MEBS6020 Sustainable Building Design

http://ibse.hk/MEBS6020/

Energy and Environmental Design (I)

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- Sustainable design process
- Architectural design impacts
- HVAC design considerations
- Predesign energy analysis
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Engineering fundamentals

- Understand the fundamentals is important for thoughtful design
- Key fundamentals of engineering that influence sustainable building design:
  - First and second laws of thermodynamics
  - Heat transfer
  - Fluid mechanics
  - Energy conversion

Engineering fundamentals

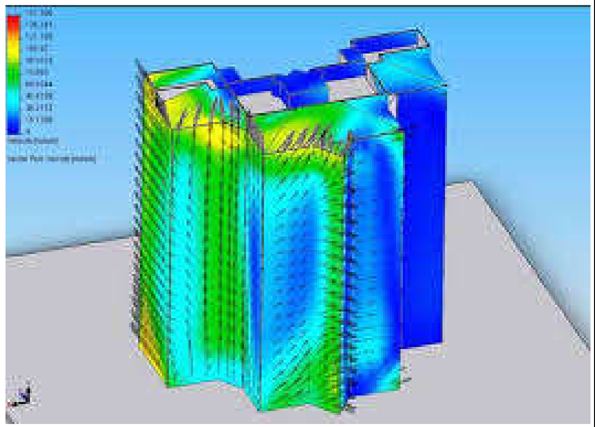
- Laws of thermodynamics
  - First Law: Energy cannot be created or destroyed
  - Second Law: All processes irreversibly increase the entropy of a system and its environment
    - Must use energy carefully and effectively
- Heat transfer
  - Conduction, $Q = U A \Delta T$
  - Convection (natural & forced convection)
  - Radiation, $Q = \varepsilon \sigma A (T_1^4 - T_2^4)$

Engineering fundamentals

- Fluid mechanics
  - Fluid flow and systems
    - Bernoulli equation: $$\frac{p}{\rho g} + \frac{v^2}{2g} + z = \text{constant}$$
  - Hydraulic machines, e.g. pumps, fans
- Energy conversion
  - Power generation and distribution
  - Cogeneration, combined heat and power (CHP)
  - Recovery of energy, system efficiencies
  - Mass transfer, latent heat

Engineering fundamentals

- Typical examples of technical analyses:
  - 1. Thermal performance
    - Building envelope, insulation, thermal comfort
  - 2. Energy analysis
    - Building energy simulation and modelling
  - 3. Ventilation and air flow
    - Computational fluid dynamics (CFD)
  - 4. HVAC and other energy systems
    - Heat recovery, control strategies

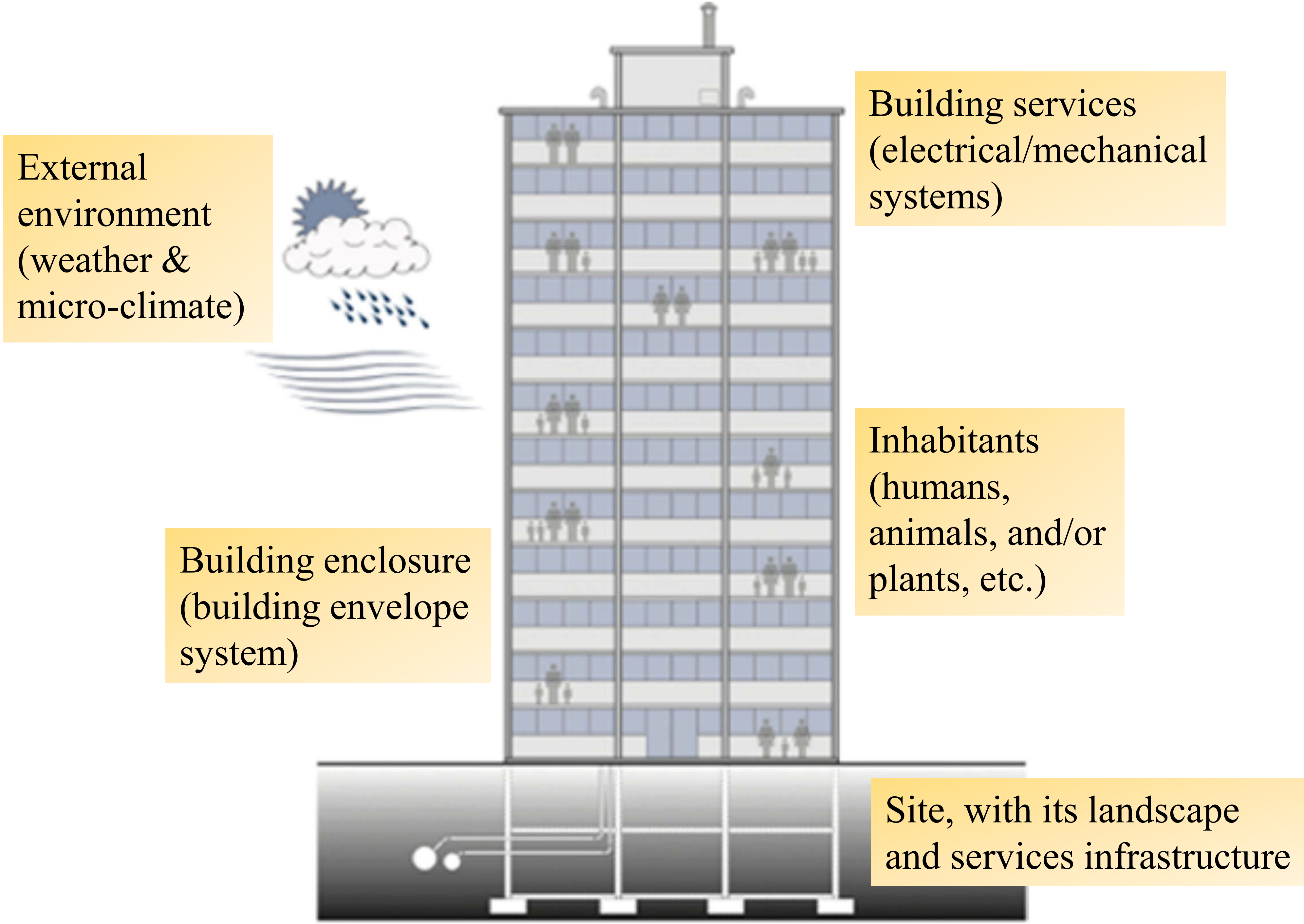


Engineering fundamentals

- Building Science Concepts
  - It is a field of knowledge that draws upon physics, chemistry, engg., architecture, and the life sciences
  - Understand the physical behaviour of *the building as a system* and how this impacts energy efficiency, durability, comfort & indoor air quality
  - Apply empirical techniques to the effective solution of design problems
  - Harmonization of the building elements is the key to well-performing buildings

(Source: Building Science Concepts (WBDG) https://www.wbdg.org/resources/building-science-concepts)

The building as a system (with sub-systems & other elements)



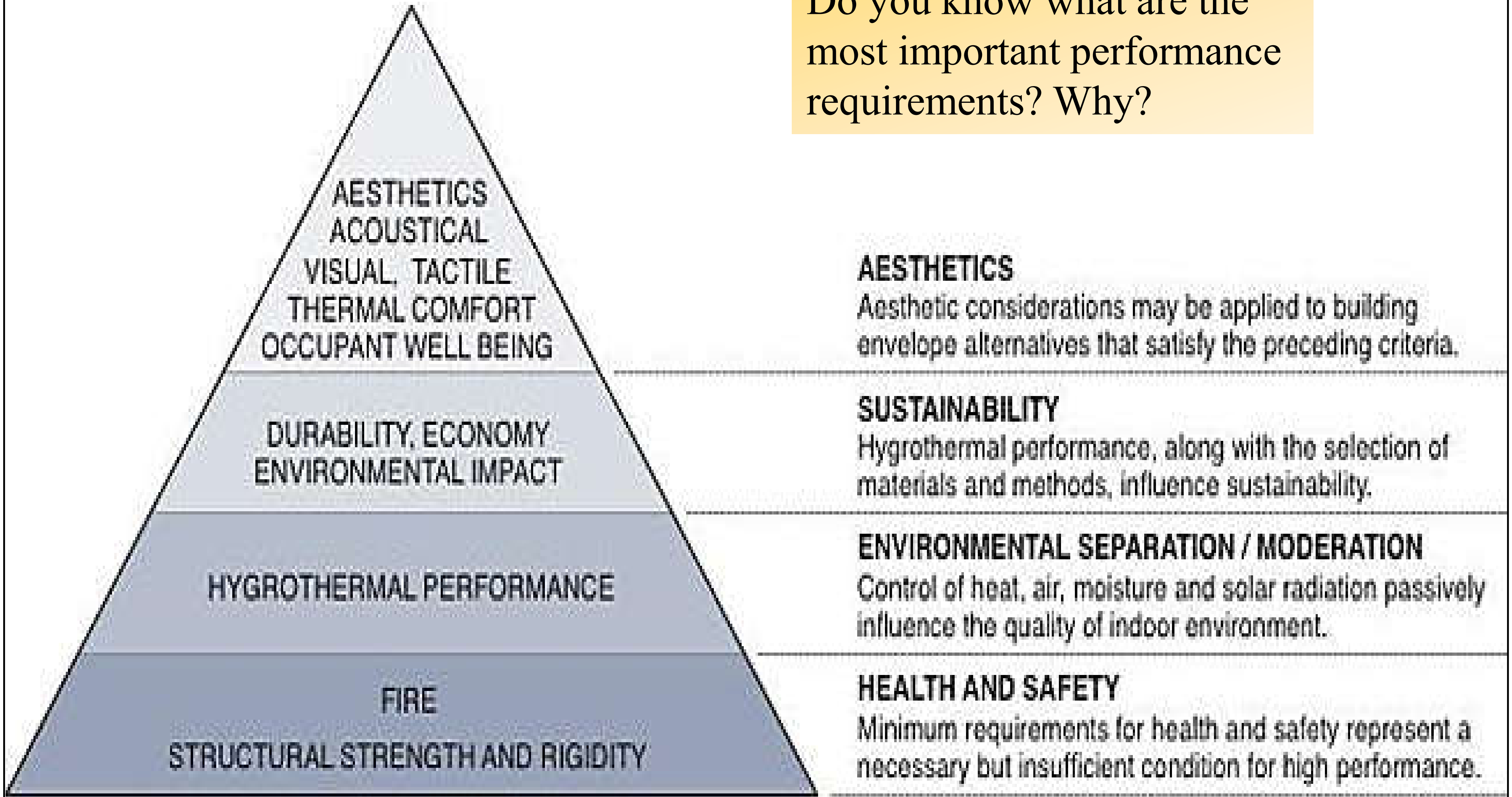
(Source: Building Science Concepts (WBDG) https://www.wbdg.org/resources/building-science-concepts)

