Seminar jointly organised by
Department of Civil Engineering and CICID, HKU
12 Aug 2013 (Mon)

Modelling of Building Energy Use and Carbon Emissions

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Aug 2013

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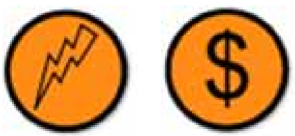
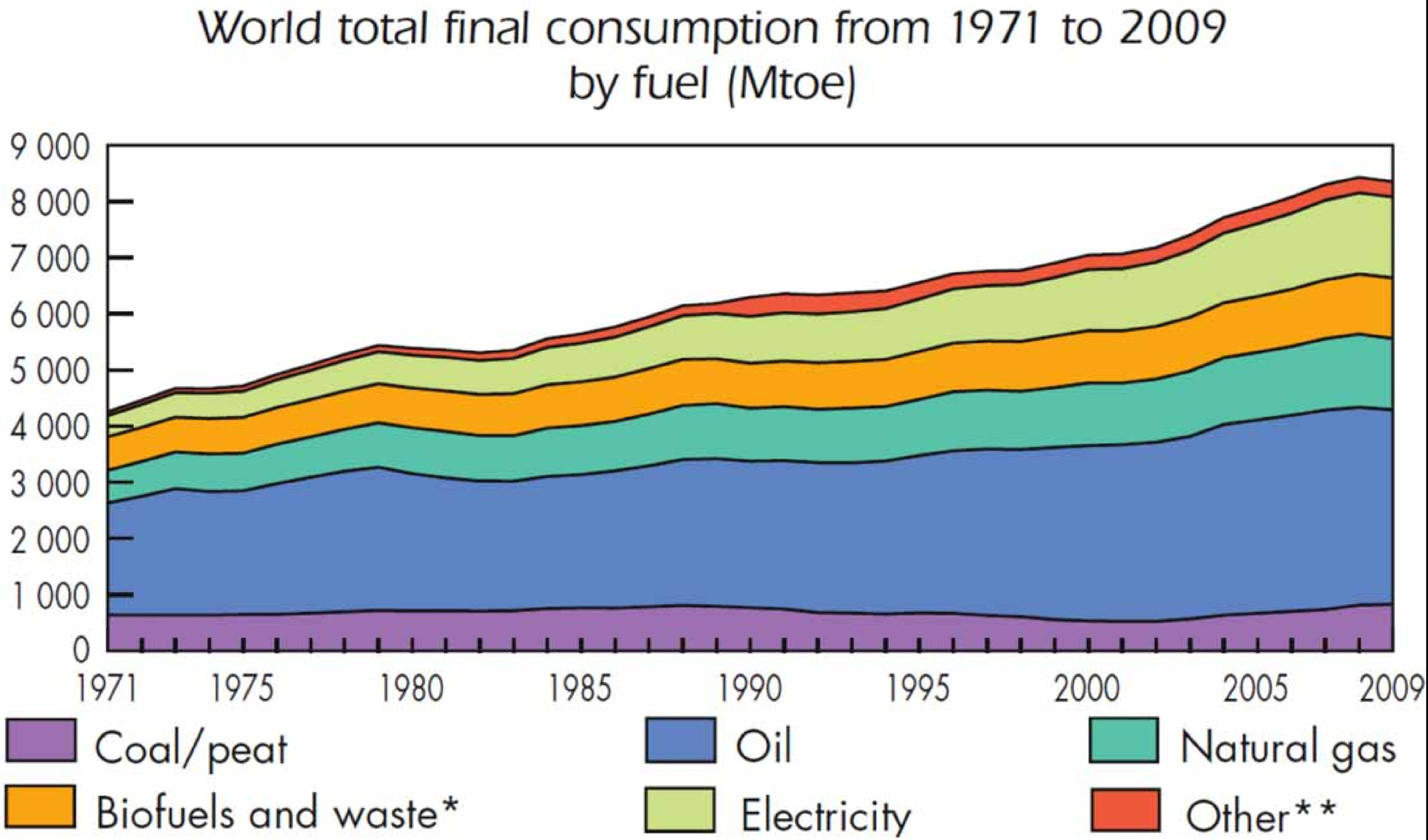
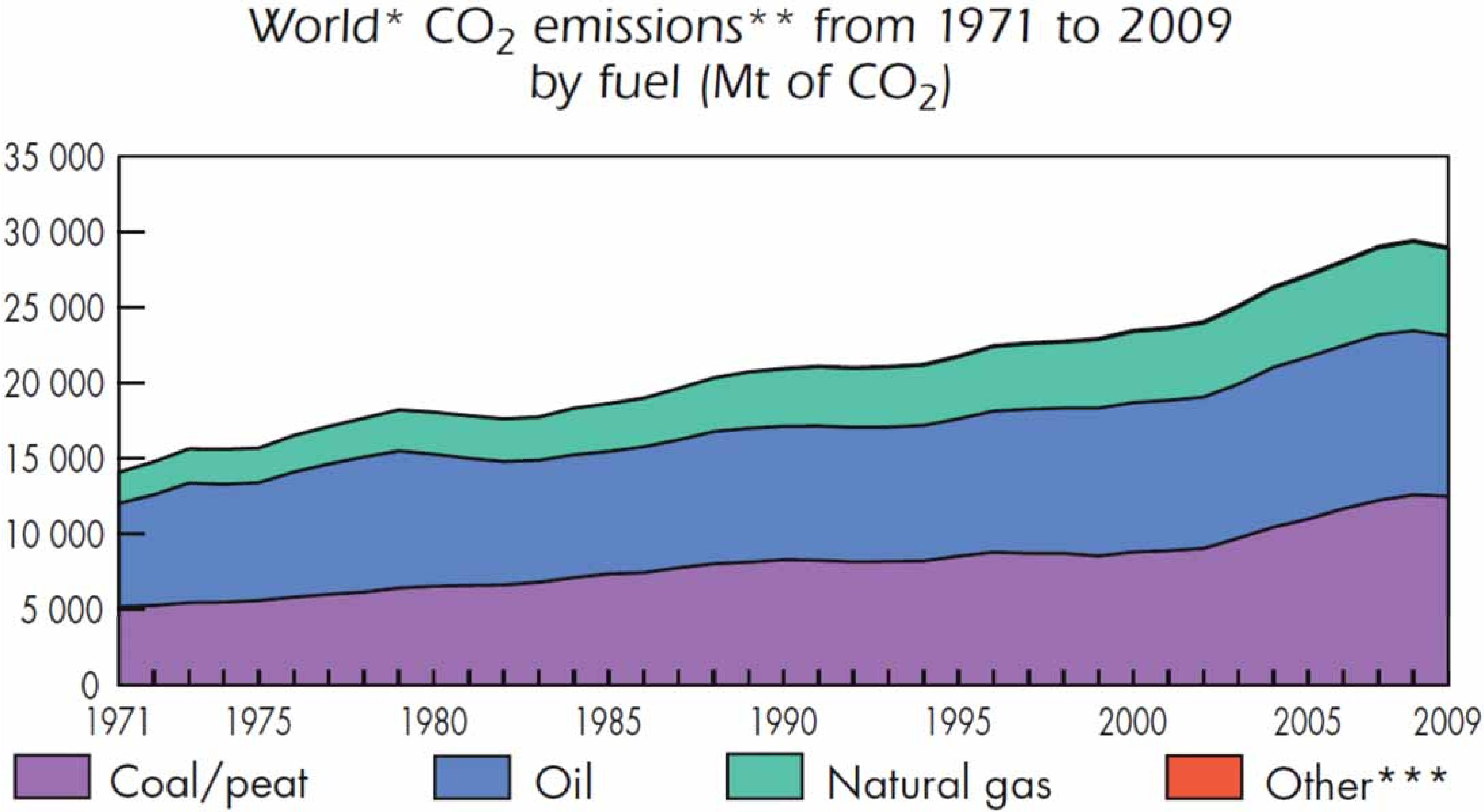
Introduction

- **Energy** is important to every society
  - Economic, environmental & social impacts
  - It is also a key issue for ***sustainable development***
- Use energy …
  - Consume finite fossil fuels (oil, coal, natural gas)
  - Cause air pollution & environmental damage
  - Contribute to global warming
  - Cost money





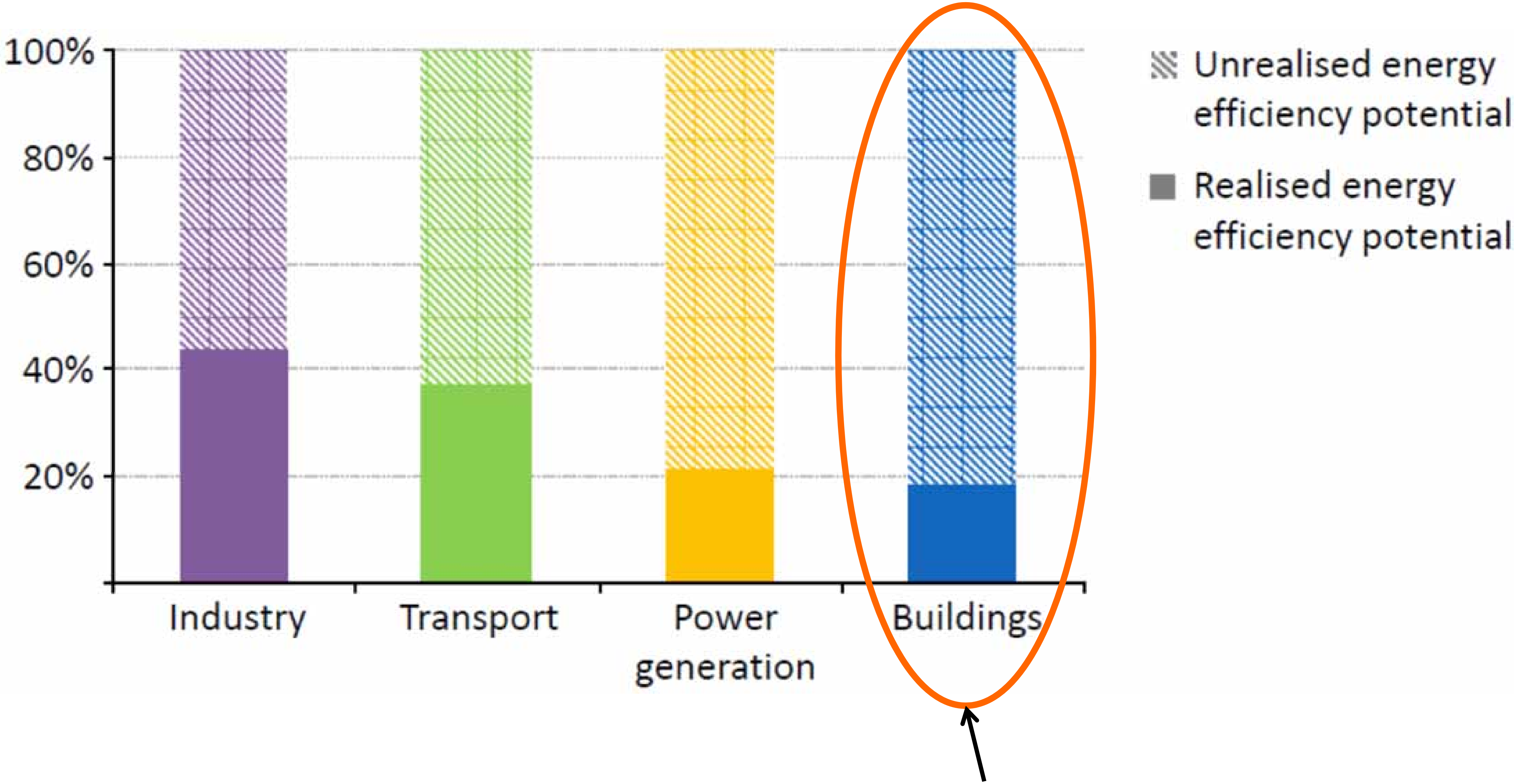
(* Source: IEA, 2011. *Key World Energy Statistics 2011*, International Energy Agency, Paris. Available at www.iea.org)



***Other includes industrial waste and non-renewable municipal waste

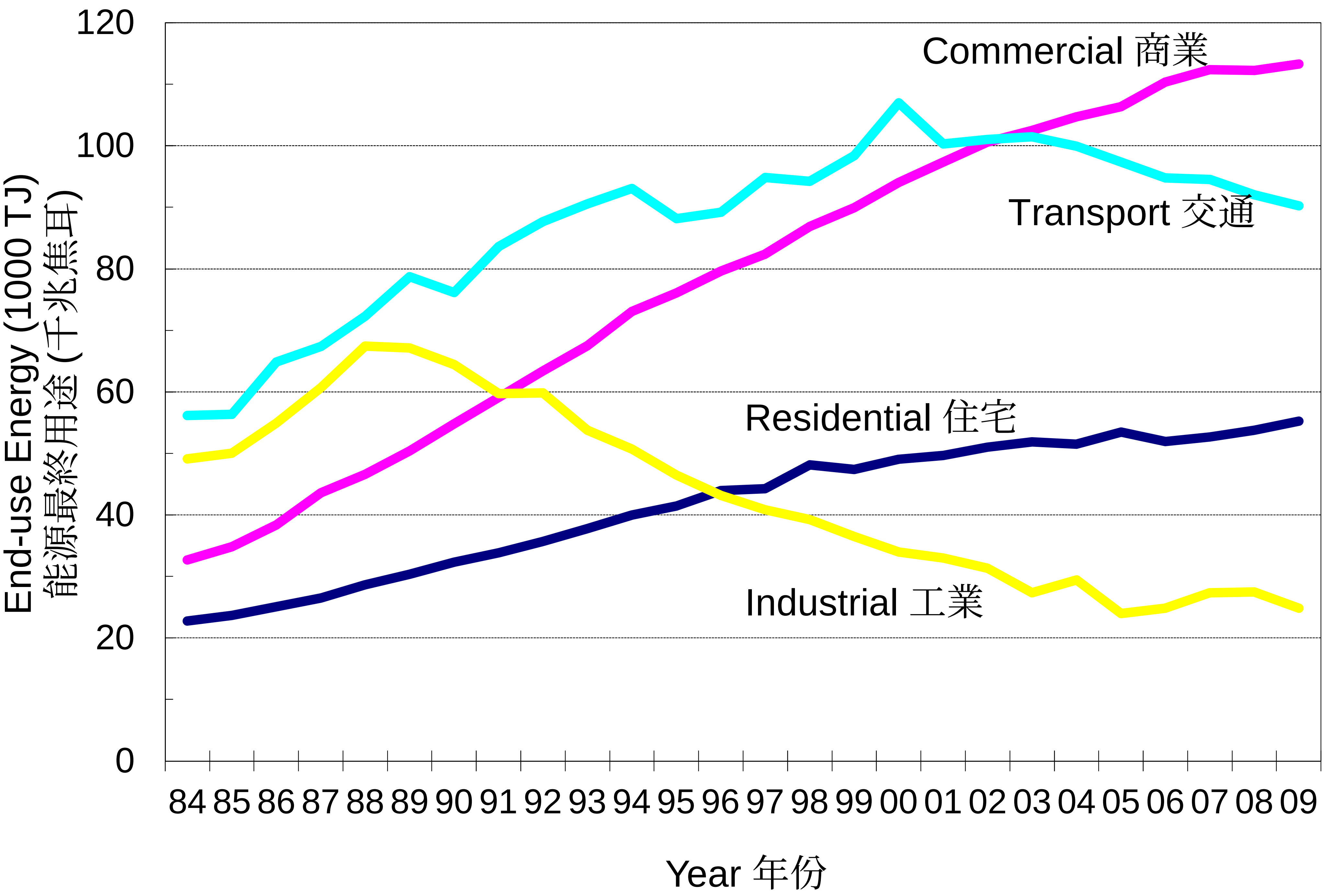
(* Source: IEA, 2011. *Key World Energy Statistics 2011*, International Energy Agency, Paris. Available at www.iea.org)

Energy efficiency potential used by sector: a huge opportunity going unrealised

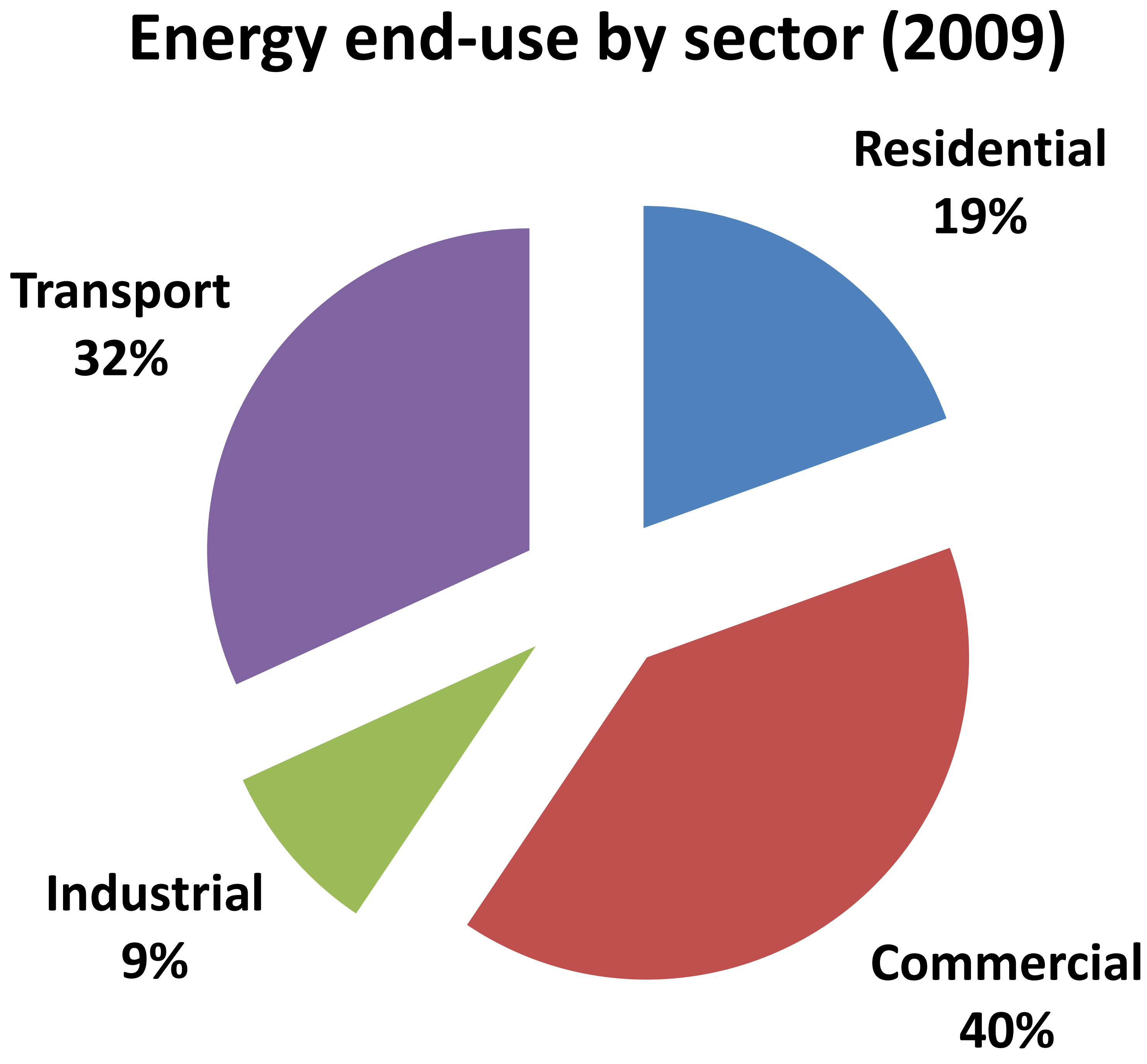


The building sector has the largest potential

(Source: Fatih Birol, Chief Economist, International Energy Agency, www.iea.org)



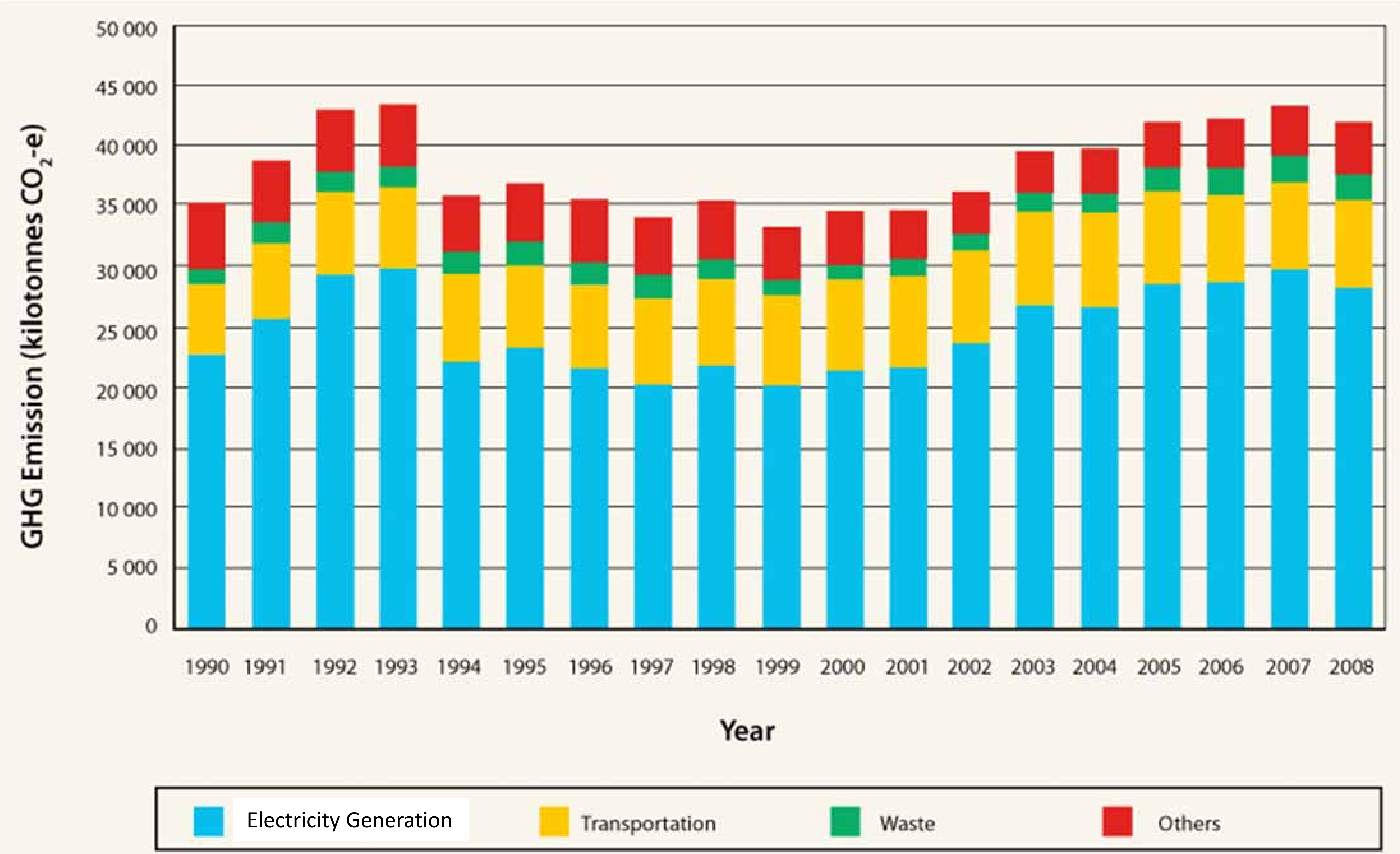
(Data source: EMSD) Energy end-use in Hong Kong by sectors, 1984-2009



