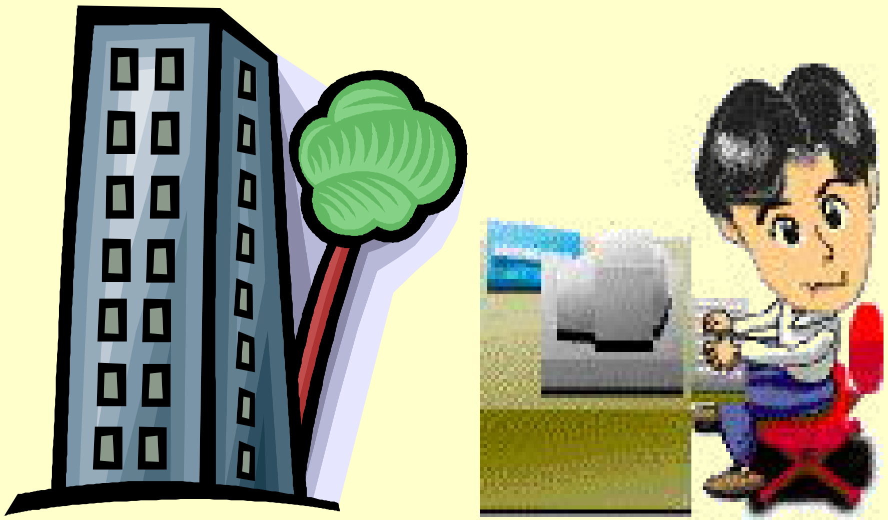

# Building Energy Simulation

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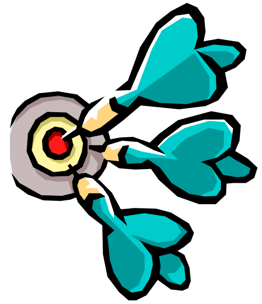
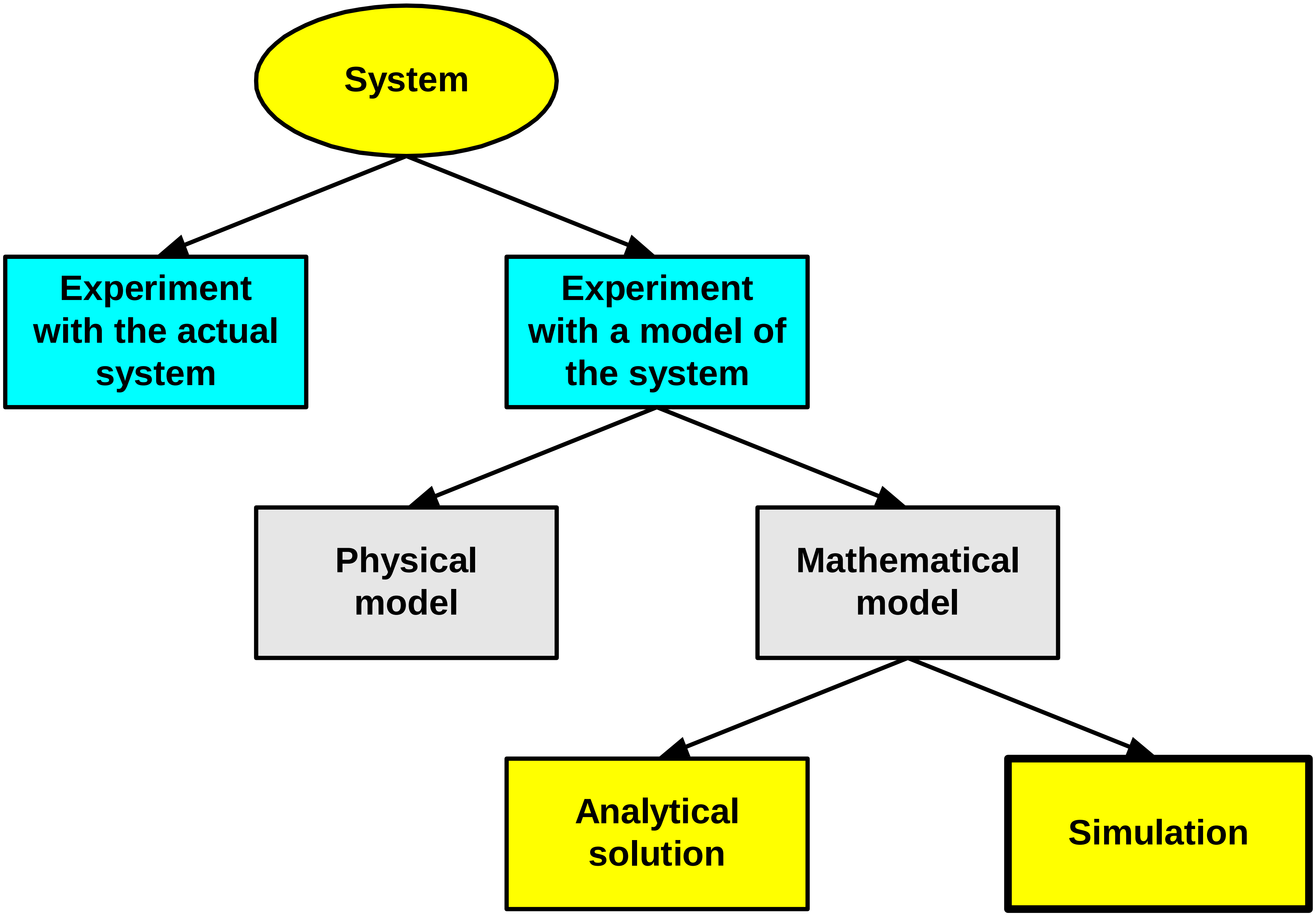
- Building Energy Simulation
- Simulation Tools
- Applying Simulation
- Modelling Process
- Simulation Skills

# Building Energy Simulation

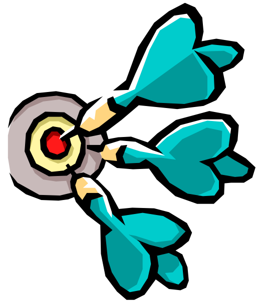


- Energy performance of buildings is usually complicated and requires detailed analysis to determine the characteristics
- Building energy simulation and modelling techniques are often used to study it so as to support decisions for building design, operation and management

# Ways to study a system



# Building Energy Simulation

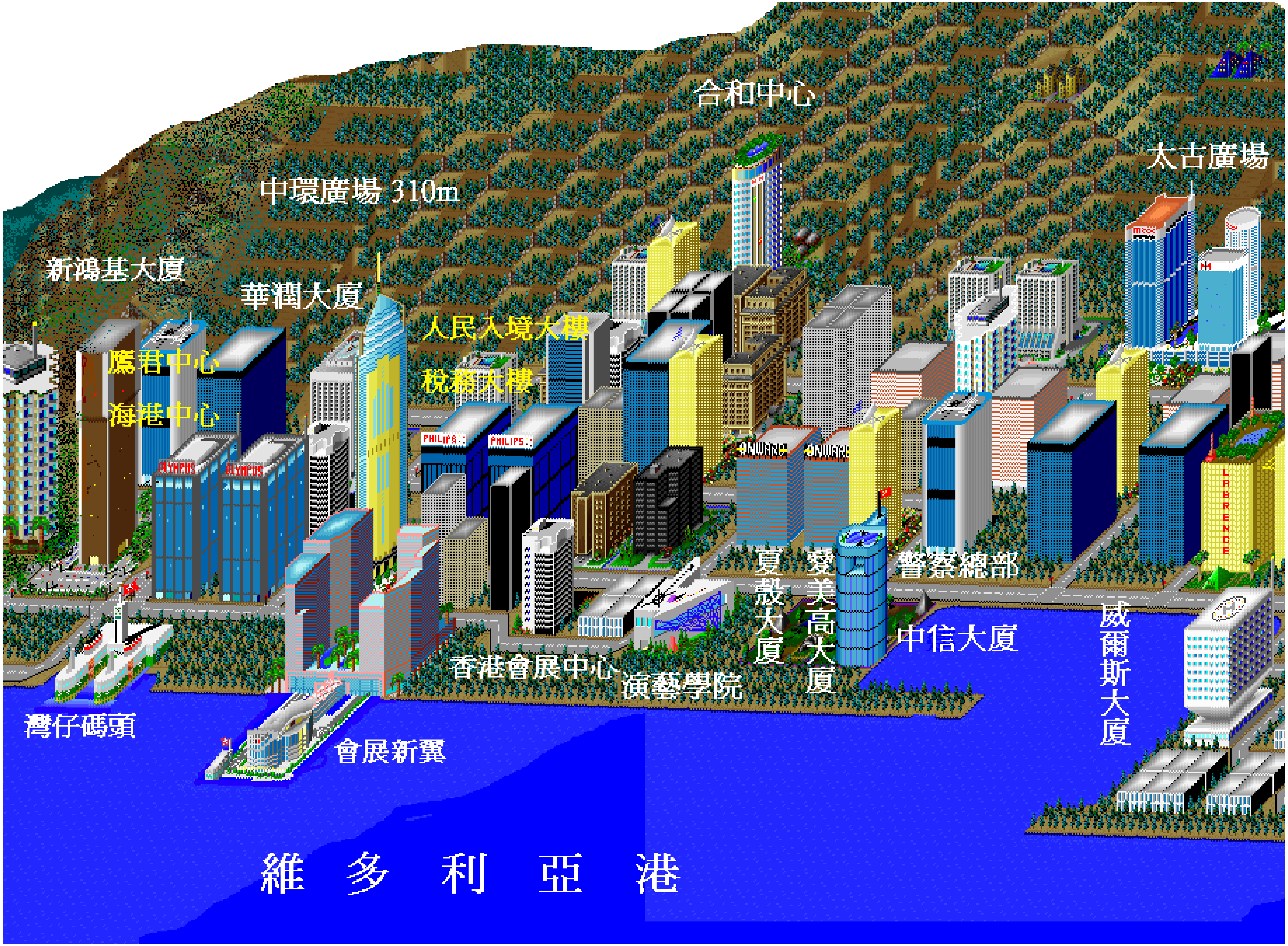


- What is Building Simulation?
  - Software which emulates the dynamic interaction of heat, light and mass (air and moisture) within the building
  - To predict its energy and environmental performance as it is exposed to climate, occupants and conditioning systems
- Building Simulation is needed if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

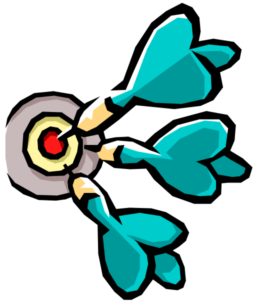
# Building Energy Simulation

- Simulation: (模擬)
  - From latin "*simulare*" – to pretend
  - Using a mathematical model of a system to predict its output for a given input
    - Asking "**what if?**" within an imaginary framework
  - To simulate => to imitate the operations of real-world facilities or process
  - Examples:
    - Computer simulation games like "SimCity"
    - A child who role plays with toys

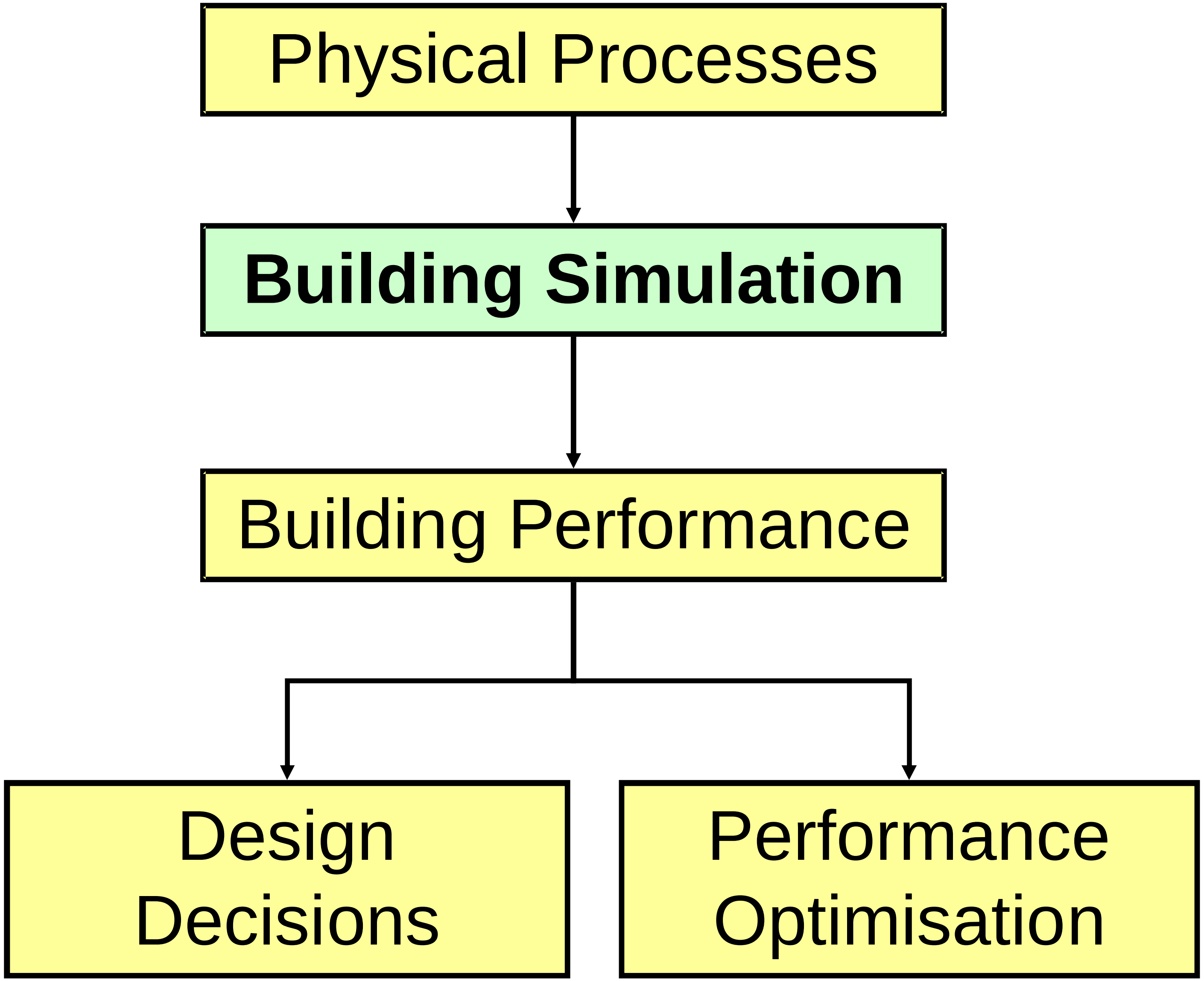
# SimCity of Hong Kong's buildings



# Building Energy Simulation

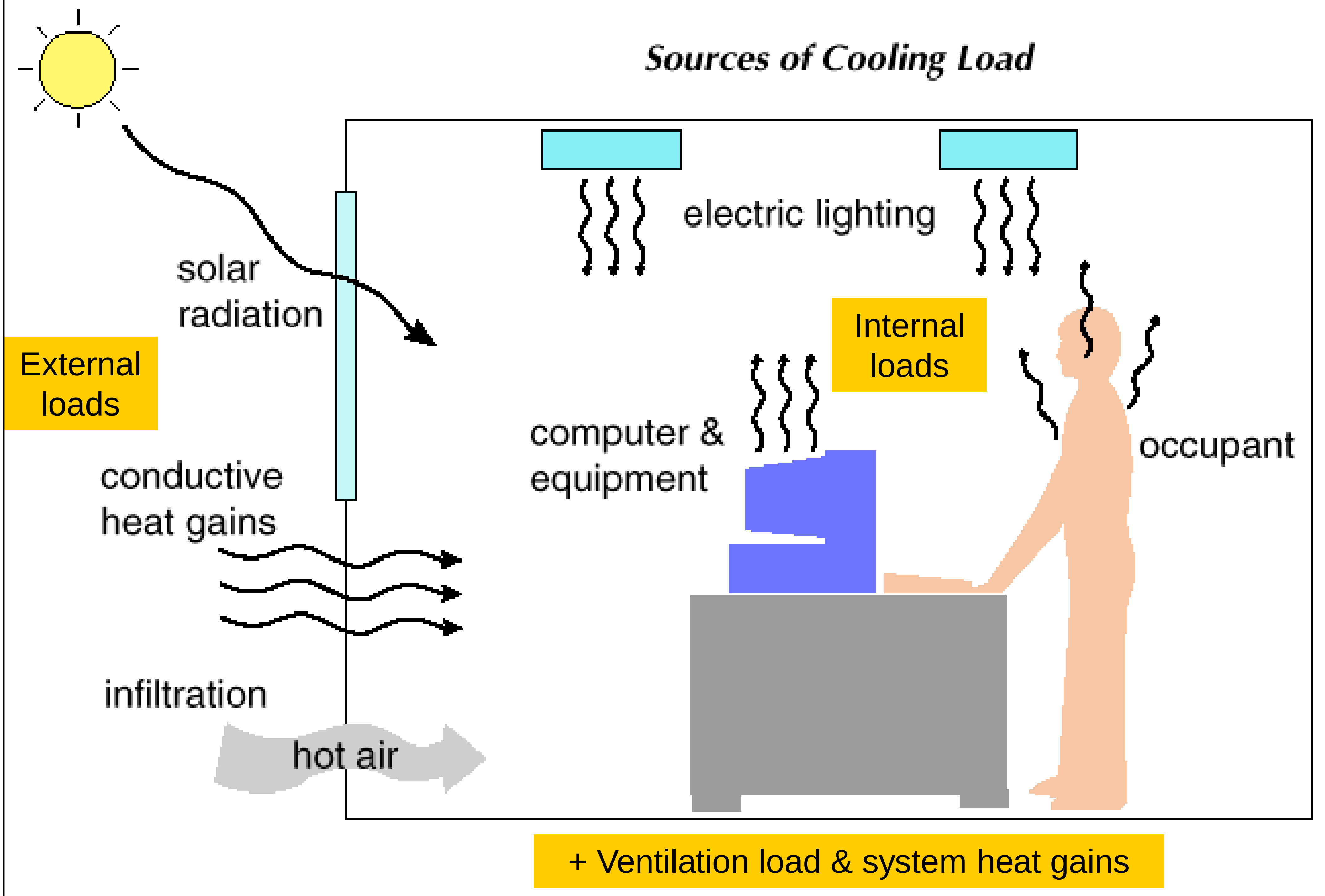


- Simulation
  - The process of developing a representative model of a system and using it to analyze and predict system behaviour and performance
- Modelling
  - Deals primarily with the relationship between actual dynamic processes and models
  - Usually involves iterations

