MECH3023 Building Energy Management & Control Systems
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Dynamic Building Performance Simulation

Dr. Sam C. M. Hui
Department of Mechanical Engineering
The University of Hong Kong
E-mail: cmhui@hku.hk

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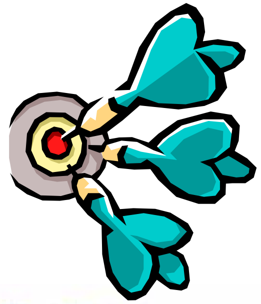
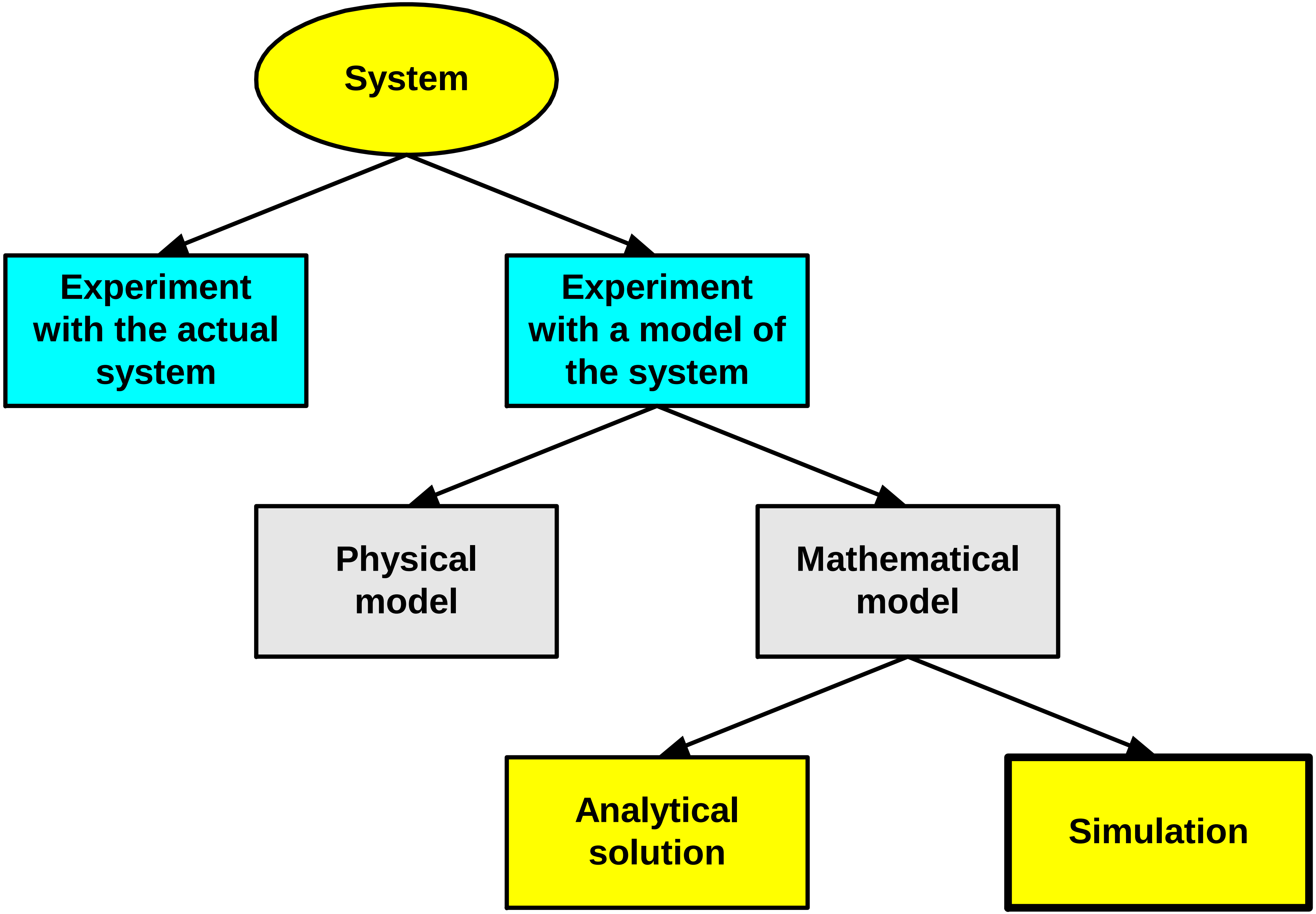
Building Energy Simulation

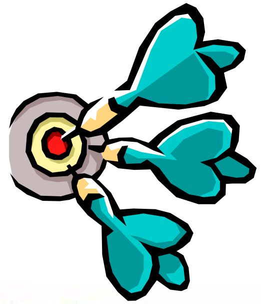


- Energy performance of buildings is usually complicated and requires detailed analysis to determine the characteristics
- Building energy simulation and modelling techniques are often used to study it so as to support decisions for building design, operation and management

Ways to study a system

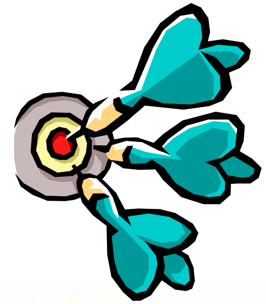


Building Energy Simulation



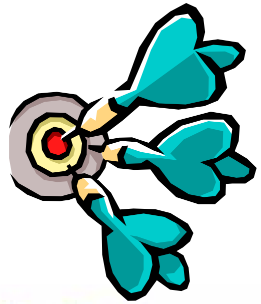
- Building performance simulation (BPS)
  - A computer model of the energy processes within a building that are integrated to provide a thermally comfortable environment for the occupants (or contents)
- Dynamic thermal simulation
  - Can predict changing internal conditions over a time period of up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

Building Energy Simulation

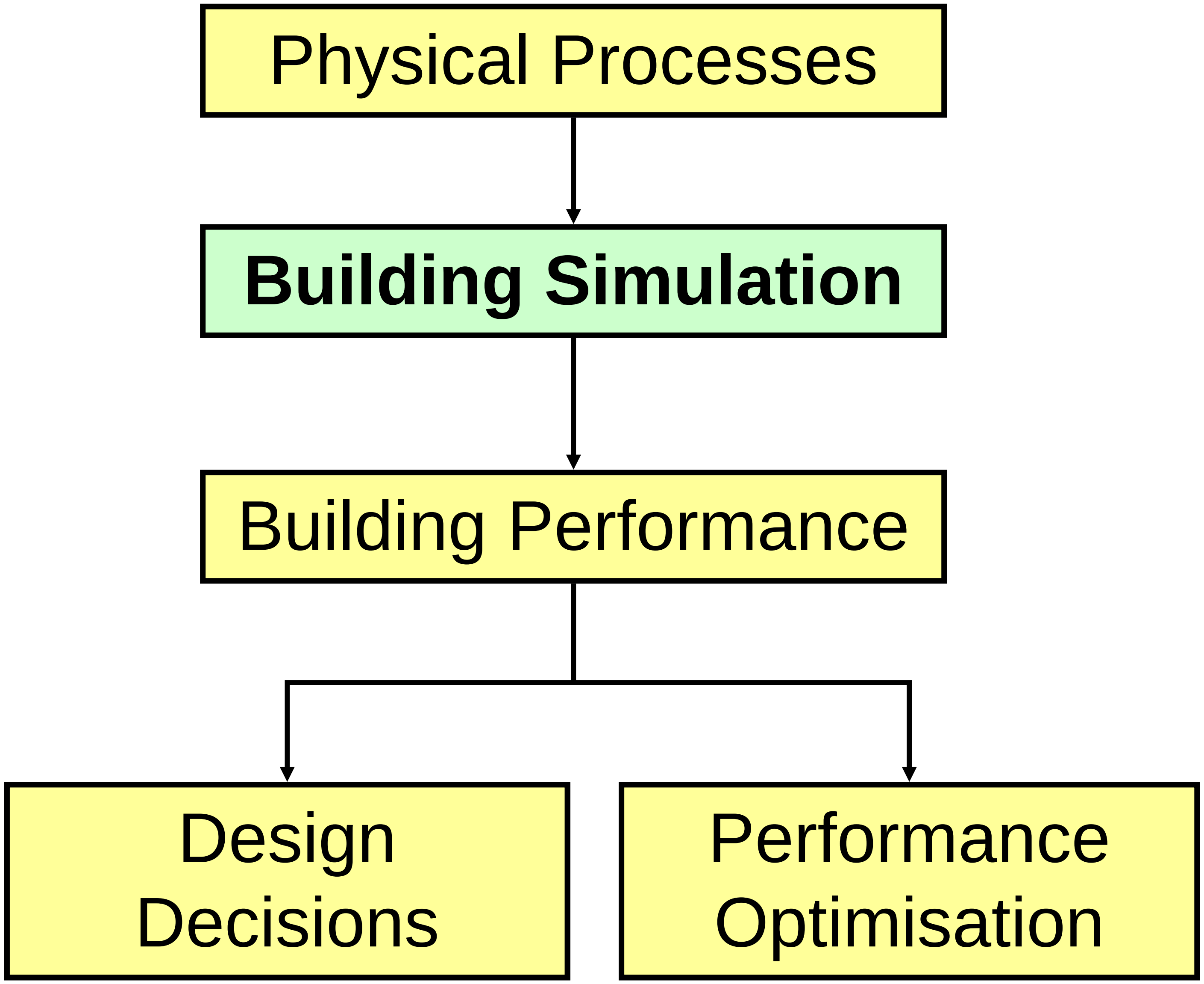


- What is Building Simulation?
  - Software which emulates the dynamic interaction of heat, light and mass (air and moisture) within the building
  - To predict its energy and environmental performance as it is exposed to climate, occupants and conditioning systems
- Building Simulation is needed if
  - 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

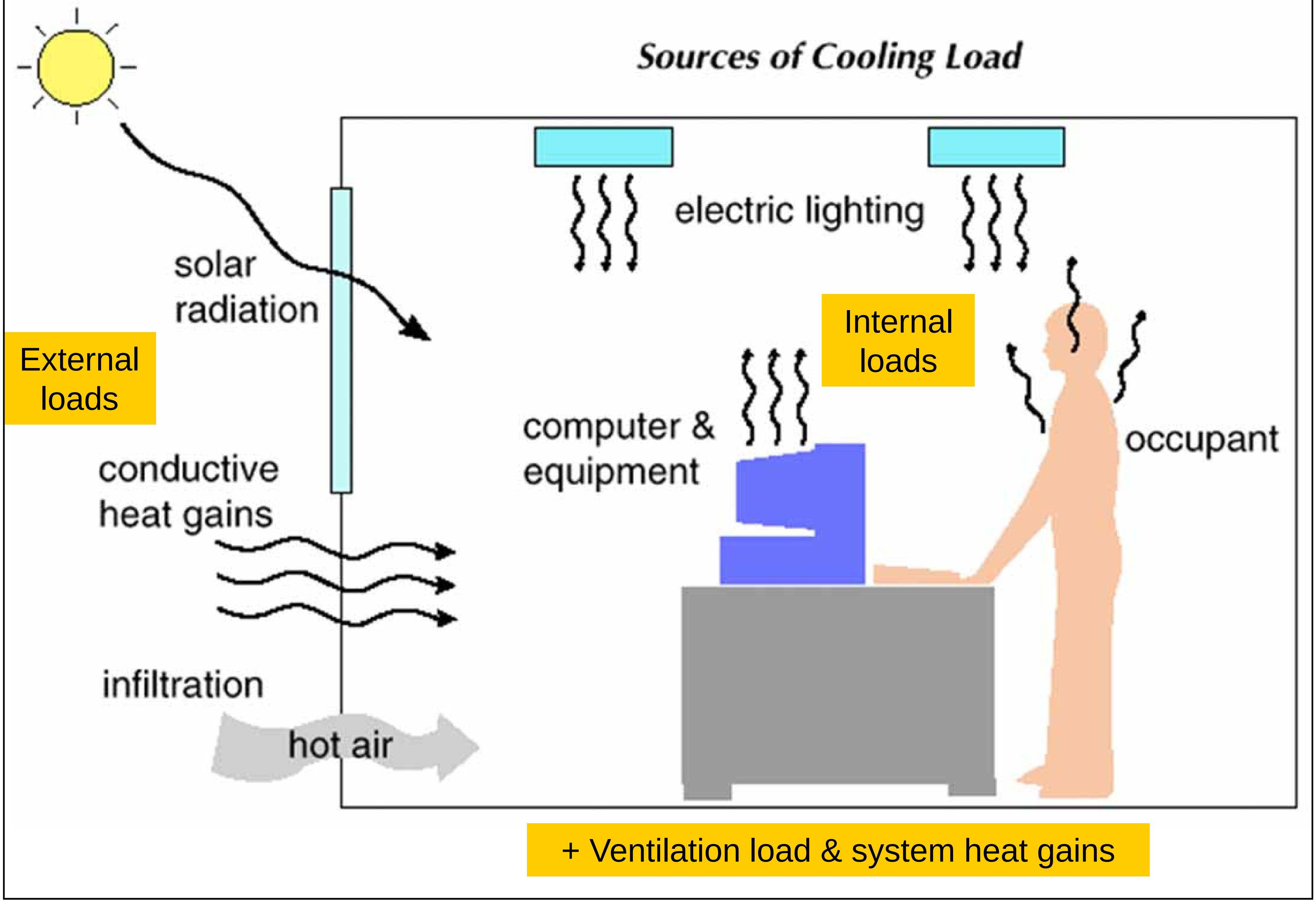


- Simulation
  - The process of developing a representative model of a system and using it to analyze and predict system behaviour and performance
- Modelling
  - Deals primarily with the relationship between actual dynamic processes and models
  - Usually involves iterations