Engineering fundamentals

- Building Performance
  - The level of service provided by a building material, component, or system, in relation to an intended, or expected, threshold or quality, e.g. structural, thermal & acoustic performance
  - How to quantify & predict performance parameters
  - Performance requirements derived from building science principles
  - Methods, tools & techniques for designing and analyzing performance

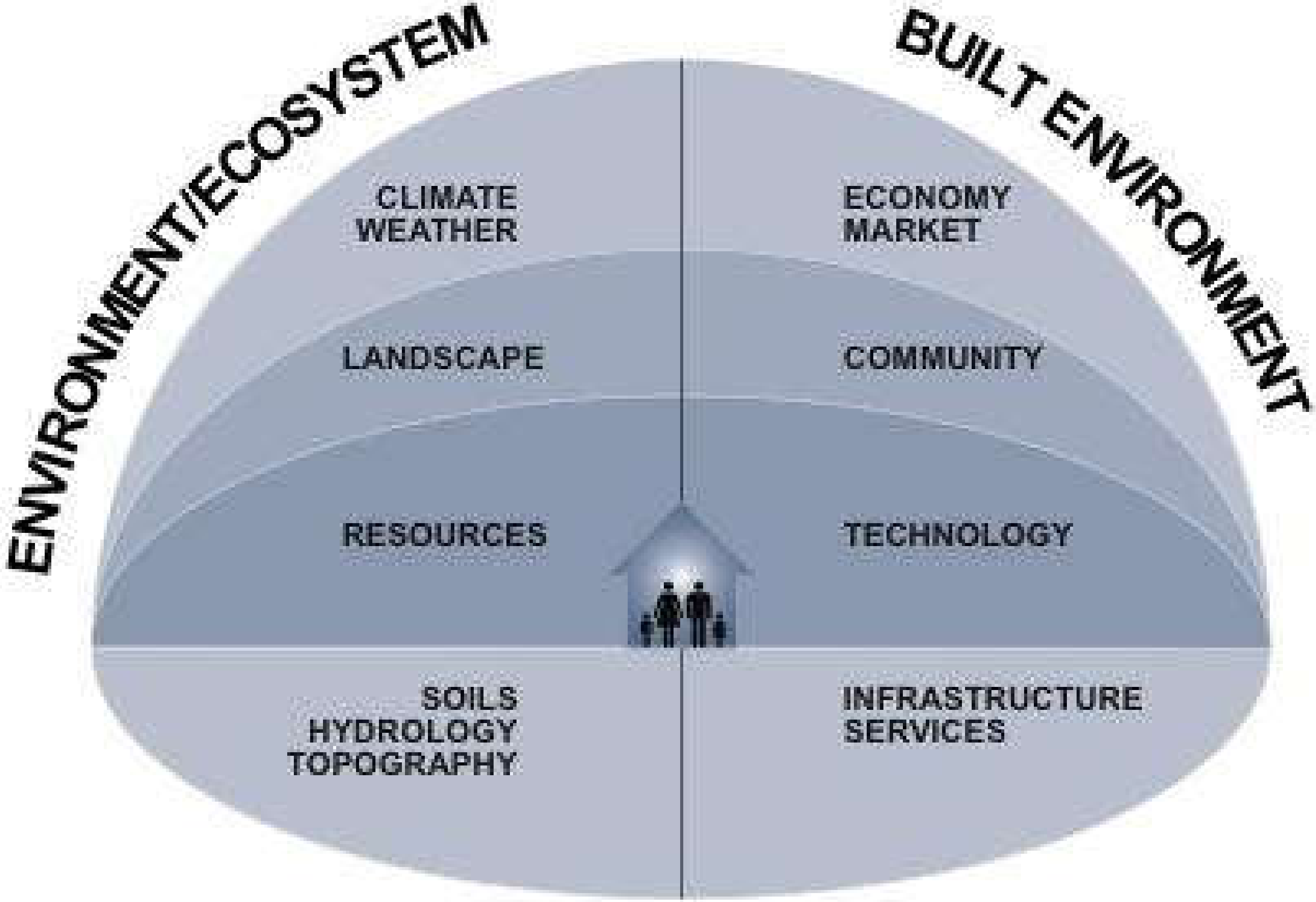
Building science hierarchy of performance requirements

Do you know what are the most important performance requirements? Why?



(Source: Building Science Concepts (WBDG) https://www.wbdg.org/resources/building-science-concepts)

Contemporary context for building performance objectives



The assessment of building performance objectives involves numerous interfaces between the building, its occupants, and the natural & built environment.

(Source: Building Science Concepts (WBDG) https://www.wbdg.org/resources/building-science-concepts)

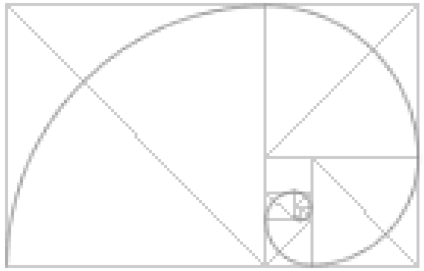
Sustainable design process

- Environmentally responsive design process
  - Pre-design
    - Develop green vision
    - Establish project goals and green design criteria
    - Set priorities; develop building programme
    - Establish budget
    - Assemble Green Team; develop partnering strategies
    - Develop project schedule
    - Review laws and standards
    - Conduct research
    - Select site

(Source: PTI, 1996. *Sustainable Building Technical Manual*)

Sustainable design process

- Environ. responsive design process (cont'd)
  - Design
    - Schematic design
      - Confirm green design criteria
      - Develop, test and select green solutions
      - Check cost



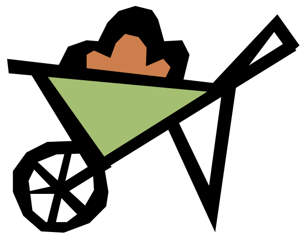
    - Design development
      - Refine green solutions
      - Develop, test, select green systems
      - Check cost

    - Construction Documents
      - Document green materials and systems; Check cost

(Source: PTI, 1996. *Sustainable Building Technical Manual*)

Sustainable design process

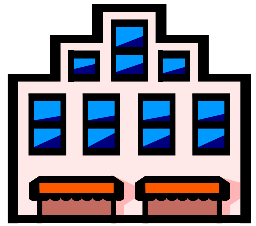
- Environ. responsive design process (cont'd)
  - Bid (Tendering)
    - Clarify green solutions
    - Establish cost
    - Sign contract
  - Construction
    - Review substitutions and submittals for green products
    - Review materials test data
    - Build project
    - Commission the systems
      - Testing; operations and maintenance manuals; training



(Source: PTI, 1996. *Sustainable Building Technical Manual*)

Sustainable design process

- Environ. responsive design process (cont'd)
  - Occupancy
    - Re-commission the systems
    - Perform maintenance
    - Conduct post-occupancy evaluation (POE)



- The "4 Es" principle:
  - Engage Everyone, Early, with Every issue
  - Enhance design decisions during the design process from pre-design to design development