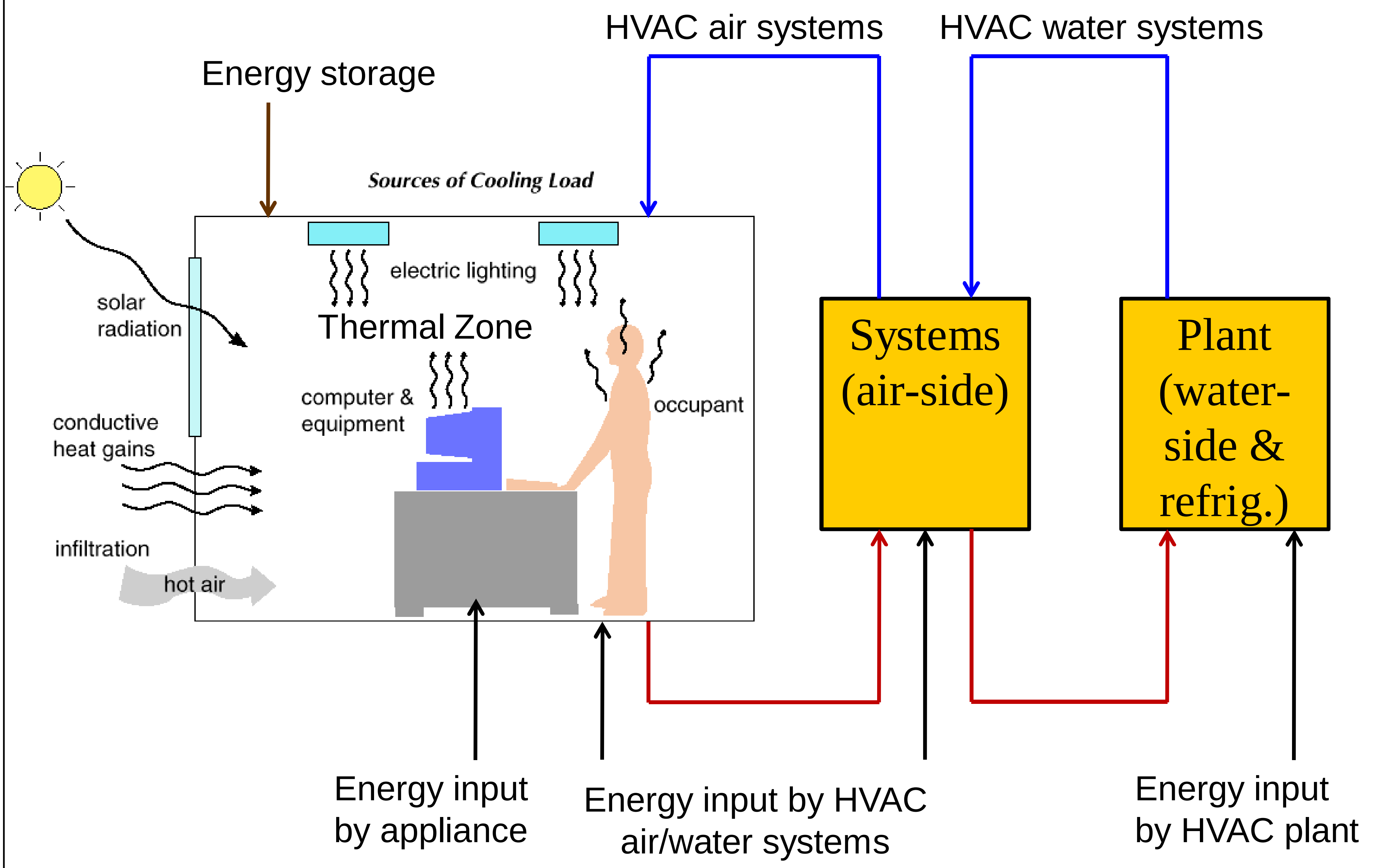



* Simulation enables the performance of the building to be established before critical design decisions are taken, enabling optimum building performance to be obtained

# Components of building cooling load



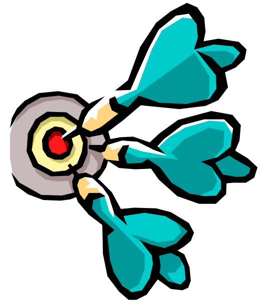
# Building energy simulation process



# Building Energy Simulation

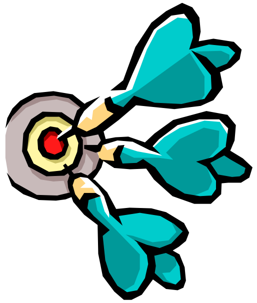
- Building energy simulation can be used to:
  - Assess building design (design evaluation tool)
  - Calculate energy saving or performance (building energy analysis tool)
  - Evaluate energy cost (economic analysis tool)
  - Design & optimise building systems (system design/optimization tool)
  - Satisfy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

# Building Energy Simulation



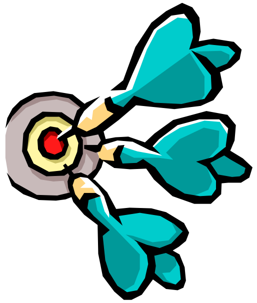
- Model existing buildings
  - Useful for “energy performance contracts”
  - Help improve the bldg’s operation/control
- Evaluate energy conservation measures (ECM)
  - Estimate energy savings
  - Study the costs and benefits
  - Provide info to design, retrofit & operation
- Comply with building energy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

# Building Energy Simulation



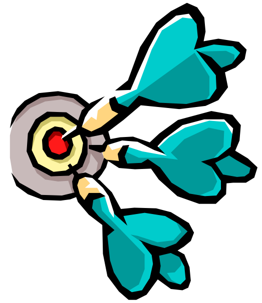
- For green building assessment (e.g. LEED)
  - Using ASHRAE 90.1 Building Energy Standard to check compliance and determine credits
  - Energy cost budget (ECB) method
    - To determine minimum compliance
    - Design Energy Cost <= Energy Cost Budget
  - Appendix G: building performance rating method
    - To rate the energy efficiency of building designs that exceed the requirements of the standard 90.1
    - % improvement = (Baseline – Proposed) / Baseline x 100%

# Building Energy Simulation



- Use of simulation at different design stages
  - Inception - feasibility ← *Simple energy analysis*
  - Outline proposals - scheme design
  - Detail design ← *Detailed energy analysis*
  - Production information
  - BQ, tender, planning, operation on site
  - Completion, testing & commissioning ← *System tuning*
  - Operation and feedback ← *Feedback for O&M*

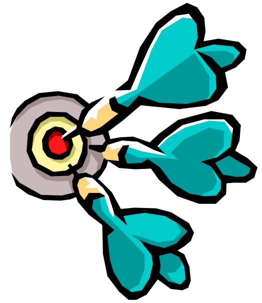
# Building Energy Simulation



- What can building simulation do?
  - Compare different design options
    - Based on energy performance, peak demand, and cost-benefit implications
  - Predict the dynamic response and performance of buildings
  - Evaluate complex, innovative and ‘green’ technologies
    - Such as natural ventilation, advanced controls operation and passive design


**“To simulate, or not to simulate. That’s the question.”**

# Building Energy Simulation



- When NOT to simulate
  - If project is too small or time is too tight
    - Not economical to carry out simulation
  - If the design has proceeded too far
    - Unlikely anything can be changed
  - If it can't answer the design question
    - Such as airflow & occupant behaviours
  - If you do not understand the benefits & limitations of the simulation

# Building Energy Simulation

- Further reading:
  - Understanding the Energy Modeling Process: Simulation Literacy 101, www.buildinggreen.com/features/mr/sim_lit_101.cfm
  - Energy Conservation Building Code Tip Sheet: Energy Simulation, www.emt-india.net/ECBC/EnergyEfficiencyinHospitals_4Mar2009/Tips/EnergySimulation.pdf
  - Thomas, P. C., 2002. Building energy performance simulation - a brief introduction, DES 17, In *BDP Environment Design Guide*

# 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

ENERGY-10

blast

EnergyPlus

DOE-2

Solar-5

ESP-r

ENER-WIN©

Hourly Energy Simulation Program for Buildings

# Building Energy Simulation Software

TRNSYS

Carrier

E-20-II & HAP

HOT2000

TRANE

TRACE 700

ADELINE

Tas

EE4

# Simulation Tools

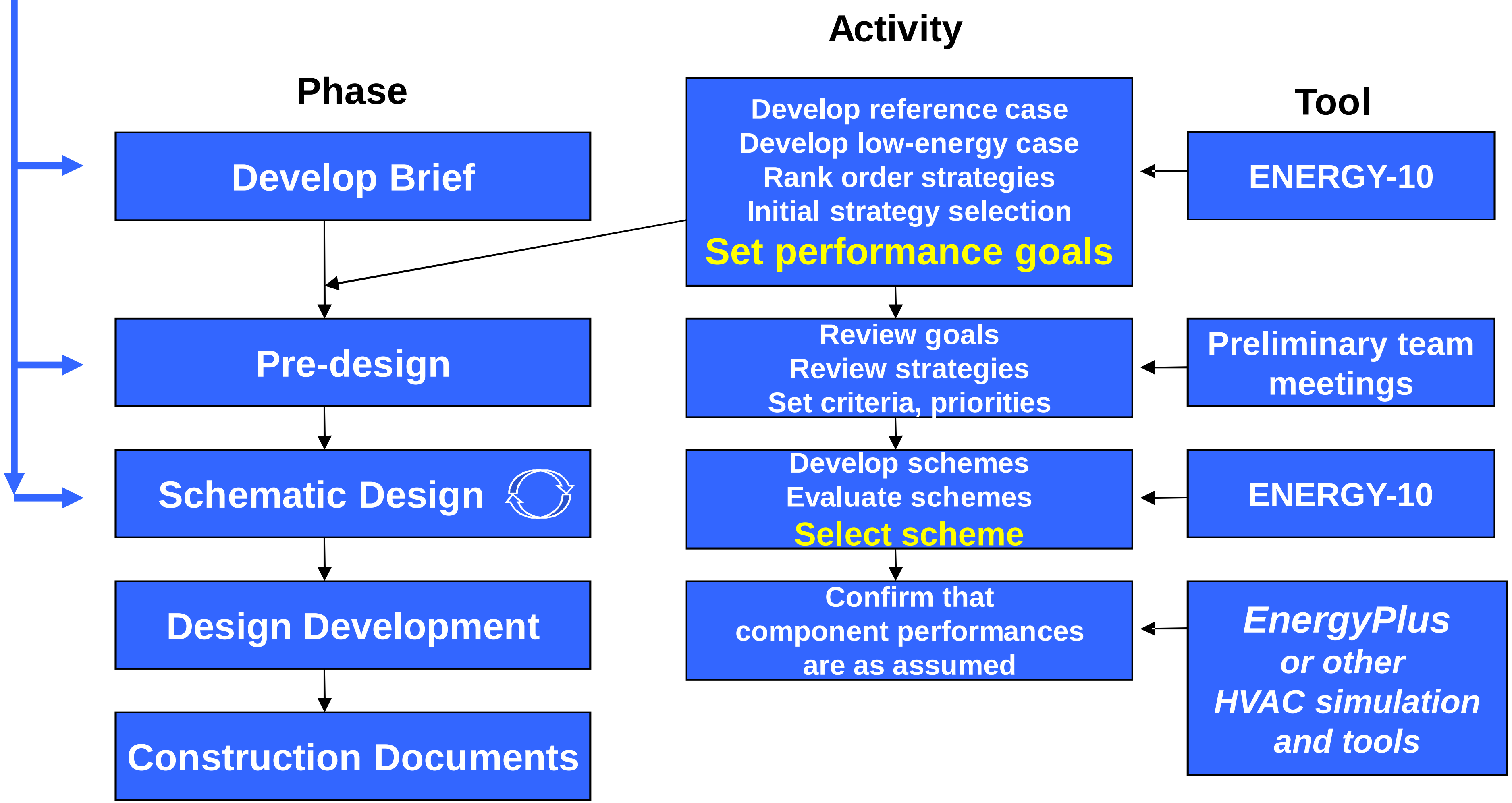
- Many software tools in the market
  - From simplified to complicated one
  - Select according to the task
- For beginners, we recommend
  - Energy-10, HAP, TRACE 700, eQUEST
- For sophisticated study, may consider
  - DOE-2, EnergyPlus, ESP-r, TRNSYS
- Further information:
  - Building Energy Software 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.**

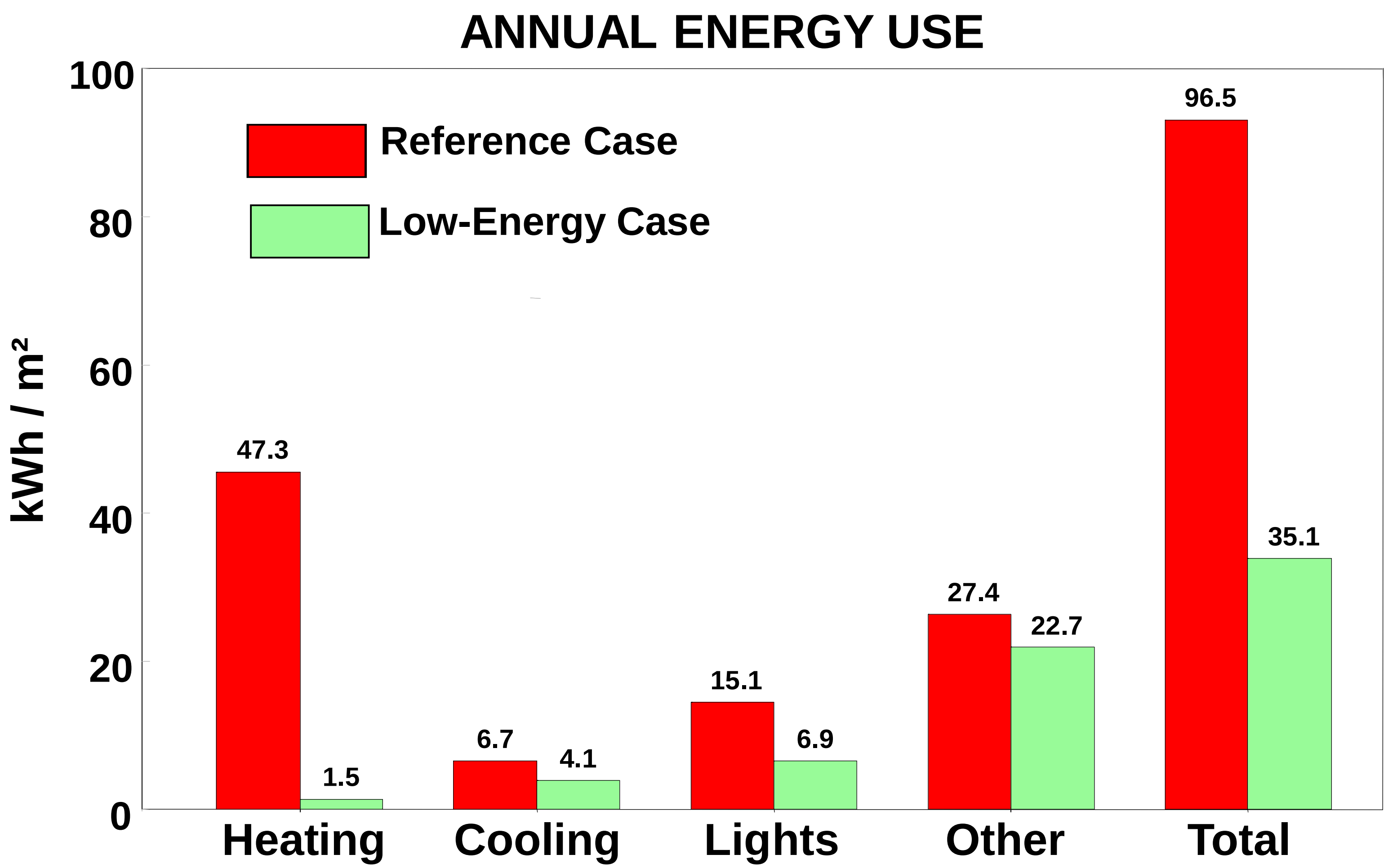
## For example:

