Introduction to building energy modeling

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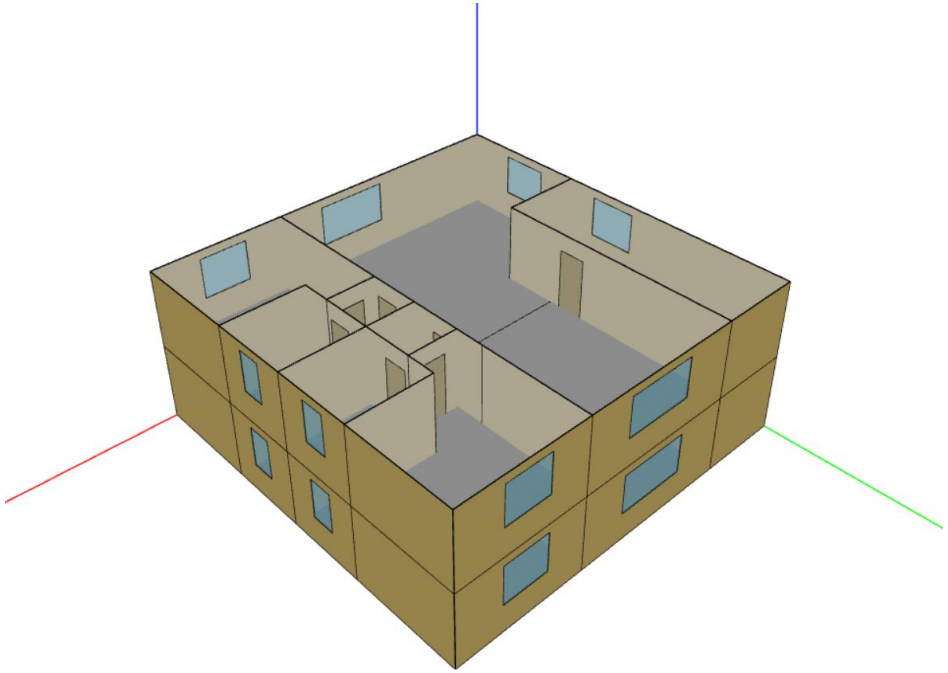
ENG-445 Energy and Comfort in Buildings

12 September 2024

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)
1	12/09	Course Introduction Climate change and energy	45'	DL	Introduction (BPS) + Start individual project + Import geometry
		Energy use in buildings	45'		
		The value of human-centric buildings Quiz On your own: Quick recall of units, heat transfer, psychrometrics	45'		
2	19/09	Thermal comfort, quick overview Overheating of buildings	45'	DL	Free work
		Thermal comfort & energy efficiency	45'		
		Exercises	45'		



Learning goals

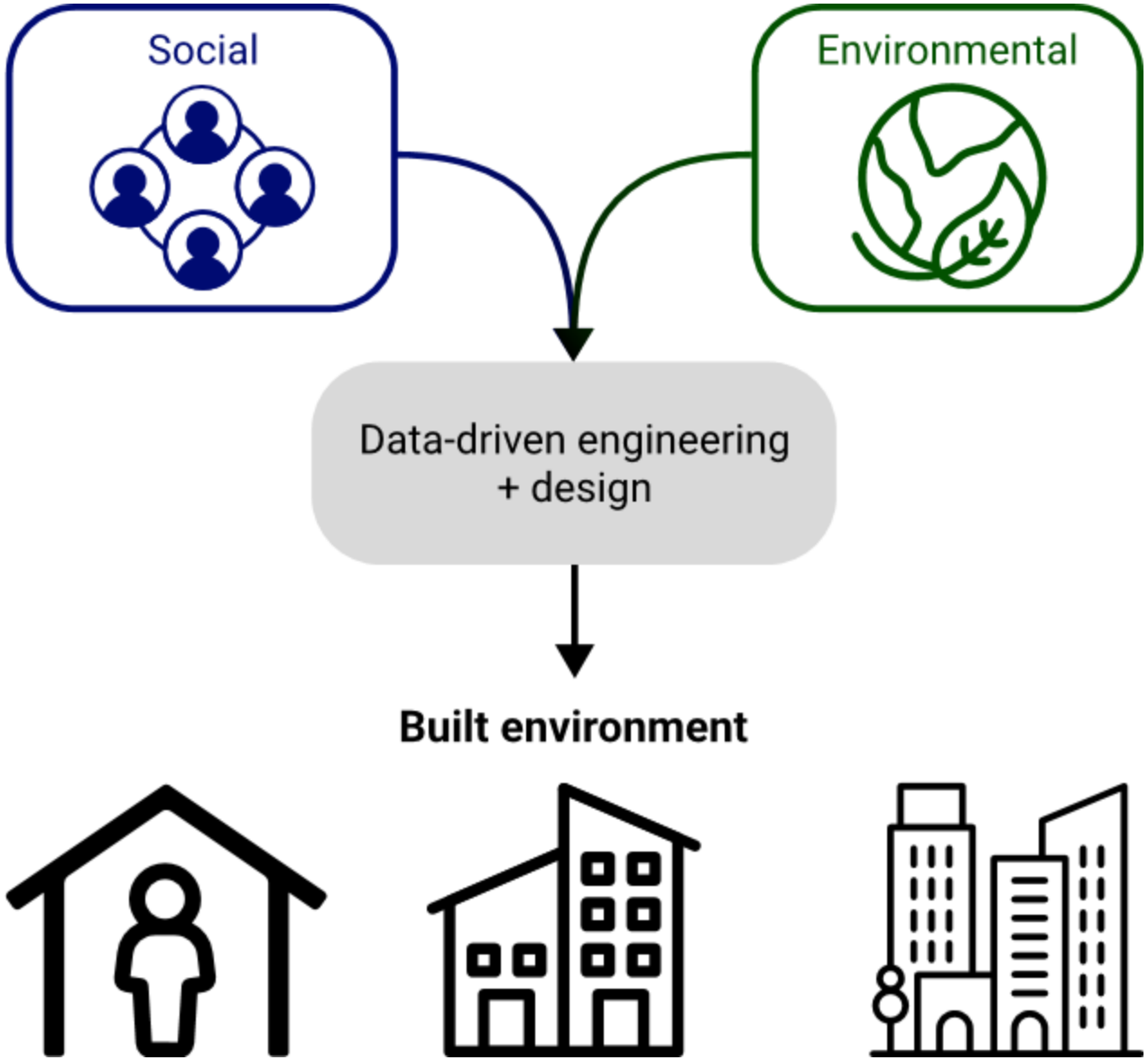
- Introduce building energy modeling
  - Inputs, outputs
  - Flow and logic
- Understand when energy modeling is appropriate
- Become familiar with EnergyPlus and OpenStudio
- Understand how energy modeling tools are used in practice

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

- Demand flexibility provision in Swiss households (PDM only)
- Occupant-centric building energy flexibility
- 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
- Clustering of urban form

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

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

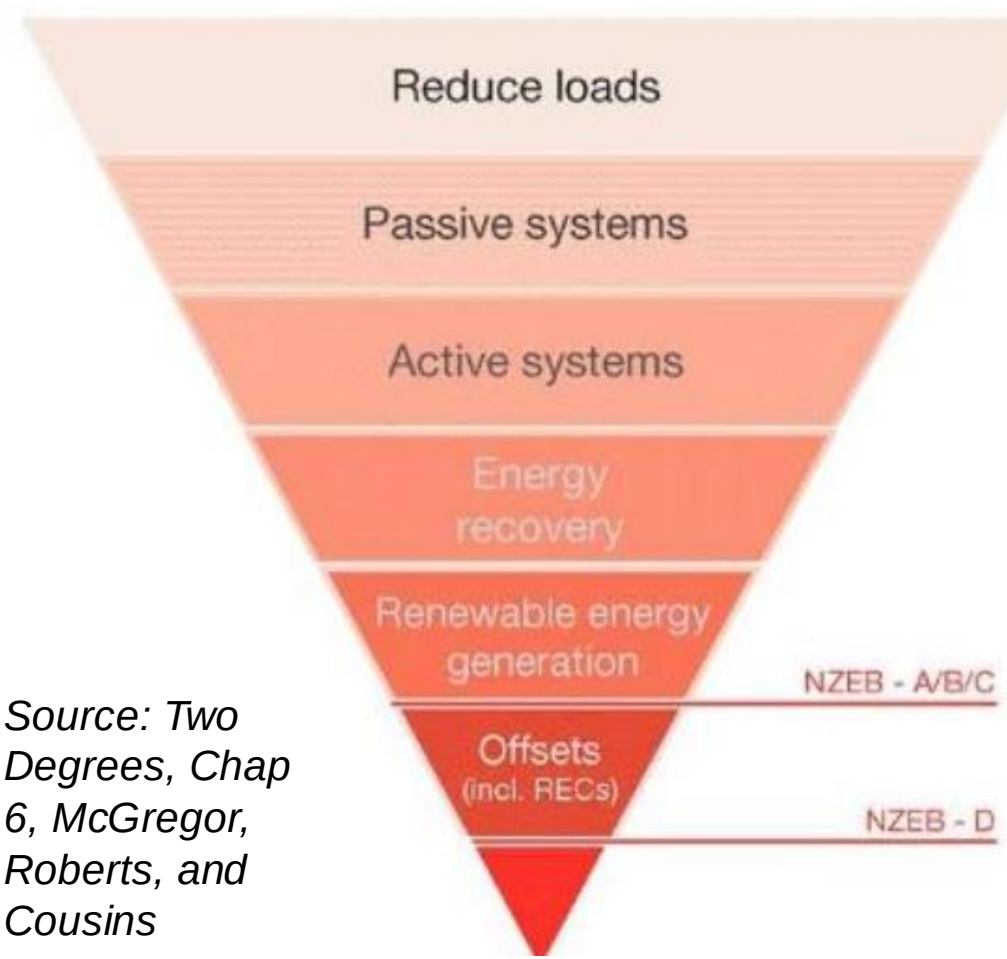
Energy

- Energy use of systems in response to loads

Cost

- Operating costs using energy data

Why perform simulation?



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

Predict energy demand

Understand the operation of buildings

Required by building standards for new constructions and renovations

What are the tools?