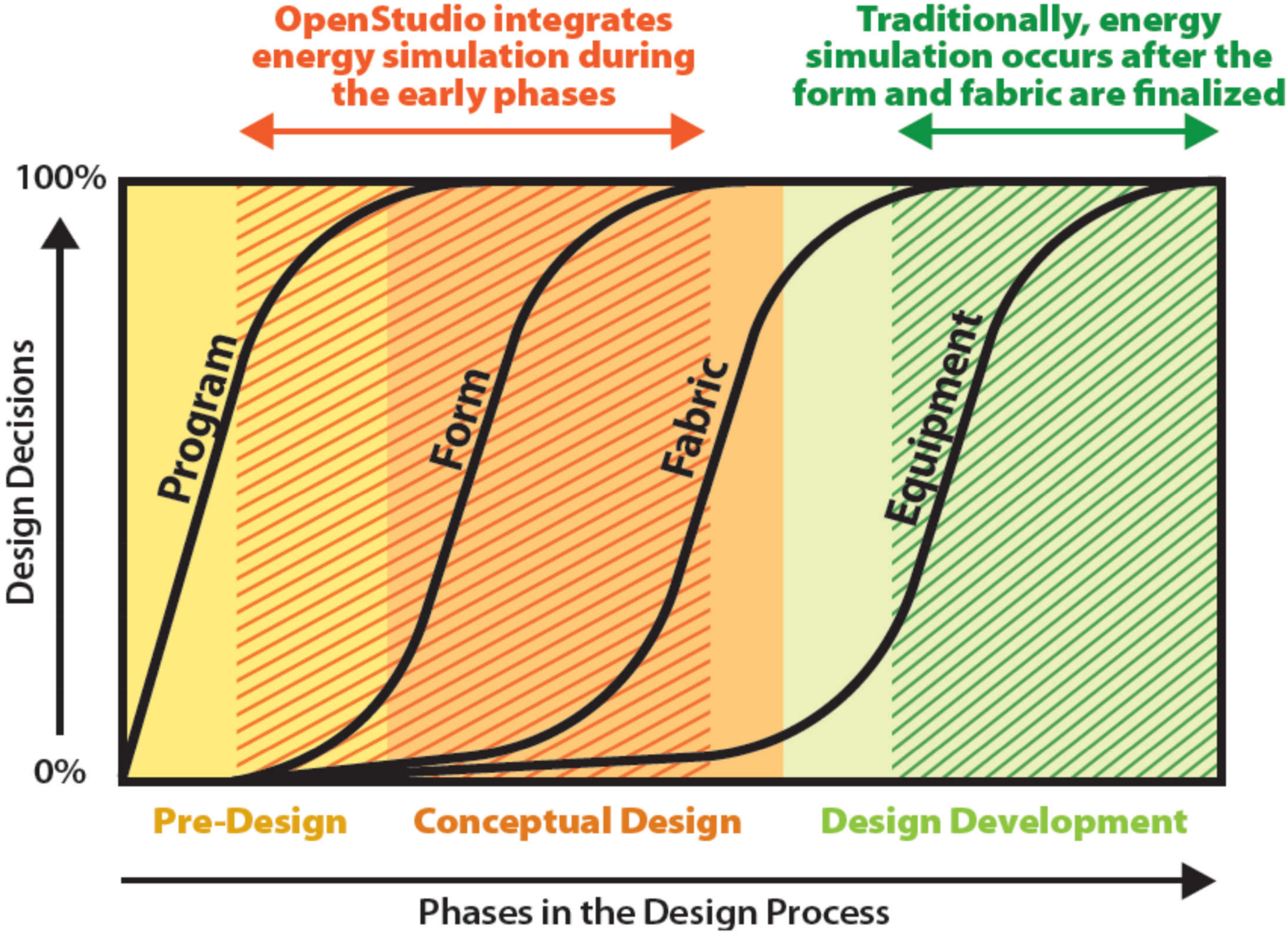
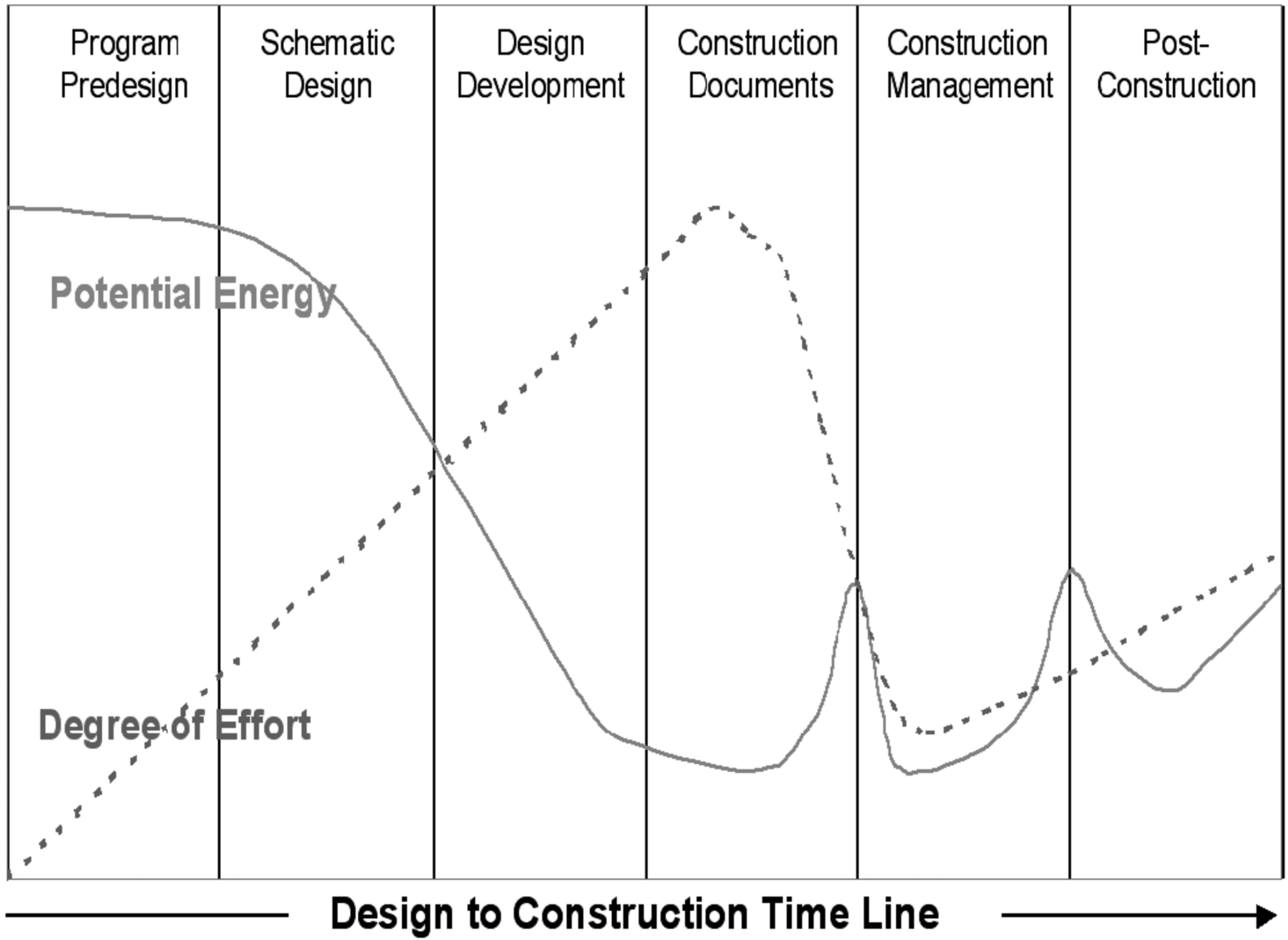


Figure 1. Design Decisions During the Design Process

(Source: Lindsey, G., et al., 2009. *A Handbook for Planning and Conducting Charrettes for High-Performance Projects*)

Impact of early design input on building performance



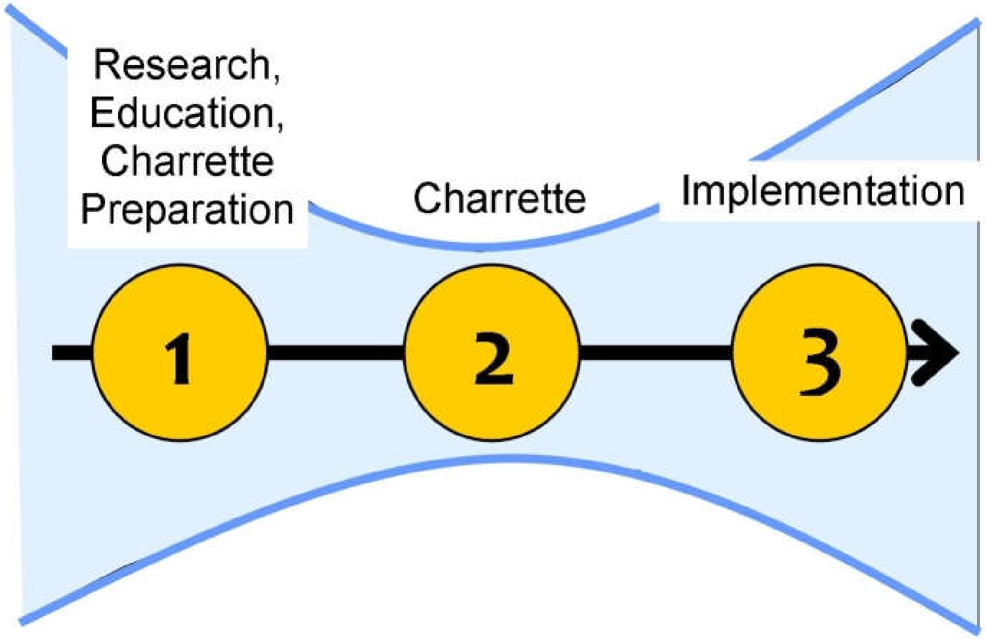
(Source: ASHRAE, 2006. *ASHRAE GreenGuide*)

Sustainable design process

- The Charrette (pronounced [*shuh-ret*])
  - *Collaborative* sessions (like design workshop) for sustainable design and planning
    - A technique often used by architects and planners
    - Bring all decision makers together for a compressed period of time to identify and solve problems
  - *Multidisciplinary* charrette team
    - Architects, designers, consultants, engineers, managers, contractors, and occupants
  - Integrate all viewpoints throughout design
  - Promotes joint ownership of solutions

(Source: Charrette http://en.wikipedia.org/wiki/Charrette)

The Charrette process



(Source: Planning and Conducting Integrated Design (ID) Charrettes [WBDG] http://www.wbdg.org/resources/charrettes.php)

Sustainable design process

- The Charrette (cont'd)
  - Benefits
    - Promote enthusiasm for a project
    - Set and agree about common project goals
    - Develop early consensus about project design priorities
    - Set performance goals for energy, emissions (carbon and others), water, site, materials, and other topics
    - Generate quantifiable metrics to measure the final energy and environmental outcomes
    - Initiate an integrated design process

Sustainable design process

- High Performance Building: Performance by Design (27:50) https://youtu.be/hIX-J83lmaI

  - By Rocky Mountain Institute (RMI)
  - Provide an in-depth look at how the integrative design process happens
  - Include examples of how design teams collaborate in new ways to integrate high-performance design elements for optimal performance
  - Experience charrette discussions and see the design process unfold on projects such as the Empire State Building retrofit, Missouri Department of Natural Resources, Phipps Conservancy, the Desert Living Center, Willow School and Chicago Botanic Gardens