apply

| 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 |

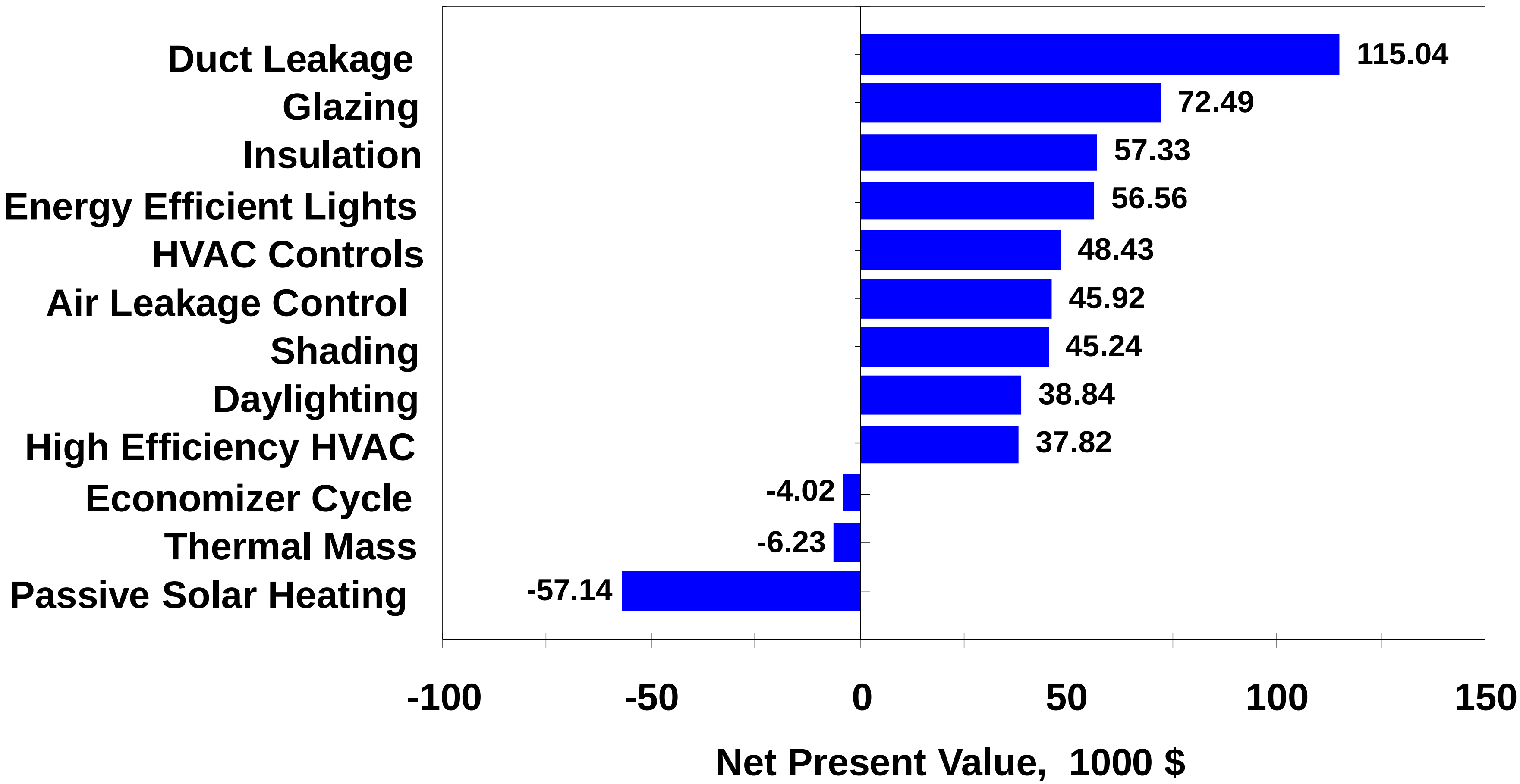
# Example: Energy-10

2,000 m² office building

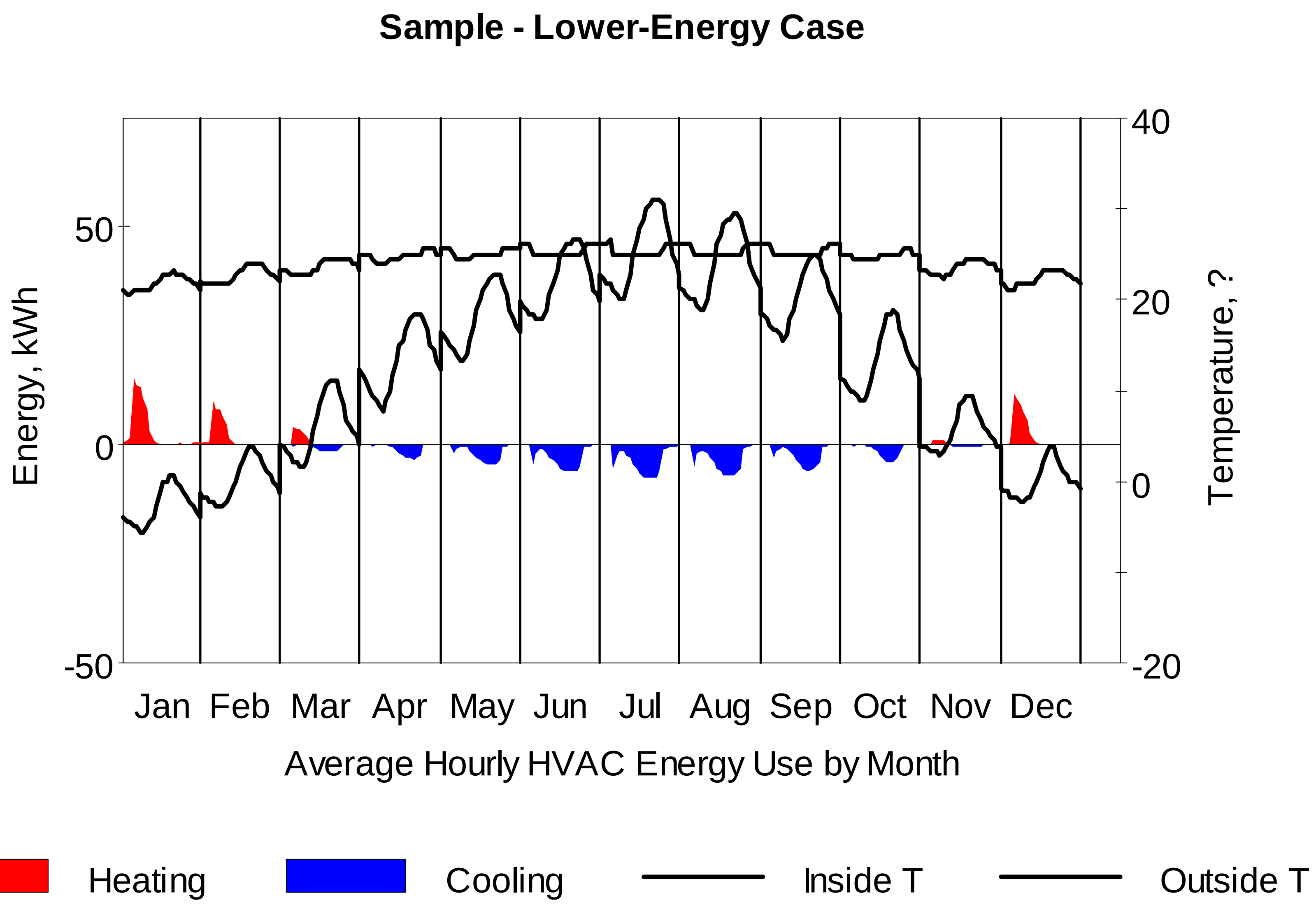


# Example: Energy-10

## RANKING OF ENERGY-EFFICIENT STRATEGIES

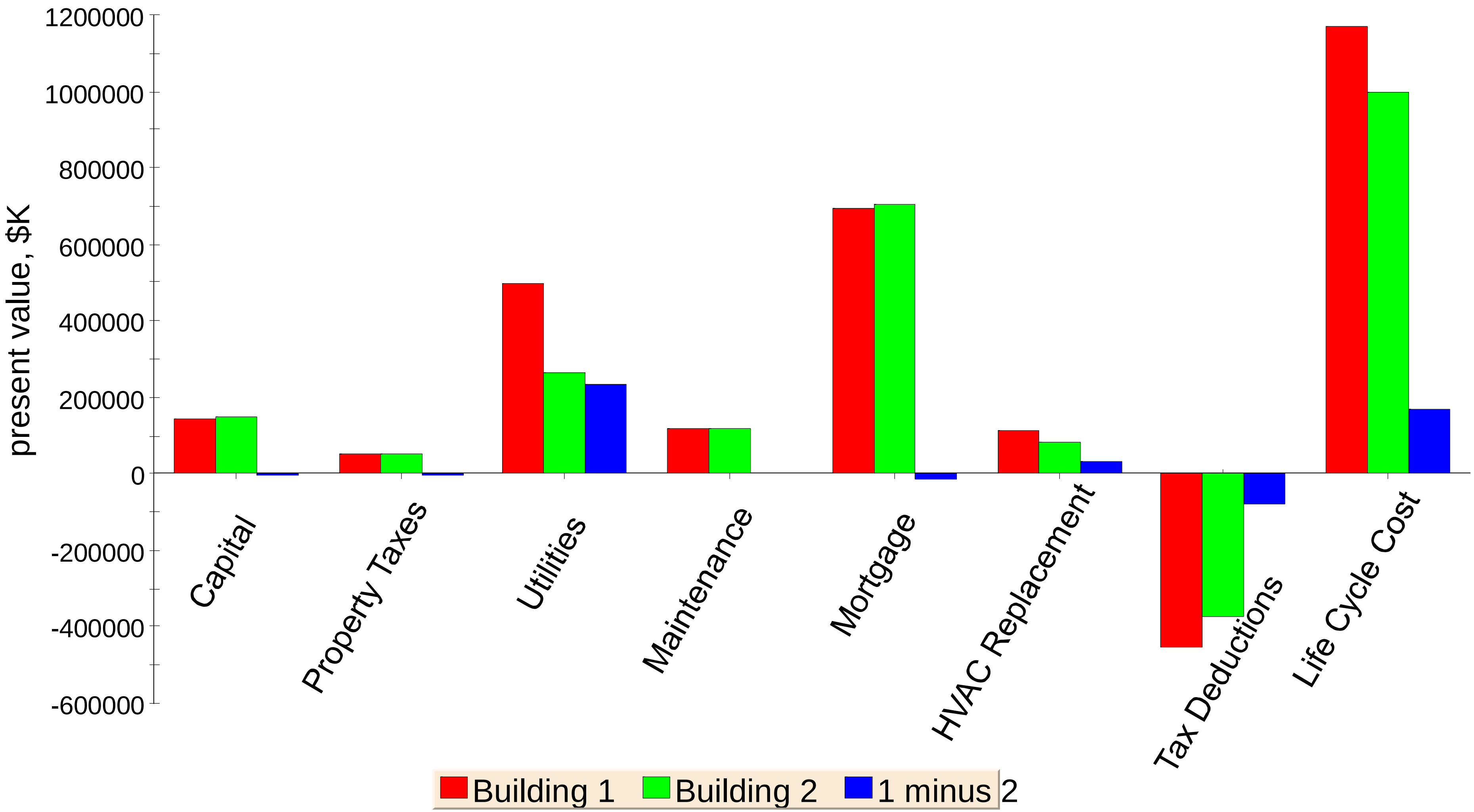


# Example: Energy-10



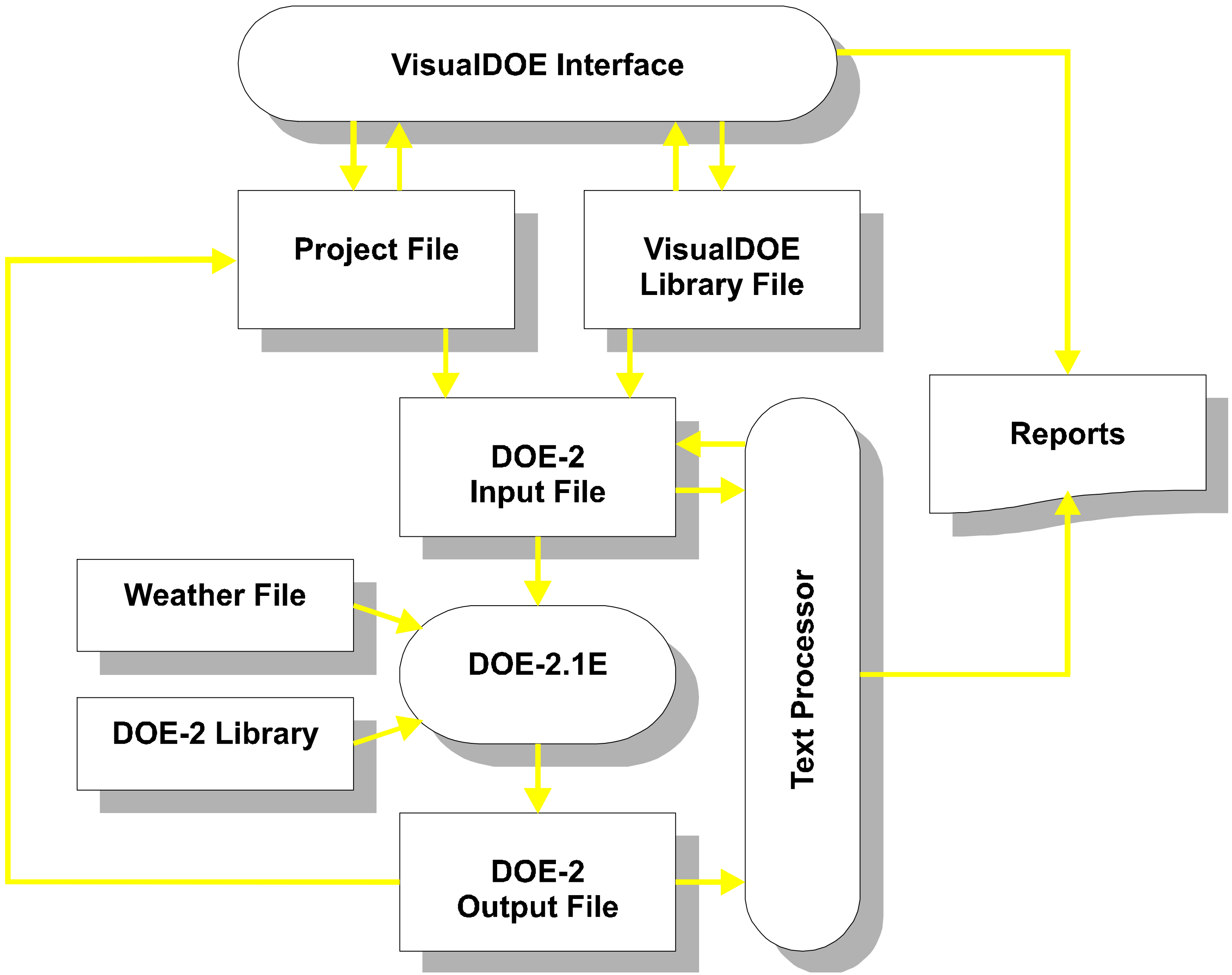
# Example: Energy-10

## Components of Life-Cycle Cost



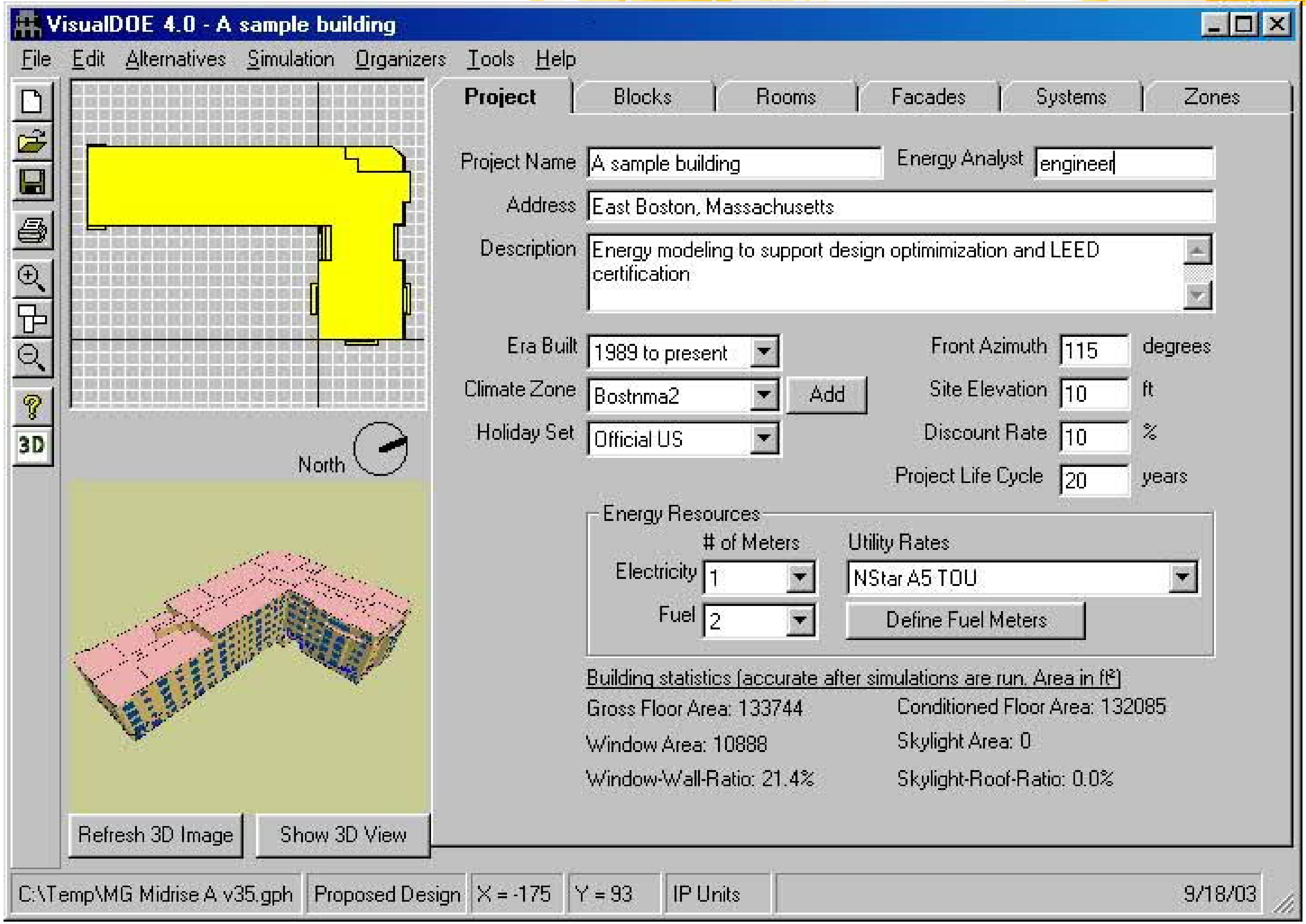
