



# Building Energy Simulation

## Introduction to EnergyPlus

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Lecture 5

Principles of Modeling for Cyber-Physical Systems

Instructor: Madhur Behl

# Previously..

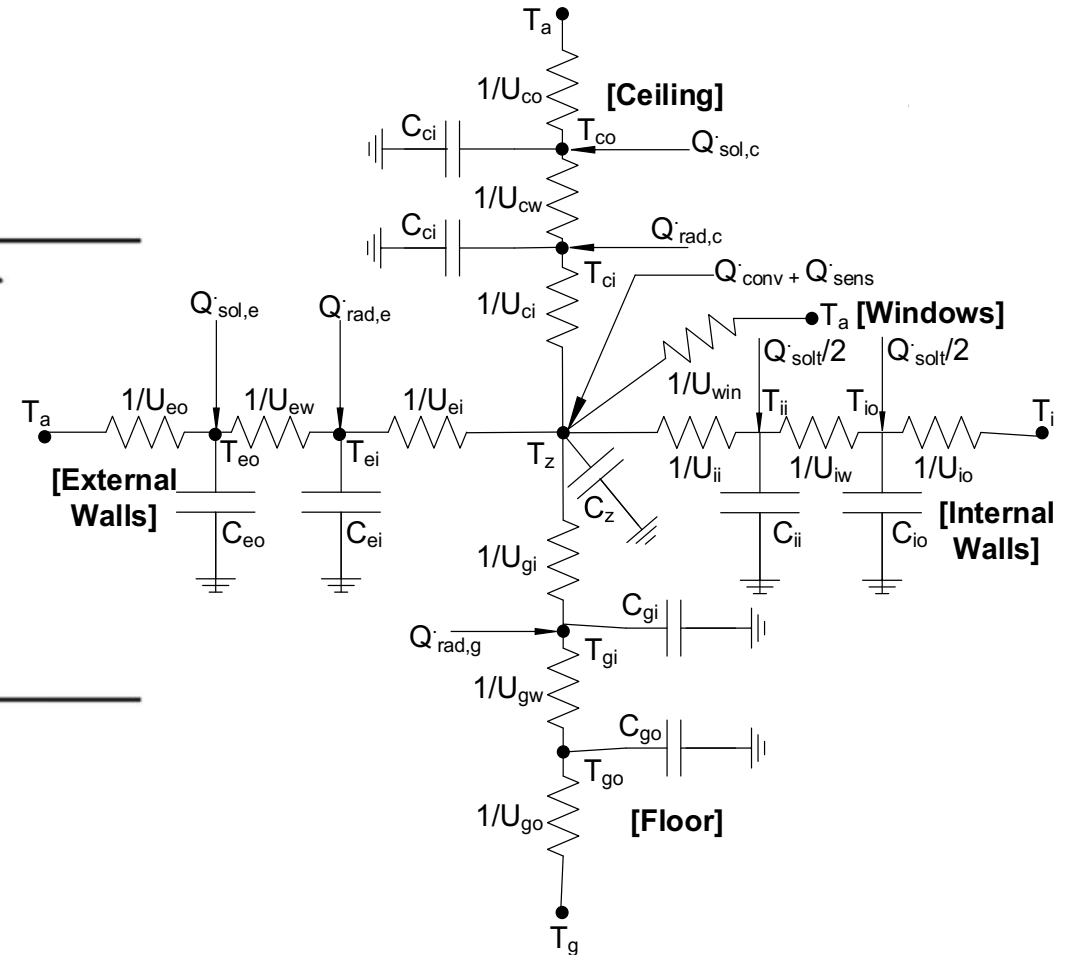
## How to find the values of the parameters ?

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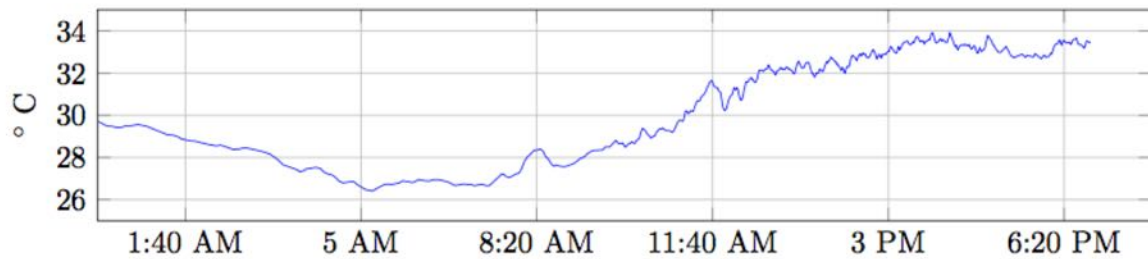
$U_{*o}$	convection coefficient between the wall and outside air
$U_{*w}$	conduction coefficient of the wall
$U_{*i}$	convection coefficient between the wall and zone air
$U_{win}$	conduction coefficient of the window
$C_{**}$	thermal capacitance of the wall
$C_z$	thermal capacity of zone $z_i$

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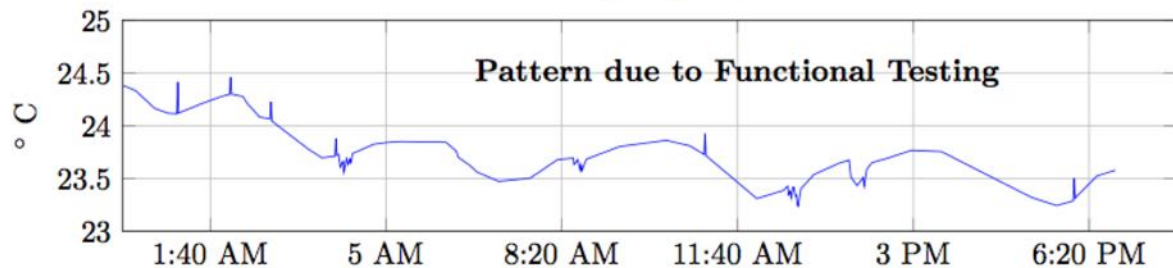
$g$ : floor;  $e$ : external wall;  $c$ : ceiling;  $i$ : internal wall