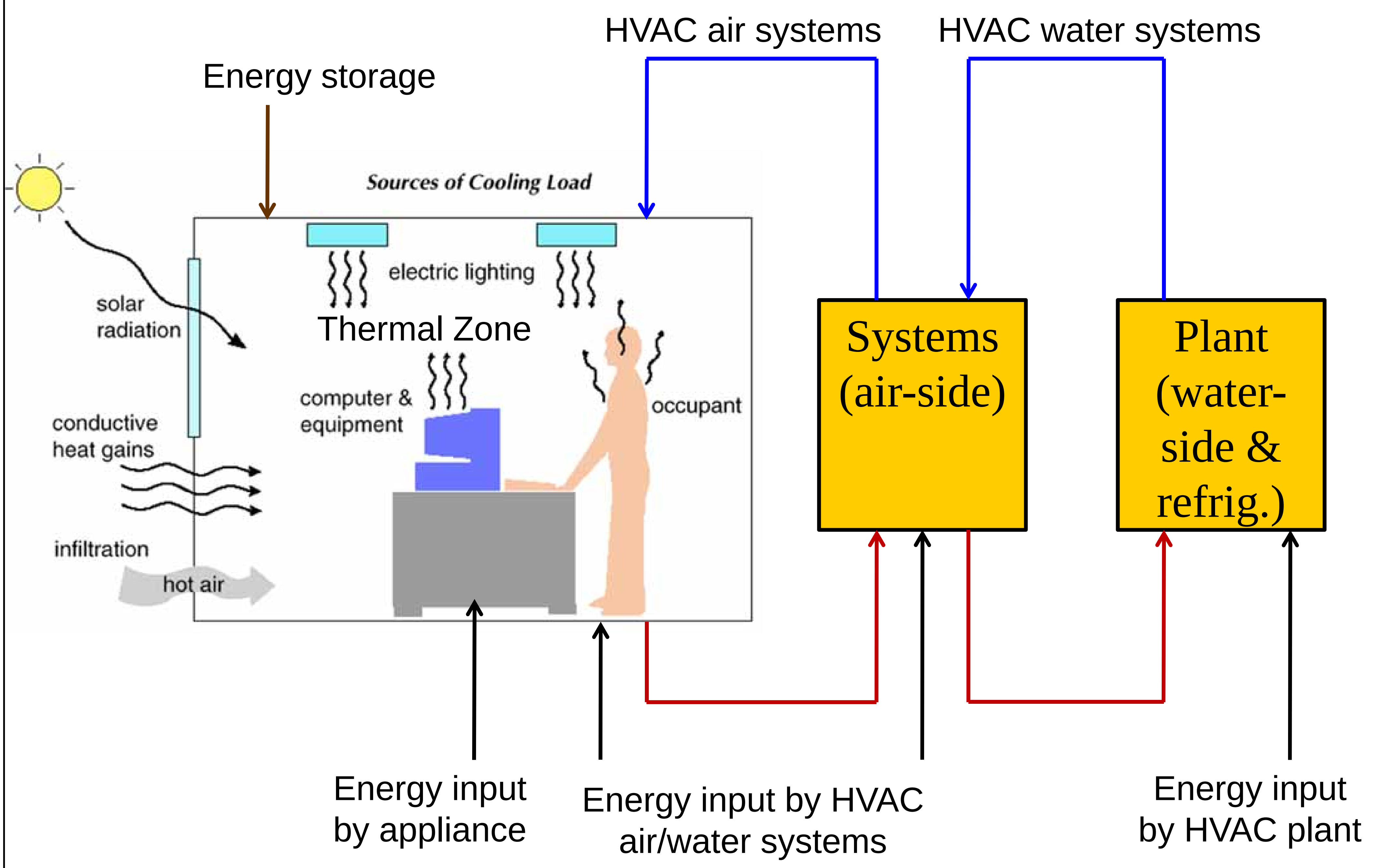


* Simulation enables the performance of the building to be established before critical design decisions are taken, enabling optimum building performance to be obtained

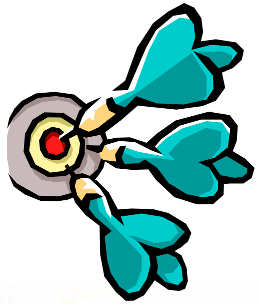
Components of building cooling load



Building energy simulation process

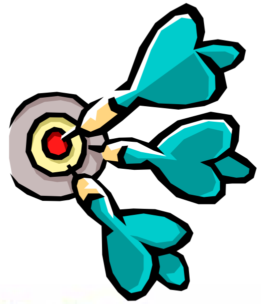


Building Energy Simulation



- 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 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 and benefits
  - Provide info to design, retrofit & operation
- Comply with building energy code
  - Such as 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- and 3-dimensional conduction calculations
  - Integrated design and analysis systems which combine a number of the above categories

Building Energy Simulation Software

ENERGY-10

blast

EnergyPlus

DOE-2

Solar-5

ESP-r

ENER-WIN®

Hourly Energy Simulation Program for Buildings

TRNSYS

Carrier

E-20-II & HAP

HOT2000

TRANE

TRACE 700

ADELINE

Tas

EE4

Simulation Tools

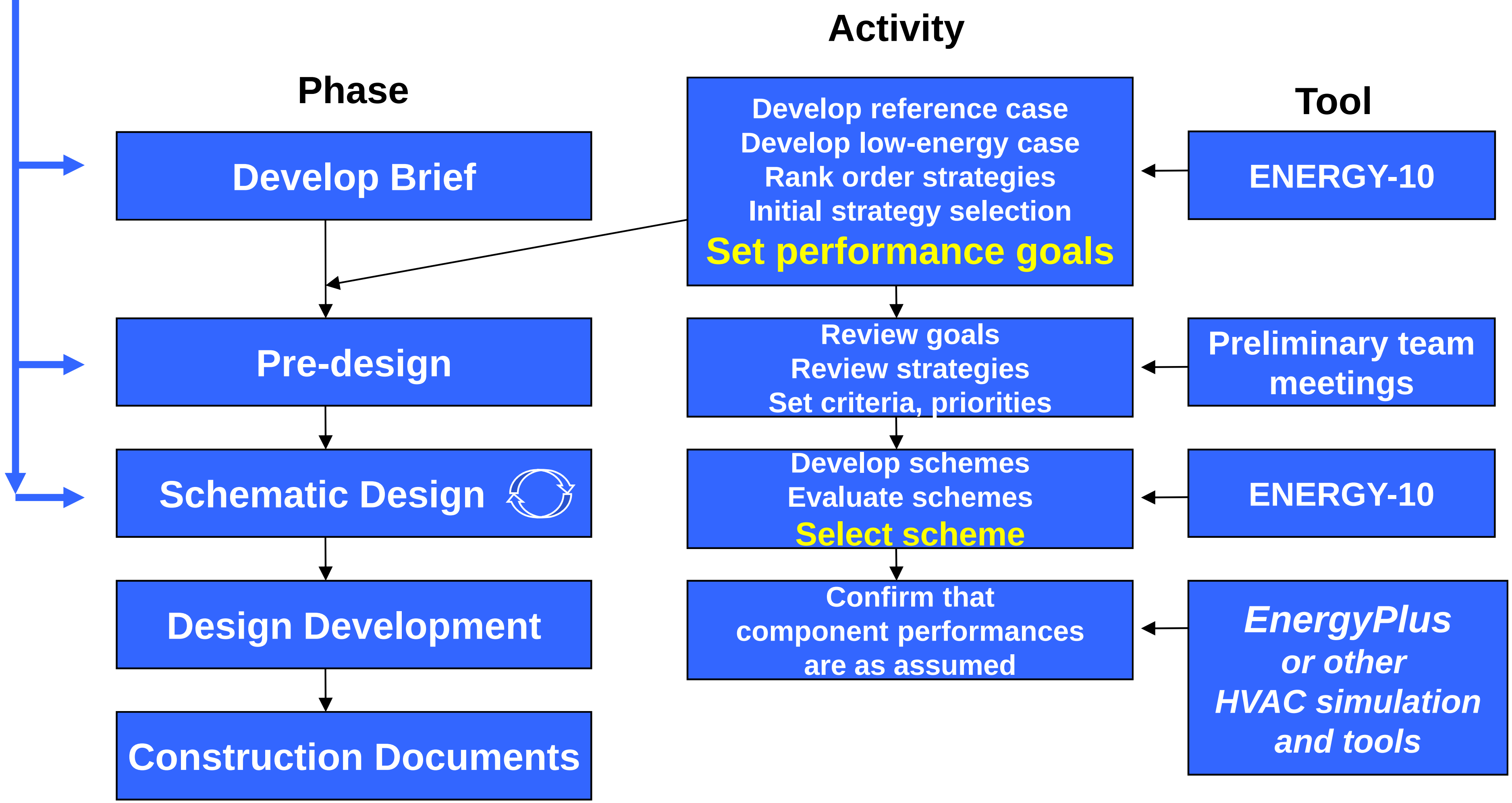
- Many software tools in the market
  - From simplified to complicated one
  - Select according to the task
- For beginners, we recommend
  - Energy-10, HAP, TRACE 700, eQUEST
- For sophisticated study, may consider
  - DOE-2, EnergyPlus, ESP-r, TRNSYS
- Further information:
  - Building Energy Software Tools Directory (by US-DOE)
    - http://www.eere.energy.gov/buildings/tools_directory/

Simulation Tools

- Examples of building energy simulation tools
  - **Energy-10**
    - http://www.sbicouncil.org/energy-10-software
  - **VisualDOE** (based on DOE-2.1e)
    - http://www.archenergy.com/products/visualdoe/
    - http://gundog.lbl.gov/dirsoft/d2whatis.html
  - **MIT Design Advisor** (do online simulation)
    - http://designadvisor.mit.edu/design/

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**

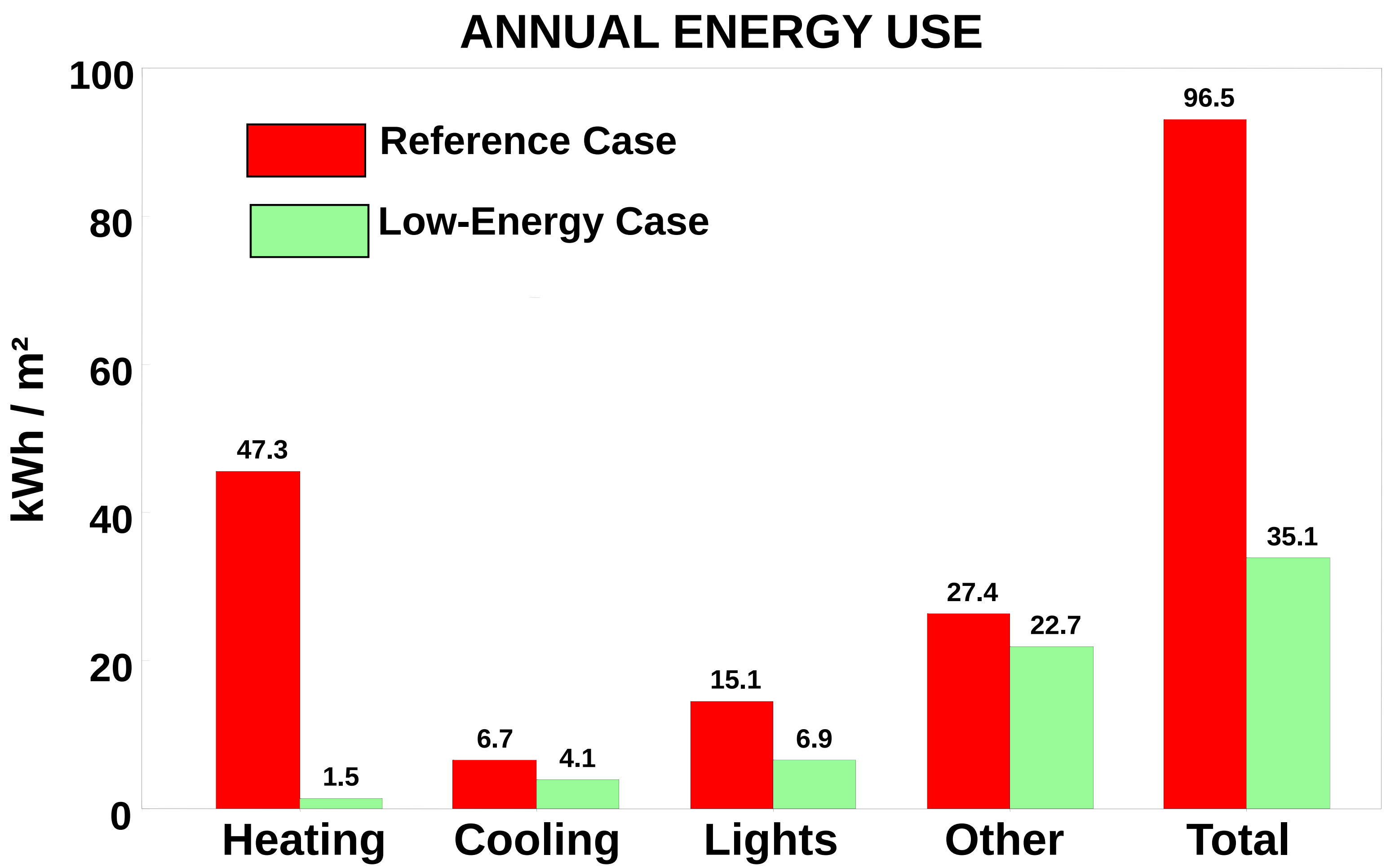
Gets you started quickly.