# Example: VisualDOE

DOE-2



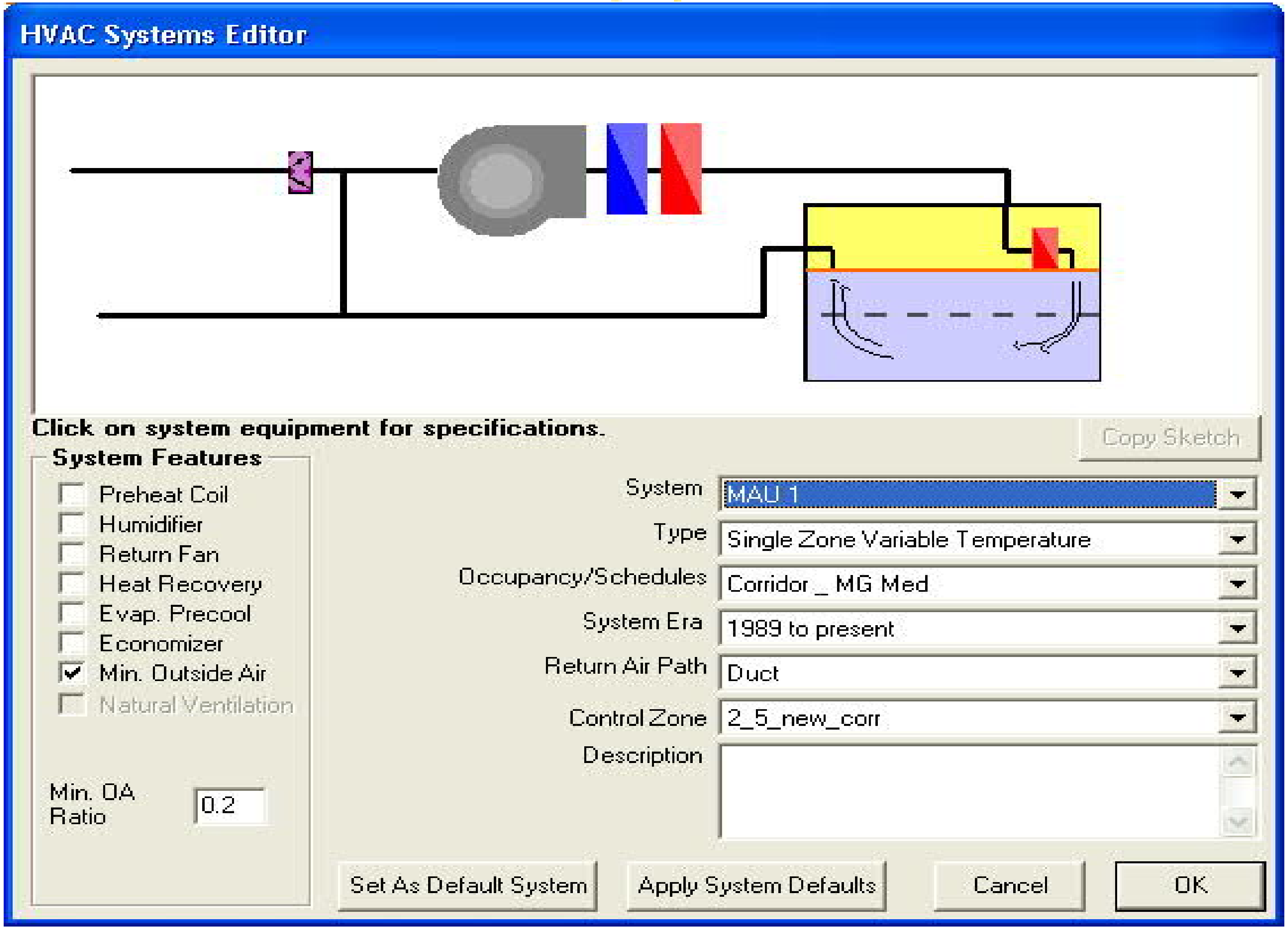
# Example: VisualDOE

DOE-2



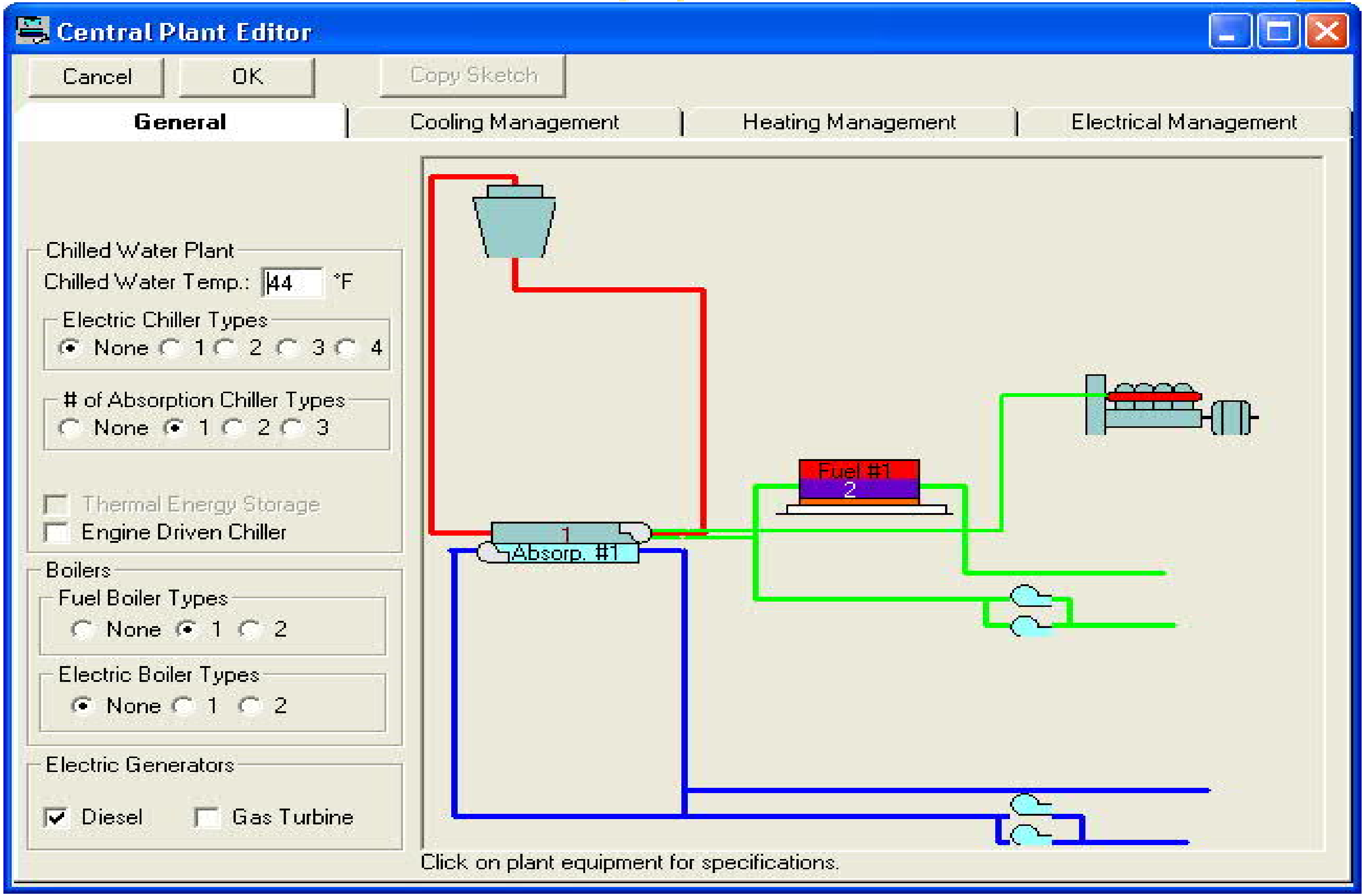
# Example: VisualDOE

DOE-2



# Example: VisualDOE

DOE-2



# Example: VisualDOE

DOE-2

Print Preview

Export RTF | Export PDF | Close

3/4

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

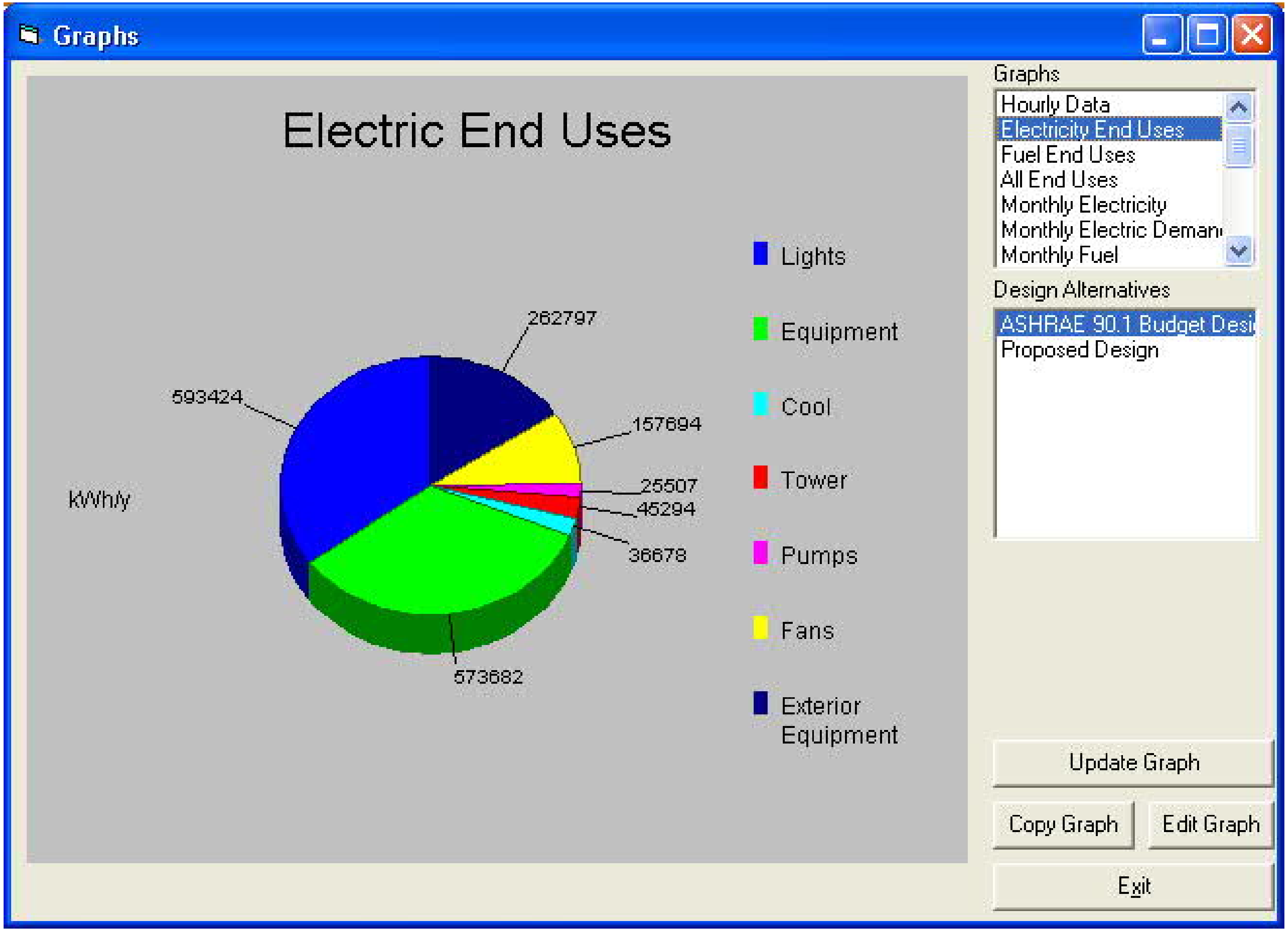
**Energy Cost Summary ($/y)**

| 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.