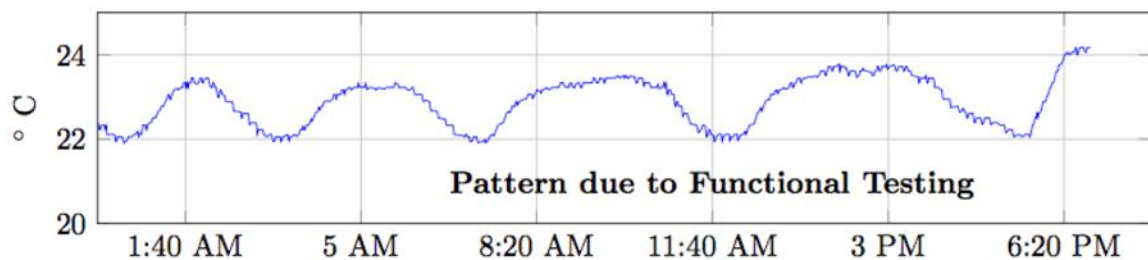
Ambient temperature



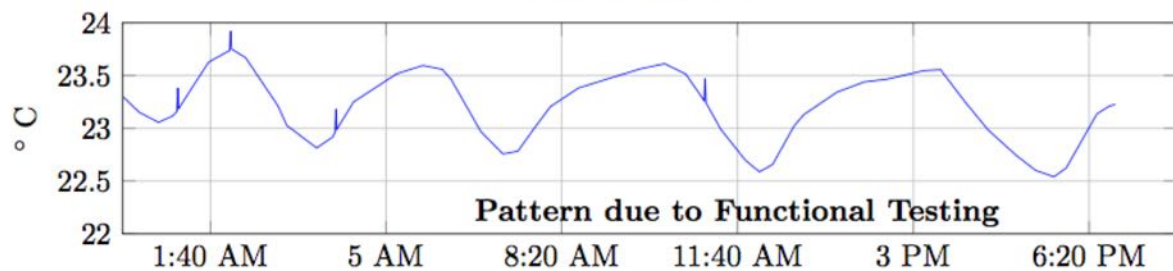
Ceiling temperature



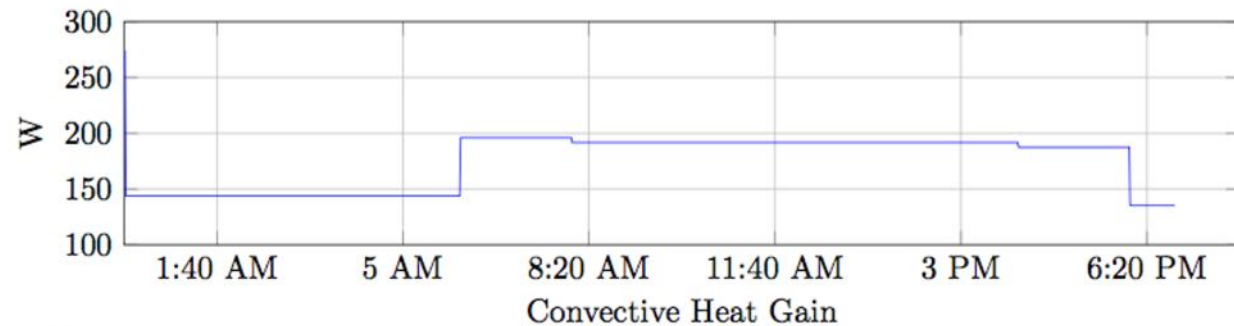
Porch Temperature



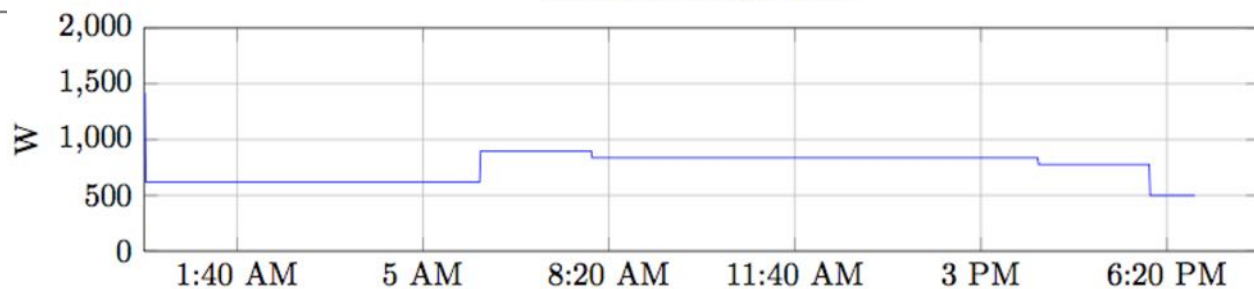
Floor Temperature



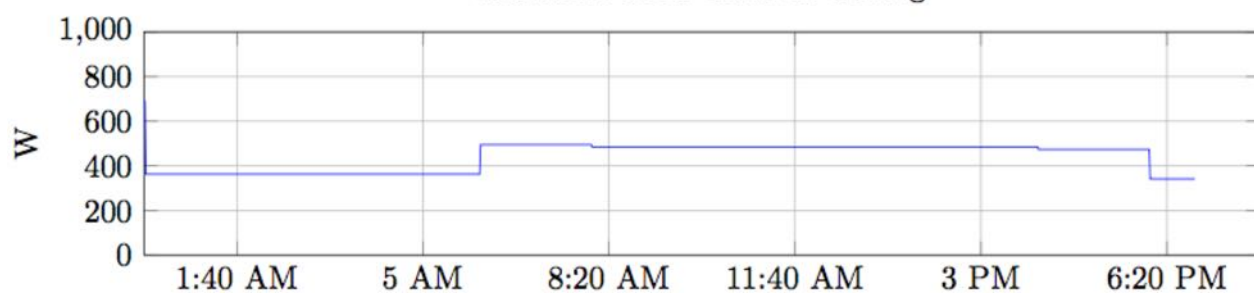
External Solar Irradiation



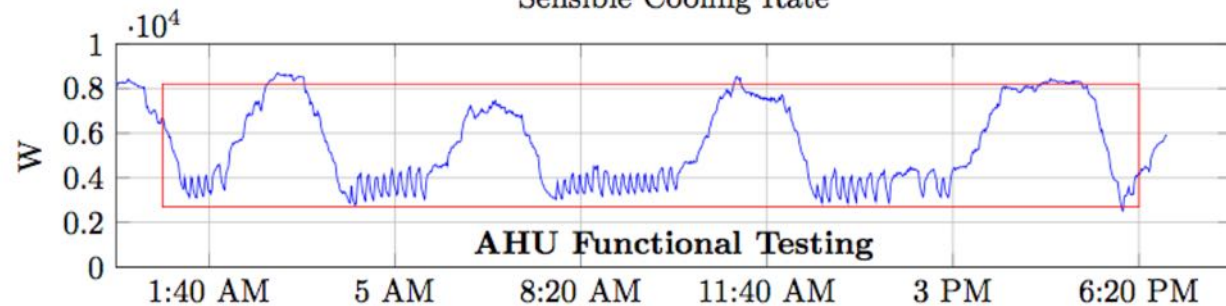
Convective Heat Gain



