MECH4423 Building Energy Management and Control Systems

http://ibse.hk/MECH4423/

Dynamic Building Performance Simulation

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Feb 2024

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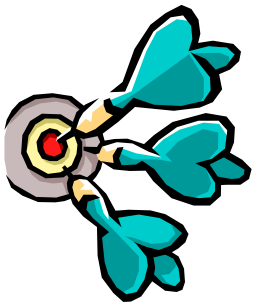
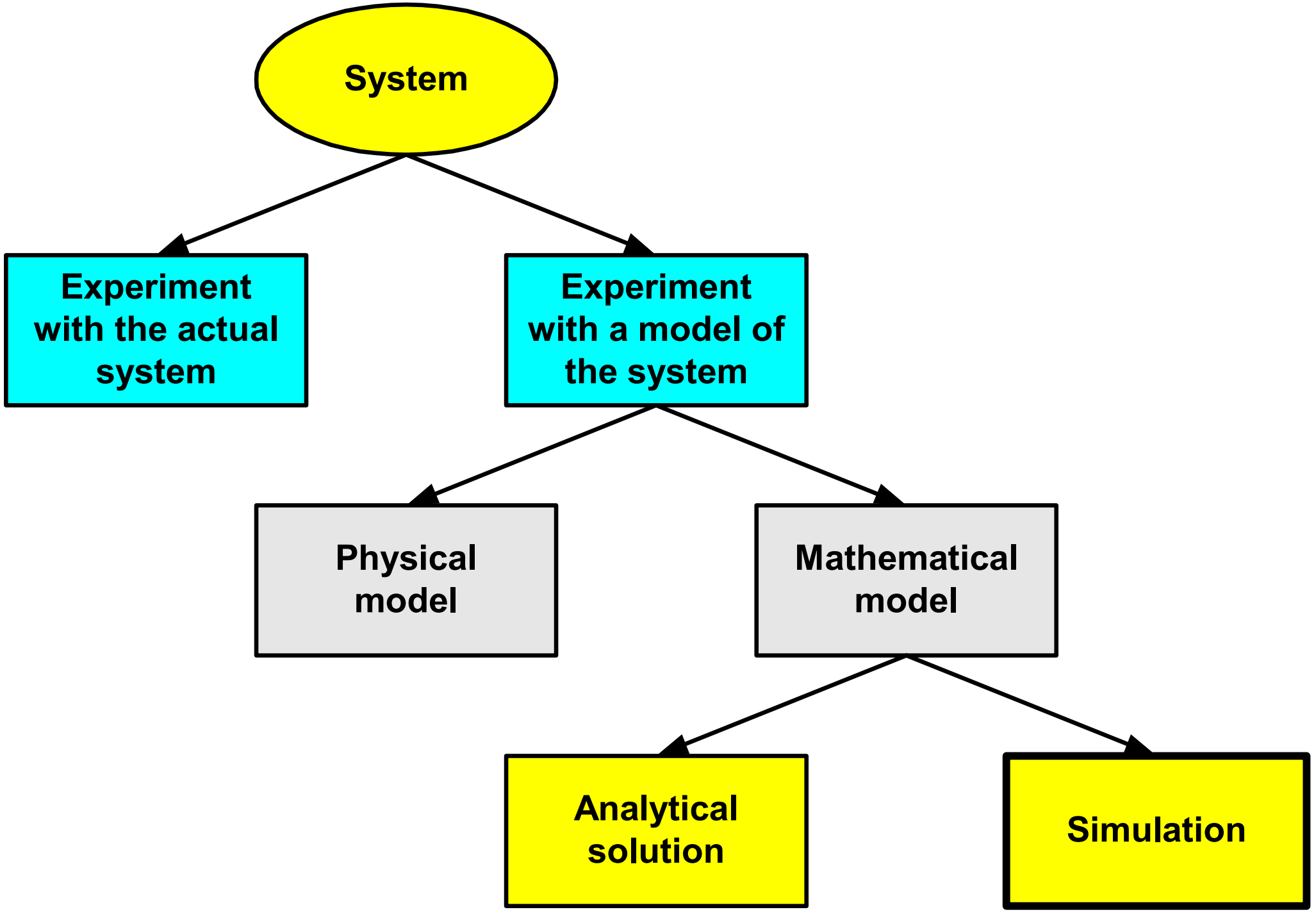
- Building energy simulation
- Simulation tools
- Applying simulation
- Modelling process
- Simulation skills

Building energy simulation

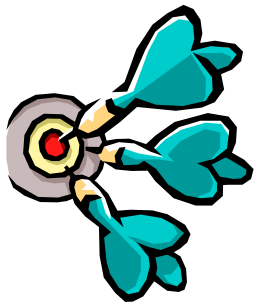


- Energy performance of buildings is usually complicated & requires detailed analysis to determine the characteristics
- Building energy simulation & modelling techniques are often used to study it so as to support decisions for building design, operation & management
  - Physics-based simulation software used in the prediction & analysis of building energy use

Ways to study a system

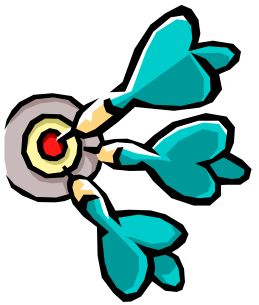


Building energy simulation



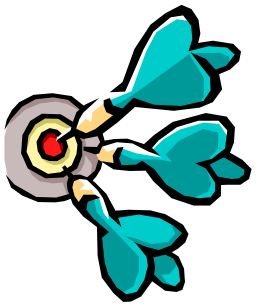
- Building performance simulation (BPS)
  - A computer model of the energy processes within a building that are integrated to provide a thermally comfortable environment for the occupants (or contents)
- Dynamic thermal simulation
  - Can predict changing internal conditions over a time period of up to 1 year – 8760 hours
  - The technique predicts zonal (or room) values for parameters e.g. air temperature

Building energy simulation

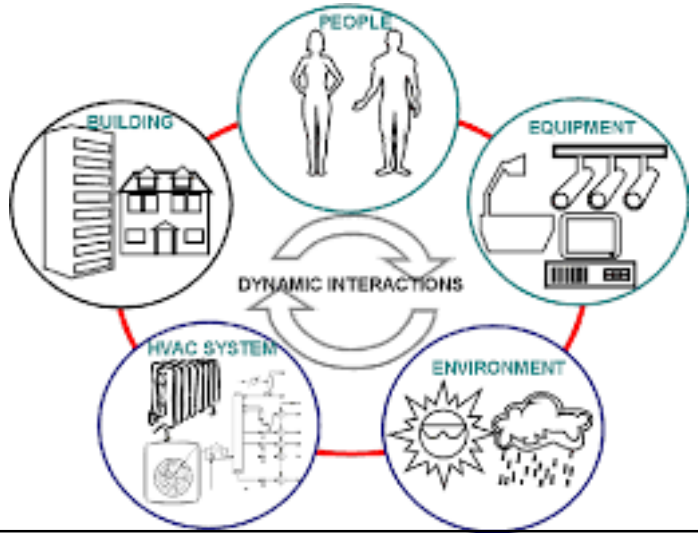


- What is Building Simulation?
  - Software which emulates the dynamic interaction of heat, light & mass (air & moisture) within the building
  - To predict its energy & environmental performance as it is exposed to climate, occupants & conditioning systems
- Building Simulation is needed if
  - Other methods are not feasible (e.g. physical model is too complicated or not economical)
  - You need to understand & analyse the building's performance in details

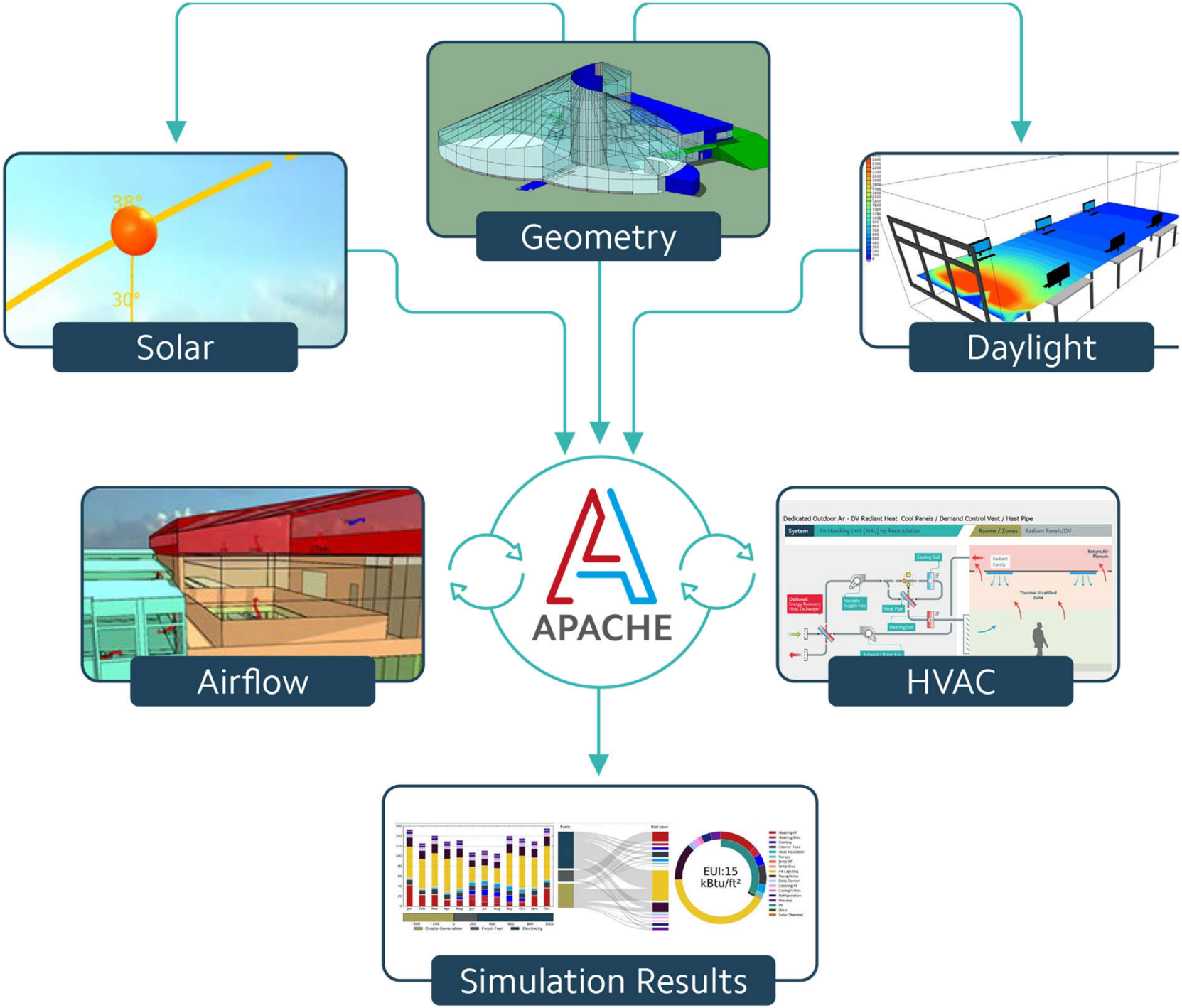
Building energy simulation



- A simulation model is an abstraction of the real building which allows to consider the influences on high level of detail & to analyse key performance indicators at relatively low effort & cost (without cost-intensive measurements)
- Sub-domains of building performance simulation
  - Thermal simulation
  - Lighting simulation
  - Air flow simulation
  - Acoustical simulation

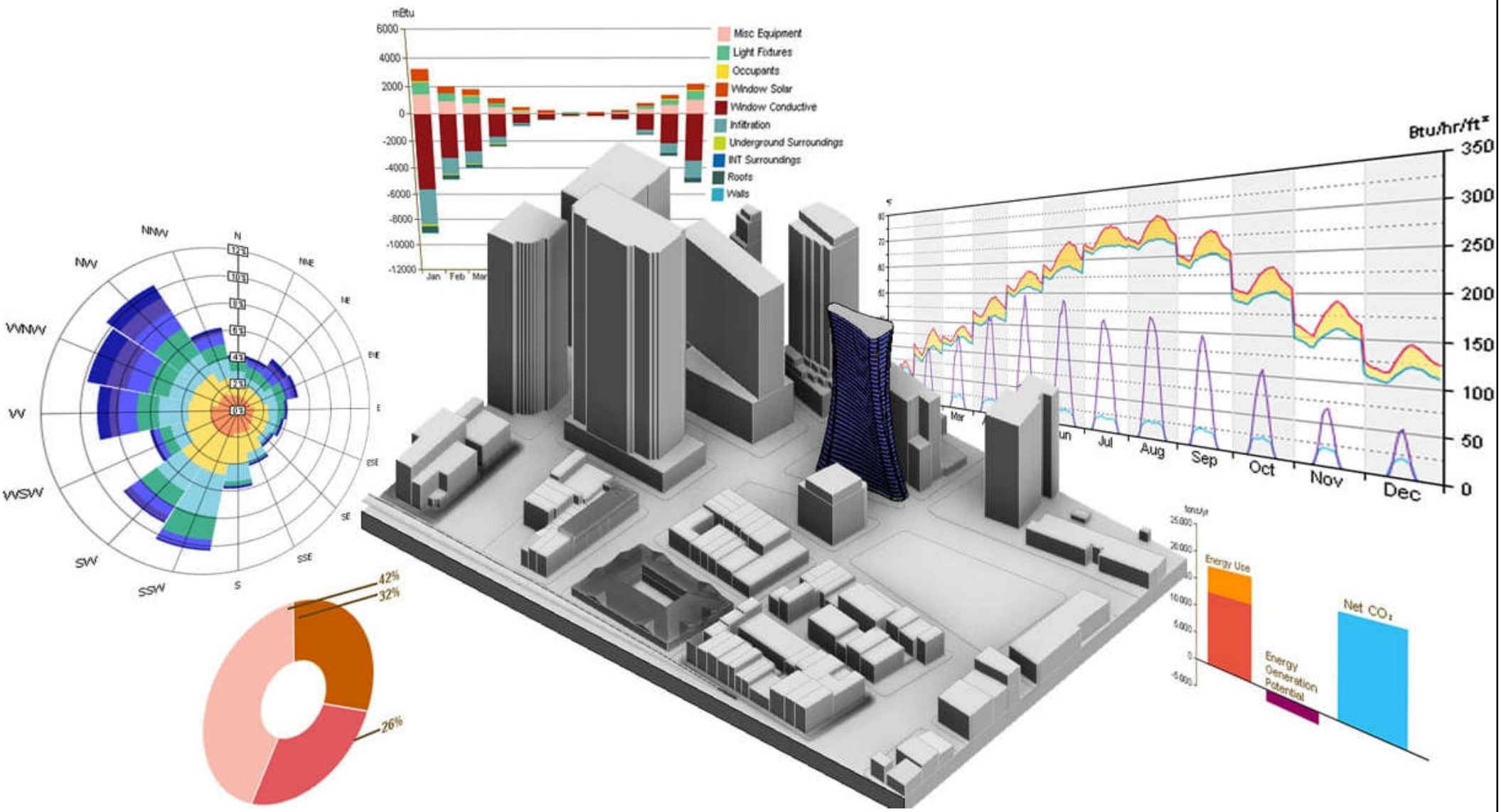


Examples of building performance simulation functions (IESVE Apache)



(Source: https://www.novatr.com/blog/building-energy-analysis-guide)