For our class

Lesosai

TRNSYS

DIAL
Using Radiance

DesignBuilder
SOFTWARE

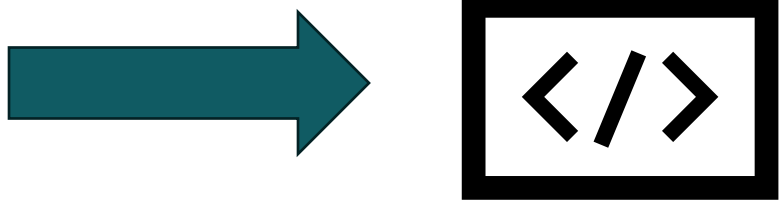
IDA ICE

Energy simulation flow

Inputs

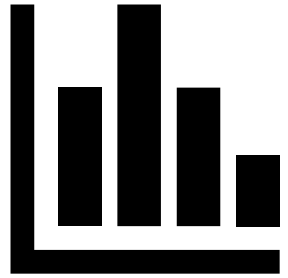
- Building characteristics
- System type
- Operation schedules
- (more on next slide…)

Solver



- Thermal balancing equations

Ouputs

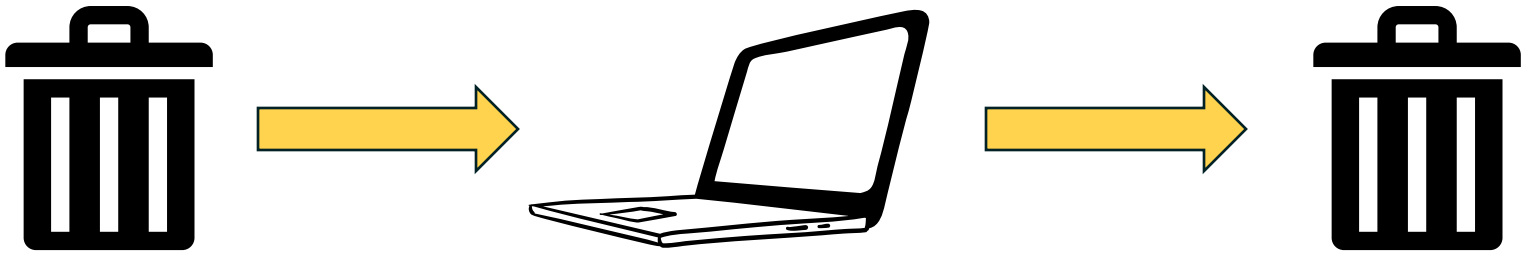


- Energy demand and consumption
- Indoor environmental conditions
- Graphs/comparisons

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)