Energy end-use in Hong Kong

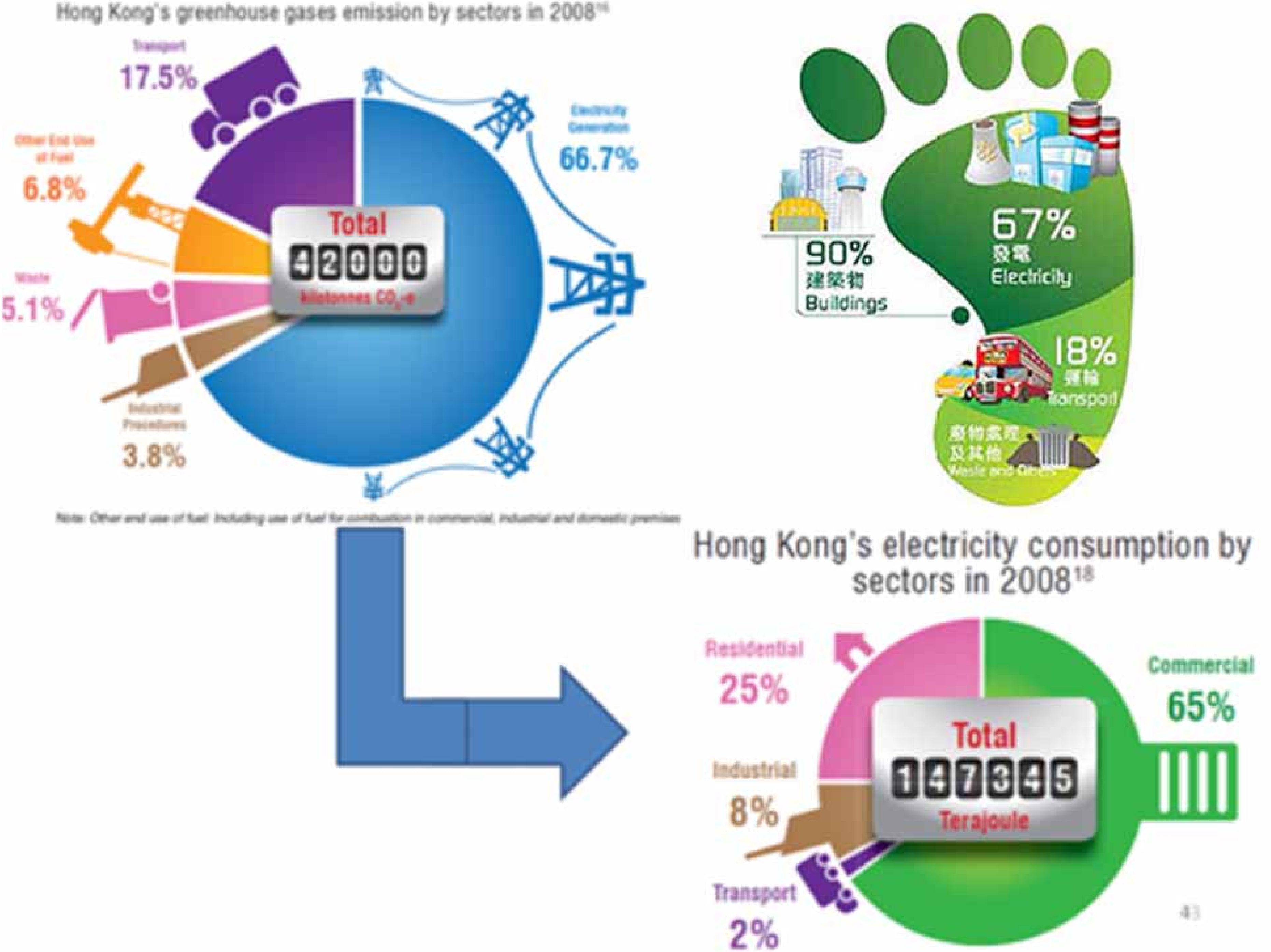
(Data source: EMSD)

Greenhouse gas (GHG) emission trends of Hong Kong 1990-2008



(Source: www.epd.gov.hk)

Greenhouse gas (GHG) emission of Hong Kong 2008



(Source: www.epd.gov.hk)

Timeline of building energy efficiency regulations in Hong Kong

1991-1995

- 1991 Feasibility study on introduction of OTTV control in Hong Kong
- 1995 Building (Energy Efficiency) Regulations (Cap. 123 sub. Leg. M); HK OTTV Code of Practice

1996-2000

- 1998 Lighting Code and AC Code; launch of the Energy Efficiency Registration Scheme for Buildings (voluntary)
- 1999 Electrical Code
- 2000 Lift and Escalator Code; Revised OTTV limits

2001-2005

- 2004 Performance-based Code; Guidelines on Energy Audit
- 2005 Updated edition of the five codes

2006-2010

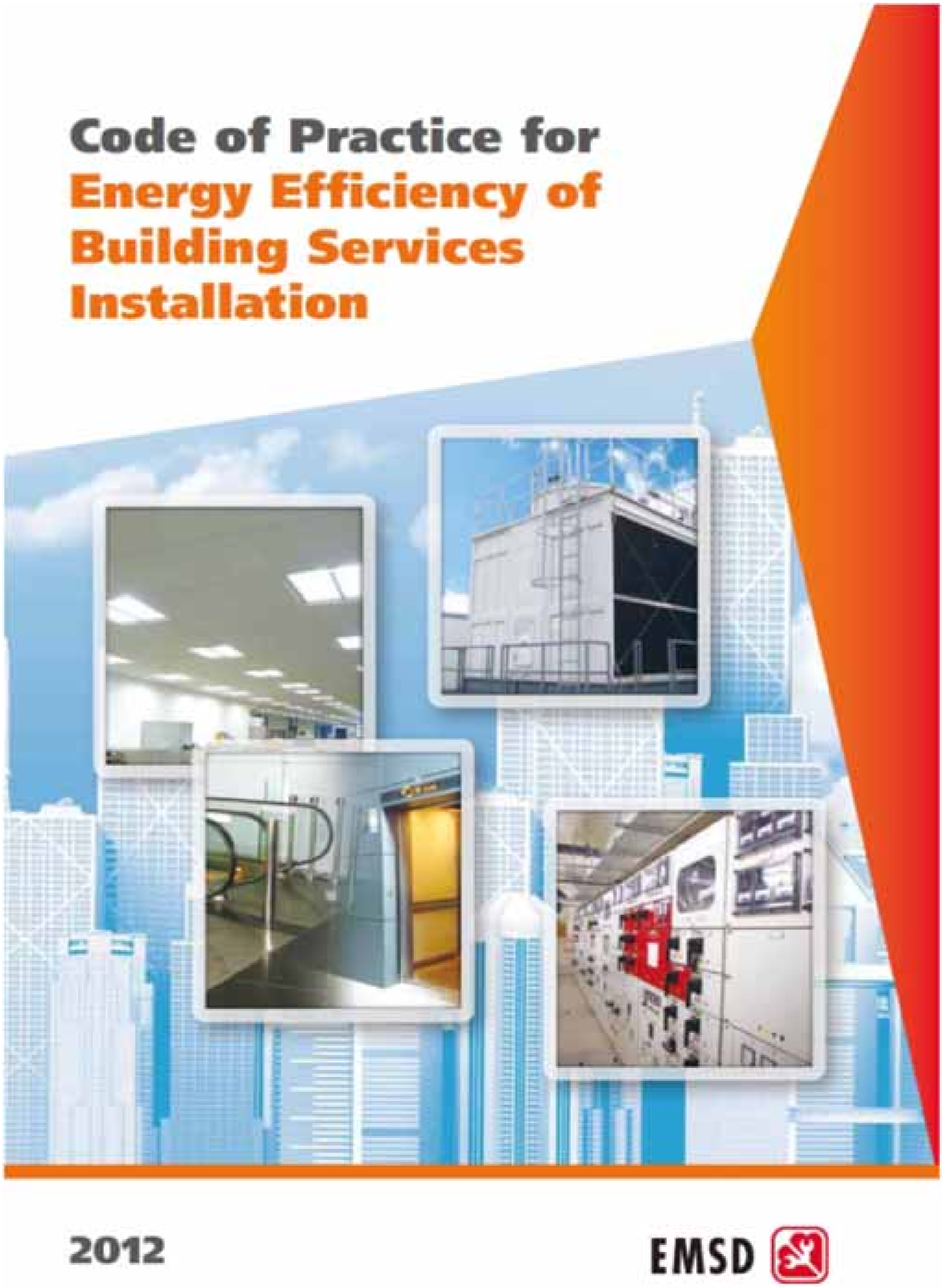
- 2007 Updated edition of the five codes; Updated Guidelines on Energy Audit
- 2010 Buildings Energy Efficiency Ordinance (Cap. 610) (mandatory)

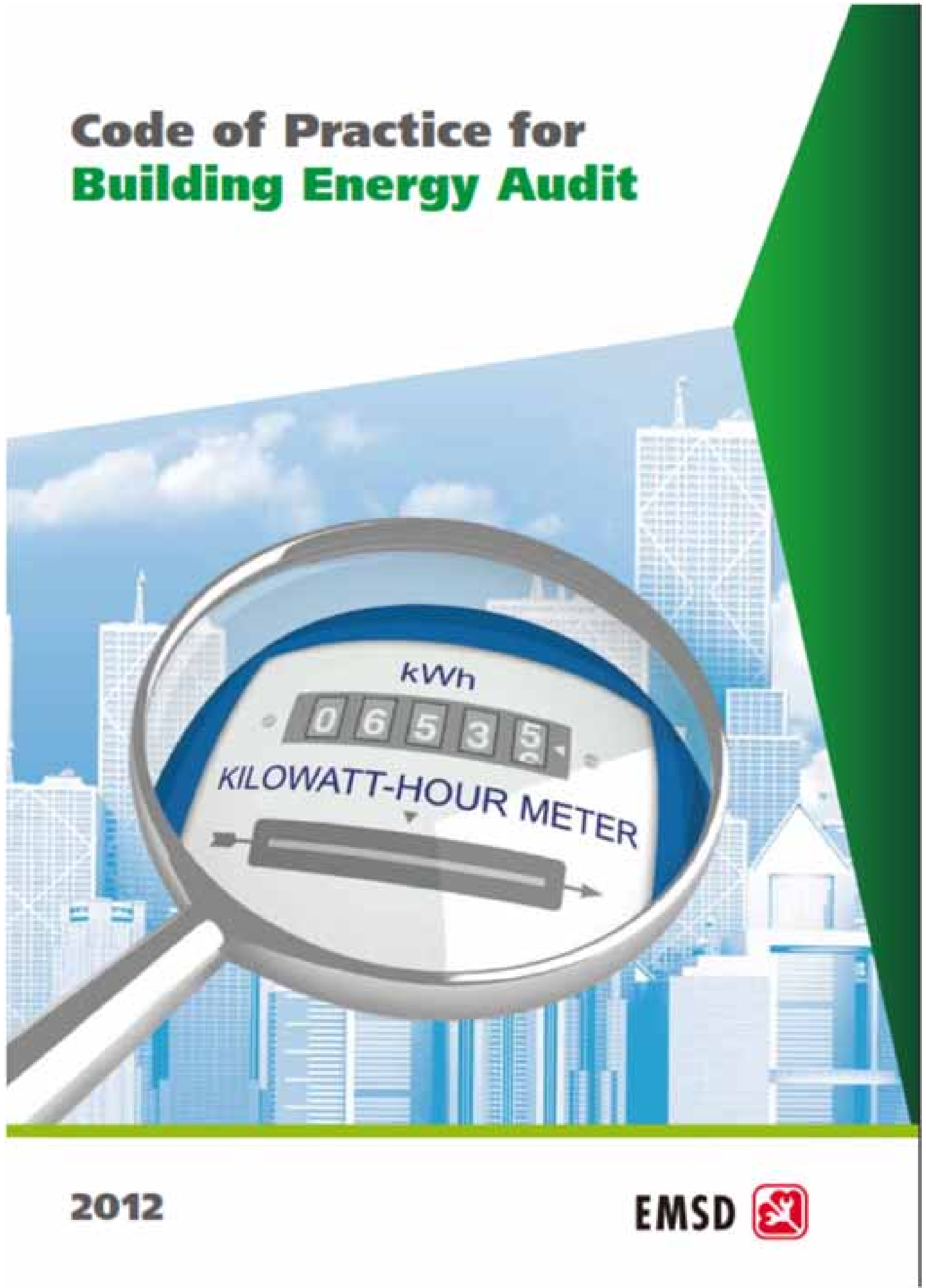
2011-Now

- 2011 Revised OTTV limits
- 2012 Full operation of the Buildings Energy Efficiency Ordinance (including Building Energy Code and Energy Audit Code)

(Source: EMSD)

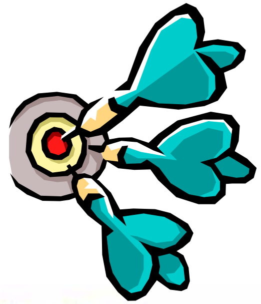
(See http://www.beeo.emsd.gov.hk for details)





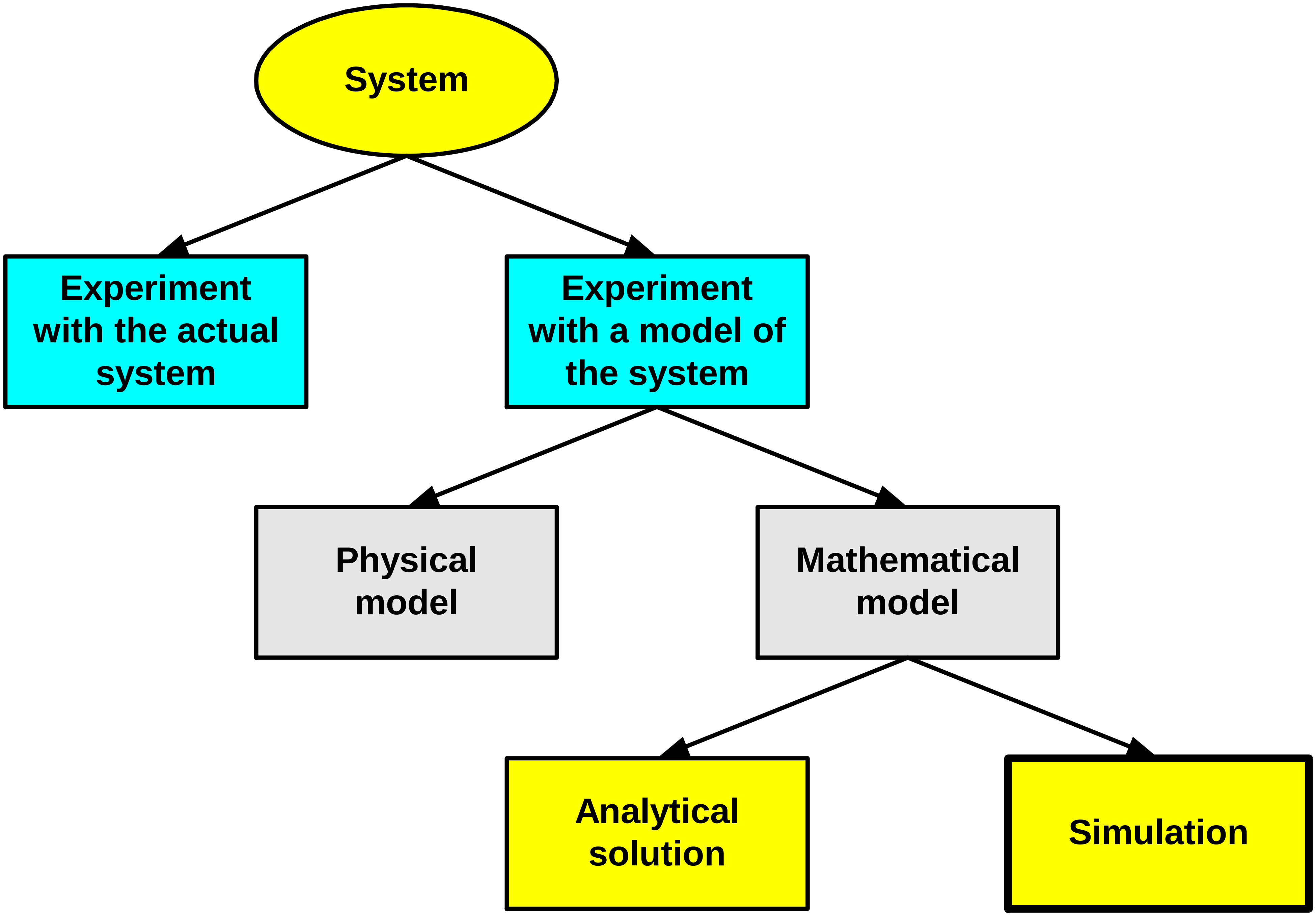
(Source: www.emsd.gov.hk)

Building Energy Simulation

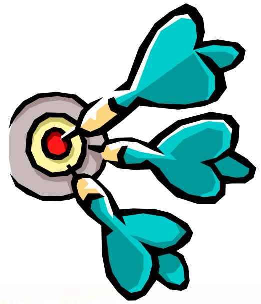


- Energy performance of buildings is usually complicated and requires detailed analysis to determine the characteristics
- Building energy simulation and modelling techniques are often used to study it so as to support decisions for building design, operation and management

Ways to study a system

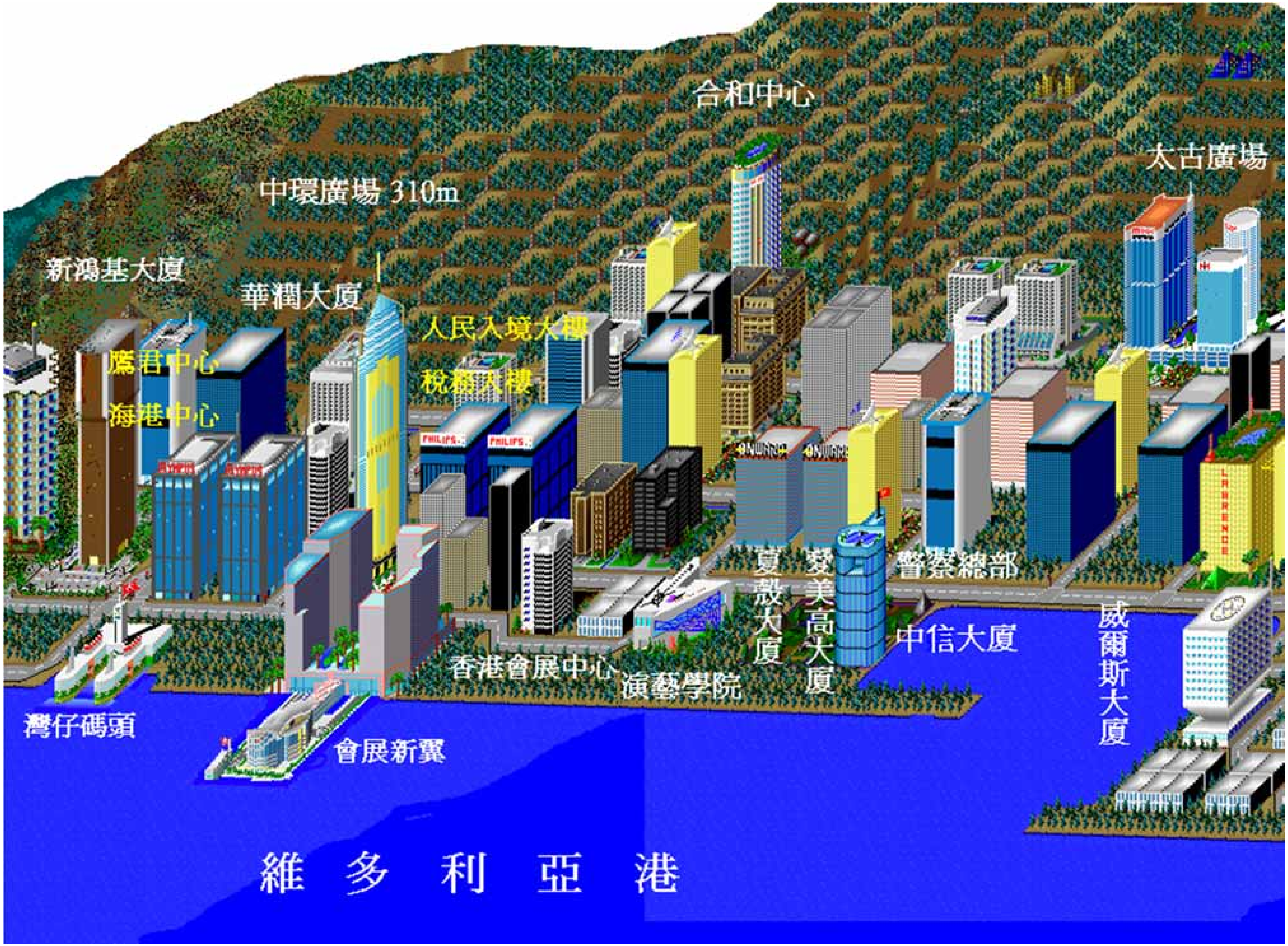


Building Energy Simulation

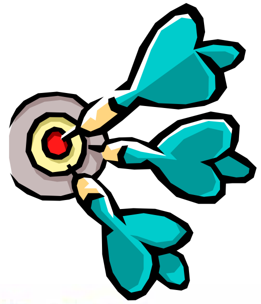


- Simulation: (模擬)
  - From latin "*simulare*" – to pretend
  - Using a mathematical model of a system to predict its output for a given input
    - Asking "**what if?**" within an imaginary framework
  - To simulate => to imitate the operations of real-world facilities or process
  - Examples:
    -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