Basic concept of building energy simulation & analysis



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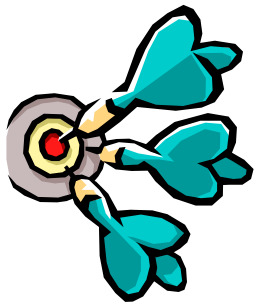
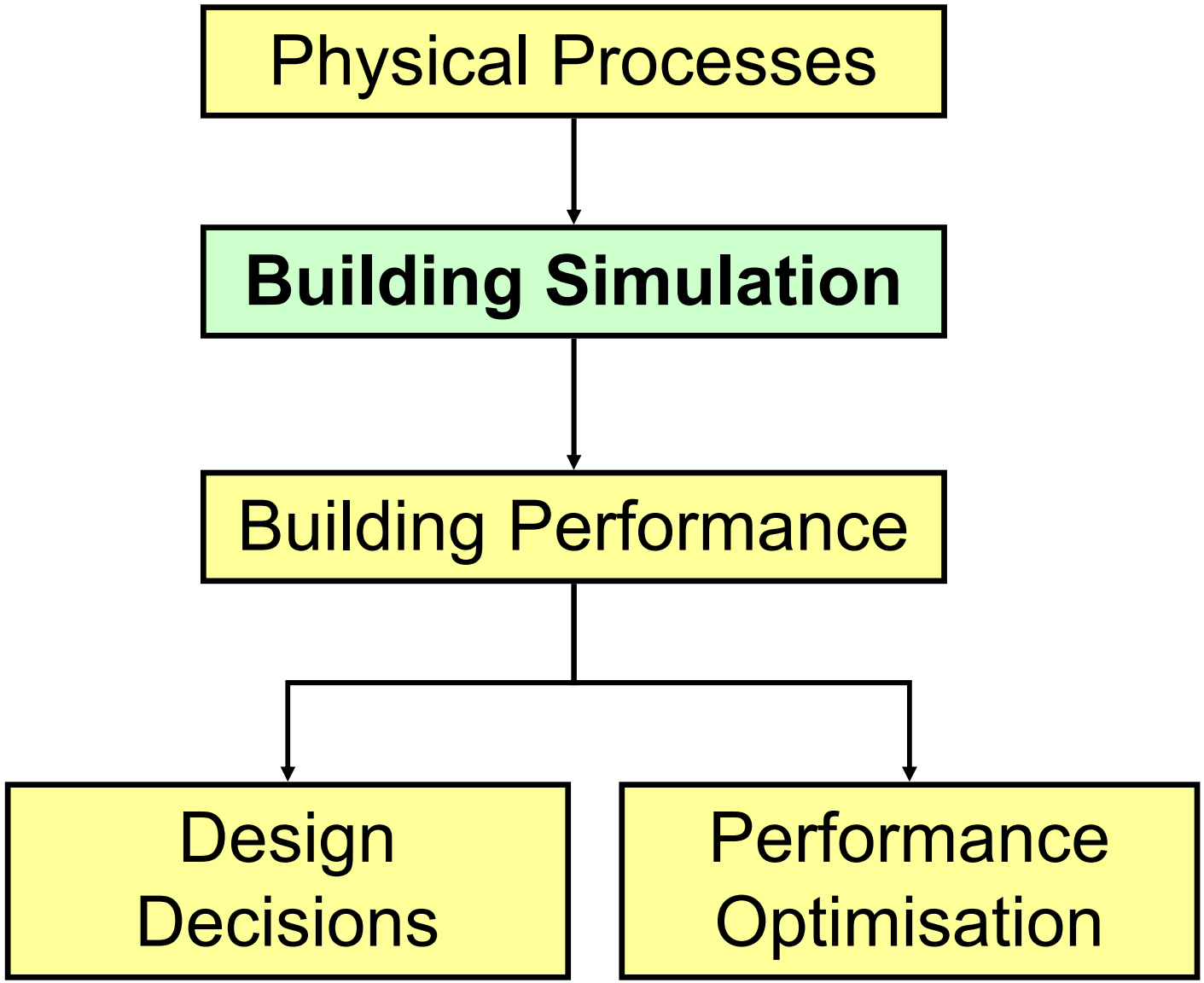
Building energy simulation



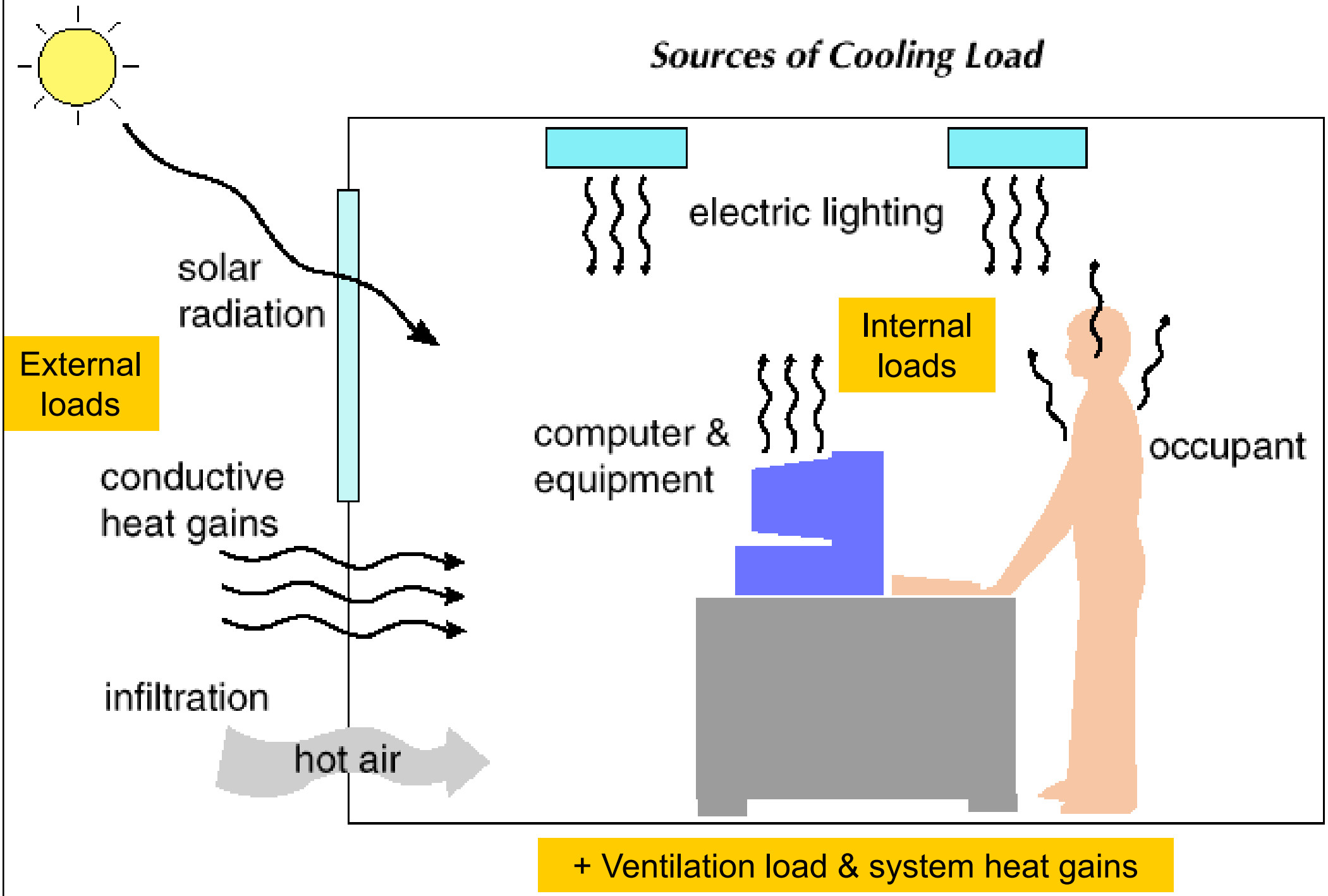
- Simulation
  - The process of developing a representative model of a system & using it to analyze & predict system behaviour & performance
- Modelling
  - Deals primarily with the relationship between actual dynamic processes & models
  - Usually involves iterations

Basic concept & functions of building simulation

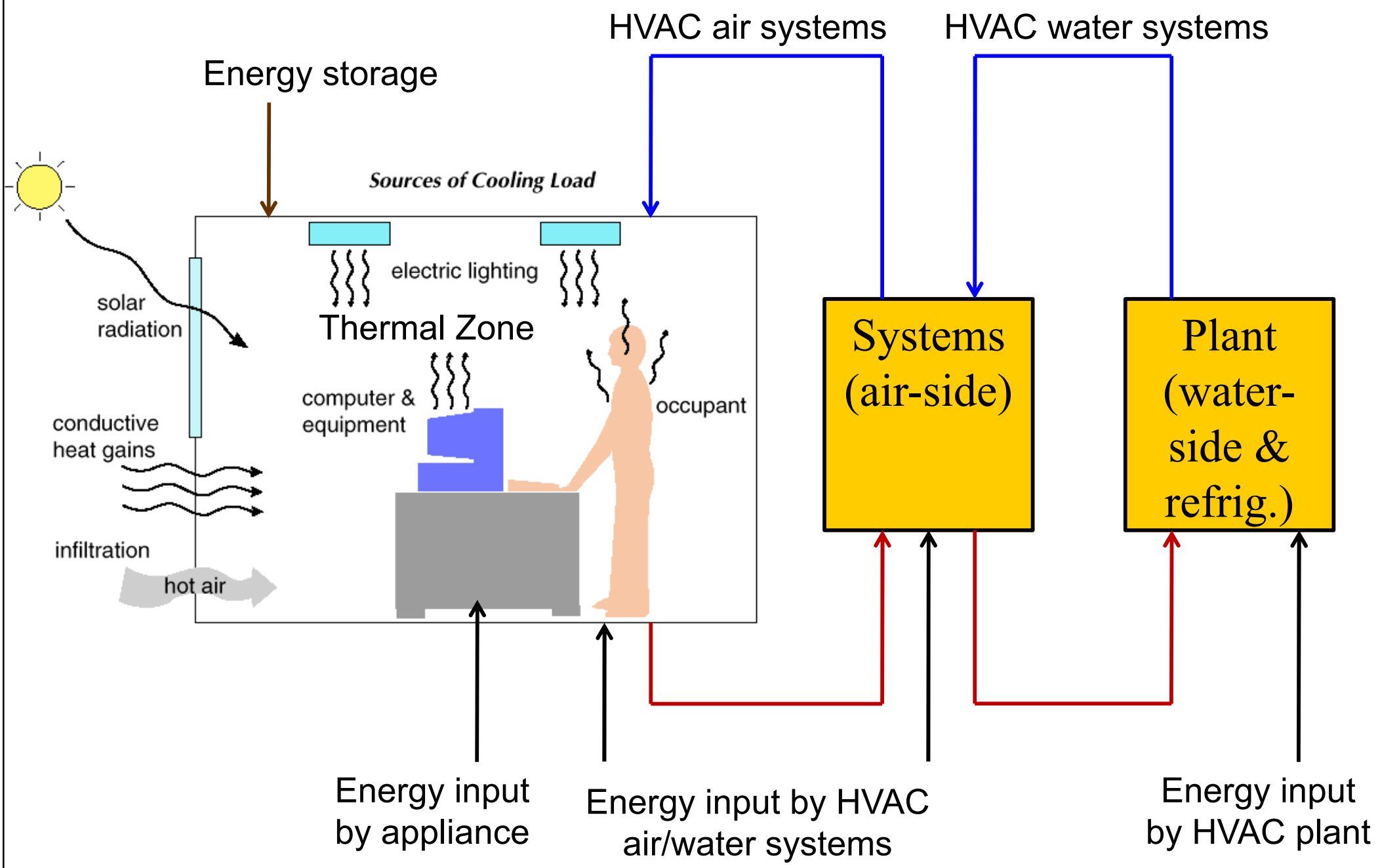


* Simulation enables the performance of the building to be established before critical design decisions are taken, enabling optimum building performance to be obtained

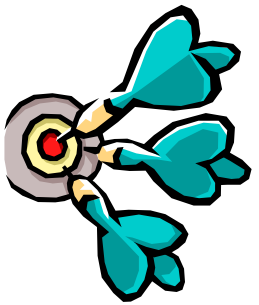
Components of building cooling load



Building energy simulation process

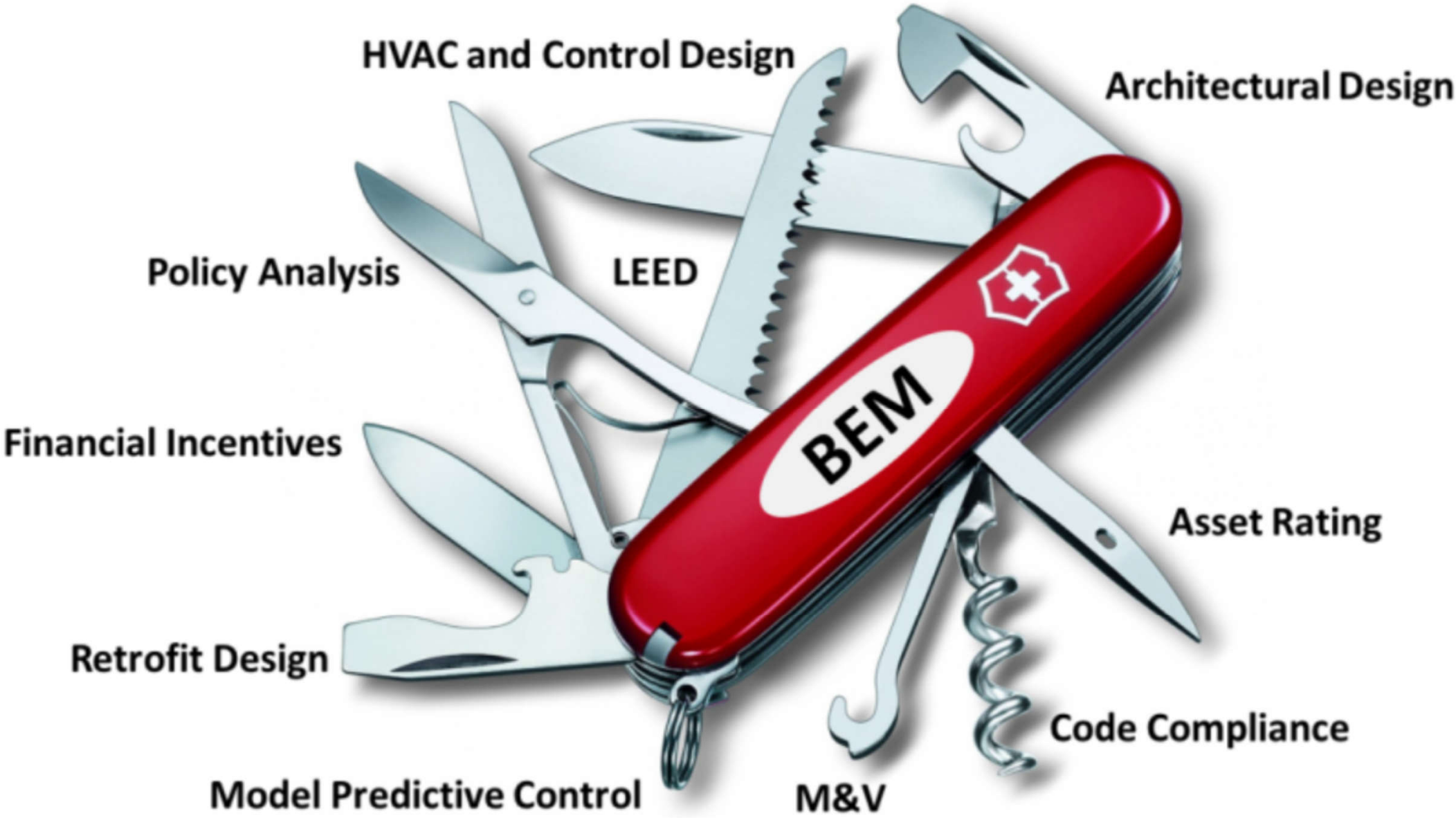


Building energy simulation



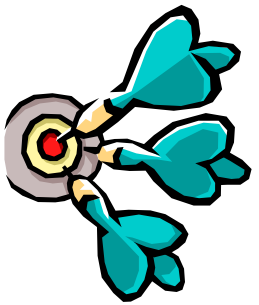
- Major functions of building energy simulation:
  - Assess building design (design evaluation tool)
  - Calculate energy saving or performance (building energy analysis tool)
  - Evaluate energy cost (economic analysis tool)
  - Design & optimise building systems (system design/optimization tool)
  - Satisfy energy code (code compliance tool)
  - Support green building assessment (green design tool)

Building energy modelling (BEM) is a multi-purpose tool for building energy efficiency



(Source: https://www.energy.gov/eere/buildings/about-building-energy-modeling)

Building energy simulation

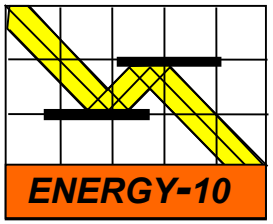


- Model existing buildings
  - Useful for “energy performance contracts”
  - Help improve the bldg’s operation/control
- Evaluate energy conservation measures (ECM)
  - Estimate energy savings
  - Study the costs & benefits
  - Provide info to design, retrofit & operation
- Comply with building energy code
  - e.g. performance-based building energy code

Simulation tools

- Types of building simulation tools
  - Simplified software for overall energy consumption assessment, peak temperature prediction, cooling/heating load calculations
  - Sophisticated software for hourly simulation of heat, light & air movement
  - Complex specialist software, for lighting, computational fluid dynamics (CFD), 2- & 3-dimensional conduction calculations
  - Integrated design & analysis systems which combine a number of the above categories