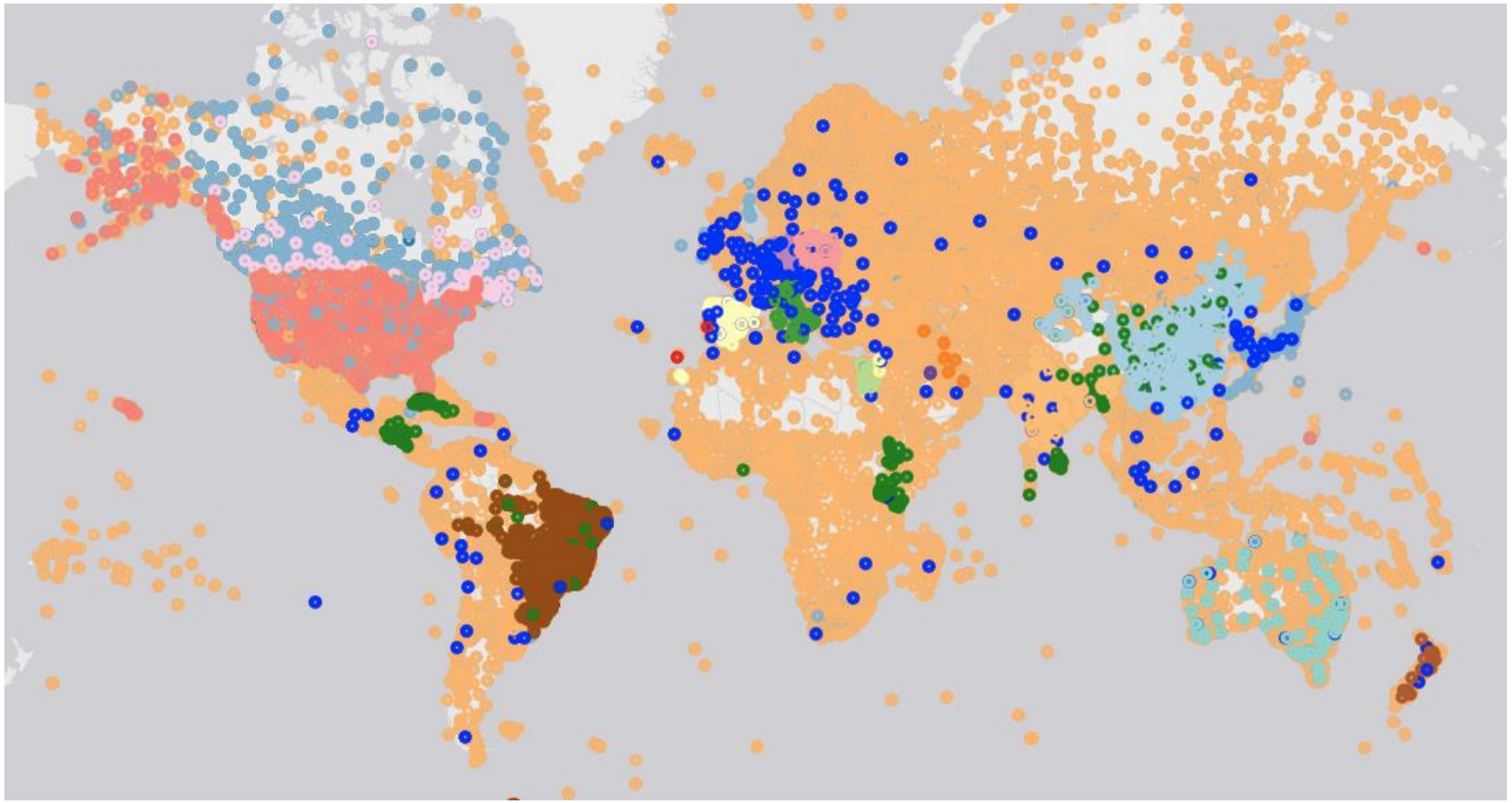
Important rule of modeling…



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

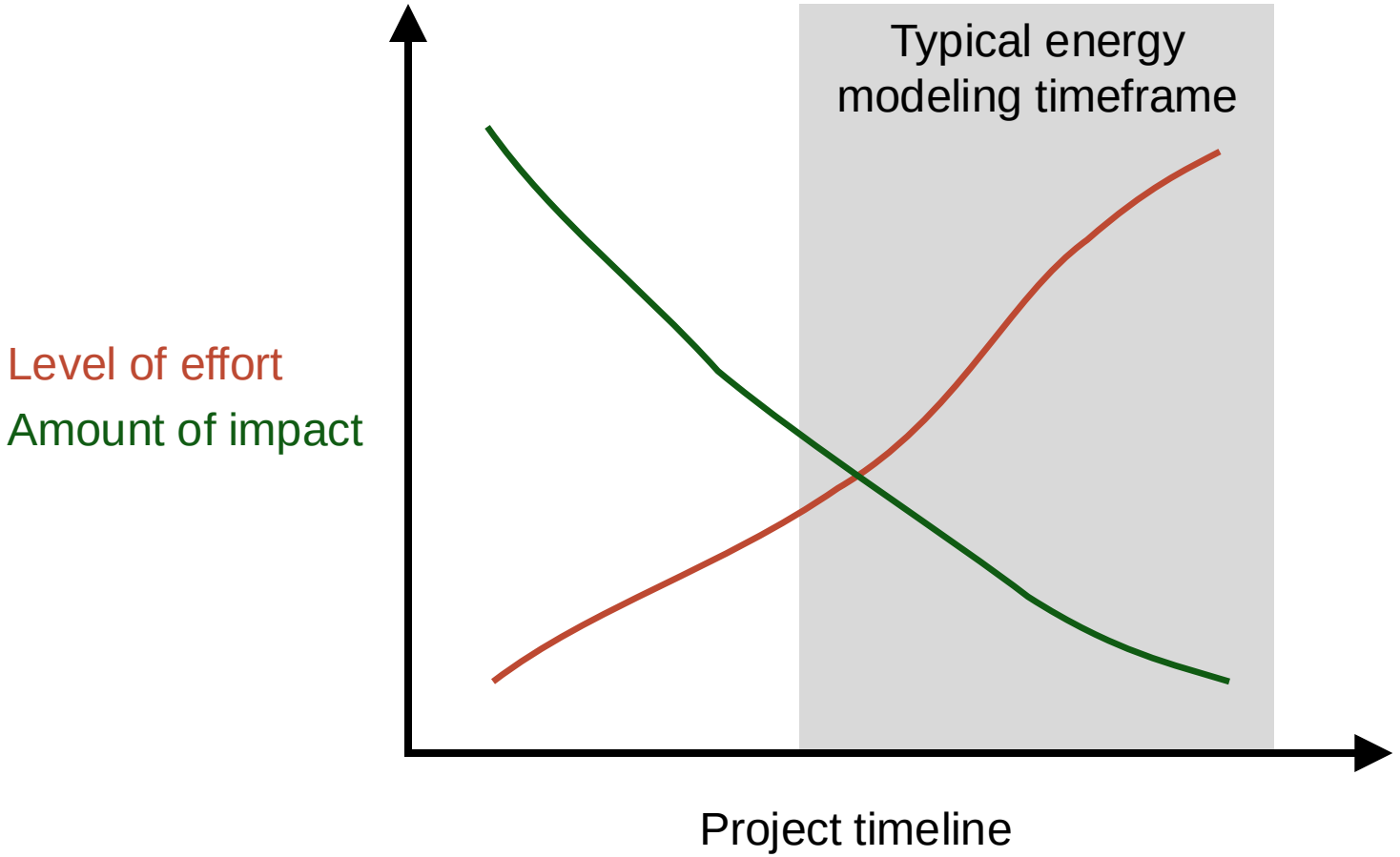
Source: Lady Bug Tools

Outputs

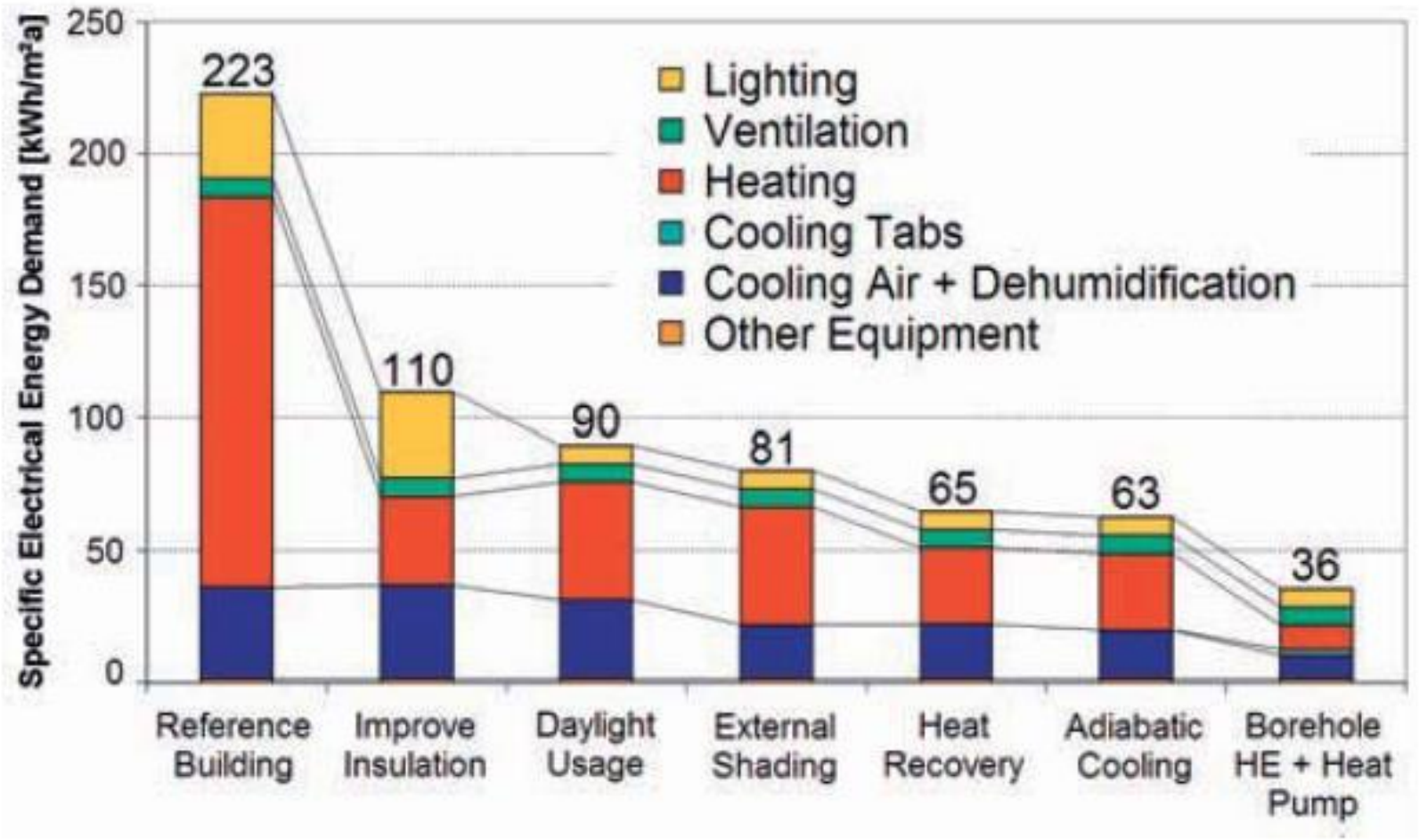
- Energy consumption
- Heating and cooling loads
- Indoor environment
- Others:
  - IAQ
  - Lighting levels
  - Air speeds

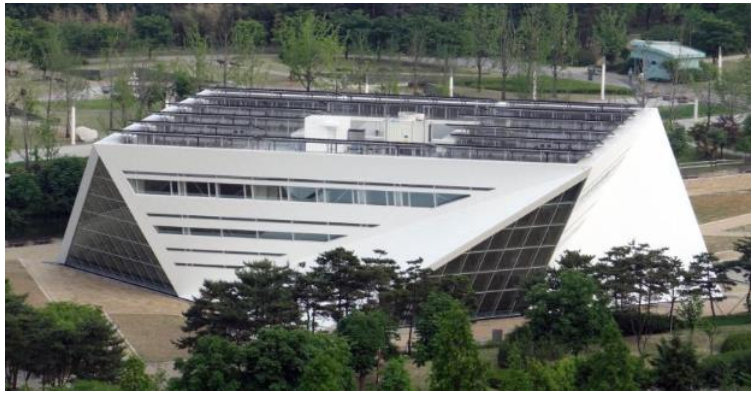
- Format:
  - Annual
  - Monthly
  - Hourly
- Requires visualization

The importance of getting started early



From earlier today





Source: Seoul Energy Dream Center – Fraunhofer ISE info folder

Energy modeling calculation – how it works

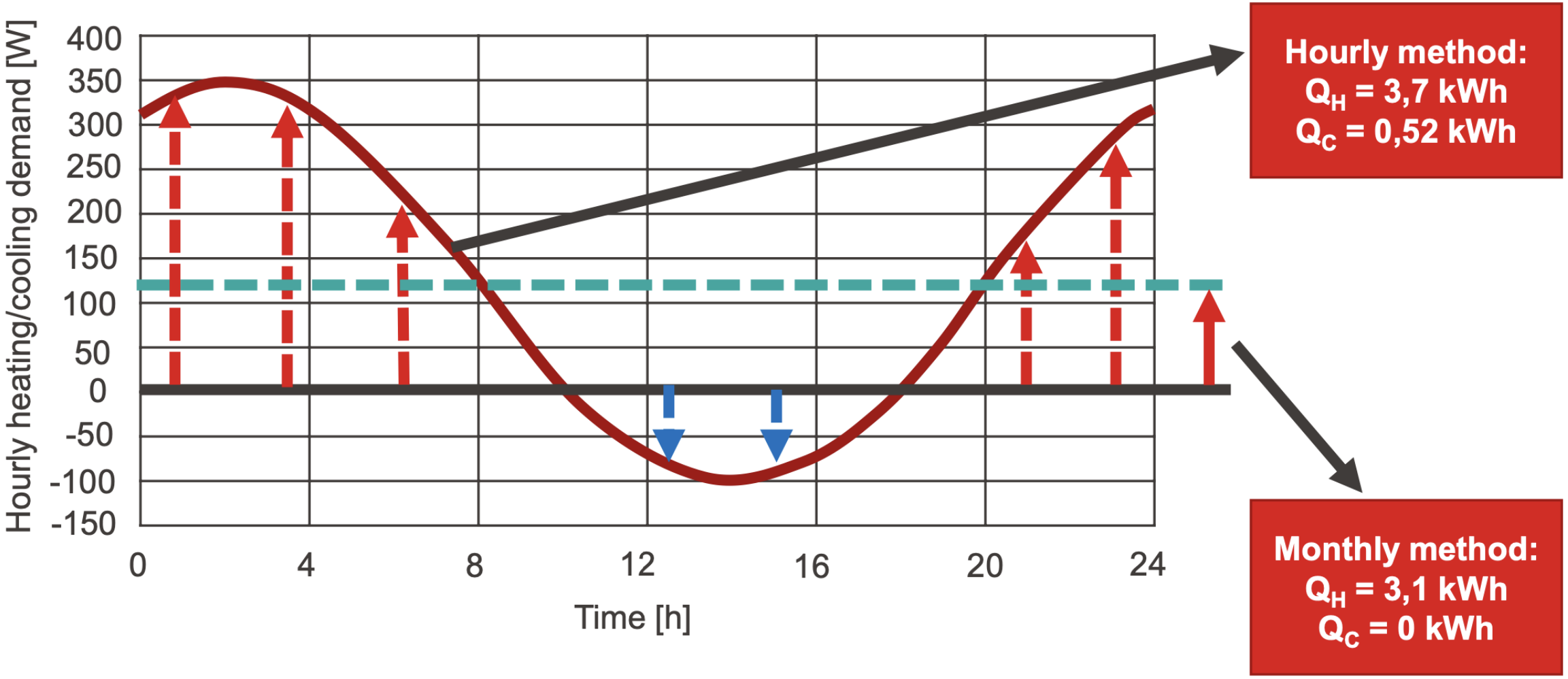
ISO 52000-1:2017 Energy Performance of Buildings

Different options for the time step of the energy calculations:

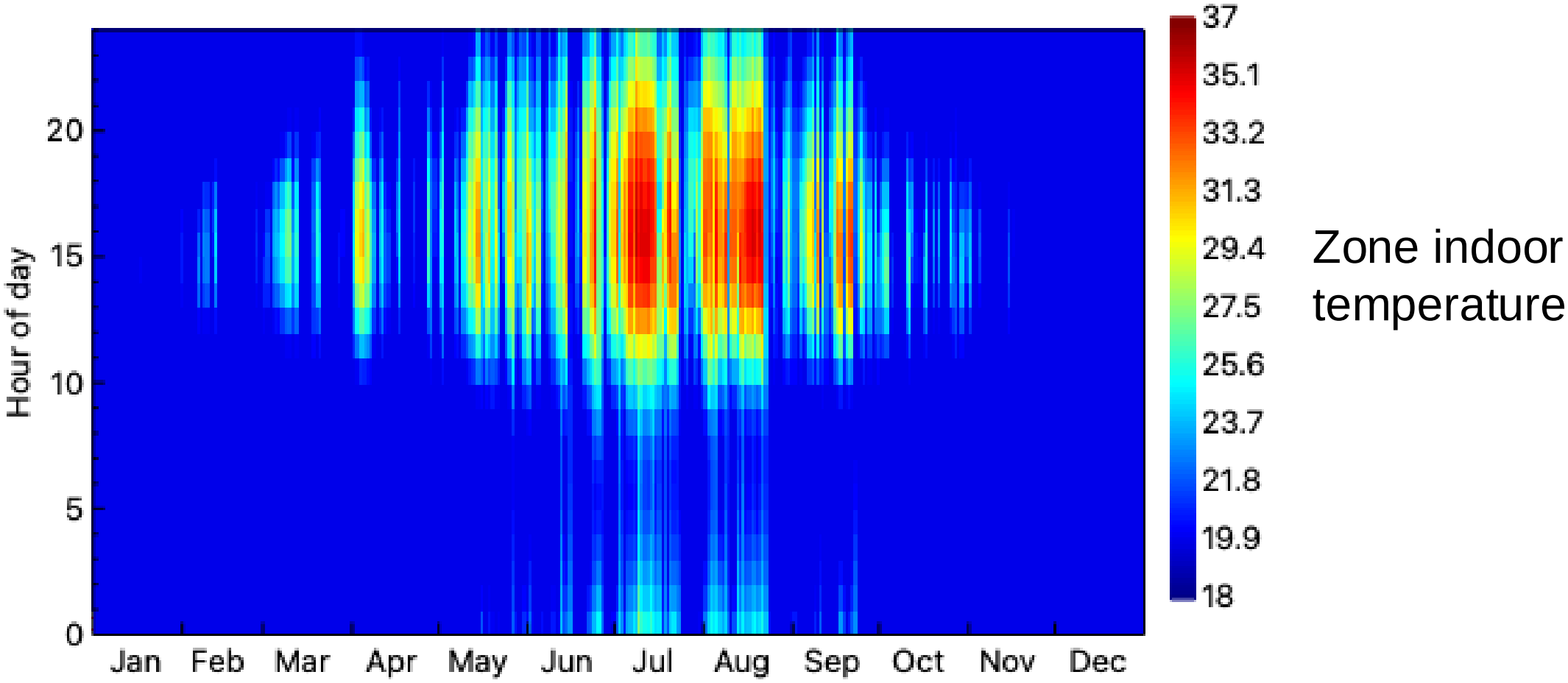
- Hourly
- Monthly
- Seasonal
- Annual

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

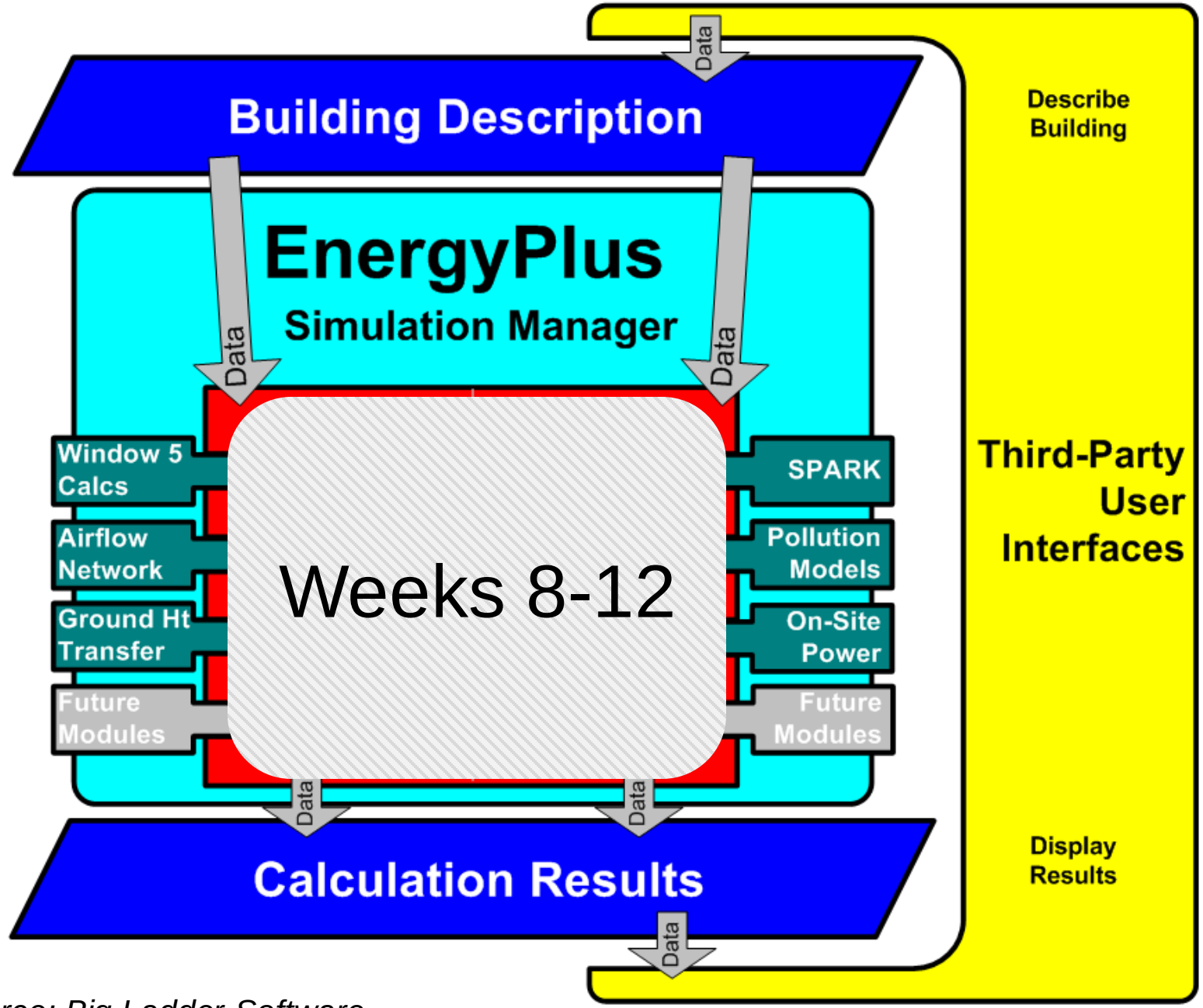
Timestep accuracy



Other benefits of hourly simulation



Zone indoor temperature



Source: Big Ladder Software

EnergyPlus inner workings

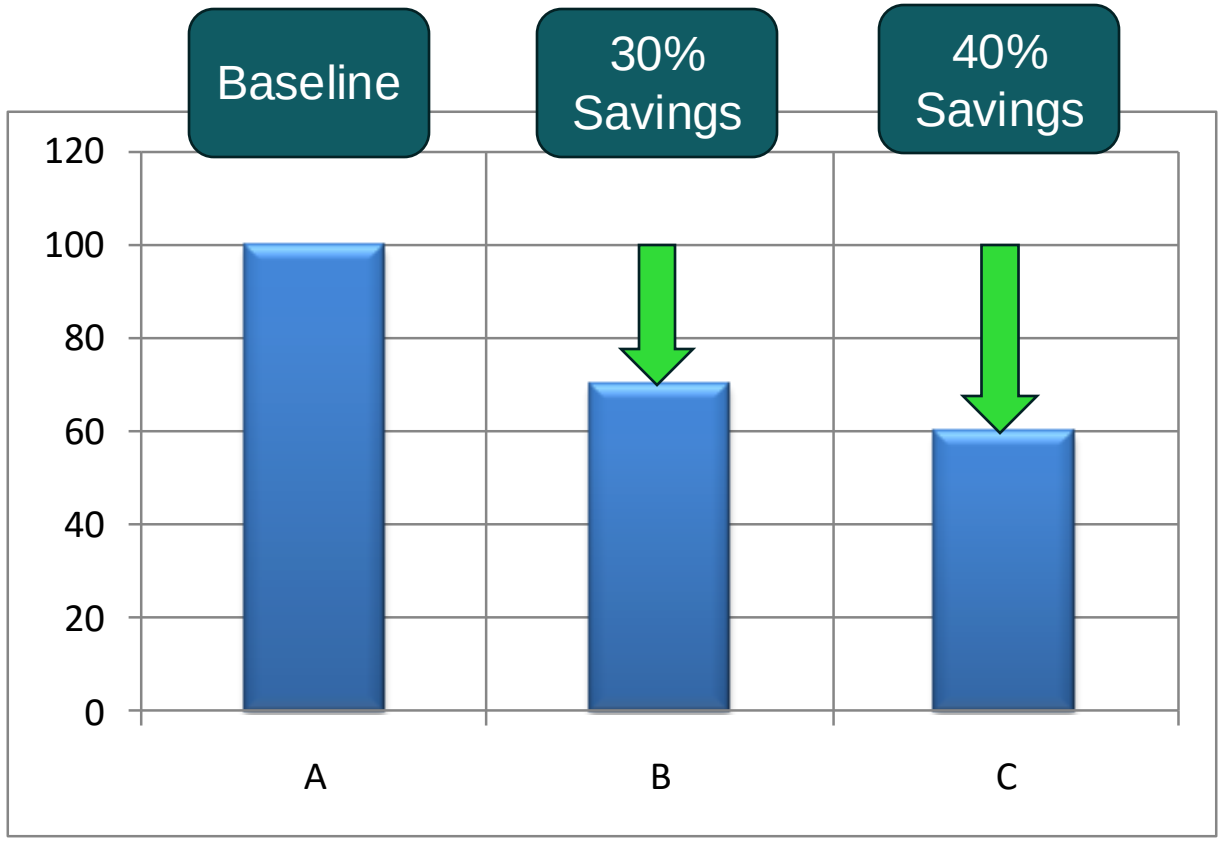
Energy modeling use cases

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



Source: Kolderup Consulting

Appropriate uses for energy modeling

Safe operating space:
Relative performance of design alternatives

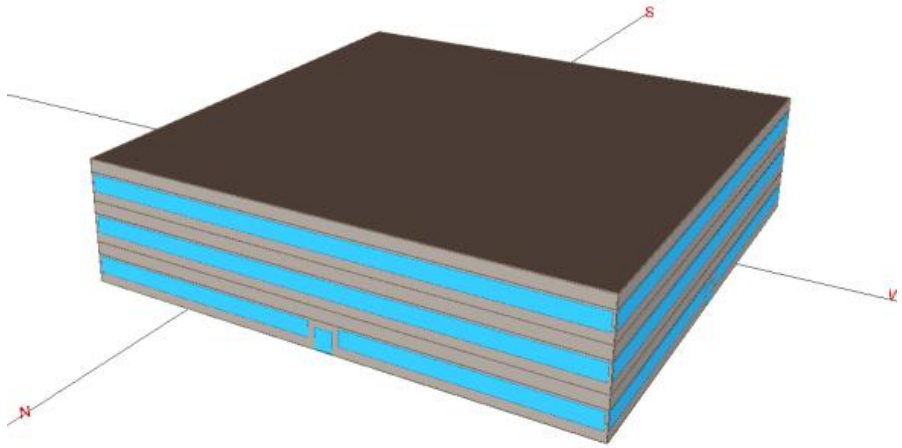
- Design studies
- Compliance analysis
- Retrofit analysis

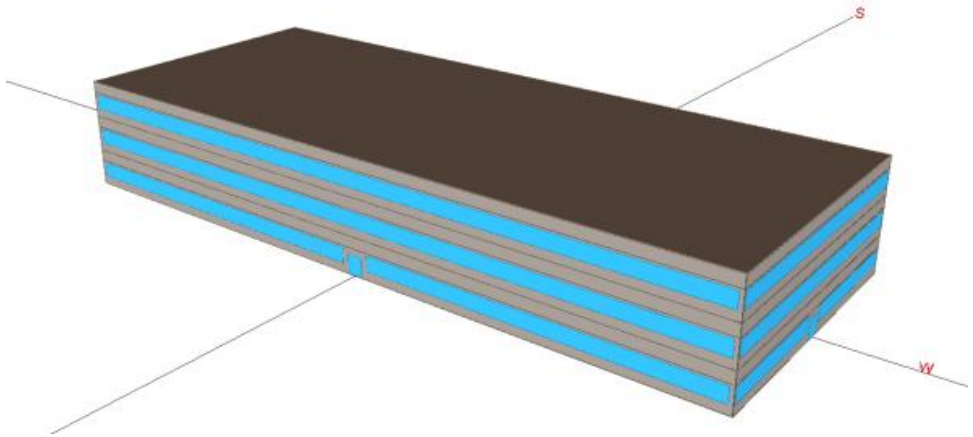
With caution:
Predicting **actual** energy consumption

- Building massing
  - Form
  - Orientation
- Building envelope
  - Insulation
  - Glazing
  - Shading
- HVAC system types (many options)
- Control optimization

Source: Kolderup Consulting

Very early stage design decisions





Daylight?
Energy gain from the sun?

