



# Dynamic Building Performance Simulation



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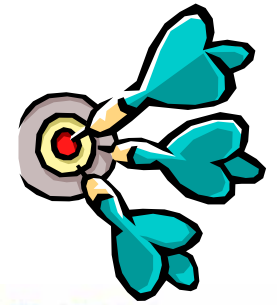
# Contents



- Building Energy Simulation
- Simulation Tools
- Applying Simulation
- Modelling Process
- Simulation Skills

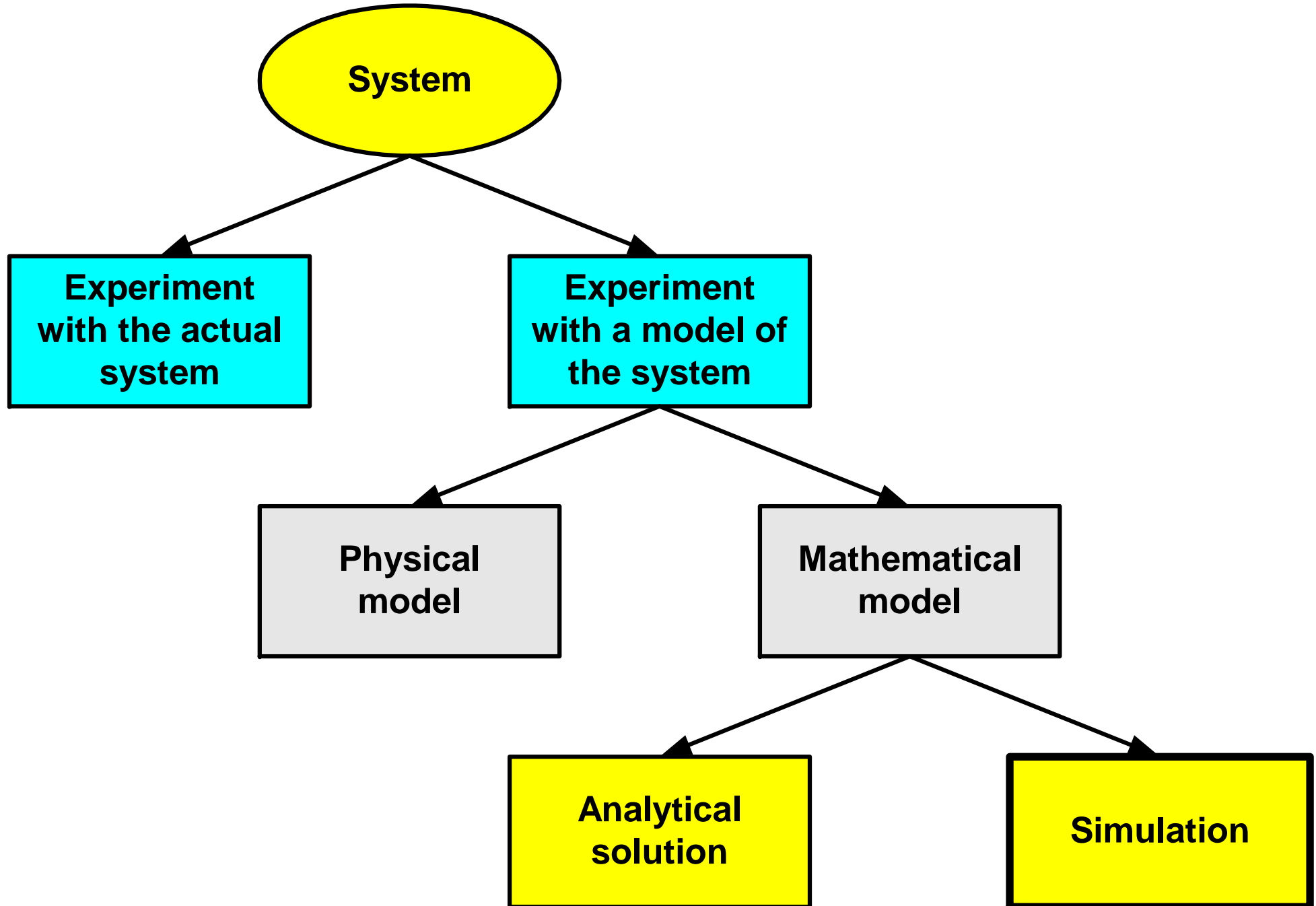


# Building Energy Simulation

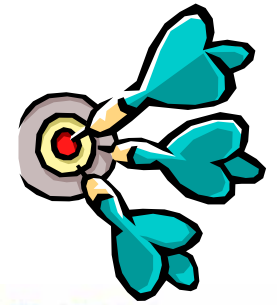


- Energy performance of buildings is usually complicated and requires detailed analysis to determine the characteristics
- Building energy simulation and modelling techniques are often used to study it so as to support decisions for building design, operation and management

# Ways to study a system

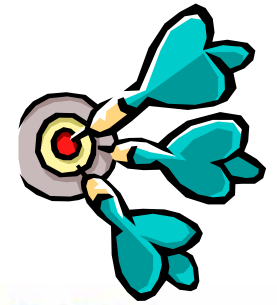


# Building Energy Simulation



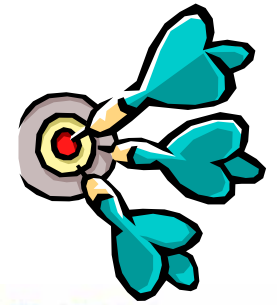
- Building performance simulation (BPS)
  - A computer model of the energy processes within a building that are integrated to provide a thermally comfortable environment for the occupants (or contents)
- Dynamic thermal simulation
  - Can predict changing internal conditions over a time period of up 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

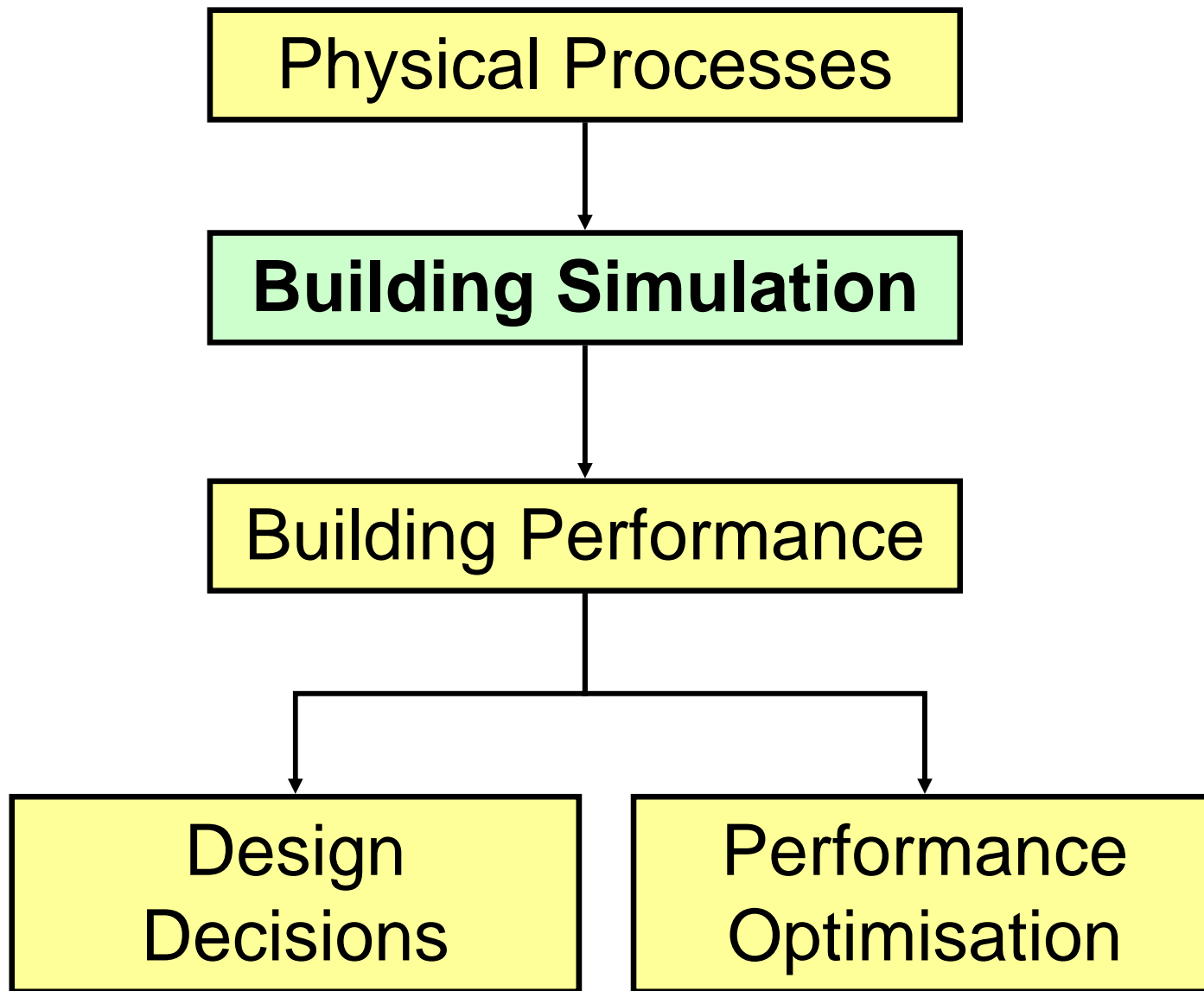


- Simulation

- The process of developing a representative model of a system and using it to analyze and predict system behaviour and performance

- Modelling

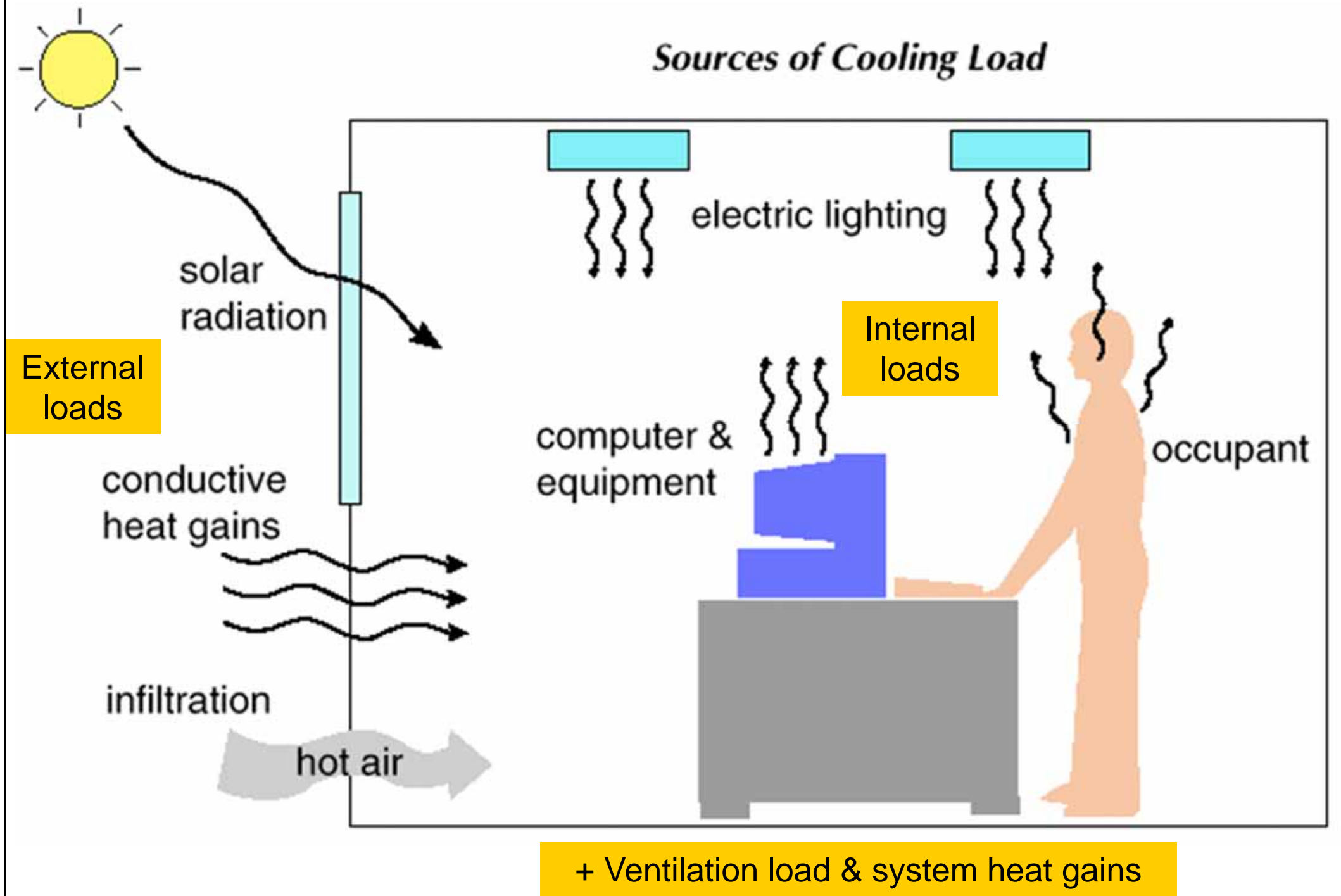
- Deals primarily with the relationship between actual dynamic processes and models
- Usually involves iterations