Examples of building energy simulation software



blast

DOE-2

Solar-5

ESP-r

ENER-WIN©

Hourly Energy Simulation Program for Buildings

Building Energy Simulation Software

TRNSYS

E-20-II & HAP

TRACE 700

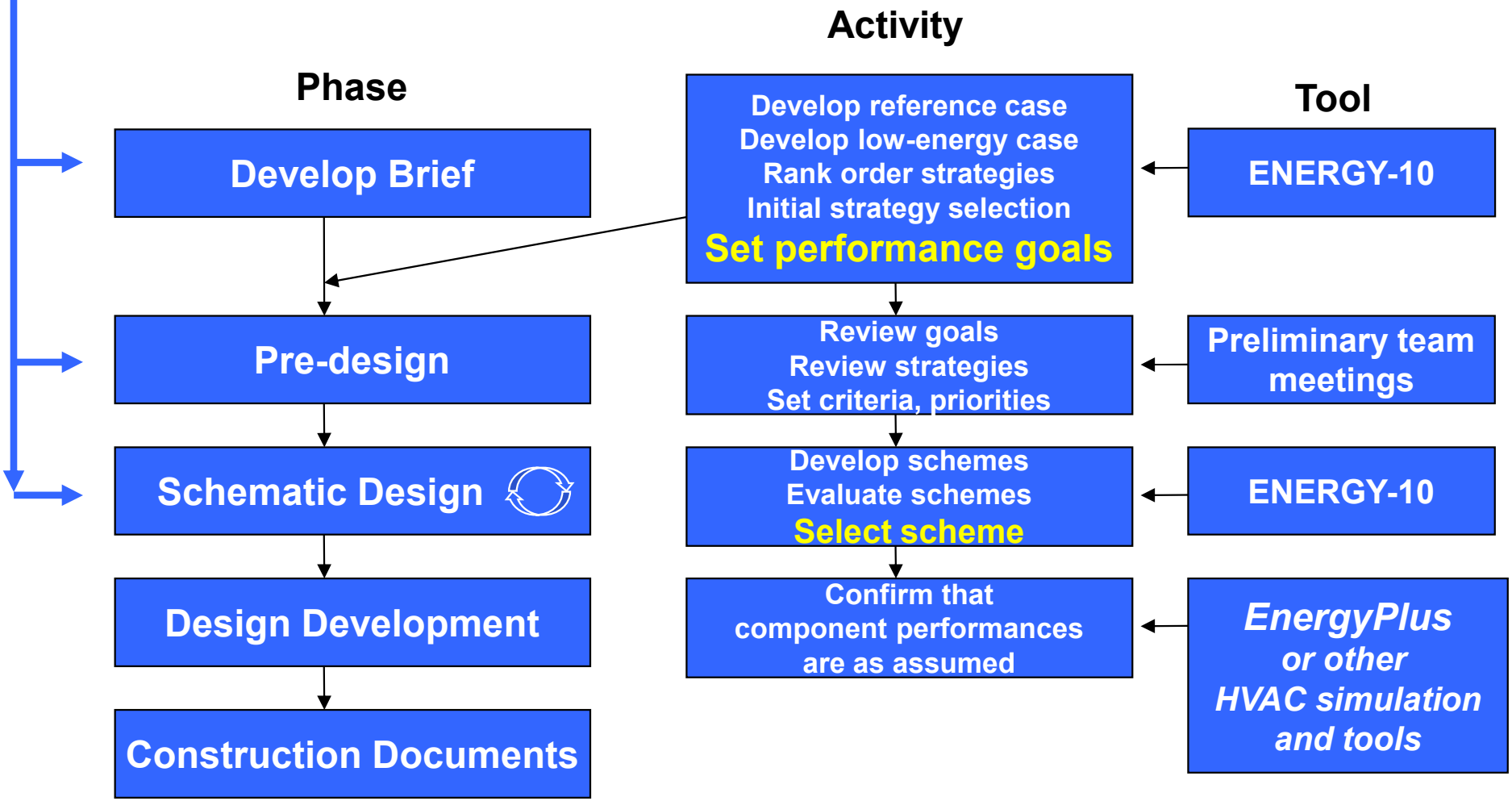
EE4

Simulation tools

- Many software tools in the market
  - From simplified to complicated one
  - Select according to the task
- For beginners, we recommend
  - Energy-10, HAP, TRACE 700, eQUEST
- For sophisticated study, may consider
  - DOE-2, EnergyPlus, ESP-r, TRNSYS
- Further information:
  - Building Energy Software Tools Directory (by IBPSA-US)
    - https://www.ibpsa.us/best-directory-list/

Example: Energy-10

***ENERGY-10* focuses on the first phases (conceptual design)**



Example: Energy-10

- Creates two building descriptions based on five inputs and user-defined defaults.

•Location
•Building Use
•Floor area
•Number of stories
•HVAC system

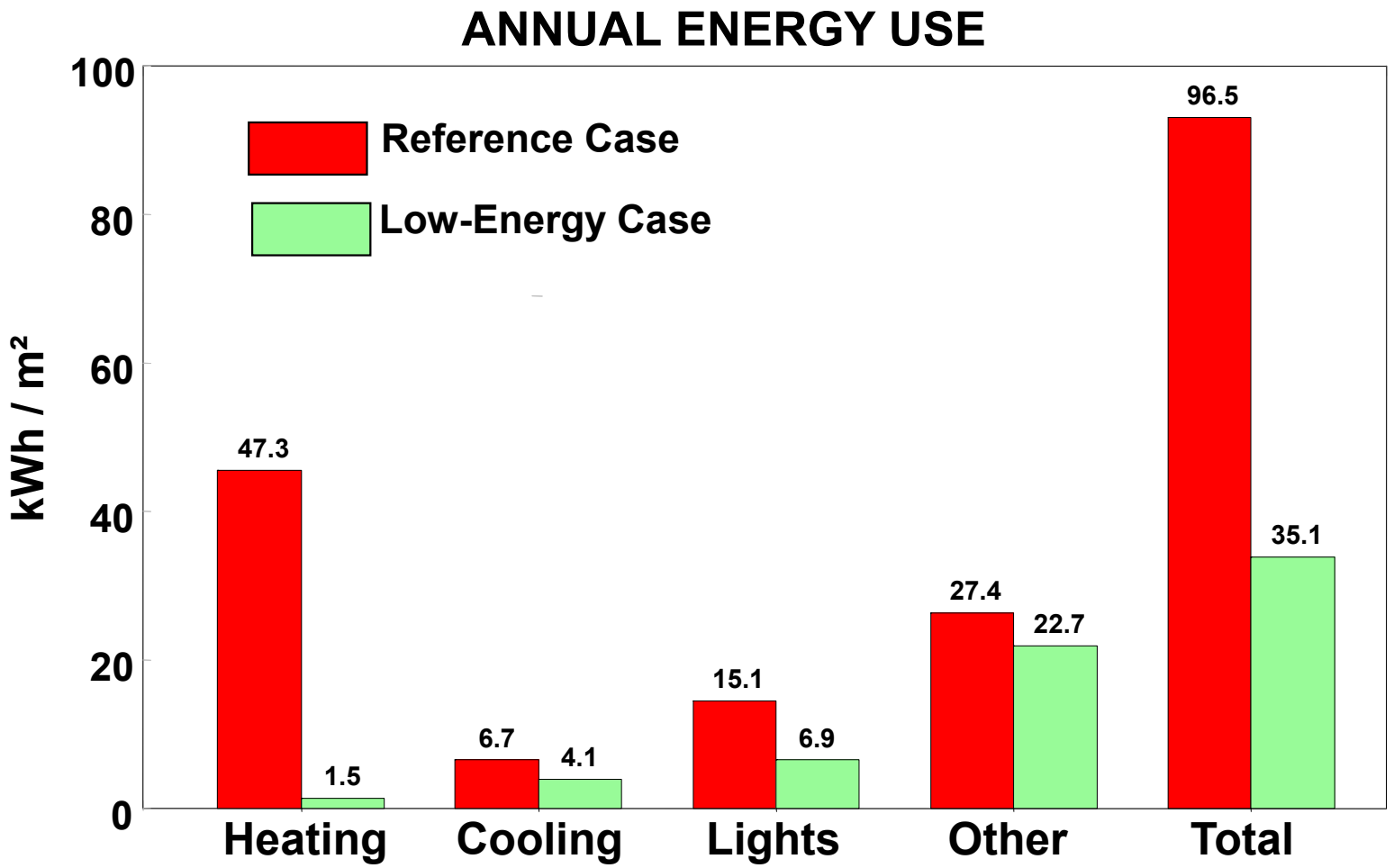
Gets you started quickly.

For example:

Reference Case	Low Energy Case
R-8.9 walls (4" steel stud)	R-19.6 Walls (6" steel stud with 2" foam)
R-19 roof	R-38 roof
No perimeter insulation	R-10 perimeter insulation
Conventional double windows	Best low-e double windows
Conventional lighting	Efficient lights with daylight dimming
Conventional HVAC	High efficiency HVAC
Conventional air-tightness	Leakage reduced 75%
Uniform window orientation	Passive solar orientation
Conventional HVAC controls	Improved HVAC controls
Conventional duct placement	Ducts located inside, tightened