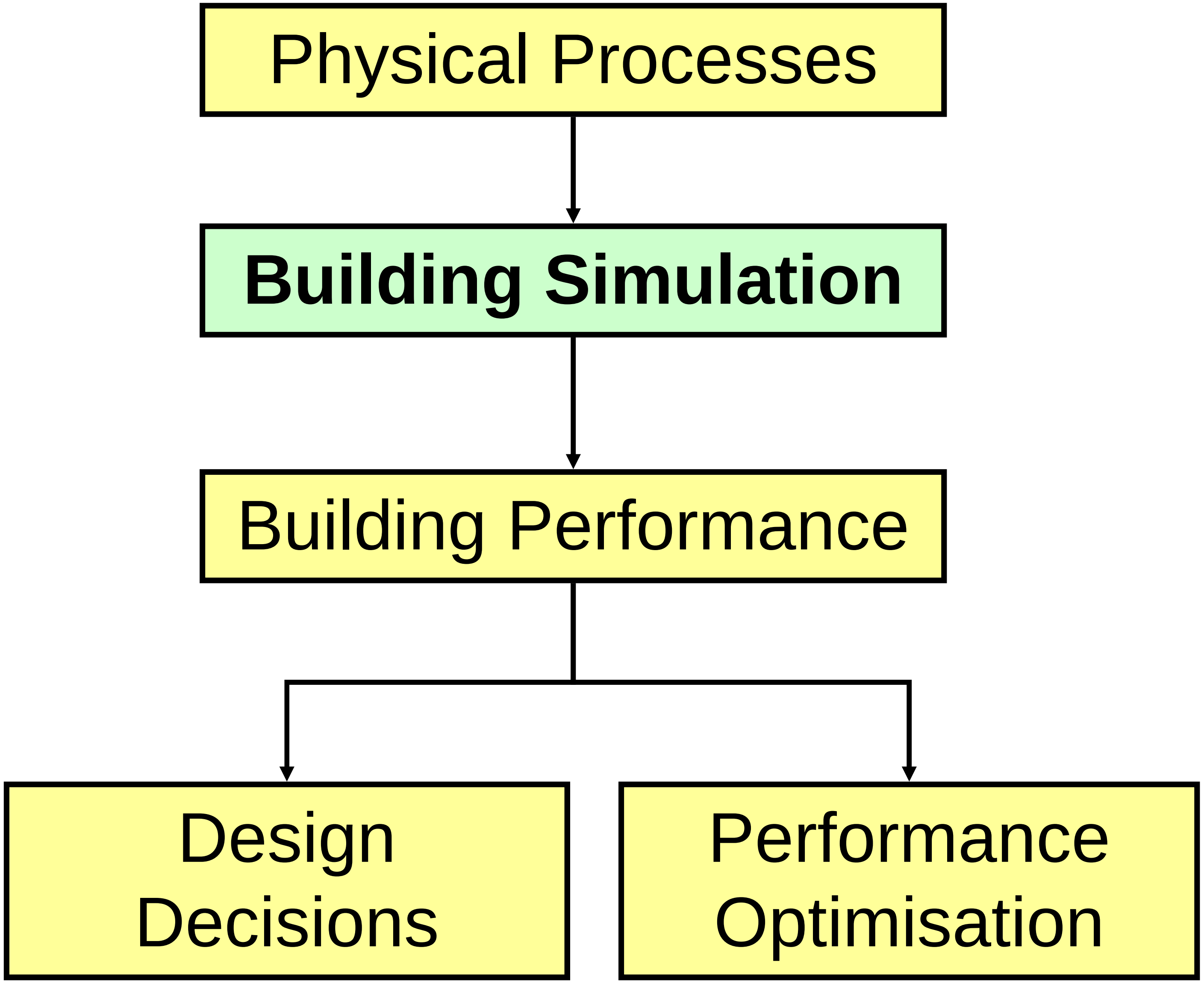
SimCity of Hong Kong's buildings



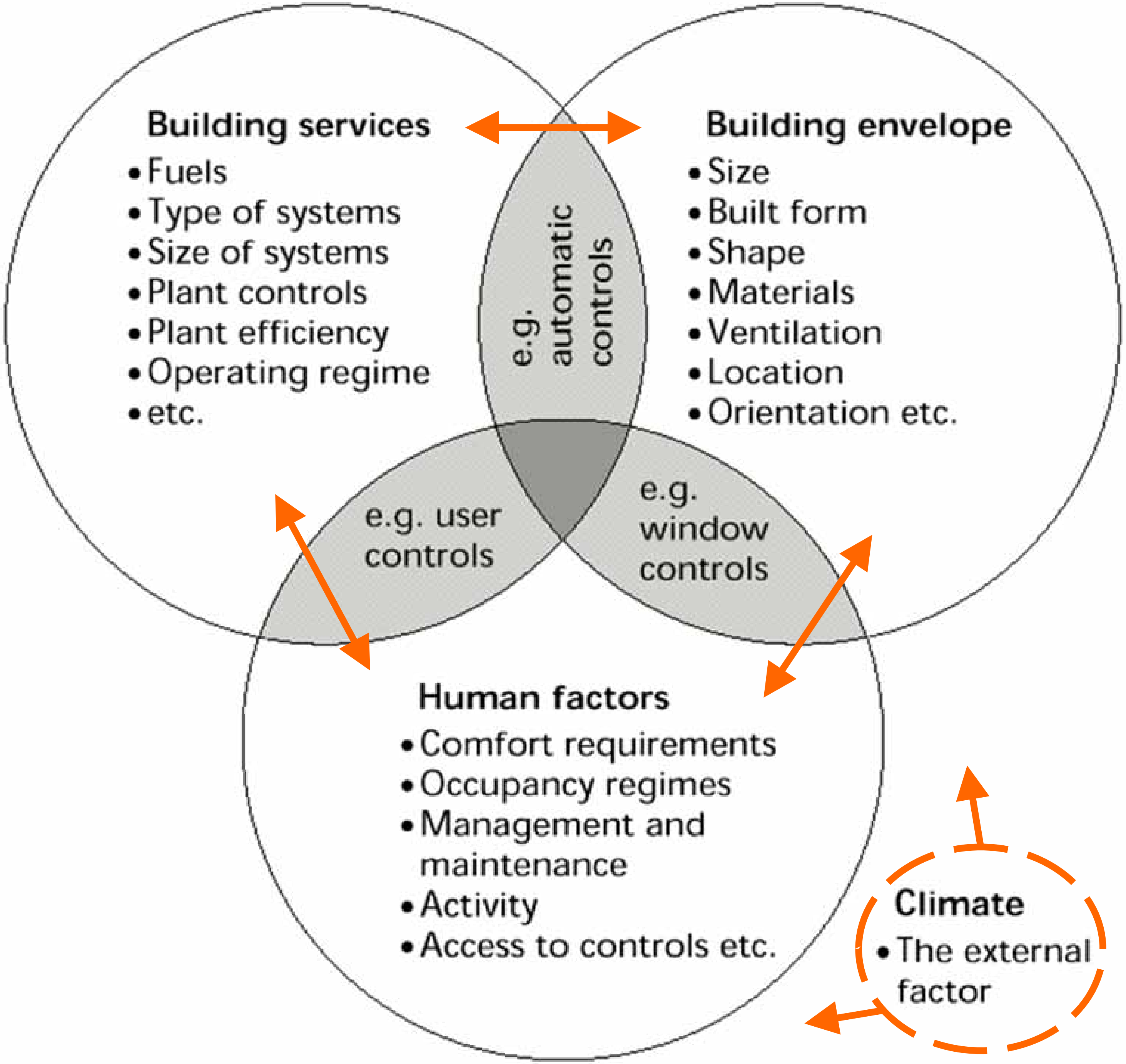
Building Energy Simulation



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

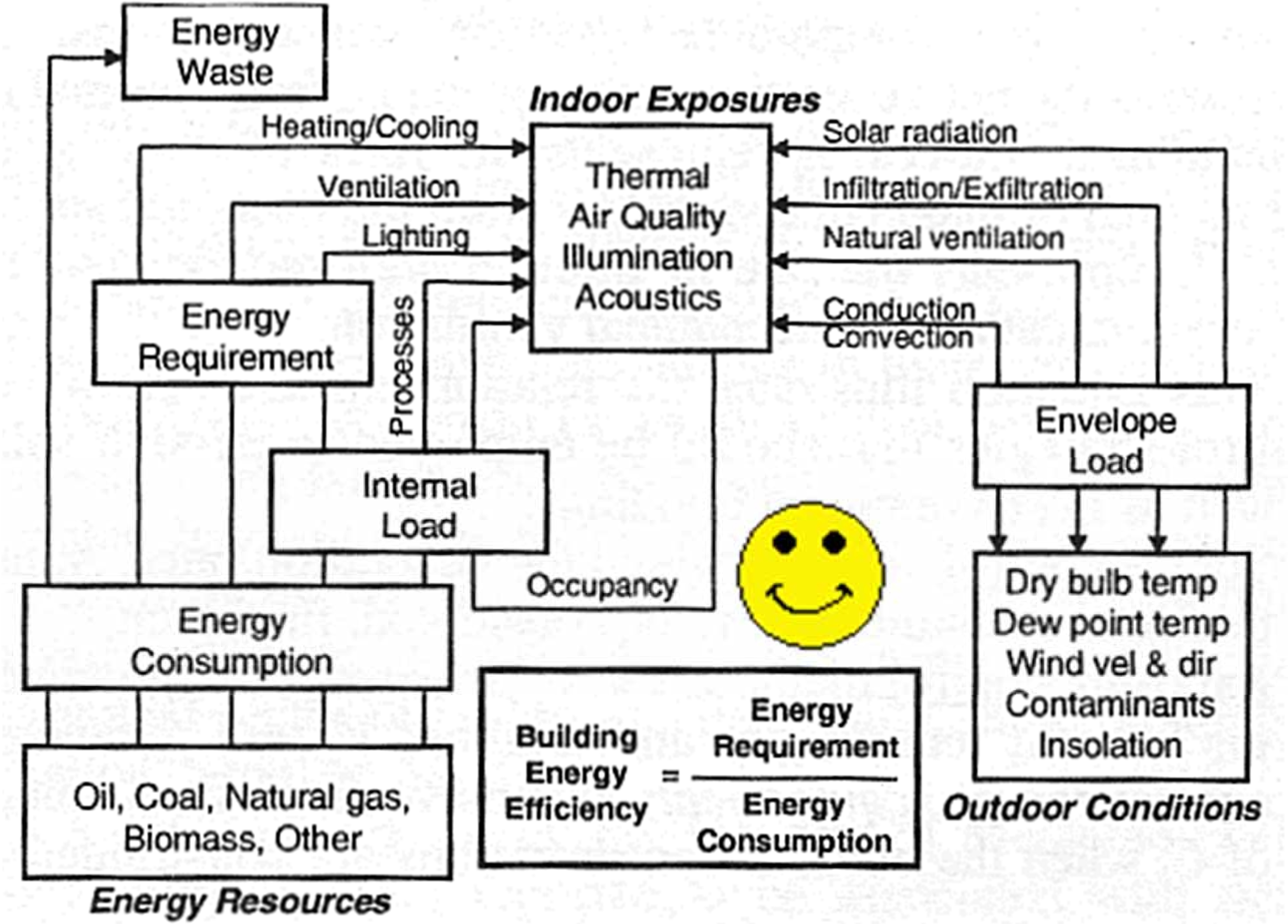


* Simulation enables the performance of the building to be established before critical design decisions are taken, enabling optimum building performance to be obtained



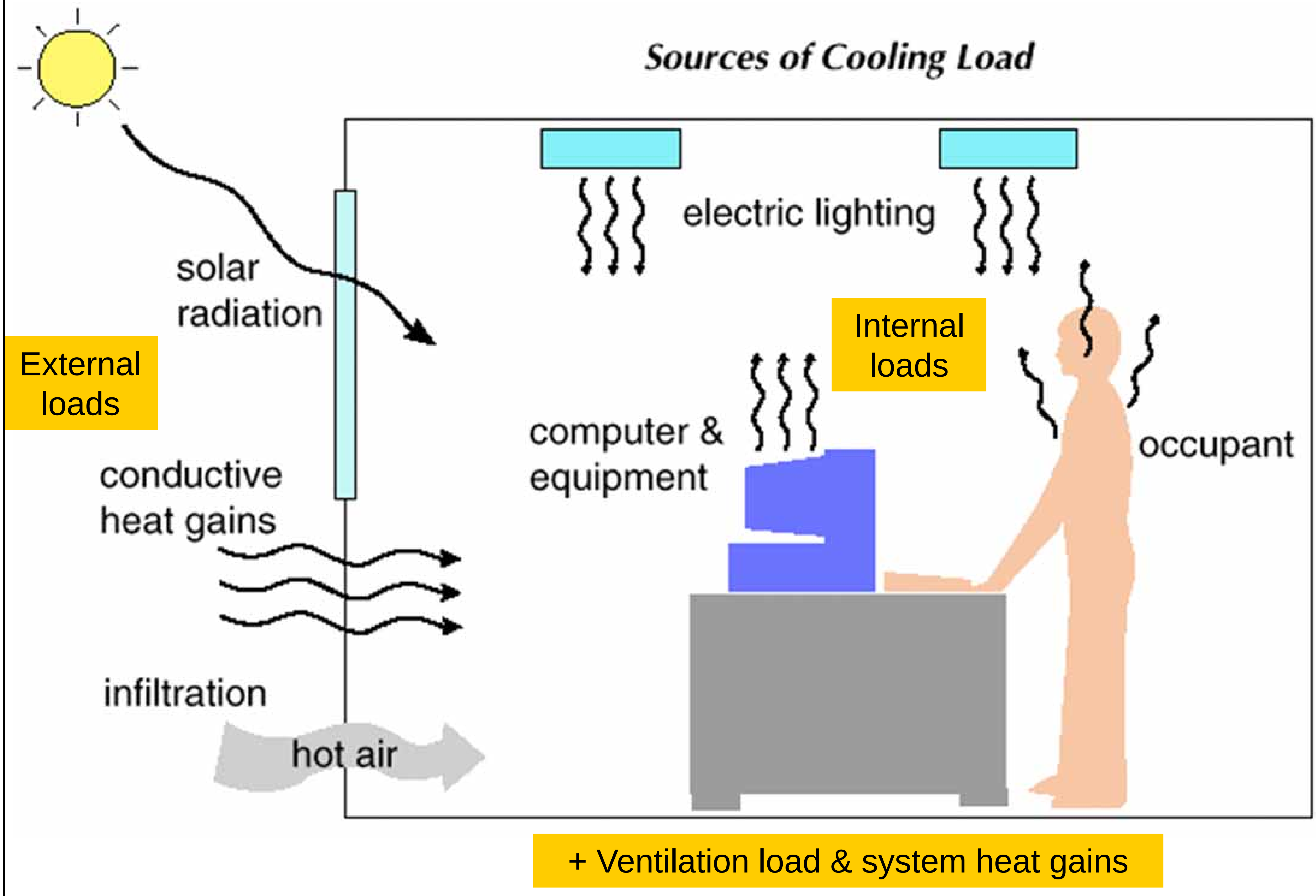
Key factors influencing energy consumption

(Source: Energy Efficiency in Buildings: CIBSE Guide F)

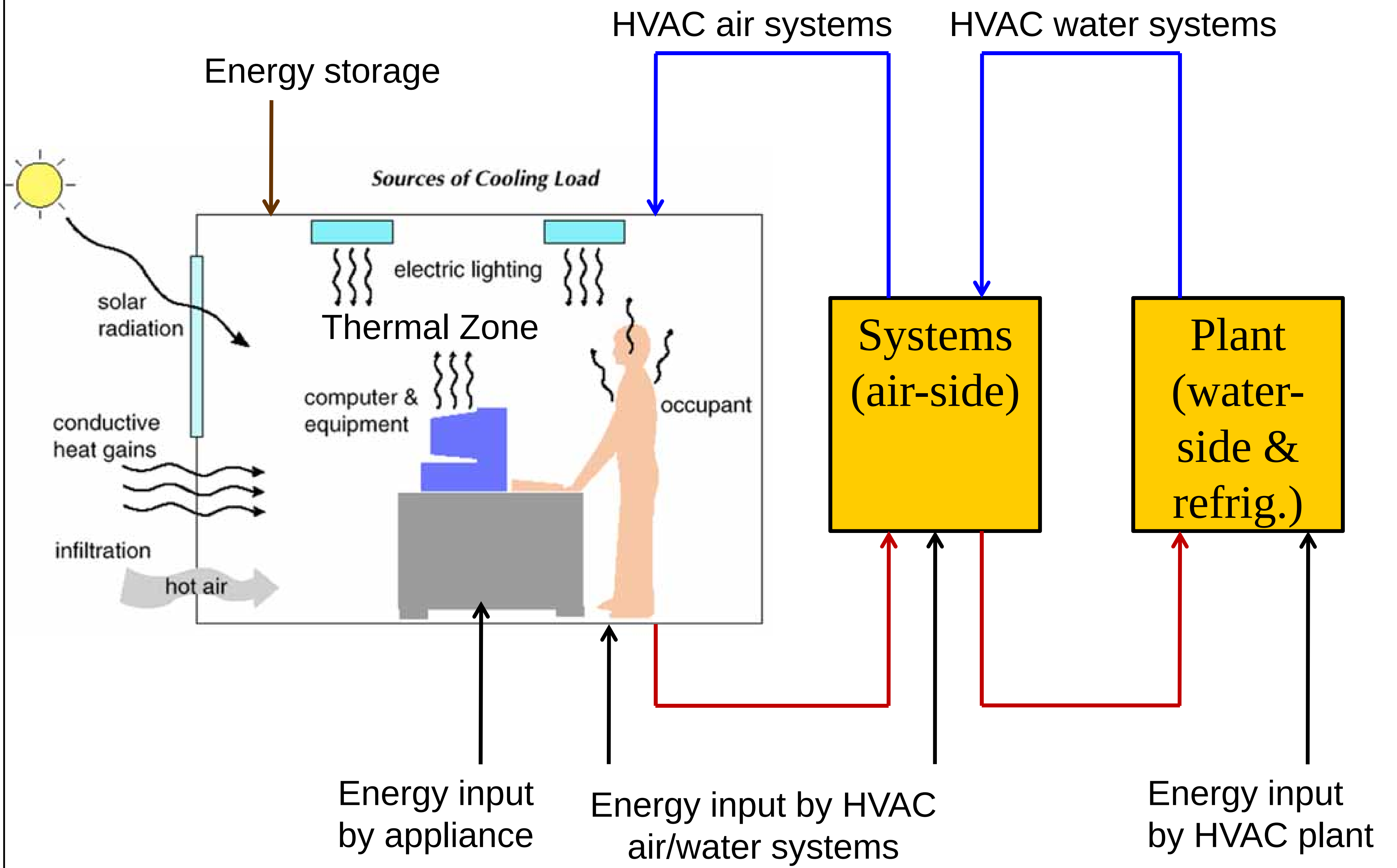


Energy flow and concept in buildings

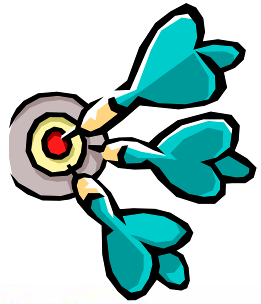
Components of building cooling load



Building energy simulation process

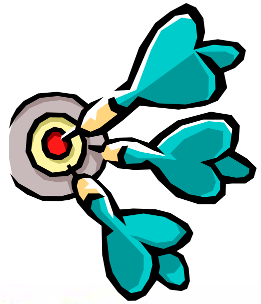


Building Energy Simulation



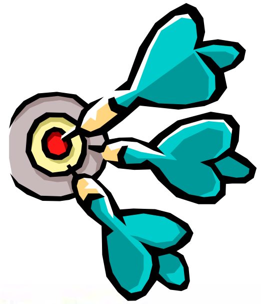
- Building energy simulation can be used to:
  - Assess building design (design evaluation tool)
  - Calculate energy saving or performance (building energy analysis tool)
  - Evaluate energy cost (economic analysis tool)
  - Design & optimise building systems (system design/optimization tool)
  - Satisfy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

Building Energy Simulation



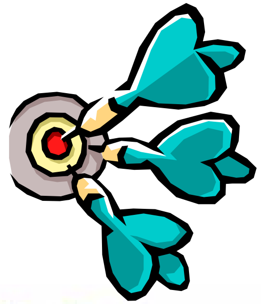
- Model existing buildings
  - Useful for “energy performance contracts”
  - Help improve the bldg’s operation/control
- Evaluate energy conservation measures (ECM)
  - Estimate energy savings
  - Study the costs and benefits
  - Provide info to design, retrofit & operation
- Comply with building energy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