Sustainable design process

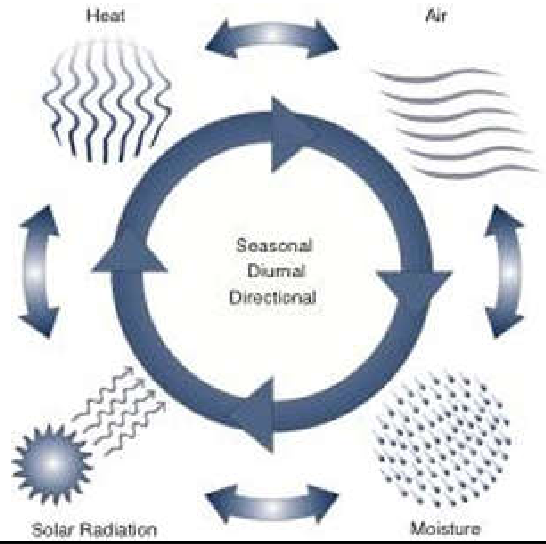
- Key areas for green specialist advices
  - Building structure
  - Envelope design
  - Lighting services
  - Electrical power
  - Cooling and heating engineering
  - Water services
  - Ventilation
  - Cost estimating
  - Landscaping

- Whole life cycle design
- Passive design, daylight design and facade optimization
- Building systems design and integration
- Post-occupancy evaluation

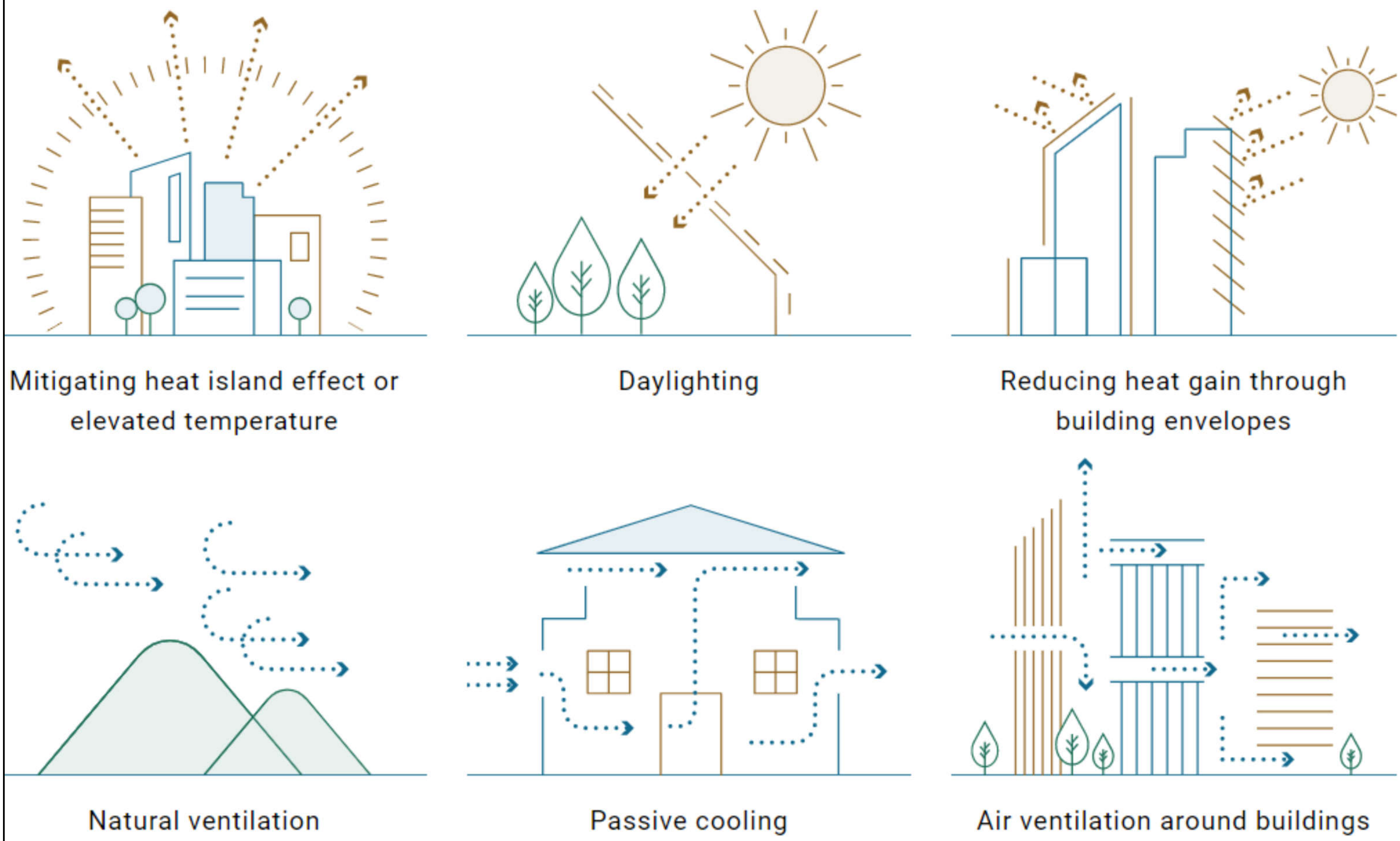
(See also: http://ibse.hk/MEBS6020/Key_Areas_For_Green_Specialist_Advice.pdf)

Architectural design impacts

- Major elements of architectural design
  - Site location (on environment, transport, amenity)
  - Building orientation (solar, daylight, wind, views)
  - Building form and geometry (stacking, massing)
  - Building envelope (windows, walls, roof)
  - Arrangement/grouping of spaces
- Climatic impacts
  - Temperature, humidity, solar, wind
  - Rainfall, air quality, pollution



Different aspects of passive design approaches

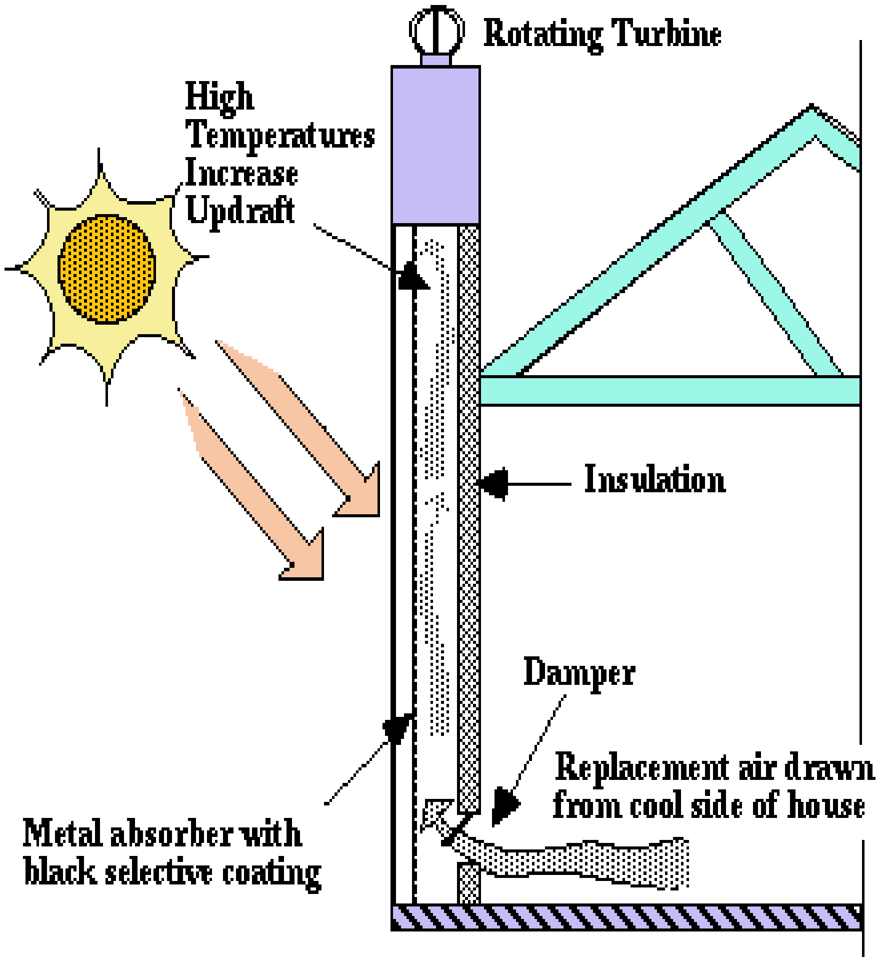


(Source: https://www.archsd.gov.hk/archsd/html/report2021/en/sustainable-building.html)