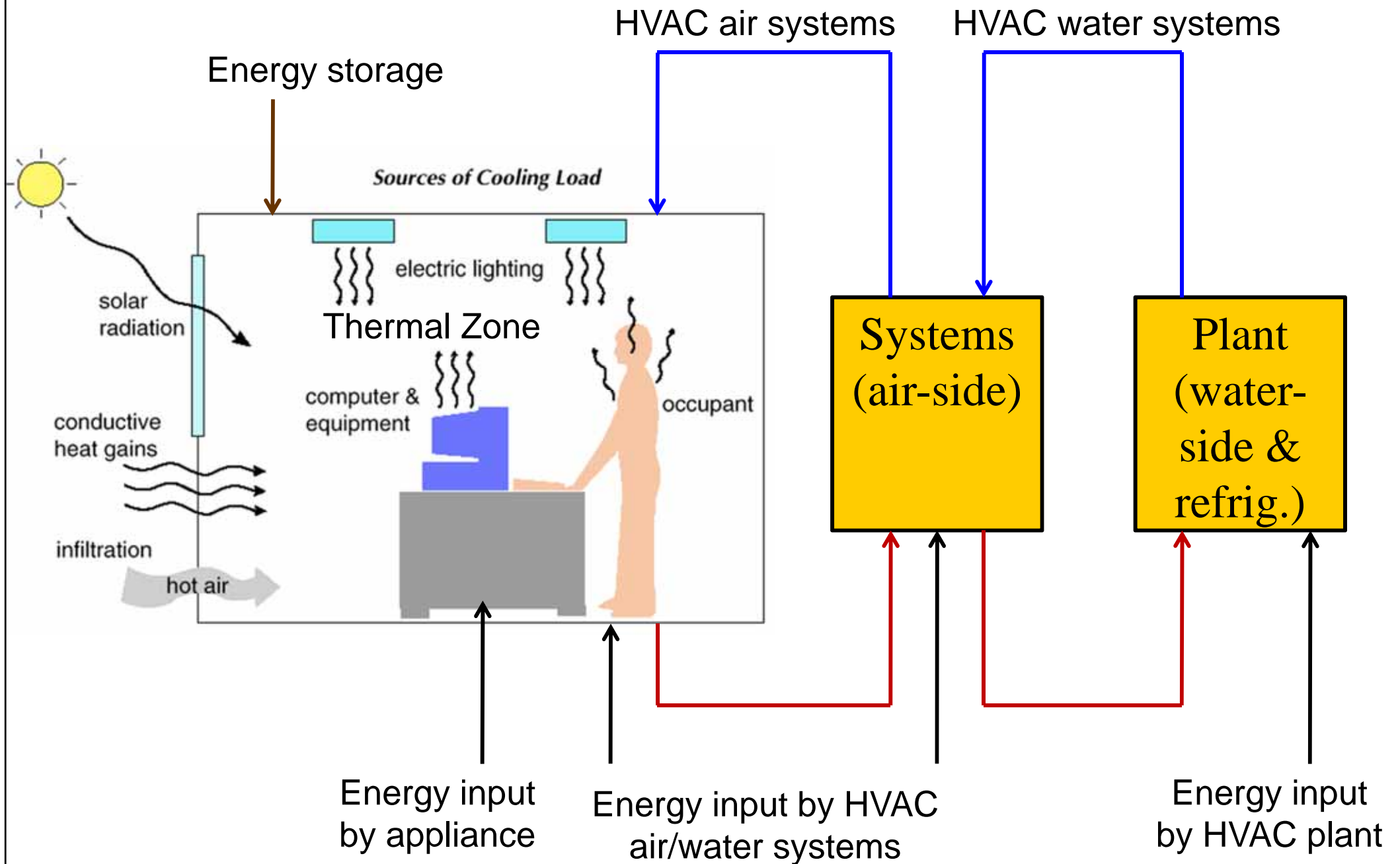
\* Simulation enables the performance of the building to be established before critical design decisions are taken, enabling optimum building performance to be obtained



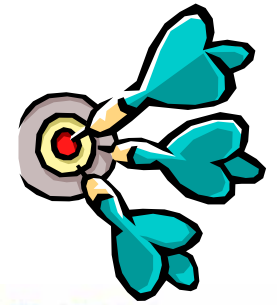
# Components of building cooling load



# Building energy simulation process

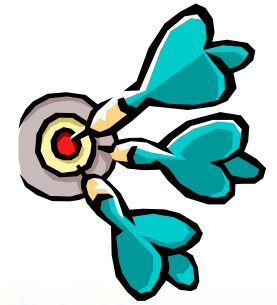


# Building Energy Simulation



- 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

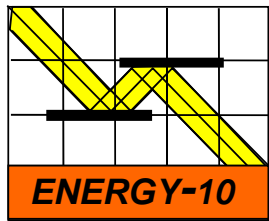


- Model existing buildings
  - Useful for “energy performance contracts”
  - Help improve the bldg’s operation/control
- Evaluate energy conservation measures (ECM)
  - Estimate energy savings
  - Study the costs and benefits
  - Provide info to design, retrofit & operation
- Comply with building energy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



**blast**



**DOE-2**

**Solar-5**

**ESP-r**



**Building Energy  
Simulation Software**



**E-20-II & HAP**



**EE4**

# Simulation Tools



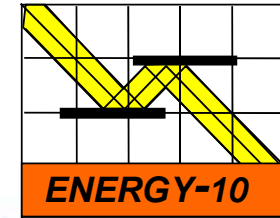
- Many software tools in the market
  - From simplified to complicated one
  - Select according to the task
- For beginners, we recommend
  - Energy-10, HAP, TRACE 700, eQUEST
- For sophisticated study, may consider
  - DOE-2, EnergyPlus, ESP-r, TRNSYS
- Further information:
  - Building Energy Software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

# Simulation Tools



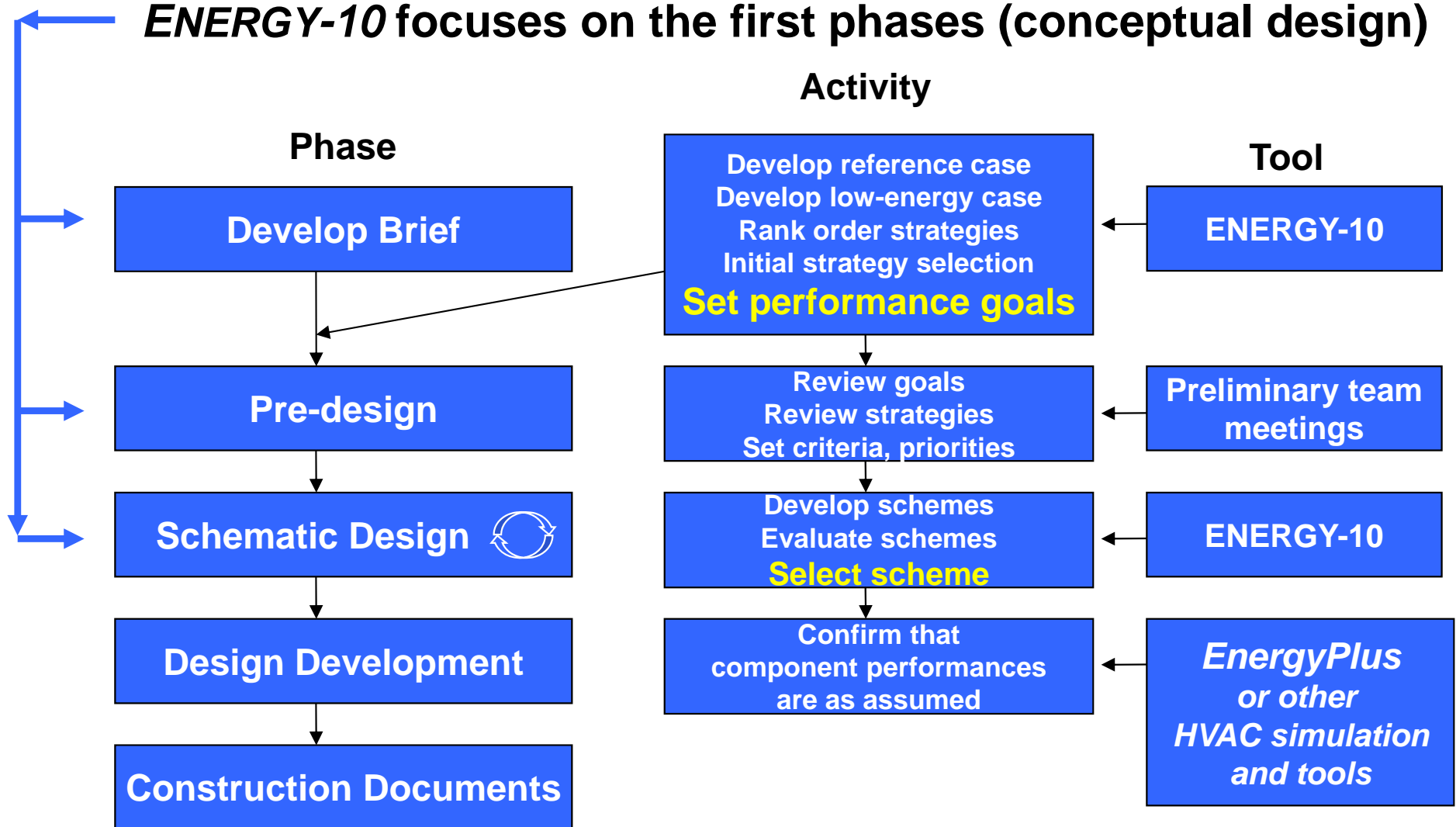
- Examples of building energy simulation tools
  - **Energy-10**
    - <http://www.sbicouncil.org/energy-10-software>
  - **VisualDOE** (based on DOE-2.1e)
    - <http://www.archenergy.com/products/visualdoe/>
    - <http://gundog.lbl.gov/dirsoft/d2whatis.html>
  - **MIT Design Advisor** (do online simulation)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

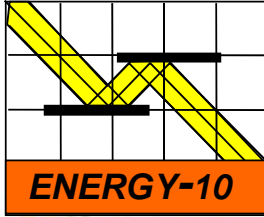




# Example: Energy-10

**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

For example:



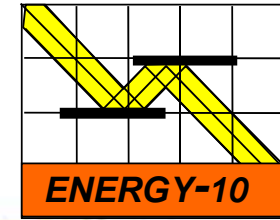
Reference Case

Low Energy Case

**Gets you started quickly.**

R-8.9 walls (4" steel stud)  
 R-19 roof  
 No perimeter insulation  
 Conventional double windows  
 Conventional lighting  
 Conventional HVAC  
 Conventional air-tightness  
 Uniform window orientation  
 Conventional HVAC controls  
 Conventional duct placement

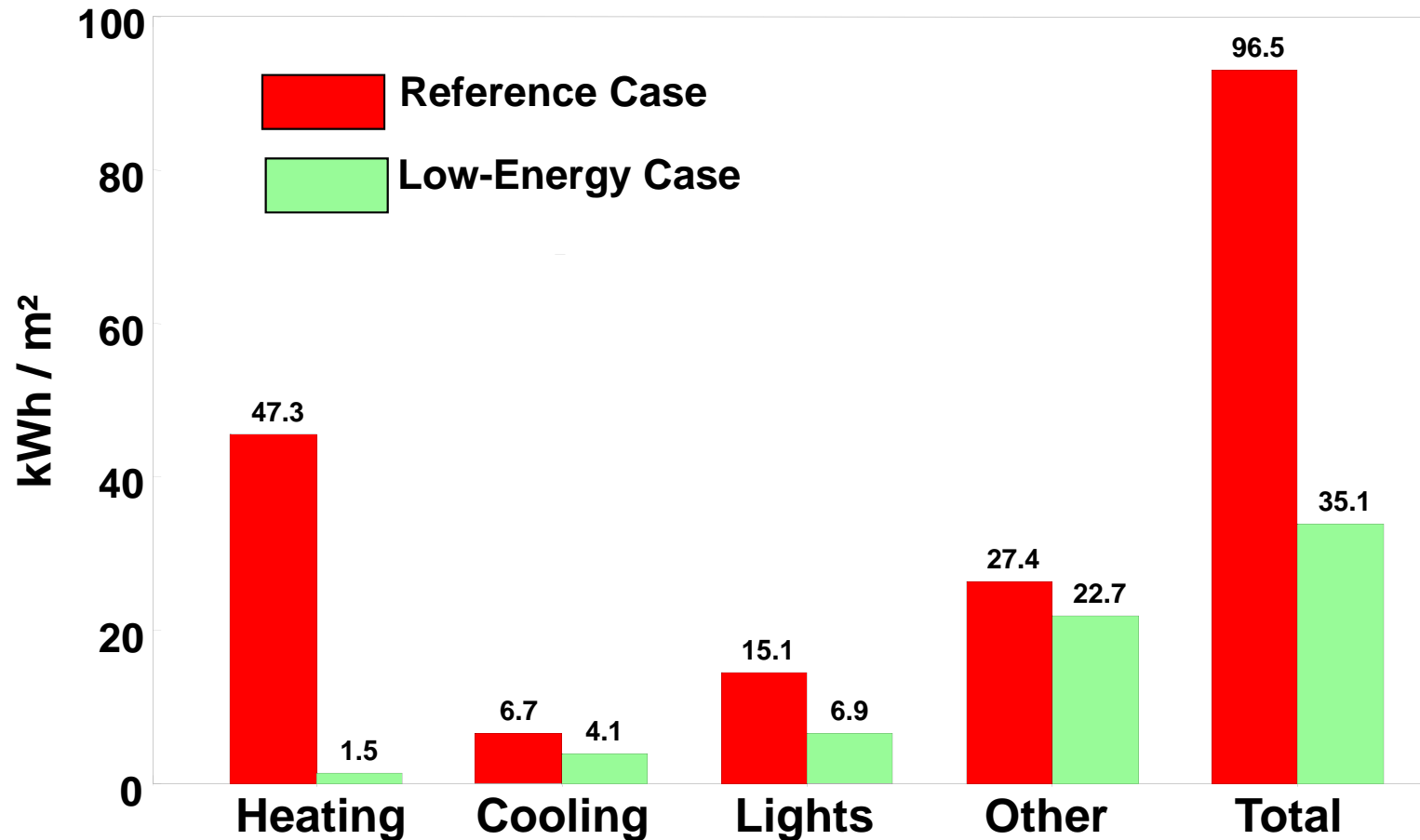
R-19.6 Walls (6" steel stud with 2" foam)  
 R-38 roof  
 R-10 perimeter insulation  
 Best low-e double windows  
 Efficient lights with daylight dimming  
 High efficiency HVAC  
 Leakage reduced 75%  
 Passive solar orientation  
 Improved HVAC controls  
 Ducts located inside, tightened

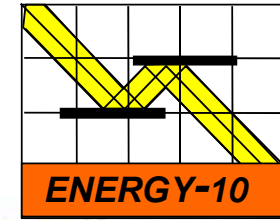


# Example: Energy-10

2,000 m<sup>2</sup> office building

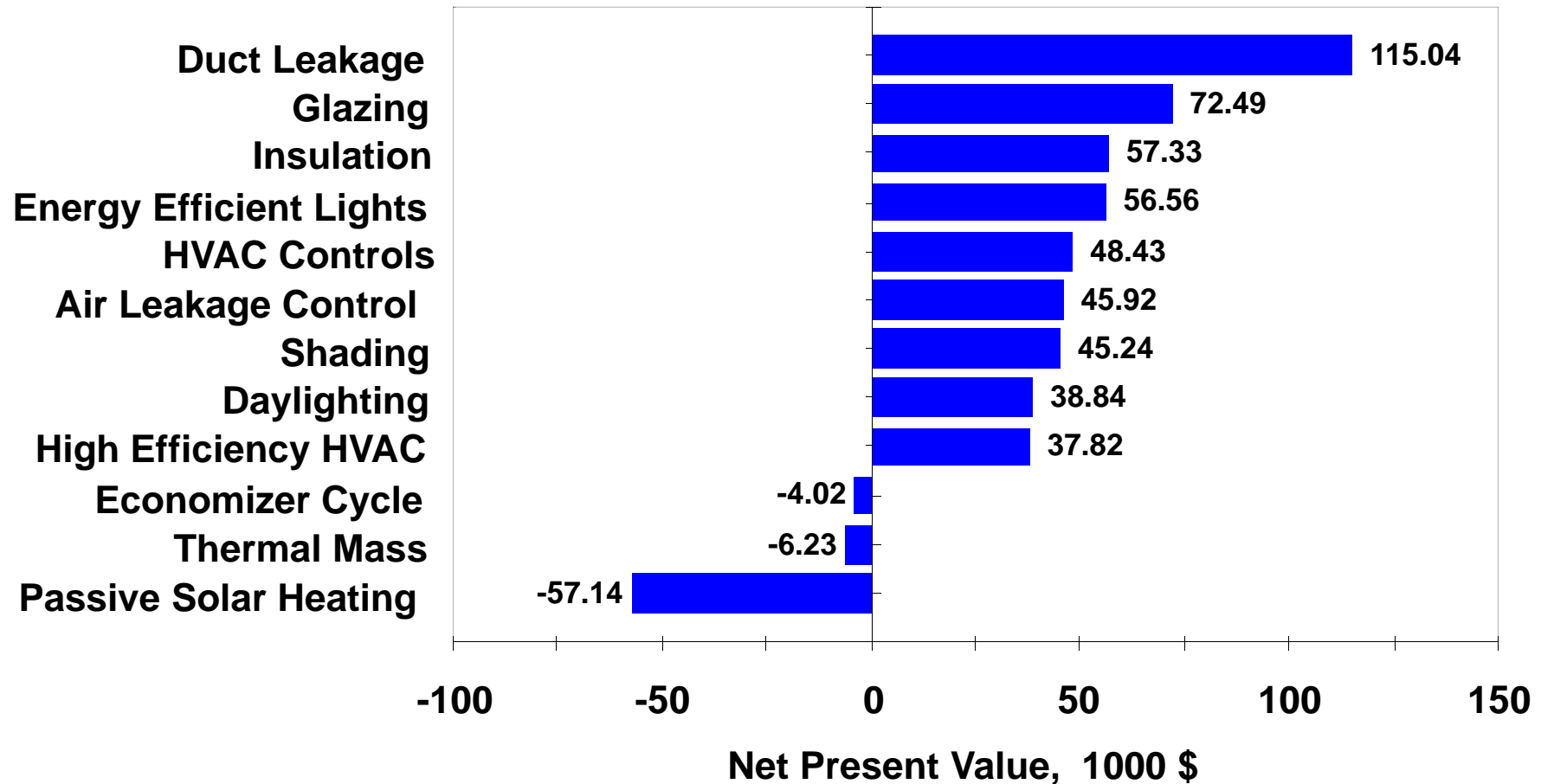
## ANNUAL ENERGY USE



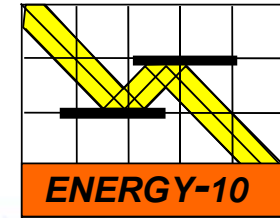


# Example: Energy-10

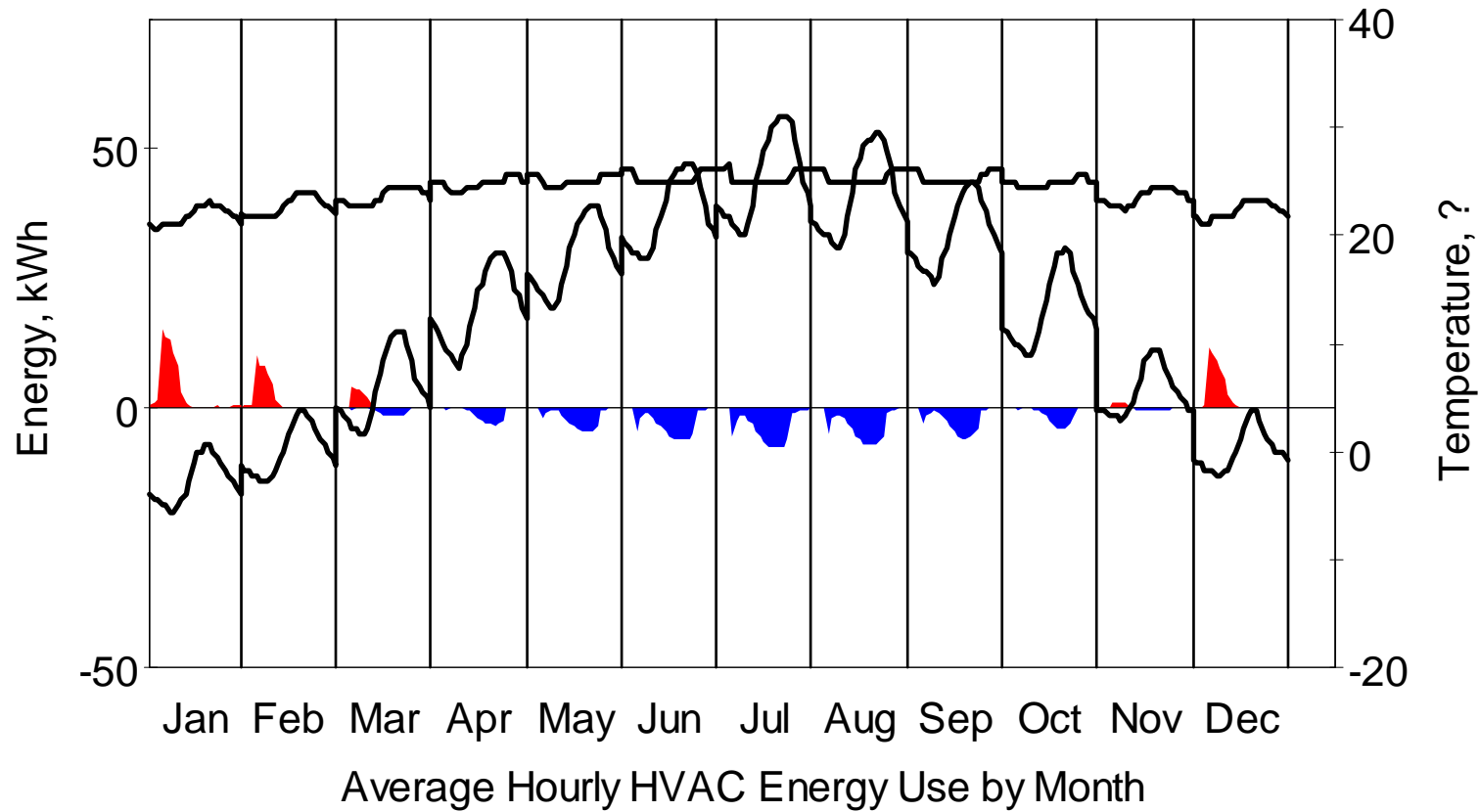
## RANKING OF ENERGY-EFFICIENT STRATEGIES