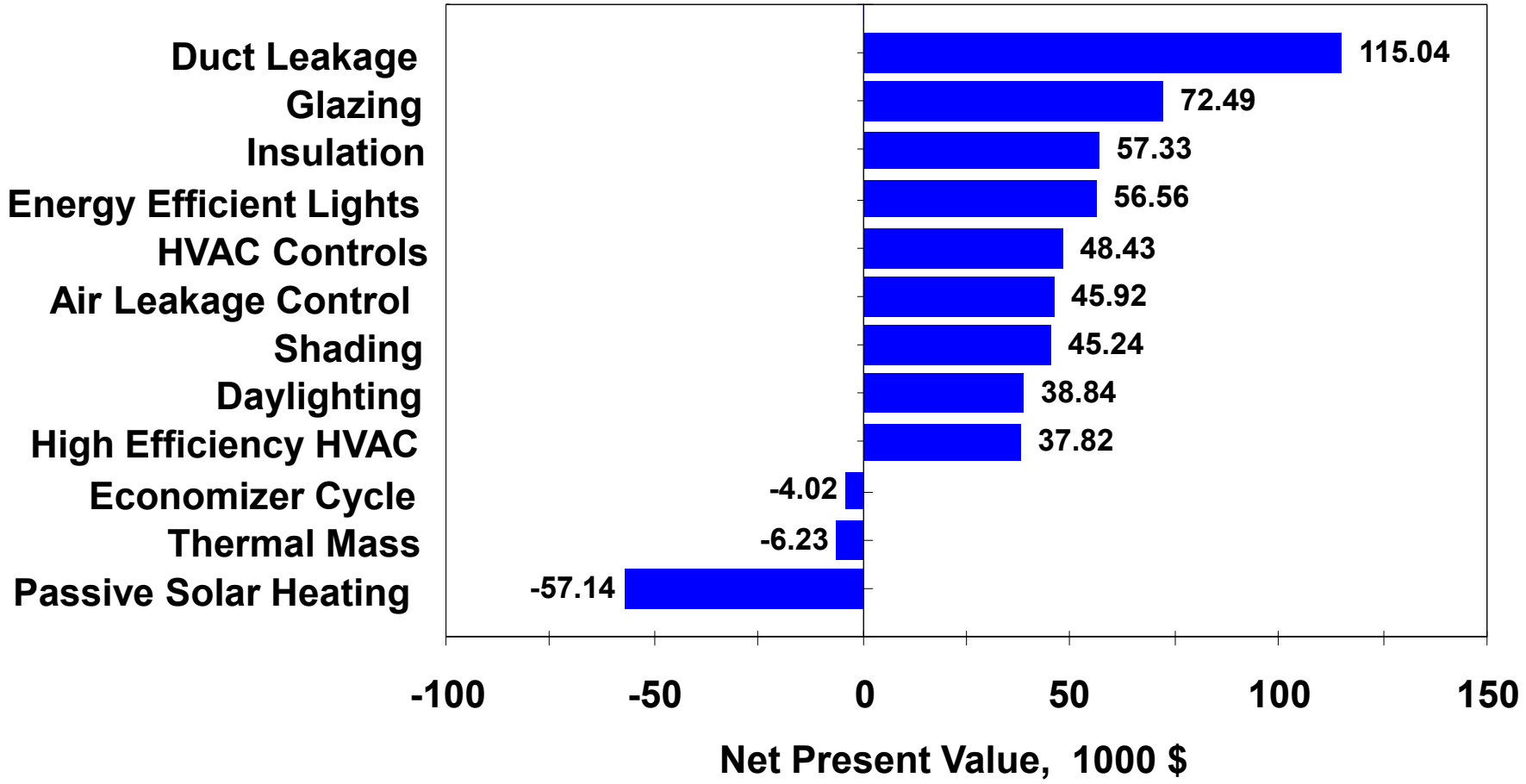
Example: Energy-10

2,000 m² office building



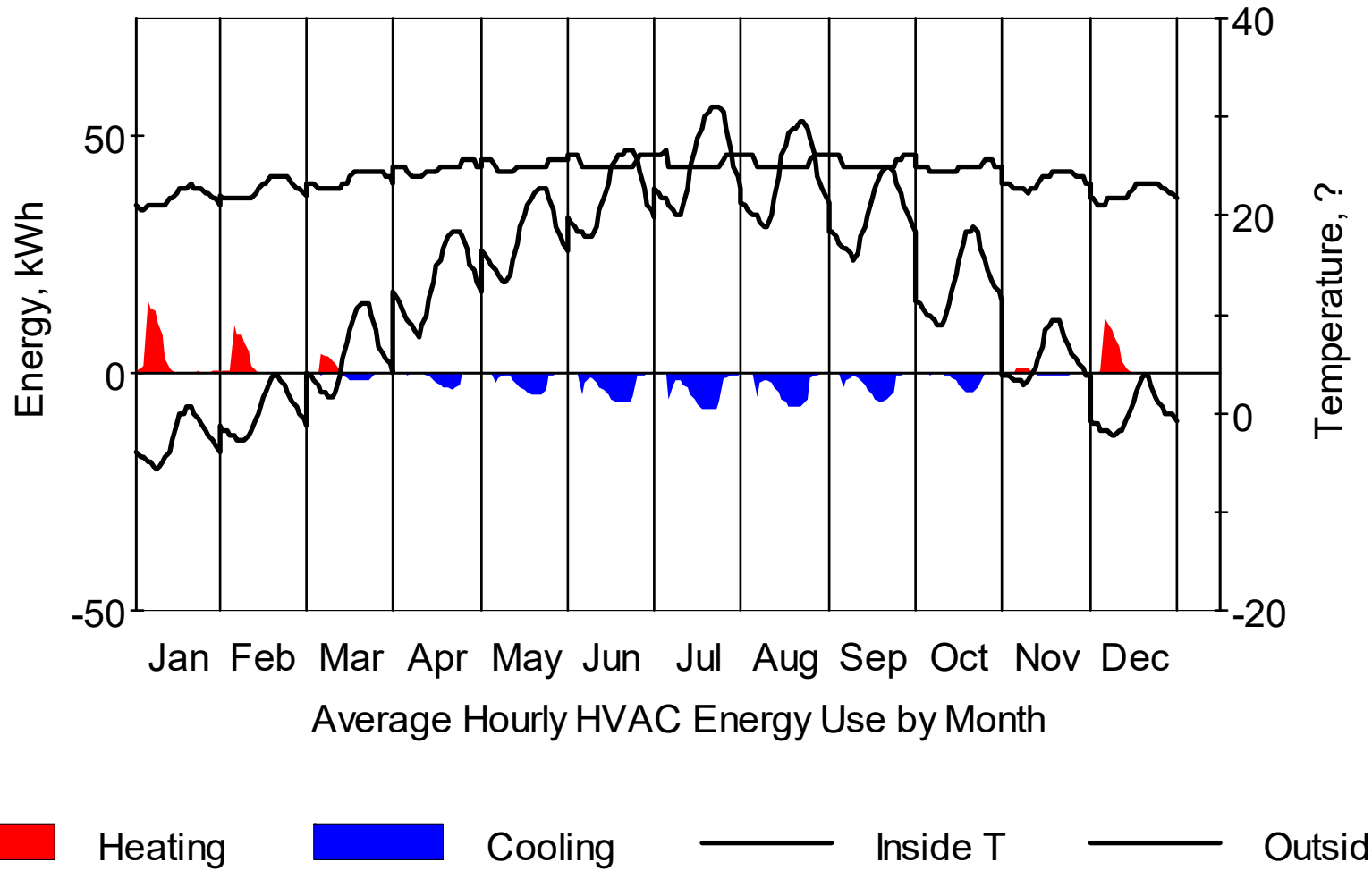
Example: Energy-10

RANKING OF ENERGY-EFFICIENT STRATEGIES

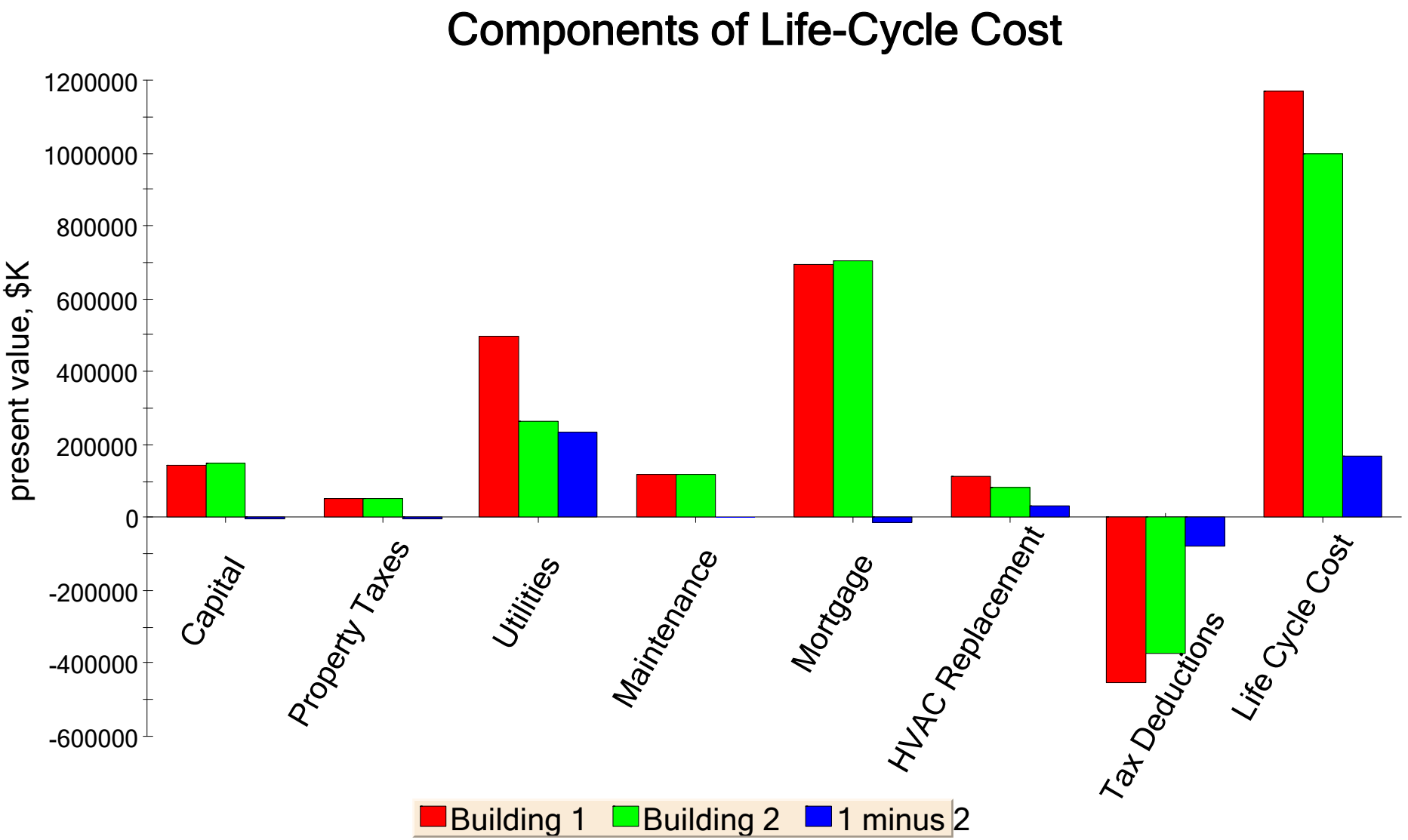


Example: Energy-10

Sample - Lower-Energy Case

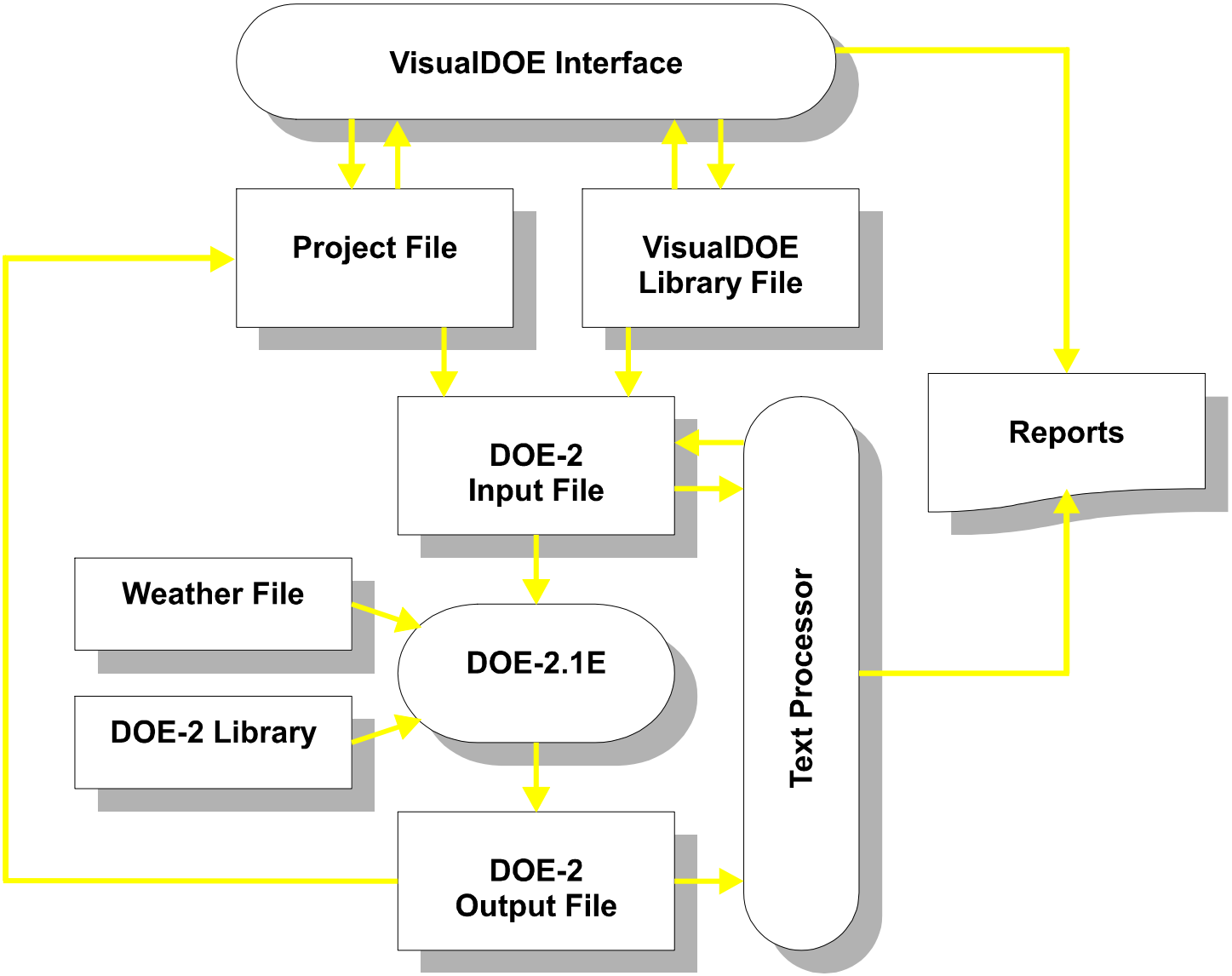


Example: Energy-10



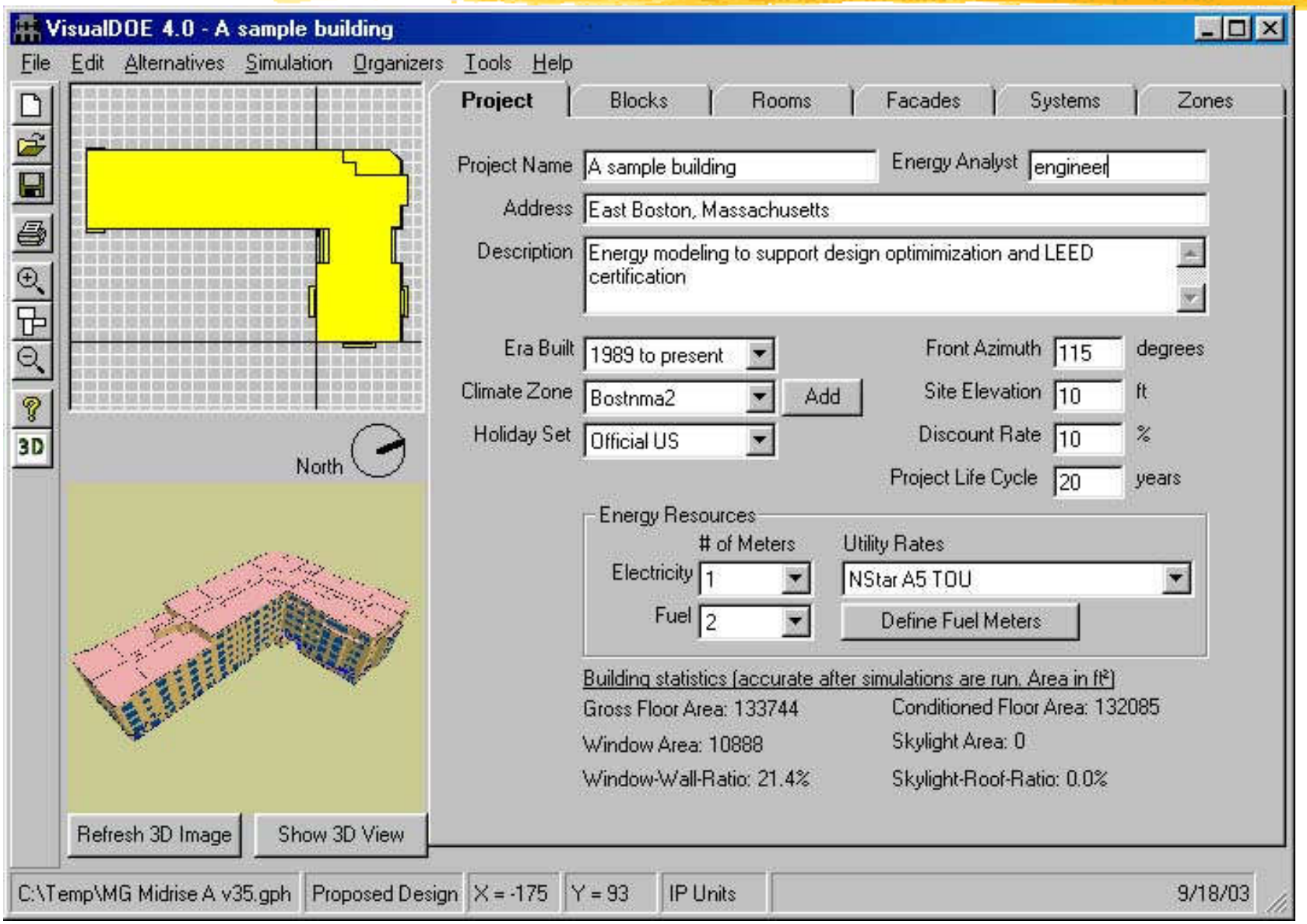
Example: VisualDOE

DOE-2



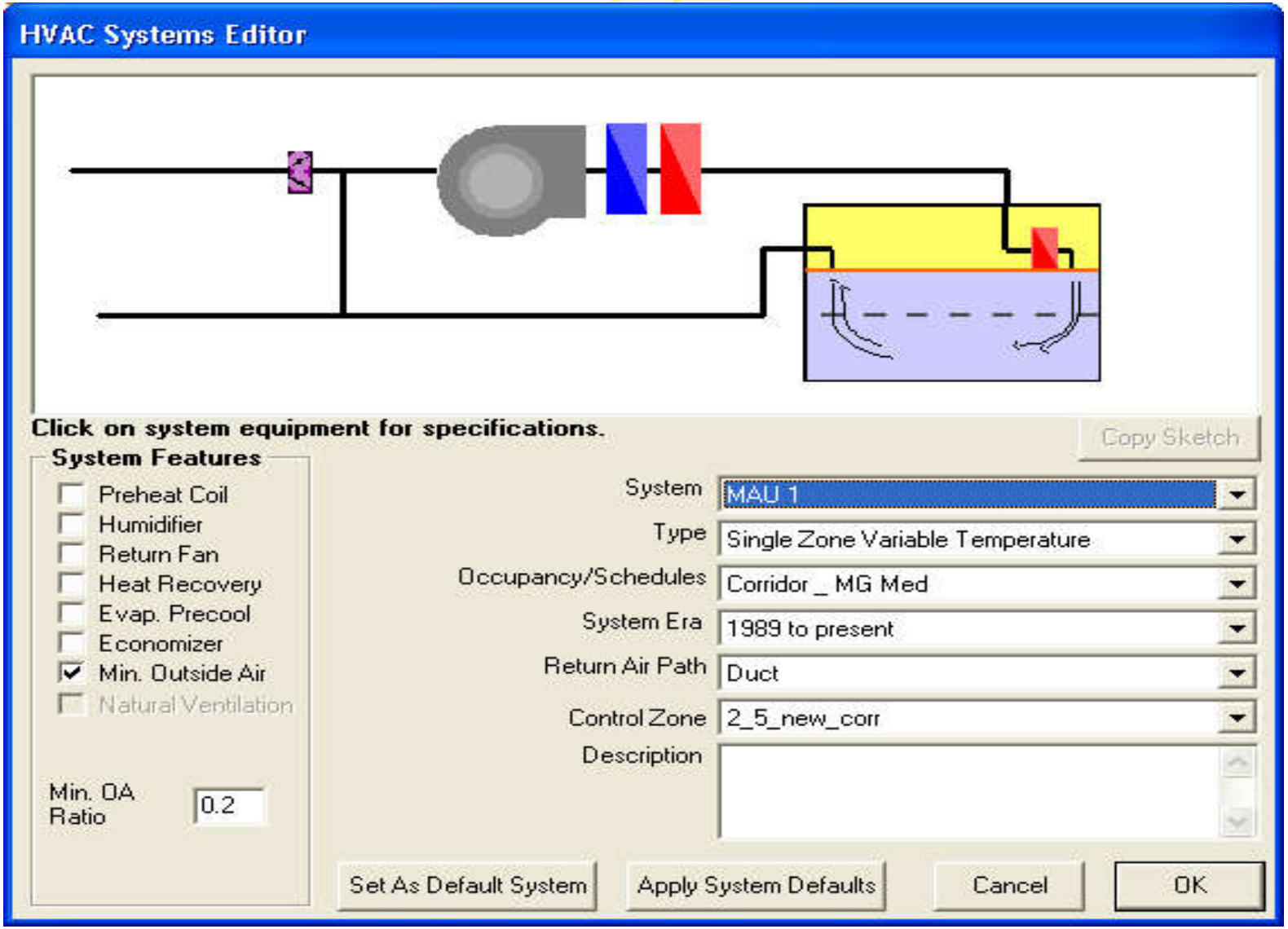
Example: VisualDOE

DOE-2



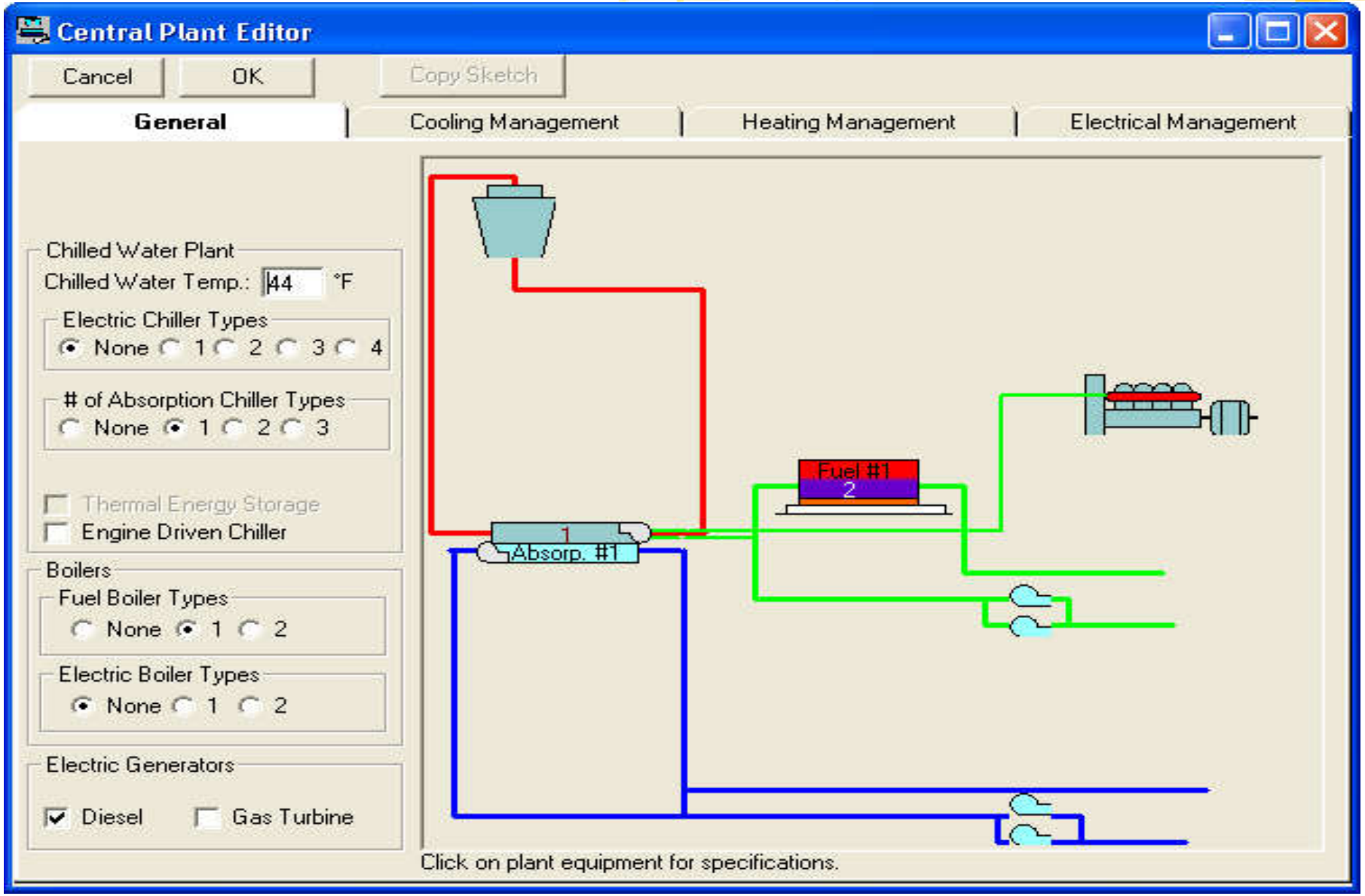
Example: VisualDOE

DOE-2



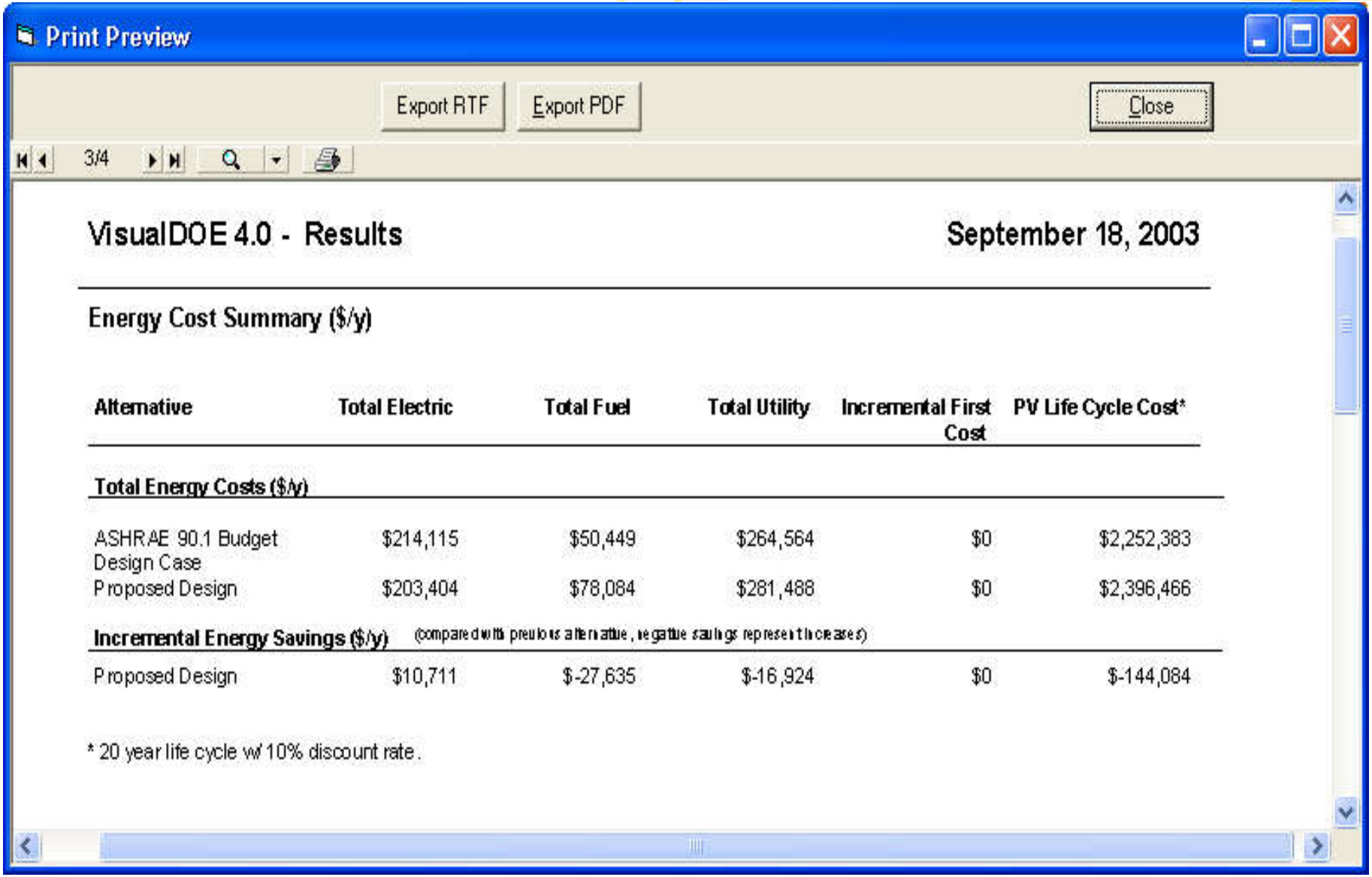
Example: VisualDOE

DOE-2



Example: VisualDOE

DOE-2



VisualDOE 4.0 - Results

September 18, 2003

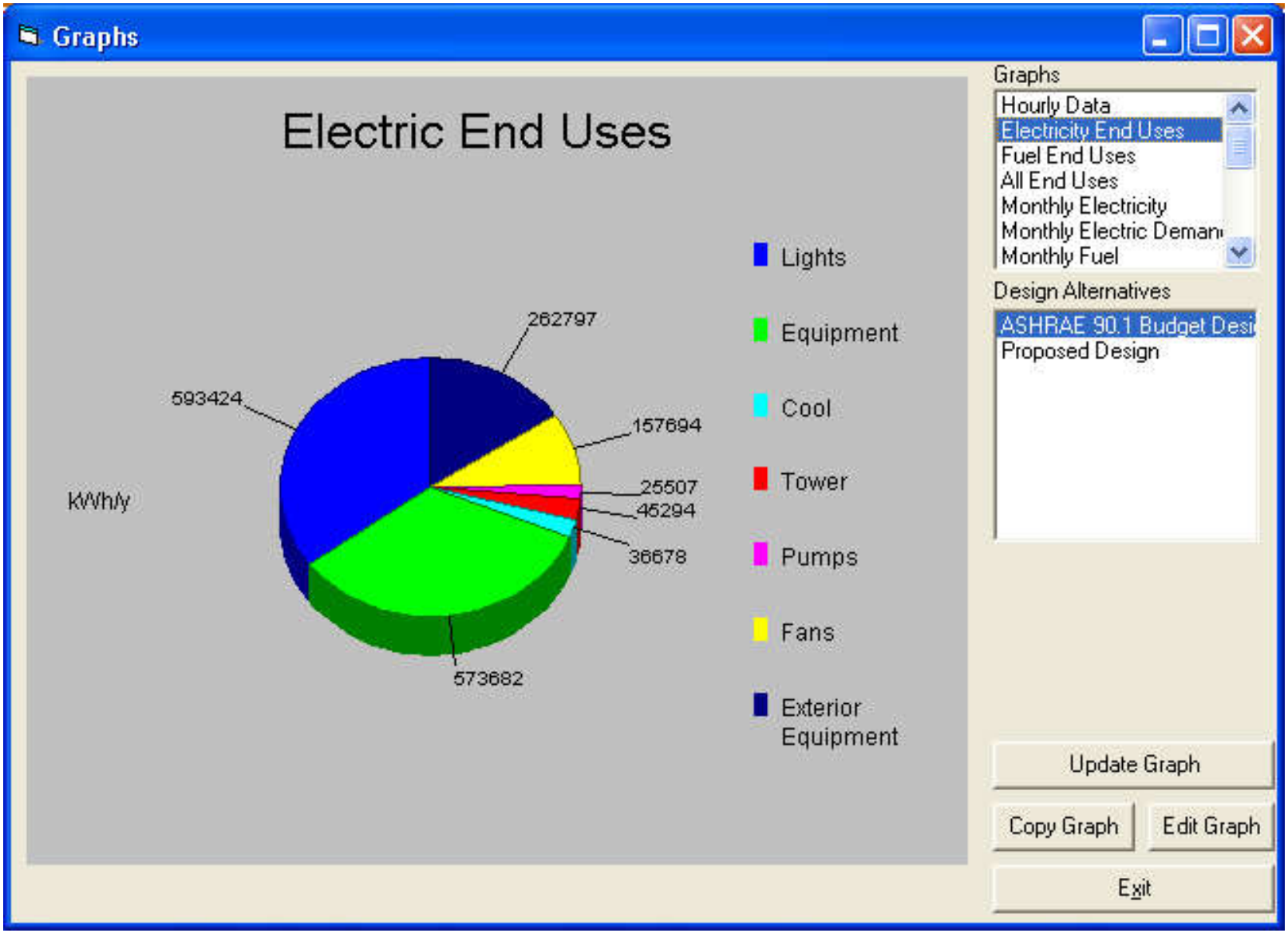
Energy Cost Summary ($/y)

Alternative	Total Electric	Total Fuel	Total Utility	Incremental First Cost	PV Life Cycle Cost*
Total Energy Costs ($/y)					
ASHRAE 90.1 Budget Design Case	$214,115	$50,449	$264,564	$0	$2,252,383
Proposed Design	$203,404	$78,084	$281,488	$0	$2,396,466
Incremental Energy Savings ($/y)	(compared with previous alternative, negative savings represent increases)				
Proposed Design	$10,711	$-27,635	$-16,924	$0	$-144,084

* 20 year life cycle w/ 10% discount rate.

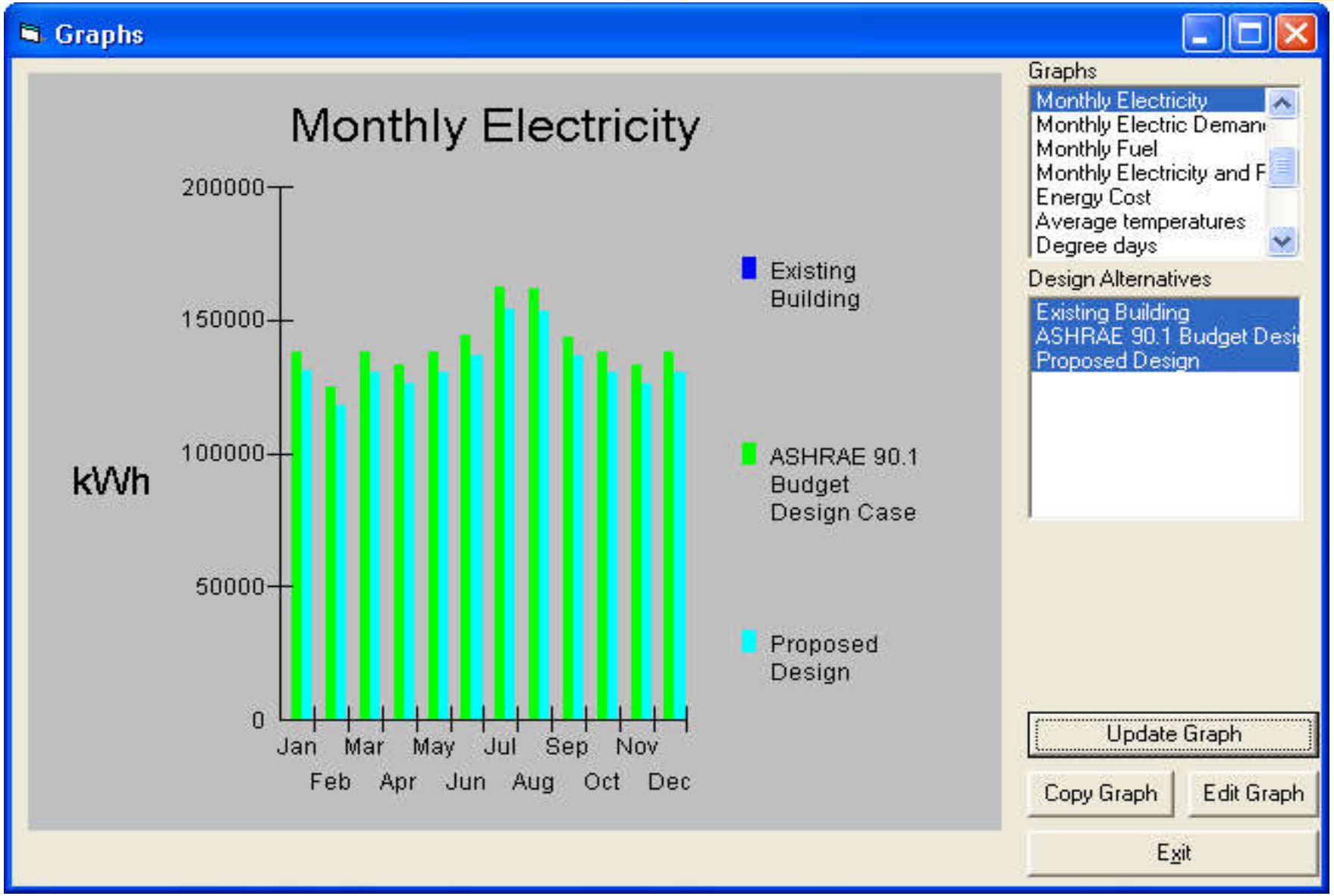
Example: VisualDOE

DOE-2



Example: VisualDOE

DOE-2



Simulation tools

- Practical use examples of building energy simulation (freeware tool & online simulation)
  - **eQUEST** (the QUick Energy Simulation Tool) (freeware tool for download)(DOE-2 based)
    - https://www.doe2.com/equest/
    - https://energy-models.com/software/equest
    - Tutorial & manuals available
  - **MIT Design Advisor** (do online simulation)
    - http://designadvisor.mit.edu/design/