Radiative Heat Gain on Ceiling

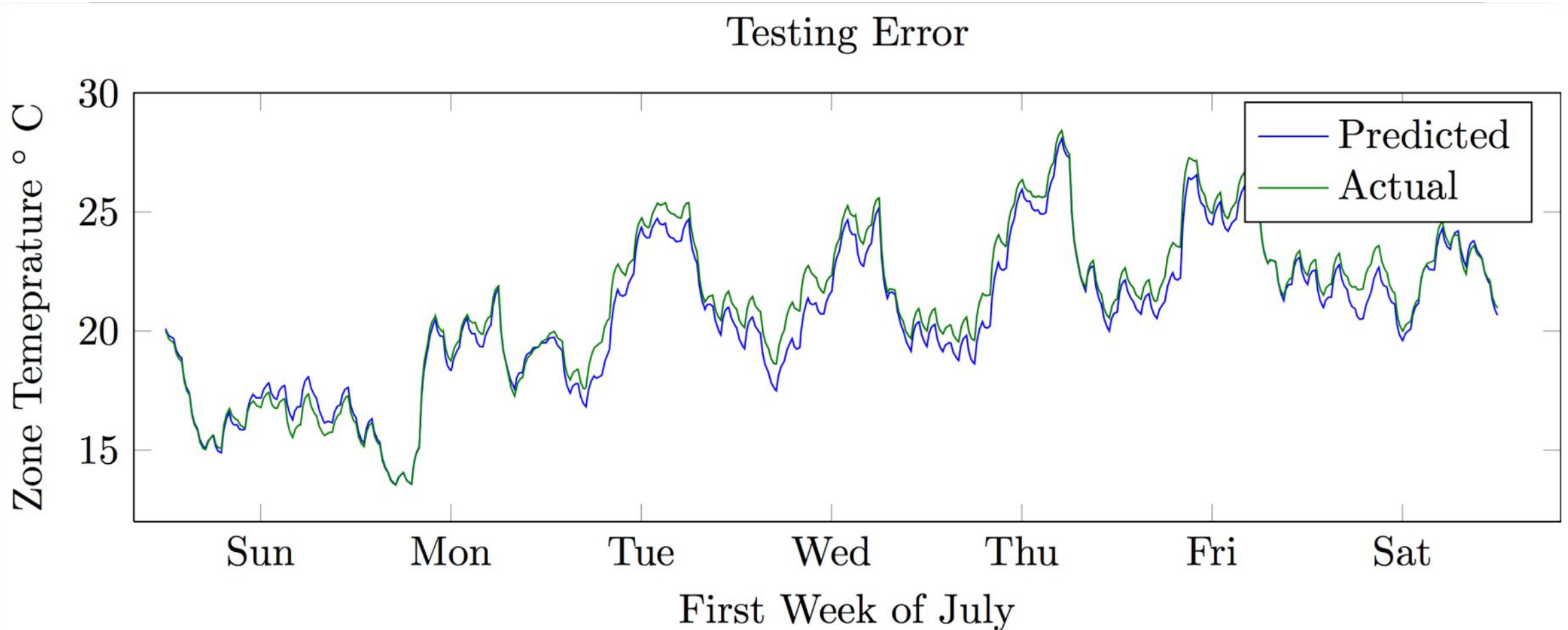


Sensible Cooling Rate



AHU Functional Testing

Given the disturbances and inputs, the model should predict the zone temperature.

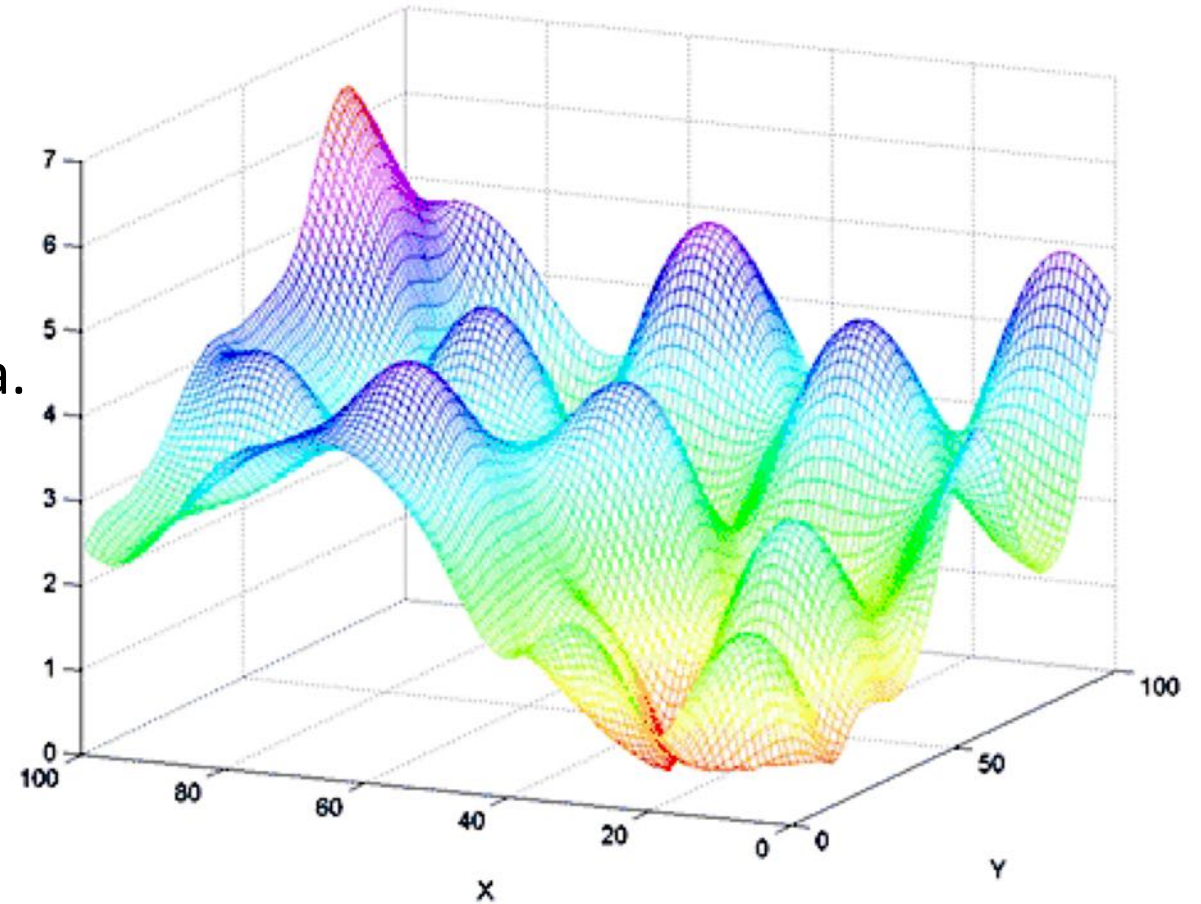


# Parameter estimation is a search

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Need a good starting point to avoid local minima.

