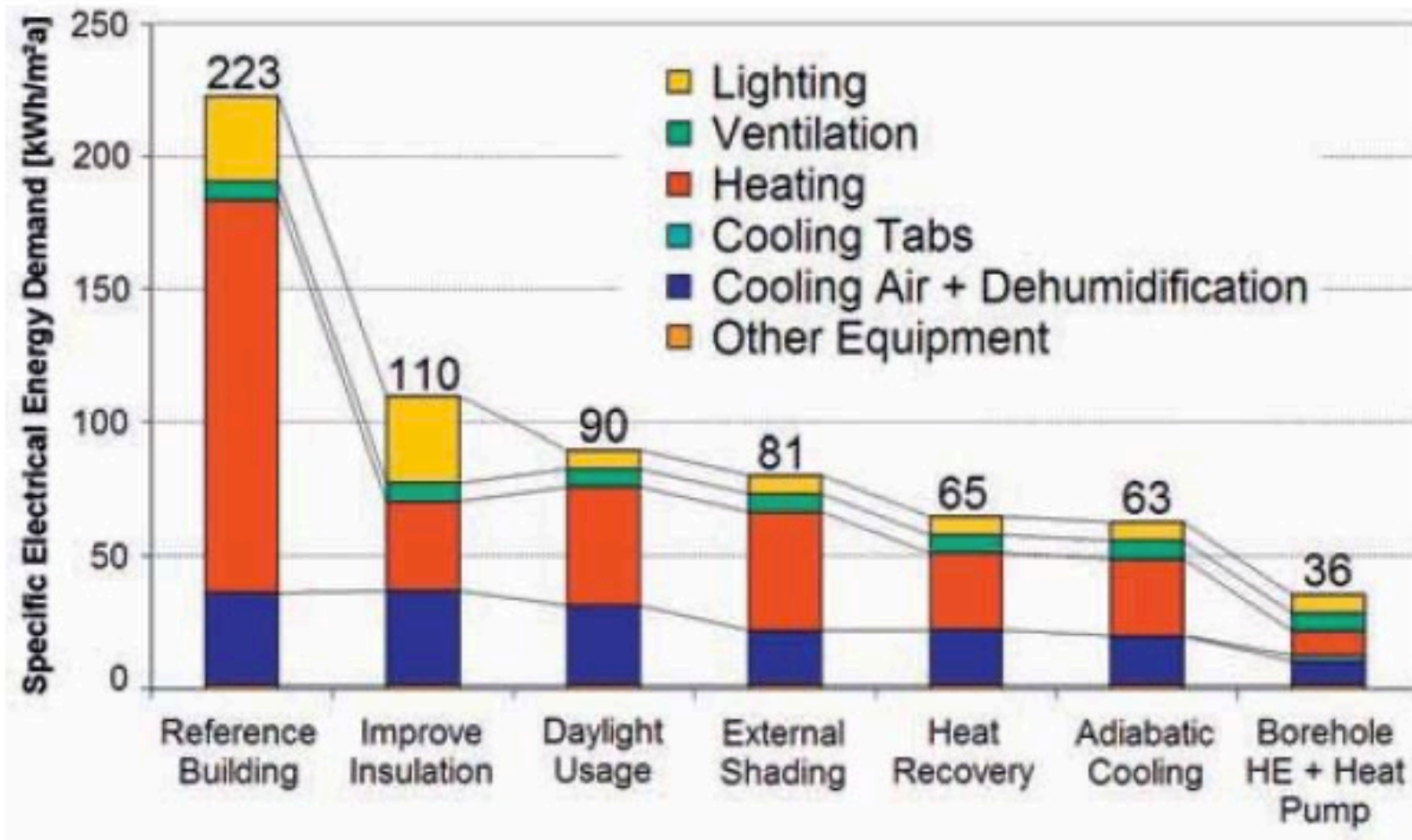
Outputs

- Energy consumption
- Heating and cooling loads
- Indoor environment
- Others:
 - IAQ
 - Lighting levels
 - Air speeds
- Format:
 - Annual
 - Monthly
 - Hourly
- Requires visualization

The importance of getting started early



From earlier today



Source: Seoul Energy Dream Center – Fraunhofer ISE info folder

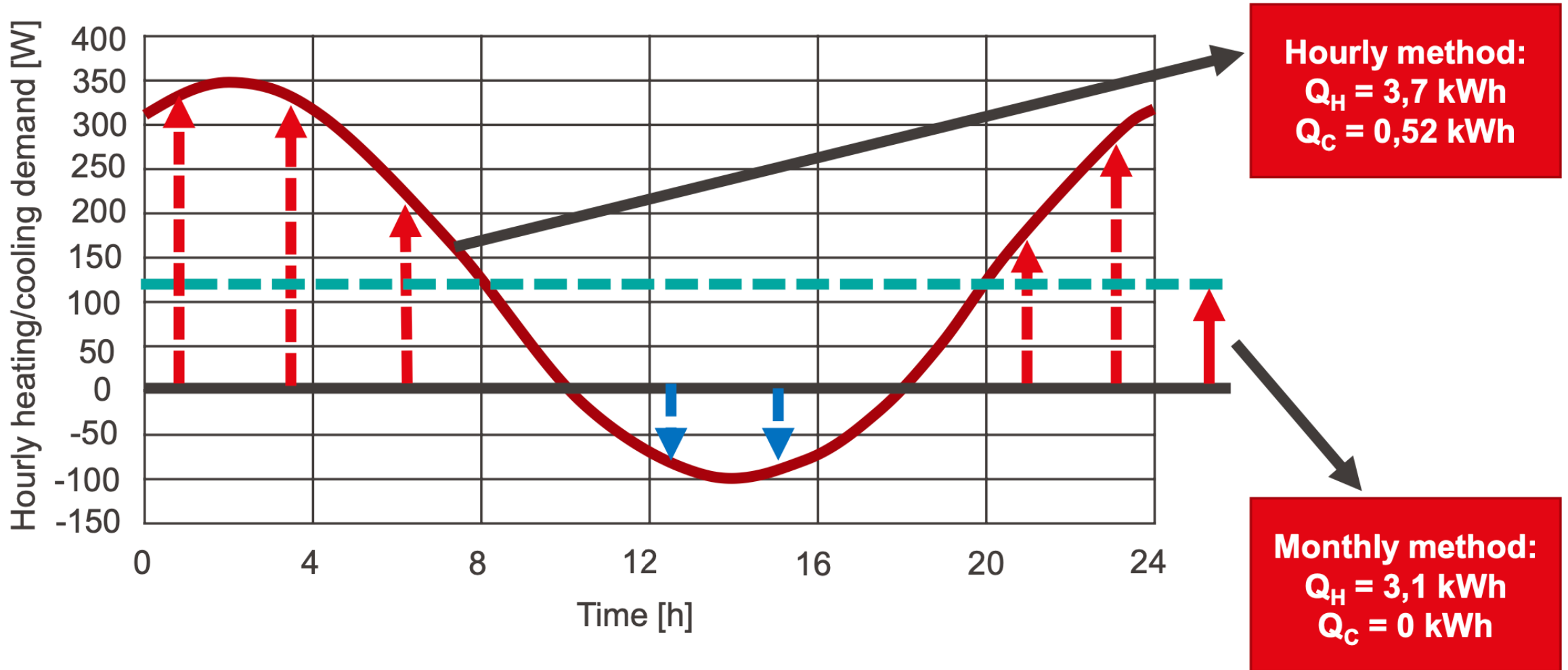
Energy modeling calculation – how it works

ISO 52000-1:2017 Energy Performance of Buildings

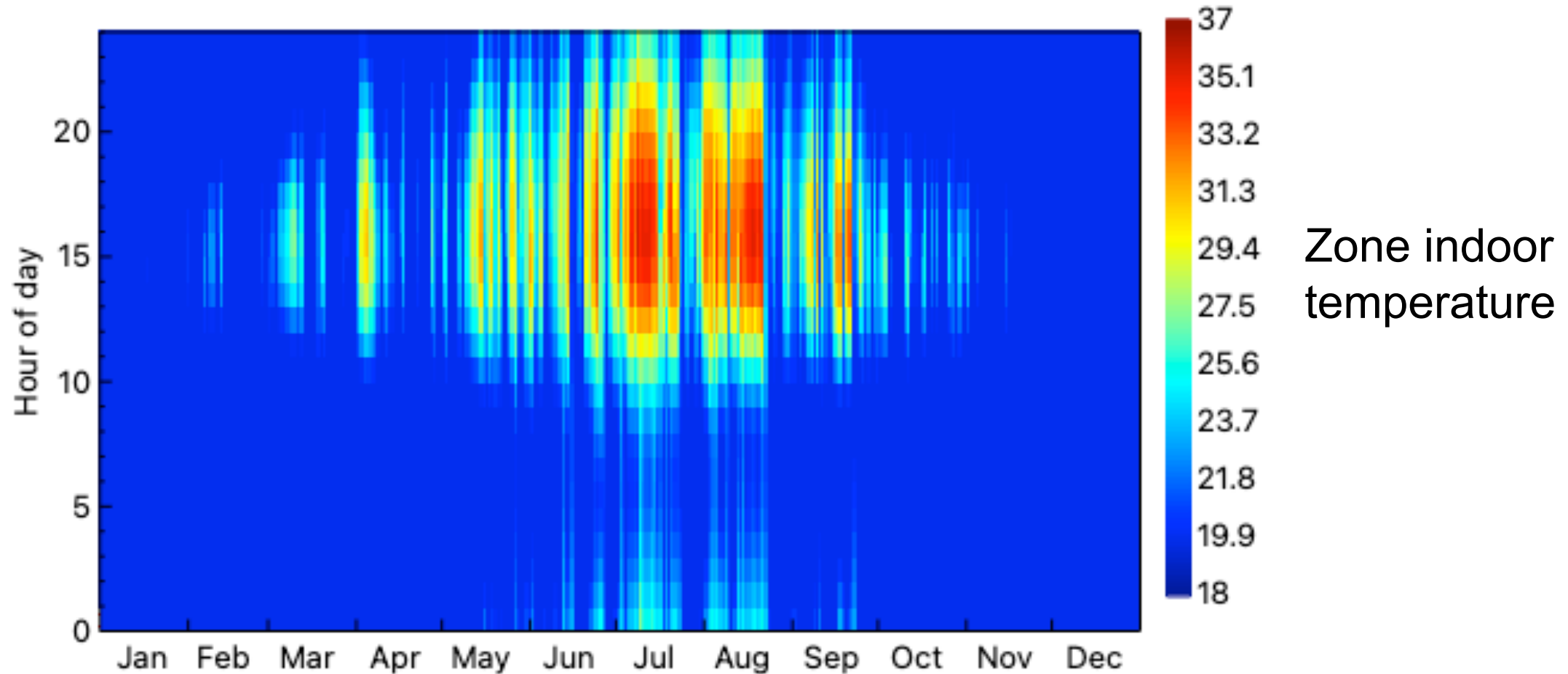
Different options for the time step of the energy calculations:

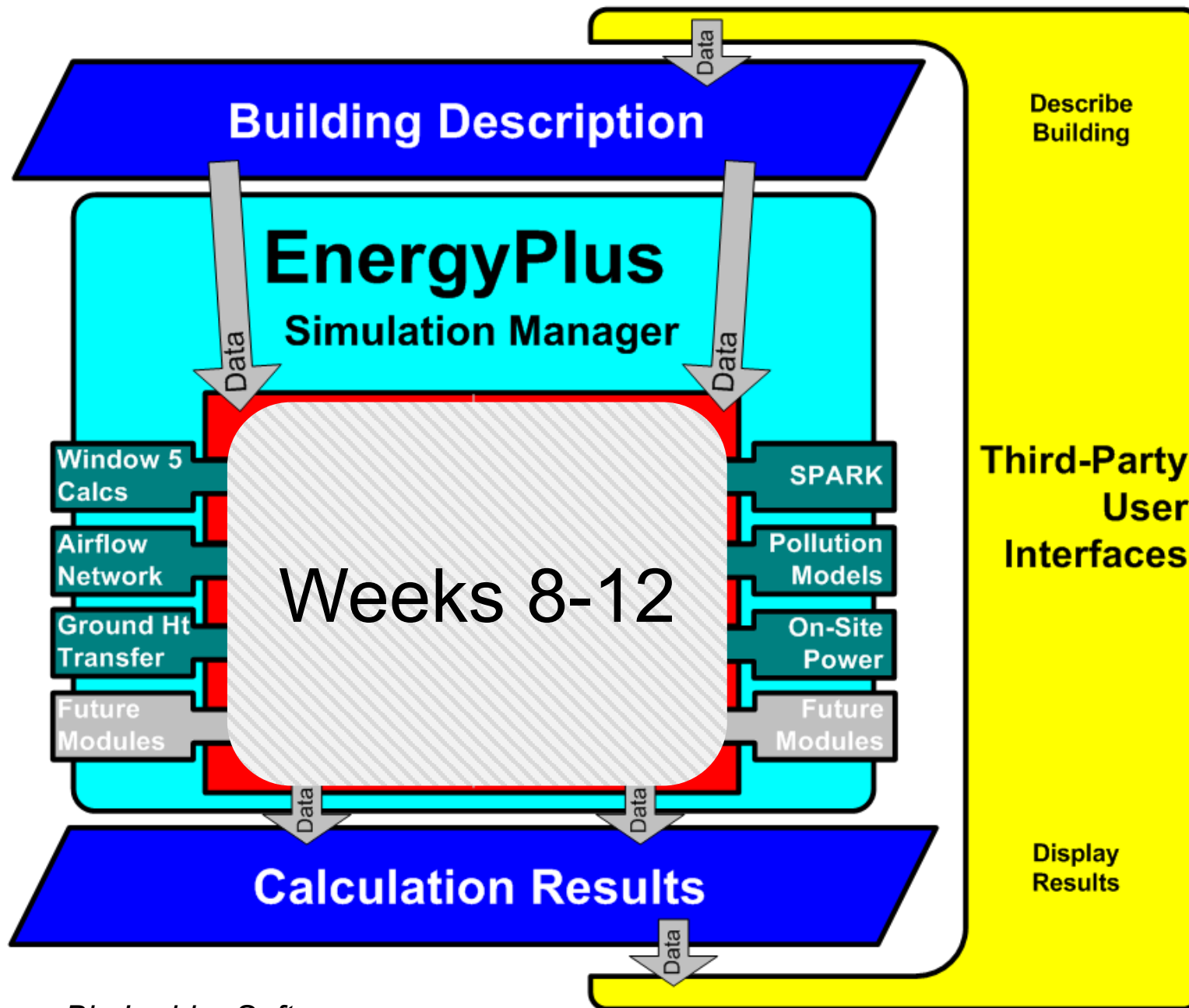
- Hourly
- Monthly
- Seasonal
- Annual
- Many countries' regulations only demand monthly calculations for energy performance certification
- Most simulation tools use hourly simulation

Timestep accuracy



Other benefits of hourly simulation





EnergyPlus inner workings

Source: Big Ladder Software

Energy modeling use cases

Appropriate uses for energy modeling

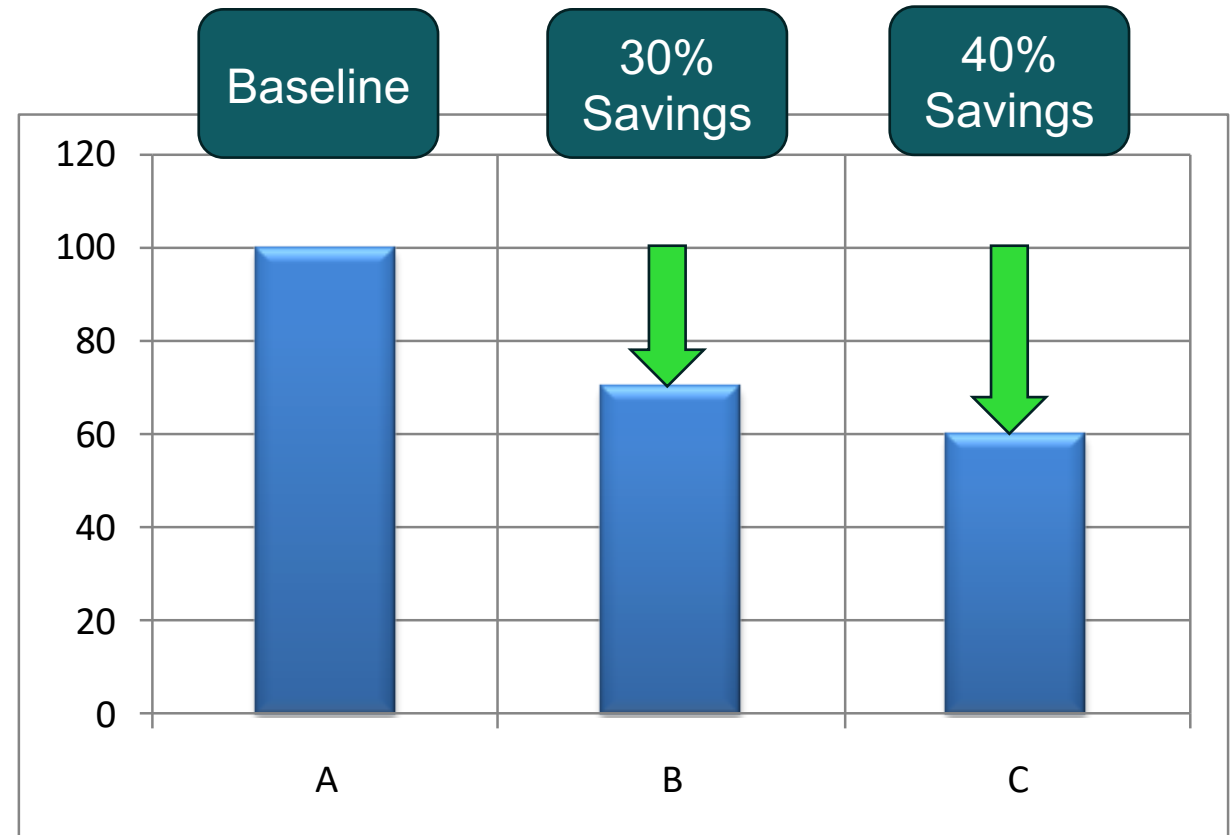
Safe operating space:
Relative performance of
design alternatives