Building Energy Simulation



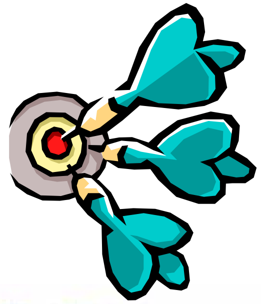
- For green building assessment (e.g. LEED)
  - Using ASHRAE 90.1 Building Energy Standard to check compliance and determine credits
  - Energy cost budget (ECB) method
    - To determine minimum compliance
    - Design Energy Cost <= Energy Cost Budget
  - Appendix G: building performance rating method
    - 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



- 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

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

blast

ENERGY-10

EnergyPlus

DOE-2

Solar-5

IES-VE

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

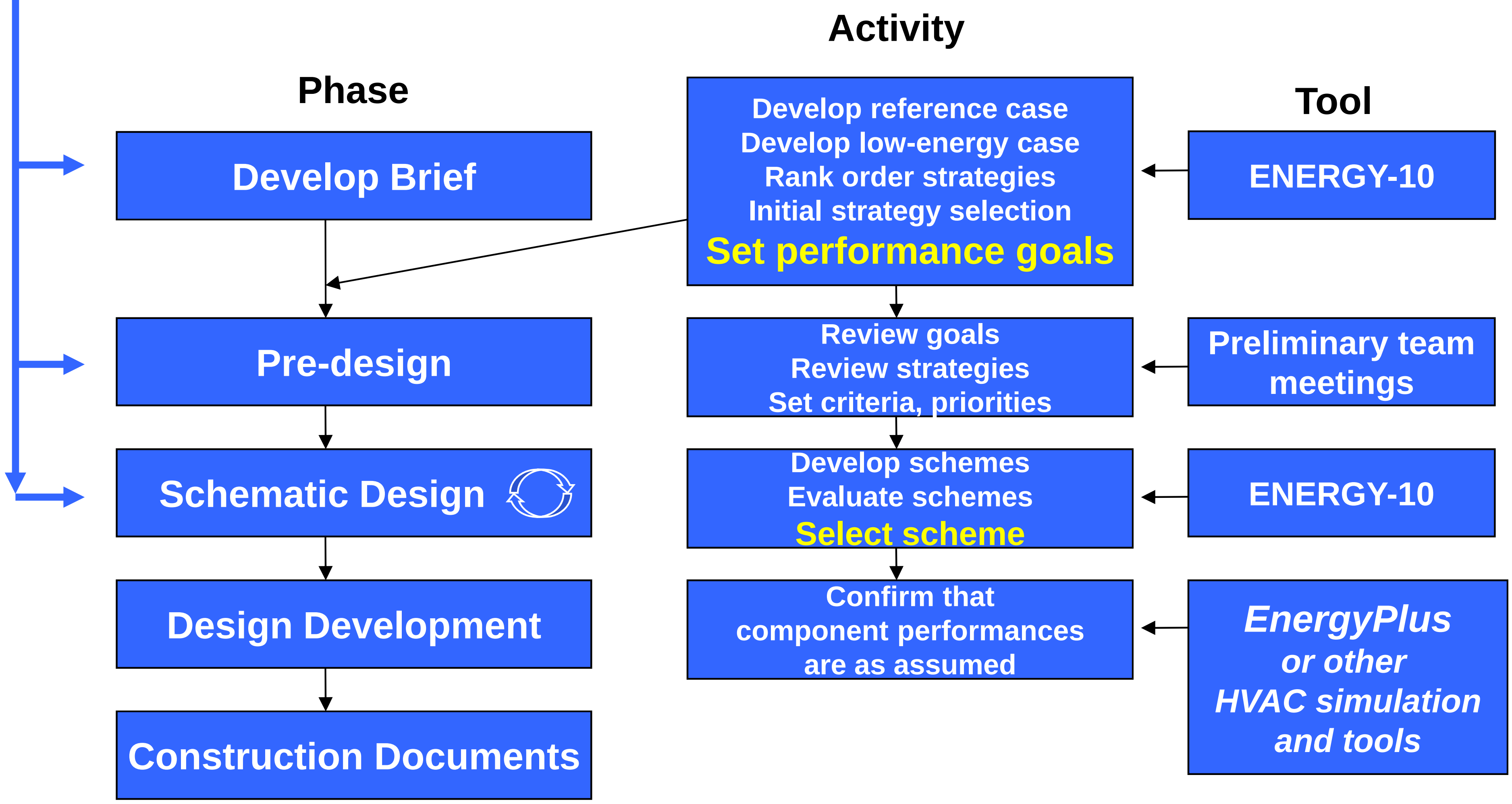
- Many software tools in the market
  - From simplified to complicated one
  - Select according to the task
- For beginners, we recommend
  - Energy-10, HAP, TRACE 700, eQUEST
- For sophisticated study, may consider
  - DOE-2, EnergyPlus, ESP-r, TRNSYS, IES-VE
- Further information:
  - Building Energy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



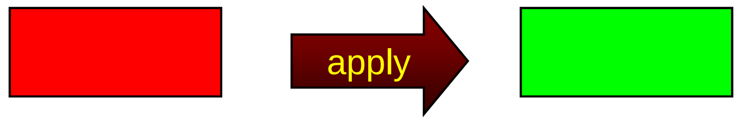
Example: Energy-10

- 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.

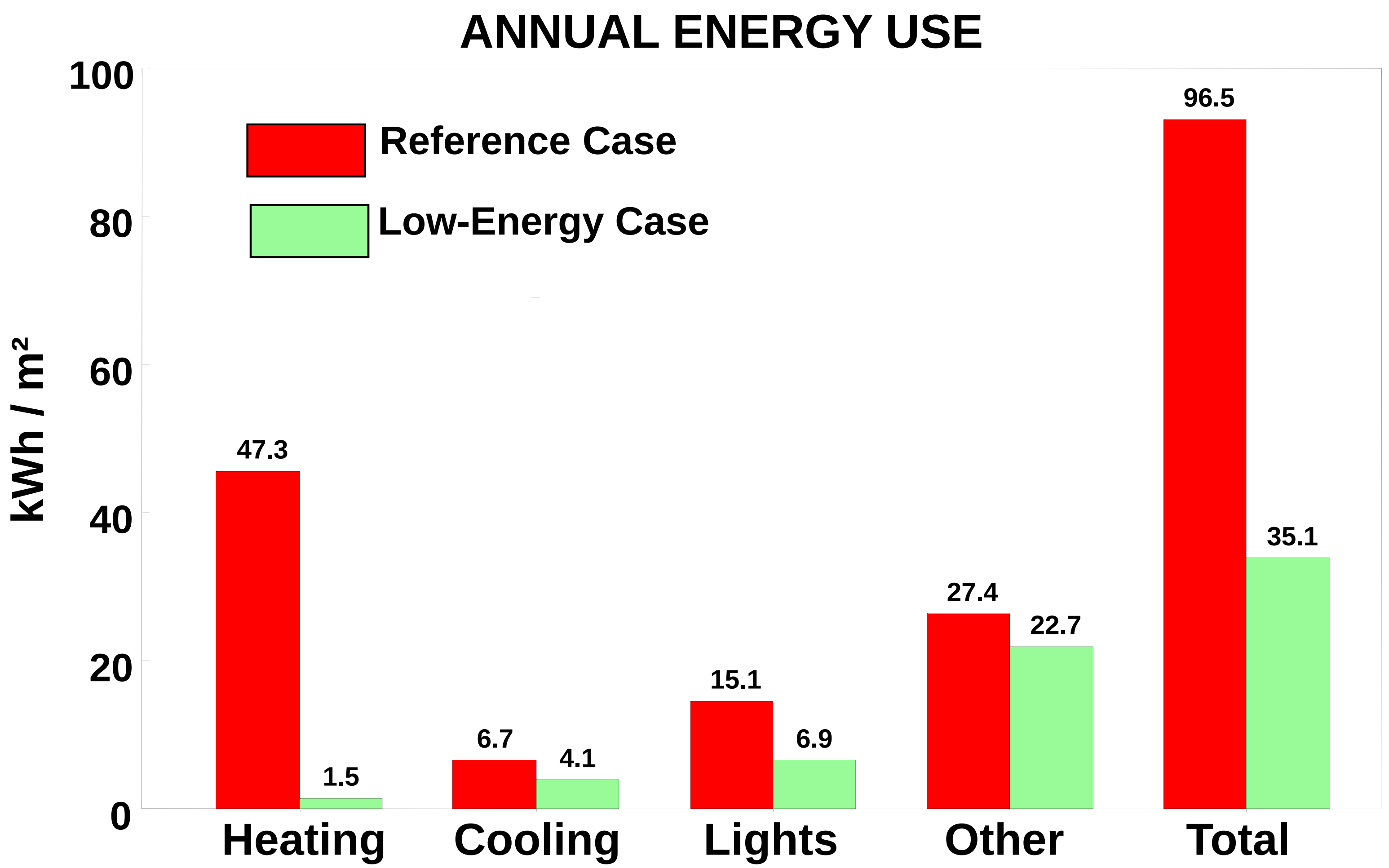
For example:



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

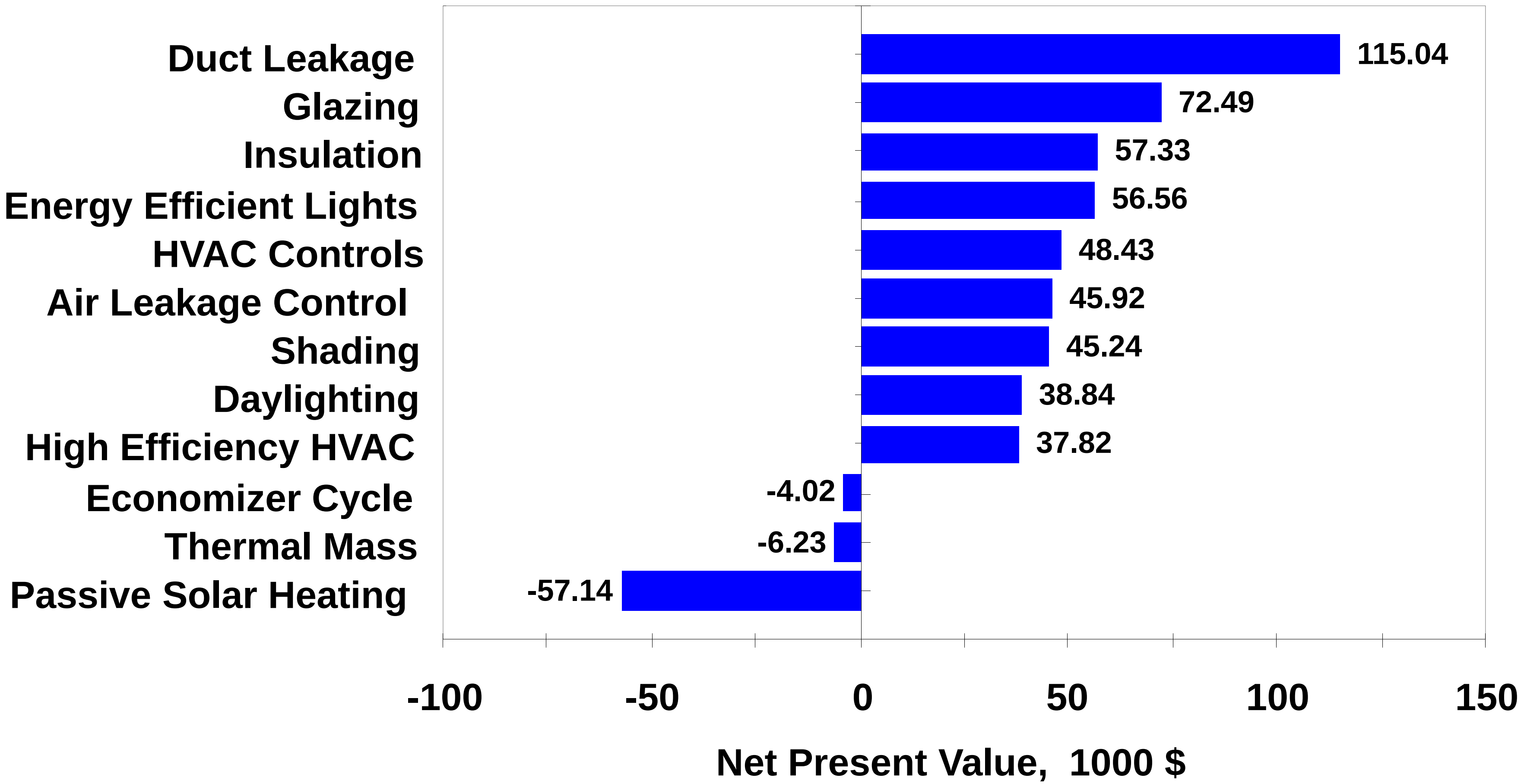
Example: Energy-10

2,000 m^2 office building

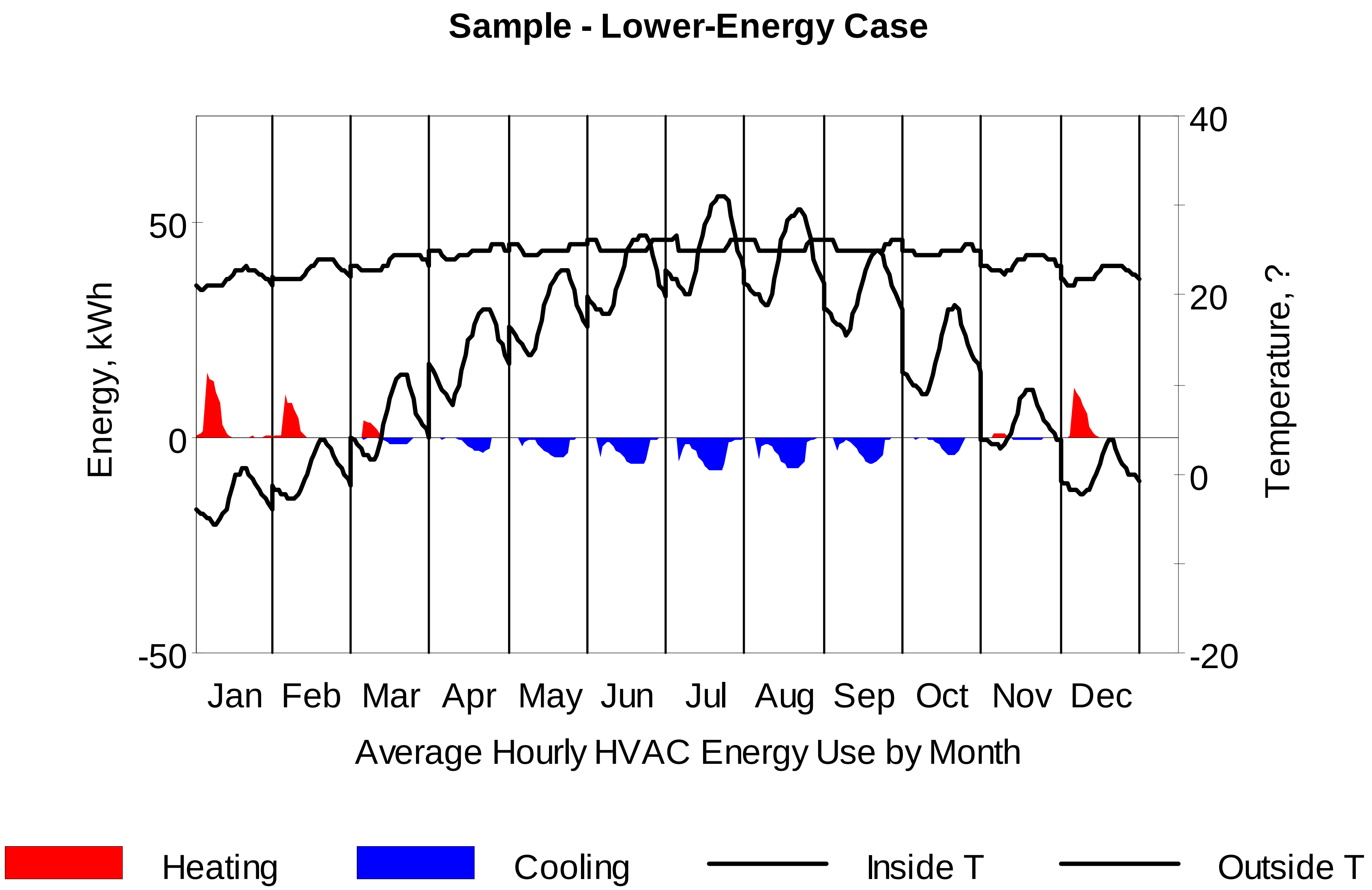


Example: Energy-10

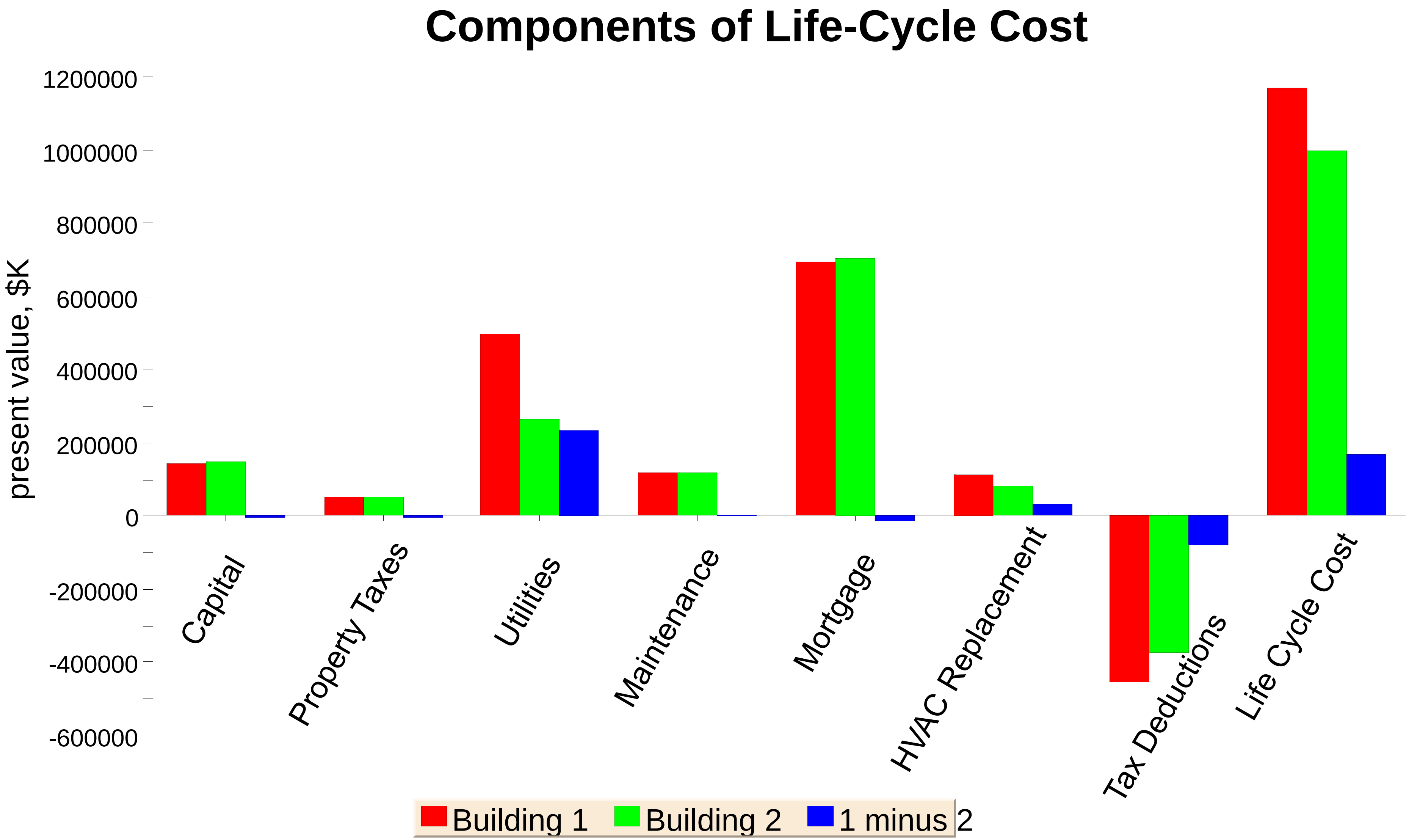
RANKING OF ENERGY-EFFICIENT STRATEGIES



Example: Energy-10

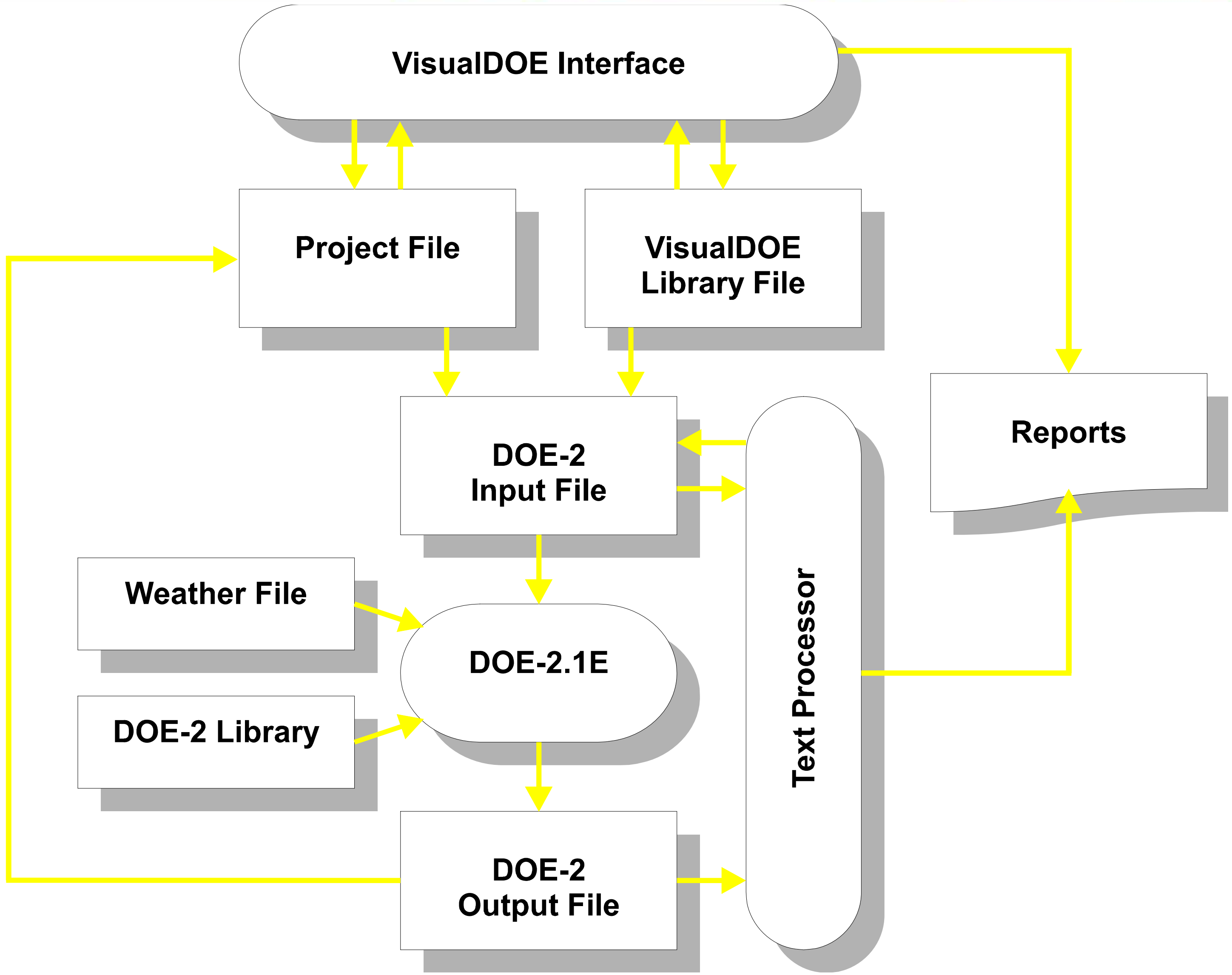


Example: Energy-10



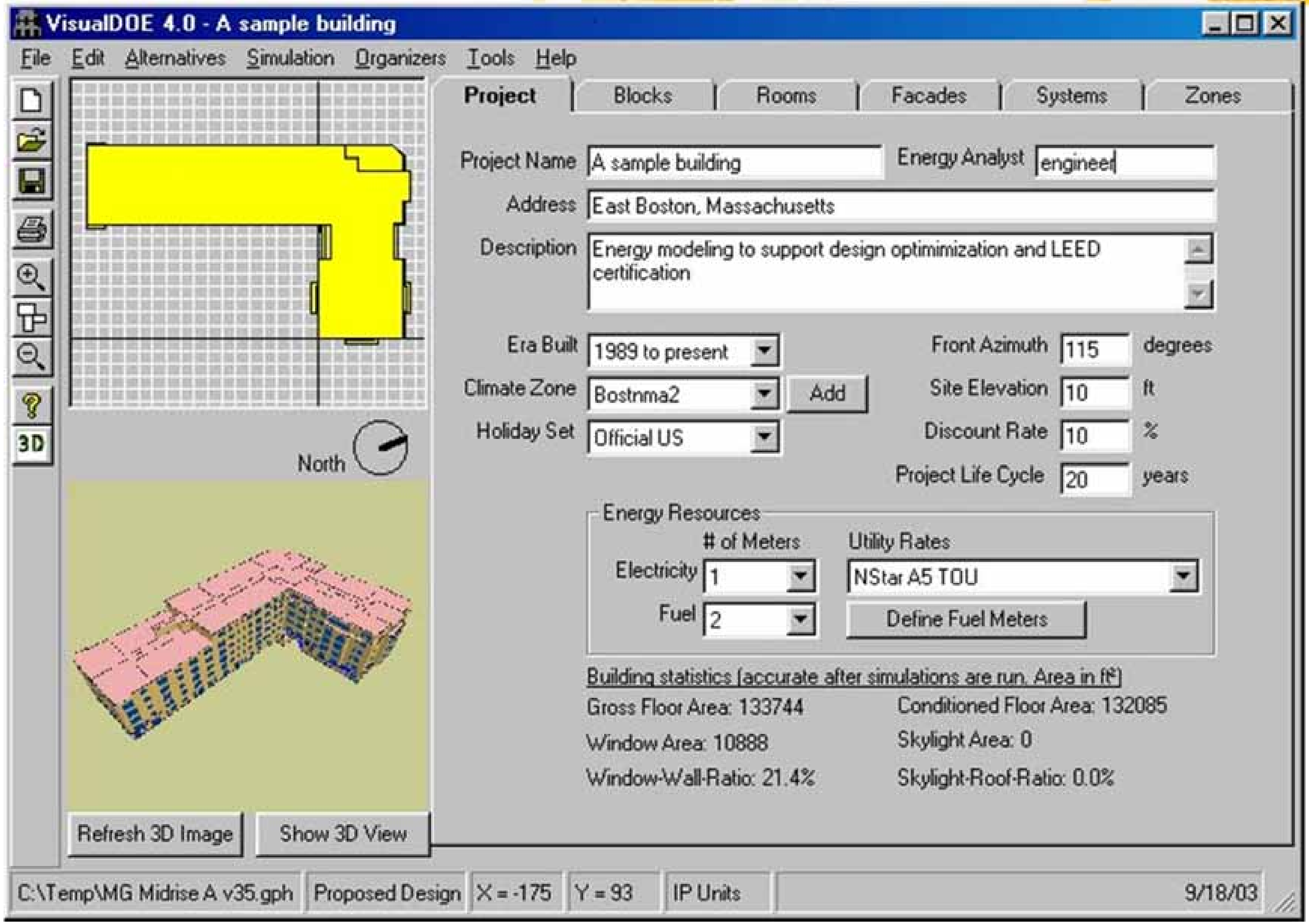
Example: VisualDOE

DOE-2



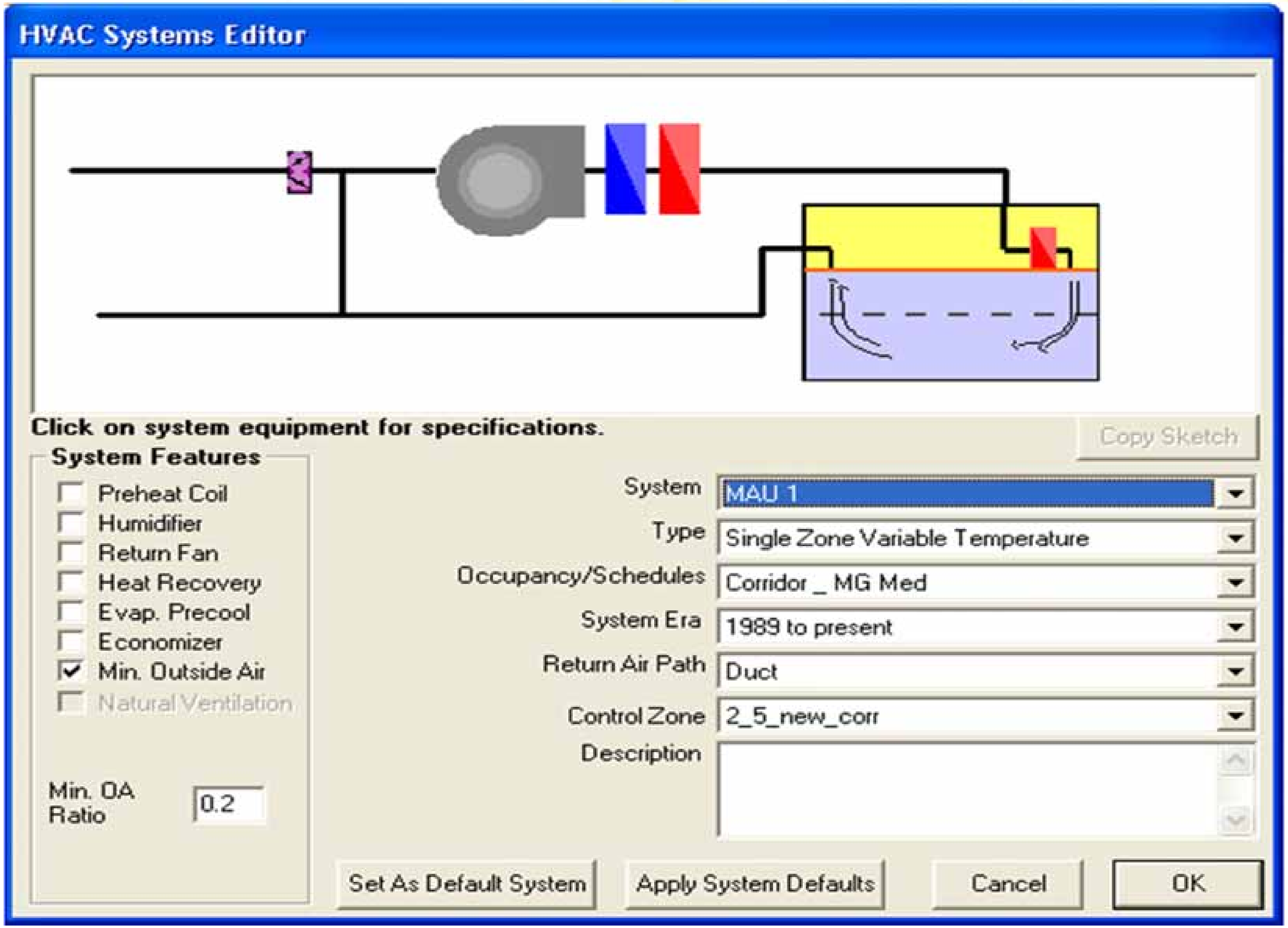
Example: VisualDOE

DOE-2



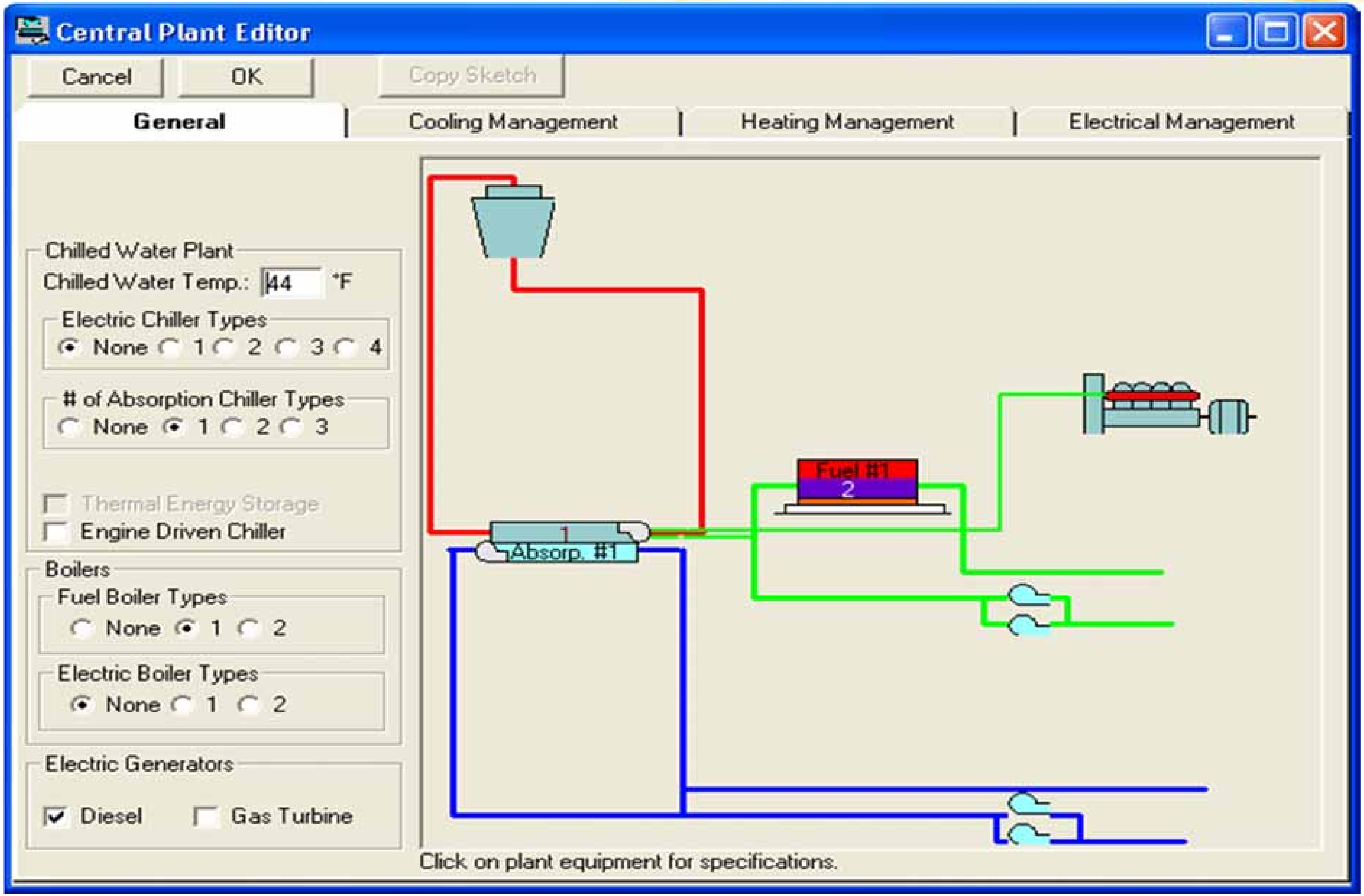
Example: VisualDOE

DOE-2



Example: VisualDOE

DOE-2



Example: VisualDOE

DOE-2

Print Preview

Export RTF | Export PDF | Close

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VisualDOE 4.0 - Results

September 18, 2003

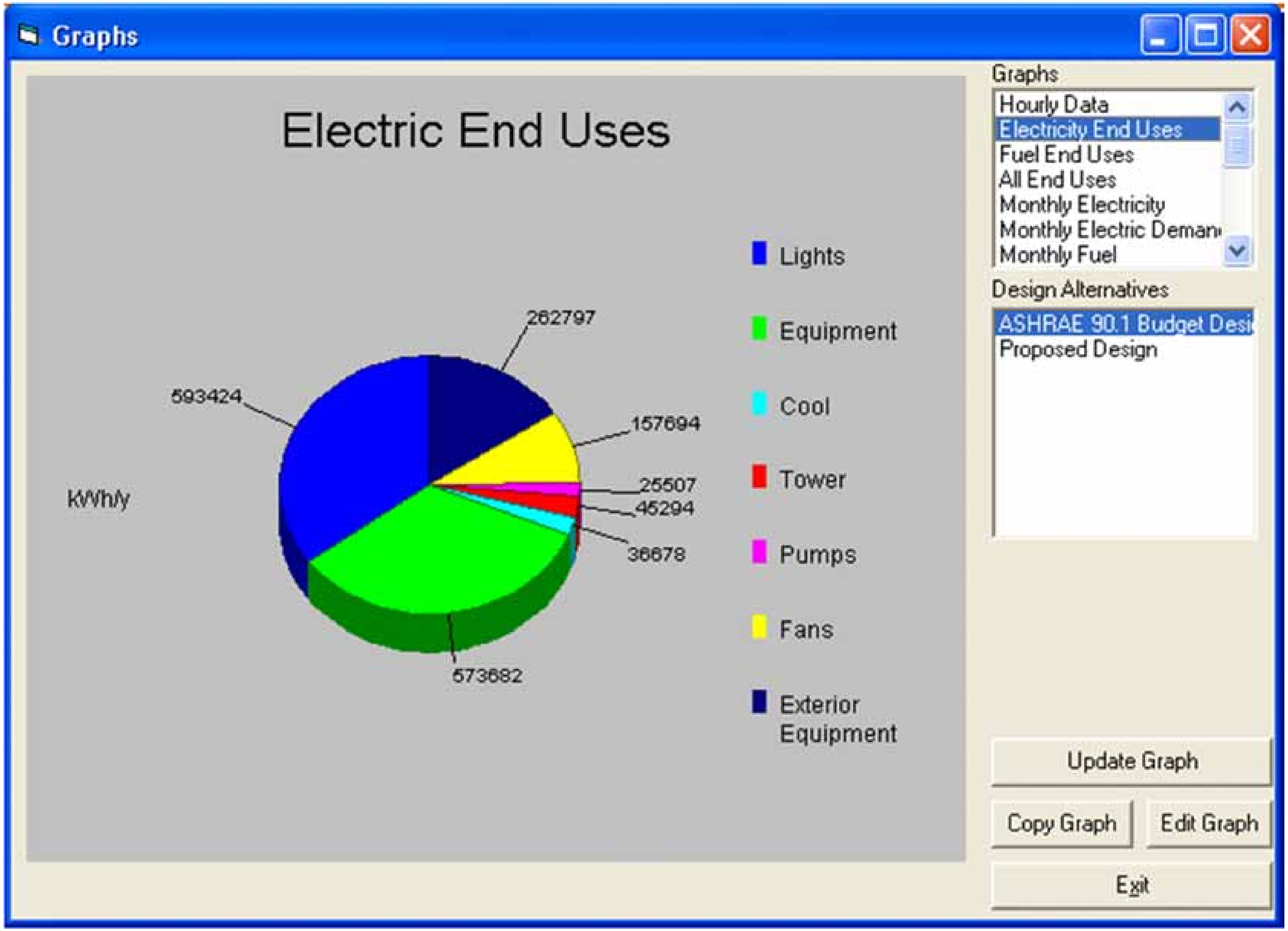
Energy Cost Summary ($/y)

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.

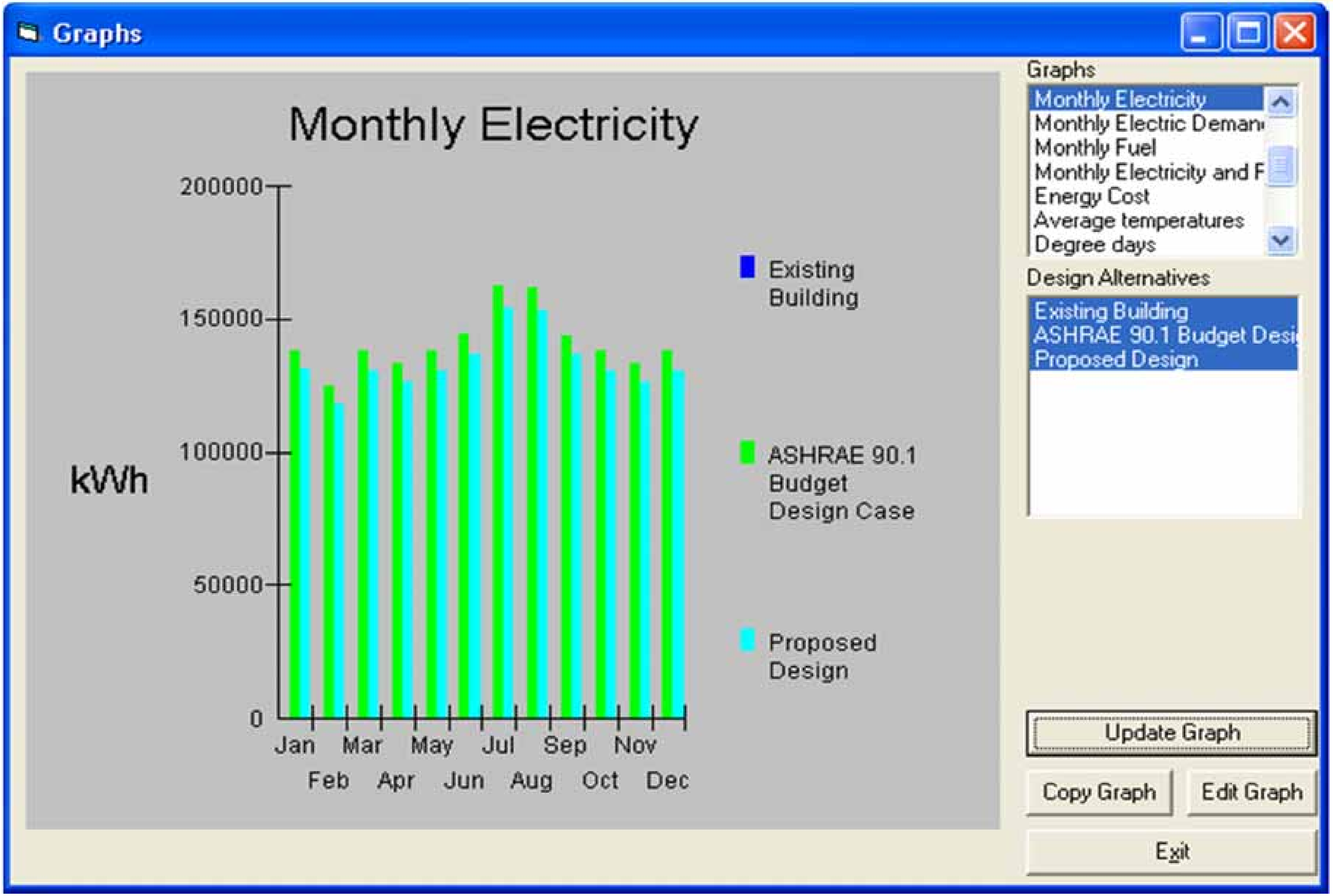
Example: VisualDOE

DOE-2

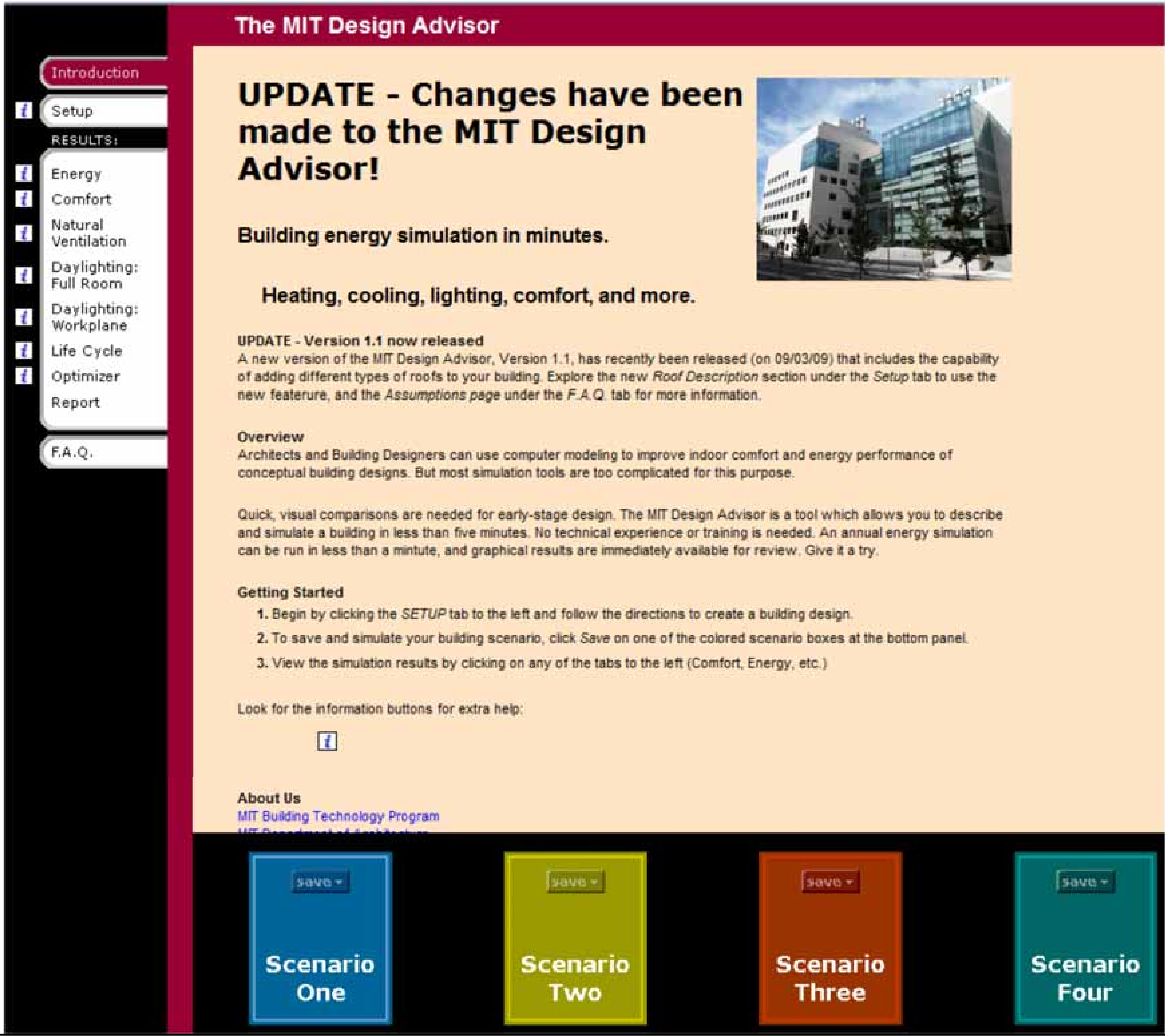


Example: VisualDOE

DOE-2



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



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.