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

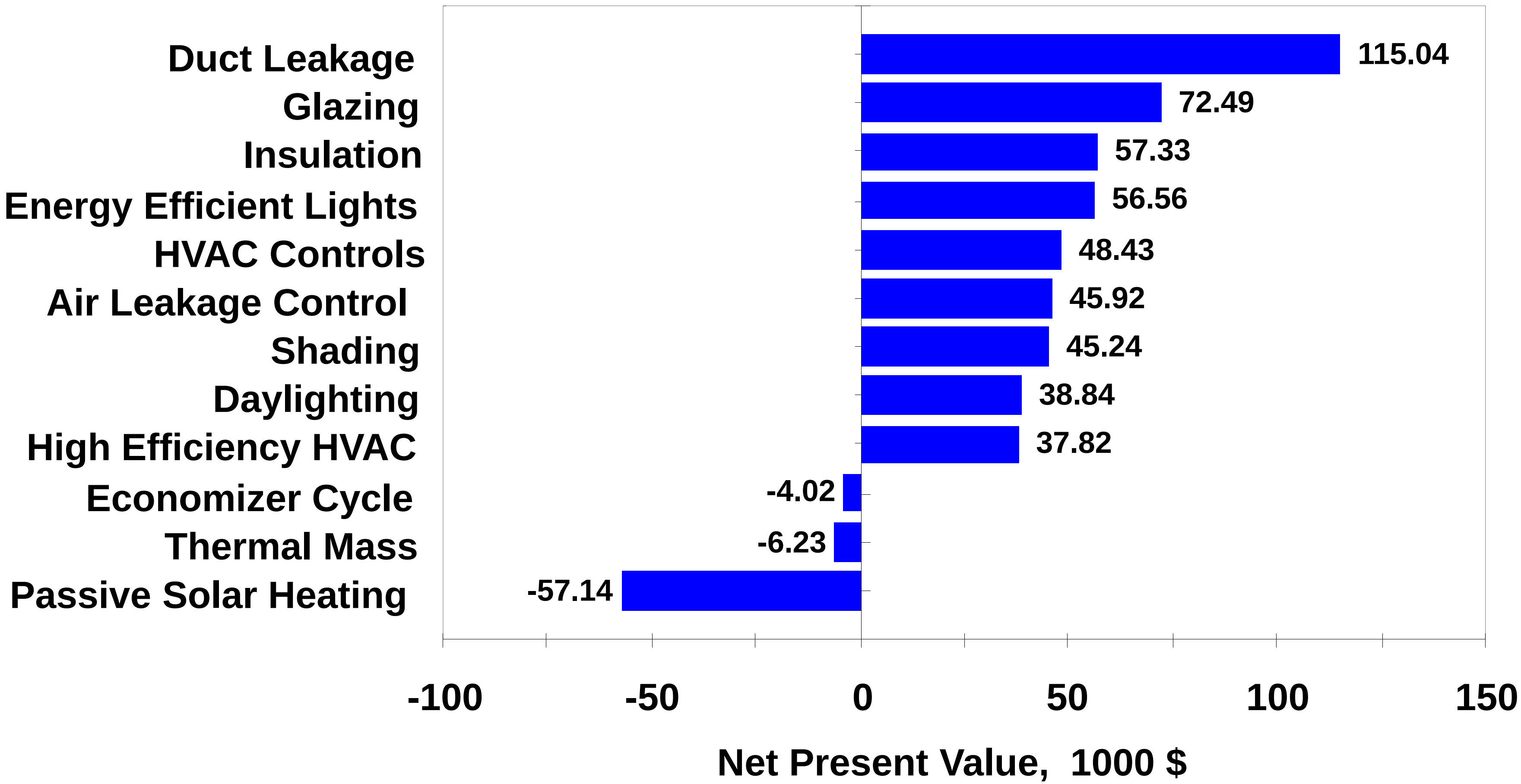
Example: Energy-10

2,000 m² office building

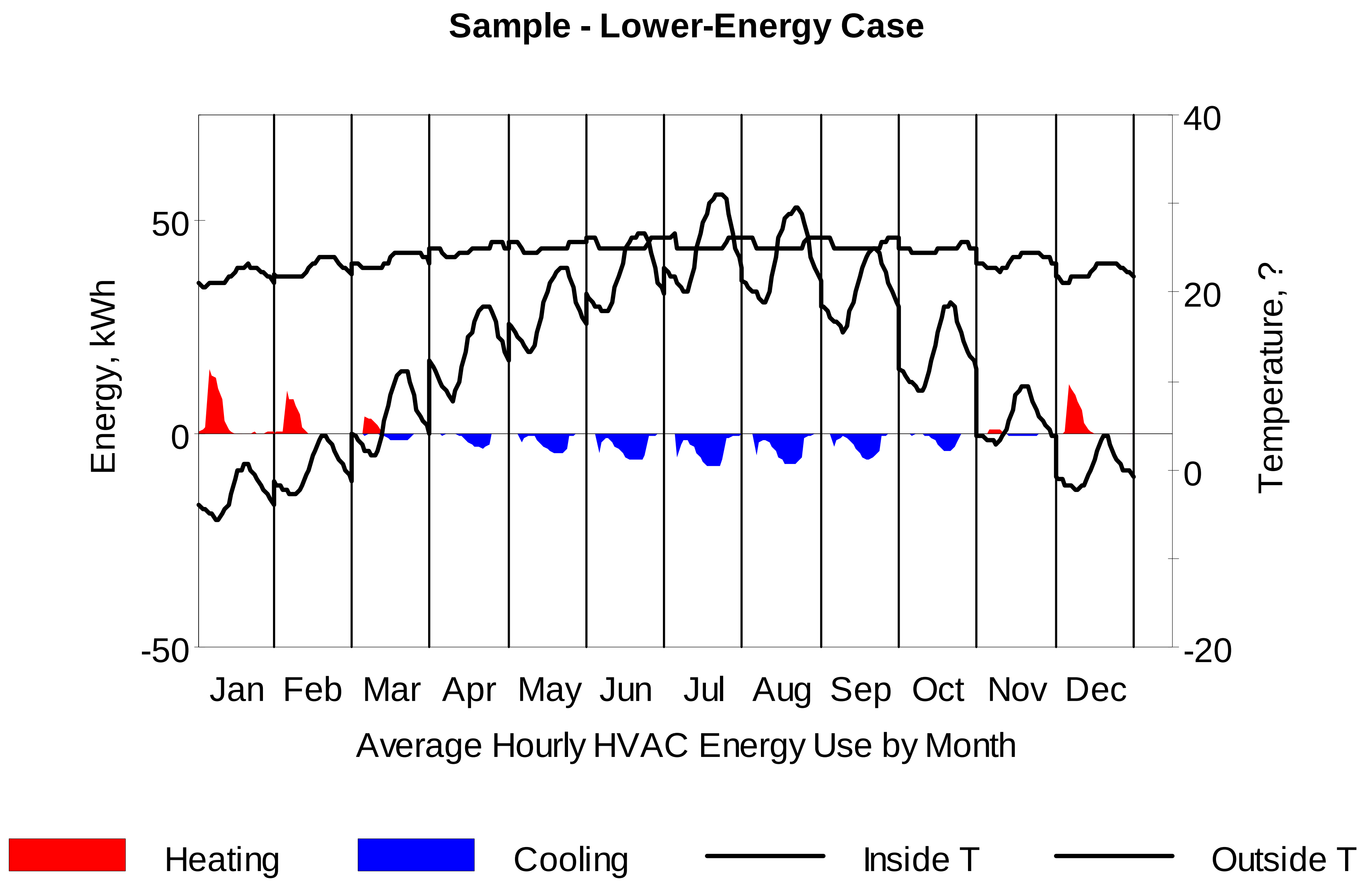


Example: Energy-10

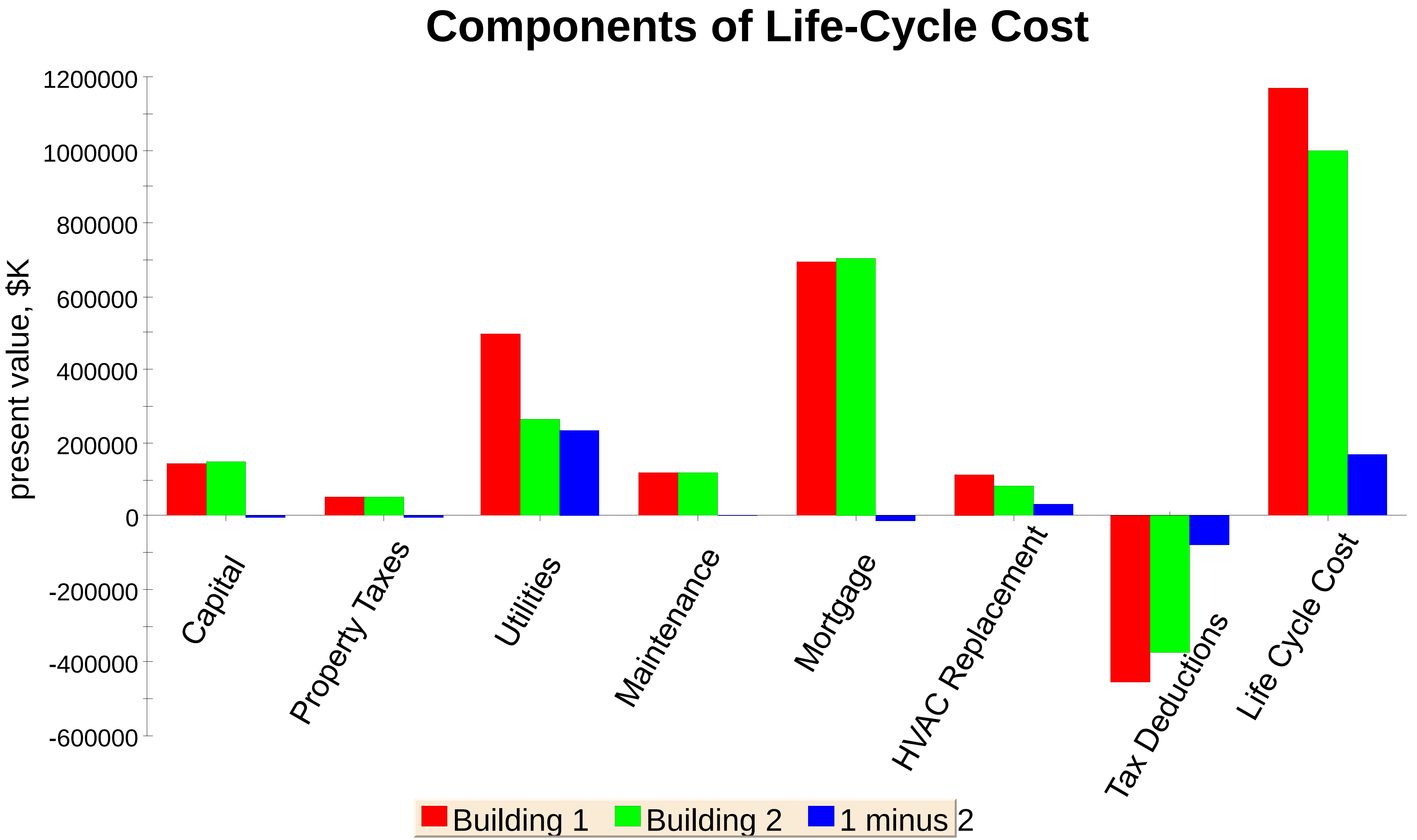
RANKING OF ENERGY-EFFICIENT STRATEGIES