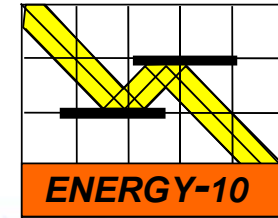
# Example: Energy-10



Sample - Lower-Energy Case

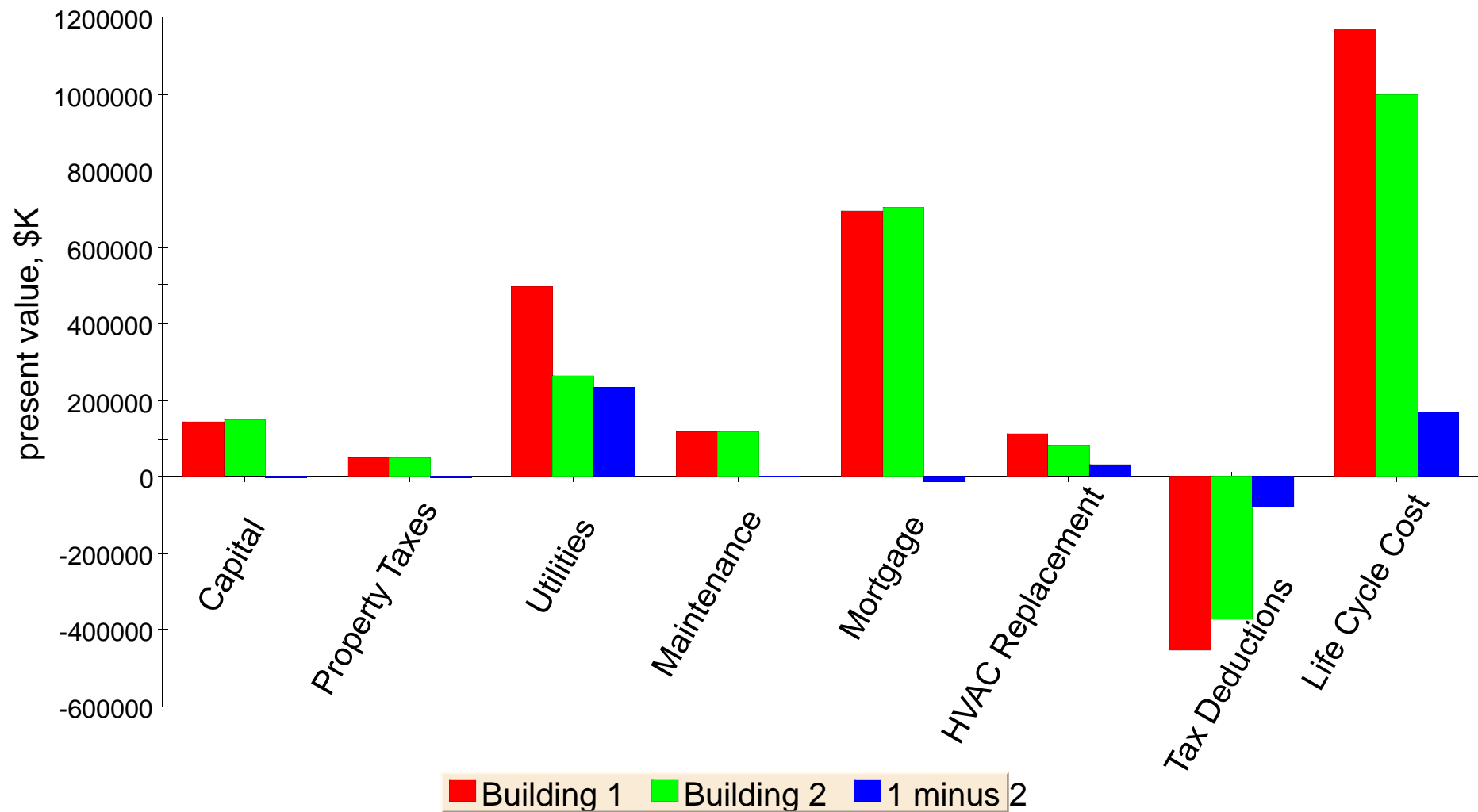


Heating Cooling Inside T Outside T



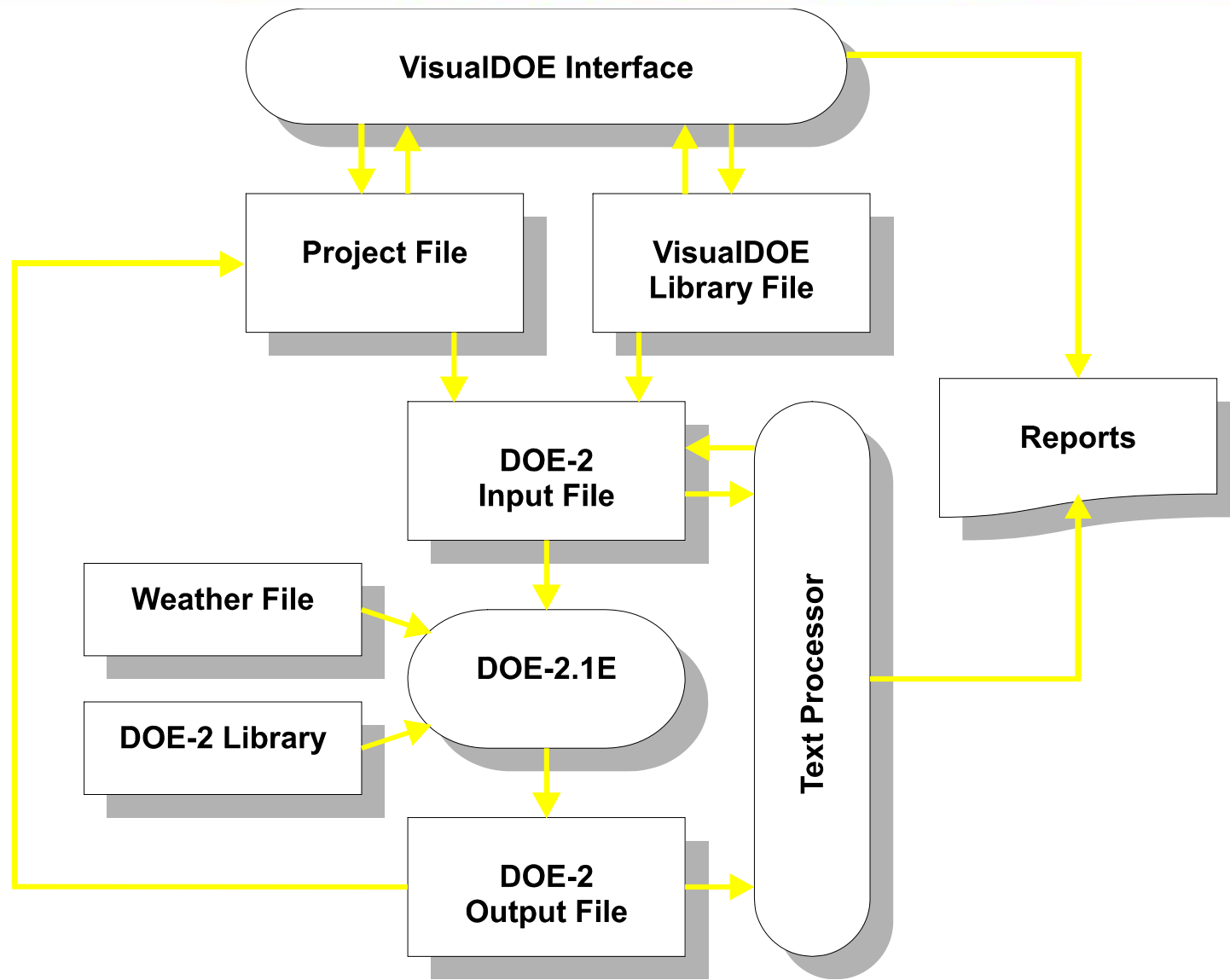
# Example: Energy-10

## Components of Life-Cycle Cost



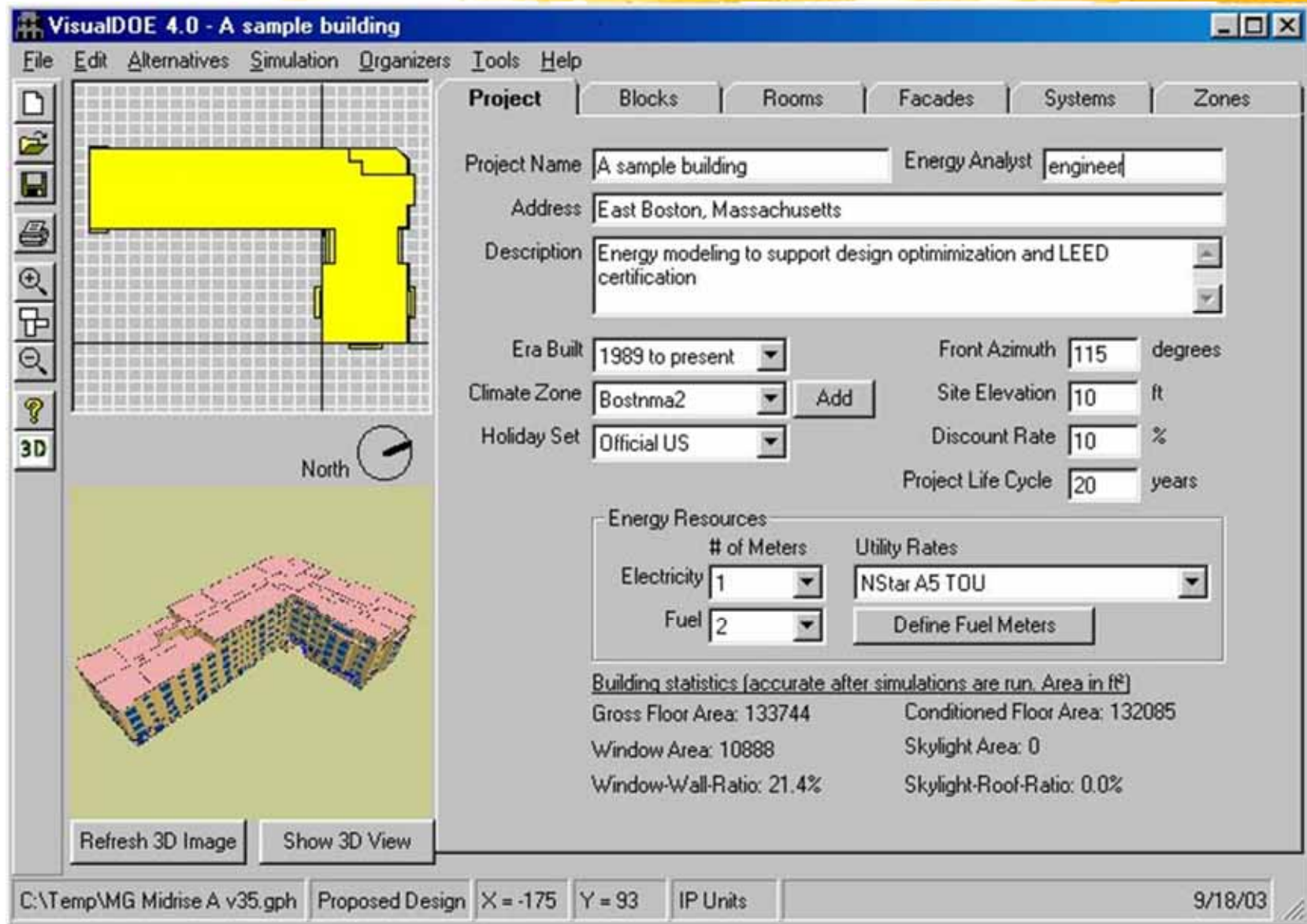
# Example: VisualDOE

DOE-2



# Example: VisualDOE

DOE-2





# Example: VisualDOE

DOE-2

**HVAC Systems Editor**

Click on system equipment for specifications. Copy Sketch

**System Features**

- Preheat Coil
- Humidifier
- Return Fan
- Heat Recovery
- Evap. Precool
- Economizer
- Min. Outside Air
- Natural Ventilation