    - Quick simulation analysis for early-stage design

MIT Design Advisor http://designadvisor.mit.edu/design/

The MIT Design Advisor

- Introduction
- Setup
- RESULTS:
- Energy
- Comfort
- Natural Ventilation
- Daylighting: Full Room
- Daylighting: Workplane
- Life Cycle
- Optimizer
- Report
- F.A.Q.

UPDATE - Changes have been made to the MIT Design Advisor!

Building energy simulation in minutes.

Heating, cooling, lighting, comfort, and more.

UPDATE - Version 1.1 now released
A new version of the MIT Design Advisor, Version 1.1, has recently been released (on 09/03/09) that includes the capability of adding different types of roofs to your building. Explore the new *Roof Description* section under the *Setup* tab to use the new featerure, and the *Assumptions page* under the *F.A.Q.* tab for more information.

Overview
Architects and Building Designers can use computer modeling to improve indoor comfort and energy performance of conceptual building designs. But most simulation tools are too complicated for this purpose.

Quick, visual comparisons are needed for early-stage design. The MIT Design Advisor is a tool which allows you to describe and simulate a building in less than five minutes. No technical experience or training is needed. An annual energy simulation can be run in less than a mintute, and graphical results are immediately available for review. Give it a try.

Getting Started

1. Begin by clicking the *SETUP* tab to the left and follow the directions to create a building design.
2. To save and simulate your building scenario, click *Save* on one of the colored scenario boxes at the bottom panel.
3. View the simulation results by clicking on any of the tabs to the left (Comfort, Energy, etc.)