Example: Energy-10

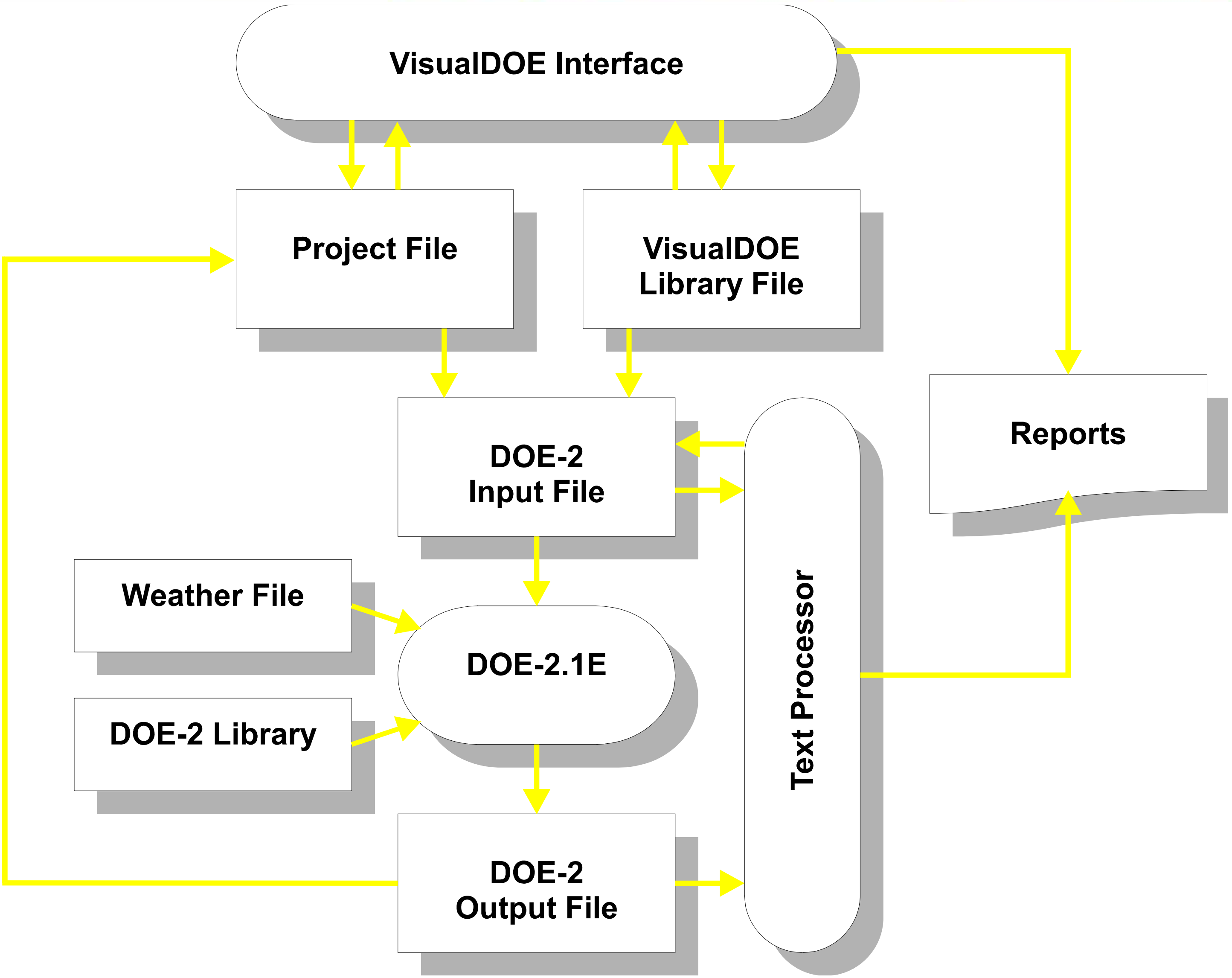


Example: Energy-10



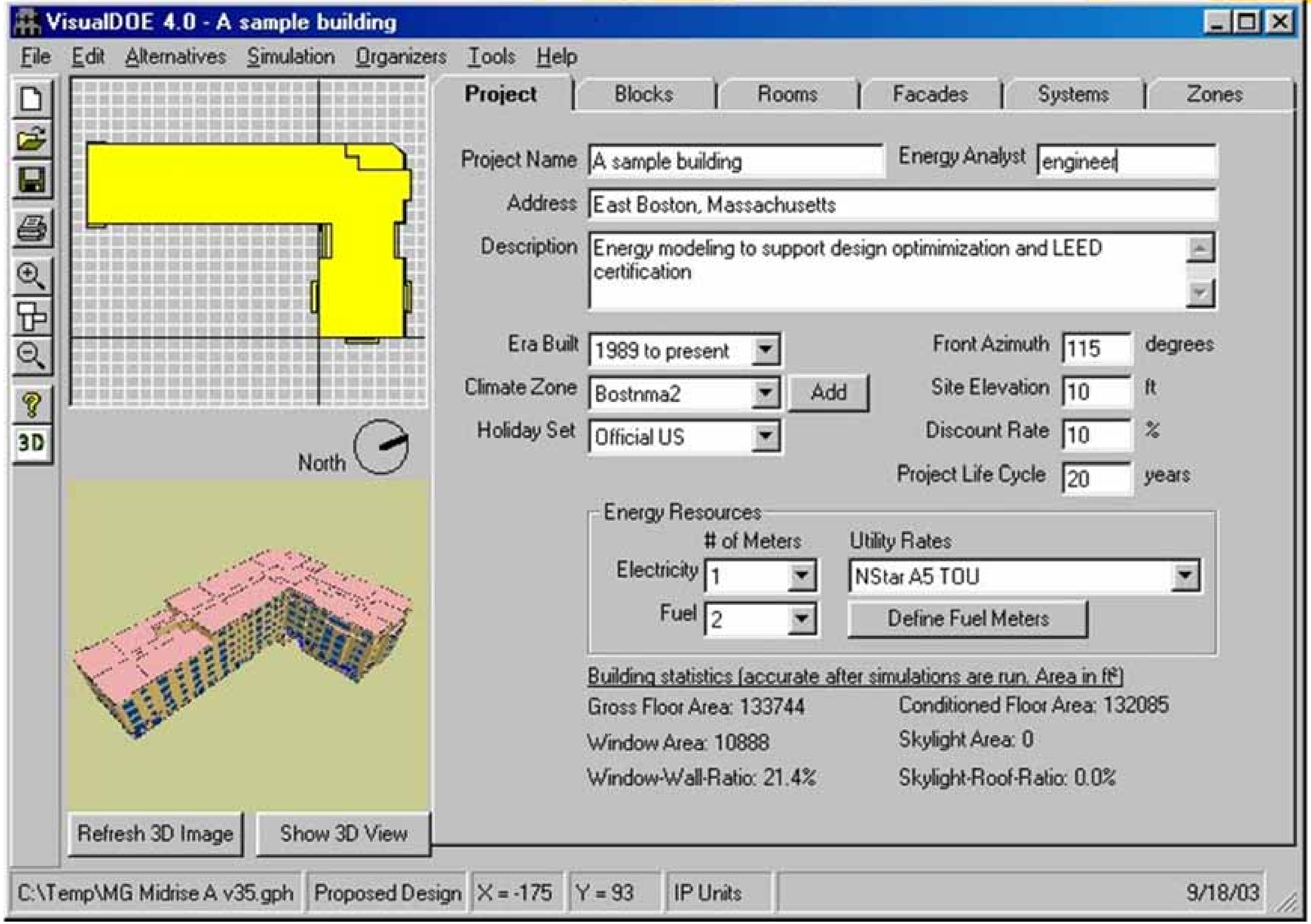
Example: VisualDOE

DOE-2



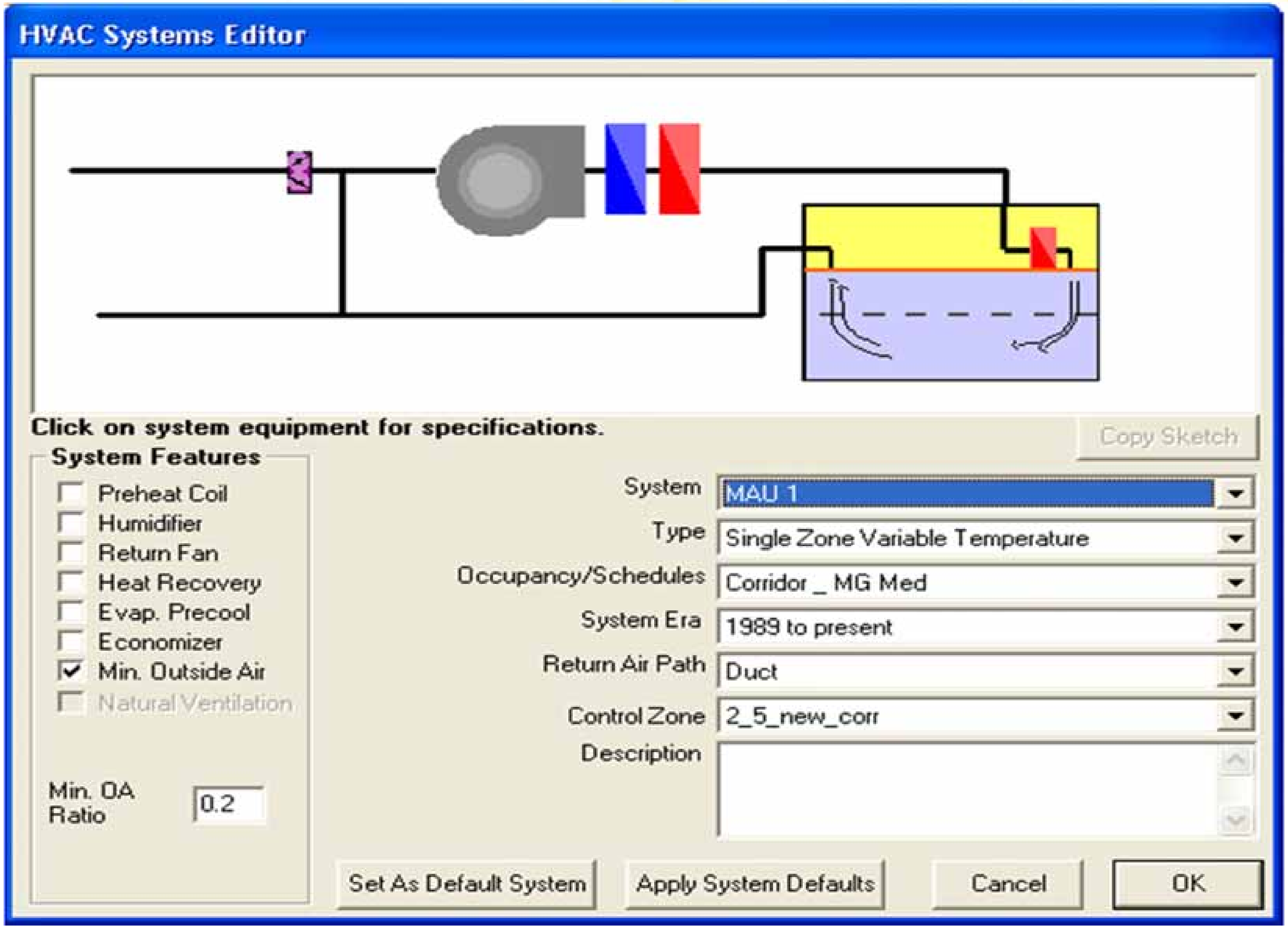
Example: VisualDOE

DOE-2



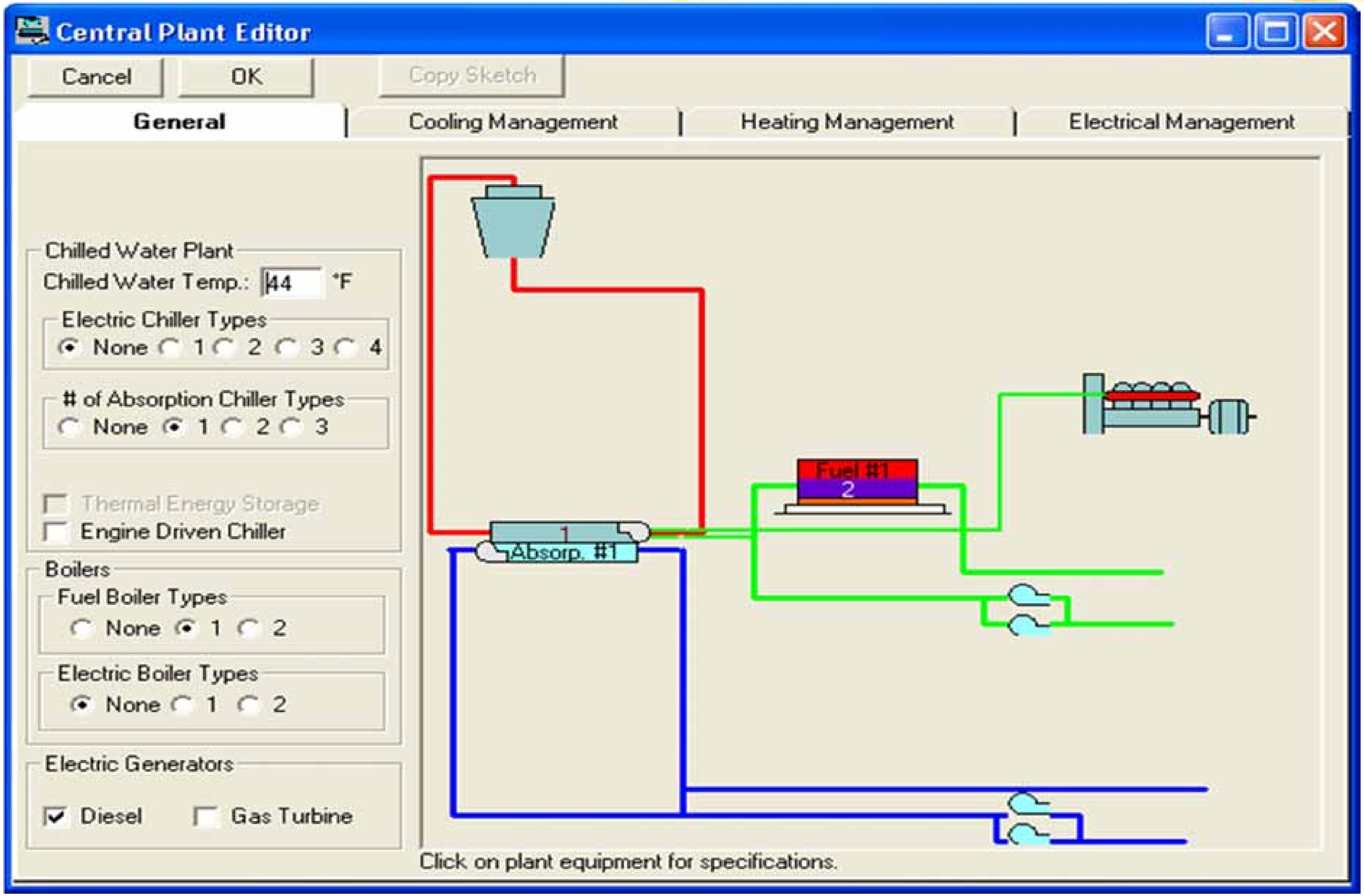
Example: VisualDOE