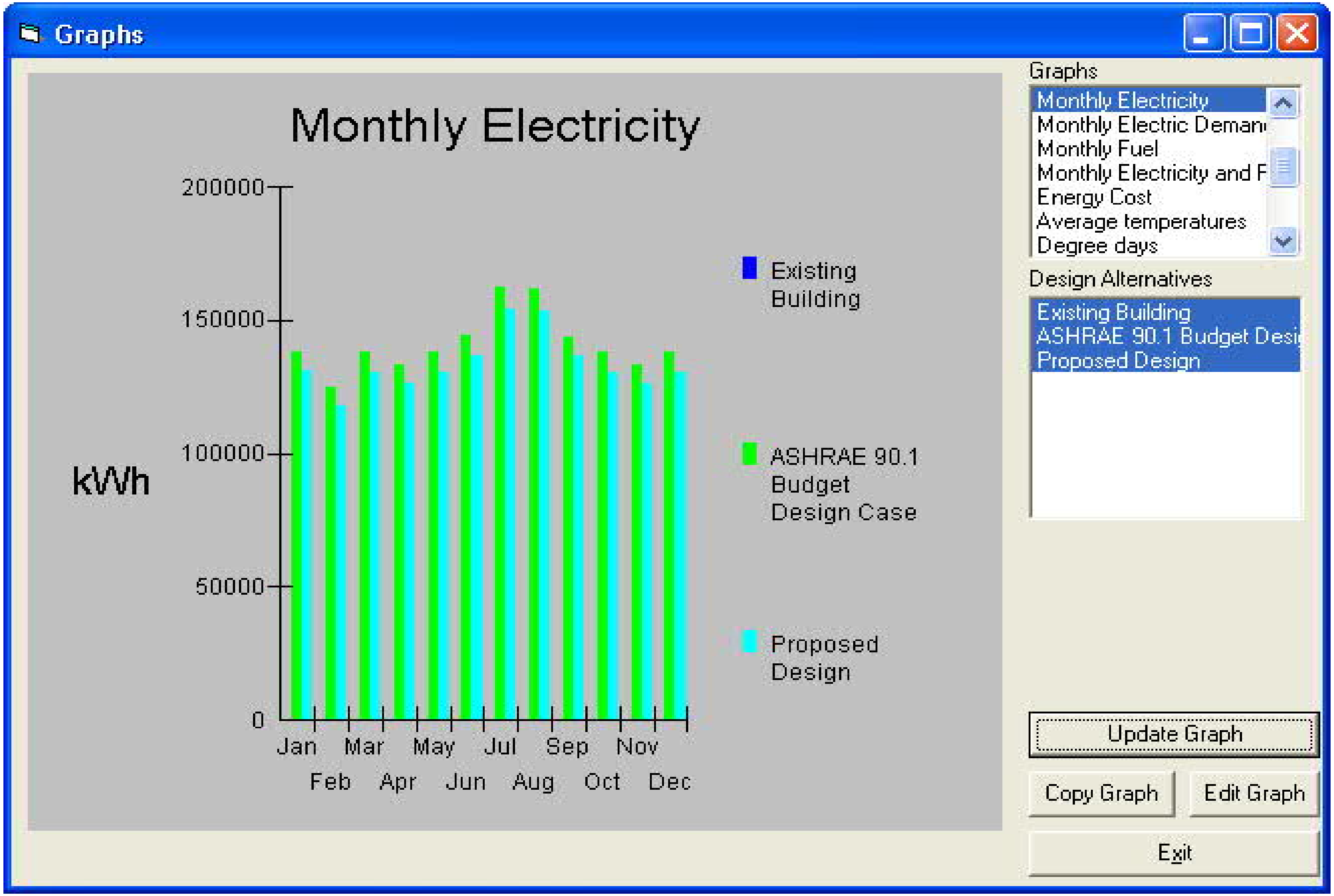
# Example: VisualDOE

DOE-2

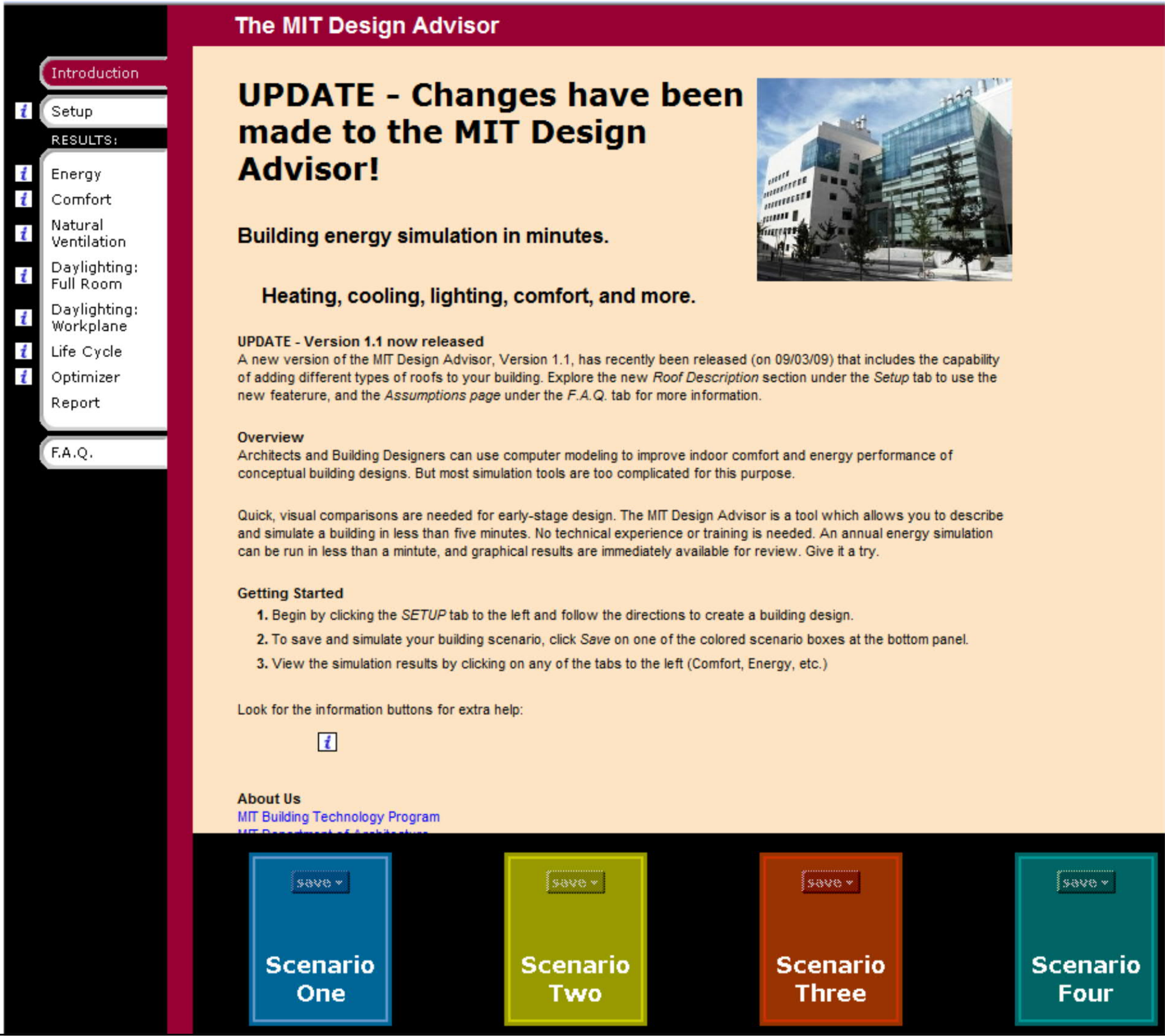


# Example: VisualDOE

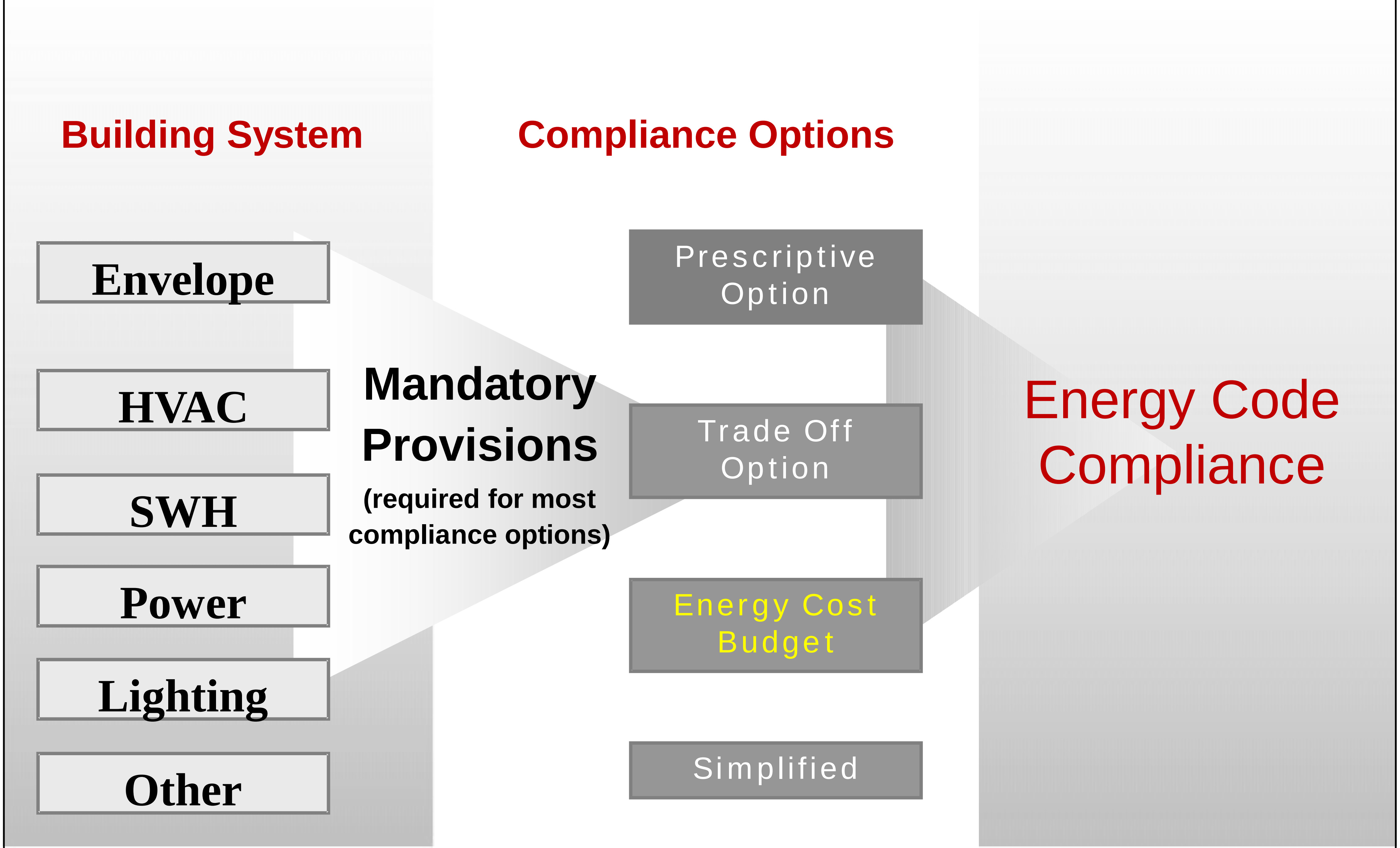
DOE-2



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

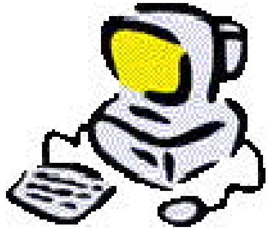


ASHRAE 90.1 compliance approaches




(Source: US Department of Energy)

# Applying Simulation



- Requirements for simulation software:
  - Software must be approved by the adopting authority & conform explicitly to the modeling requirements in Section 11 and Appendix G
    - Most of the capabilities required to model the Energy Cost Budget (ECB) Method and the Performance Rating (PR) Method are identical
  - Examples of suitable software: TRACE700, DOE-2, EnergyPlus, BLAST and Carrier HAP
    - If the software cannot adequately model some aspect of the design, the authority may approve an “exceptional” calculation method

# Modeling requirements for the Performance Rating Method (1)

| Model element | Proposed building design | Baseline building design |
|---|---|---|
| Building configuration, size | Consistent with design documents | Number of floors and conditioned floor area matches proposed design |
| Space use classification | Specify a single building type (per Section 9.5.1), unless the building is a mixed-use facility; or one or more spacetype classifications (per Section 9.6.1) | Same as proposed design |
| Schedules | Hourly variations in occupancy, lighting power, miscellaneous equipment power, thermostat setpoints, and HVAC system operation are typical of the proposed building type<br>*Exception*: May model energy-saving strategies if approved by the rating authority | Same as proposed design … unless the proposed design models nonstandard efficiency measures |
| | Model all conditioned spaces as both heated and cooled | Same as proposed design |

# Modeling requirements for the Performance Rating Method (2)

| Model element | Proposed building design | Baseline building design |
|---|---|---|
| Building envelope | Consistent with architectural drawings (or "as-built" for existing buildings) | Dimensions: Exterior envelope components, roofs, doors, floors, and exposed perimeters of concrete slabs on grade are equivalent to proposed design |
| | | Opaque assemblies: Use lightweight assembly types and U-factors, F-factors, and C-factors from Tables 5.5-1 through 5.5-8 |
| | | Vertical fenestration: Model as 40% of the above-grade wall area (or equal to the proposed design, whichever is smaller), configured as horizontal bands distributed uniformly across all orientations |
| | Include effects of automated shades/blinds and permanent shading devices, such as fins, overhangs, and light shelves | Omit effects of shading projections, manual window shading devices, and self-shading of the building due to orientation |

# Modeling requirements for the Performance Rating Method (3)

| Model element | Proposed building design | Baseline building design |
|---|---|---|
| Lighting | Use actual lighting power if the system exists; or lighting power allowance in accordance with Sections 9.1.3 and 9.1.4 if the system is designed; or lighting power in accordance with the Building Area Method if the lighting system is yet to be specified | Use the maximum lighting power allowed for the building or space-type classification(s) in the proposed design |
| | Includes task, furniture-mounted, parking garage, and façade lighting | Same as proposed design |
| | Account for automatic lighting controls, such as daylighting | Excludes automatic lighting controls (The baseline lighting schedule reflects the mandatory control requirements in Standard 90.1) |

# Modeling requirements for the Performance Rating Method (4)

| **Model element** | **Proposed building design** | **Baseline building design** |
|---|---|---|
| Thermal blocks (HVAC zones) | Model each HVAC zone as a separate thermal block | Same as proposed design |
| HVAC systems | Model HVAC system, equipment, and controls types as designed. If no heating and/or cooling system exists, then system characteristics match those in baseline model | Use HVAC system types and descriptions specified in Tables G3.1.1A, G3.1.1B, and in Sections G3.1.2 and G3.1.3 For fan and pump energy, use values specified in Sections G3.1.2 and G3.1.3 |
| Receptacle and other loads | Use estimates based on the building- or space-type classification | Same as proposed design<br>*Exception*: Use the lowest allowable efficiency for components subject to the efficiency requirements in Section 10 |

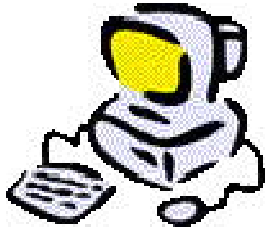
# Applying Simulation

- Table G3.1:–
- Schedules: Changes to schedules allowed for energy efficiency measures, e.g.
  - Lighting controls
  - Natural ventilation
  - Demand control ventilation (DCV)
  - Measures that reduce service water heating loads

# Applying Simulation

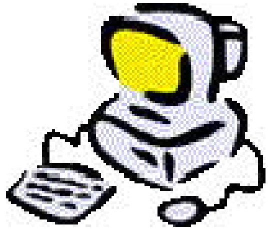
- Table G3.1 (cont'd.)
- Building Envelope:
  - Baseline Building orientation and fenestration locations normalized in model
  - Baseline Envelope meets code requirements for common construction type (lightweight assembly)
  - Only automatically controlled shading devices may be modeled

# Applying Simulation



- Table G3.1 (cont'd.)
- Lighting:
  - Model daylighting via software or schedules
  - Lighting Controls – Table G3.2 or schedules
- HVAC Systems
  - Per Tables G3.1.1A and G3.1.1B

# Applying Simulation



- Step 1: Model the proposed design in accordance with Section G3
- Step 2: Model the baseline design
- Step 3: Calculate the energy performance of the proposed design
- Step 4: Calculate the energy performance of the baseline design
- Step 5: Calculate the performance improvement of the proposed design
- Step 6: Verify model accuracy

# Applying Simulation

- Document the results:
  - USGBC defines submittal requirements for each of the prerequisites and credits for LEED
    - LEED submittal template
    - Supporting documentation
  - Evidence required to support EAp2 and EAc1:
    - Calculated values for baseline and proposed building performance
    - A list of all energy-related features in the actual design, with the differences between the two models clearly identified

# LEED 2009 New Construction Checklist

| | | | |
|---|---|---|---|
| ☑ | Prerequisite 1 | Fundamental Commissioning of Building Energy Systems | Required |
| ☑ | Prerequisite 2 | Minimum Energy Performance | Required |
| ☑ | Prerequisite 3 | Fundamental Refrigerant Management | Required |
| ☐ | Credit 1 | Optimize Energy Performance | 1–19 |
| ☐ | Credit 2 | On-site Renewable Energy | 1–7 |
| ☐ | Credit 3 | Enhanced Commissioning | 2 |
| ☐ | Credit 4 | Enhanced Refrigerant Management | 2 |
| ☐ | Credit 5 | Measurement and Verification | 3 |
| ☐ | Credit 6 | Green Power | 2 |

| | | | |
|---|---|---|---|
| ☑ | Prerequisite 1 | Storage and Collection of Recyclables | Required |
| ☐ | Credit 1.1 | Building Reuse—Maintain Existing Walls, Floors and Roof | 1-3 |
| ☐ | Credit 1.2 | Building Reuse—Maintain Existing Interior Nonstructural Elements | 1 |
| ☐ | Credit 2 | Construction Waste Management | 1-2 |
| ☐ | Credit 3 | Materials Reuse | 1-2 |
| ☐ | Credit 4 | Recycled Content | 1-2 |
| ☐ | Credit 5 | Regional Materials | 1-2 |
| ☐ | Credit 6 | Rapidly Renewable Materials | 1 |
| ☐ | Credit 7 | Certified Wood | 1 |

(Source: USGBC)

# Applying Simulation

- Document the results:
  - Evidence to support EAp2 and EAc1: (cont'd)
    - Simulation results that break down energy usage (at minimum) by lights, internal equipment loads, service water heating equipment, space heating equipment, space cooling and heat rejection equipment, fans, and other HVAC equipment (such as pumps)
    - Simulation results showing the amount of time that any loads are not met by the HVAC system in each model
    - An explanation of errors, if any, reported by the simulation software in the simulation results

# Applying Simulation

- Documentation checklists
  - Input quality control checklist
  - Output quality control checklist
  - Output-input consistency checklist
- Non-typical energy systems & scenarios
  - Exceptional calculations
  - Calculations for additions to existing buildings
  - Calculations for multiple Buildings
  - District energy systems
  - Combined heat and power (CHP) systems

### 3.2.3 Output-Input Consistency Checklist

The last step for verifying the accuracy of the energy savings is to check for consistency between outputs and inputs. Table 3.3 is a checklist for reviewing the consistency of energy modeling outputs and inputs and provides calculation methods and rules of thumb to predict rough order-of-magnitude results. It can assist with quality assurance on projects using ASHRAE 90.1–2004, California Title 24, and the Oregon Energy Code.