Min. OA Ratio:

System: MAU 1

Type: Single Zone Variable Temperature

Occupancy/Schedules: Corridor \_ MG Med

System Era: 1989 to present

Return Air Path: Duct

Control Zone: 2\_5\_new\_corr

Description:

Set As Default System Apply System Defaults Cancel OK

# Example: VisualDOE

DOE-2

The screenshot displays the 'Central Plant Editor' software window. The interface includes a title bar with standard window controls, a toolbar with 'Cancel', 'OK', and 'Copy Sketch' buttons, and a tabbed menu with 'General', 'Cooling Management', 'Heating Management', and 'Electrical Management'. The 'General' tab is active, showing configuration options for various plant components. On the left, the 'Chilled Water Plant' section is set to a temperature of 44°F, with 'None' selected for electric chiller types and '1' for absorption chiller types. The 'Boilers' section has '1' selected for fuel boiler types and 'None' for electric boiler types. Under 'Electric Generators', 'Diesel' is checked. The main workspace contains a schematic diagram with a red loop for chilled water, a blue loop for heating, and a green loop for power. Key components include a cooling tower, 'Absorp. #1', 'Fuel #1', and a generator. A note at the bottom reads 'Click on plant equipment for specifications.'

Central Plant Editor

Cancel OK Copy Sketch

General Cooling Management Heating Management Electrical Management

Chilled Water Plant  
Chilled Water Temp.: 44 °F

Electric Chiller Types  
 None  1  2  3  4

# of Absorption Chiller Types  
 None  1  2  3

Thermal Energy Storage  
 Engine Driven Chiller

Boilers  
Fuel Boiler Types  
 None  1  2

Electric Boiler Types  
 None  1  2

Electric Generators  
 Diesel  Gas Turbine

Click on plant equipment for specifications.

# Example: VisualDOE

DOE-2

The screenshot shows a 'Print Preview' window for VisualDOE 4.0. The window title is 'Print Preview' and it includes standard window controls (minimize, maximize, close) in the top right. Below the title bar, there are buttons for 'Export RTF', 'Export PDF', and 'Close'. A navigation bar shows '3/4' pages, a search icon, and a print icon. The main content area displays the following information:

**VisualDOE 4.0 - Results** **September 18, 2003**

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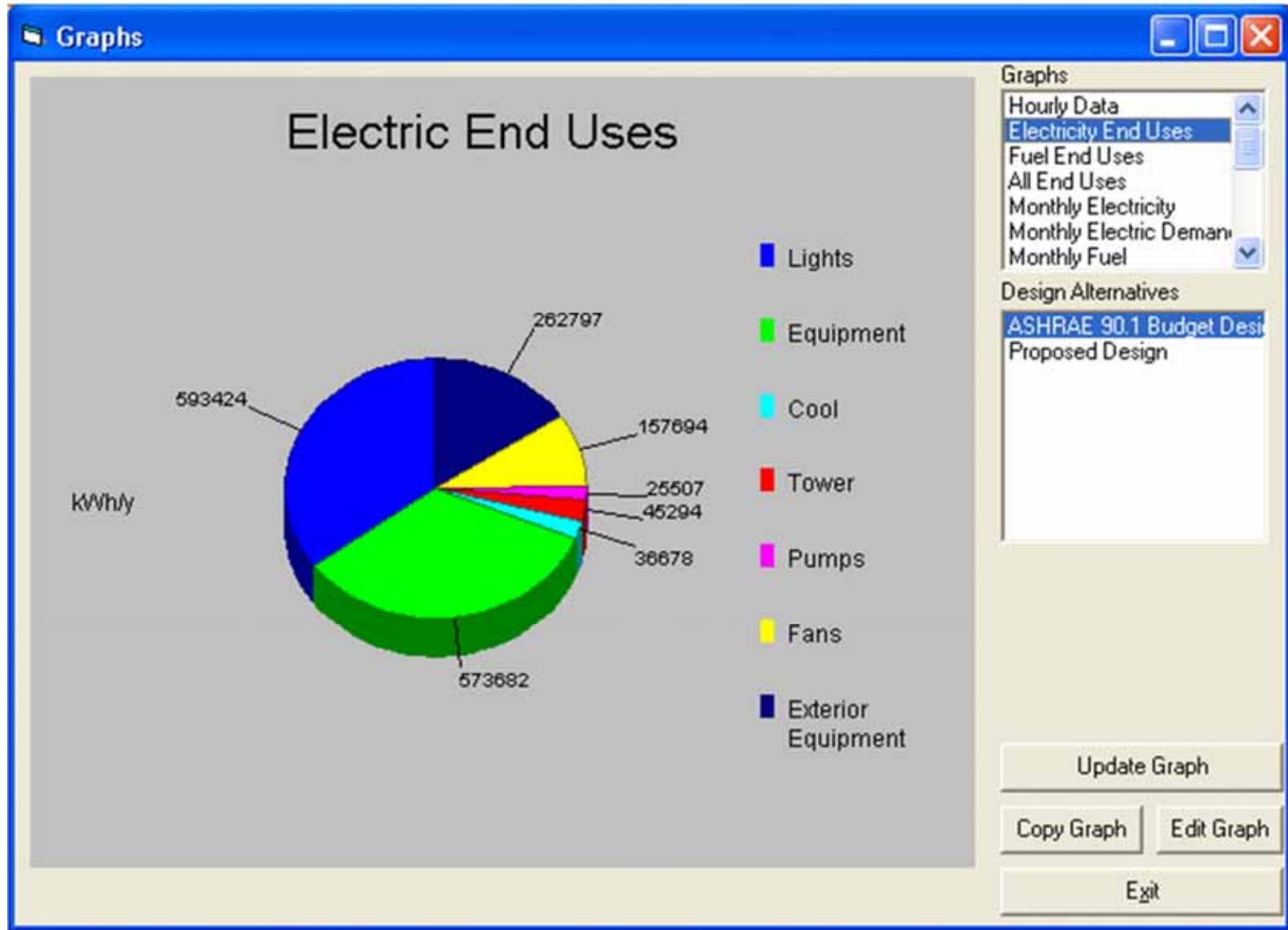
**Energy Cost Summary (\$/y)**

Alternative	Total Electric	Total Fuel	Total Utility	Incremental First Cost	PV Life Cycle Cost*
<b>Total Energy Costs (\$/y)</b>					
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
<b>Incremental Energy Savings (\$/y)</b> (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.

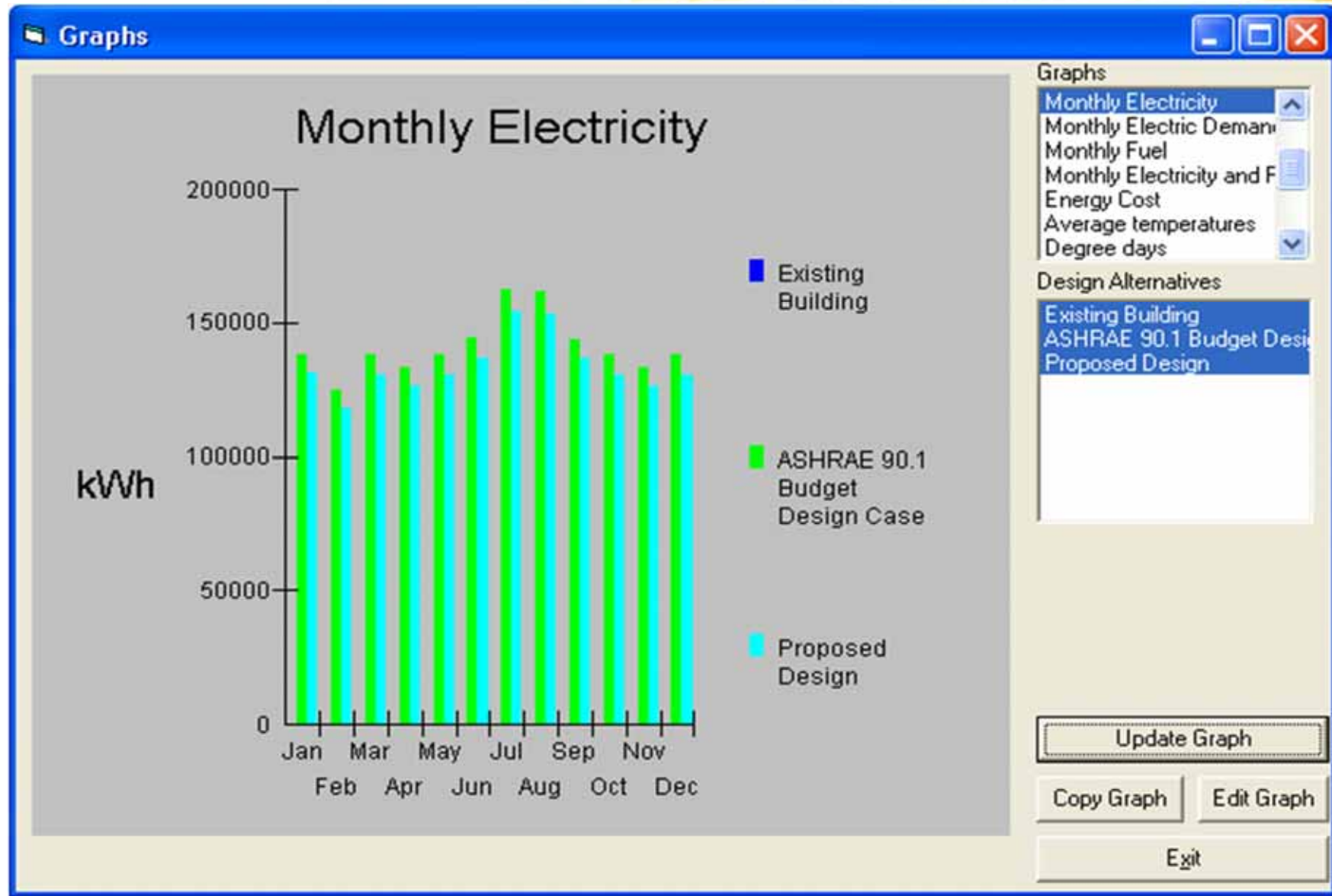
# Example: VisualDOE

DOE-2



# Example: VisualDOE

DOE-2



## 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 feature, 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 minute, 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