Design studies

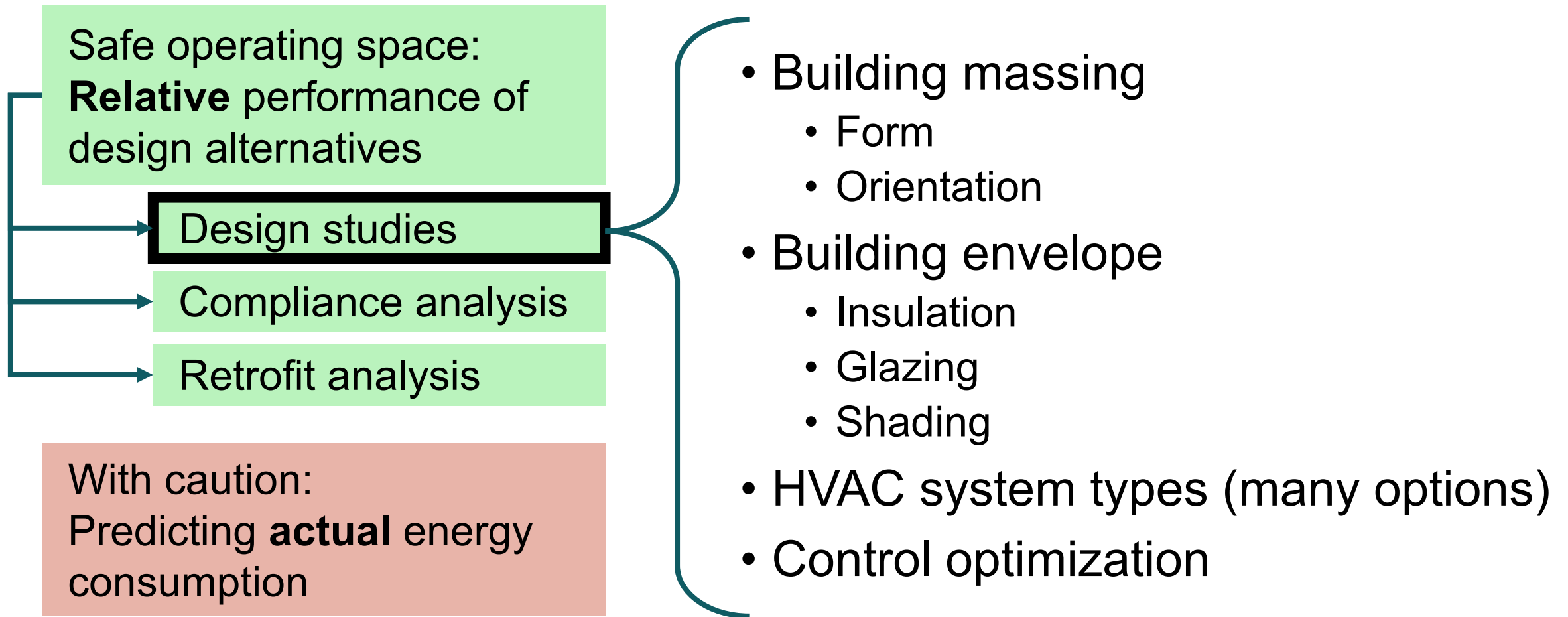
Compliance analysis

Retrofit analysis

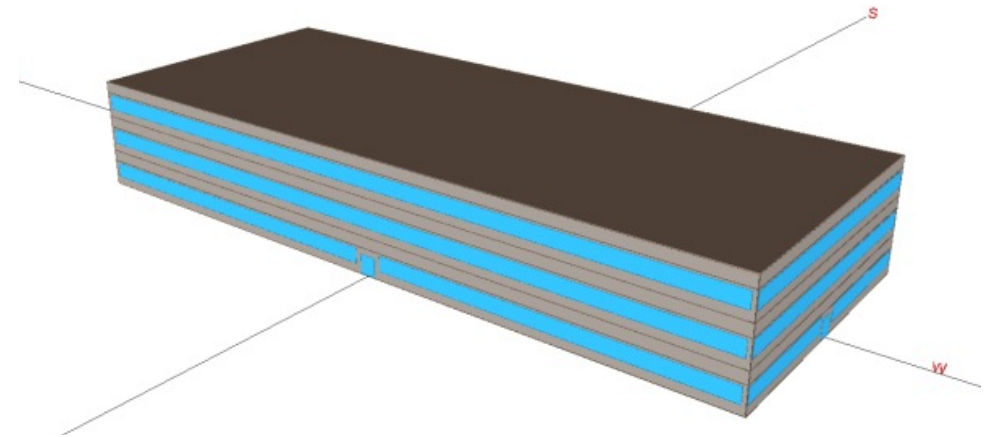
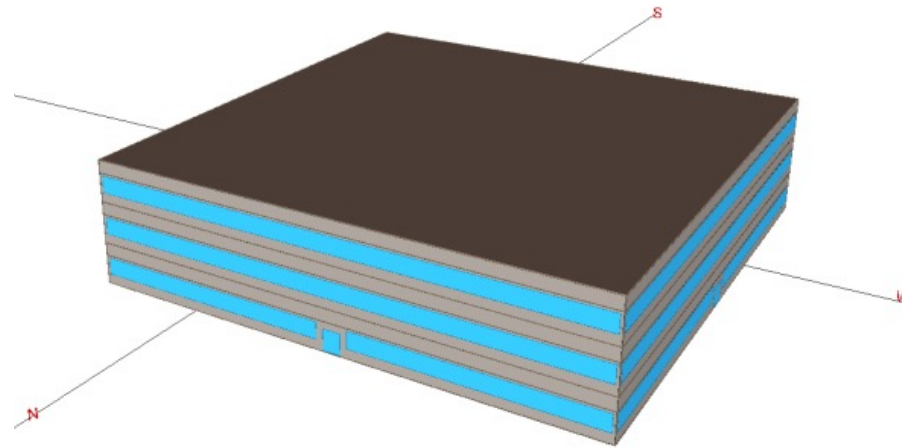
With caution:
Predicting **actual** energy
consumption