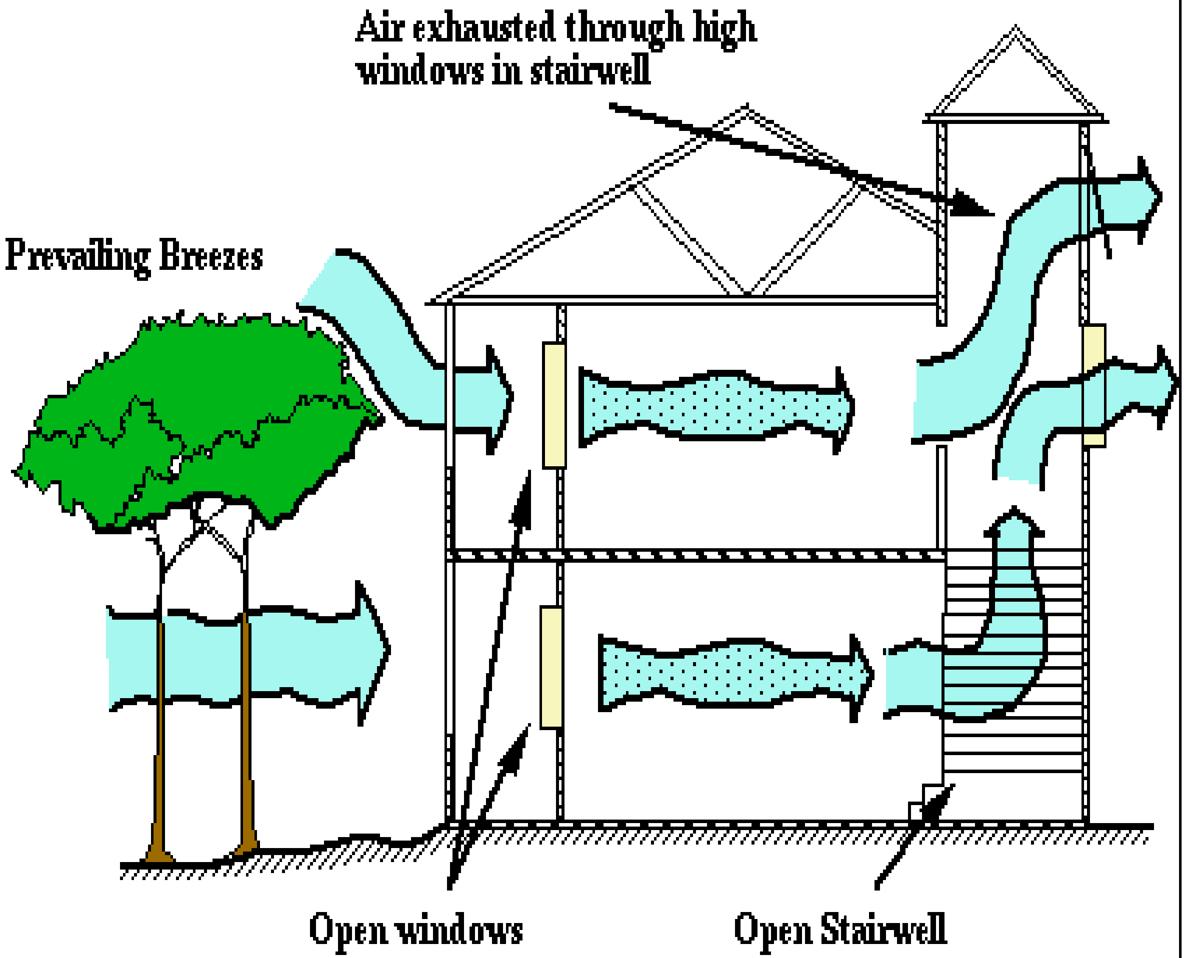
Architectural design impacts

- Passive cooling
  
  - A building design approach that focuses on *heat gain control* and *heat dissipation* in a building in order to improve the indoor thermal comfort with low or nil energy consumption
  - This approach works either by preventing heat from entering the interior (*heat gain prevention*) or by removing heat from the building (*natural cooling*)

Examples of passive cooling designs



Thermal chimney

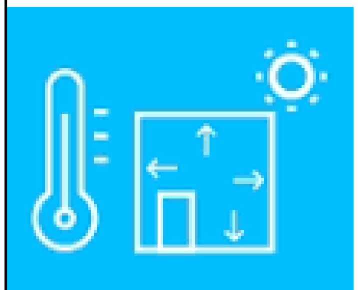


Natural ventilation

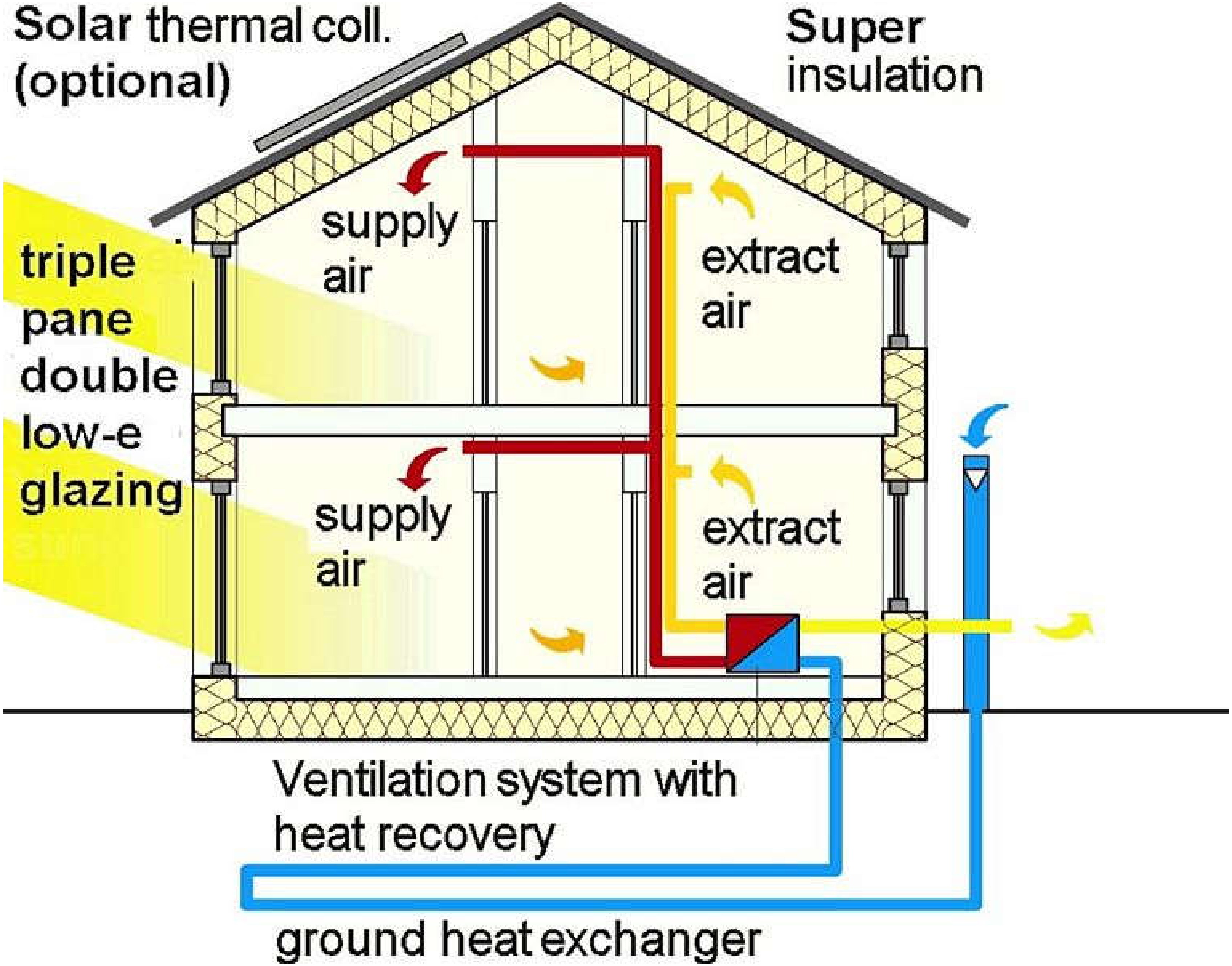
(See also: http://en.wikipedia.org/wiki/Passive_cooling and http://passivesolar.sustainablesources.com/)

Architectural design impacts

- Passive cooling (cont'd)
  - Natural cooling utilizes on-site energy, available from the natural environment, combined with the architectural design of building components (e.g. building envelope), rather than mechanical systems to dissipate heat
    - It depends not only on the architectural design but how it uses the local site natural resources as heat sinks (i.e. everything that absorbs or dissipates heat). Examples of on-site heat sinks are the upper atmosphere (night sky), the outdoor air (wind), and the earth/soil

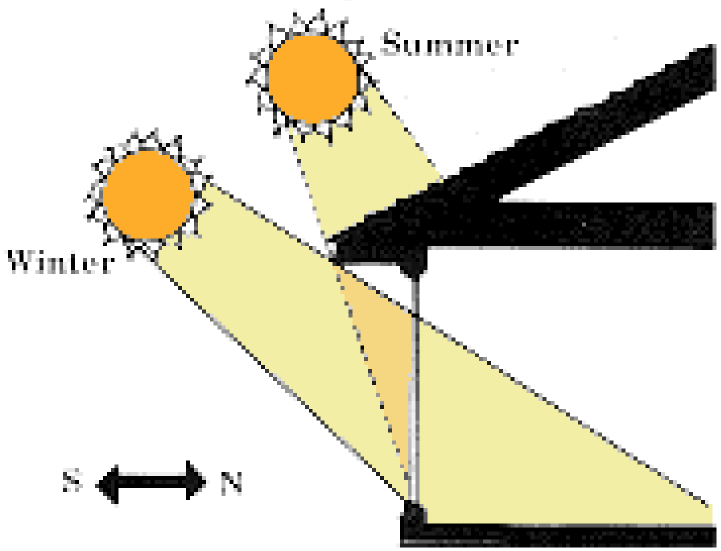


Typical techniques for passive house (from Germany)



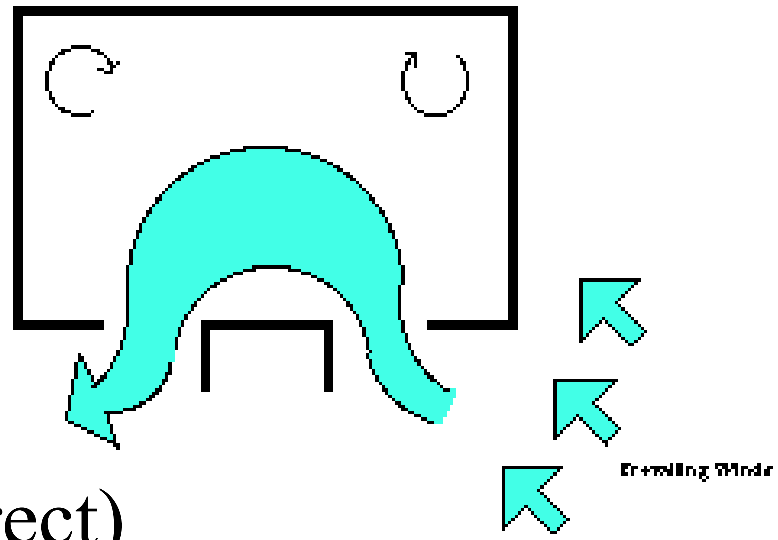
Architectural design impacts

- Passive cooling (cont'd)
  - Preventative techniques
    - Microclimate and site design
    - Solar control
    - Building form and layout
    - Thermal insulation
    - Behavioral and occupancy patterns
    - Internal gain control
  - Modulation and heat dissipation techniques
    - Thermal mass + Natural cooling