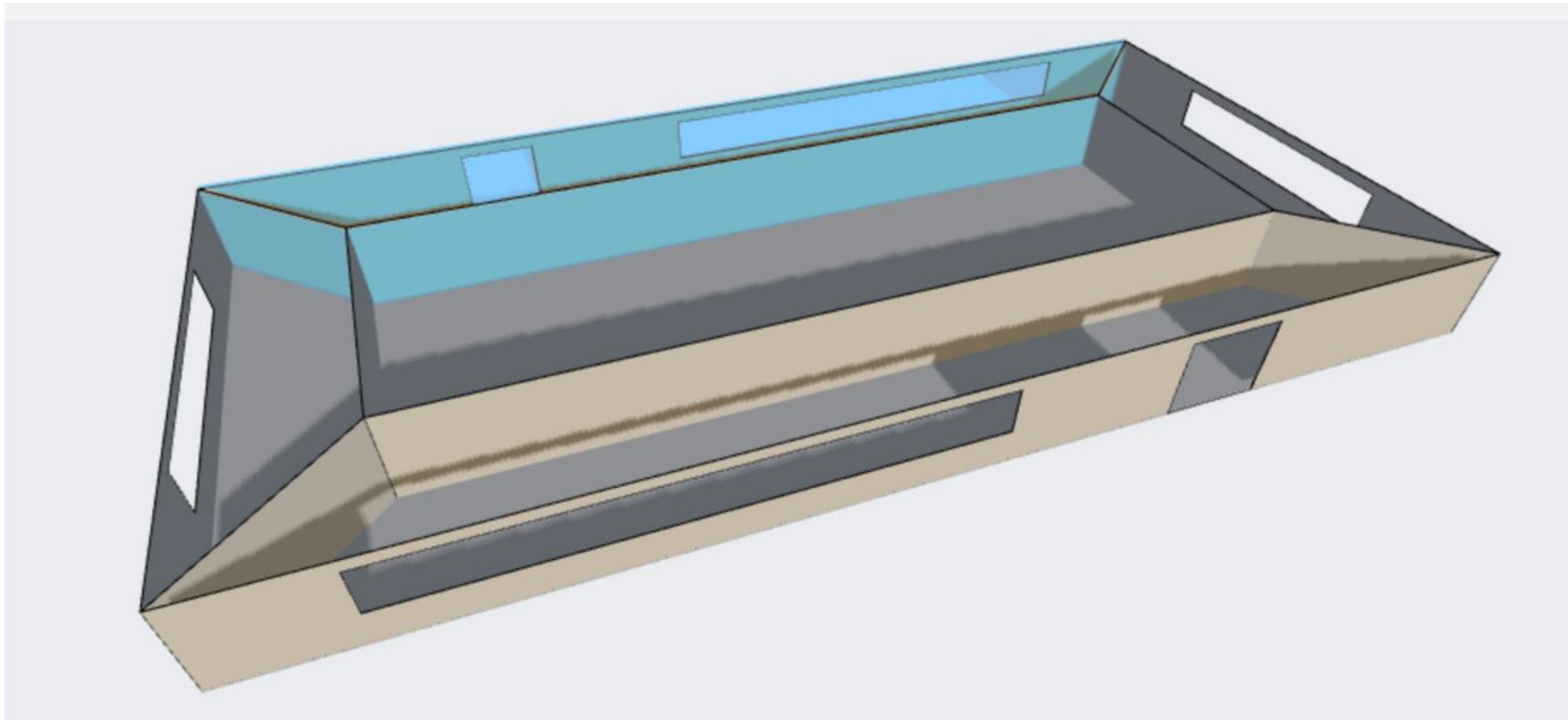
Compute **nominal values** of the parameters.





For our model:  
EnergyPlus == A real building

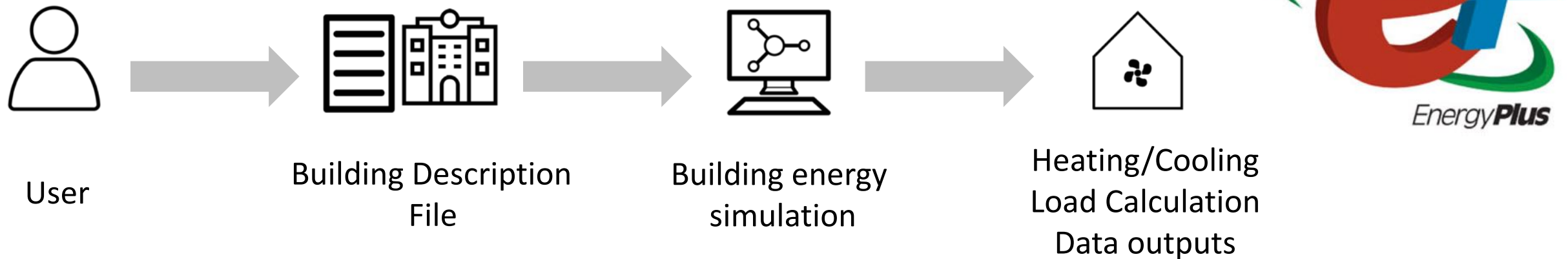
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# What is EnergyPlus ?