Appropriate uses for energy modeling

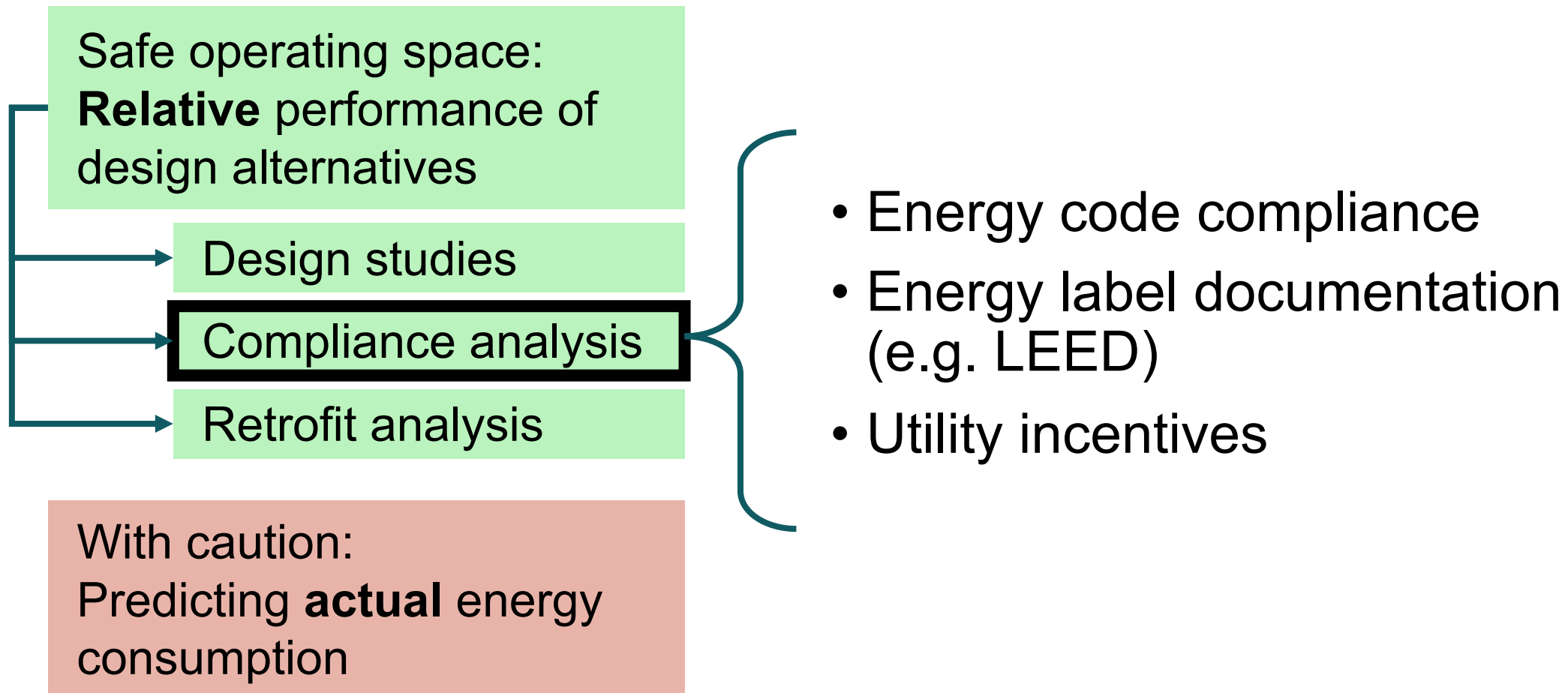


Very early stage design decisions

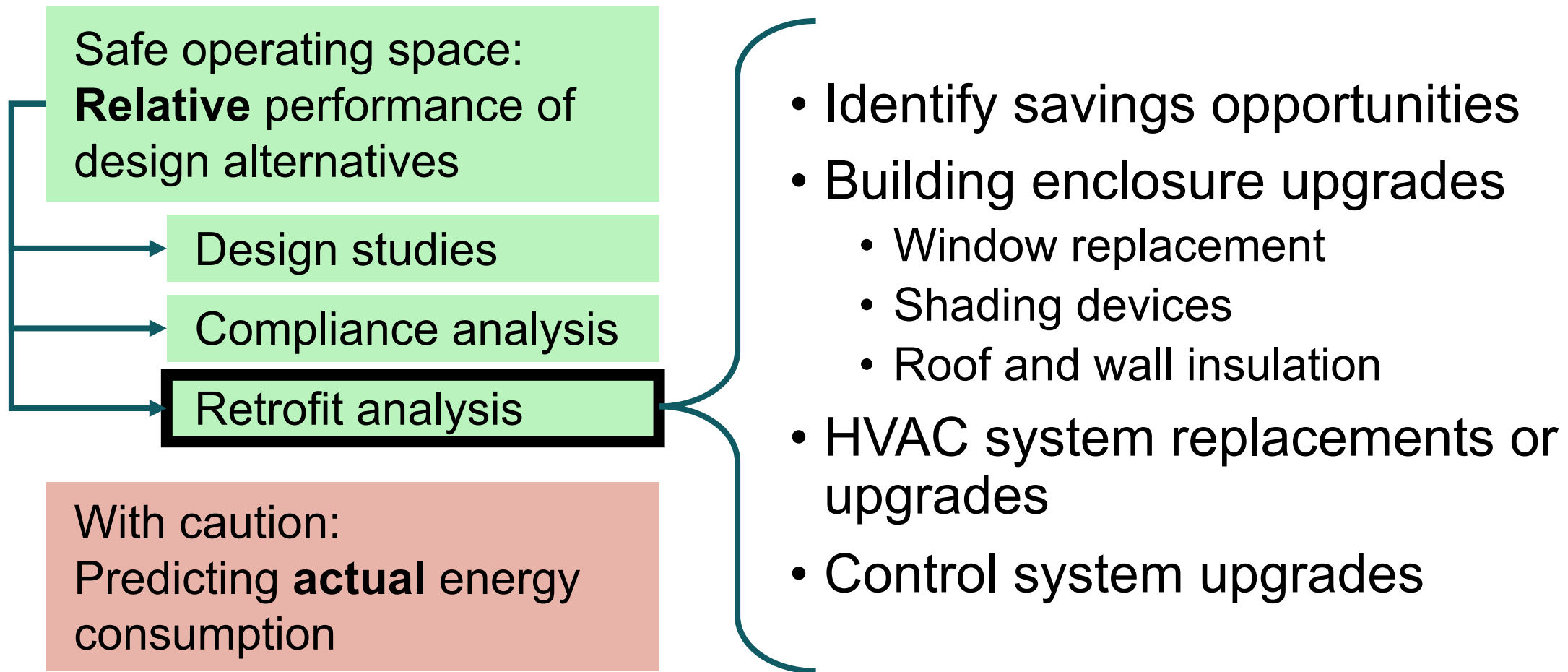


Daylight?
Energy gain from the sun?

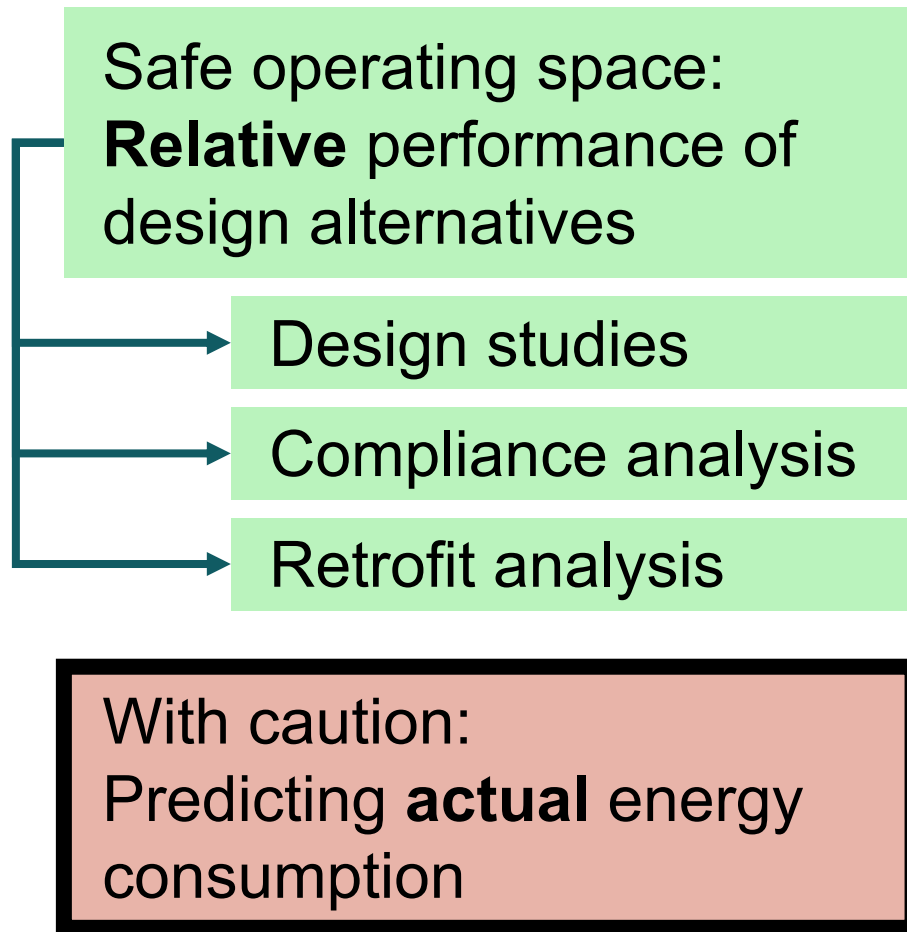
Appropriate uses for energy modeling



Appropriate uses for energy modeling



Appropriate uses for energy modeling



- Very difficult to predict actual energy consumption
 - Cannot know certain loads (e.g., plug loads)
 - Cannot control what occupants do
- Used for benchmarking
- Necessary for net zero energy design

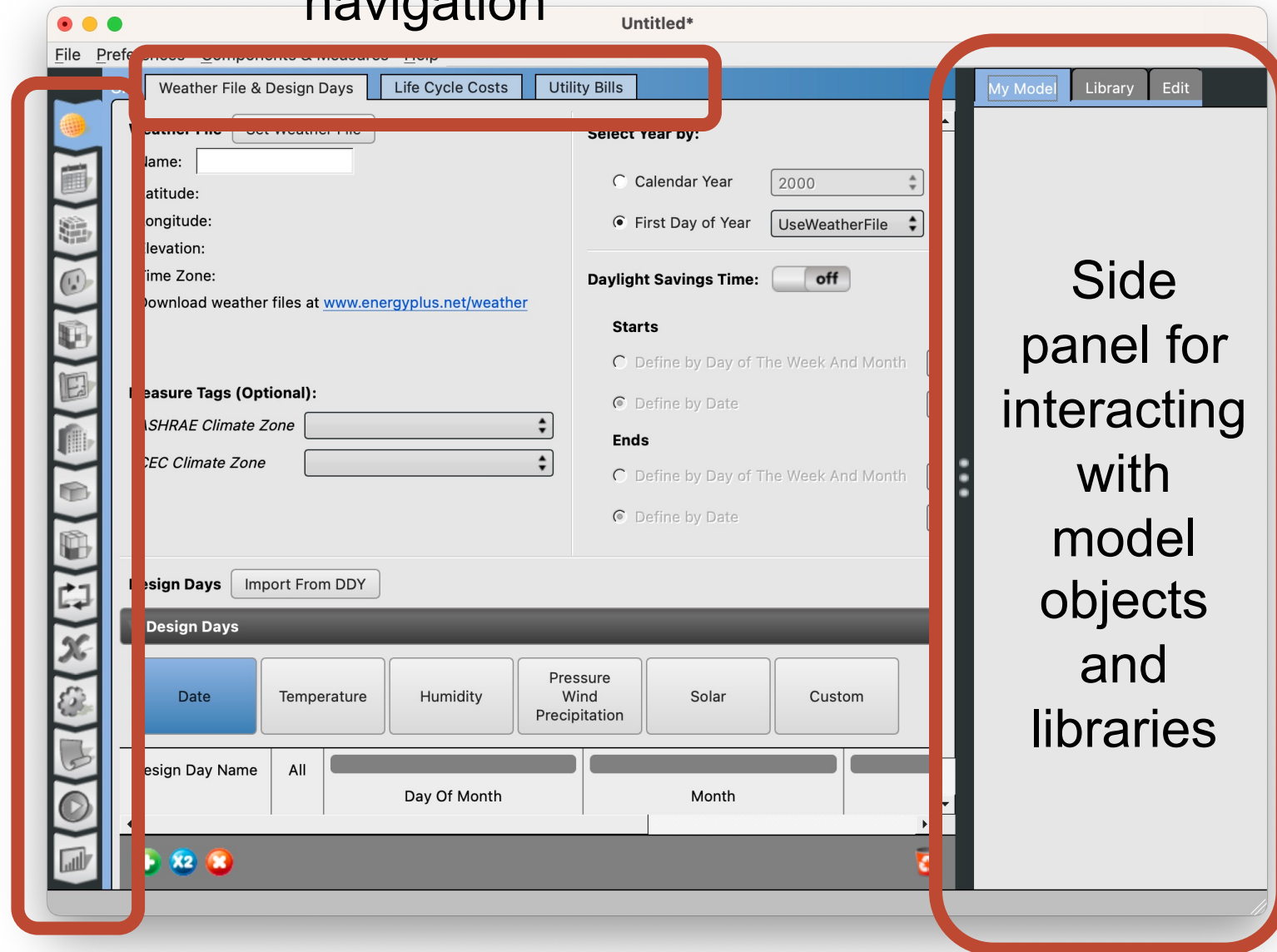
Working with energy models

EnergyPlus and OpenStudio



- Simulation engine
 - Developed by the US Department of Energy Building Technologies Office
 - Reads inputs and writes outputs as text files
 - Free and open source
-
- Graphical user interface (GUI) for E+
 - Developed at the National Renewable Energy Laboratory of the US DOE
 - Also works as a SketchUp Plugin
 - Free and open source