DOE-2



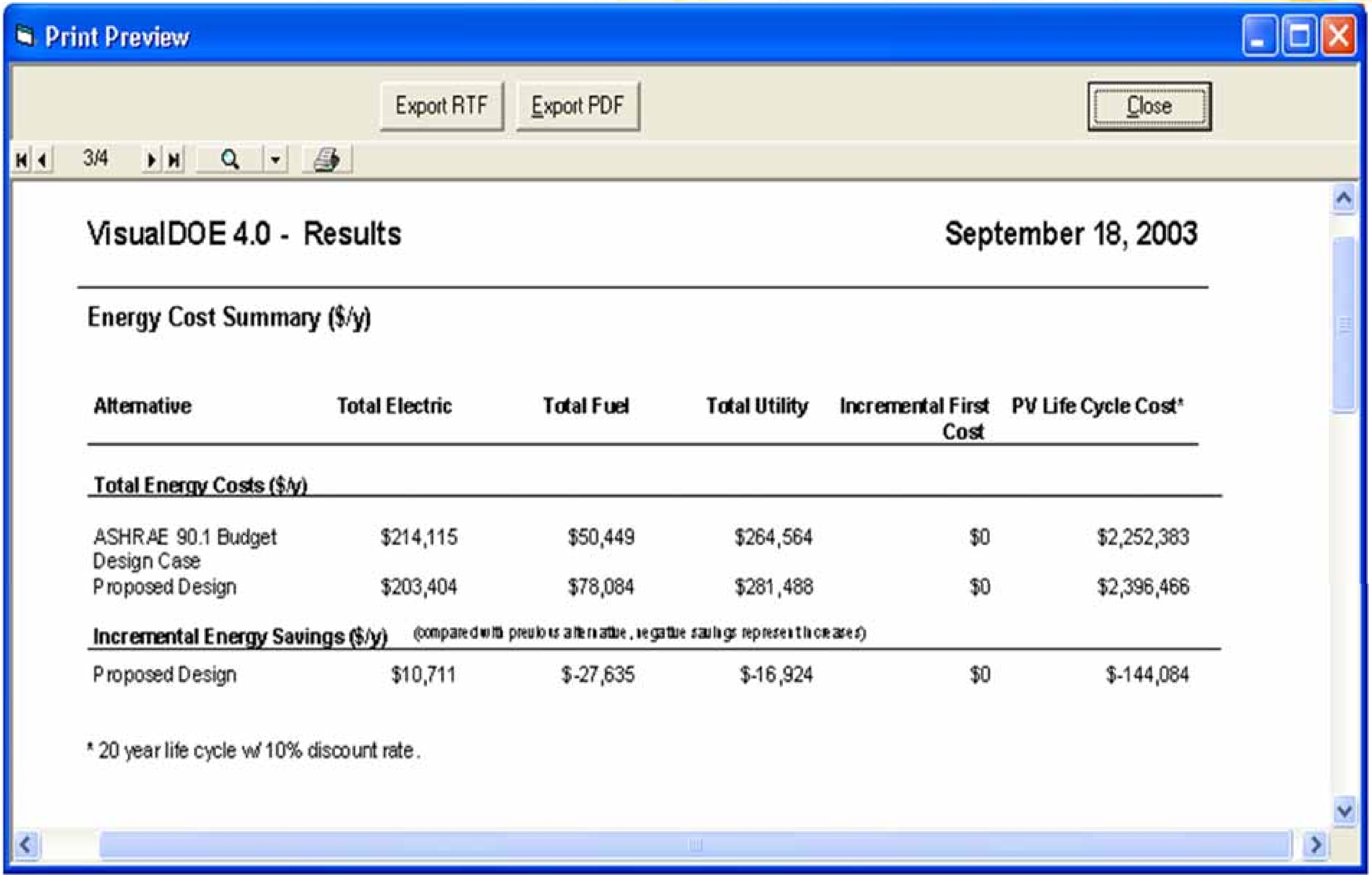
DOE-2

Example: VisualDOE



Example: VisualDOE

DOE-2



VisualDOE 4.0 - Results

September 18, 2003

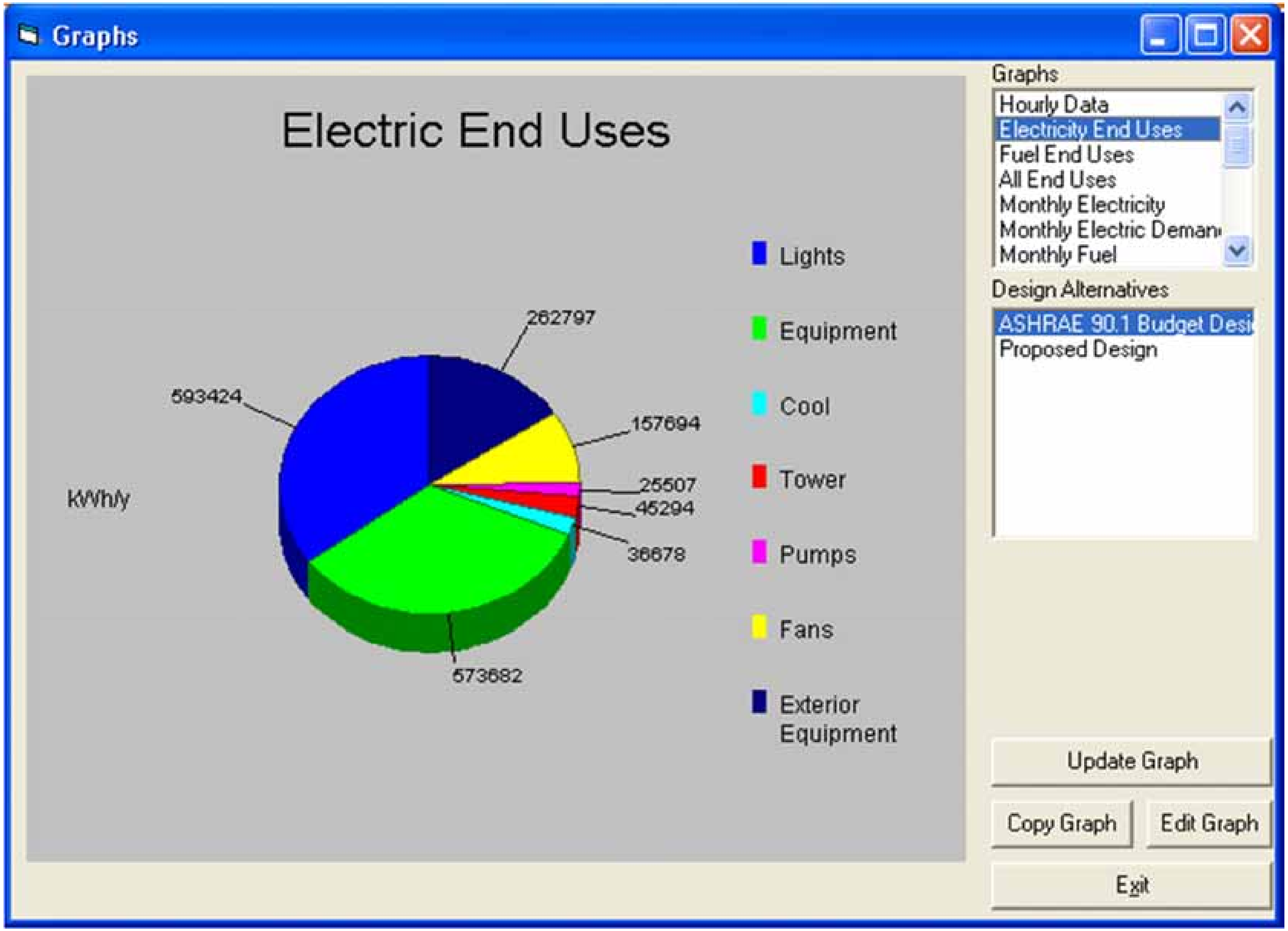
Energy Cost Summary ($/y)

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.