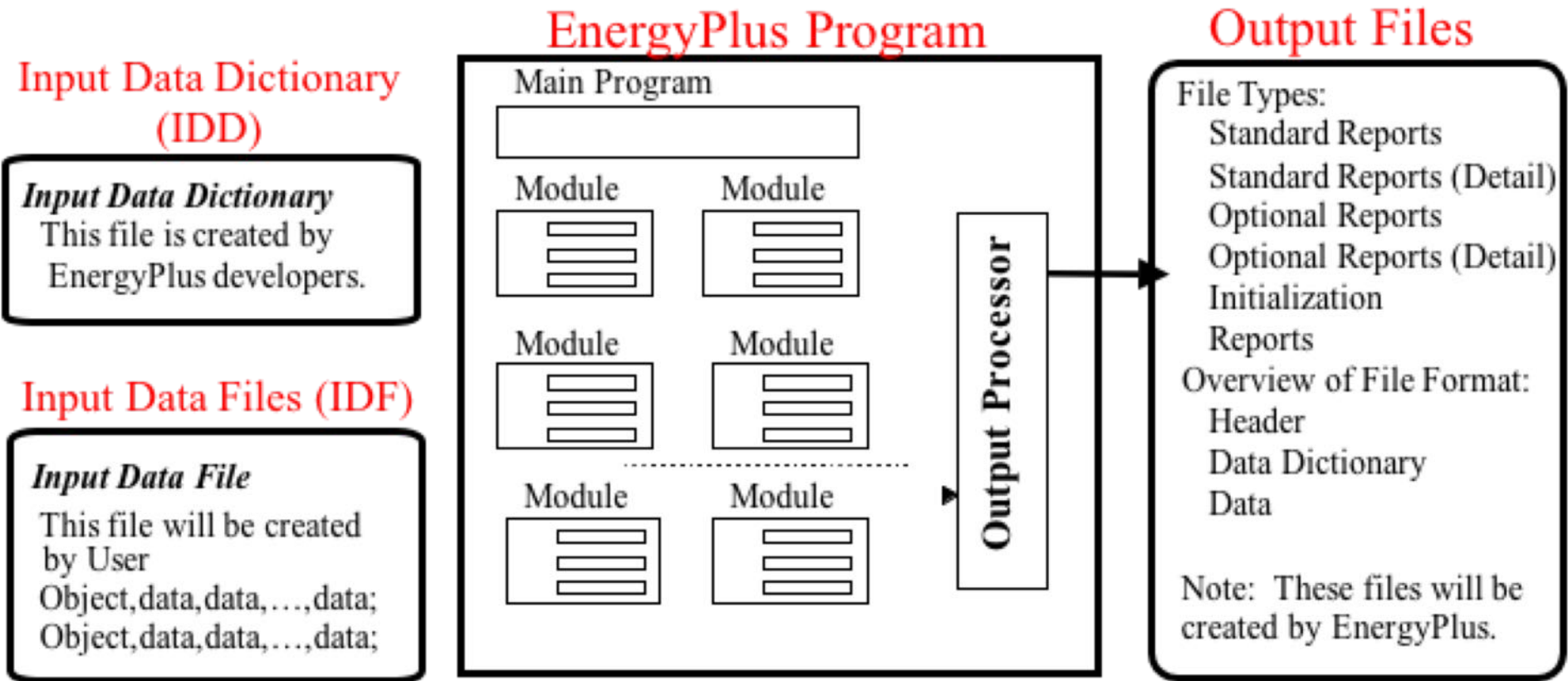
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EnergyPlus is an energy analysis and thermal load simulation program



<https://github.com/NREL/EnergyPlus>

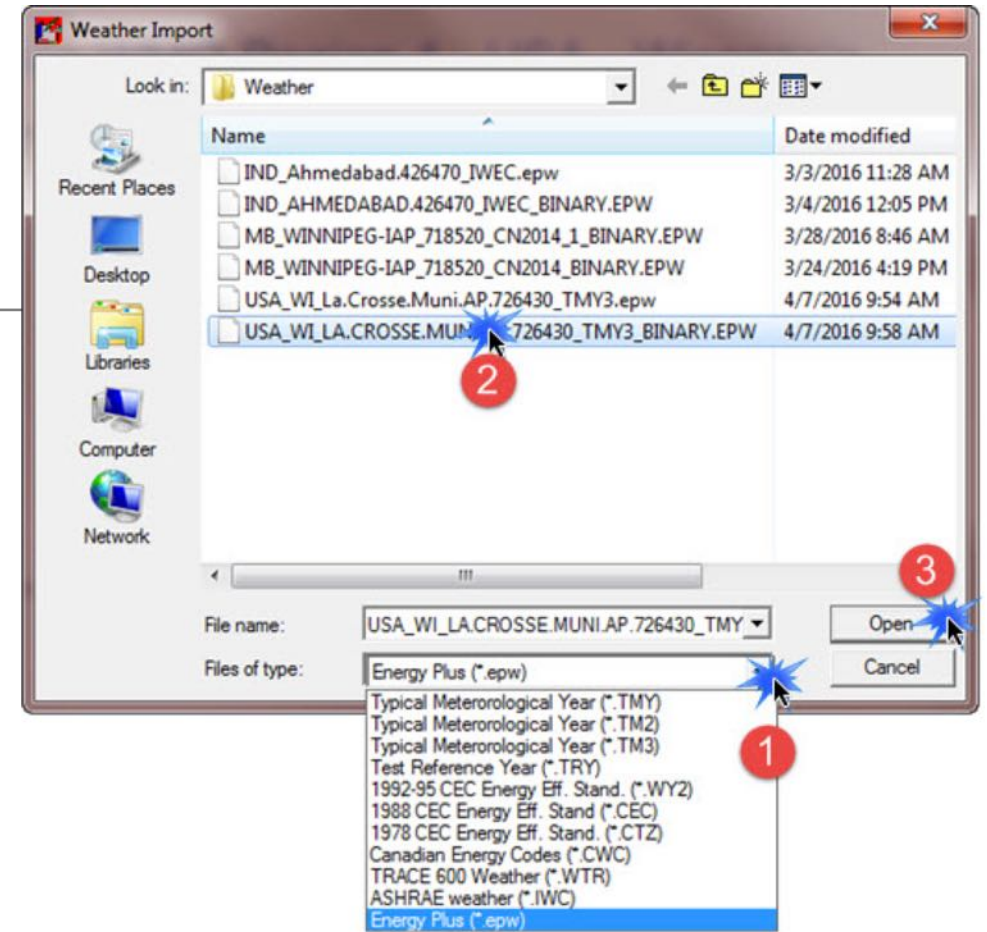
# io files





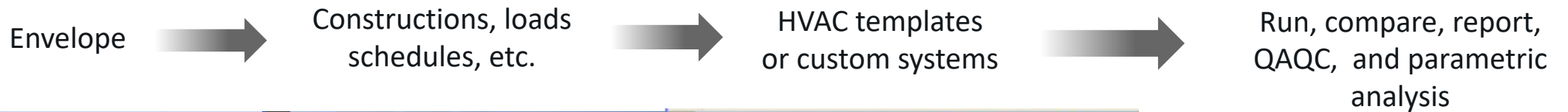
# Weather data

- Data include
  - temperature,
  - humidity,
  - solar,
  - wind,
  - rain, and
  - snow flags, etc.
- Hourly data typical, can be sub-hourly
  - Interpolated for EnergyPlus time steps