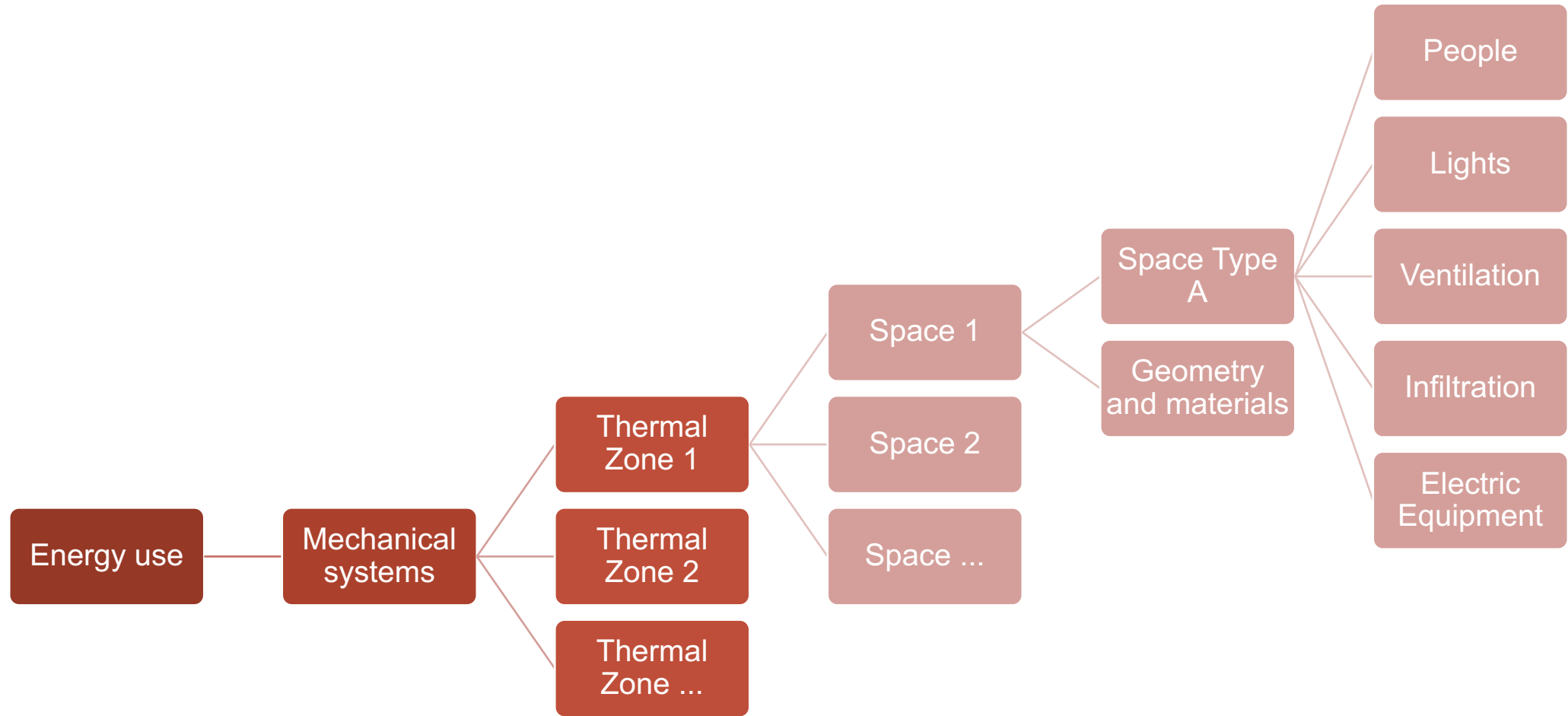
Secondary navigation



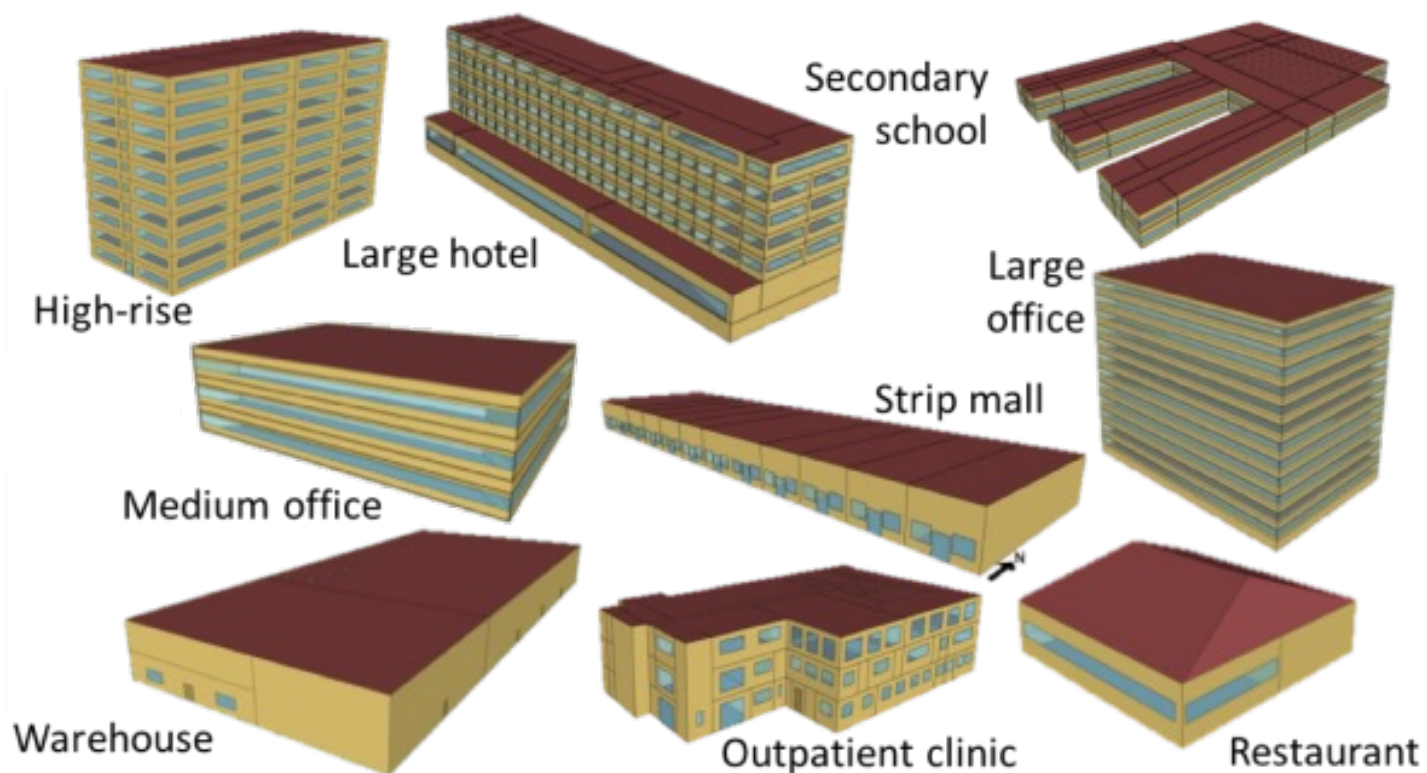
Primary navigation

Side panel for interacting with model objects and libraries

OpenStudio objects overview (simplified)