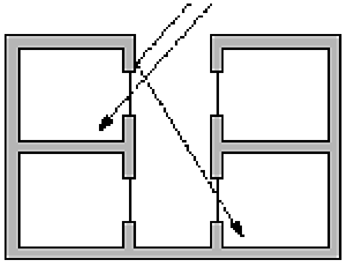
Architectural design impacts

- Passive cooling (cont'd)
  - Ventilation
    - Cross ventilation
    - Stack ventilation
    - Night flush ventilation
  - Radiative cooling (direct/indirect)
  - Evaporative cooling
  - Earth coupling (direct/indirect)

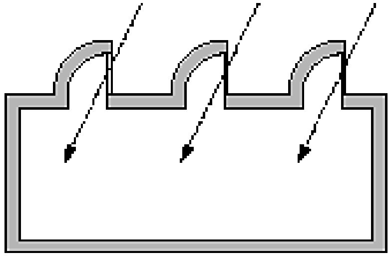


(See also: http://en.wikipedia.org/wiki/Passive_cooling)

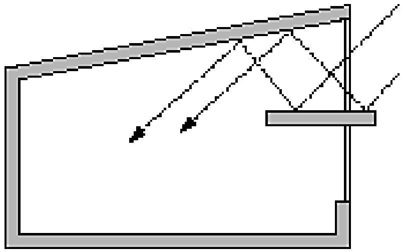
Daylighting design and control



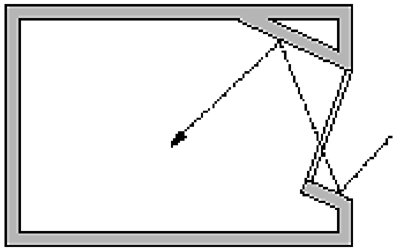
Light well



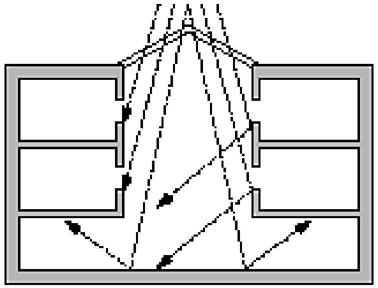
Roof monitor



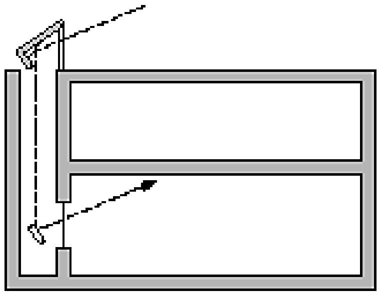
Light shelf



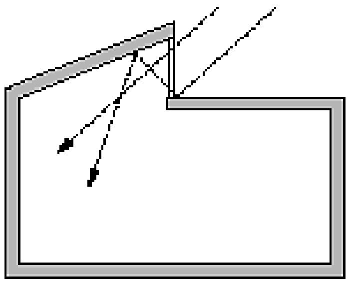
External reflectors



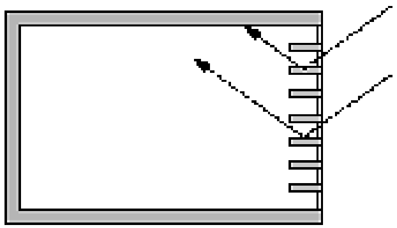
Atrium



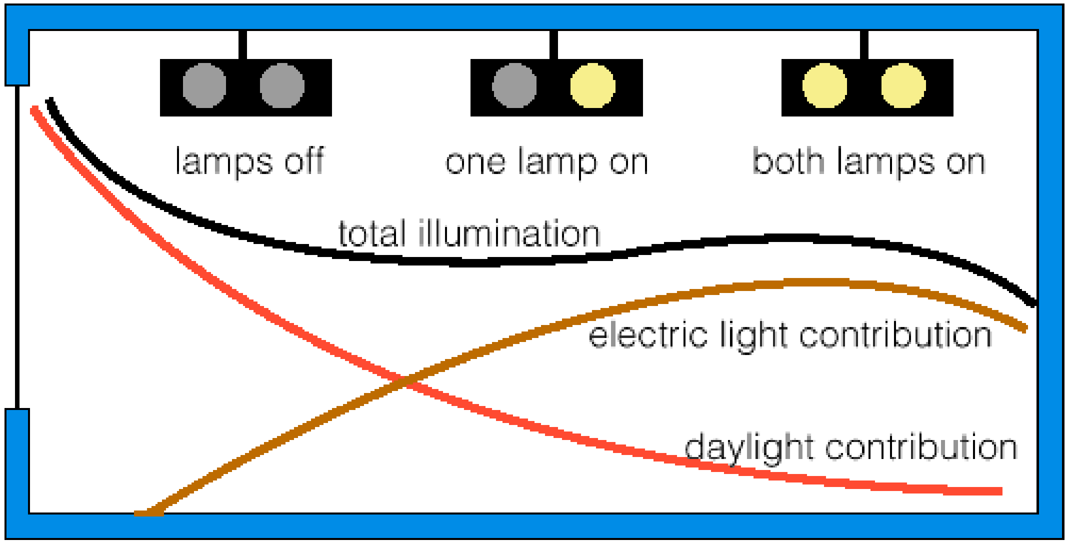
Light duct

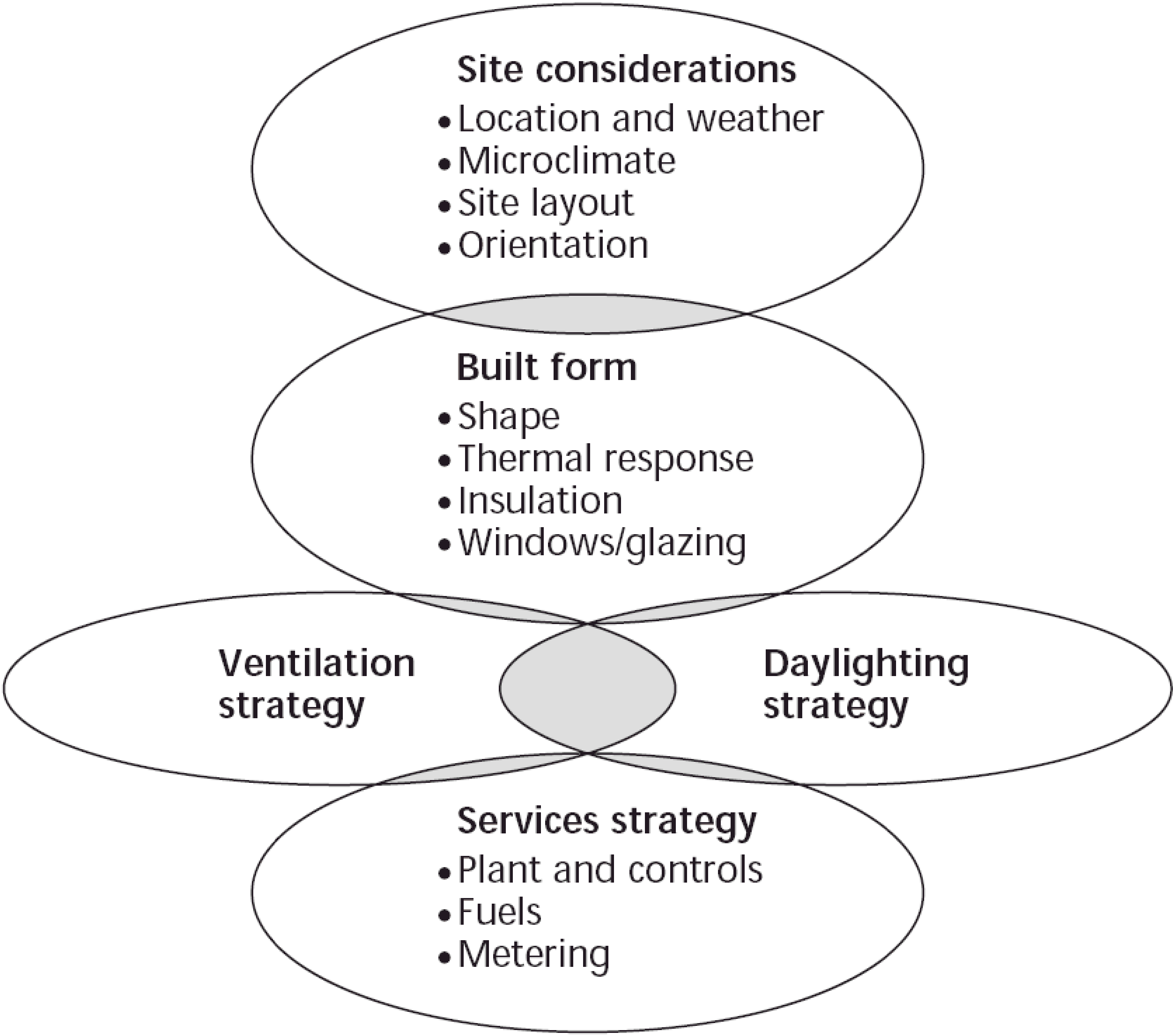


Clerestory



Reflective blinds



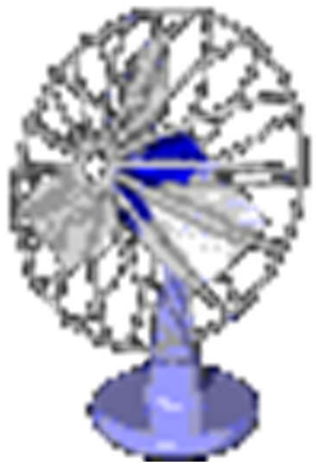


(Source: Energy Efficiency in Buildings: CIBSE Guide F)