Look for the information buttons for extra help:

About Us
MIT Building Technology Program

save
Scenario One

save
Scenario Two

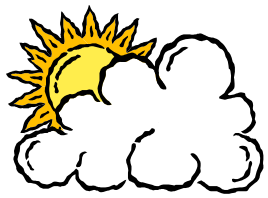
save
Scenario Three

save
Scenario Four

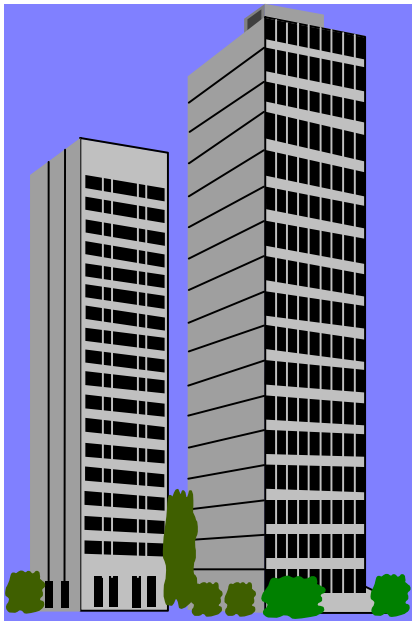
Modelling process

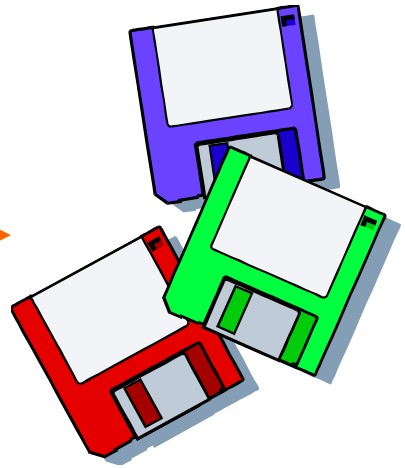
- How to perform building simulation?
  - Gather data & collect detailed information
  - Select & master how to use a program
  - Represent the building & HVAC systems
    - Construct the simulation model
    - Develop the building description/model
  - Prepare the input data
  - Run & control the program
  - Interpret the results, analysis & reporting
    - e.g. determine energy & cost savings

Building energy simulation process



Weather data





Building description

- physical data
- design parameters

Simulation tool (computer program)

Simulation outputs

- energy consumption (MWh)
- energy demands (kW)
- environmental conditions

Building energy simulation: Inputs & Outputs

INPUTS:	**OUTPUTS:**

- Climate/Weather data
- Site conditions
- Building geometry
- Construction type
- HVAC type / usage
- Controls
- Lighting systems
- Occupancy info.
  - Quantity of users
  - Lights
  - Equipment
  - Usage
	- Space temperatures
	- Surface temperatures
	- Humidity levels
	- HVAC parameters
	- Energy demand
	- Energy consumption
	  - Component
	  - System
	  - Whole-building
	- Heat balances
	- Load profiles

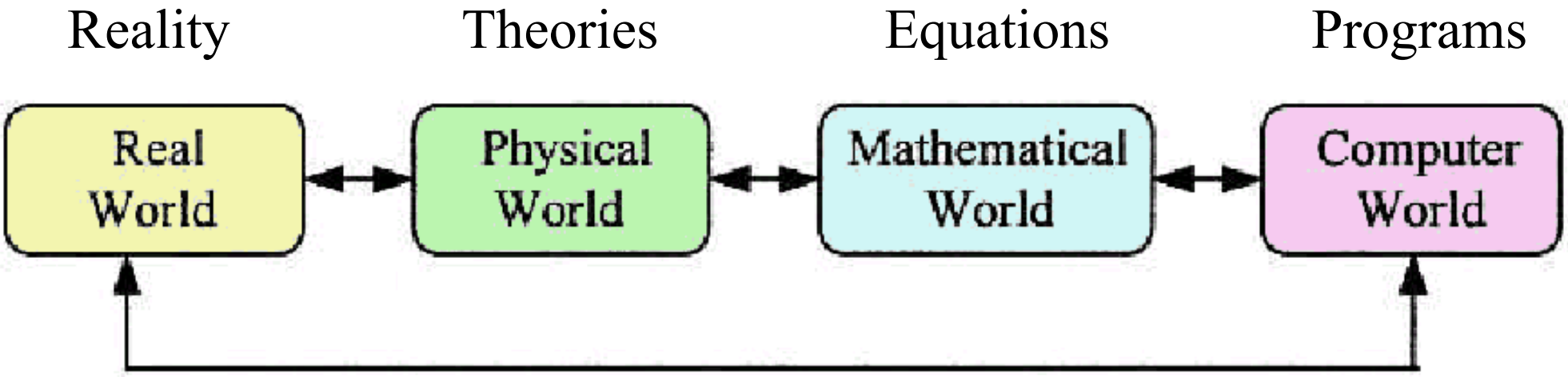
Garbage In, Garbage Out (GIGO)

Modelling process

- Important considerations
  - *Start early*: incorporate building simulation into the early design stages
  - *Keep it simple*: add no more detail to a simulation model than is necessary (simple but accurate)
  - *Refine as you go*, so that the simulation model evolves with the design
  - *Avoid mistakes* & reduce the potential for error

Modelling process

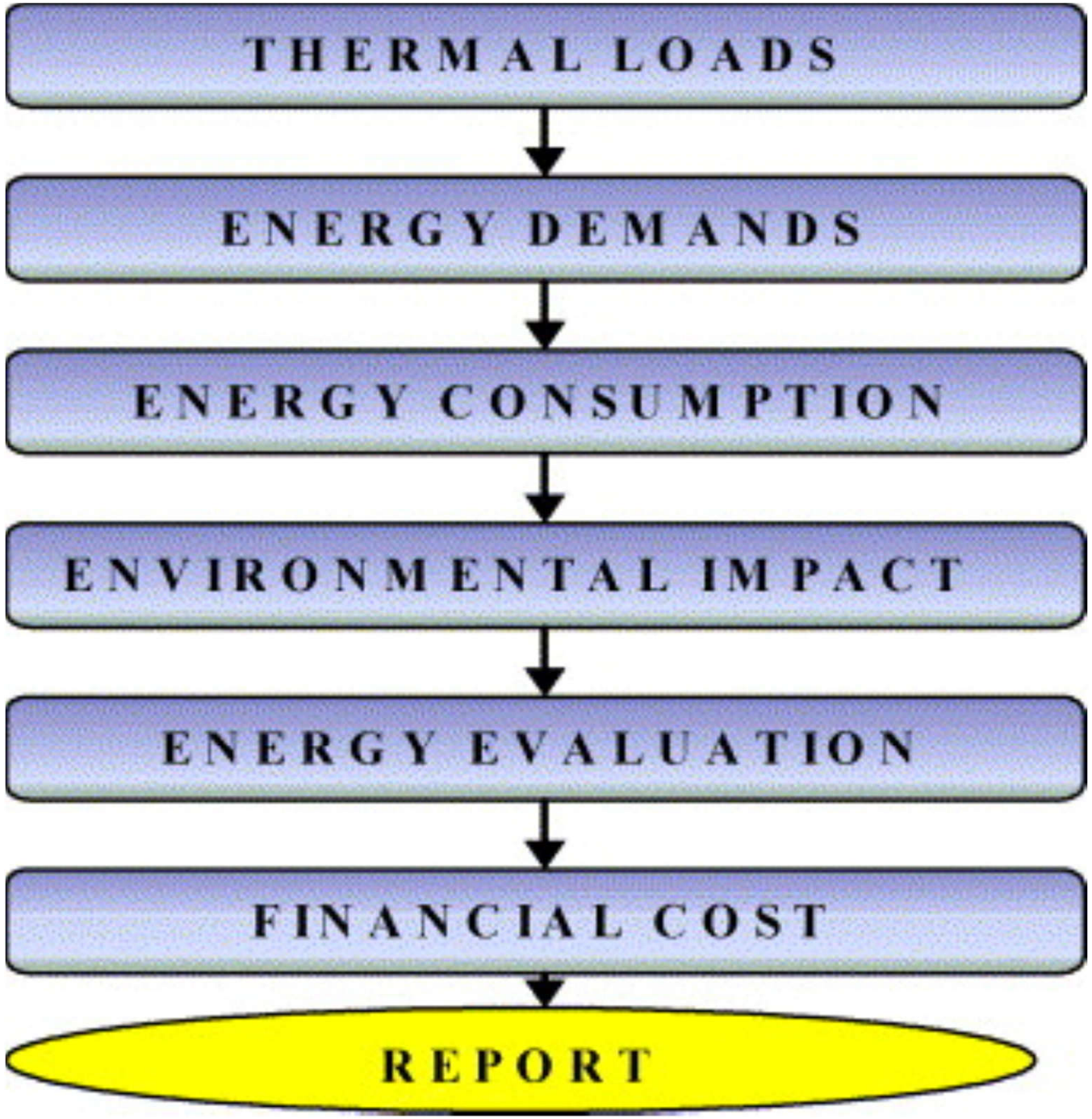
- Important to know how the program “thinks” about systems, designs & interactions
- How to approximate real-world problem to fit the limitations of the model



Modelling process

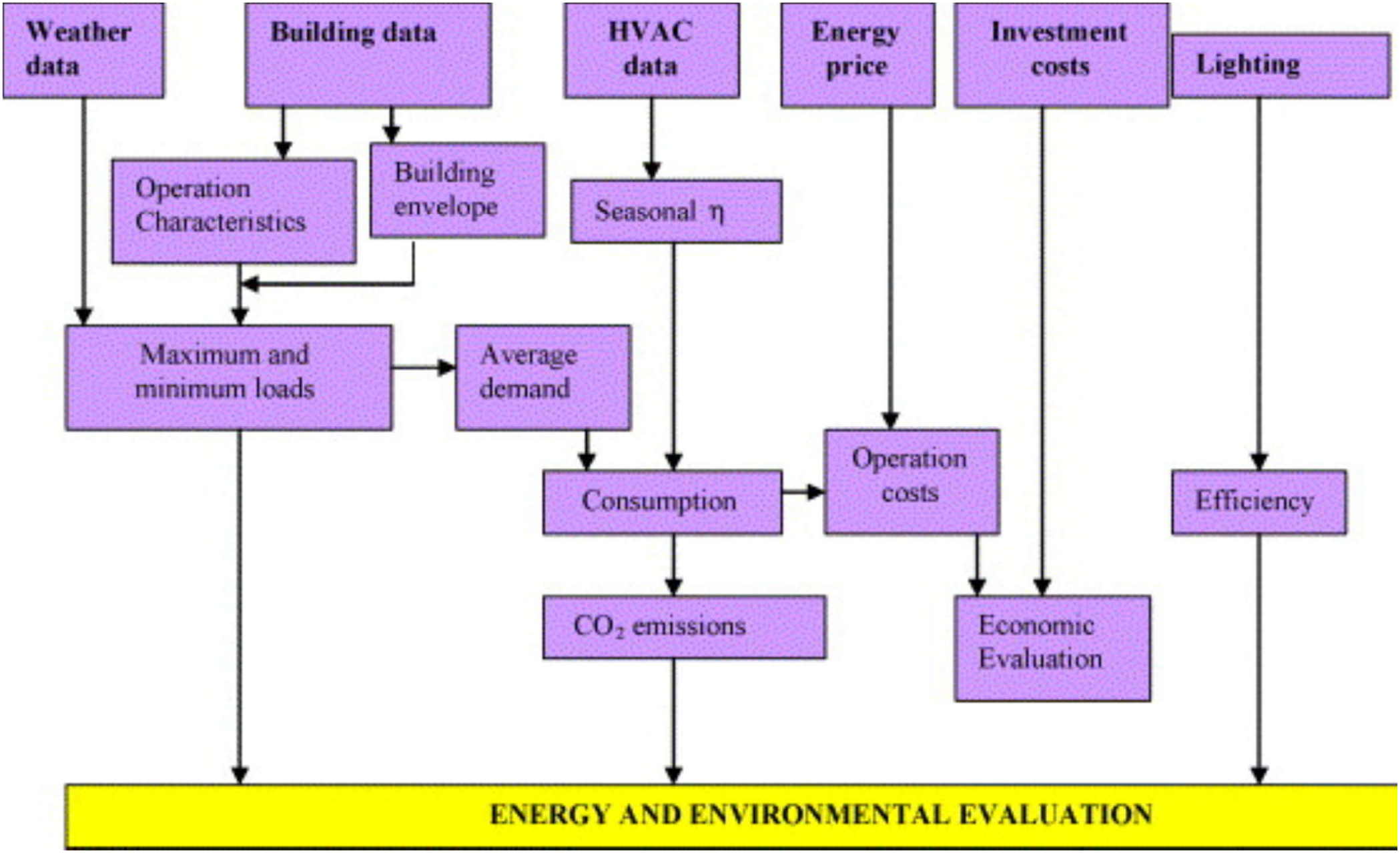
- Building energy simulation is based upon
  - *Load calculation* – thermal or HVAC
    - Determine peak HVAC design loads
  - *Energy calculation* – energy to meet the loads
    - Estimate annual energy requirements
- Time intervals
  - Full hour-by-hour (**8,760 hours** = 365 x 24)
  - Simplified hourly: e.g. one day per month
  - Bin method or degree days

Stages of the building energy analysis methodology



(Source: Rey F. J., Velasco E. & Varela F., 2007. Building Energy Analysis (BEA): A methodology to assess building energy labelling, *Energy and Buildings*, 39 (6) 709-716. https://doi.org/10.1016/j.enbuild.2006.07.009)

Steps for the development of building energy analysis methodology



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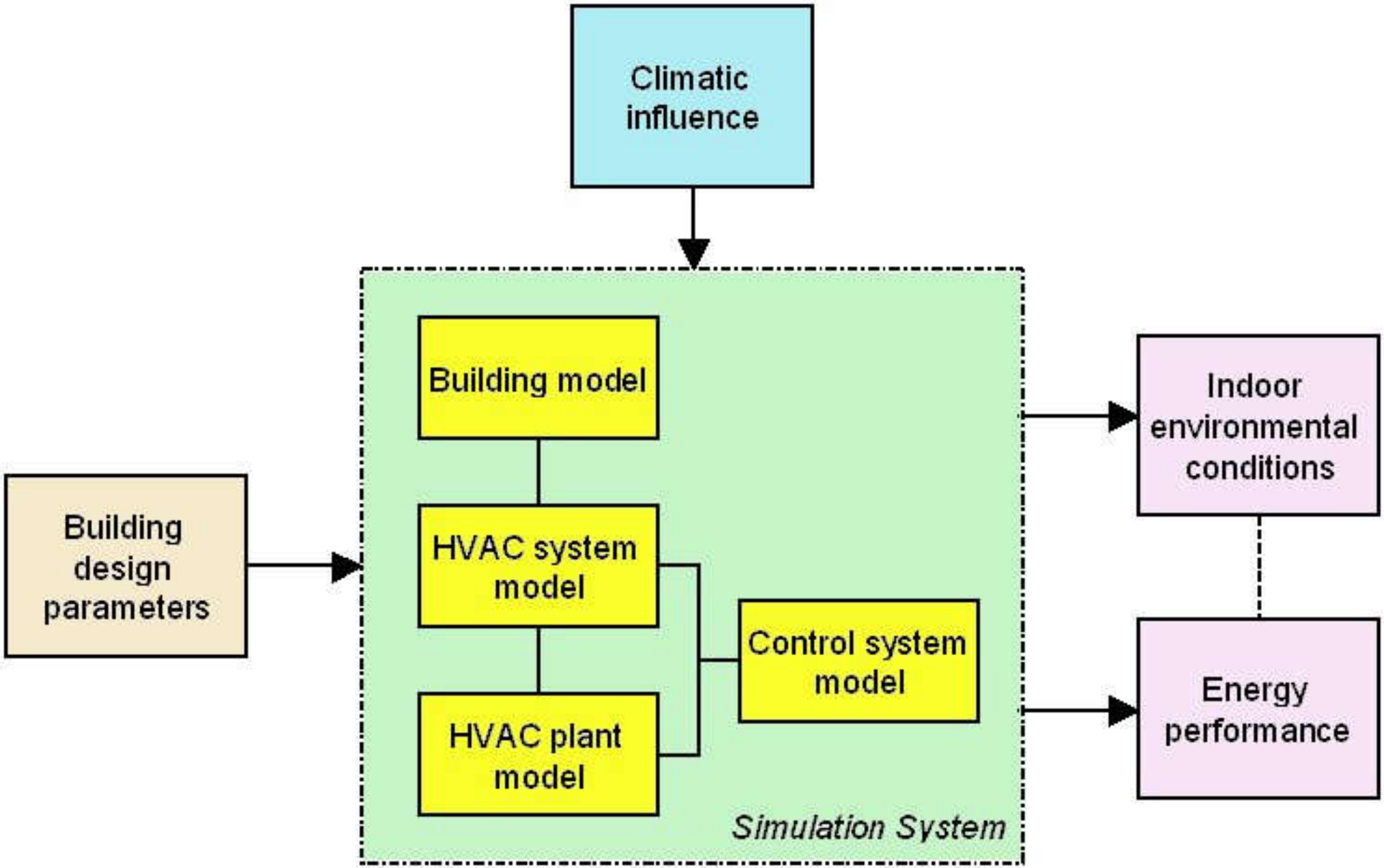
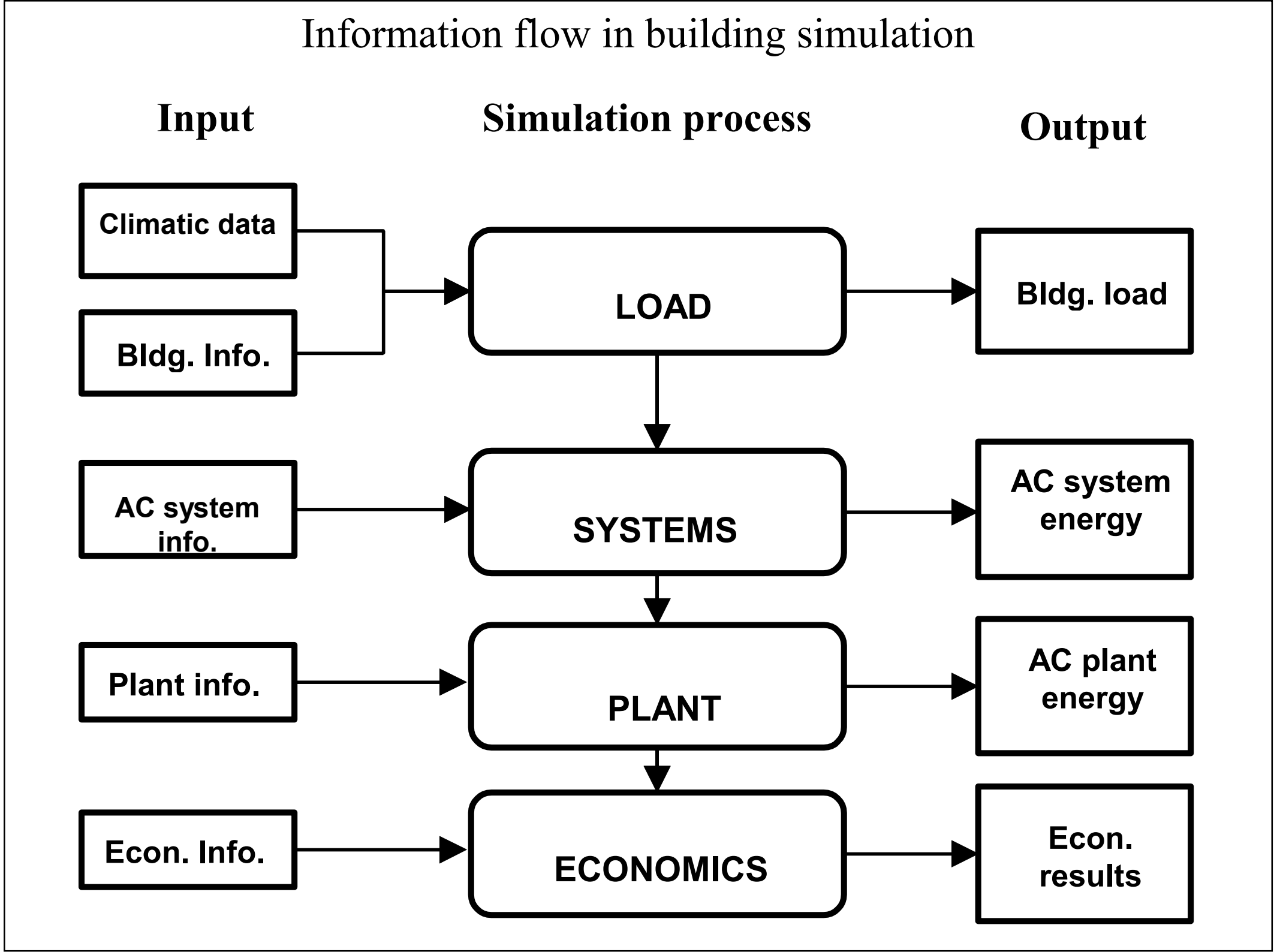
Modelling process