MIT Department of Architecture

save ▾

Scenario  
One

save ▾

Scenario  
Two

save ▾

Scenario  
Three

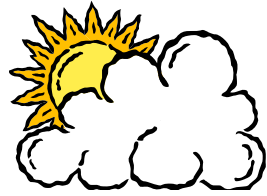
save ▾

Scenario  
Four

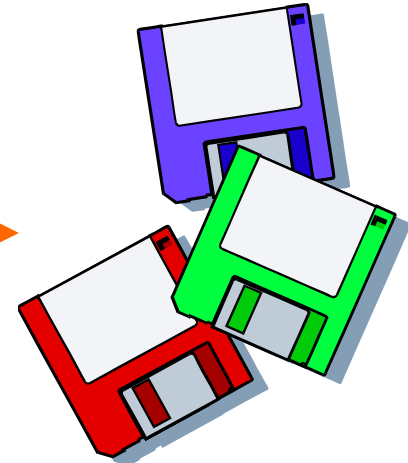
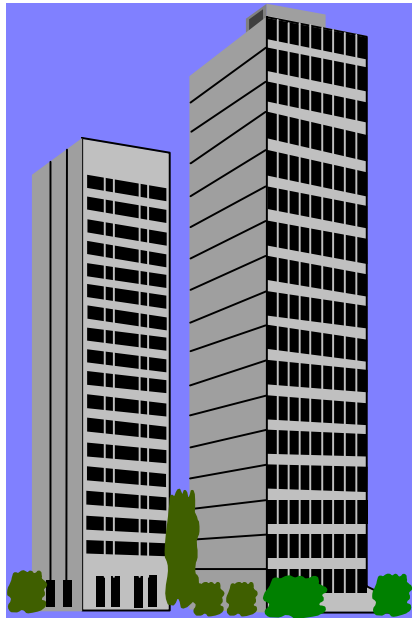
# Modelling Process



- 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

- physical data
- design parameters

## Simulation tool (computer program)

## Simulation outputs

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



# Building energy simulation: Inputs and Outputs

## **INPUTS:**

- Weather data
- Building geometry
- Construction type
- HVAC type / usage
- Occupancy info
  - Quantity of users
  - Lights
  - Equipment
  - Usage

## **OUTPUTS:**

- Space temperatures
- Surface temperatures
- Humidity levels
- HVAC parameters
- Energy consumption
  - Component
  - System
  - Whole-building

# Garbage In, Garbage Out (GIGO)



# Modelling Process

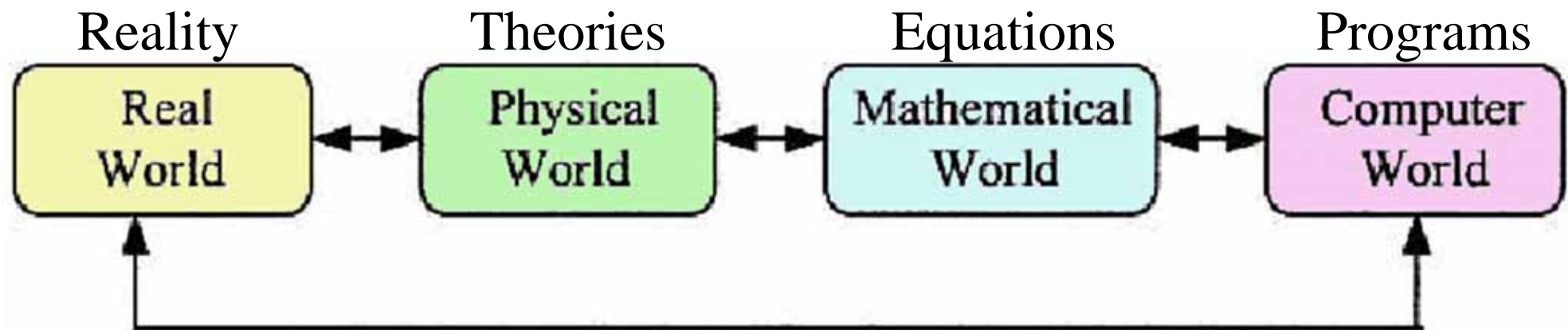


- Important considerations
  - *Start early*: incorporate building simulation into the early design stages
  - *Keep it simple*: add no more detail to a simulation model than is necessary (simple but accurate)
  - *Refine as you go*, so that the simulation model evolves with the design
  - *Avoid mistakes*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

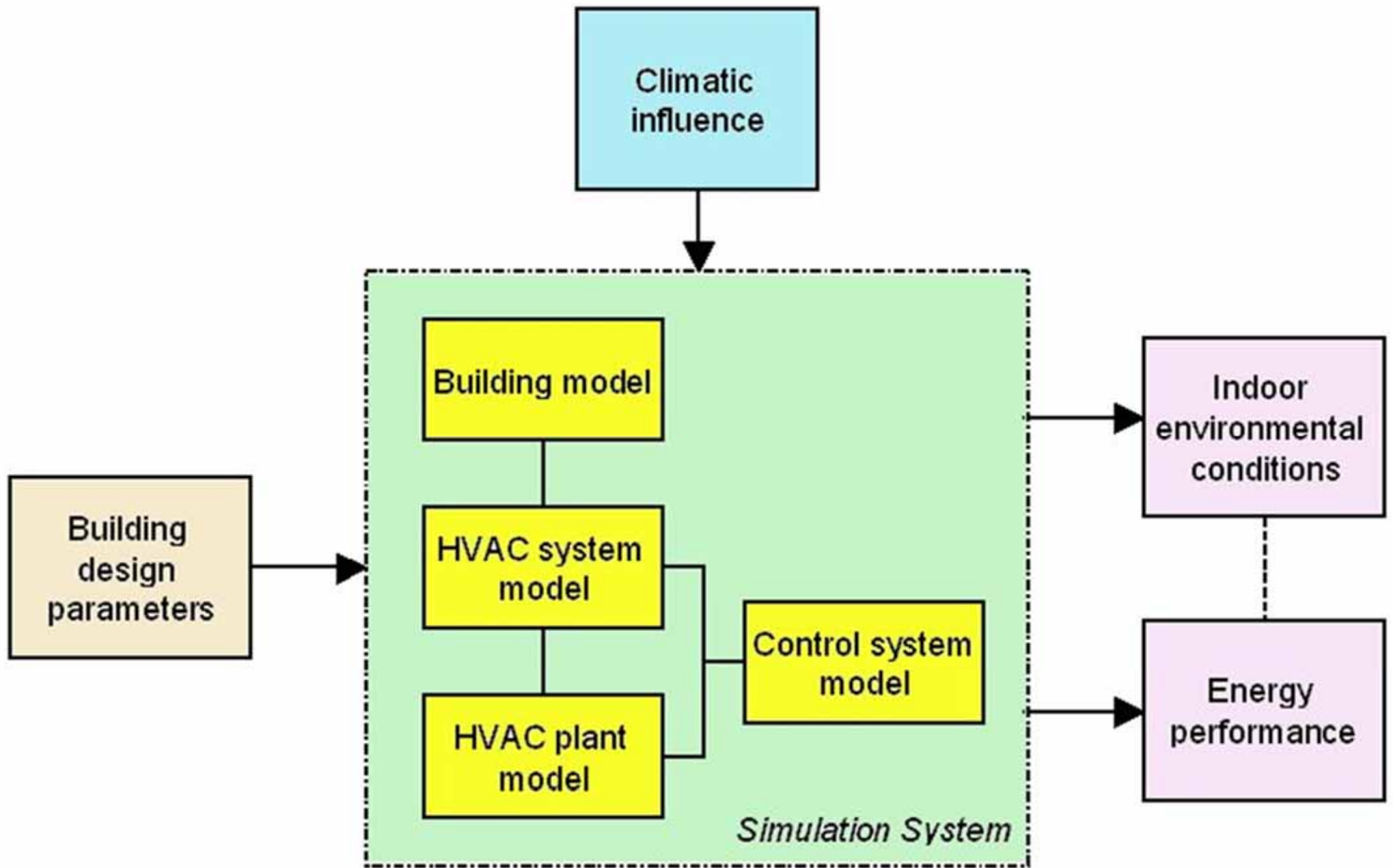


- Building energy simulation is based upon
  - *Load calculation* – thermal or HVAC
    - Determine peak HVAC design loads
  - *Energy calculation* – energy to meet the loads
    - Estimate annual energy requirements
- Time intervals
  - Full hour-by-hour (**8,760 hours** = 365 x 24)
  - Simplified hourly: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