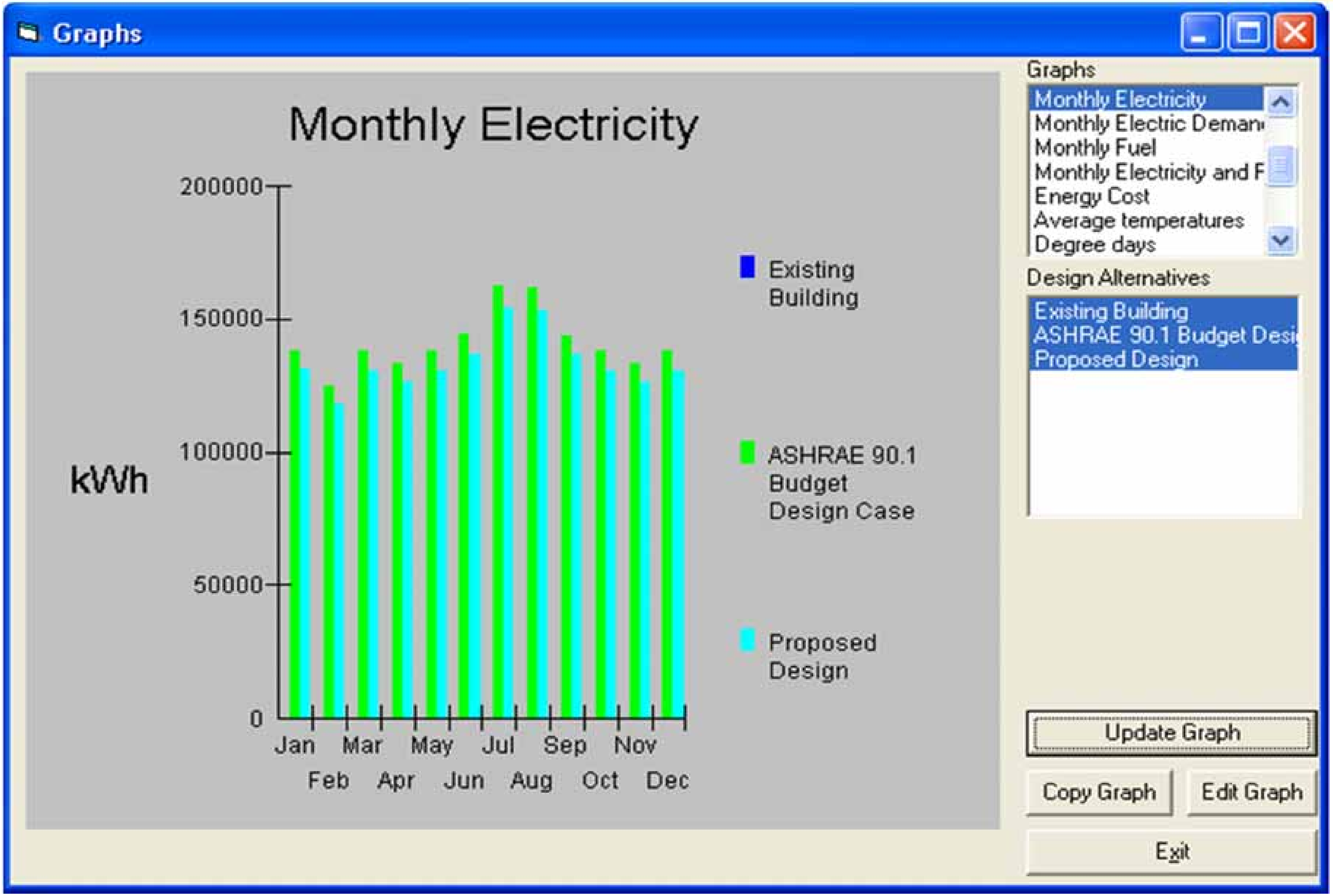
Example: VisualDOE

DOE-2

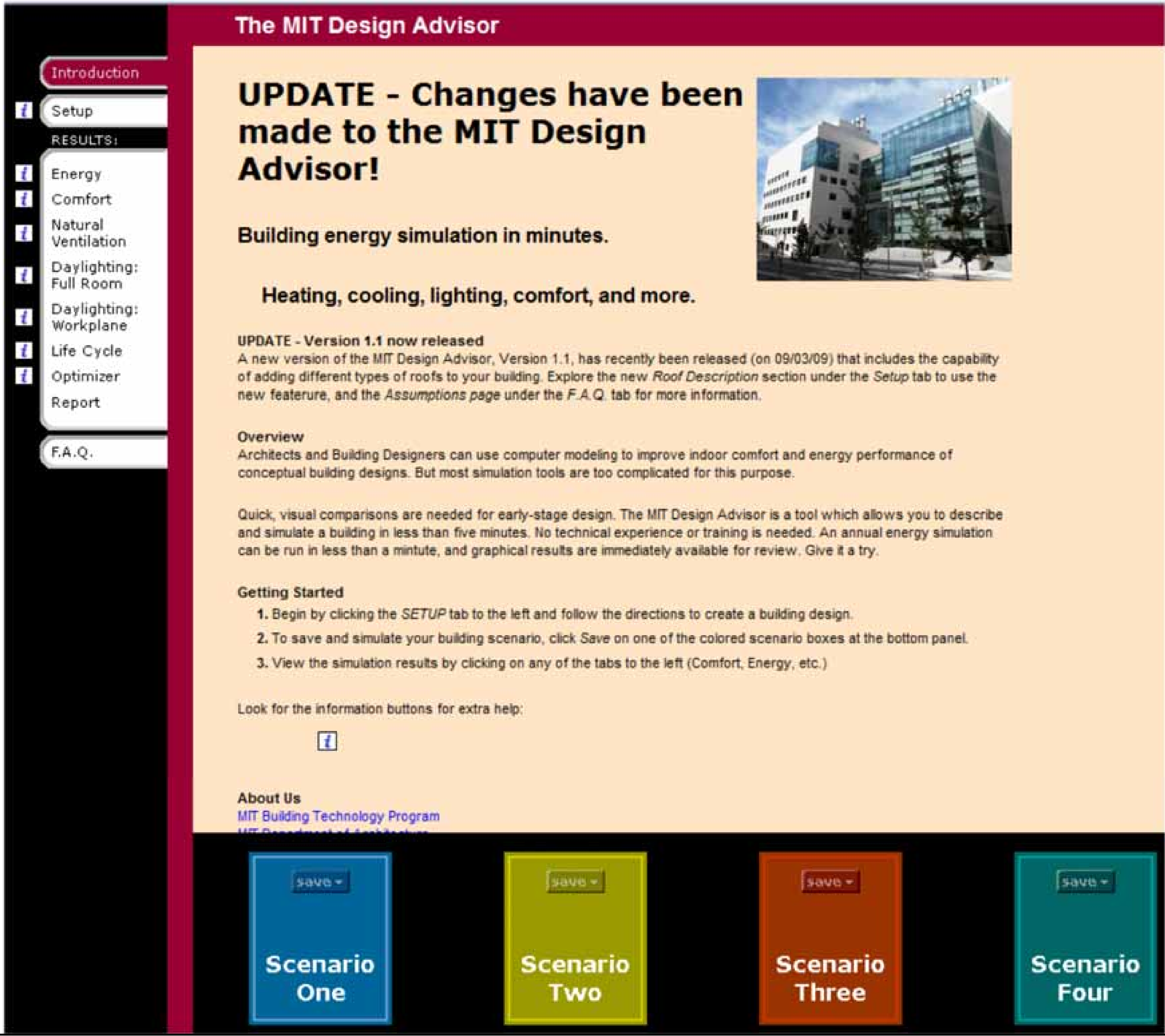


Example: VisualDOE

DOE-2

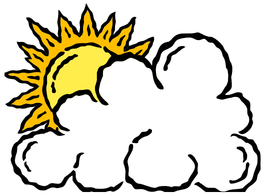


MIT Design Advisor, http://designadvisor.mit.edu/design/

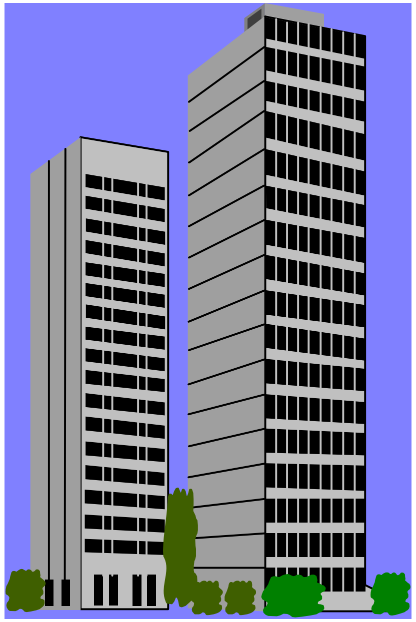


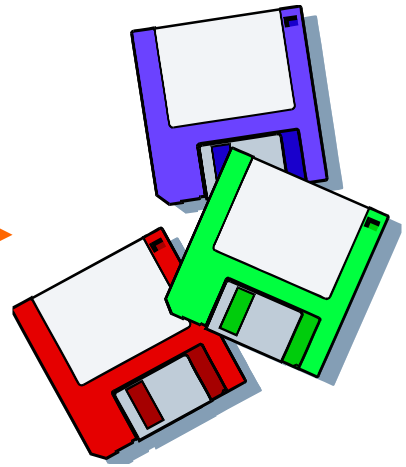
Modelling Process

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



Weather data





Building description

Simulation tool (computer program)

Simulation outputs

- physical data
- design parameters

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

Building energy simulation: Inputs and Outputs

INPUTS:	**OUTPUTS:**

- Weather data
- Building geometry
- Construction type
- HVAC type / usage
- Occupancy info
    - Quantity of users
    - Lights
    - Equipment
    - Usage
	- Space temperatures
	- Surface temperatures
	- Humidity levels
	- HVAC parameters
	- Energy consumption
	    - Component
	    - System
	    - Whole-building

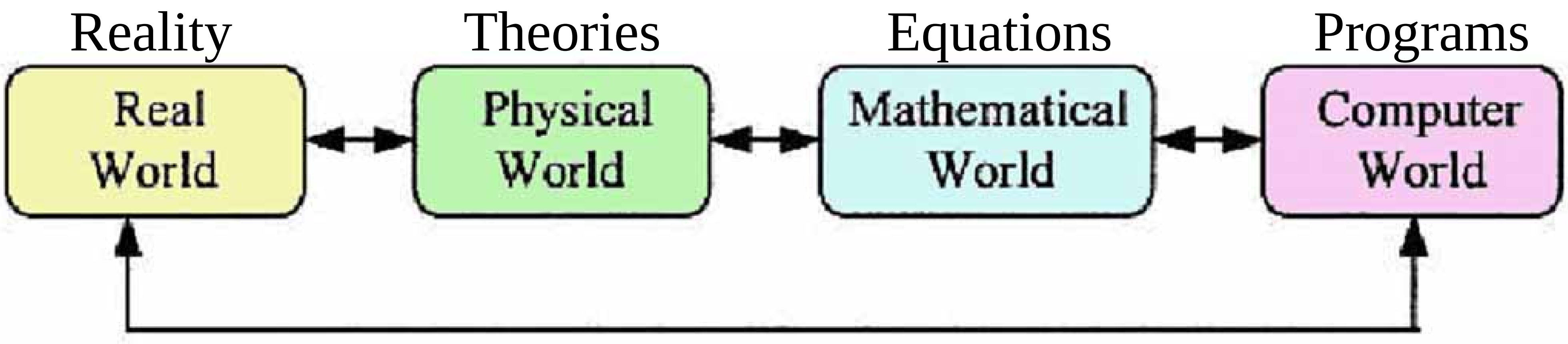
Garbage In, Garbage Out (GIGO)

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* and reduce the potential for error

Modelling Process

- Important to know how the program "thinks" about systems and designs and interactions
- How to approximate real-world problem to fit the limitations of the model

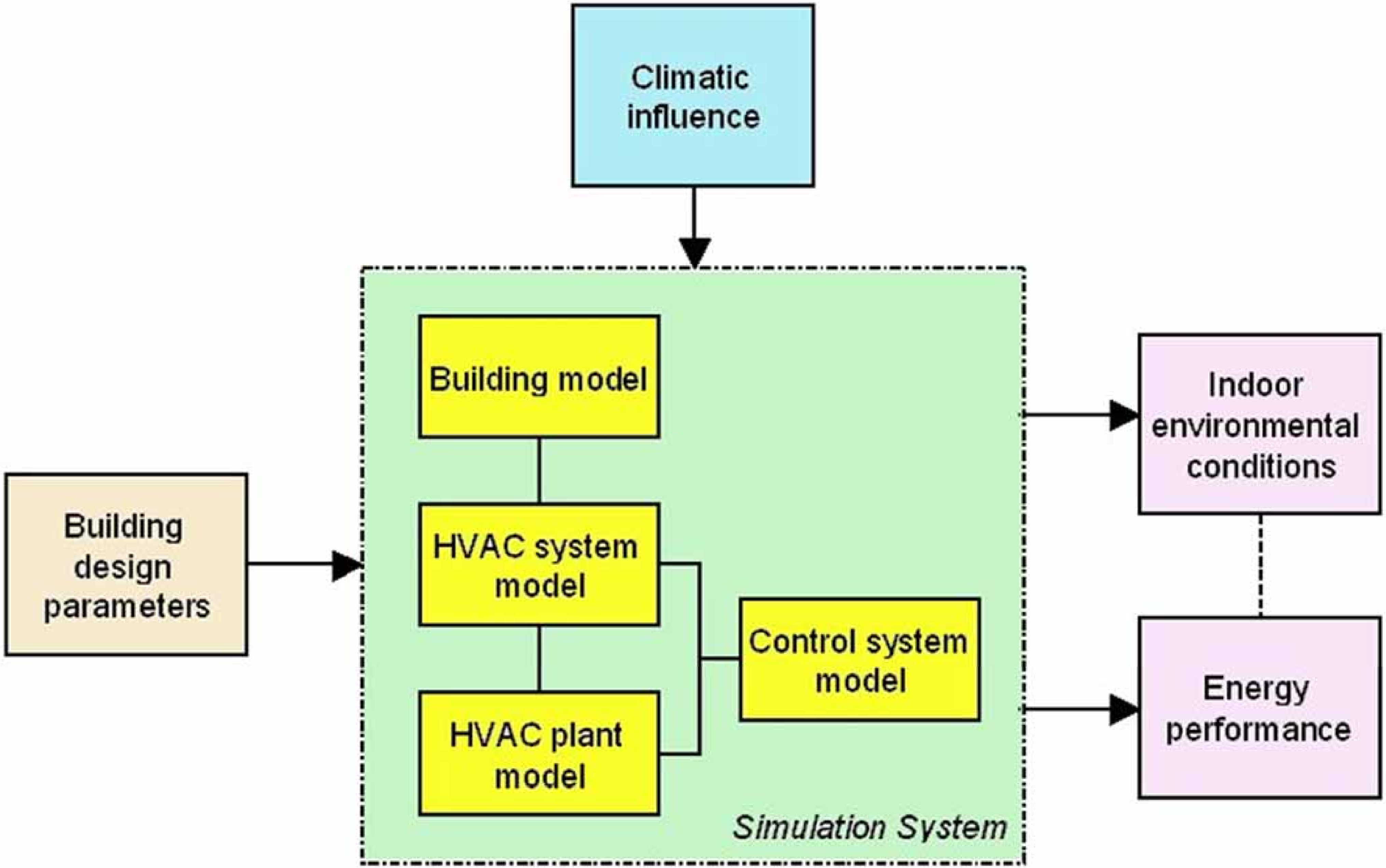


Modelling Process

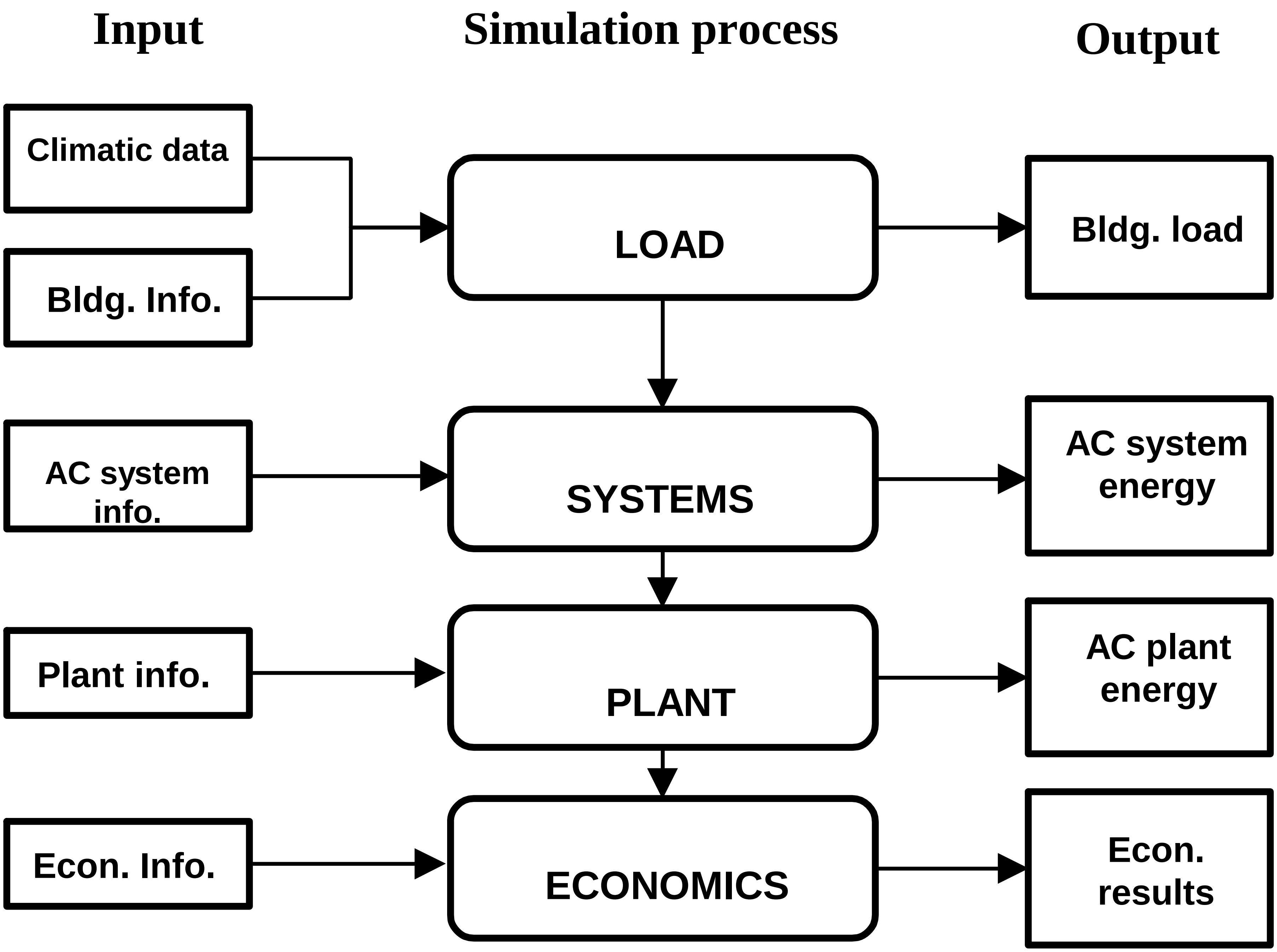
- Building energy simulation is based upon
  - *Load calculation* – thermal or HVAC
    - Determine peak HVAC design loads
  - *Energy calculation* – energy to meet the loads
    - Estimate annual energy requirements
- Time intervals
  - Full hour-by-hour (**8,760 hours** = 365 x 24)
  - Simplified hourly: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