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

- Energy code compliance
- Energy label documentation (e.g. LEED)
- Utility incentives

Source: Kolderup Consulting

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

- Identify savings opportunities
- Building enclosure upgrades
  - Window replacement
  - Shading devices
  - Roof and wall insulation
- HVAC system replacements or upgrades
- Control system upgrades

Source: Kolderup Consulting

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

- 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

Source: Kolderup Consulting

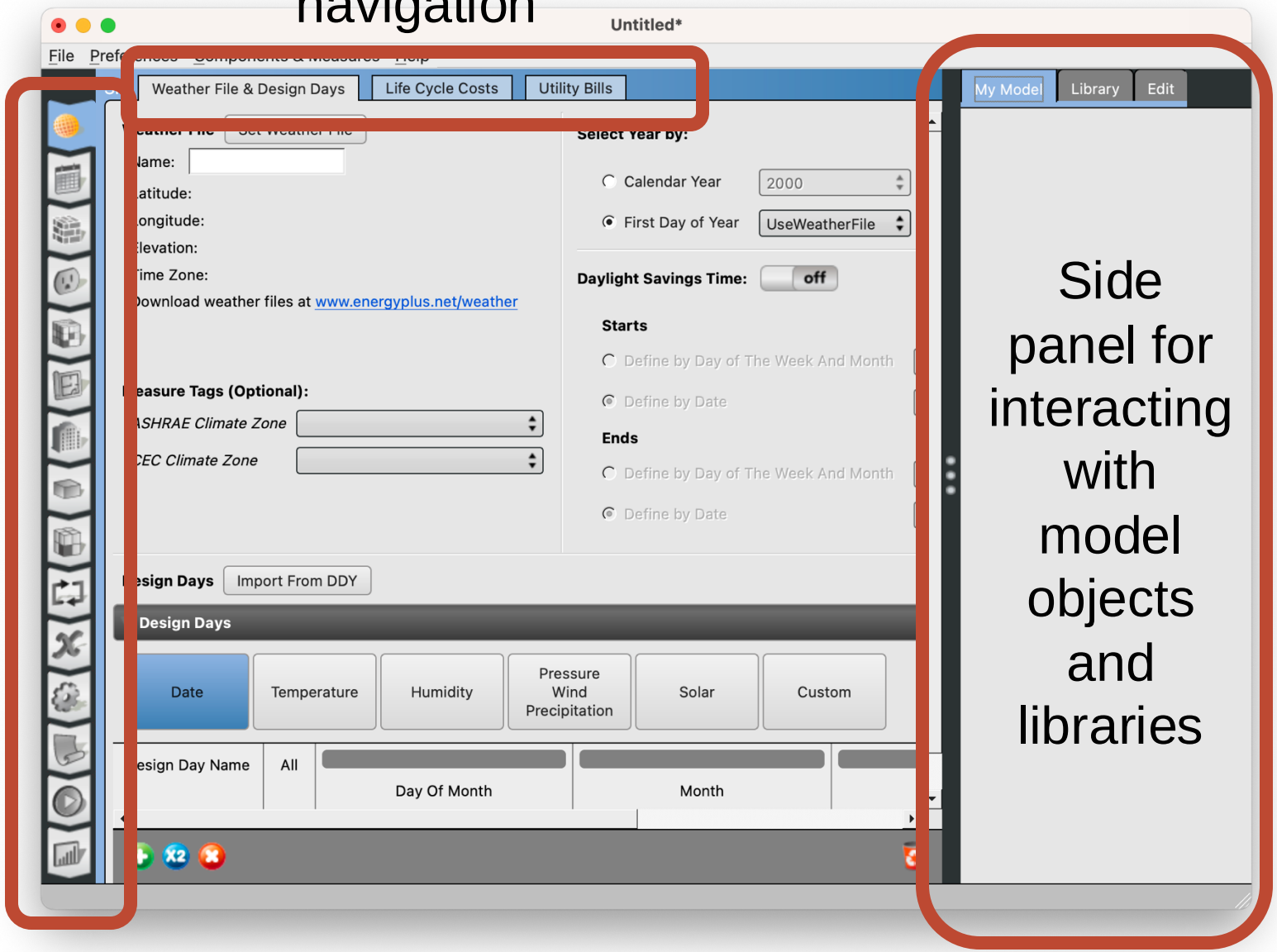
Working with energy models

EnergyPlus and OpenStudio

- Simlation 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

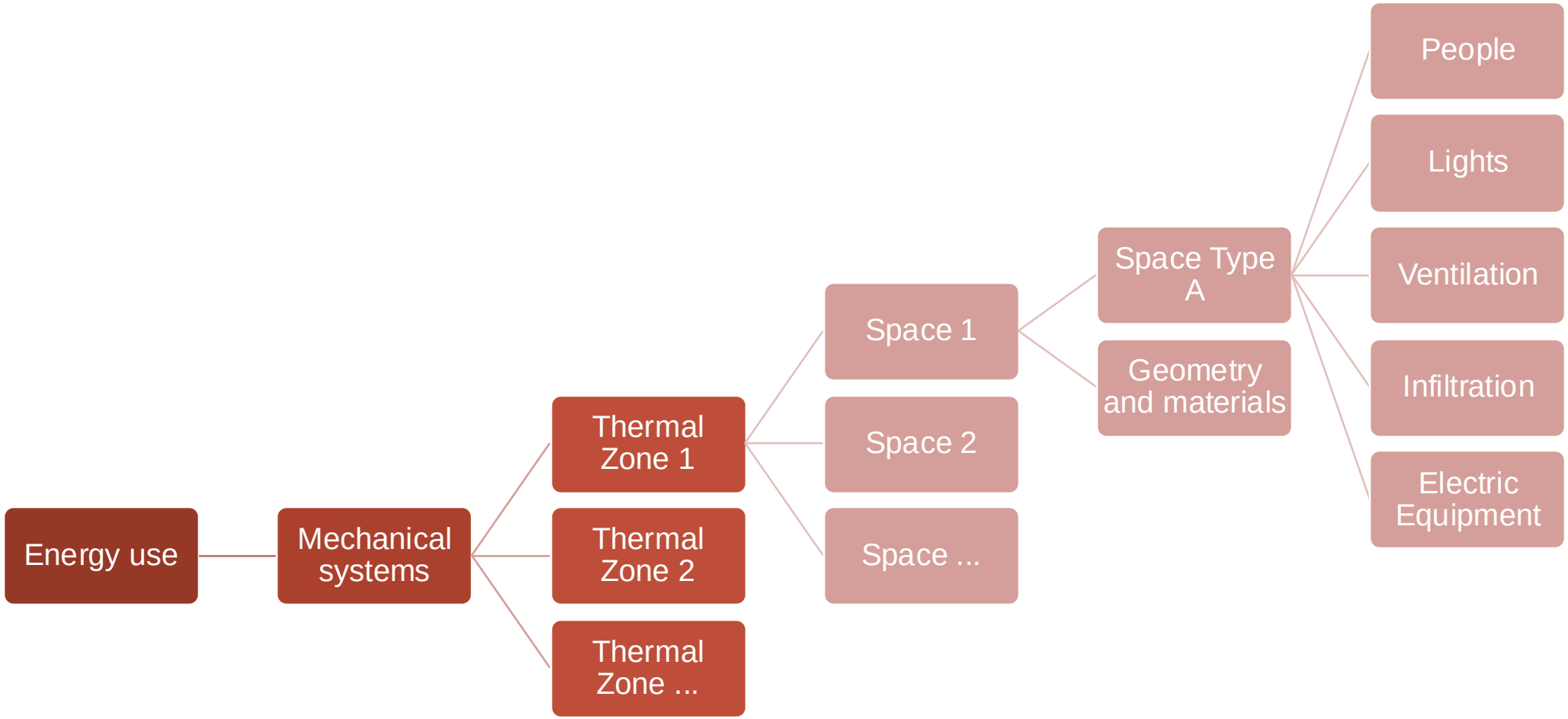
Secondary navigation



Primary navigation

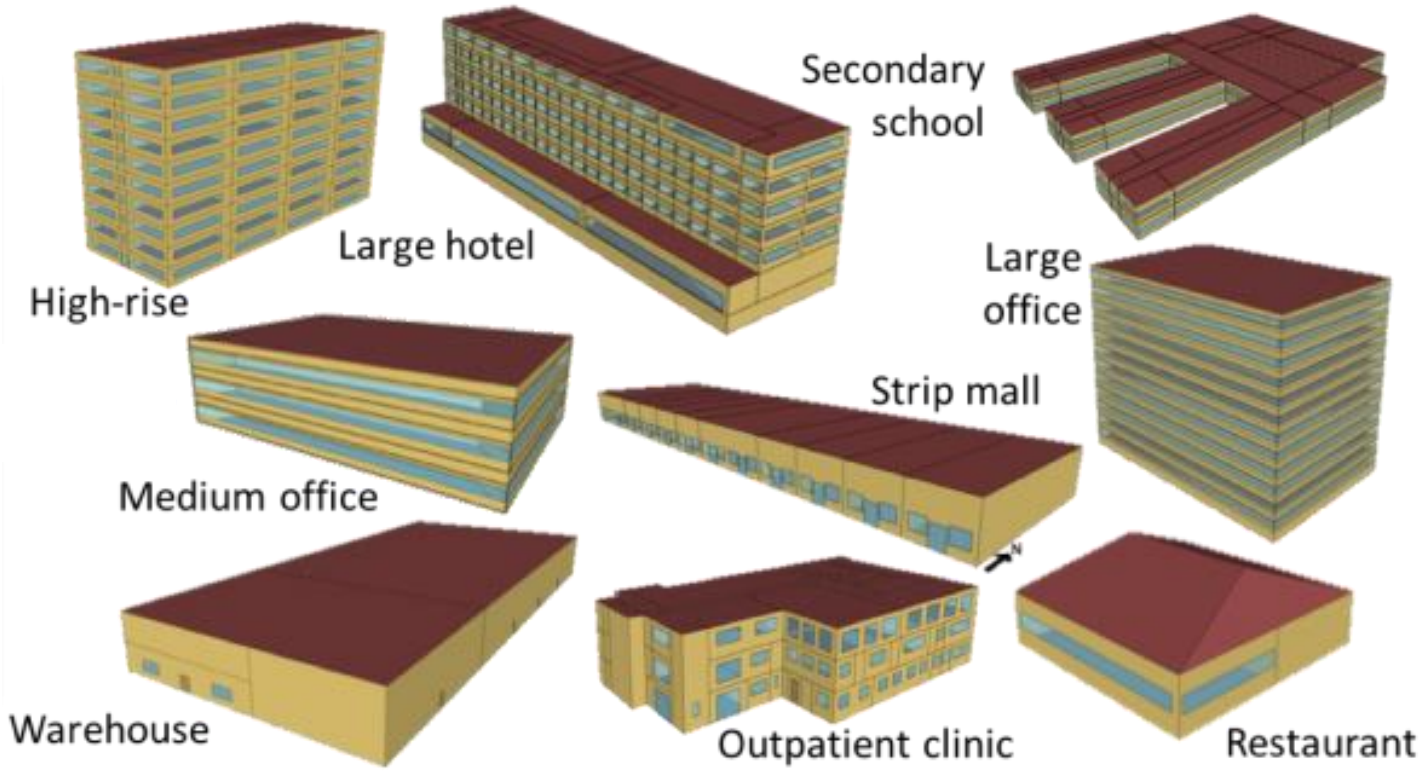
Side panel for interacting with model objects and libraries

OpenStudio objects overview (simplified)