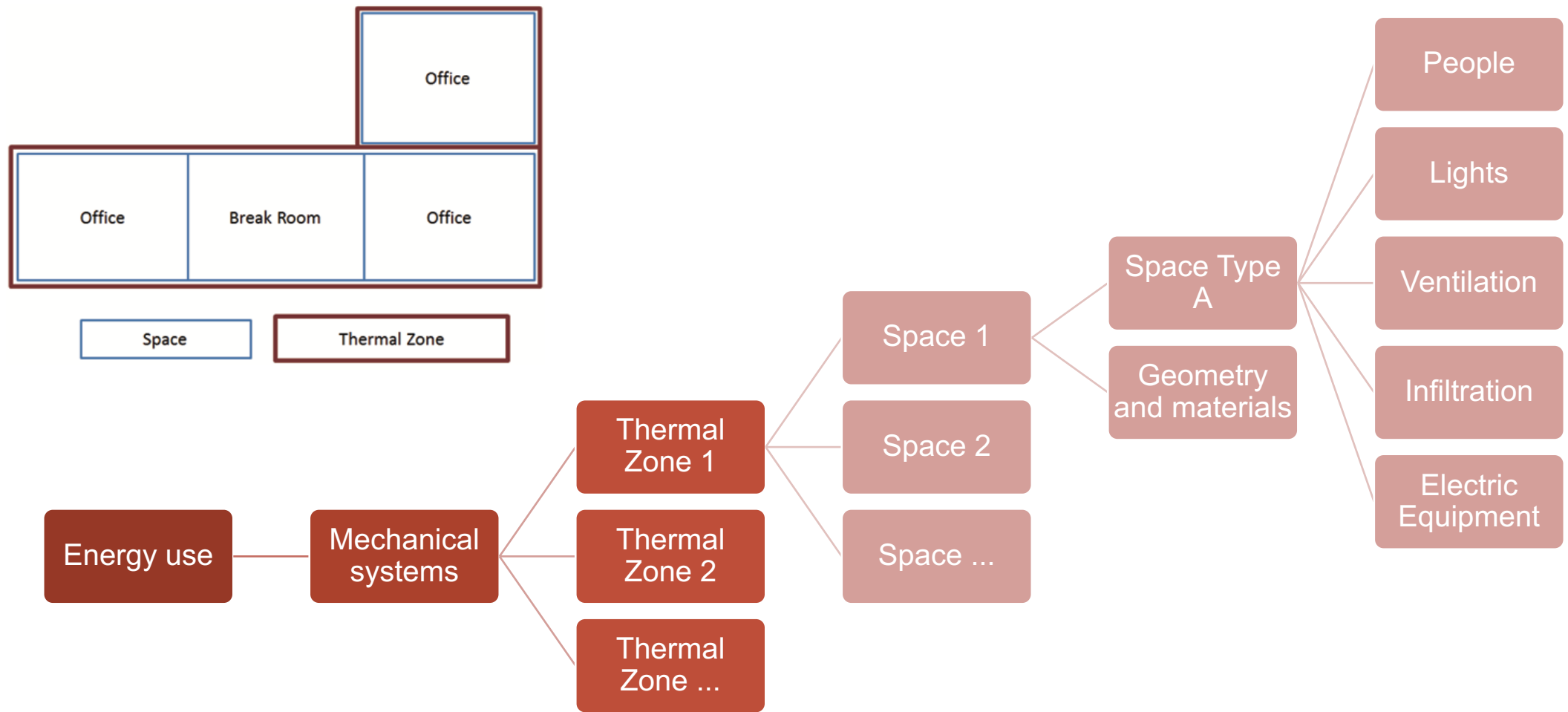


Reference buildings + libraries

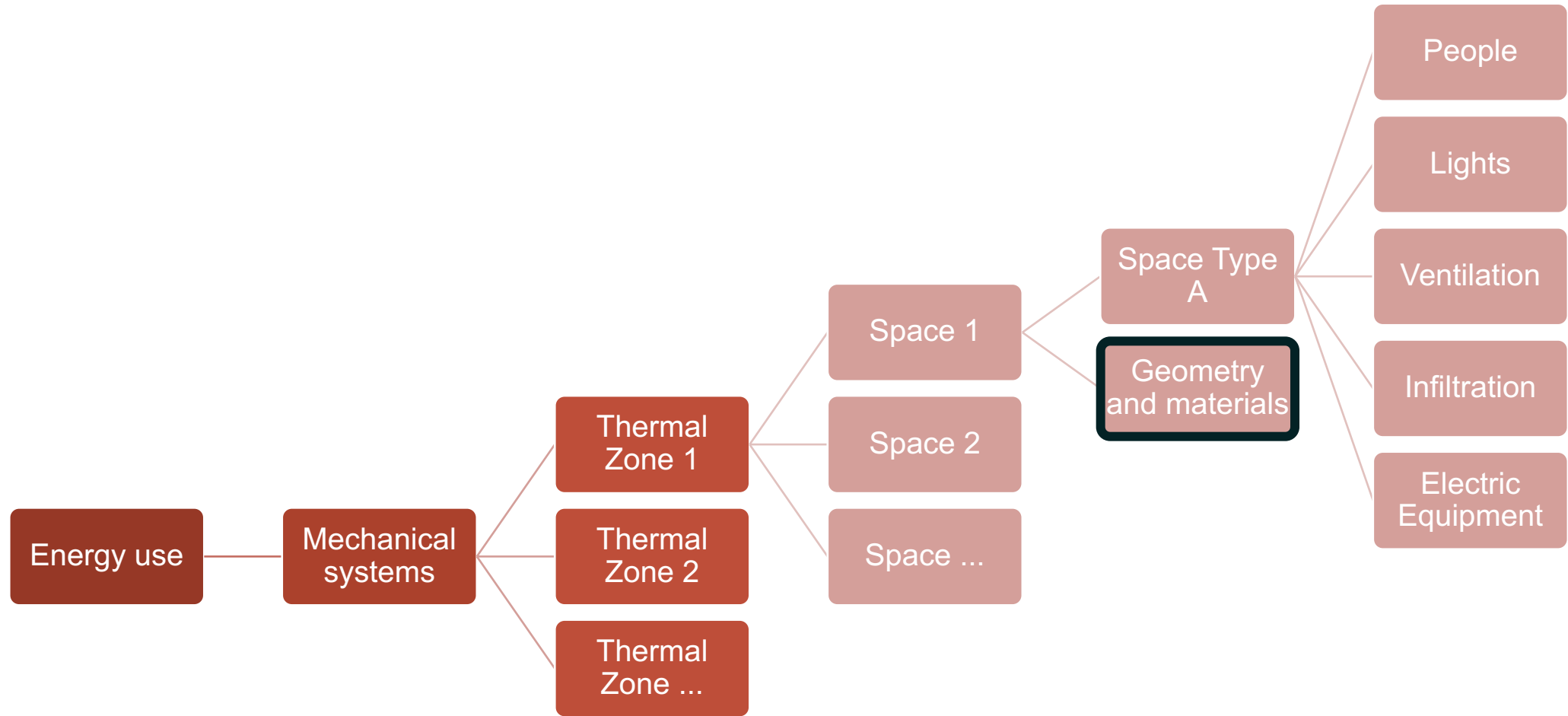


OpenStudio includes libraries associated with typical **construction** and **building features**

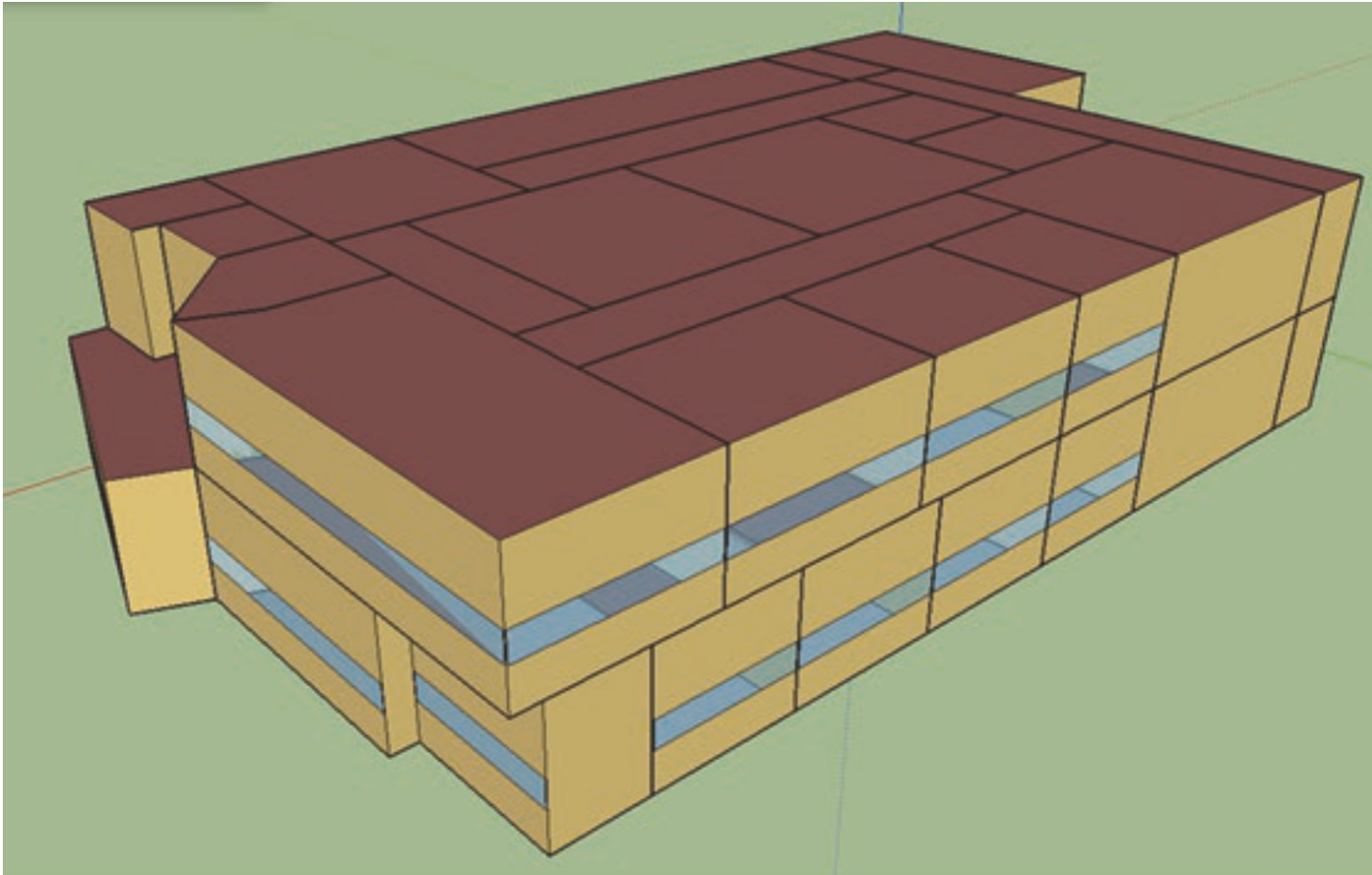
OpenStudio objects overview (simplified)



OpenStudio objects overview (simplified)