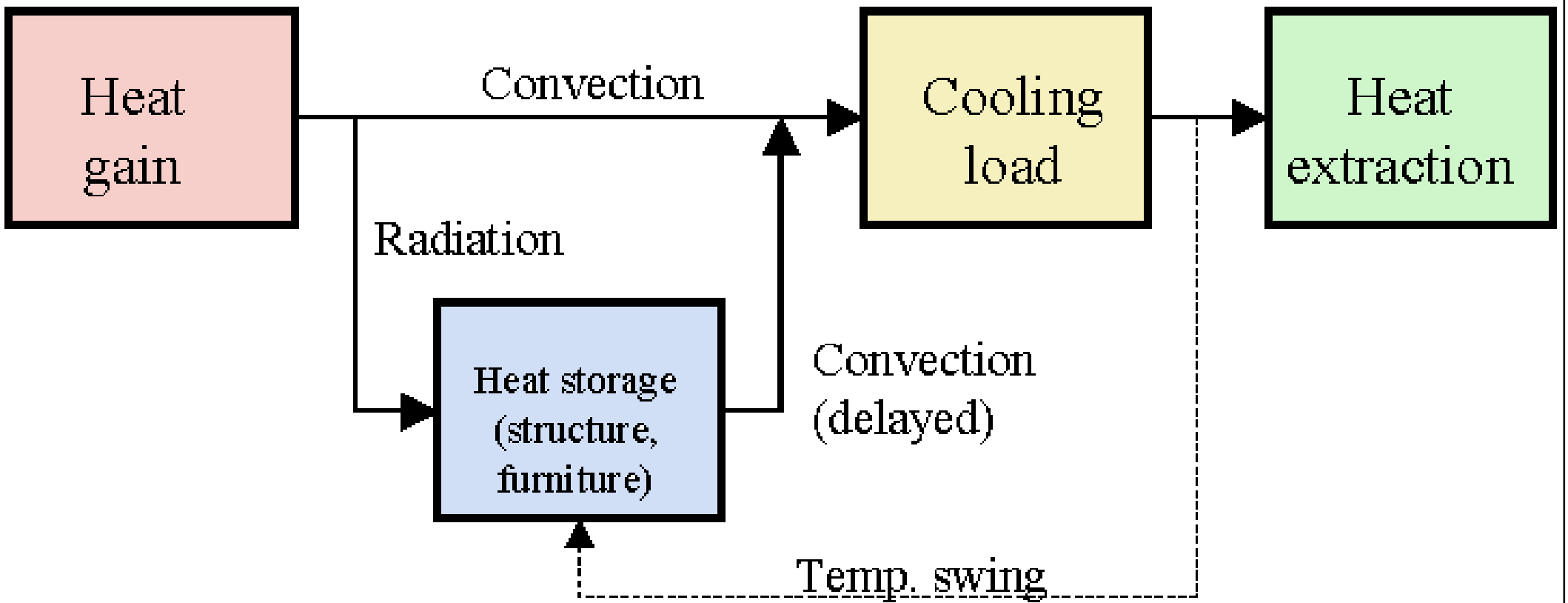
- Four major elements
  - Building model
  - HVAC system model
  - HVAC plant model
  - Control system model
- An economic model (optional) may be added for economic analysis & life cycle costing

Major elements of building energy simulation

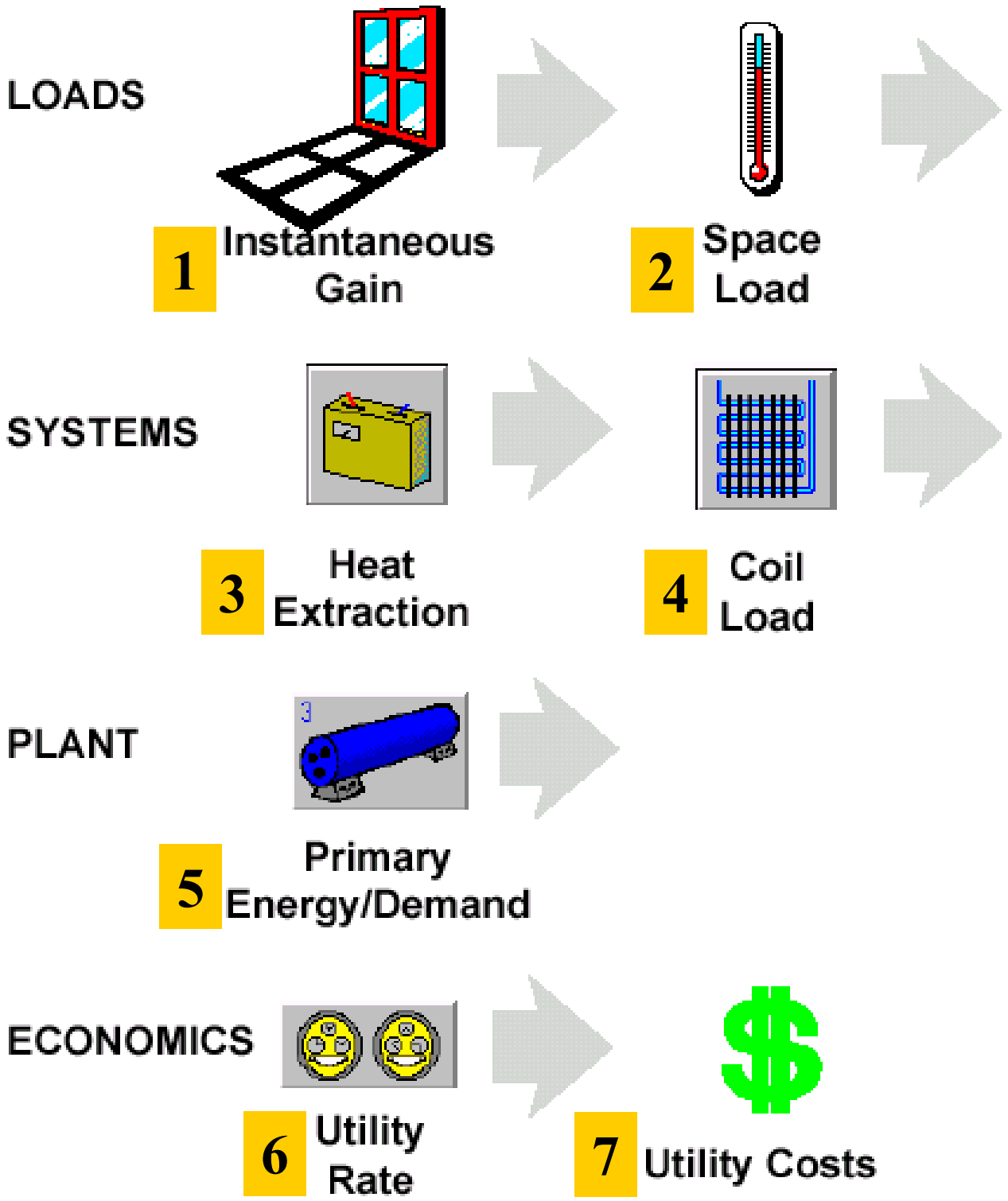



Information flow in building simulation
Input
Simulation process
Output
Climatic data
Bldg. Info.
LOAD
Bldg. load
AC system info.
SYSTEMS
AC system energy
Plant info.
PLANT
AC plant energy
Econ. Info.
ECONOMICS
Econ. results

Concept of heat transmission & conversion in buildings



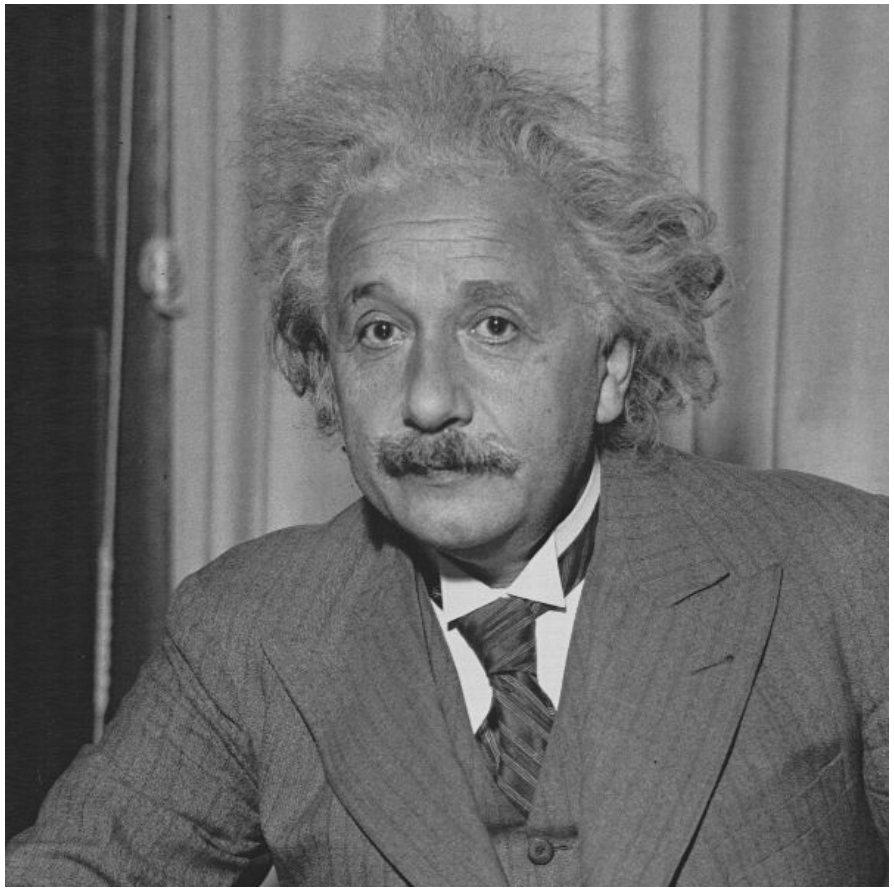
"Seven steps" of simulation output



(Source: eQUEST Tutorial Manual)

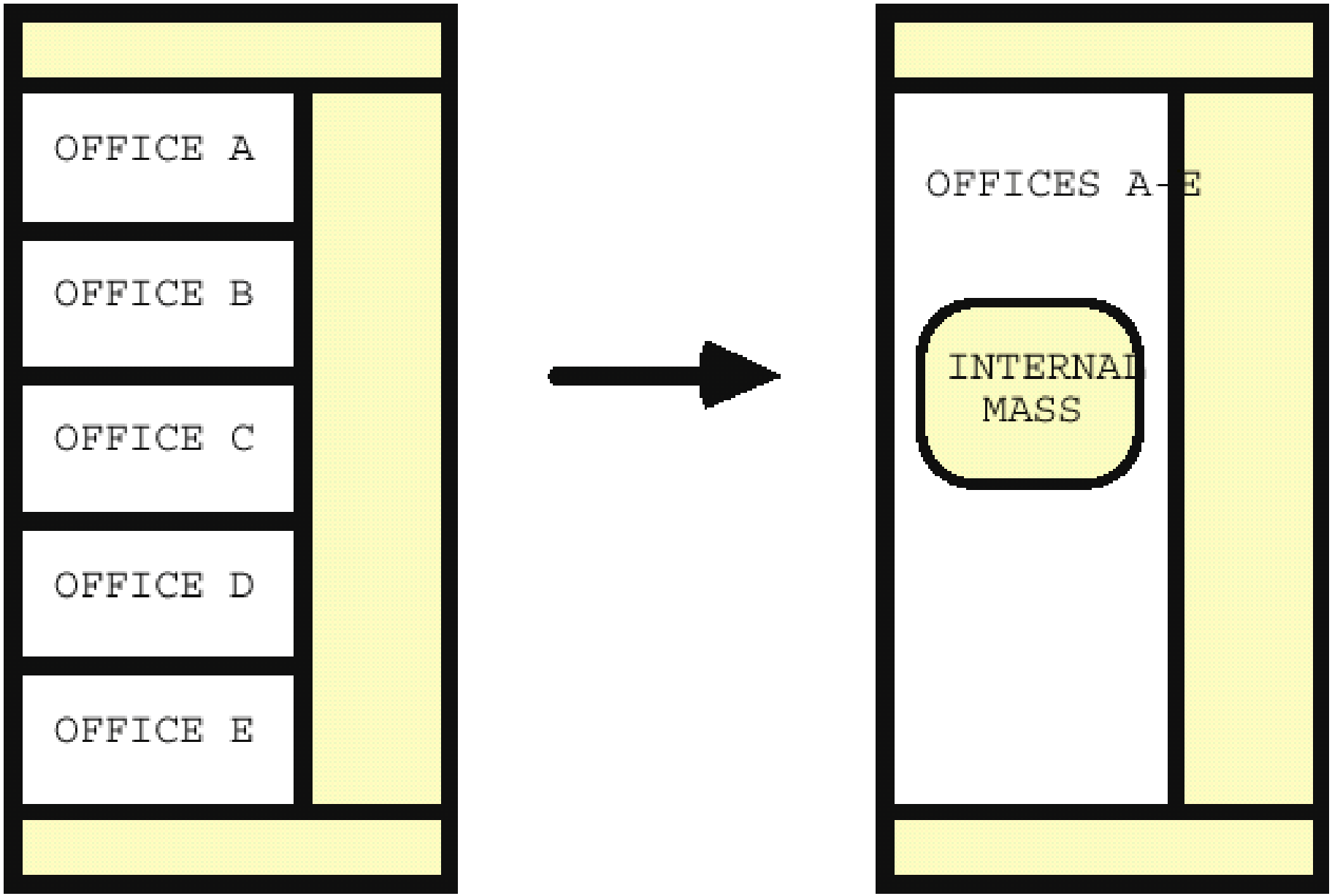
Simulation skills

- Model zoning (*thermal*, not geometric)
  - Consider thermal loads (e.g. interior-perimeter), occupancy, lighting type & schedule
    - For existing buildings, refer to actual zoning
  - Need to *simplify* the model
    - Combine zones with similar load & usage
    - Intermediate typical floors treated as one floor
    - Combine HVAC systems
    - Sometimes, use ONE zone to quickly calculate the total load first



Make things as simple as possible,
and no simpler. (Albert Einstein)

Combine several rooms into one zone



Simulation skills

- General rules for zoning
  - One exterior zone per major orientation (4 to 5 m deep)
  - One internal zone per use schedule
  - One plenum zone (if plenum returns) for each air handler
  - One zone each for special uses
  - Separate ground & top floor zones

Simulation skills

- Overall building characteristics
  - Simple building driven by external loads
  - Complex building driven by internal loads
- Types of loads
  - Weather-related loads
  - Time-related loads
- HVAC characteristics & controls
  - Is dynamic response of the system critical?