Source: OpenStudio SDK User Docs

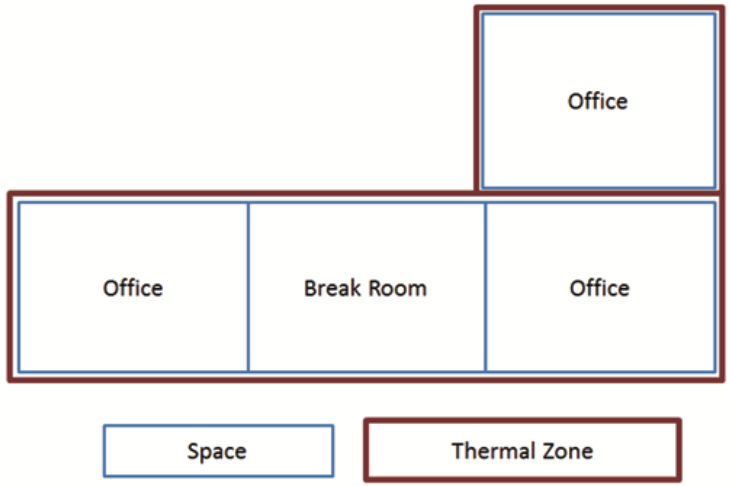
Reference buildings + libraries

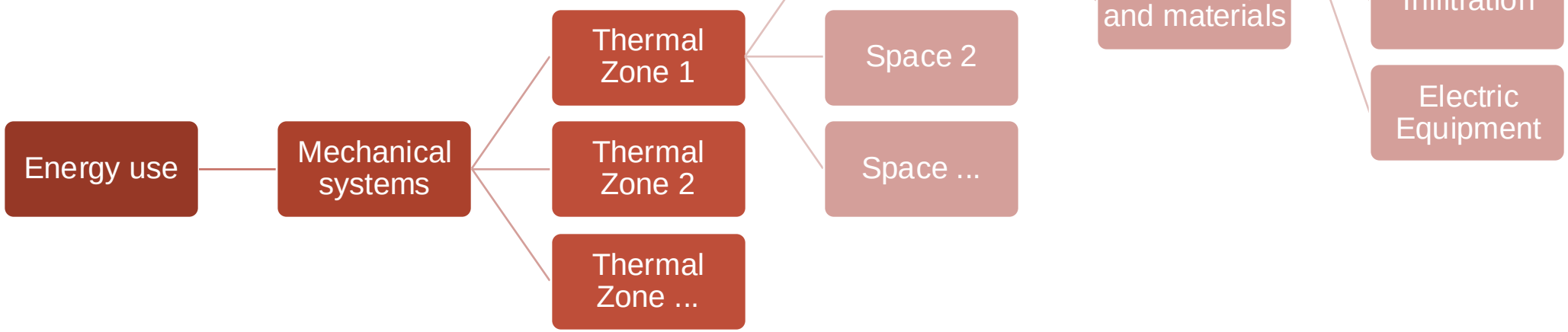


OpenStudio includes libraries associated with typical **construction** and **building features**

Source: US Department of Energy

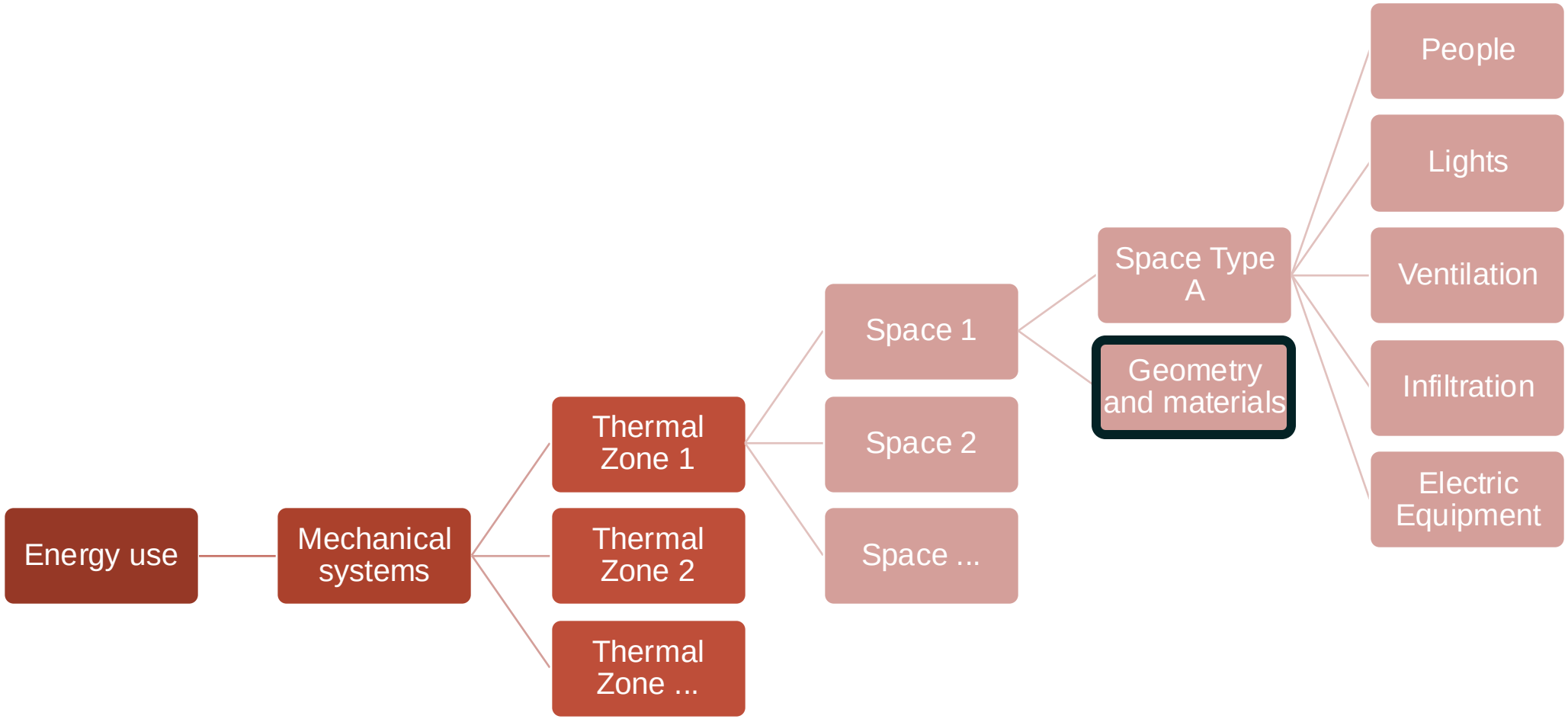
OpenStudio objects overview (simplified)





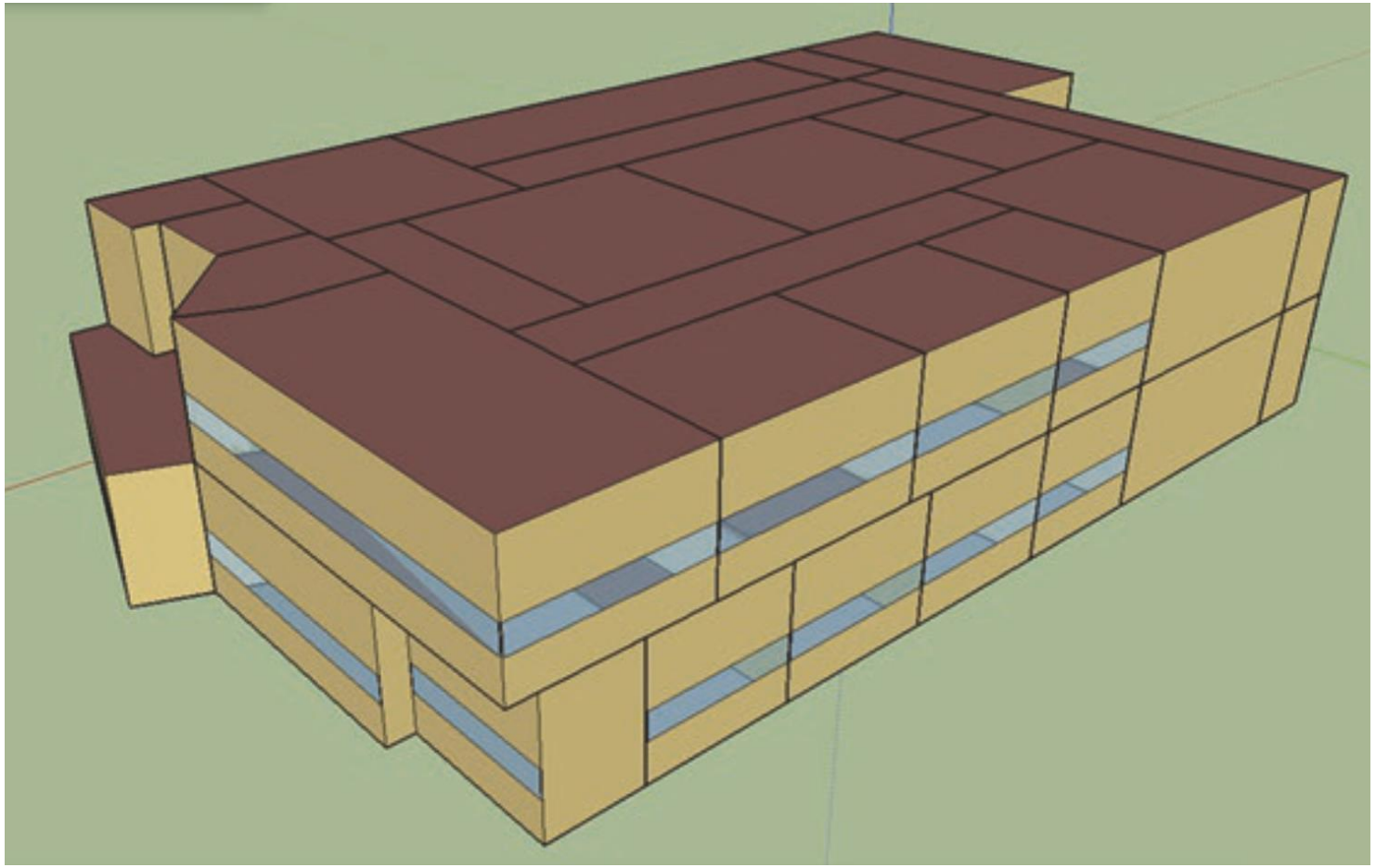
Source: OpenStudio SDK User Docs

OpenStudio objects overview (simplified)