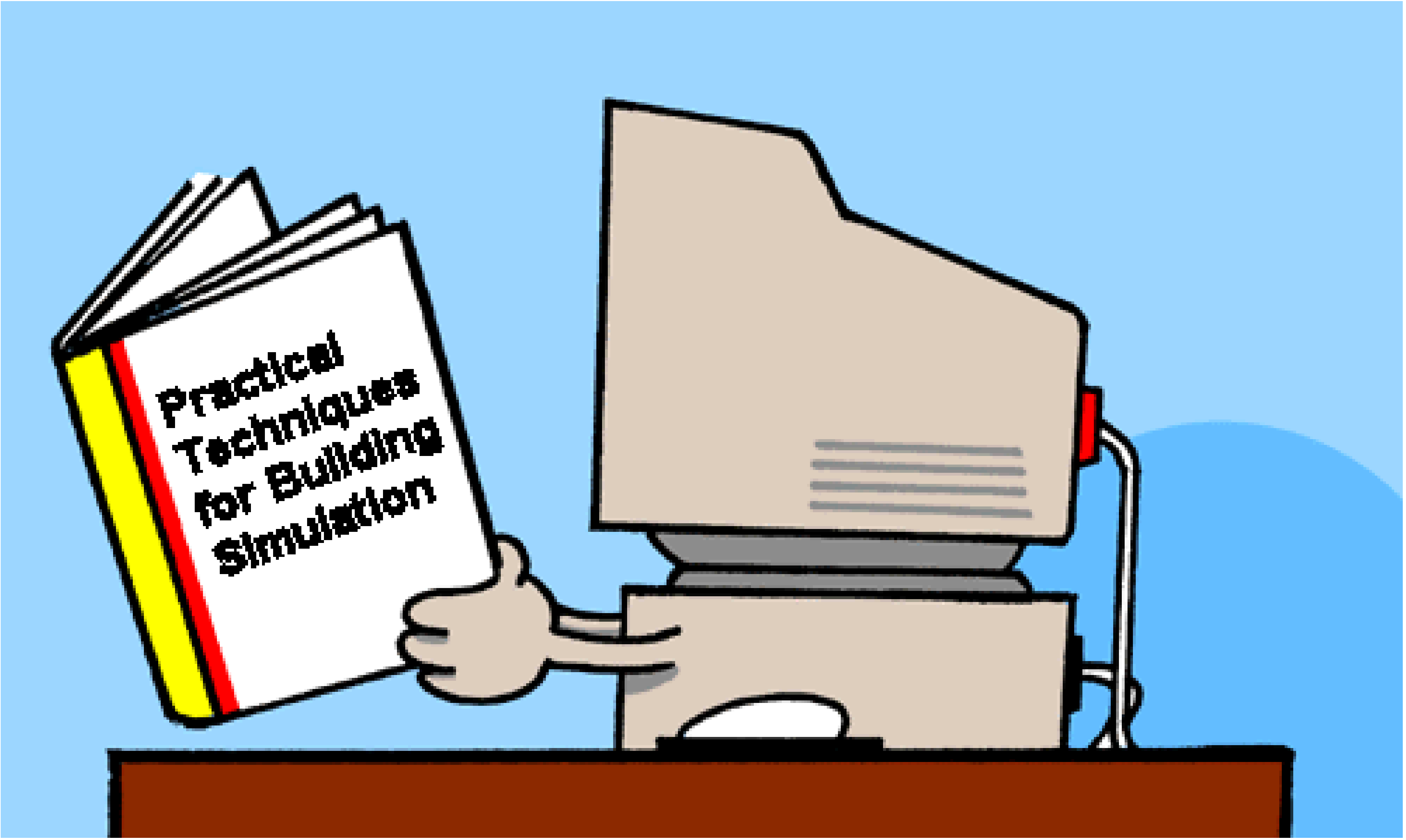
**Table 3.1.** Input QC Checklist

| Topic | Check | ASHRAE 90.1-2004 common errors | Resources |
|---|---|---|---|
| **General information** | | | |
| Simulation program | Verify that approved energy simulation software has been used. | • Using unqualified simulation software, e.g. using Energy-10 for buildings with more than 2 thermal zones or larger than 10,000 sf. | ASHRAE 90.1-2004, Appendix G, Section G 2.2 |
| Weather file and climate zone | Verify that correct weather file and climate zone have been used. | • n/a | n/a |
| Referenced standard | Verify that approved referenced standard has been used. | • Using referenced standard other than ASHRAE 90.1-2004 for project not located in California or Oregon. | n/a |
| New construction percentage | Verify reported percentage of new construction consistent with LEED Online project summary. | • Reporting different percentages on submittal template and LEED Online. | n/a |
| Target finder score | Confirm that Target Finder Score is provided. If not provided, check Table 1.2 of EA Credit 1 submittal template to verify project's primary occupancy. | • Not providing Target Finder Score even though project has Target Finder standard occupancy type. | Target Finder Web site |
| **Space summary** | | | |
| Building floor area | Verify that building floor area is consistent with other credits. Verify conditioned area with IEQ Prerequisite 1. Consider ±10% variance to account for built-up area. | • Building floor area is inconsistent with other credits. | n/a |
| **Building envelope** | | | |
| Existing building | Verify baseline energy modeling approach for existing building renovation. | • Baseline building shell of existing construction is not modeled as it exists prior to any revisions. | ASHRAE 90.1-2004, Table G3.1, Section 5(f) |
| Opaque assemblies | Verify that opaque envelope input reflects correct assembly construction and U-values. | • Incorrect envelope constructions are modeled in baseline building (e.g., exterior walls not modeled with lightweight, steel-framed assemblies). | ASHRAE 90.1-2004, Table G3.1, Section 5(b) |
| Fenestration | Verify that fenestration area modeled for baseline meets referenced standard requirements. | • Baseline vertical fenestration exceeds 40% of gross above-grade wall. | ASHRAE 90.1-2004, Table G3.1, Section 5(c) |
| | Verify that Baseline and Proposed design U-values reflect assembly U-values. | • Proposed design uses center-of-glass U-values rather than whole window | |

(Source: USGBC)

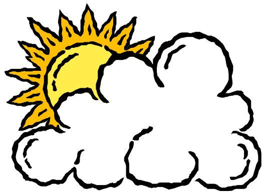
# Applying Simulation

- Related LEED credits:
  - EA Credit 2, On-Site renewable energy
  - EA Credit 6, Green Power
- Exceptional calculation: examples
  - Natural ventilation
  - Process loads
  - Domestic hot water heat recovery
  - Domestic hot water reduction energy savings
  - Interior lighting controls

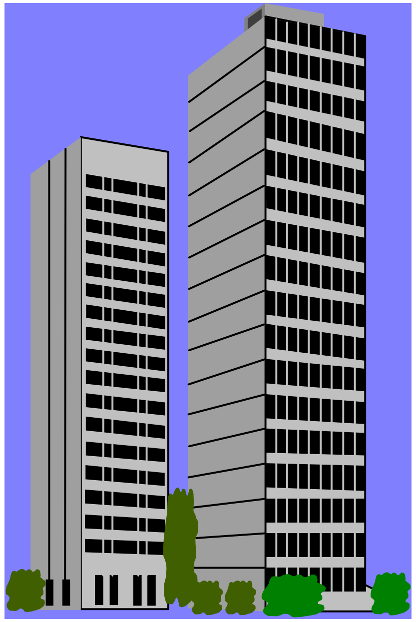

Practical
Techniques
for Building
Simulation

# 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
  - Prepare the input data
  - Run and control the program
  - Interpret the results, analysis and reporting
    - e.g. determine energy and cost savings



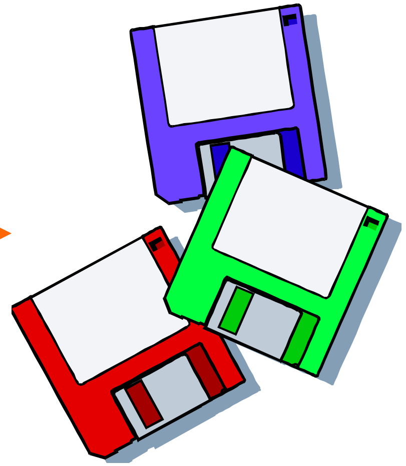
Weather data



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

# Modelling Process

- Ways to prepare simulation input
  - Interactive (filling forms/menus)
  - Built-in graphics
  - Pre-prepared files
  - Import CADD files (geometry data)
- Preparing the input data can be tedious, time-consuming and prone to error

# Modelling Process

- Input data
  - Site data
    - Building type, location, geometry, construction
    - Weather data: design weather, weather files
  - Building data
    - Surface areas, windows, zoning, room shapes
    - Building materials, mass, finishes, shades
    - Operating schedules & profiles
    - Internal loads, design conditions

# Modelling Process

- Input data (cont'd)
  - Building systems
    - HVAC (air side) system type & performance
    - Lighting & electrical services
  - Building plant and equipment
    - Performance of refrigeration, boiler & other plants
  - Data for economic analysis
    - Electricity tariffs/rates, fuel prices
    - Equipment costs, interest rates

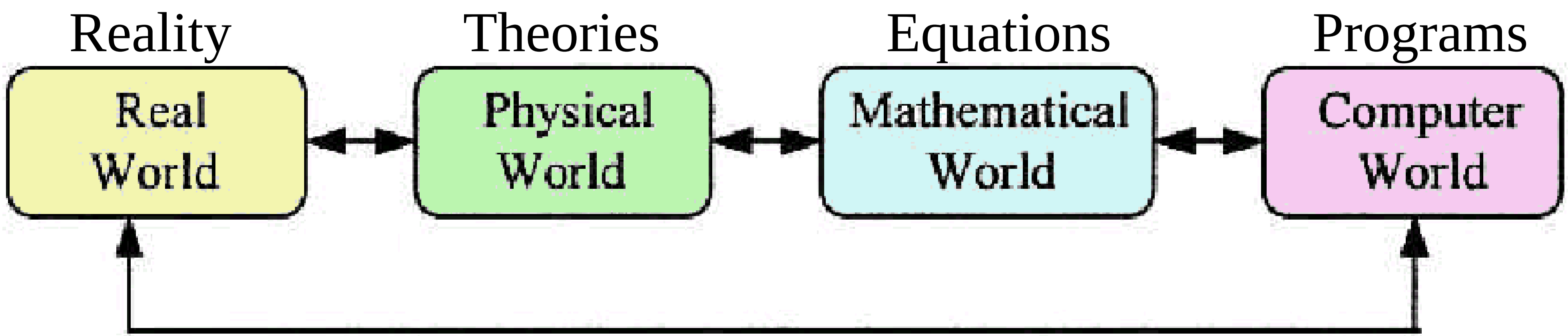
# Garbage In, Garbage Out (GIGO)