**TMY: Typical Meteorological Year data**

# EnergyPlus workflow and building description

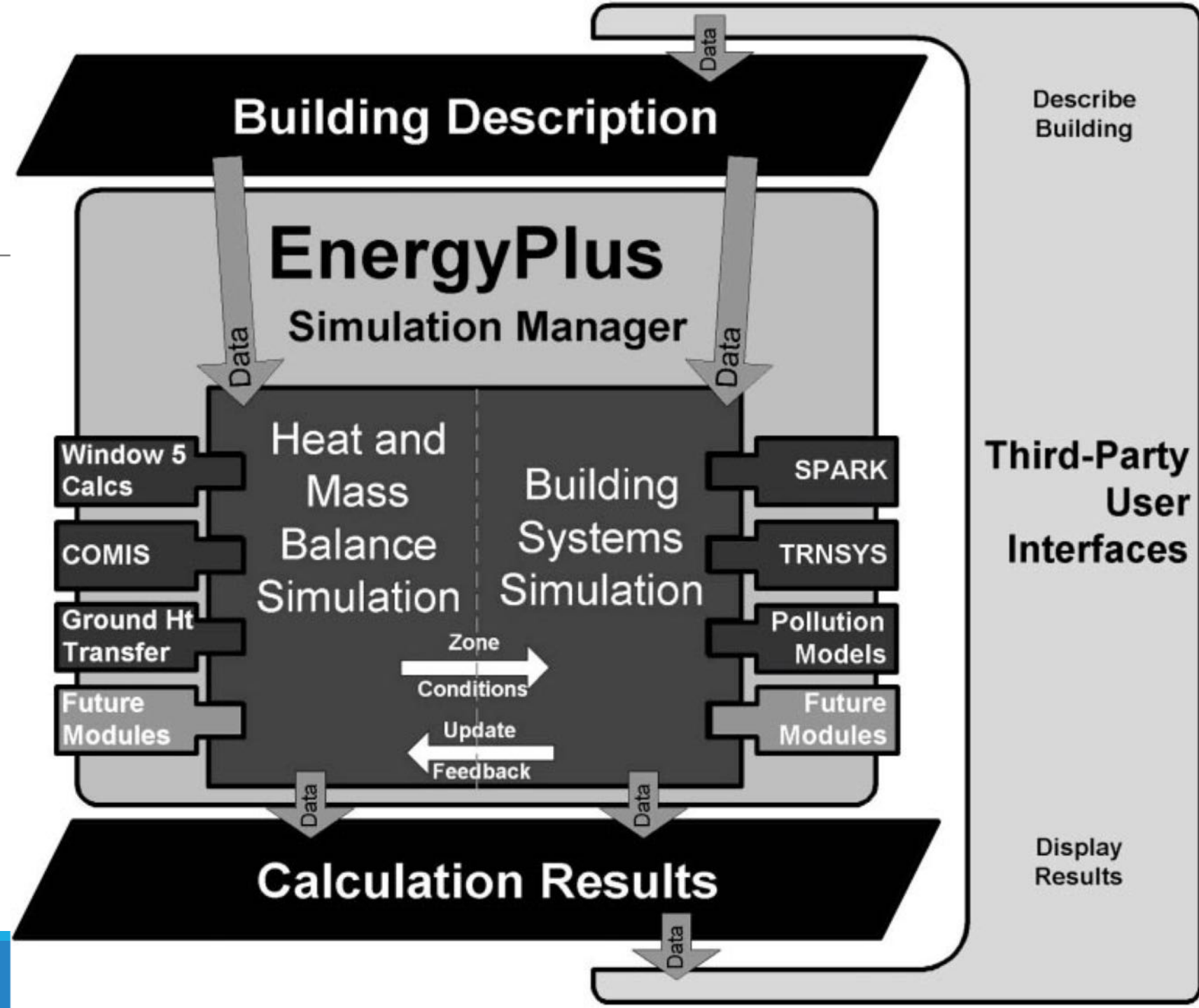


The image displays four screenshots from the EnergyPlus software suite:

- 3D Model:** A perspective view of a building model with a red roof and yellow walls.
- Construction Sets:** A panel showing various construction types categorized by Walls, Floors, Roofs, Interior Surface, Ground Contact Surface, Exterior Sub Surface, Fixed Windows, Operable Windows, and Doors. Each category contains specific construction objects with their names and IDs.
- HVAC Systems:** A schematic diagram of a HVAC system showing supply and demand equipment connected to packaged rooftop VAV units.
- OpenStudio Reports:** A table of performance metrics for different building configurations.