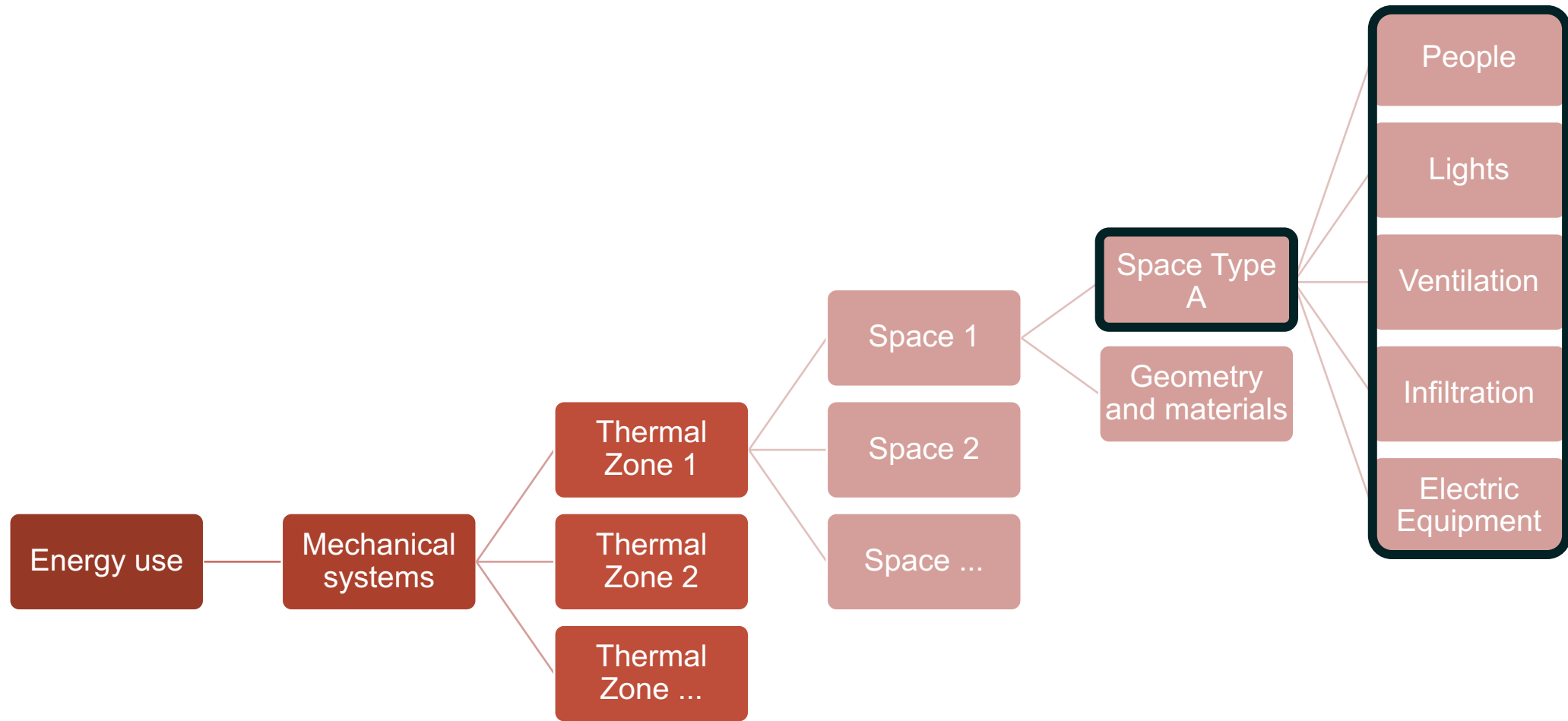
OpenStudio geometry



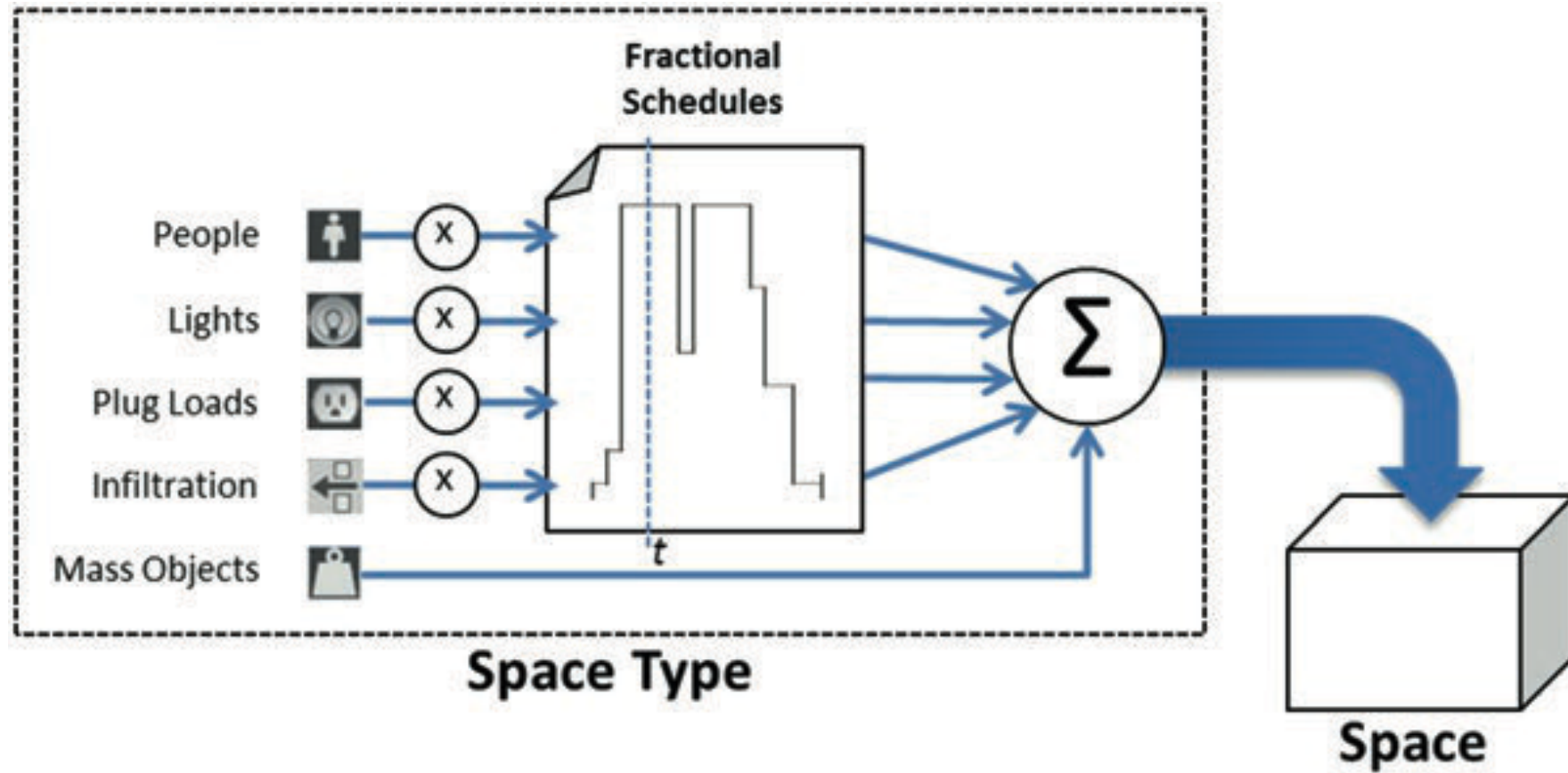
Simplification of
detailed building
geometry

Defined as a set of
spaces and surfaces
(some external)

OpenStudio objects overview (simplified)