# 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

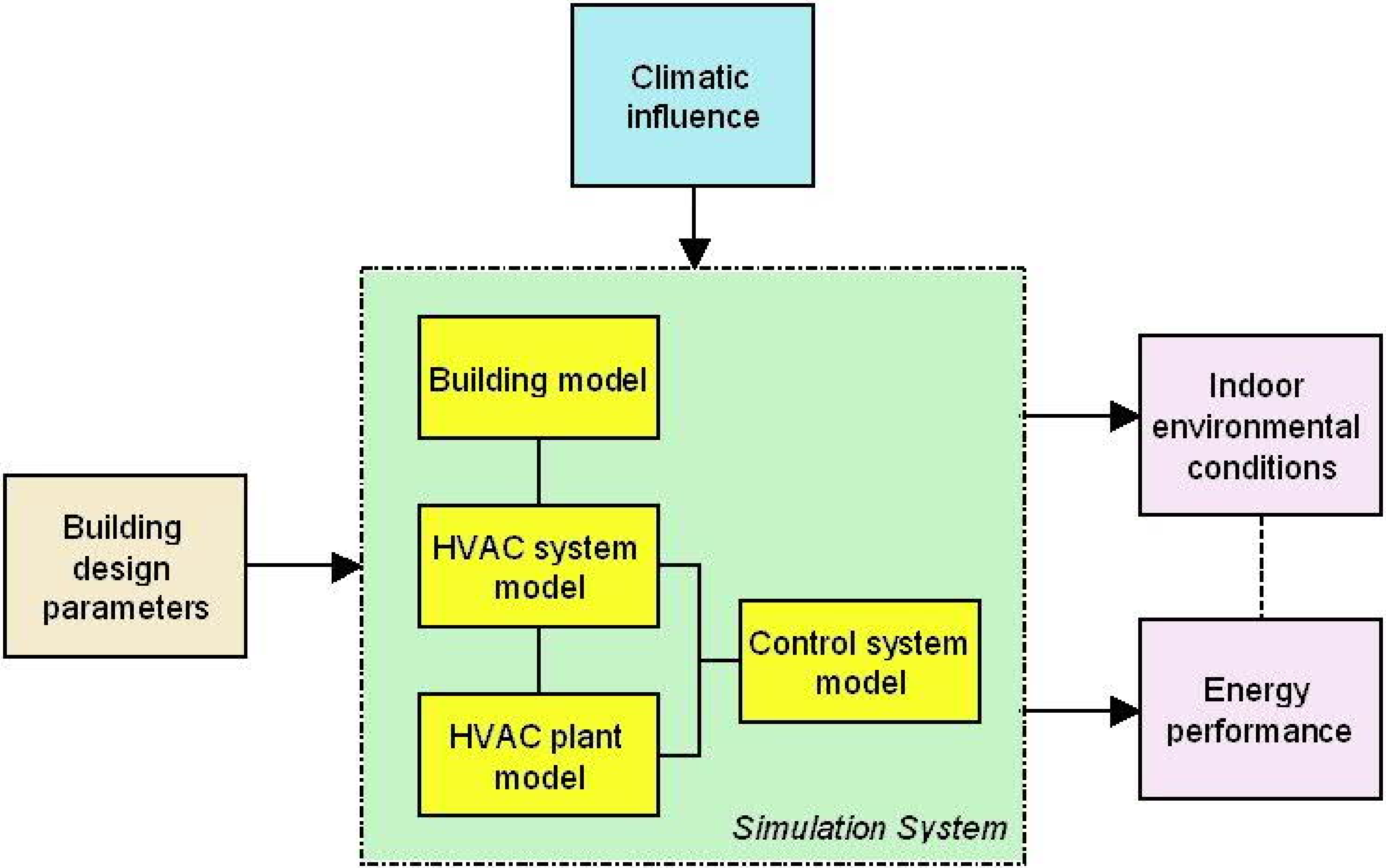


# Modelling Process

- 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

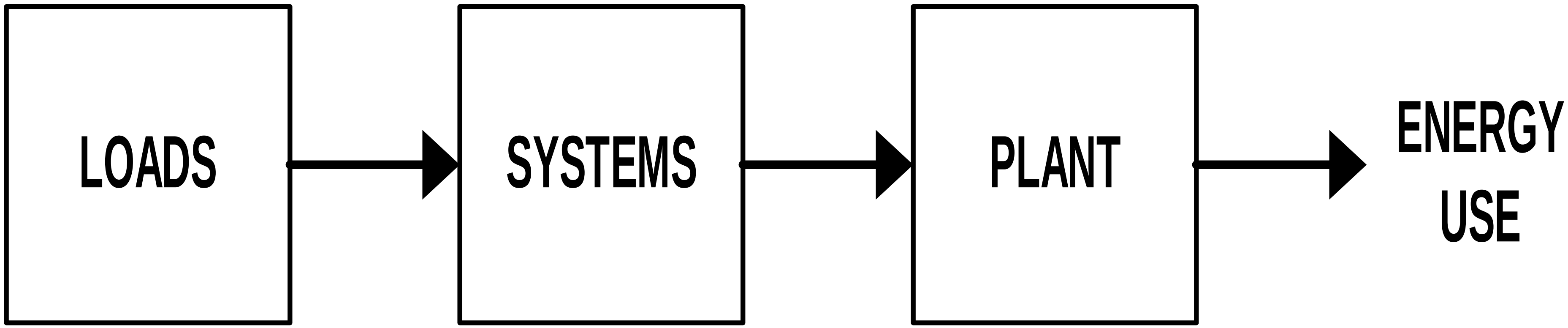
# Modelling Process

- 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

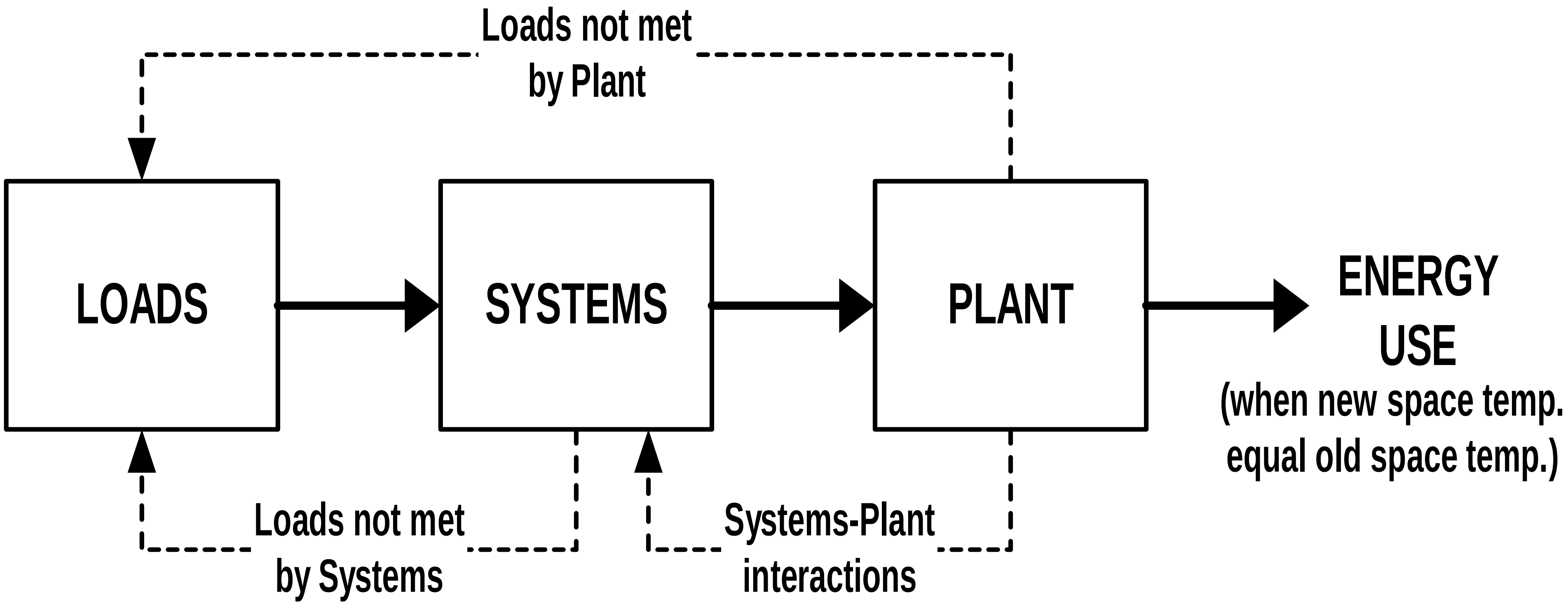


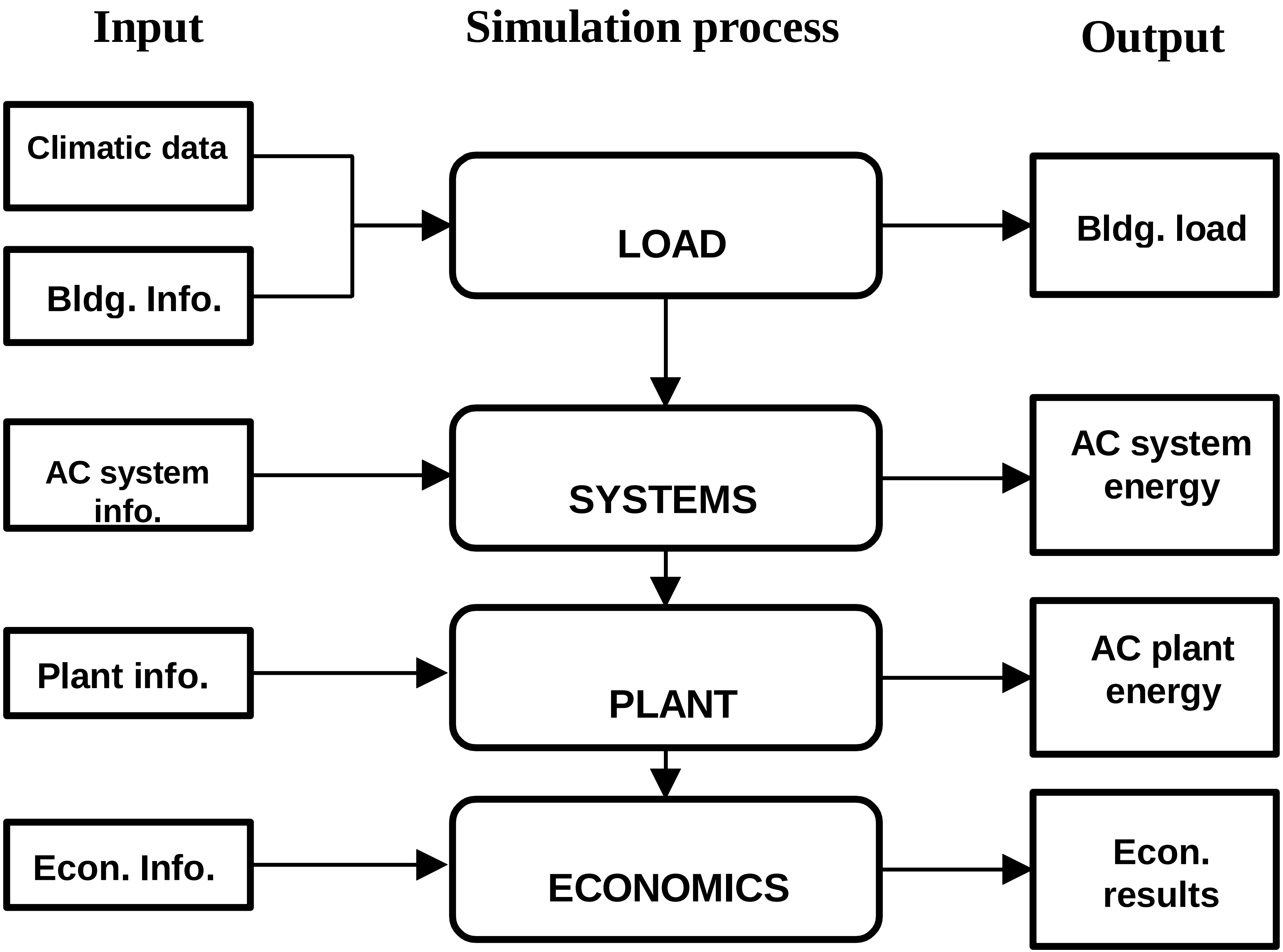

Major elements of building energy simulation

*Sequential approach to building simulation*

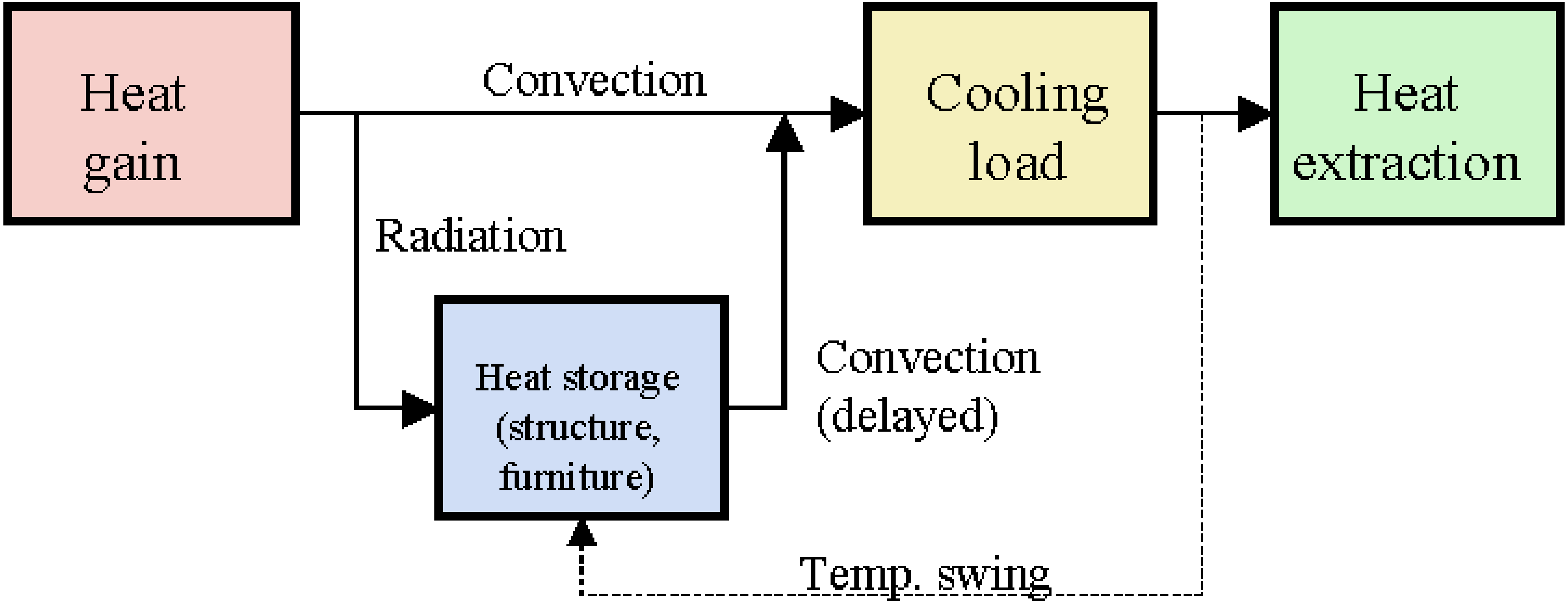



*Simultaneous solution approach to building simulation*



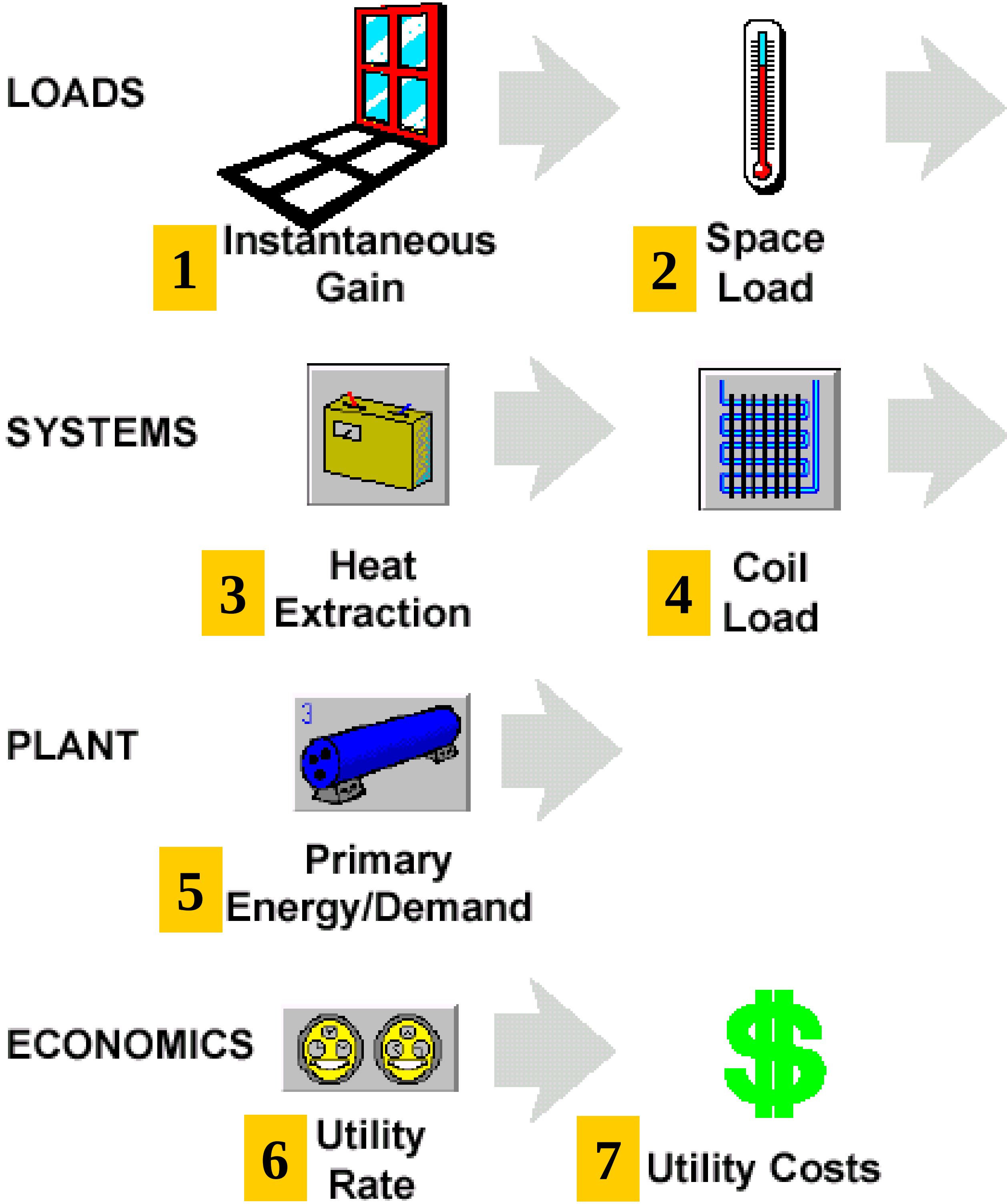



*Information flow in building simulation*




Concept of heat transmission and conversion in buildings

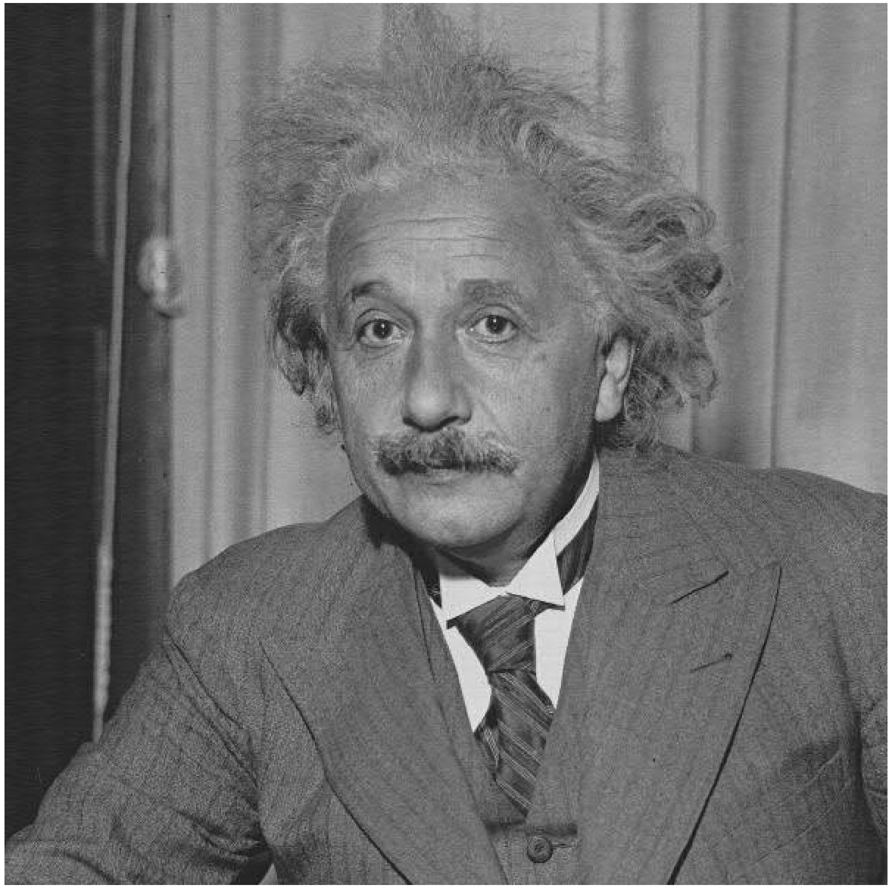
“Seven steps” of simulation output




(Source: eQUEST Tutorial Manual)

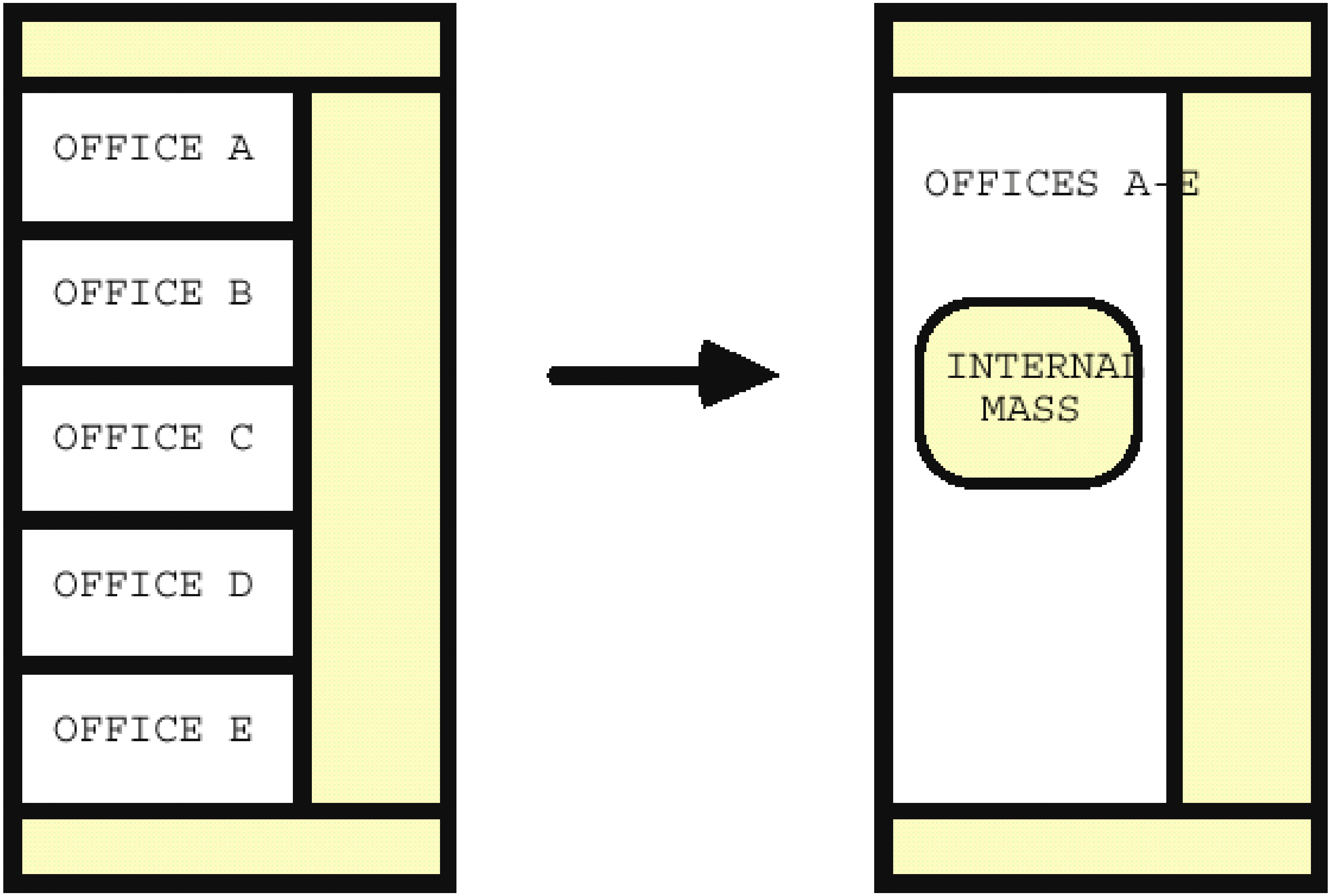
# Simulation Skills

- 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

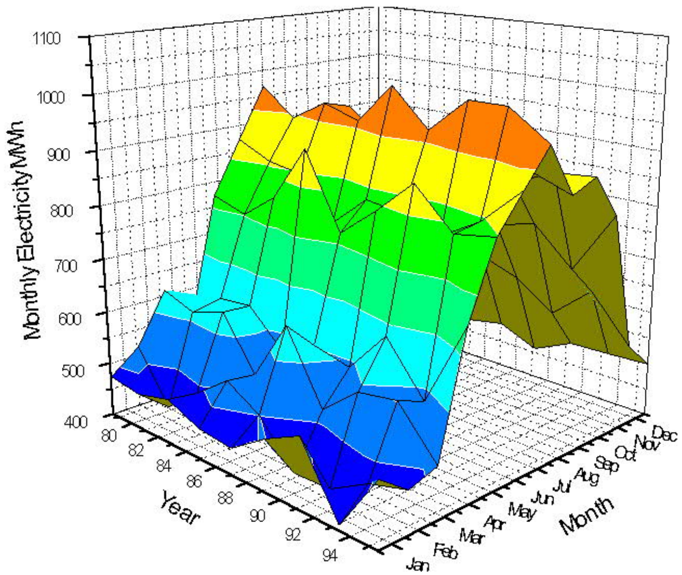
- For existing buildings
  - Study the as-built drawings and existing features
  - Collect historical data and logs
  - Take appropriate measurements
  - Observe building occupancy
- May coordinate energy audit and simulation to calibrate or tune the simulation model