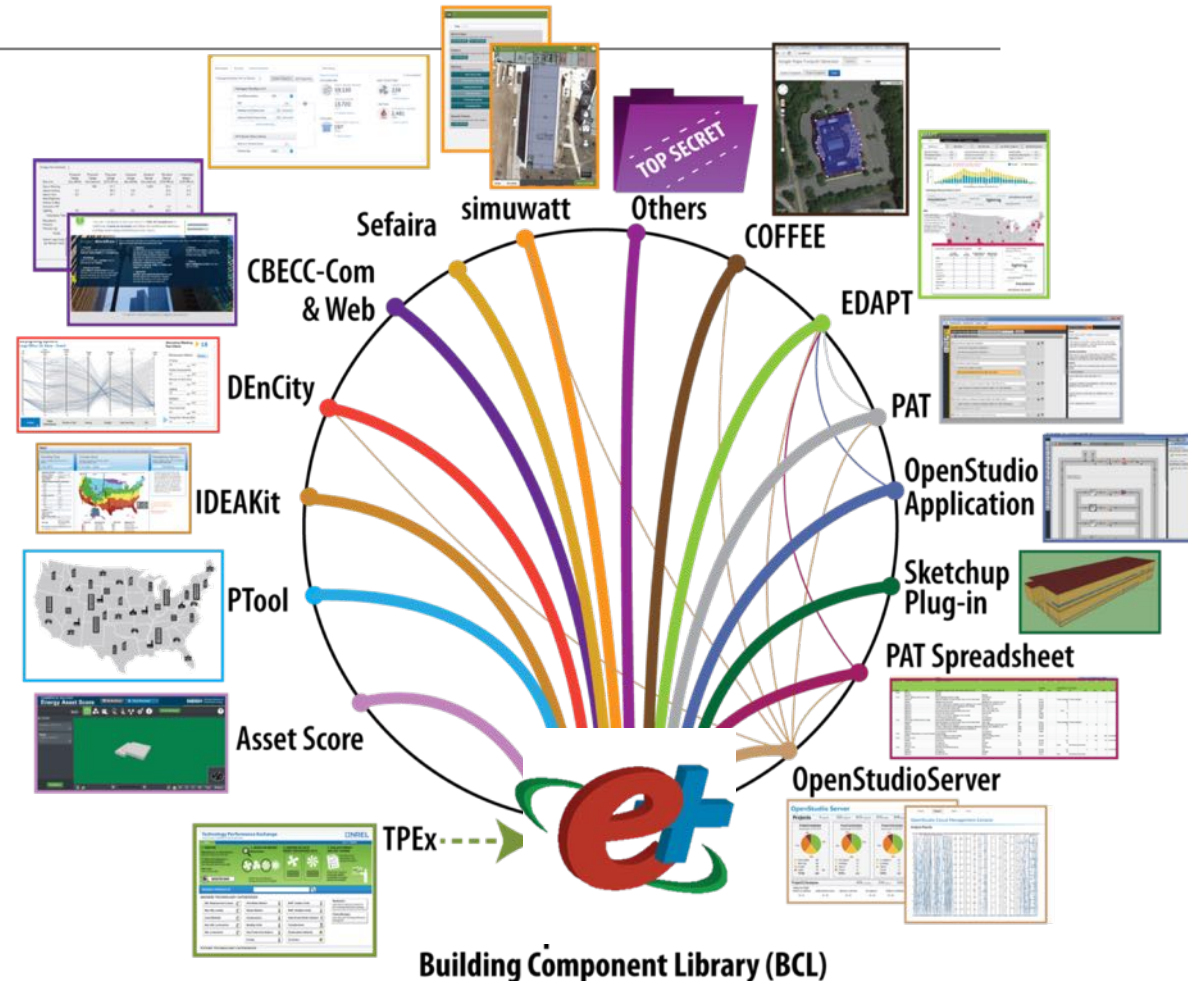
Model	Average Site Heating (kBtu/yr)	Average Site Cooling (kBtu/yr)	Electricity Consumption (kWh/yr)	Natural Gas Consumption (kBtu/yr)	Water Heating (kBtu/yr)	Domestic Hot Water Heating (kBtu/yr)	Yearly Capital Cost (\$)	Annual Utility Cost (\$)	Simple Payback (Years)	Simple IRR (%)
Design Alternative Name	10	10	10,000	1,000	0	0	1,000,000	10,000	10.0	10.0
Model Name	25	25	10,000	1,000	0	0	1,000,000	10,000	10.0	10.0
Model Name	25	25	10,000	1,000	0	0	1,000,000	10,000	10.0	10.0
Model Name	25	25	10,000	1,000	0	0	1,000,000	10,000	10.0	10.0
Model Name	25	25	10,000	1,000	0	0	1,000,000	10,000	10.0	10.0
Model Name	25	25	10,000	1,000	0	0	1,000,000	10,000	10.0	10.0
Model Name	25	25	10,000	1,000	0	0	1,000,000	10,000	10.0	10.0
Model Name	25	25	10,000	1,000	0	0	1,000,000	10,000	10.0	10.0
Model Name	25	25	10,000	1,000	0	0	1,000,000	10,000	10.0	10.0
Model Name	25	25	10,000	1,000	0	0	1,000,000	10,000	10.0	10.0