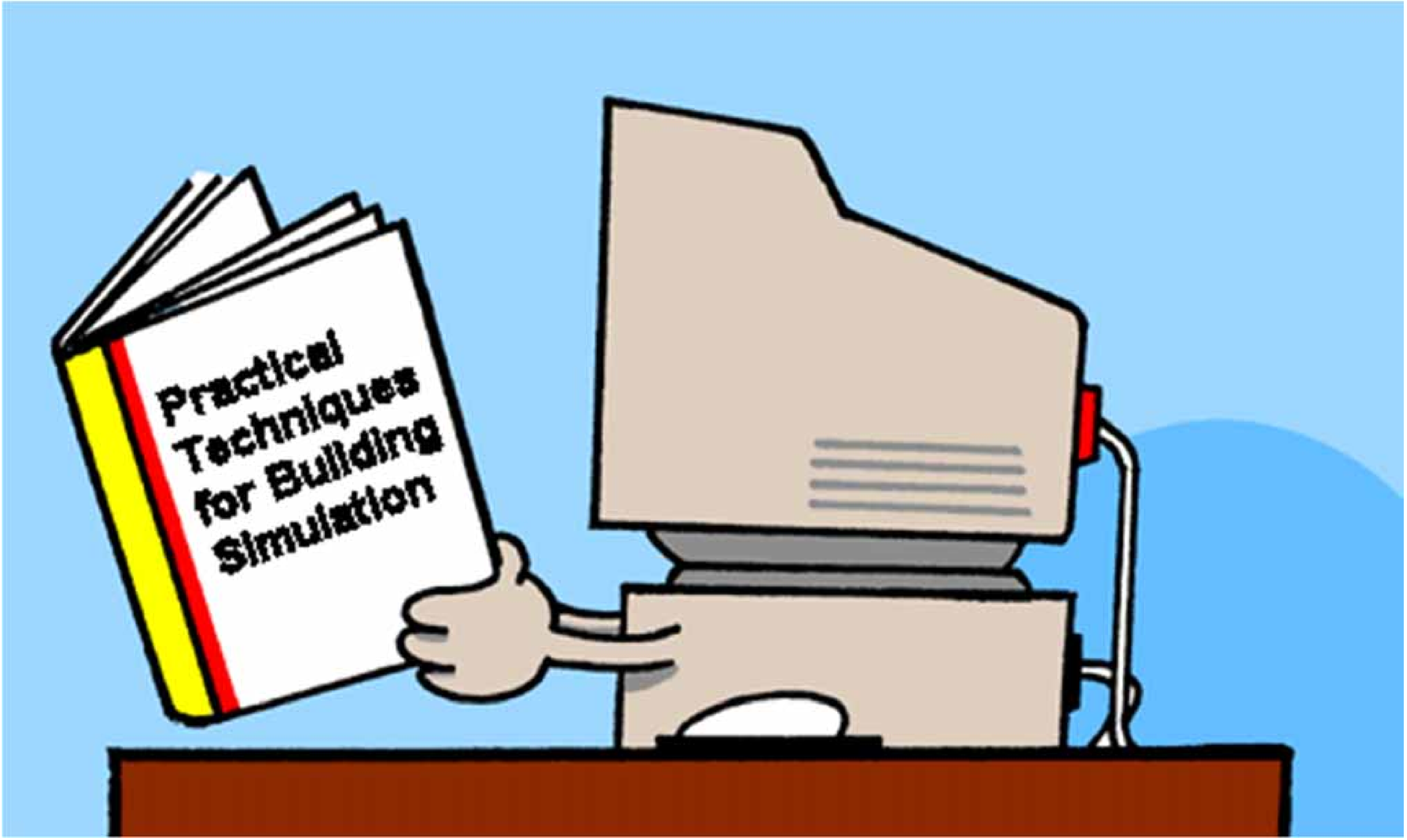
Quick, visual comparisons are needed for early-stage design. The MIT Design Advisor is a tool which allows you to describe and simulate a building in less than five minutes. No technical experience or training is needed. An annual energy simulation can be run in less than a mintute, and graphical results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

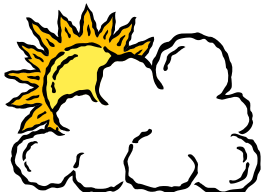
About Us
MIT Building Technology Program

save Scenario One
save Scenario Two
save Scenario Three
save Scenario Four

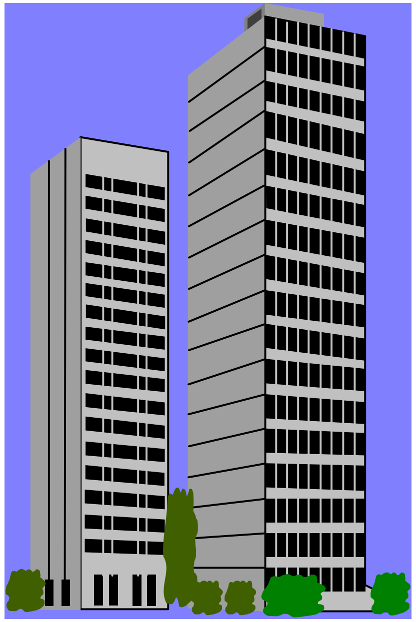

Practical
Techniques
for Building
Simulation

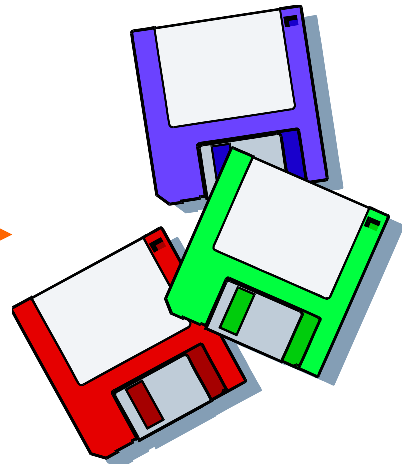
Modelling Process

- 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

Simulation tool (computer program)

Simulation outputs

- physical data
- design parameters

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

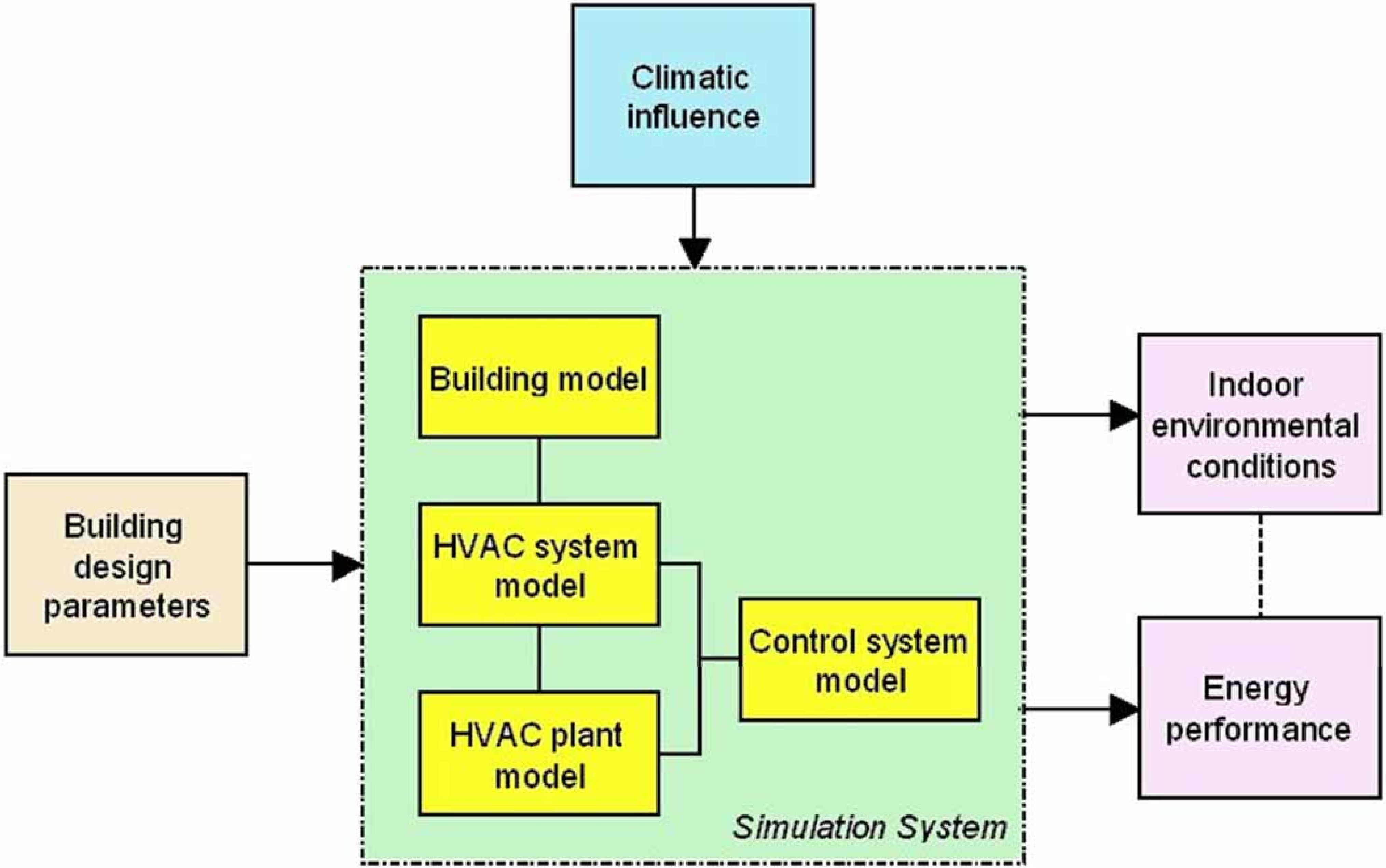
Building energy simulation: Inputs and Outputs

INPUTS:	**OUTPUTS:**
- Weather data	- 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	

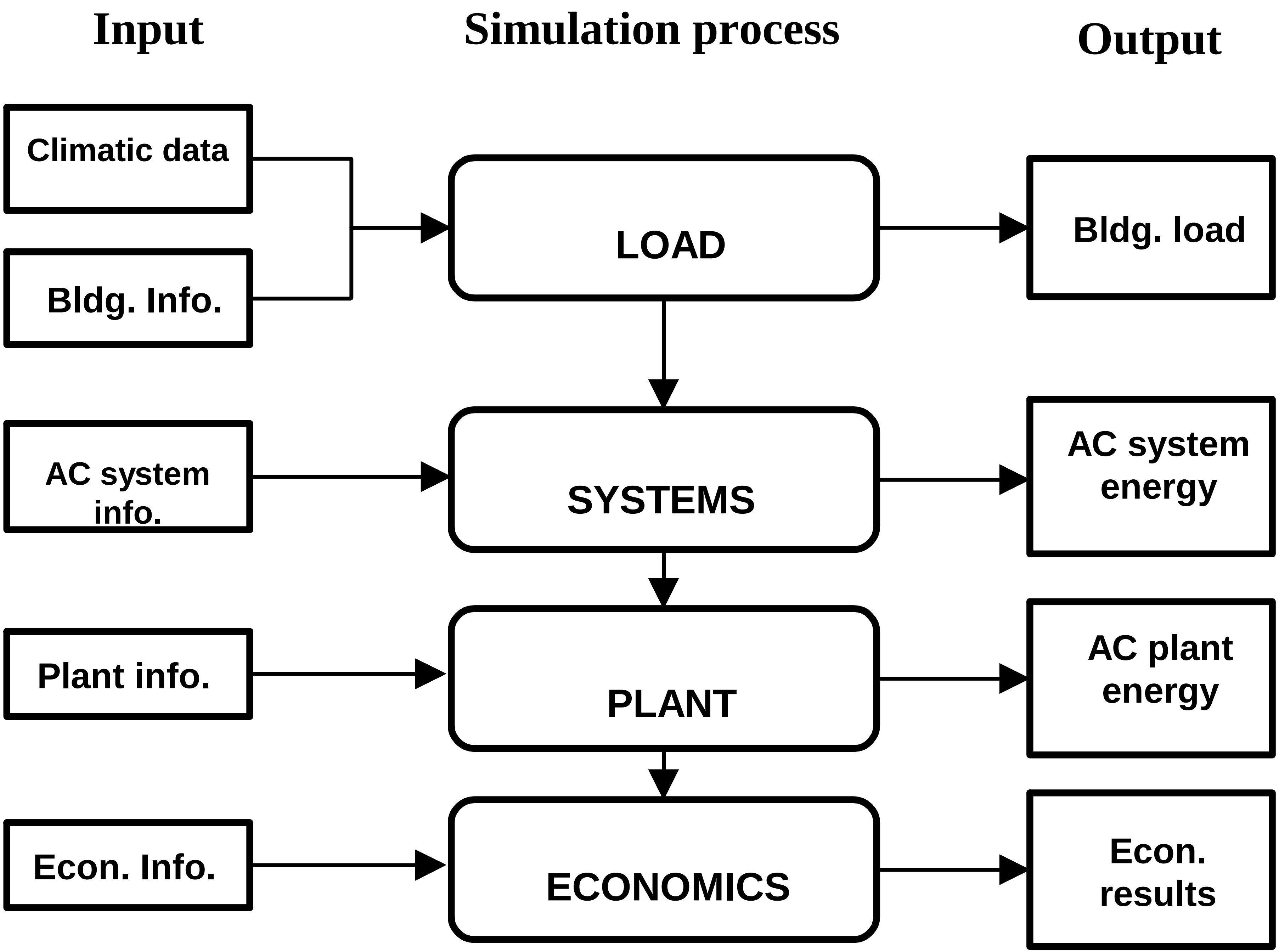
Garbage In, Garbage Out (GIGO)

Modelling Process

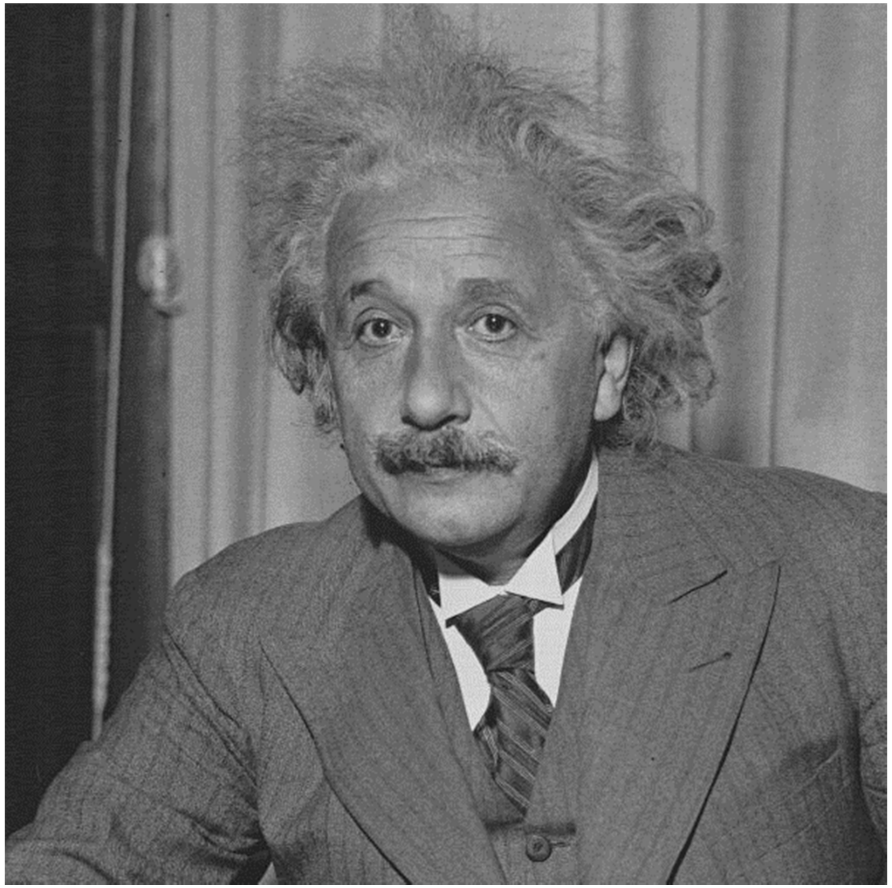
- Building energy simulation is based upon
  - *Load calculation* – thermal or HVAC
    - Determine peak HVAC design loads
  - *Energy calculation* – energy to meet the loads
    - Estimate annual energy requirements
- Time intervals
  - Full hour-by-hour (**8,760 hours** = 365 x 24)
  - Simplified hourly: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



Major elements of building energy simulation

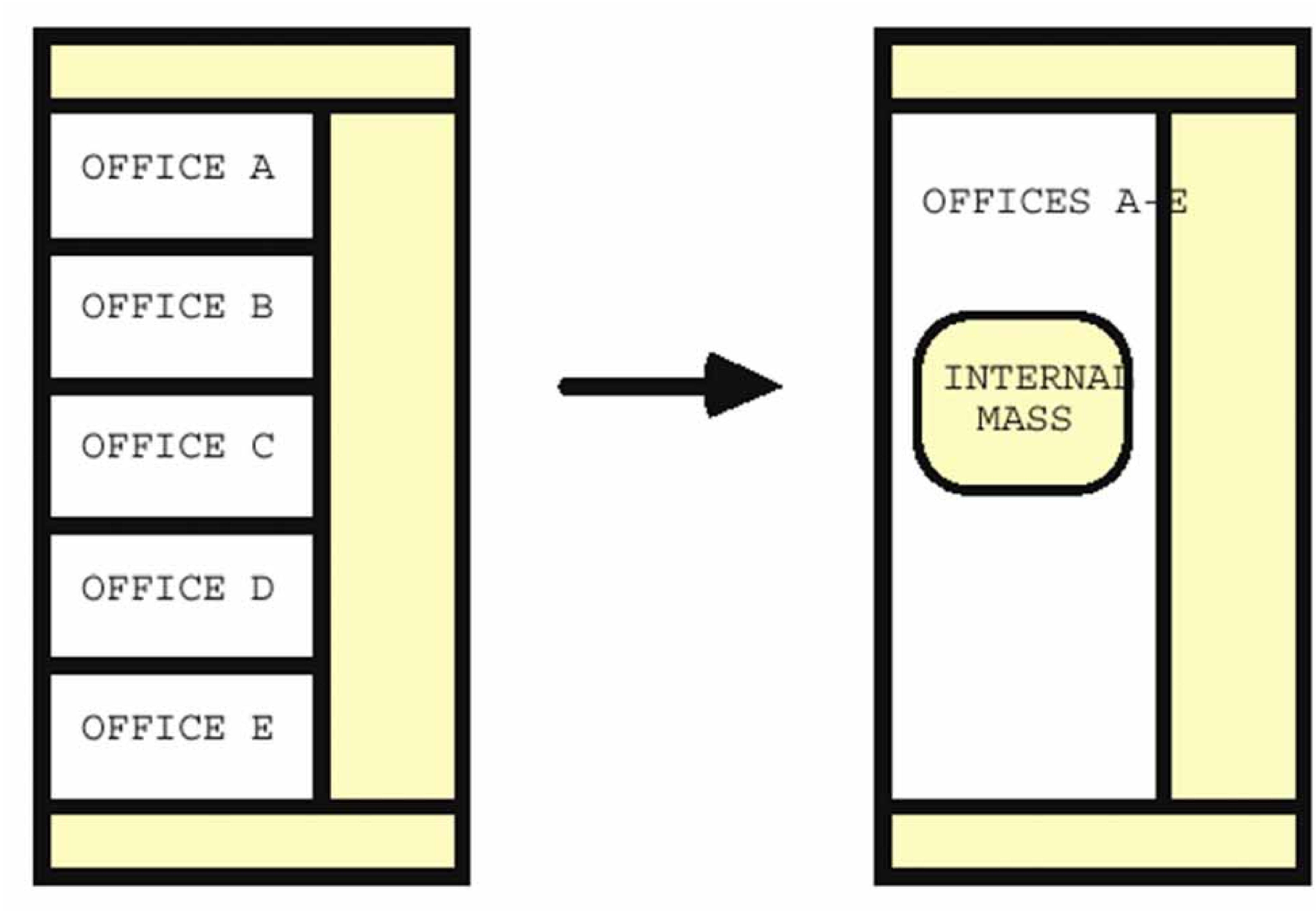


Information flow in building simulation



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

Combine several rooms into one zone



Assess Carbon Emissions

- **Carbon** is frequently used as shorthand for either carbon dioxide (CO_2) or carbon dioxide equivalents (CO_2-e) of greenhouse gases
  - Used as an indicator for environmental impact or sustainability level
- **Carbon footprint**
  - Measur the exclusive direct (on-site, internal), and indirect (off-site, external, embodied, upstream, and downstream) CO_2 emissions of an activity, or over the life cycle of a product, measured in kg