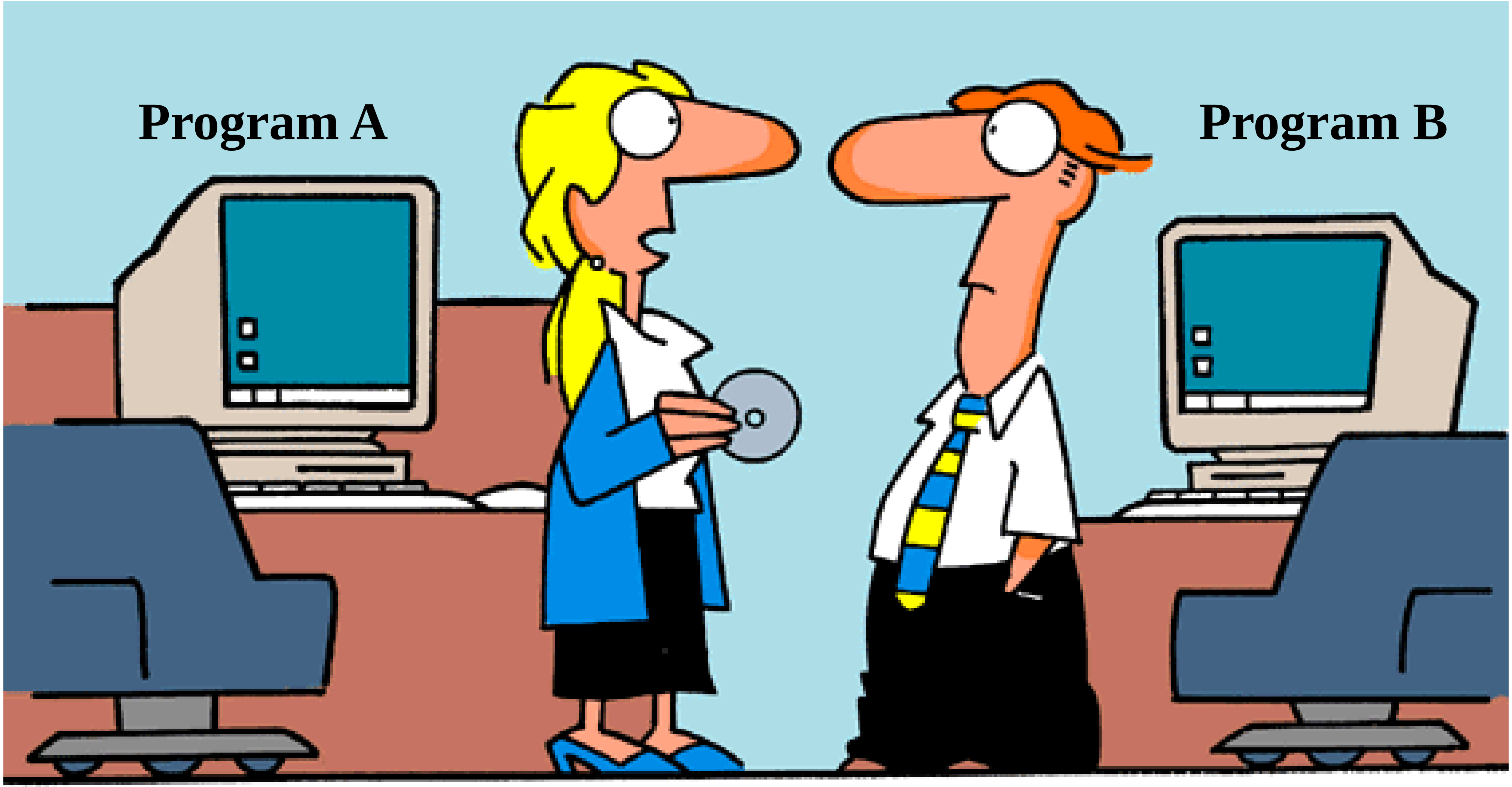
# Simulation Skills

- 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

# Simulation Skills

- Review techniques
  - Look for anomalous data (e.g. by charting)
  - Develop a quality control checklist of key parameters
  - Do the results make sense?
- "Reasonableness"
  - Compare with norms
  - Can it be reasoned?






**" 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.)

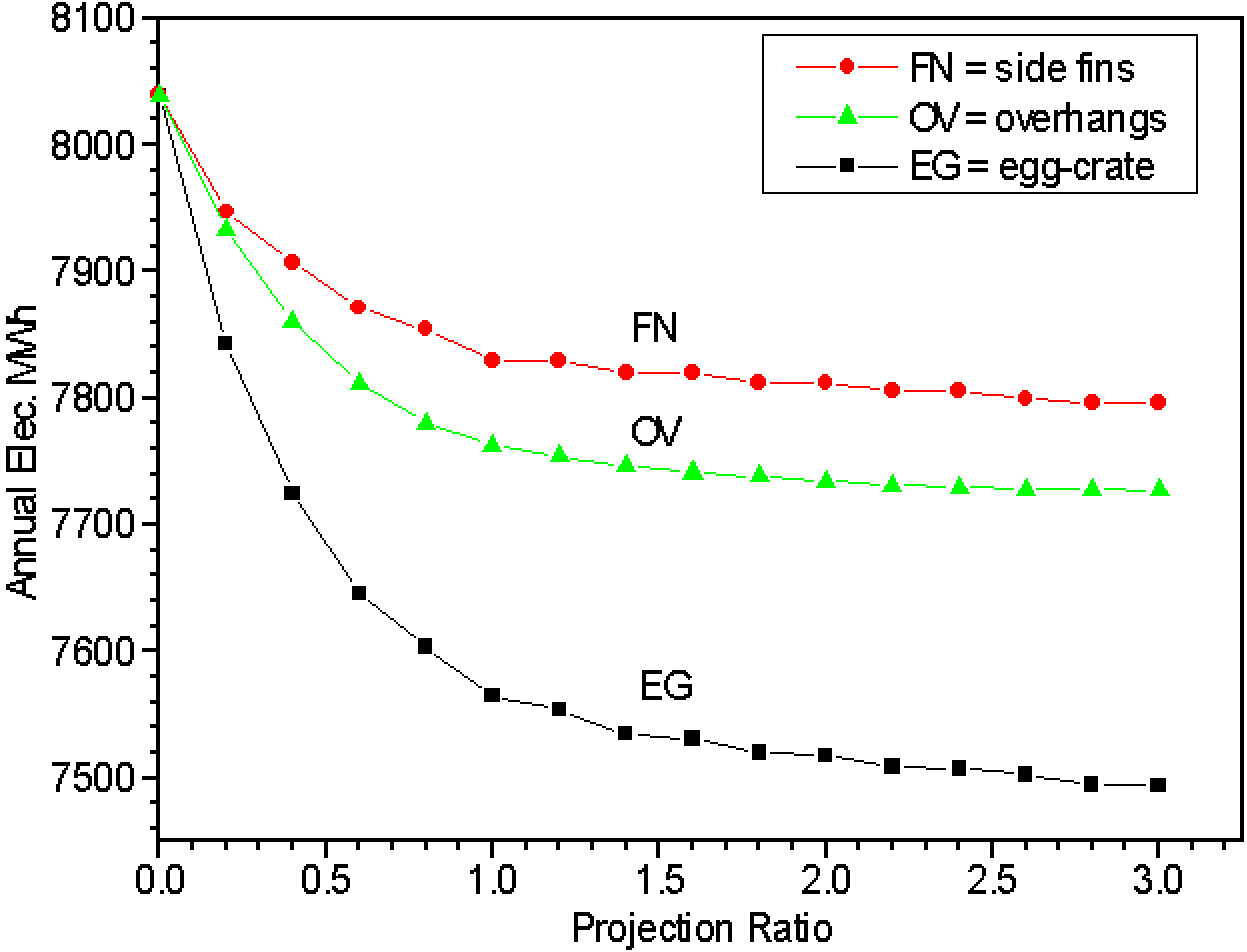
# Simulation Skills

- 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

- What is the goal of the analysis?
  - Design problem may have some missing parameters and a few possible answers
  - Define your major criteria and structure the design question, such as:
    - To evaluate different window design options based on energy performance
    - To assess several HVAC systems based on energy efficiency and costs

# Example: Effects of external shading on energy consumption

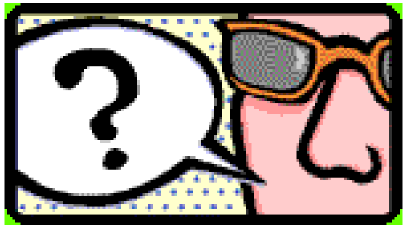


# Simulation Skills

- 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

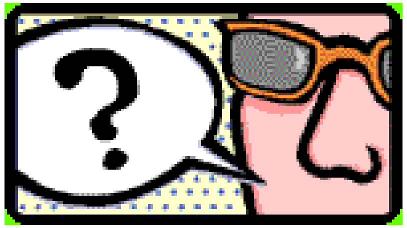

**" It's the latest innovation in office safety. When your computer crashes during the simulation process, an air bag is activated so you won't bang your head in frustration."**

# Simulation Skills

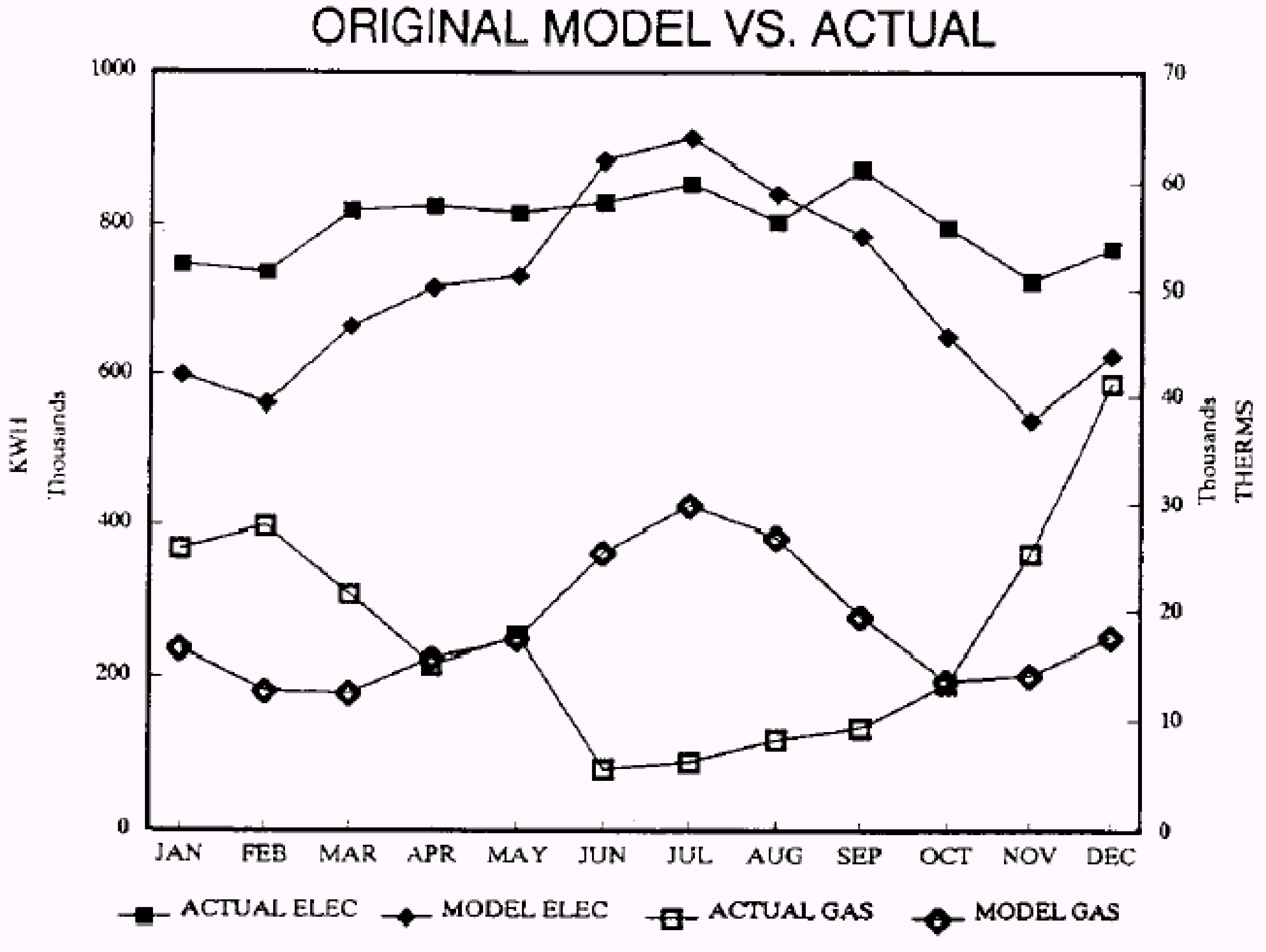


- Error checking and model debugging
  - Read carefully the error/diagnostic messages
- Check the model input and output by a second pair of sharp eyes
- Allow time for critical thought
  - Look at the overall picture
  - Think about the results from a distance
  - Allow time for calm reflection

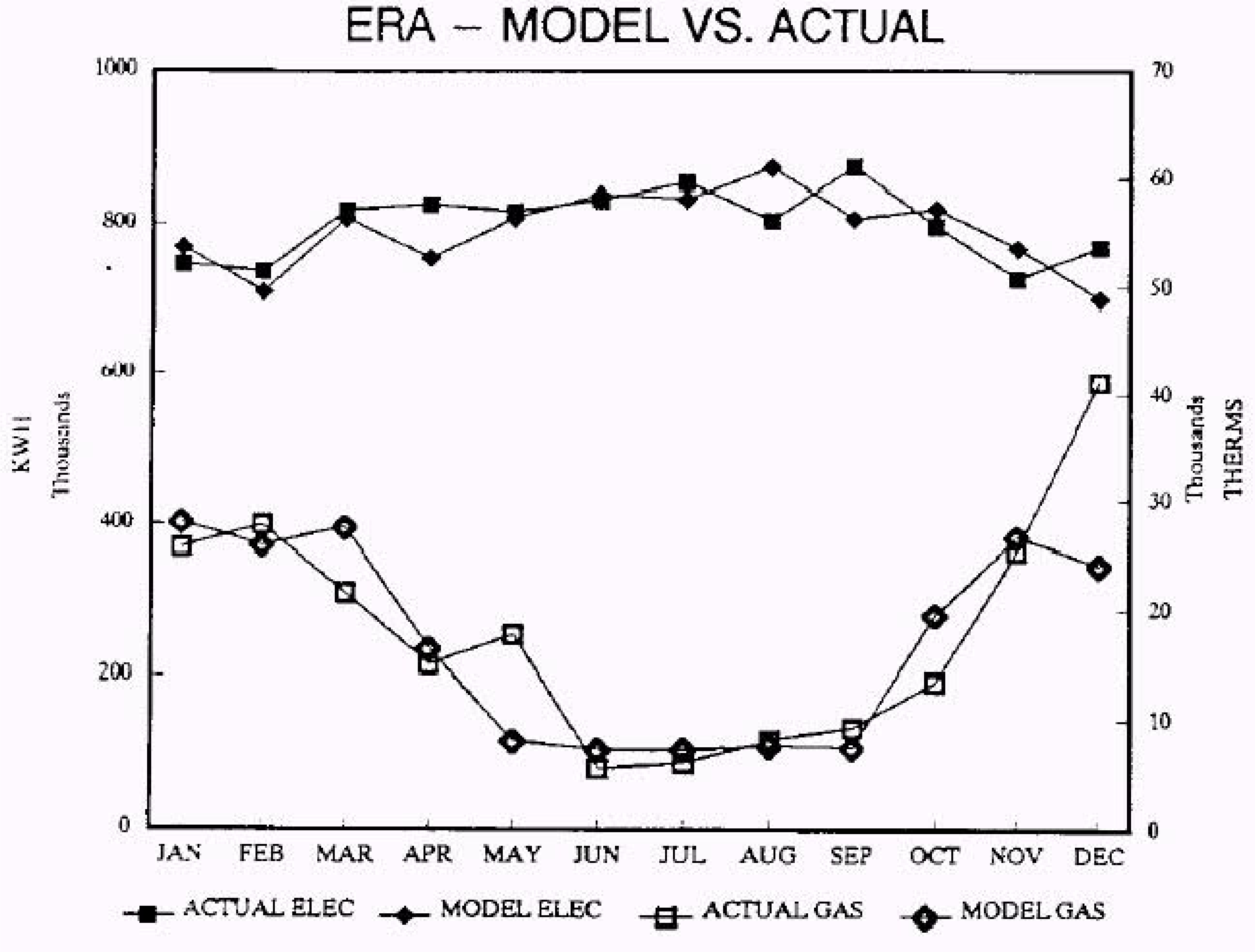
# Simulation Skills



- 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.)

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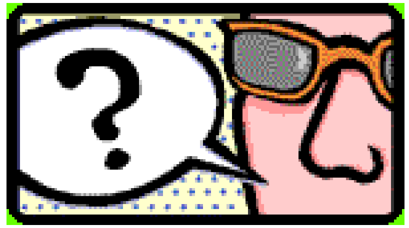
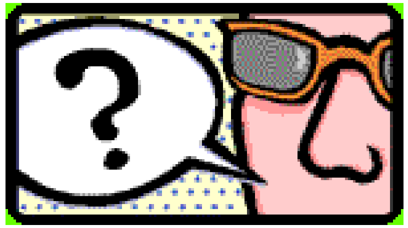
# Simulation Skills



- 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?

# Simulation Skills



- Further reading:
  - Energy Analysis Tools (Whole Building Design Guide), www.wbdg.org/resources/energyanalysis.php
  - E Source, Inc., 2000. *Energy Design Resources Design Brief: Building Simulation*, Southern California Edison, San Francisco, CA, 16 pages.
  - 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