Source: OpenStudio SDK User Docs

OpenStudio geometry

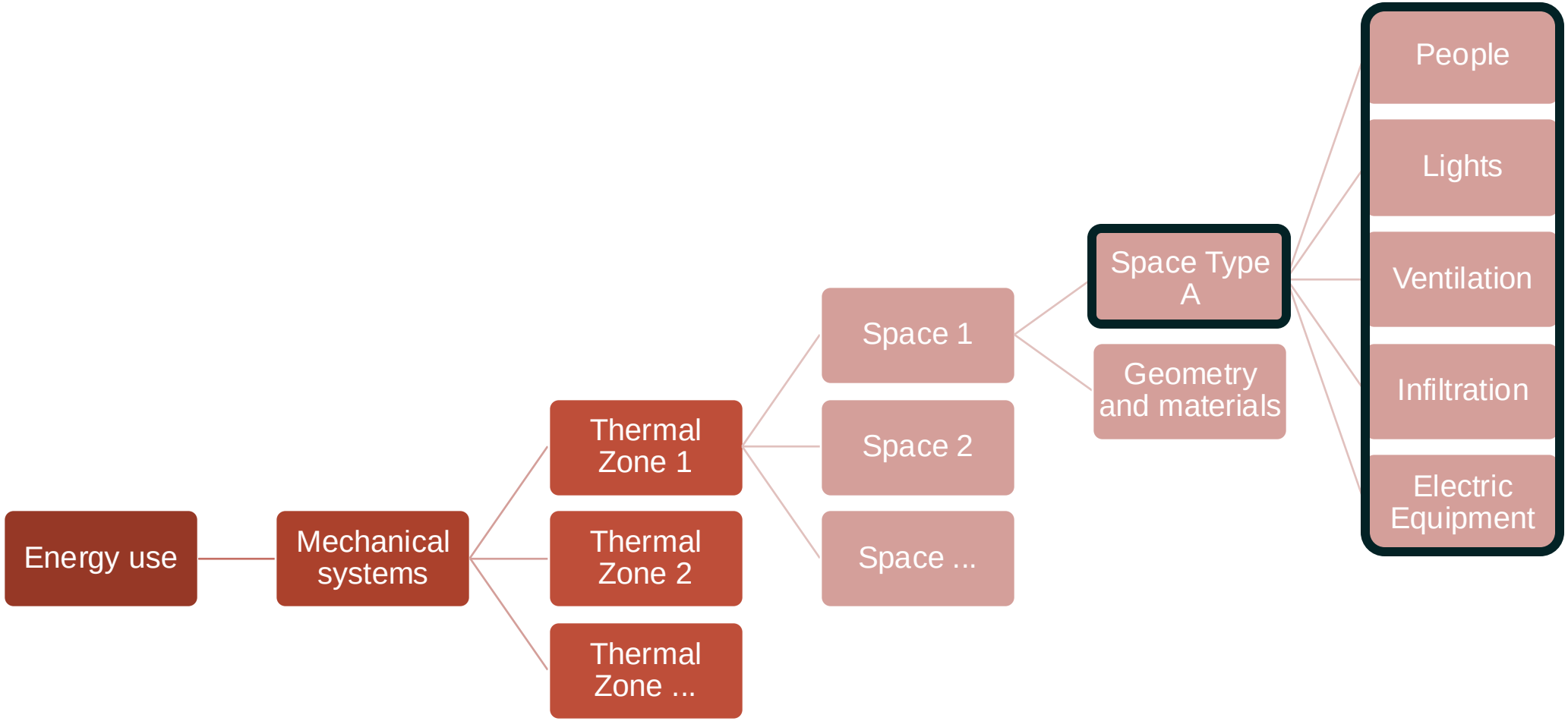


Simplification of detailed building geometry

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

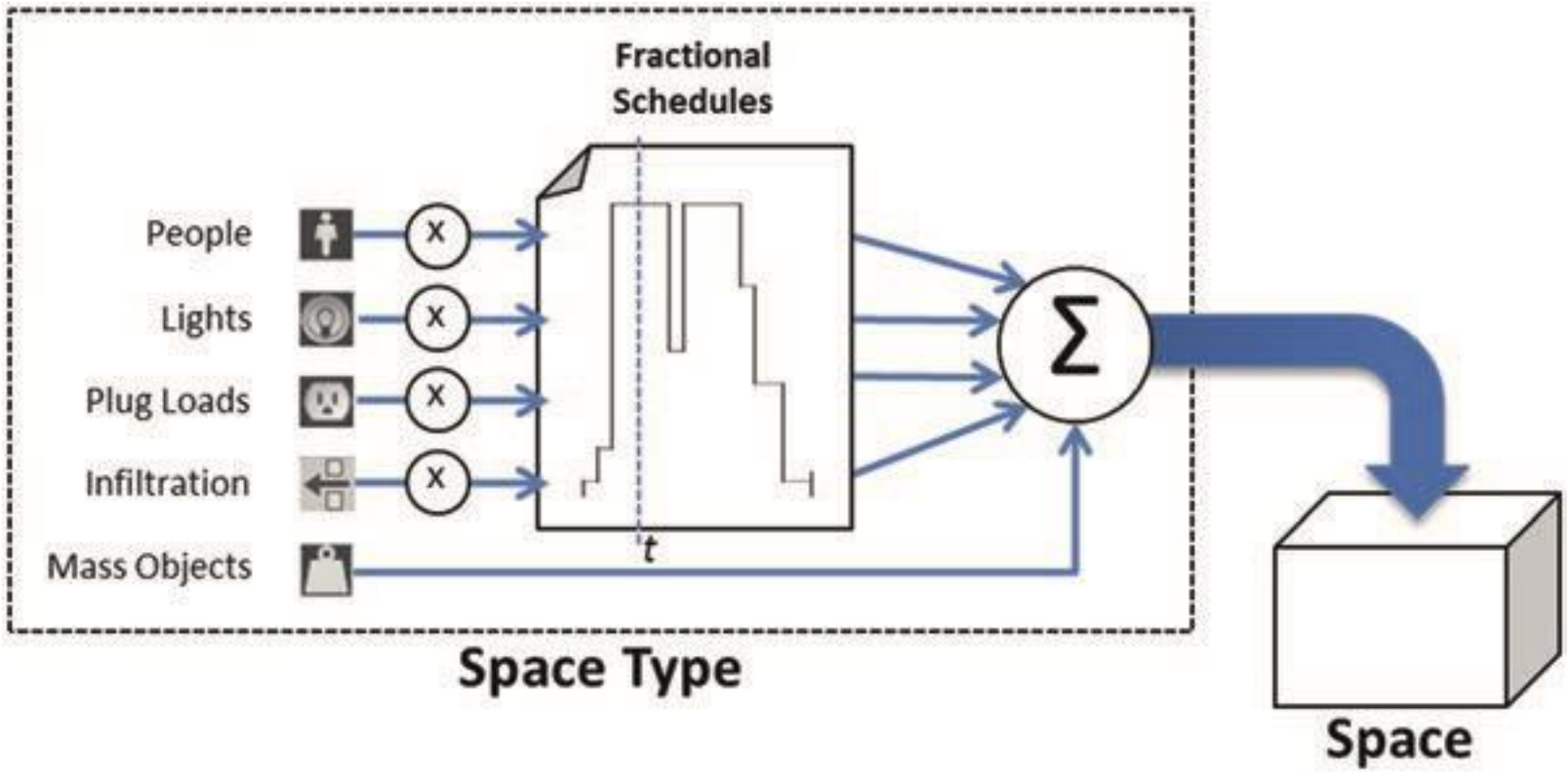
Source: Brackney, Building Energy Modeling with OpenStudio

OpenStudio objects overview (simplified)