Modelling Process

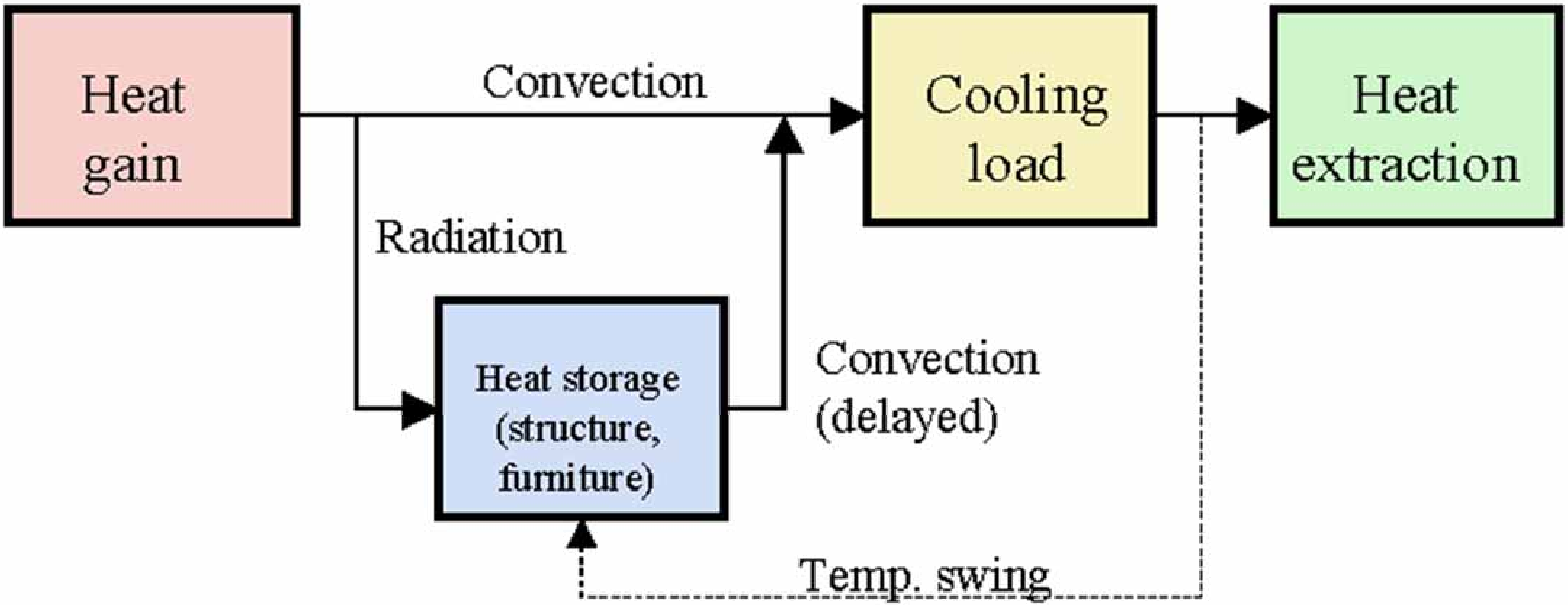
- Four major elements
  - Building model
  - HVAC system model
  - HVAC plant model
  - Control system model
- An economic model (optional) may be added for economic analysis and life cycle costing



Major elements of building energy simulation

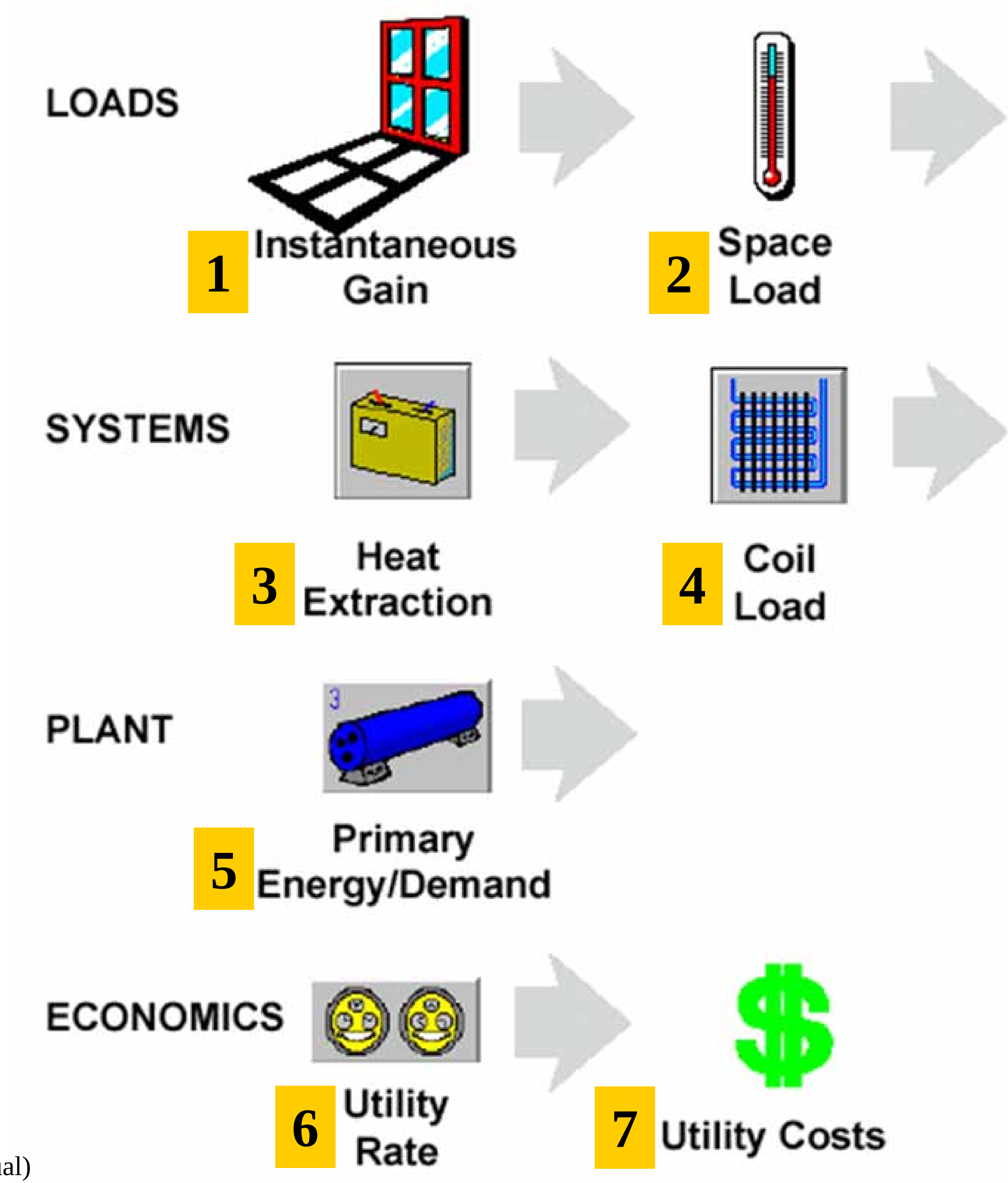


Information flow in building simulation



Concept of heat transmission and conversion in buildings

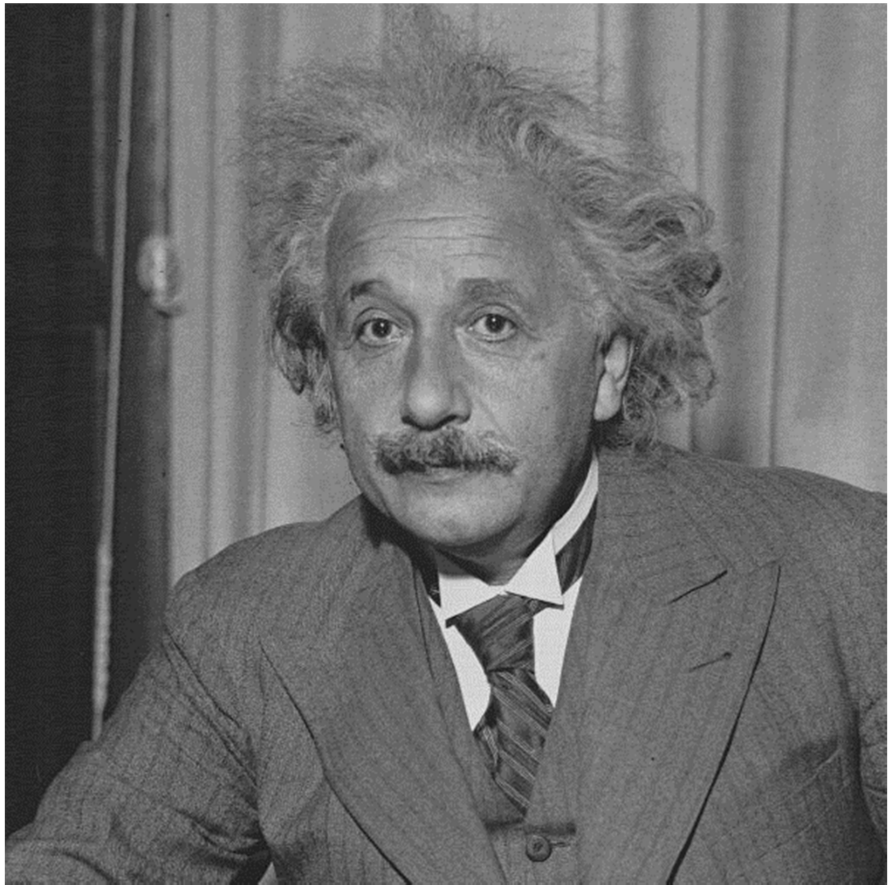
"Seven steps" of simulation output



(Source: eQUEST Tutorial Manual)

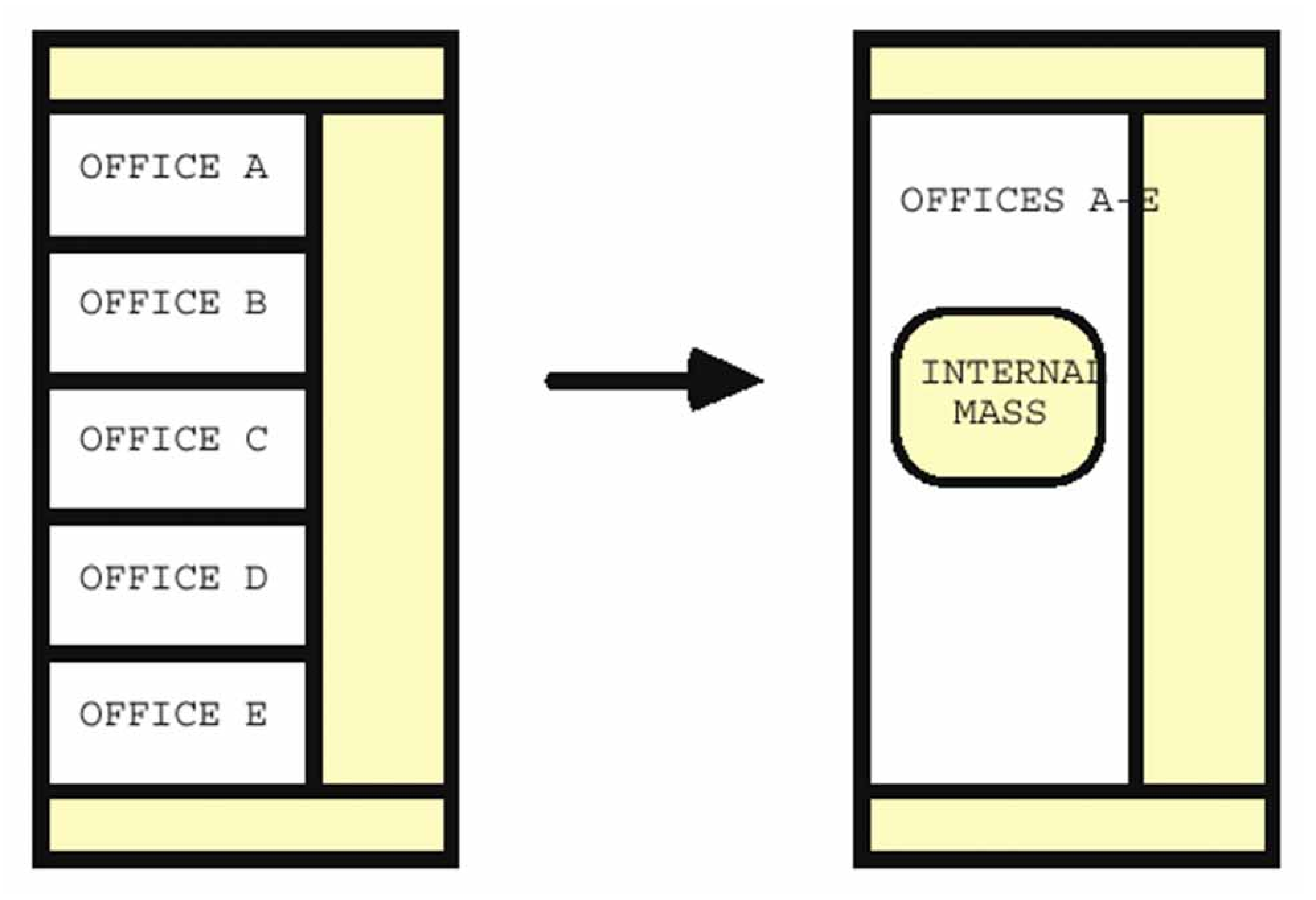
Simulation Skills

- Model zoning (*thermal*, not geometric)
  - Consider thermal loads (e.g. interior-perimeter), occupancy, lighting type and schedule
    - For existing buildings, refer to actual zoning
  - Need to *simplify* the model
    - Combine zones with similar load and 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 and 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 and controls
  - Is dynamic response of the system critical?