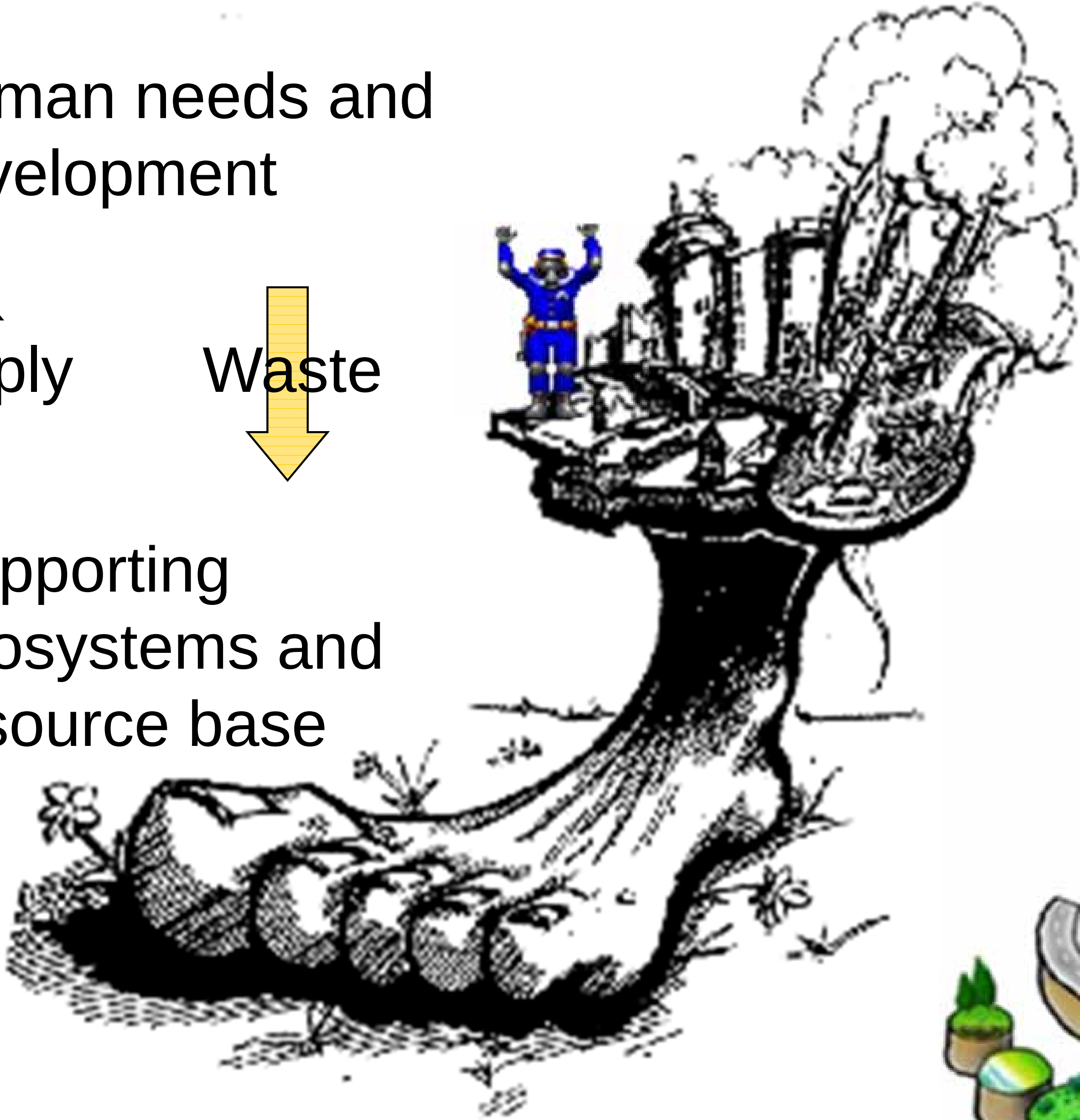
Urban cities and their ecological footprints

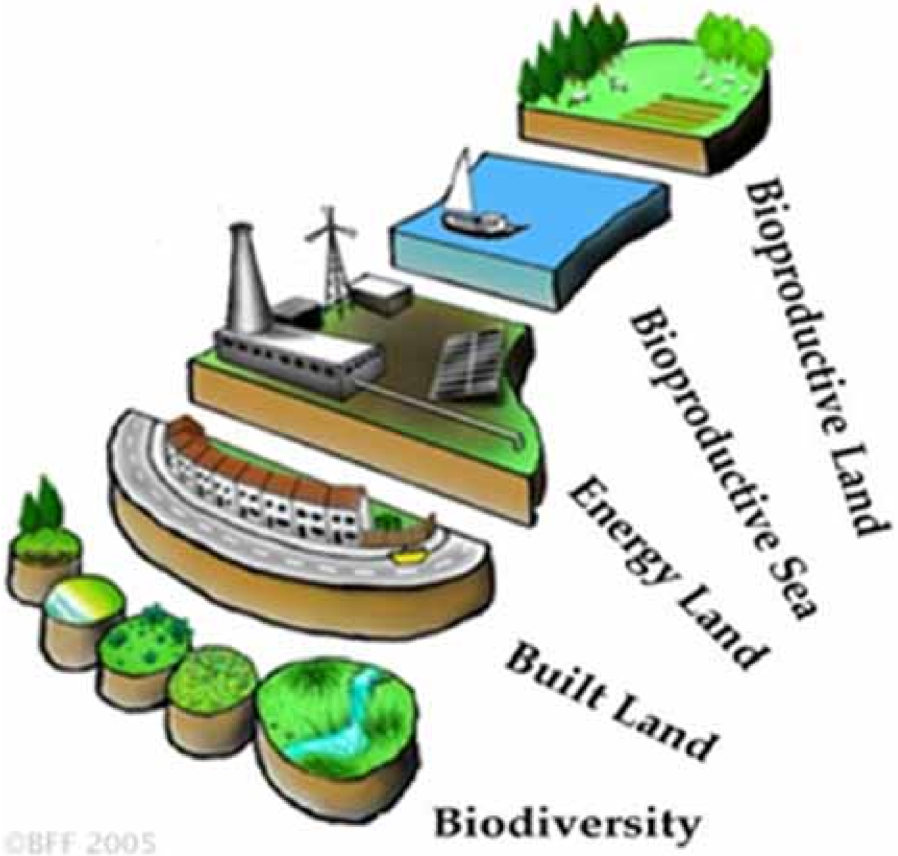
Human needs and development

Supply

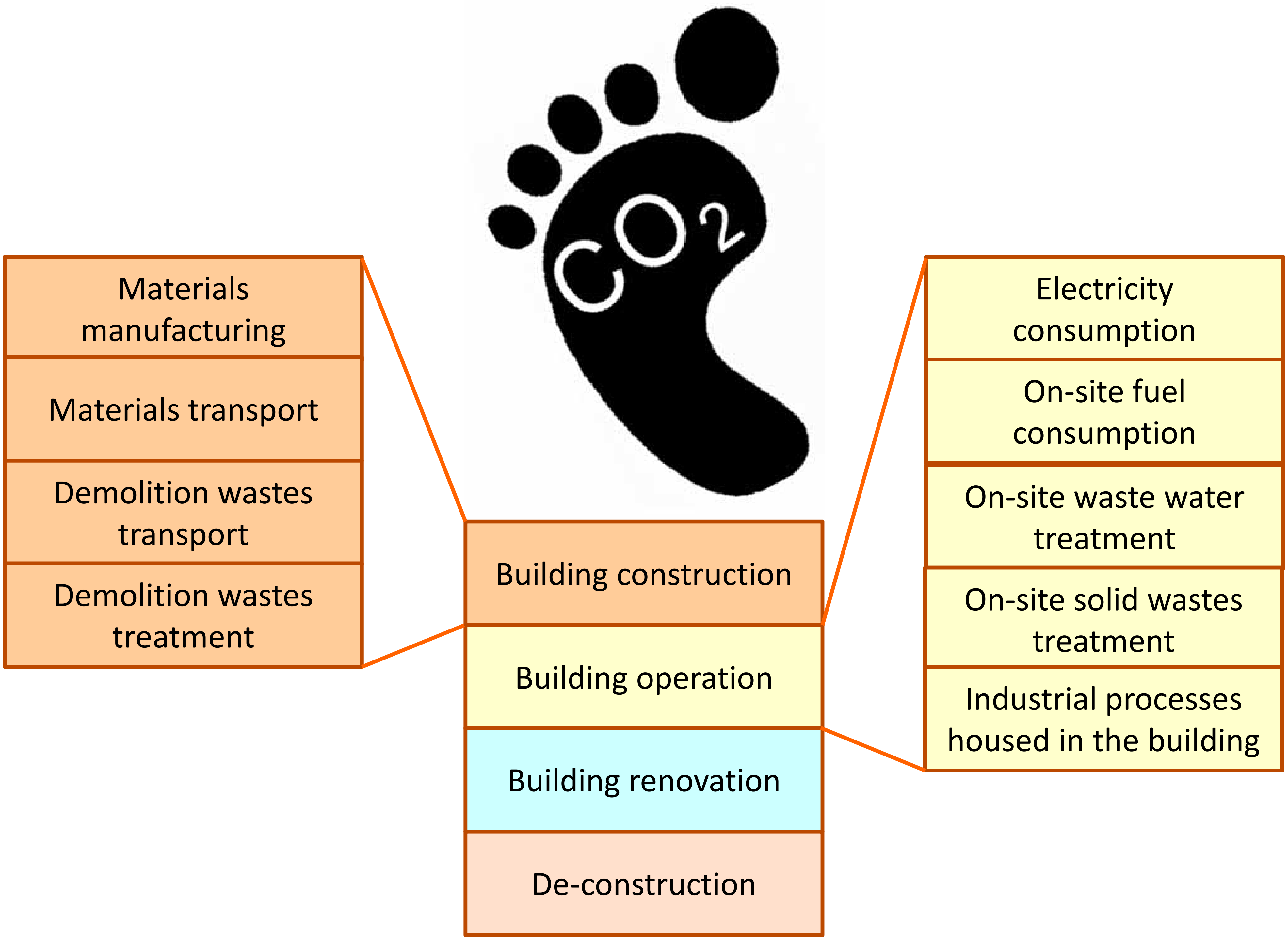
Waste

Supporting ecosystems and resource base





Carbon footprint of a building and its components

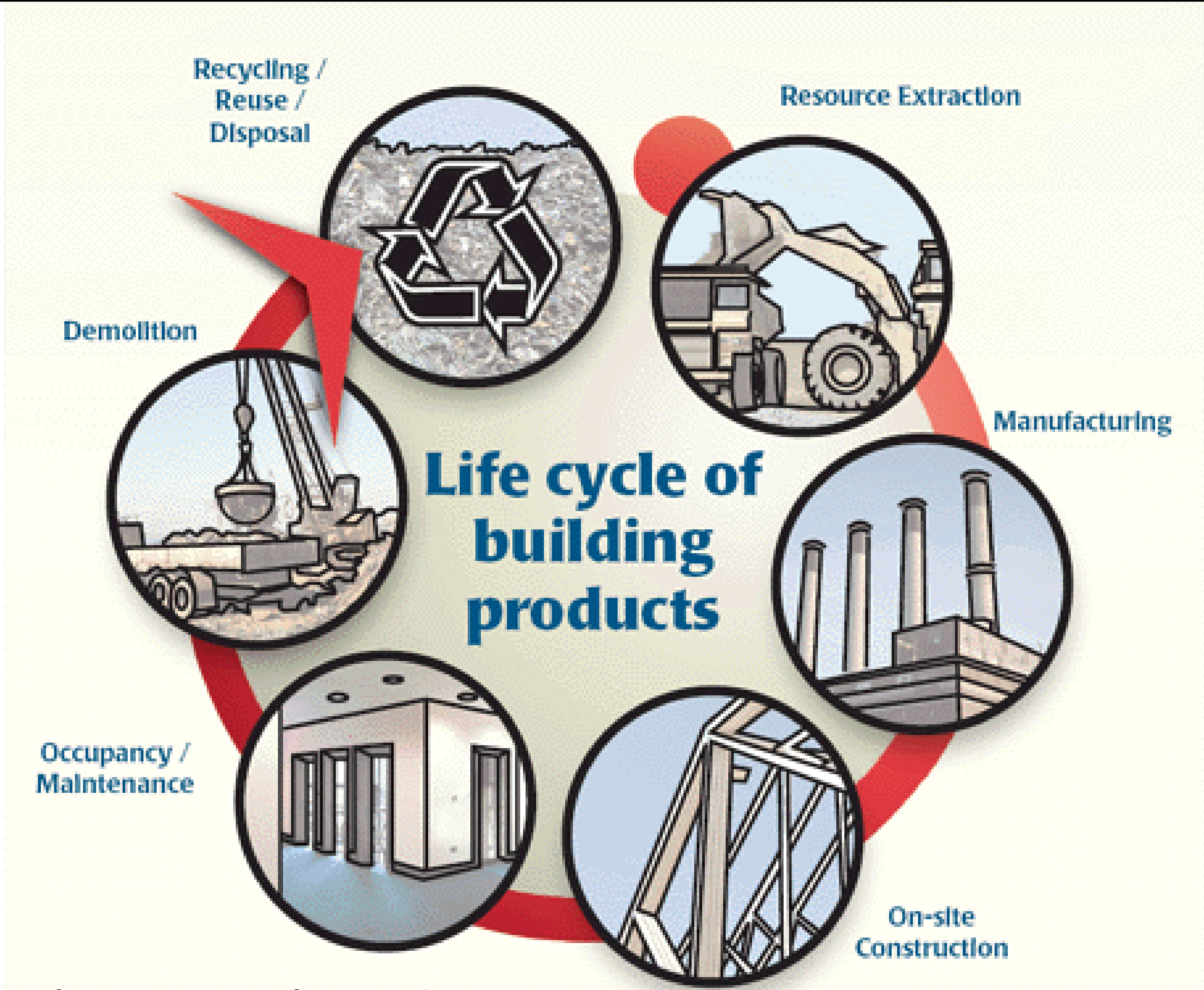


Assess Carbon Emissions

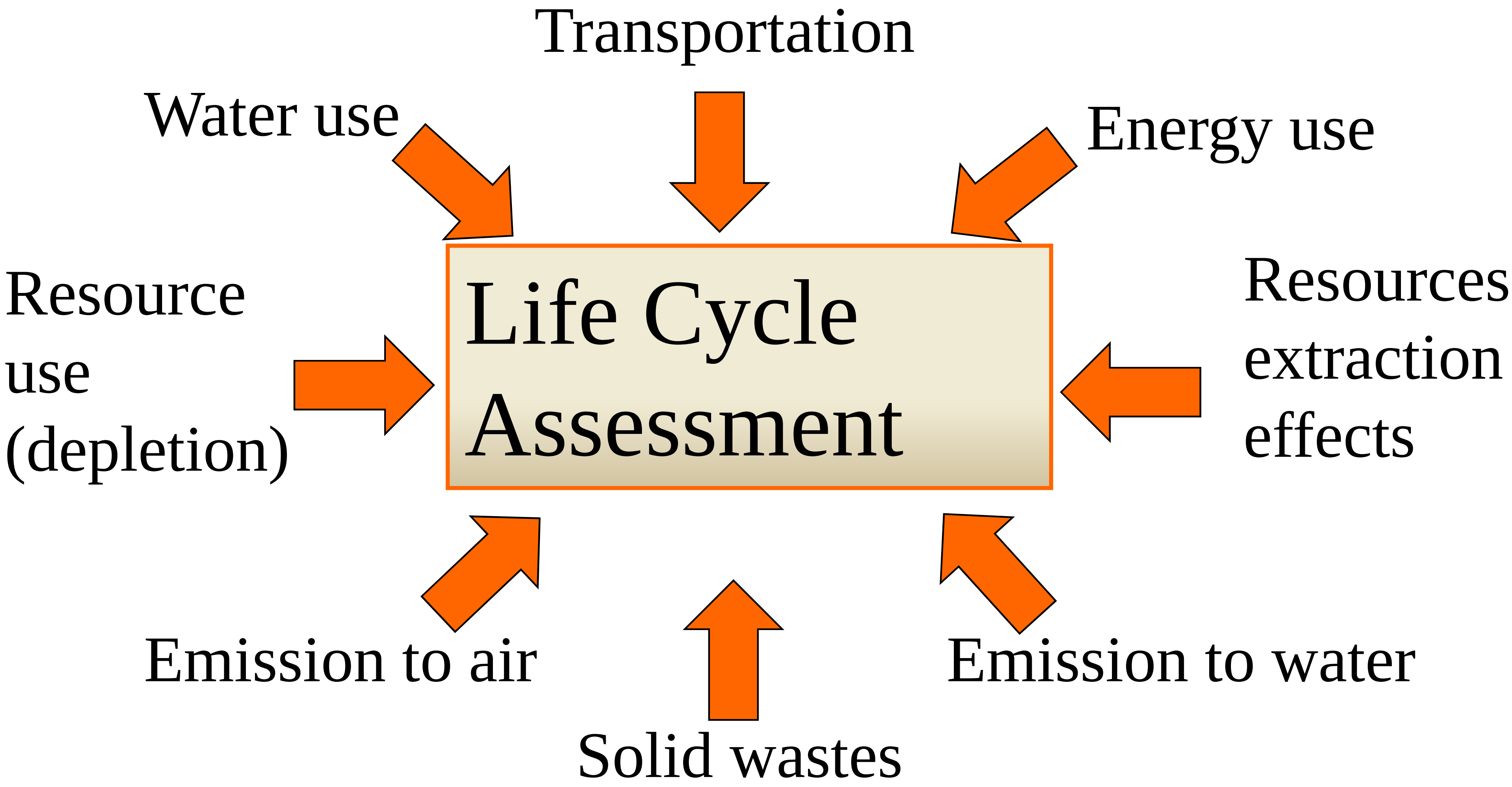
- International standards for carbon footprint calculation and analysis
  - ISO 14040: Life Cycle Assessment - Principles and Framework
  - BSI: PAS 2050 - Specification for the Assessment of Life-Cycle GHG Emissions of Goods/Services
  - WRI/WBCSD: Greenhouse Gas Protocol
  - IPCC: 2006 Guidelines for National Greenhouse Gas Inventories

Cradle-to-Grave

Cradle-to-grave is the full Life Cycle Assessment from resource extraction ('cradle') to use phase and disposal phase ('grave').