HVAC design considerations

HVAC = heating, ventilation & air conditioning

- Design intent
  - Set goals for performance
    - Energy performance
    - Environmental performance
    - Comfort (e.g. design temp. & humidity)
    - Operating cost
    - Determine how to achieve the goals
  - System by system
    - Integrated design



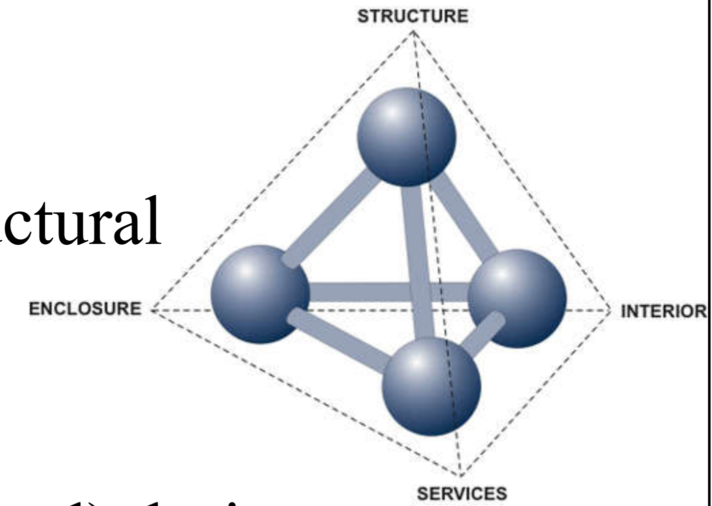
(Source: ASHRE, 2006. *ASHRAE GreenGuide*)

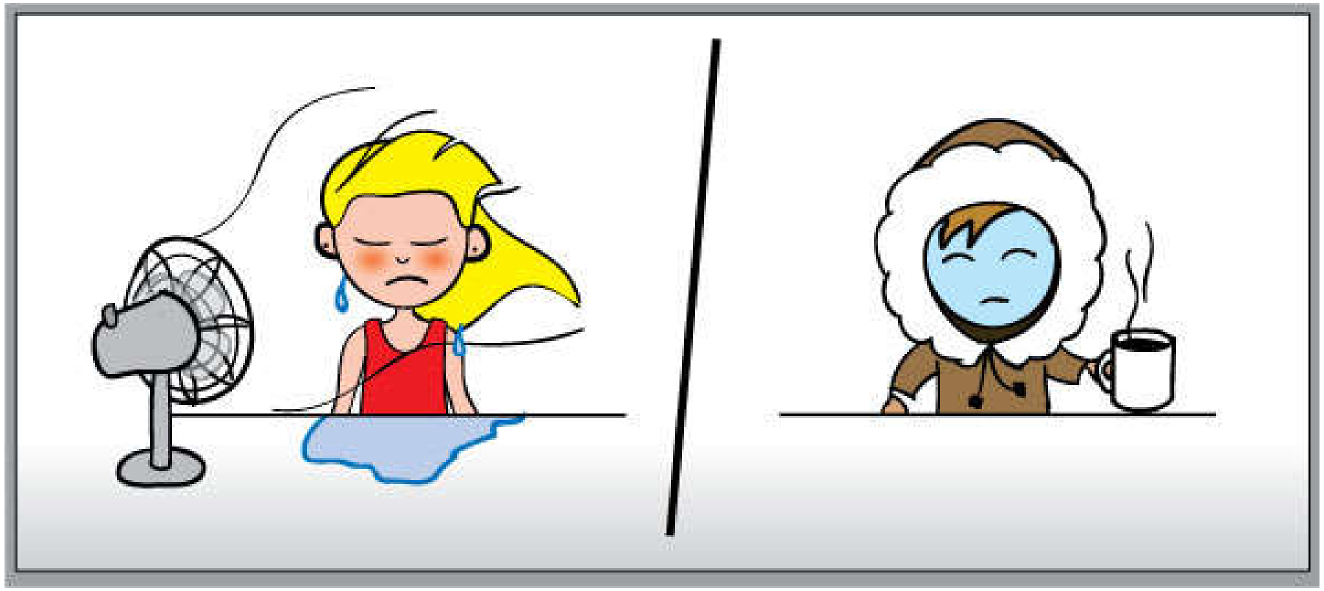
HVAC design considerations

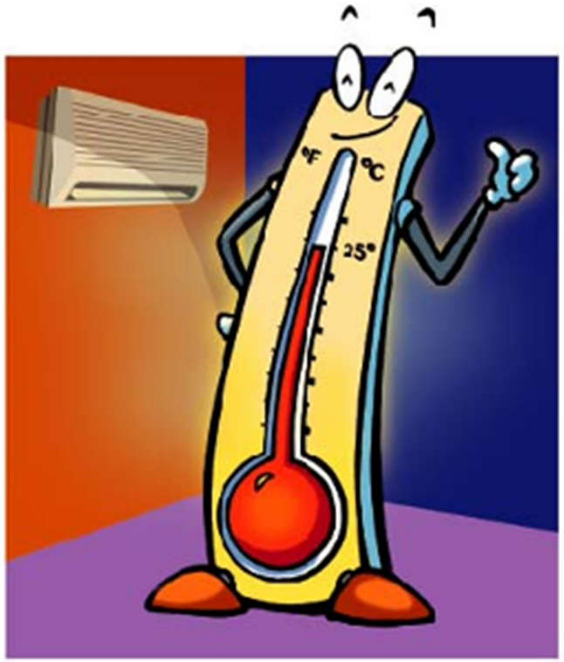
- Verify that design intent is met
  - In design
    - Verification of commissioning (Cx) goals in design
    - Coordination between design disciplines
    - Include commissioning in design documents
  - In construction
    - Procurement of equipment and materials
    - Installation
  - At start-up and testing
  - In operations

HVAC design considerations

- Design integration
  - Integration with other disciplines
    - Architecture, lighting, interiors, structural
    - Daylighting
    - Underfloor air distribution
    - “Form-follows-function” (architectural) design
  - Increased emphasis on HVAC performance
    - Thermal comfort
    - Indoor air quality (IAQ)
    - Energy efficiency







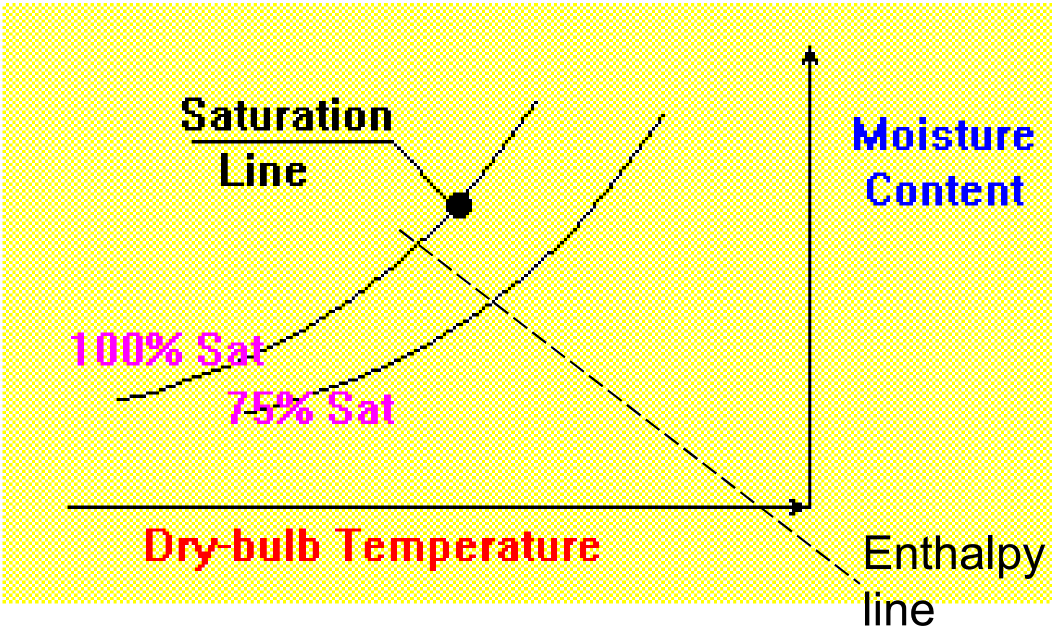
Just nice at 25°C
Electricity Efficiency Centre