Simulation Skills

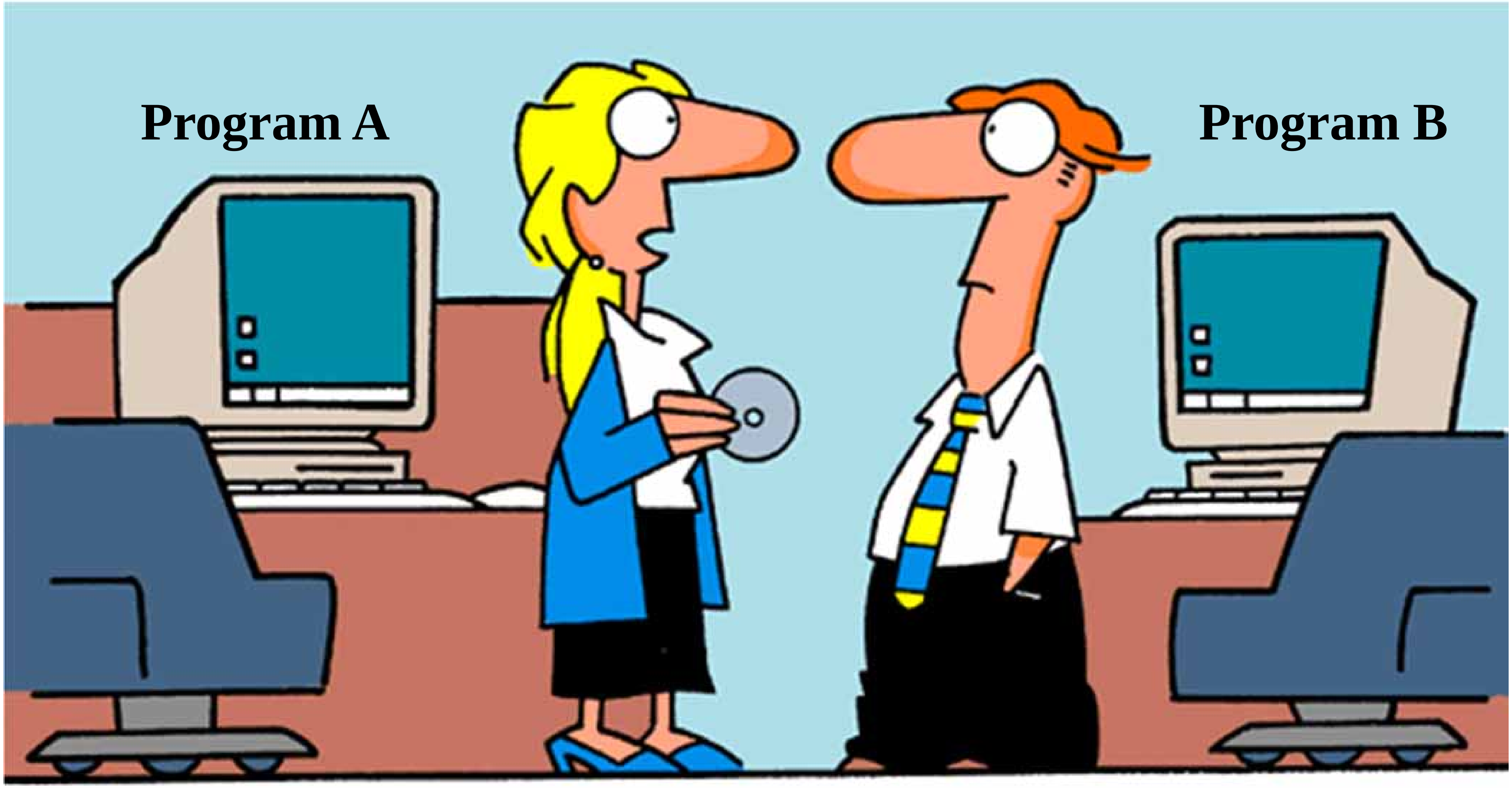
- Focus on inputs of significant impact
  - Small buildings – heat loss to ground and roof, through unconditioned spaces
  - Large buildings – zoning, controls, HVAC system types, internal loads
  - Retrofit projects – actual operating conditions, occupant behaviours, controls
- Judged by experience,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

Simulation Skills

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

Simulation Skills

- Typical simulation results and output
  - Thermal loads (of building, zones, components): by hour, day, month or year
  - Temperatures (air, surfaces)
  - Fuel and 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
  - Such as 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

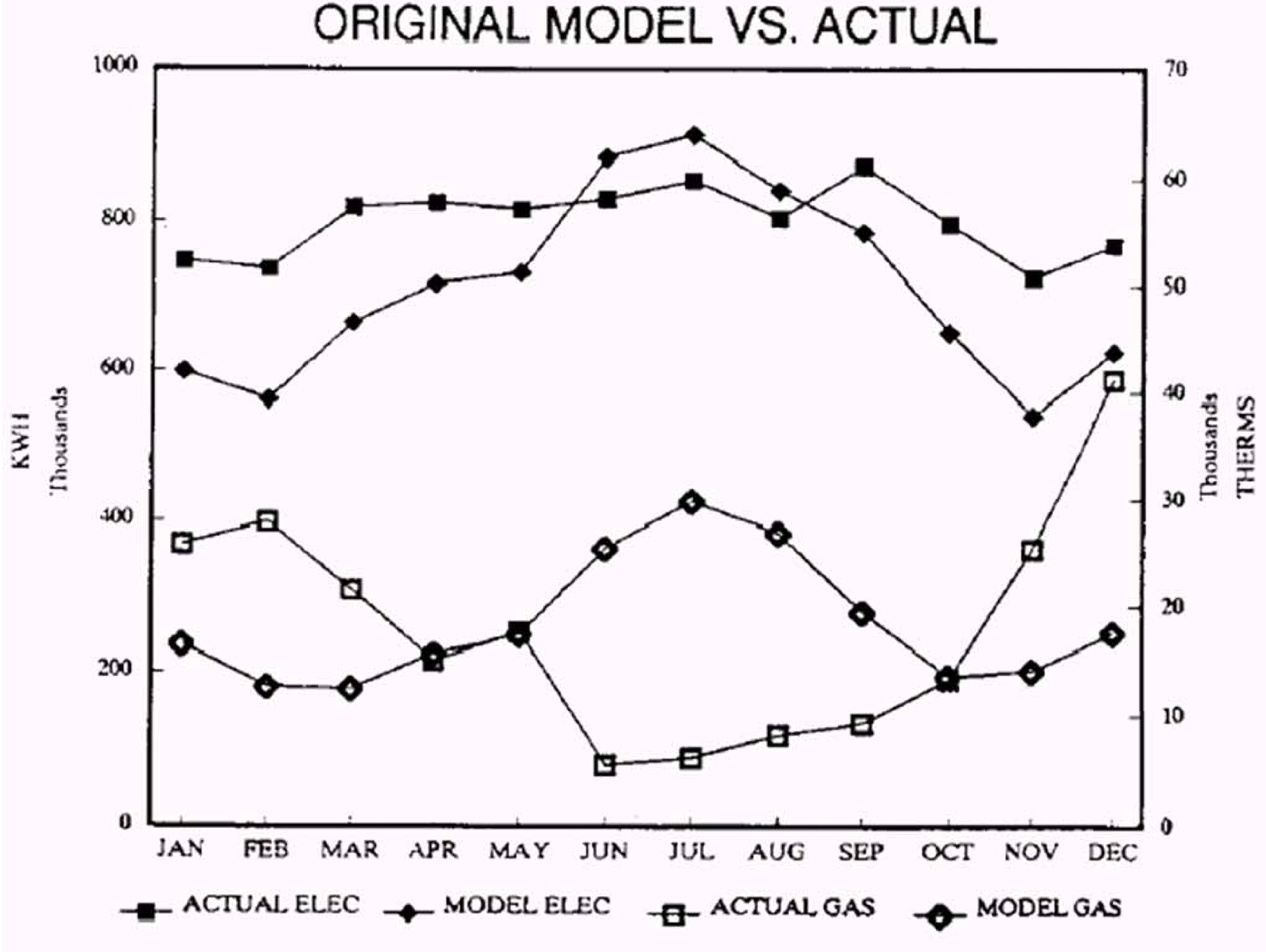
- Expected precision (general guideline only)
  - Energy
    - Average monthly error > annual error
    - ± 8-10% monthly energy
    - ± 3-5% annual energy
  - Annual
    - Average monthly error > Average annual error
    - ± 10-12% monthly peak demand
    - ± 5-6% annual average peak demand
  - Monitored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

Simulation Skills

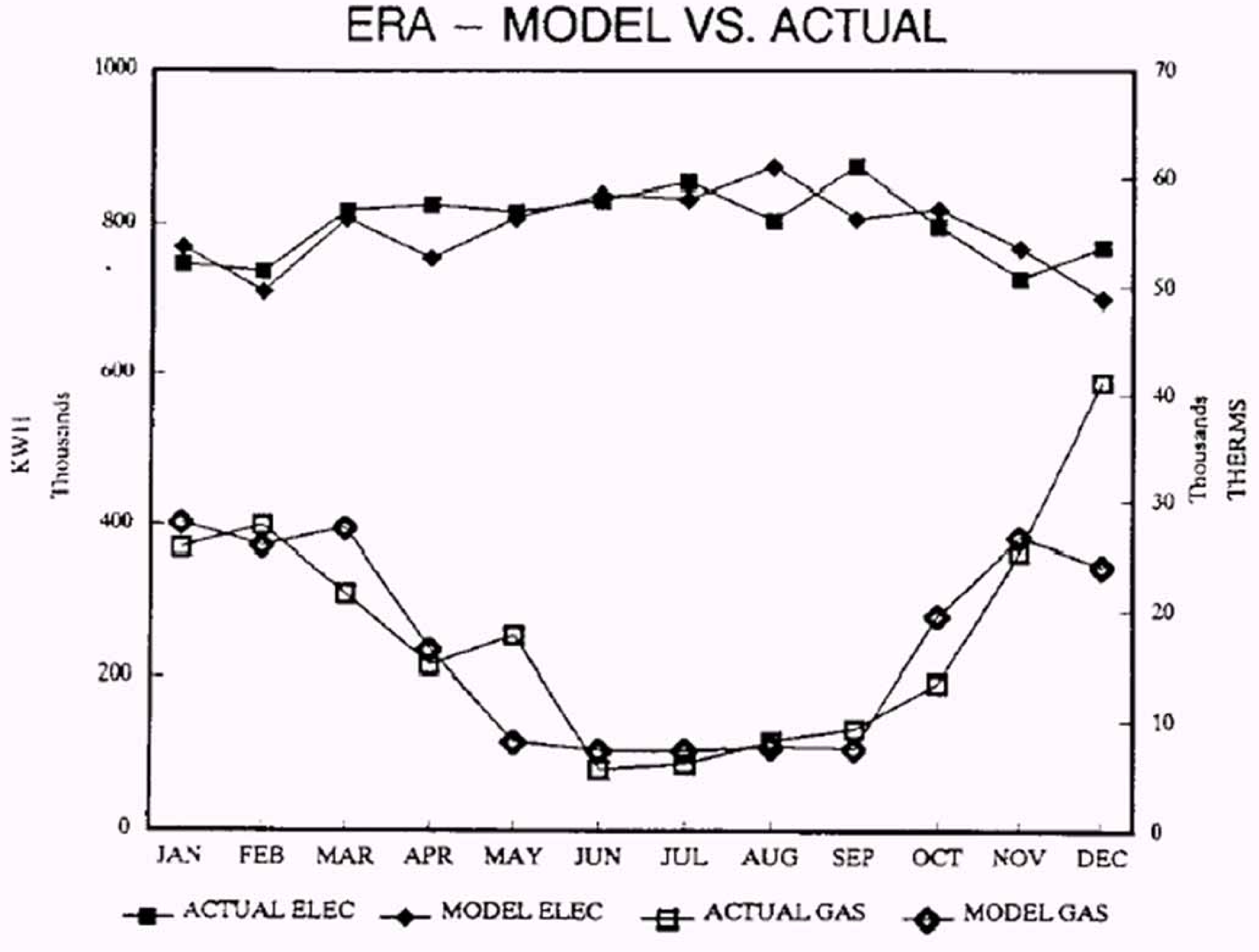
- Consider the building to be simulated
  - What building features are likely to be significant drivers of energy performance
  - Which energy conservation measure(s) are likely to be of particular interest
- Quality control to avoid/reduce errors
  - Check and review by competent persons
  - Well-organised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



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



(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 and scepticism
  - Good modellers require a lot of system design knowledge and understanding of real operations

- How well it works depends on YOU?

Further Reading

- Understanding the Energy Modeling Process: Simulation Literacy 101, http://www.buildinggreen.com/features/mr/sim_lit_101.cfm
- Energy Analysis Tools (Whole Building Design Guide), www.wbdg.org/resources/energyanalysis.php
- Hui, S. C. M., 1998. Simulation based design tools for energy efficient buildings in Hong Kong, http://web.hku.hk/~cmhui/hkpdd/hkpdd-v1.htm