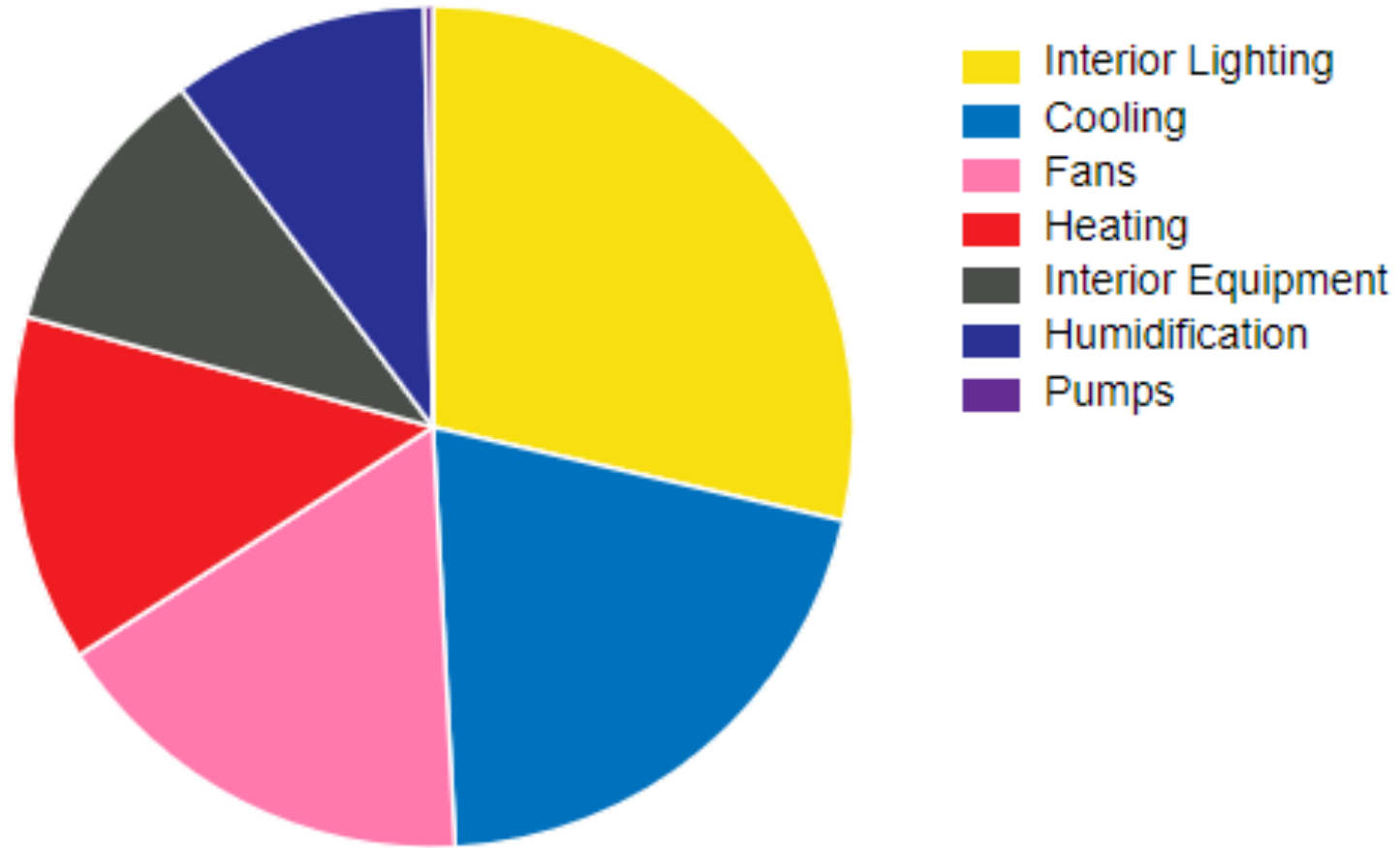


OpenStudio space types

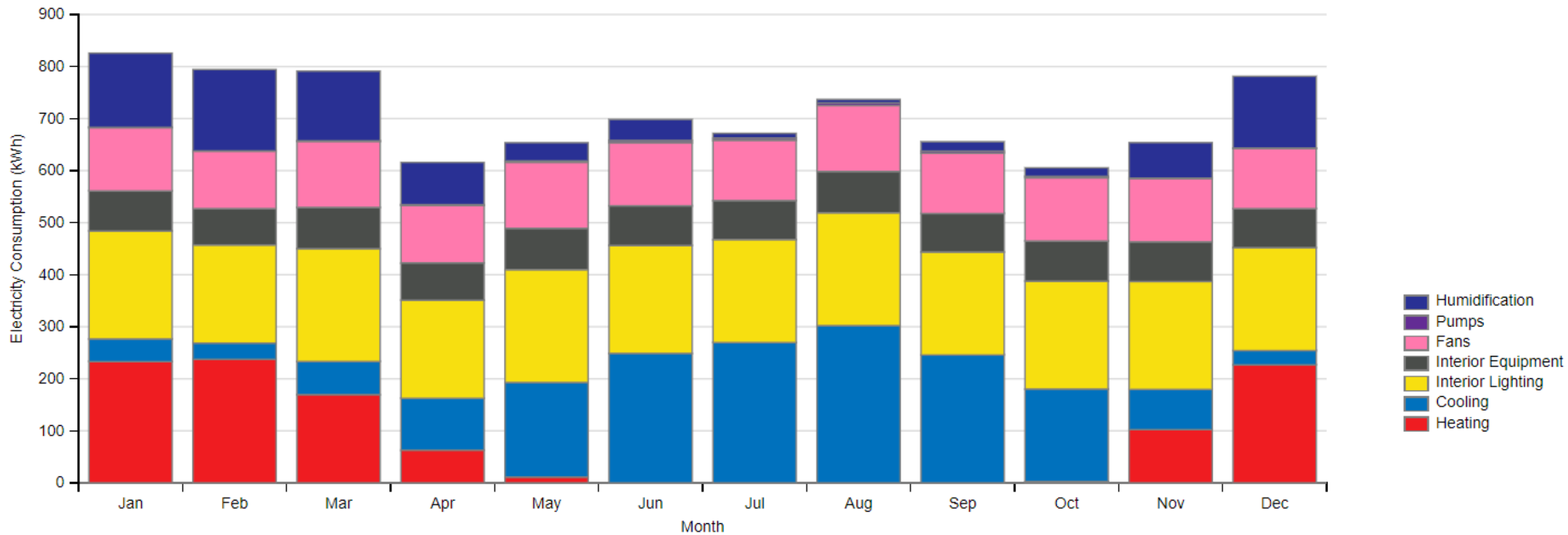


Visualizing OpenStudio results

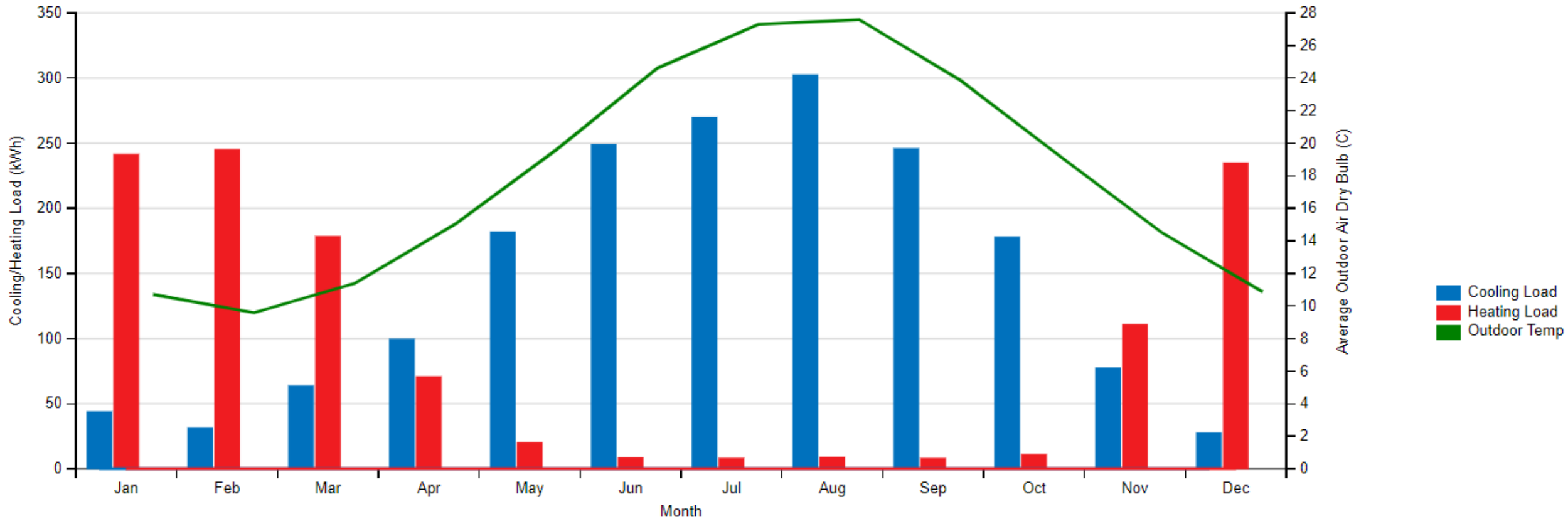
Outputs: Energy use per category



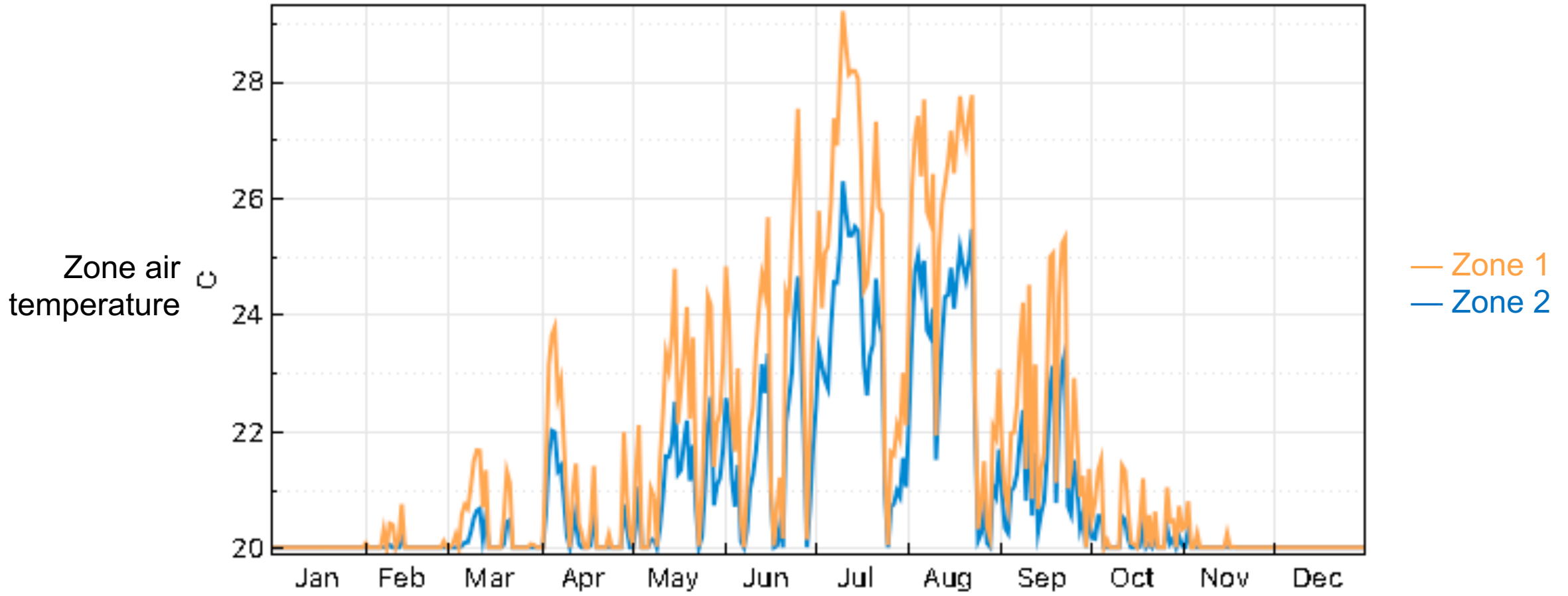
Outputs: Monthly overview



Outputs: HVAC load profiles



Outputs: Zone conditions



Outputs: Zone conditions

Temperature (Table values represent hours spent in each temperature range)

Zone	Unmet Htg (hr)	Unmet Htg - Occ (hr)	< 13 (C)	13-16 (C)	16-18 (C)	18-20 (C)	20-21 (C)	21-22 (C)	22-23 (C)	23-24 (C)	24-26 (C)	26-28 (C)	28-30 (C)	>= 30 (C)	Unmet Clg (hr)	Unmet Clg - Occ (hr)	Mean Temp (C)
CELLS:ENTRANCE THERMAL ZONE	0	0	0	55	1510	887	241	1169	585	591	2286	1047	367	22	0	0	22.4 (C)
CELLS:ROOMX1 THERMAL ZONE	0	0	0	10	1003	814	353	720	512	495	2760	940	1015	138	0	0	23.4 (C)
CELLS:ROOMX2 THERMAL ZONE	0	0	0	21	1168	753	285	752	501	474	2740	902	996	168	0	0	23.3 (C)

Humidity (Table values represent hours spent in each Humidity range)

Zone	< 30 (%)	30-35 (%)	35-40 (%)	40-45 (%)	45-50 (%)	50-55 (%)	55-60 (%)	60-65 (%)	65-70 (%)	70-75 (%)	75-80 (%)	>= 80 (%)	Mean Relative Humidity (%)
CELLS:ENTRANCE THERMAL ZONE	662	799	1116	1734	1769	1143	878	376	195	58	25	5	45.2 (%)
CELLS:ROOMX1 THERMAL ZONE	1035	1067	1286	2122	1517	921	476	212	88	31	5	0	42.1 (%)
CELLS:ROOMX2 THERMAL ZONE	1023	1039	1268	2080	1493	926	531	253	107	31	8	1	42.4 (%)