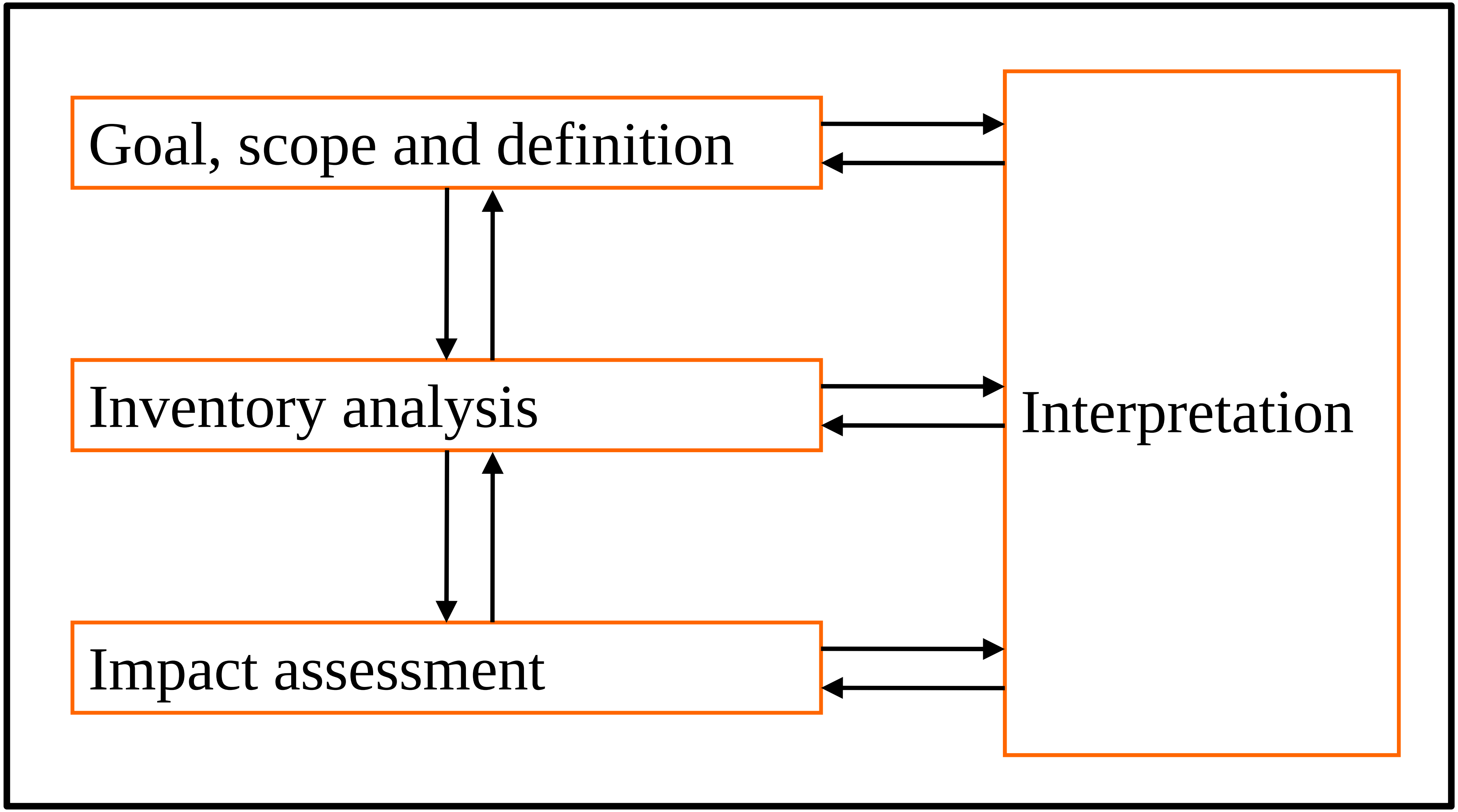
(Source: Athena Institute, www.athenasmi.org)



LCA: a methodology for assessing the life cycle environmental performance of products and processes

(Source: Athena Institute, www.athenasmi.org)

Life cycle assessment framework



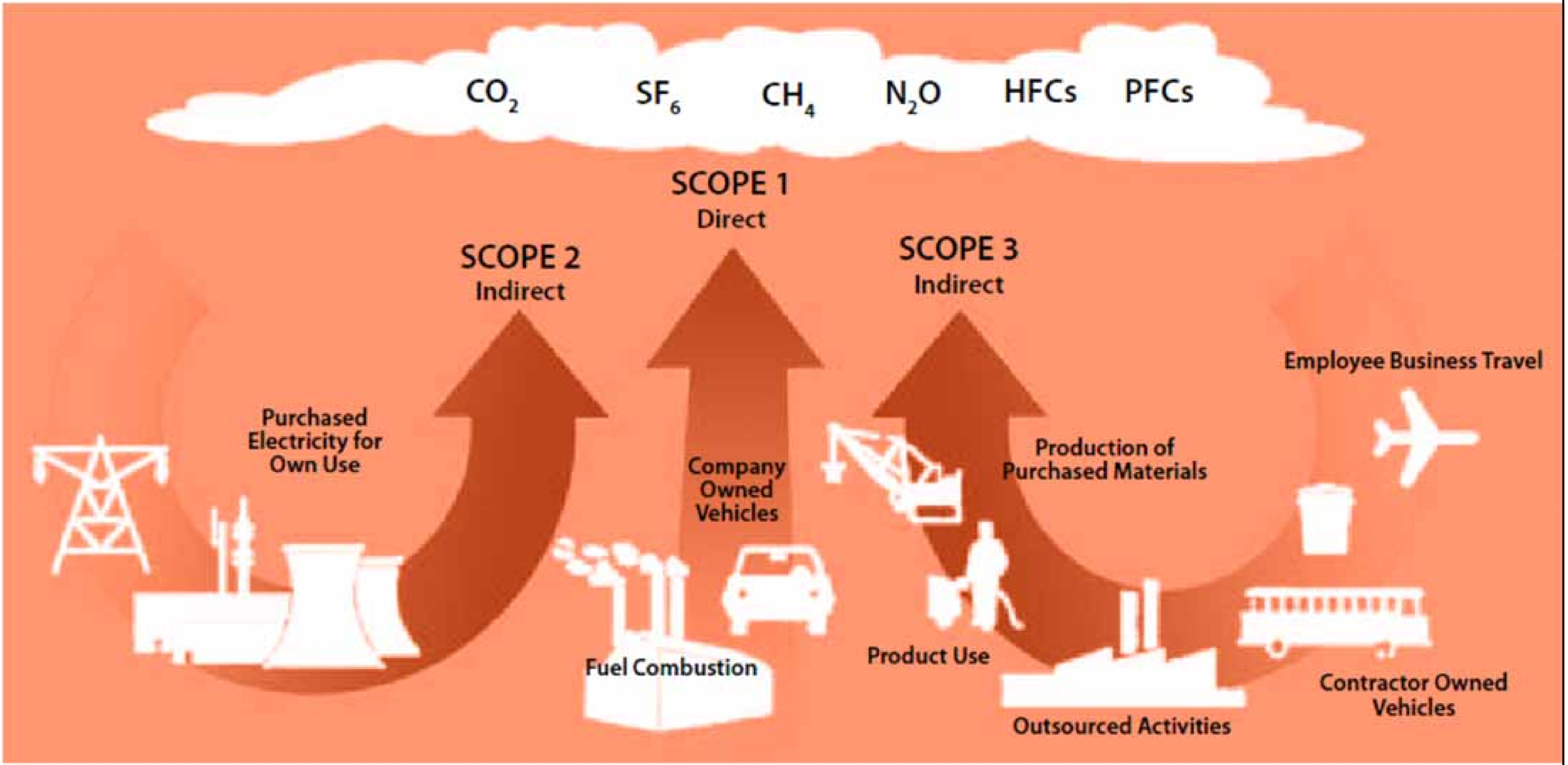
(Source: US-EPA)

Assess Carbon Emissions

- HK's carbon audit guidelines for buildings to report on greenhouse gas emissions focus on:
  - Physical boundaries (site boundaries of building)
  - Operational boundaries (to identify and classify the activities to determine the scope)
    - Scope 1 – direct emissions and removals
    - Scope 2 – energy indirect emissions
    - Scope 3 – other indirect emissions
  - Reporting period (usually one year)
  - Collecting data and information to quantify the greenhouse gas performance

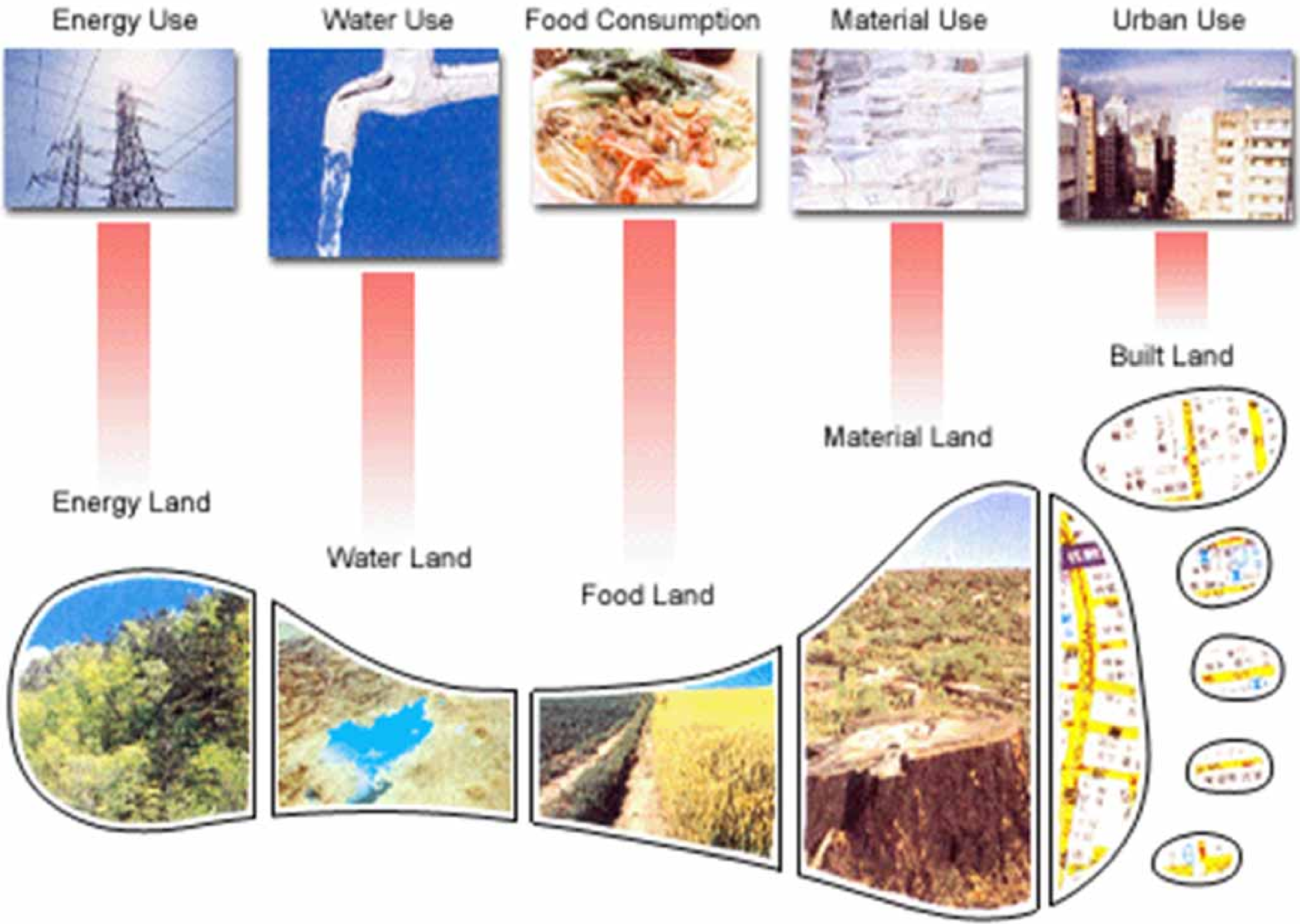
Carbon Audit 碳審計
綠色機構 Green Partner

Scope of greenhouse gas (GHG) emissions

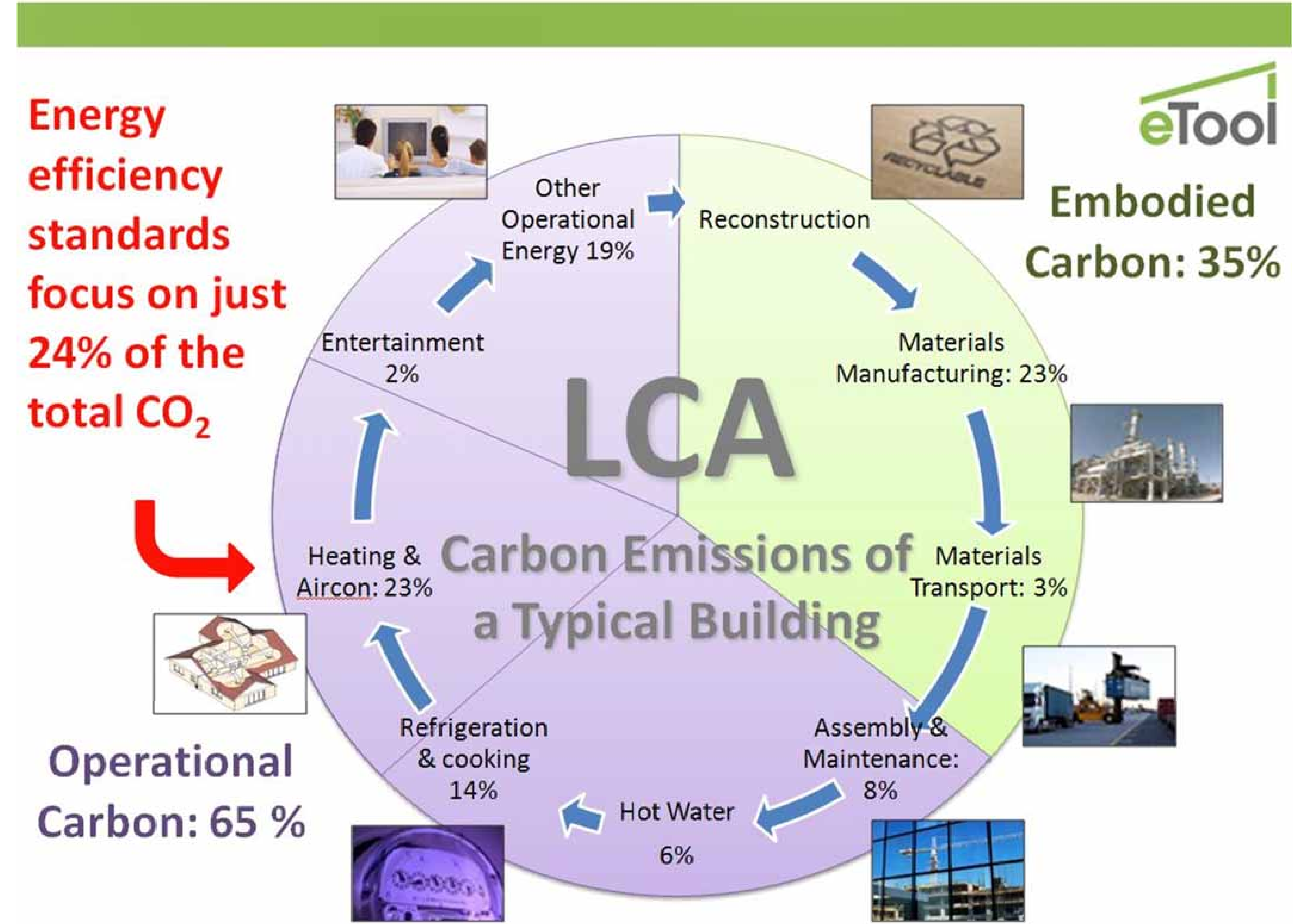


(Source: UNEP Sustainable Buildings and Climate Initiative, www.unepsbci.org)

The 5 sectors of ecological footprint (for Hong Kong)

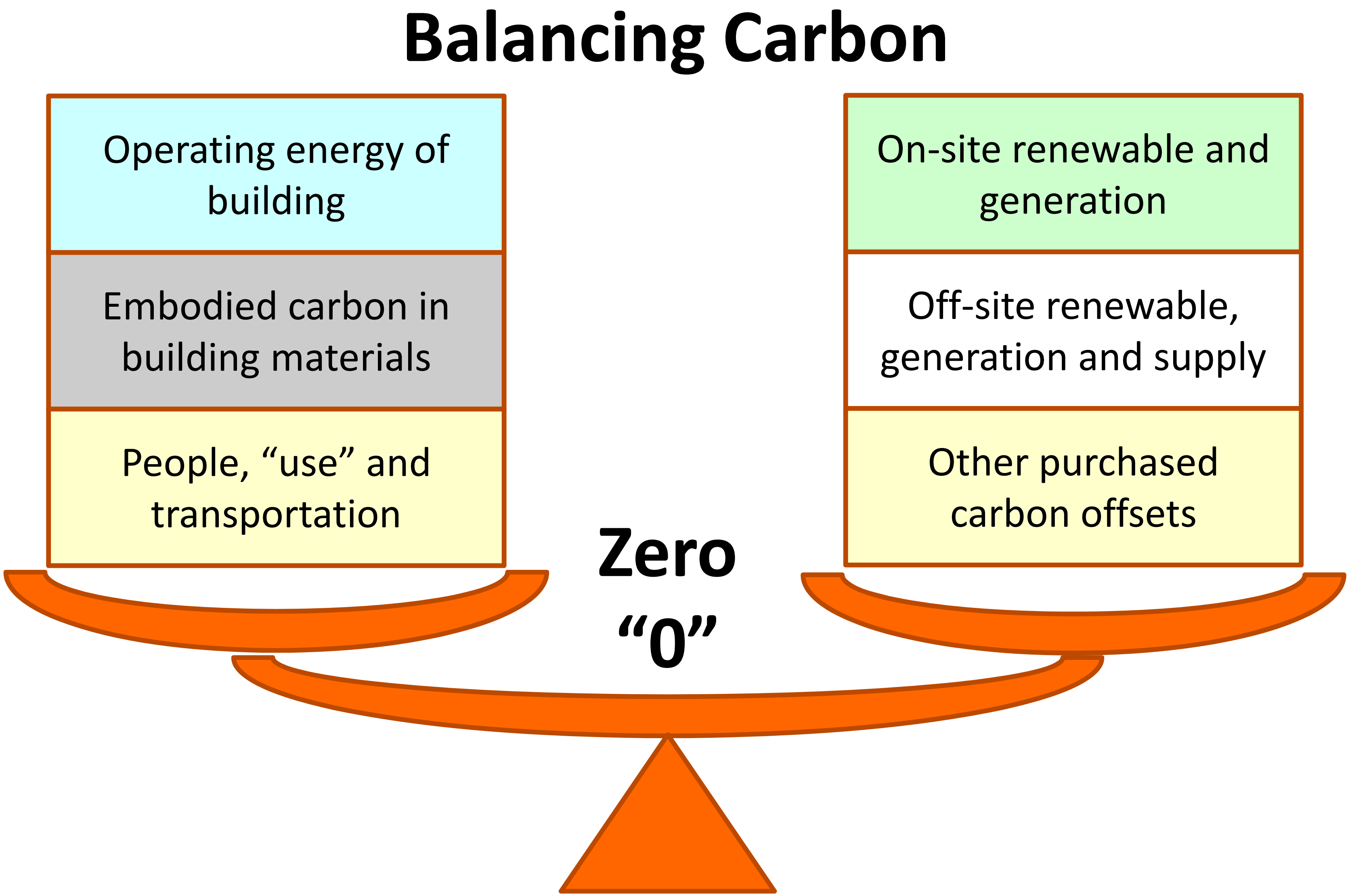


(Source: Friends of the Earth (Hong Kong), www.foe.org.hk)

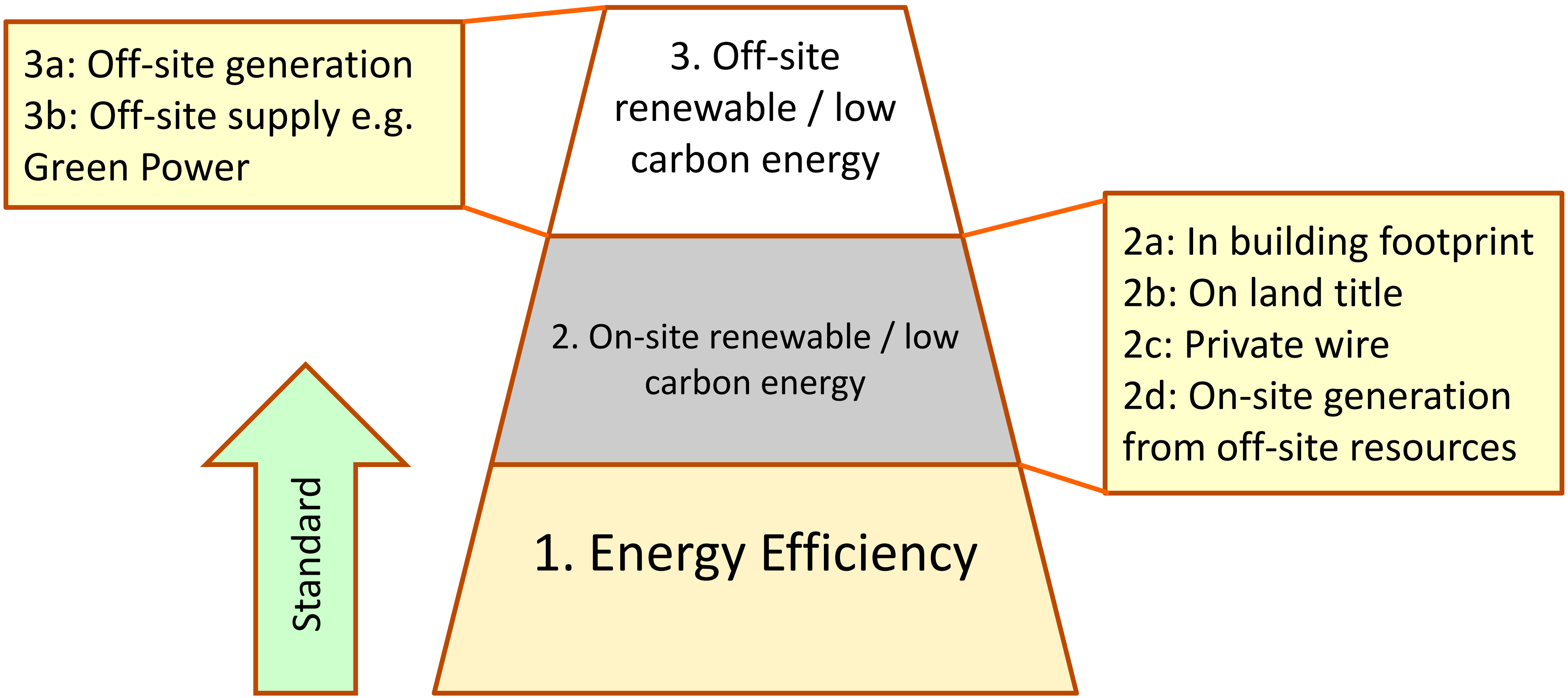


(Source: http://etool.net.au)

Balancing carbon emissions for zero carbon buildings (ZCB)



Allowable emission reduction options for zero carbon buildings



Assess Carbon Emissions

- Current limitations
  - Unclear definition of ‘zero carbon’
  - Lack of scientific assessment methods for carbon footprint of building projects
  - Limited data availability and uncertainty of data
  - Complicated process for whole life cycle analysis
  - Still weak market demand and awareness
- Future research
  - Zero carbon building: definition
  - Assessment tool for footprint analyses

THANK YOU 謝謝