# EnergyPlus – Simulation Architecture



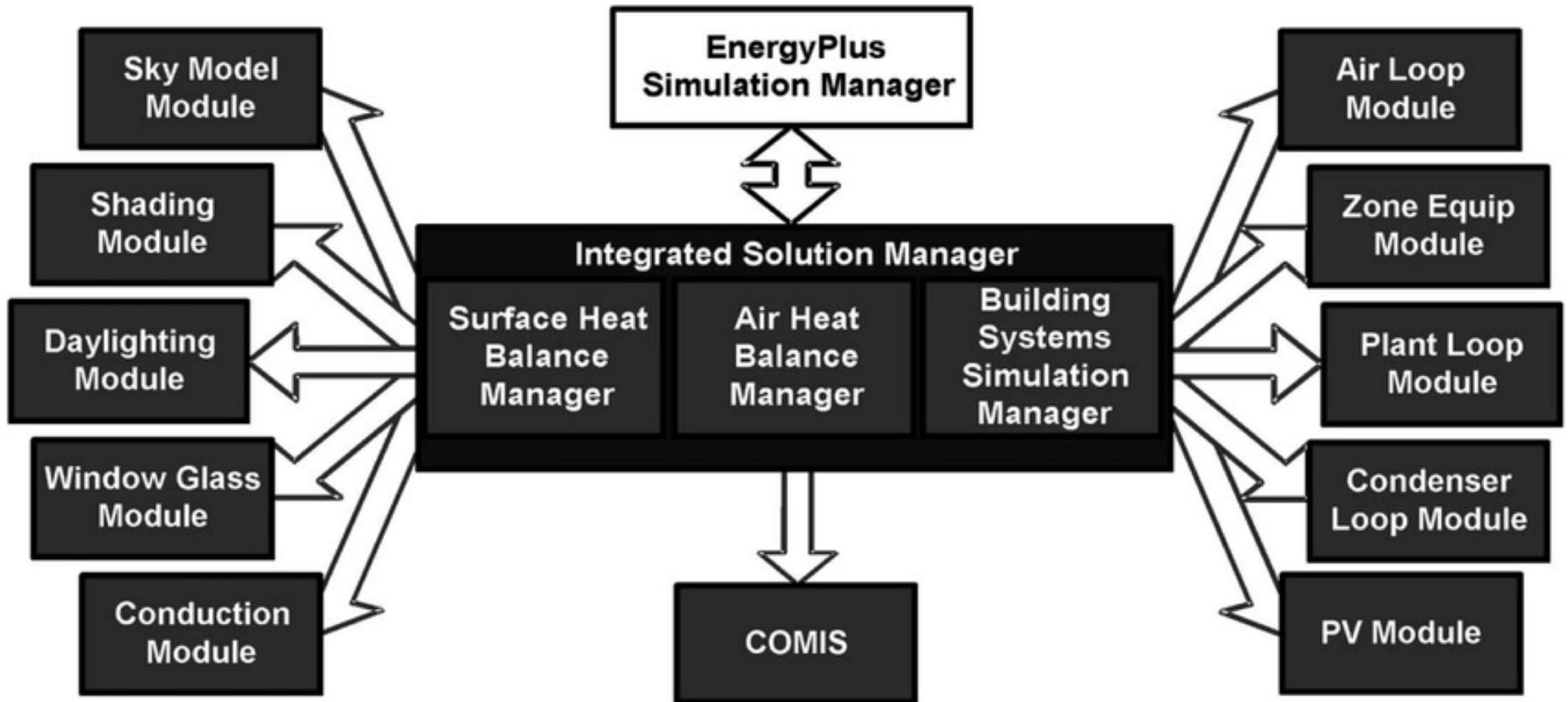
# More than an engine or a single tool

- Whole building energy simulation.
- Peak load calculation and equipment design.
- Sub-hourly, user-definable time steps.
- Advanced fenestration models.
- Illuminance and glare calculations.
- Component-based HVAC.
- Built-in HVAC and lighting control strategies.
- Functional Mockup Interface.
- Standard summary and detailed output reports.

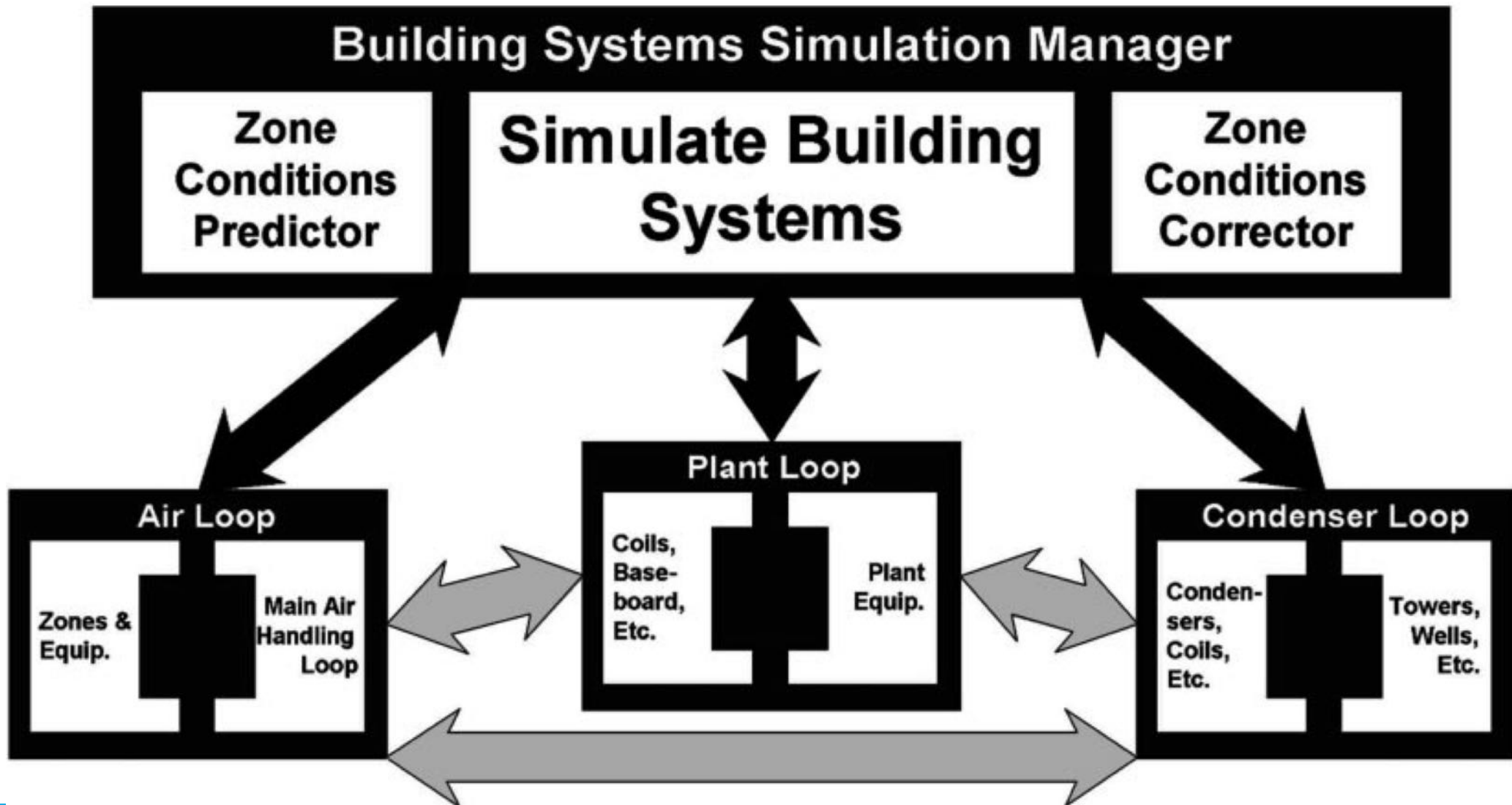




# Integrated simulation manager



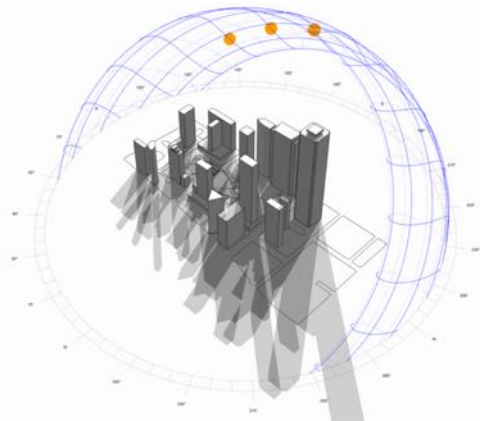
# Building systems simulation manager





# Authoring tools: Third party interfaces

OpenStudio



BuildSimHub  
BETA



# Zone and Air System Integration

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$$C_z \frac{dT_z}{dt} = \sum_{i=1}^{N_{sl}} \dot{Q}_i + \sum_{i=1}^{N_{surfaces}} h_i A_i (T_{si} - T_z) + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p (T_{zi} - T_z) + \dot{m}_{inf} C_p (T_{\infty} - T_z) + \dot{m}_{sys} C_p (T_{sup} - T_z)$$

Sum of convective internal loads

Convective heat transfer from zone surfaces

Infiltration of outside air

Inter zone air mixing

HVAC air system

# Building envelope hierarchy

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Site

>> Building

>>> Zones

>>>> Surfaces

>>>>> Constructions

>>>>>> Materials

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# Energy Plus Demo