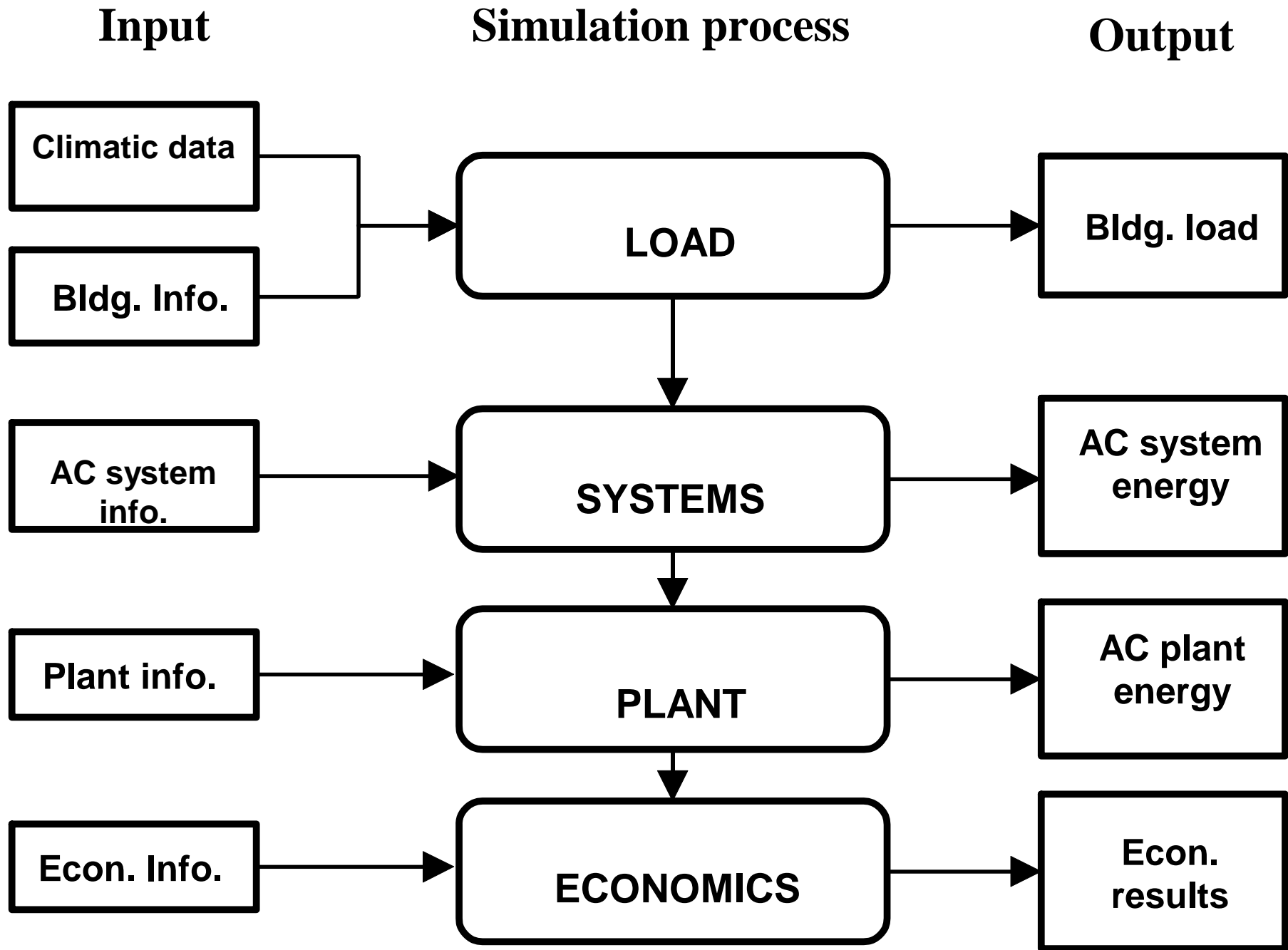
# Modelling Process



- 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

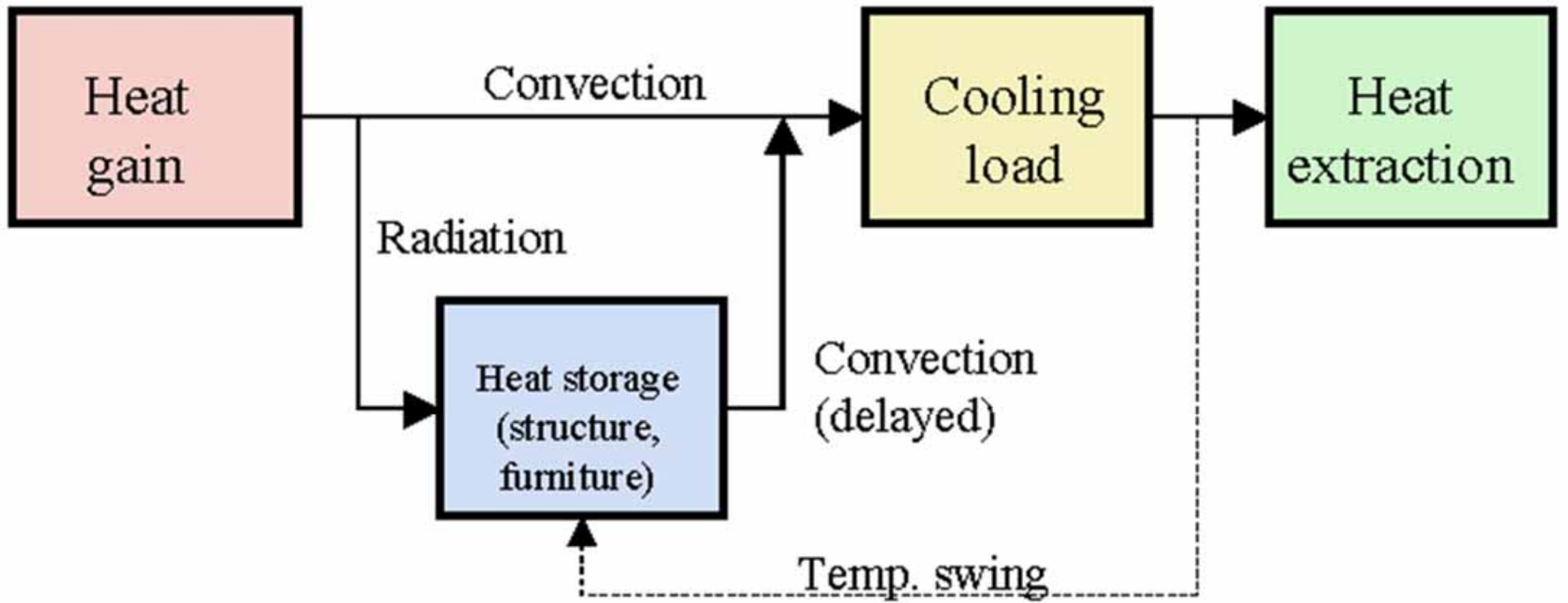


Major elements of building energy simulation



*Information flow in building simulation*





Concept of heat transmission and conversion in buildings

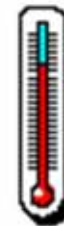
“Seven  
steps”  
of  
simulation  
output

LOADS

**1** Instantaneous  
Gain



**2** Space  
Load

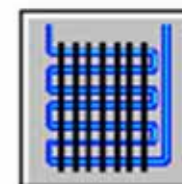


SYSTEMS

**3** Heat  
Extraction

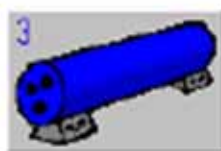


**4** Coil  
Load



PLANT

**5** Primary  
Energy/Demand



ECONOMICS

**6** Utility  
Rate



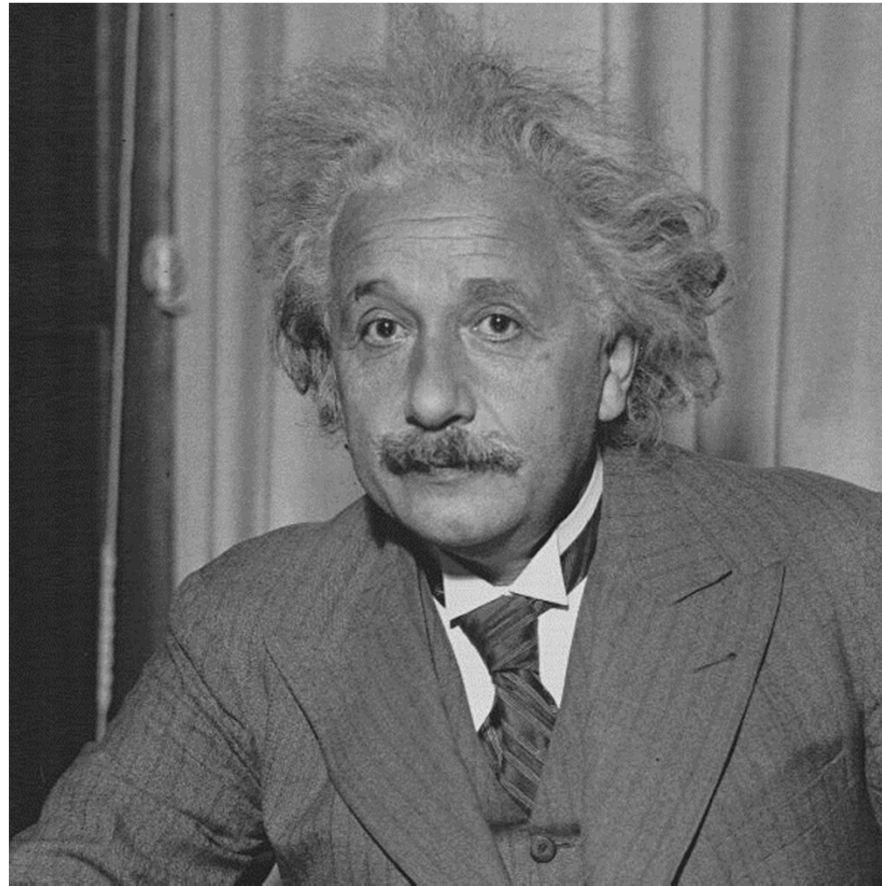
**7** Utility Costs



# Simulation Skills

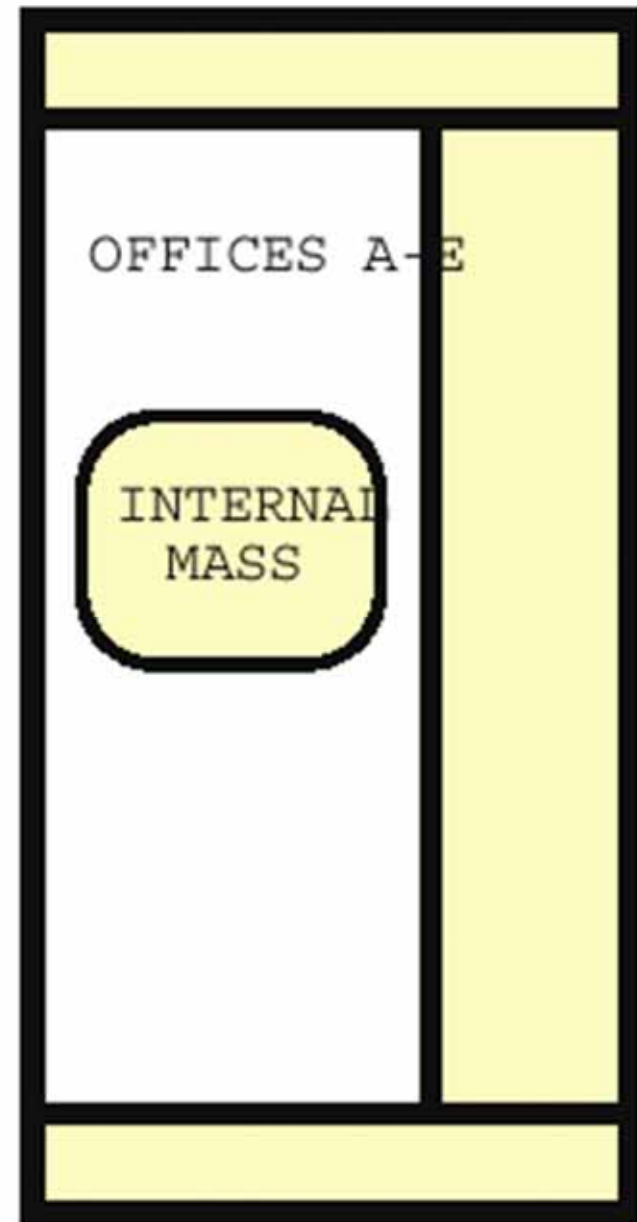
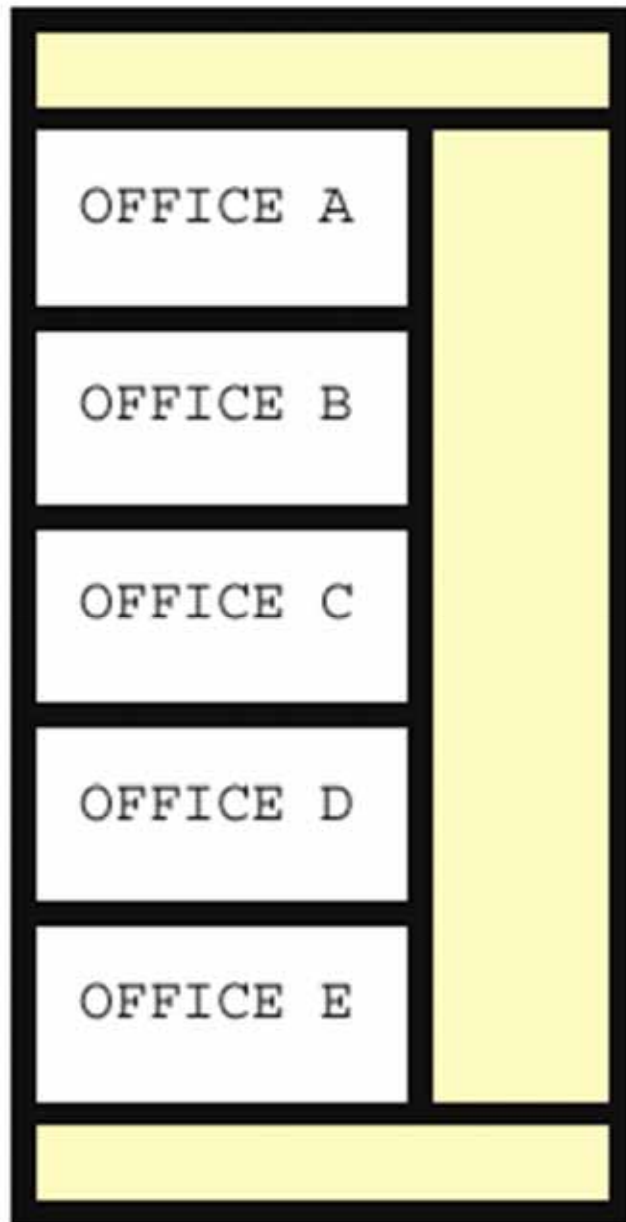


- Model zoning (*thermal*, not geometric)
  - Consider thermal loads (e.g. interior-perimeter), occupancy, lighting type and schedule
    - For existing buildings, refer to actual zoning
  - Need to *simplify* the model
    - Combine zones with similar load and usage
    - Intermediate typical floors 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