Source: OpenStudio SDK User Docs

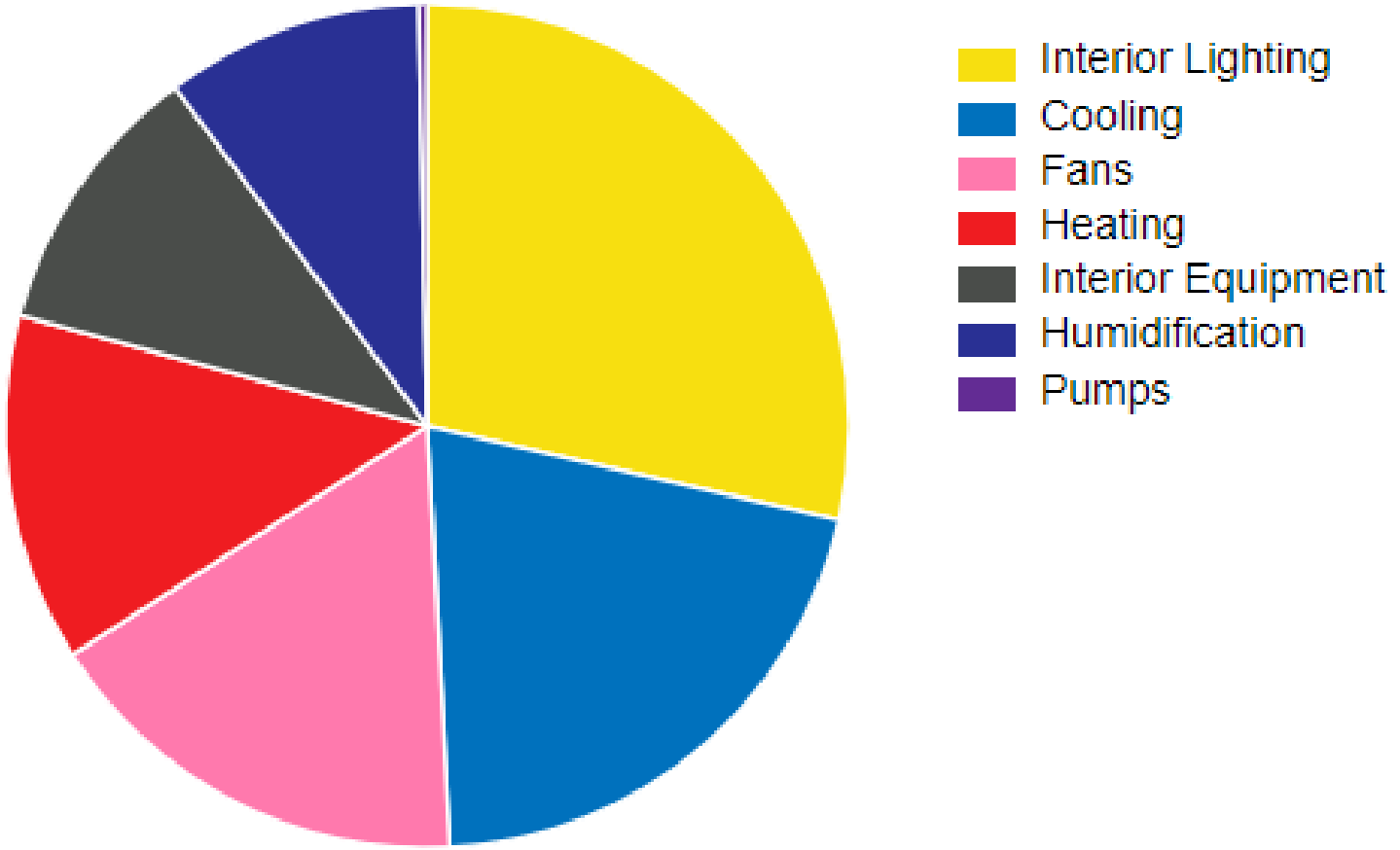
OpenStudio space types



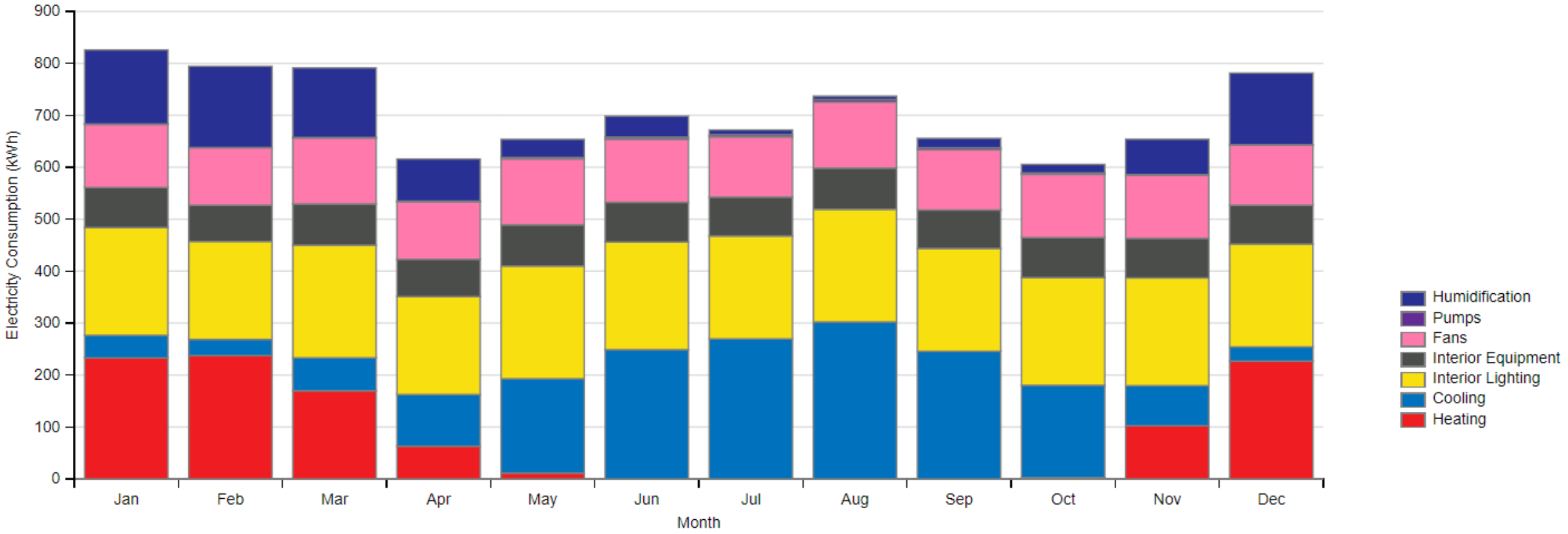
Source: Brackney, Building Energy Modeling with OpenStudio

Visualizing OpenStudio results

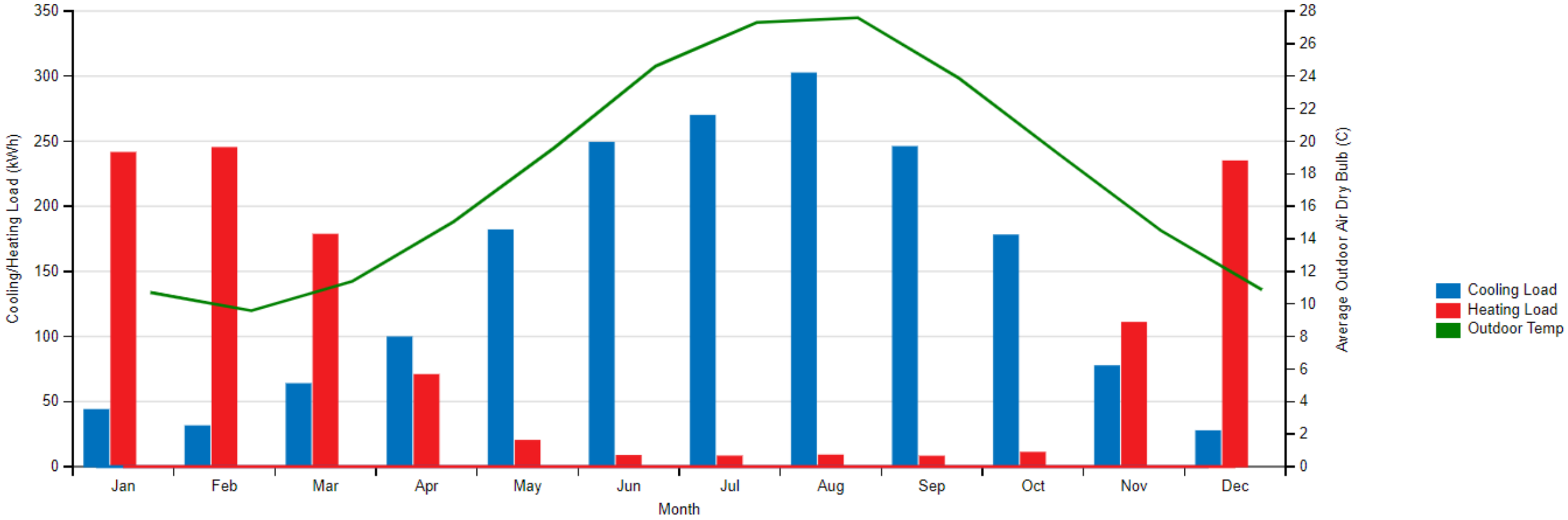
Outputs: Energy use per category



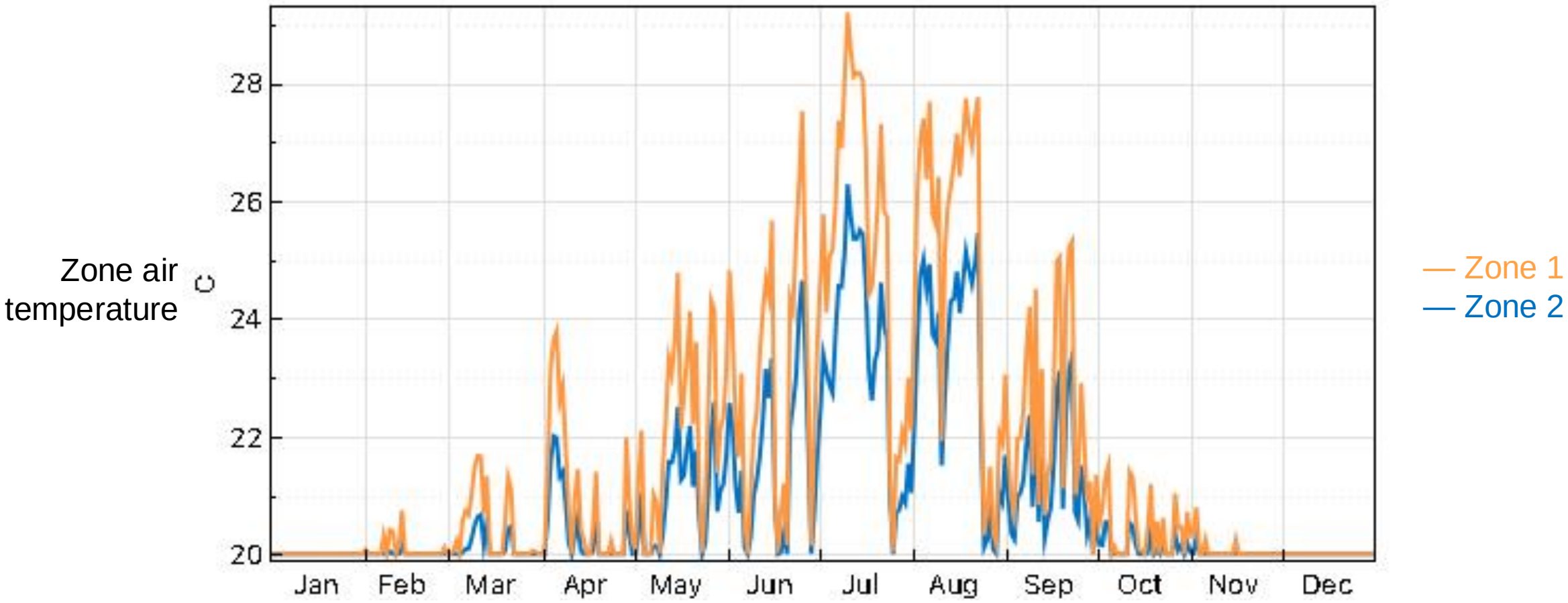
Outputs: Monthly overview



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 (%)

Building energy modeling in industry

Stages of design

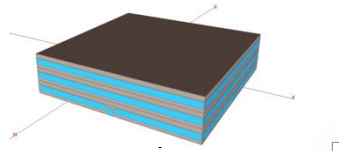
Design Phase	Activities
Pre-design	Assemble design team Owner's project requirements (OPR)
Schematic design	Building form and layout Consider system options
Design development	Select system types and configuration Select materials Finalize form and layout
Construction documents	System details Materials specifications

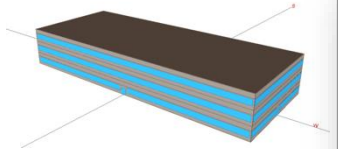
Source: MEEB Chapter 1

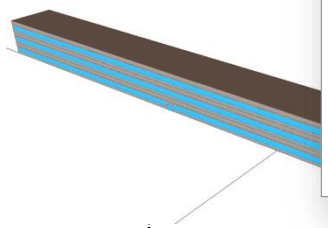
Appropriate timing for energy simulation

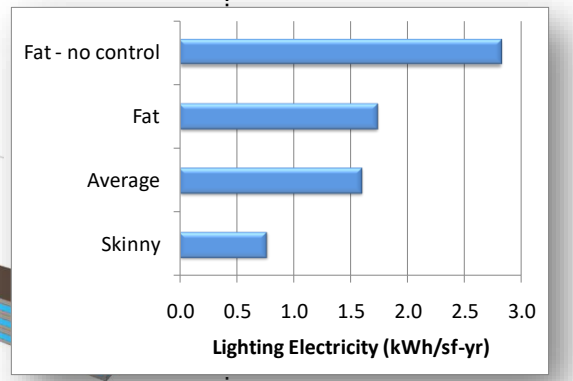
Baseline model, set performance goals, e.g. Energy Star score, LEED points

Fundamental design alternatives with simple models

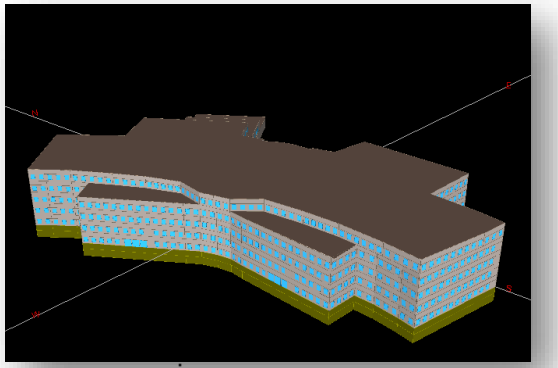








Specific design alternatives with more detailed models



LEED
LEADERSHIP IN ENERGY & ENVIRONMENTAL DESIGN

Update models, produce compliance documentation

Pre-Design

Schematic Design

Design Development

Construction Documents