Simulation skills

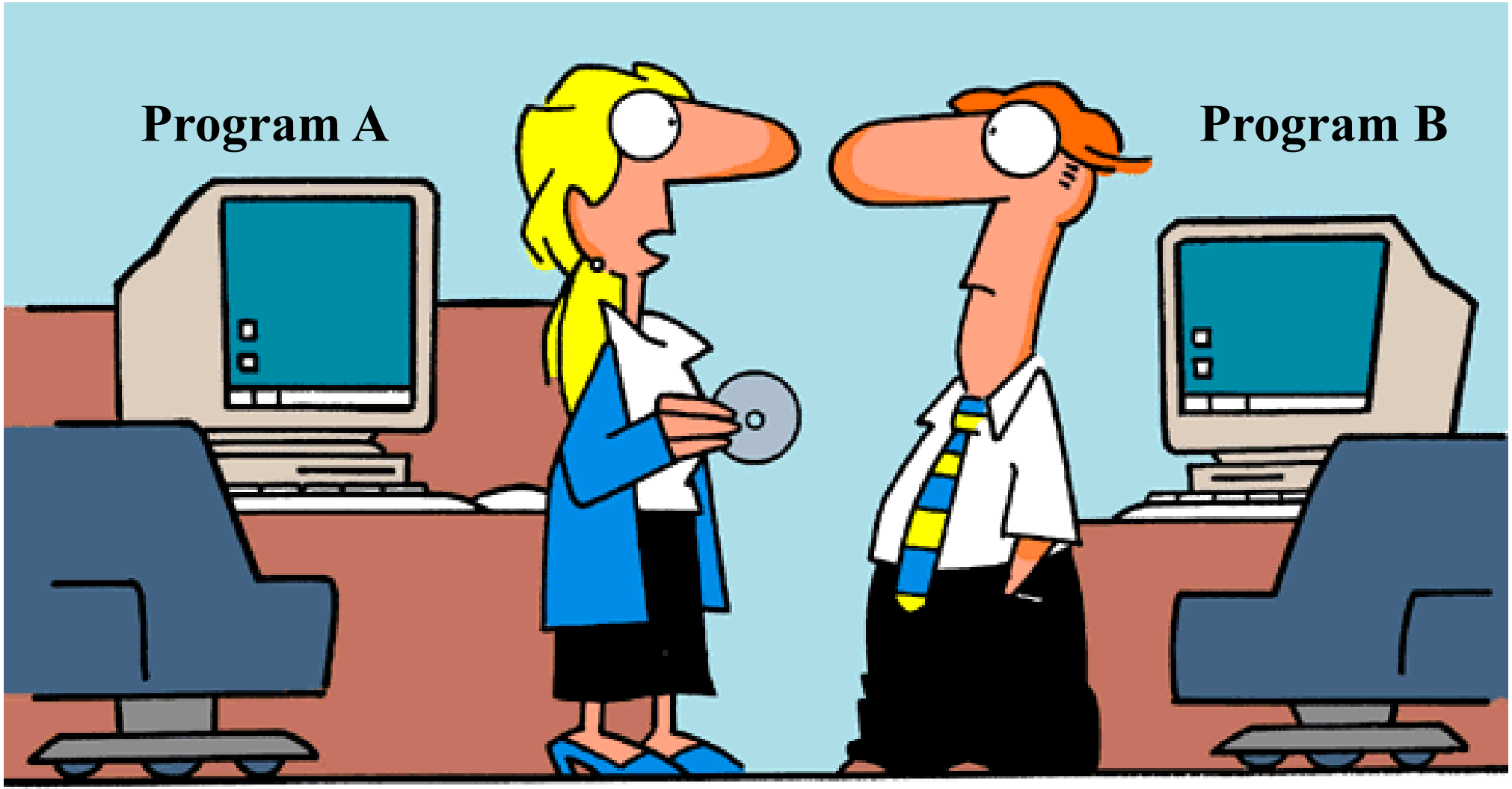
- Focus on inputs of significant impact
  - Small buildings – heat loss to ground & roof, through unconditioned spaces
  - Large buildings – zoning, controls, HVAC system types, internal loads
  - Retrofit projects – actual operating conditions, occupant behaviours & controls
- Often judged by experience, sensitivity analysis, or real measurements/data

Simulation skills

- For existing buildings
  - Study the as-built drawings & existing features
  - Collect historical data & logs
  - Take appropriate measurements
  - Observe building occupancy
- May coordinate energy audit & simulation to calibrate or tune the simulation model

Simulation skills

- Typical simulation results & output
  - Thermal loads (of building, zones, components): by hour, day, month or year
  - Temperatures (air, surfaces)
  - Fuel & energy uses
    - Consumption (month, year)
    - Peak demand (month, year)
    - System components
  - Output formats
    - Tabular, graphic, export to other analysis tools



“Several people using several simulation programs on the same building will probably not agree on the results of an energy analysis.”

Simulation skills

- What constitutes an “accurate” output? (general guideline only)
  - Annual energy use within 5-10% of actual
  - Seasonal energy use profiles should match
  - Daily energy use profiles match (if needed)
  - End-use energy components is faithfully allocated
- Check with “rules of thumb” or check figures
  - e.g. typical load densities, airflow, water flow

Accuracy checklist for building energy simulation

Building Survey:

-Adequate knowledge of building occupancy & use?
-Adequate knowledge of HVAC function & use?
-Measured/accounted for all electrical demand?

Simulation Program:

-Adequate documentation?
-Adequate experience/knowledge of program?

Output Critique:

-Thermal load check?
-Annual energy use checks?
-Annual profile checks?
-Hourly profile checks?
-Retrofit simulation make sense?
-Overall savings level is plausible?

(Source: Waltz, J. P., 2000. *Computerized Building Energy Simulation Handbook*, Fairmont Press, Lilburn, GA.)

Simulation skills

- Expected precision (general guideline only)
  - Energy
    - Average monthly error > annual error
    - ± 8-10% monthly energy
    - ± 3-5% annual energy
  - Annual
    - Average monthly error > Average annual error
    - ± 10-12% monthly peak demand
    - ± 5-6% annual average peak demand
  - Monitored data can cut the error in half

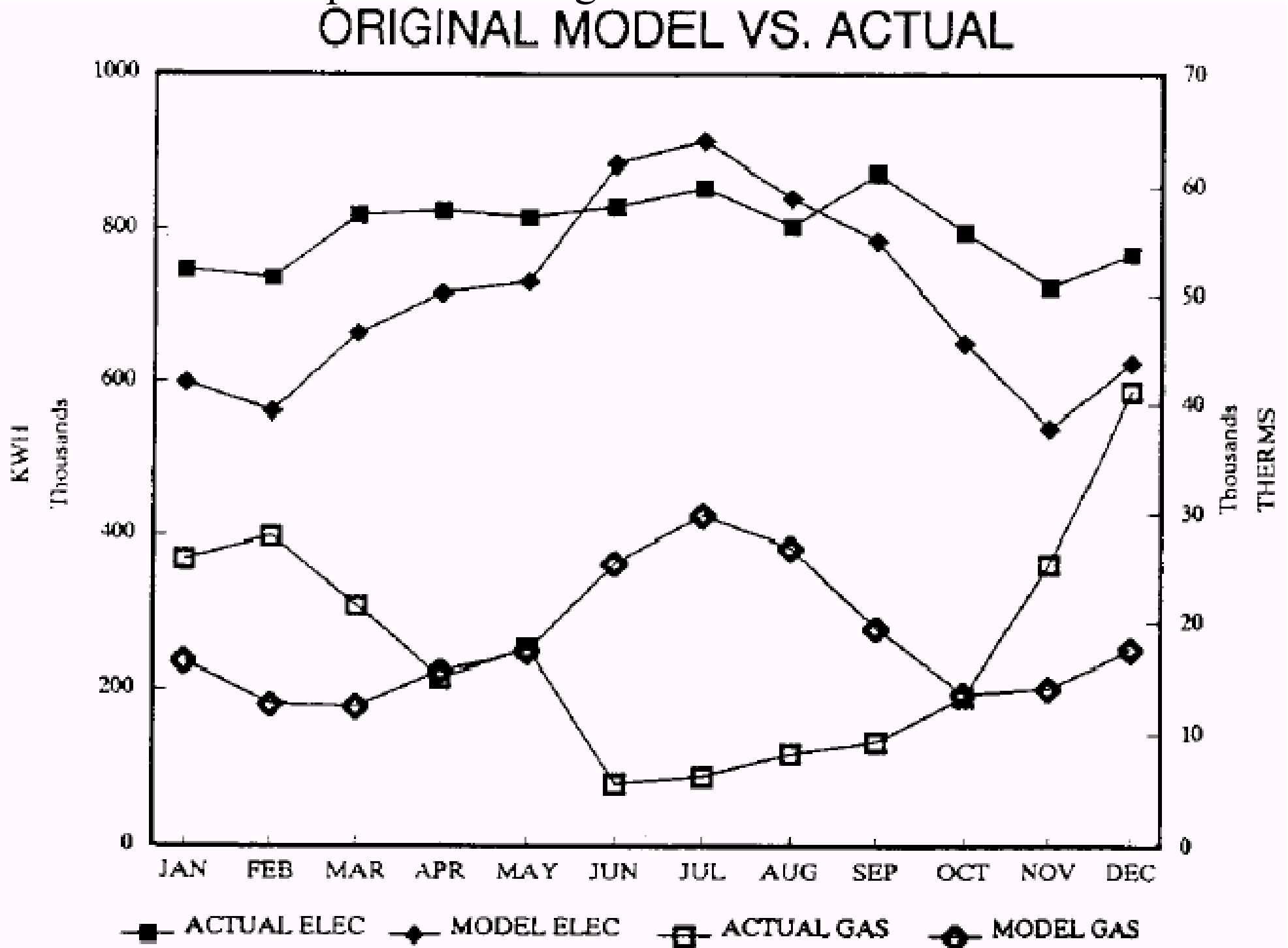
Simulation skills

- Consider the building to be simulated
  - What building features are likely to be significant drivers of energy performance
  - Which energy conservation measure(s) are likely to be of particular interest
- Quality control to avoid/reduce errors
  - Check & review by competent persons
  - Well-organised documentation

Simulation skills

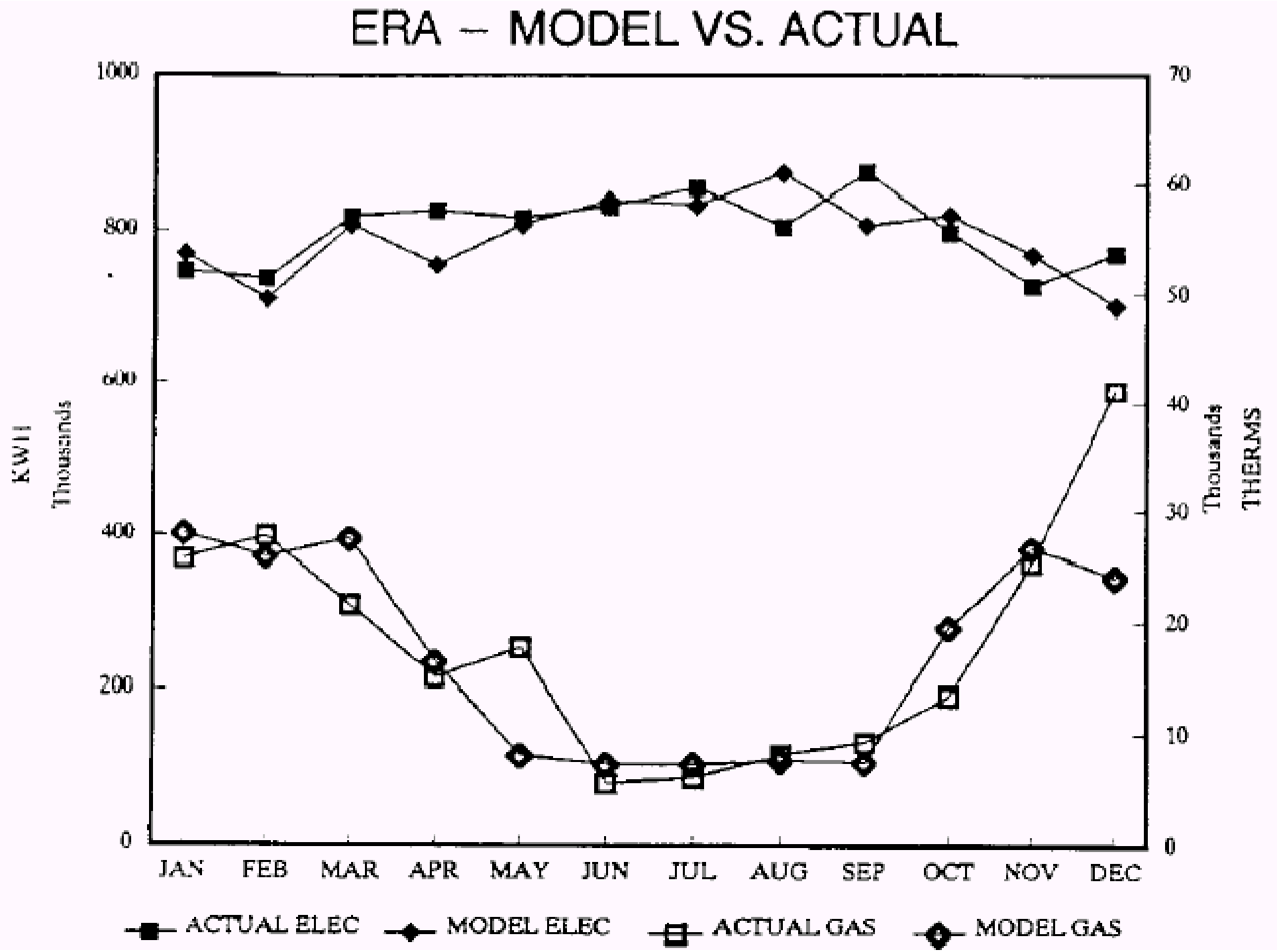
- Attacking the errors
  - Check careless errors in the inputs
  - Examine discrepancies in the output
  - Understand the simulation algorithms (reread the appropriate sections of the users' manual)
  - Understand the building or the design
  - Increased attention to detail in inputs
  - Tweak certain inputs to correct the errors

Comparison of original model & actual data



(Source: Waltz, J. P., 2000. *Computerized Building Energy Simulation Handbook*, Fairmont Press, Lilburn, GA.)

Improvement of the simulation model after attacking the errors



(Source: Waltz, J. P., 2000. *Computerized Building Energy Simulation Handbook*, Fairmont Press, Lilburn, GA.)

Simulation skills

- Remember simulation tool cannot compensate for bad assumptions or sloppy input
  - Maintain humility & scepticism
  - Good modellers require a lot of system design knowledge & understanding of real operations

- How well it works depends on YOU?

Further reading

- Building performance simulation - Wikipedia
  - https://en.wikipedia.org/wiki/Building_performance_simulation
- Energy Simulation Tip Sheet
  - https://beeindia.gov.in/sites/default/files/Energy%20Simulation%20Tip%20Sheet.pdf
- Hui S. C. M., 1998. Simulation based design tools for energy efficient buildings in Hong Kong, *Hong Kong Papers in Design and Development*, Vol. 1, 1998, pp. 40-46, Department of Architecture, University of Hong Kong. http://ibse.hk/cmhui/hkpdd/hkpdd-v1.htm