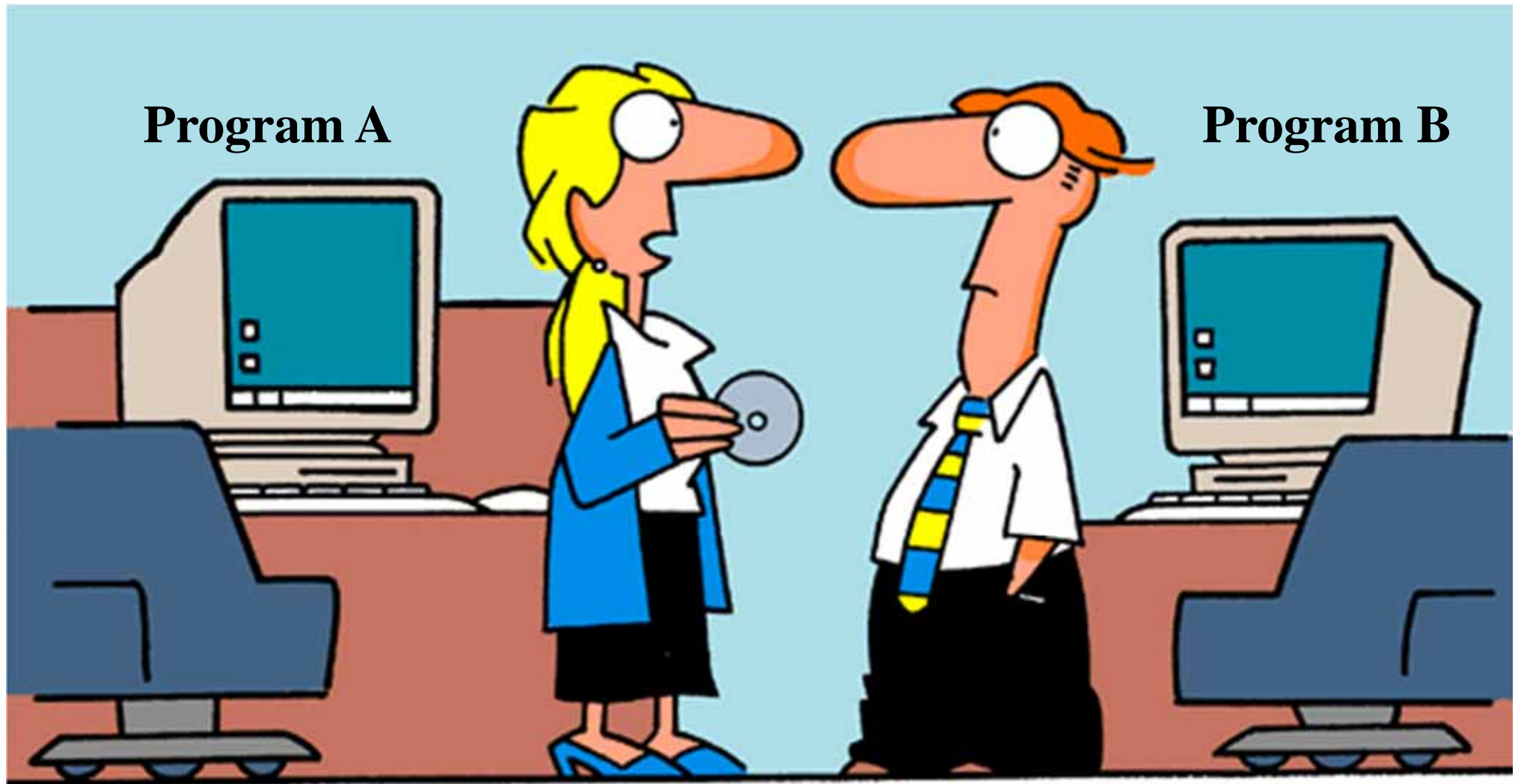


- For existing buildings
  - Study the as-built drawings and existing features
  - Collect historical data and logs
  - Take appropriate measurements
  - Observe building occupancy
- May coordinate energy audit and simulation to calibrate or tune the simulation model

# 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?

# Simulation Skills



- Expected precision (general guideline only)
  - Energy
    - Average monthly error  $>$  annual error
    - $\pm$  8-10% monthly energy
    - $\pm$  3-5% annual energy
  - Annual
    - Average monthly error  $>$  Average annual error
    - $\pm$  10-12% monthly peak demand
    - $\pm$  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

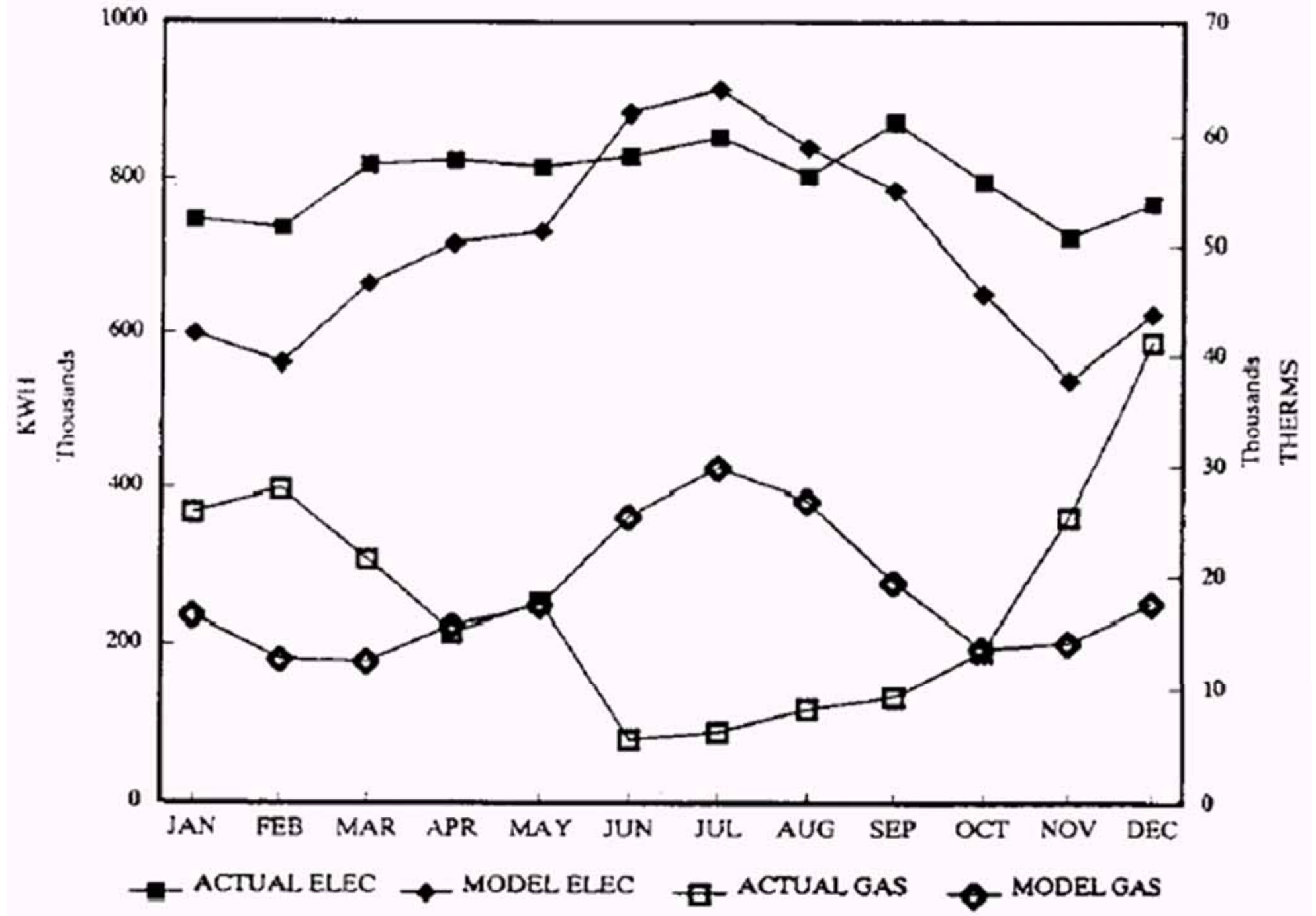
# Simulation Skills



- 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

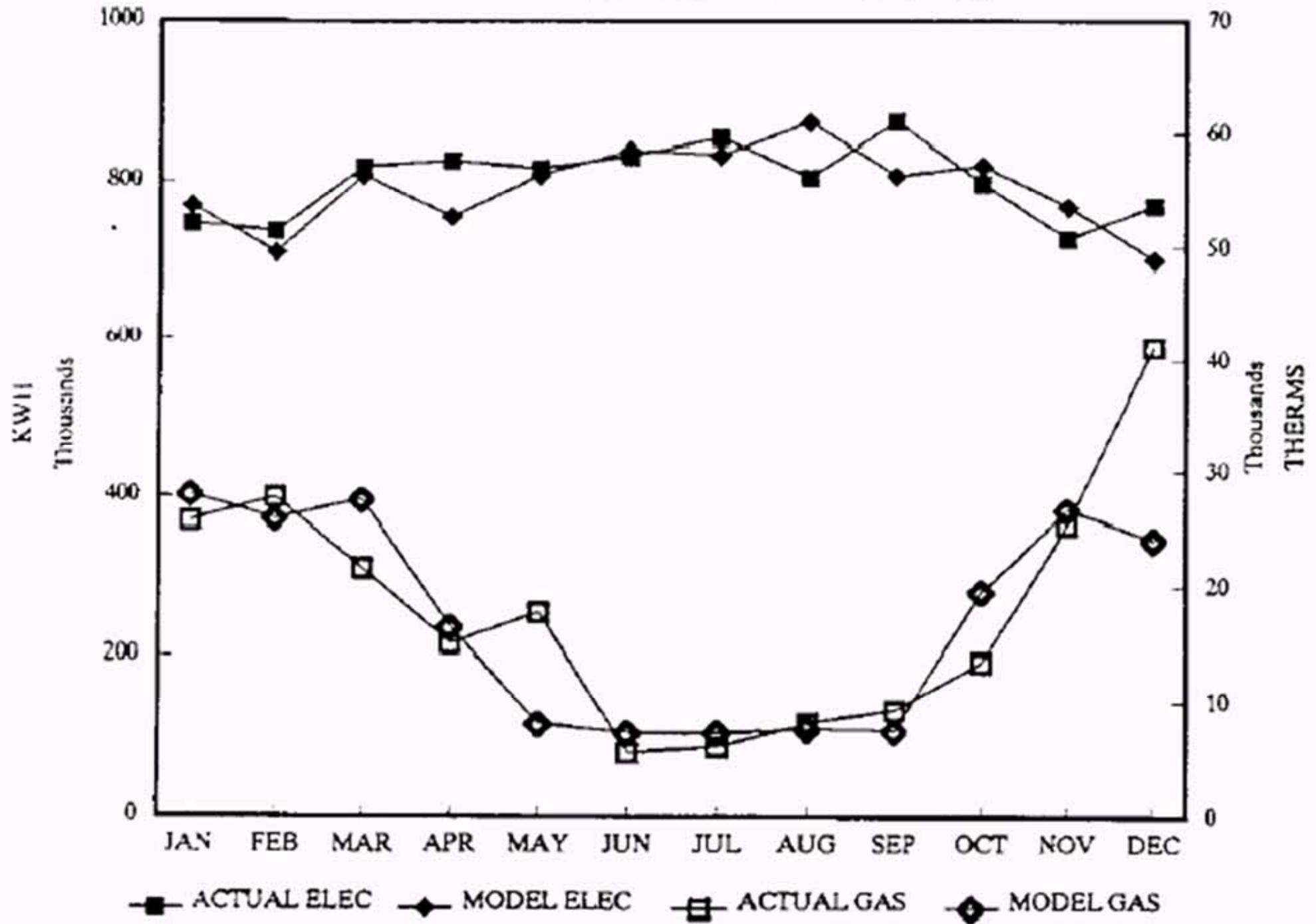


# ORIGINAL MODEL VS. ACTUAL



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

# ERA – MODEL VS. ACTUAL



(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](http://www.buildinggreen.com/features/mr/sim_lit_101.cfm)
- Energy Analysis Tools (Whole Building Design Guide), [www.wbdg.org/resources/energyanalysis.php](http://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>