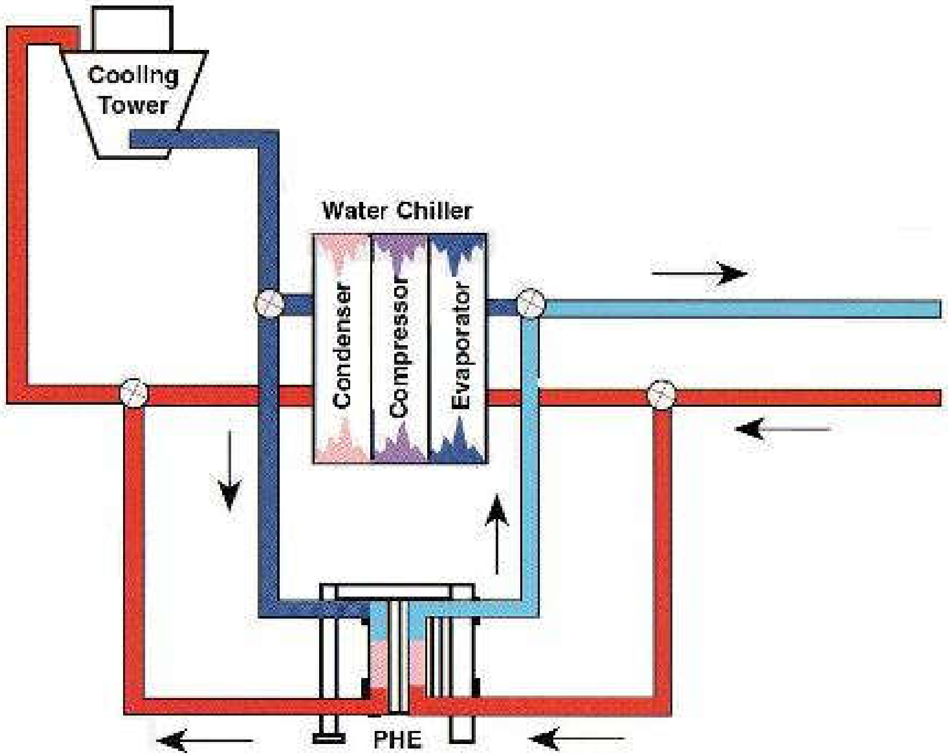
Cleaner filter filters better.
Electricity Efficency Centre

HVAC design considerations

- HVAC systems
  - High-efficiency equipment
  - Systems responsive to partial loads
    - 80% of year, system operates at <50% of peak capacity
  - Emphasis on "free" cooling and heating
    - Economizers (air, water)
    - Evaporative cooling (cooling towers, precooling)
    - Heat recovery
  - Emphasis on IAQ

‘Free’ cooling methods in HVAC system



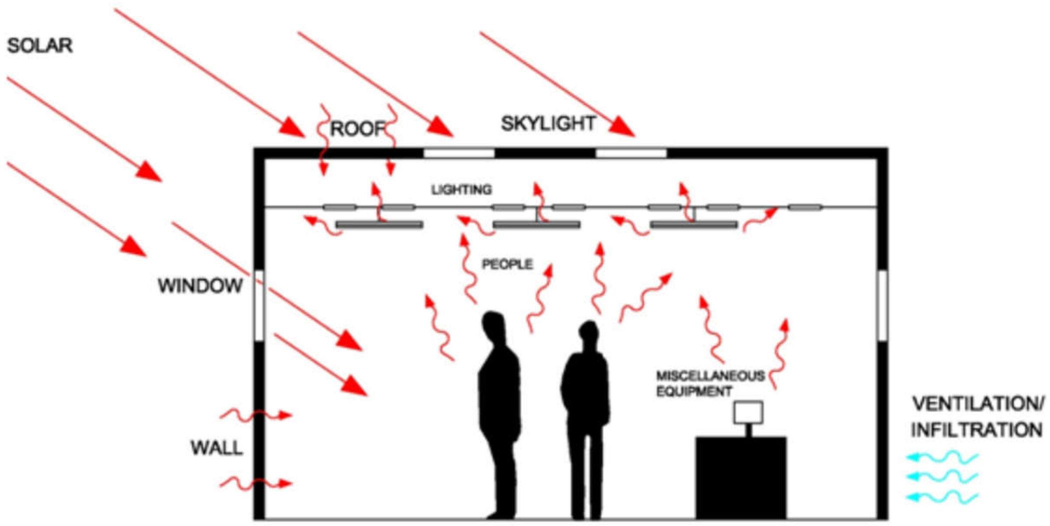


(a) Air-side economiser cycle
- intake more outdoor air when its enthalpy (energy content) is lower than indoor air

(b) ‘Free’ refrigeration
- chiller bypass when the system can be cooled by ambient

(See also: http://en.wikipedia.org/wiki/Free_cooling)

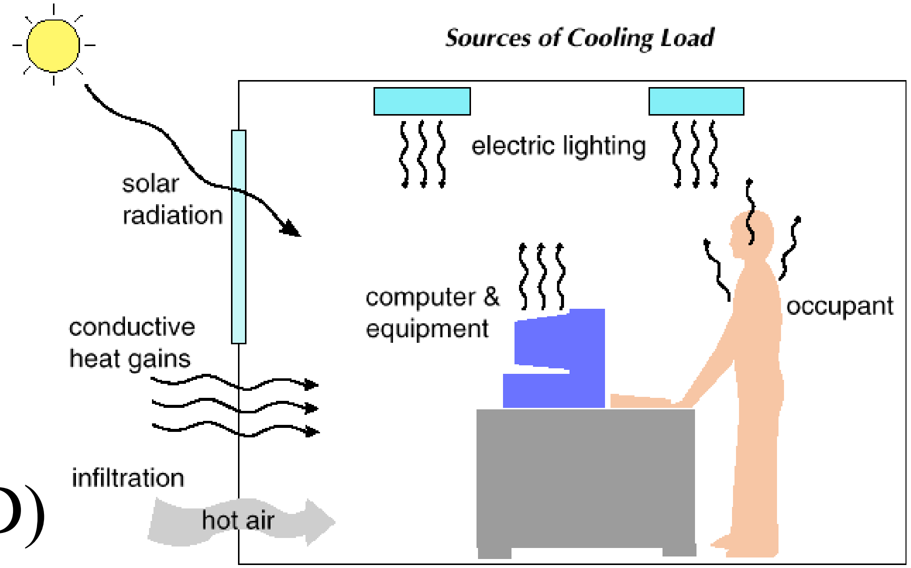
HVAC design considerations



- Load reduction
  - Reduce envelope loads
    - Solar loads
  - Reduce lighting loads
    - Follows energy codes as a design maximum
  - Reduce power loads
    - Site and building type specific, 16 W/m^2 as a maximum
  - Reduced air-conditioning tonnage
    - Provide higher air-conditioning efficiency for same cost

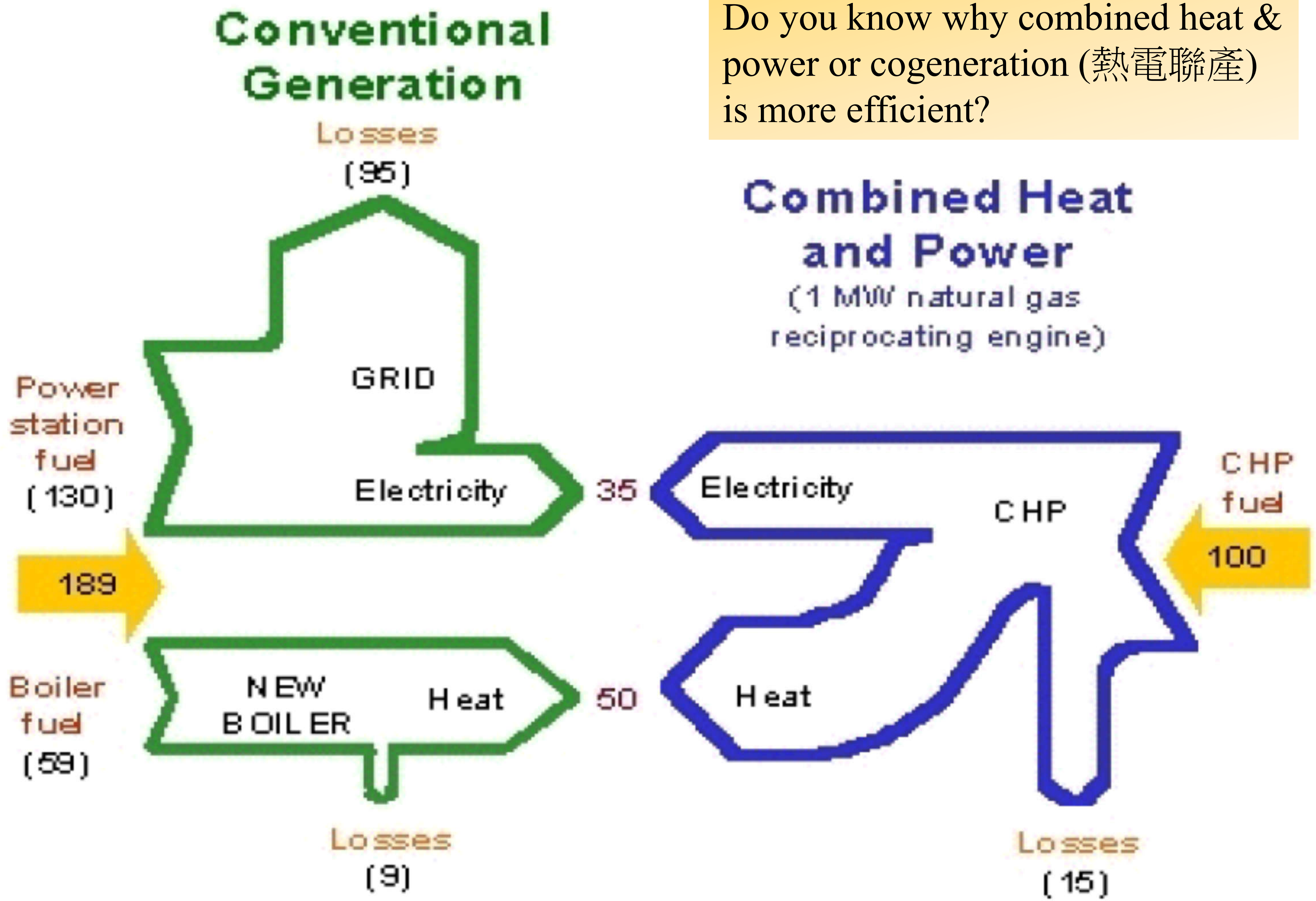
HVAC design considerations

- Cooling and heating load reduction
  - Envelope loads
    - Shading
    - Glass selection
    - Glass percentage
  - Internal loads
    - Lighting power density (LPD)
    - Equipment loads
    - Controls/occupancy sensors



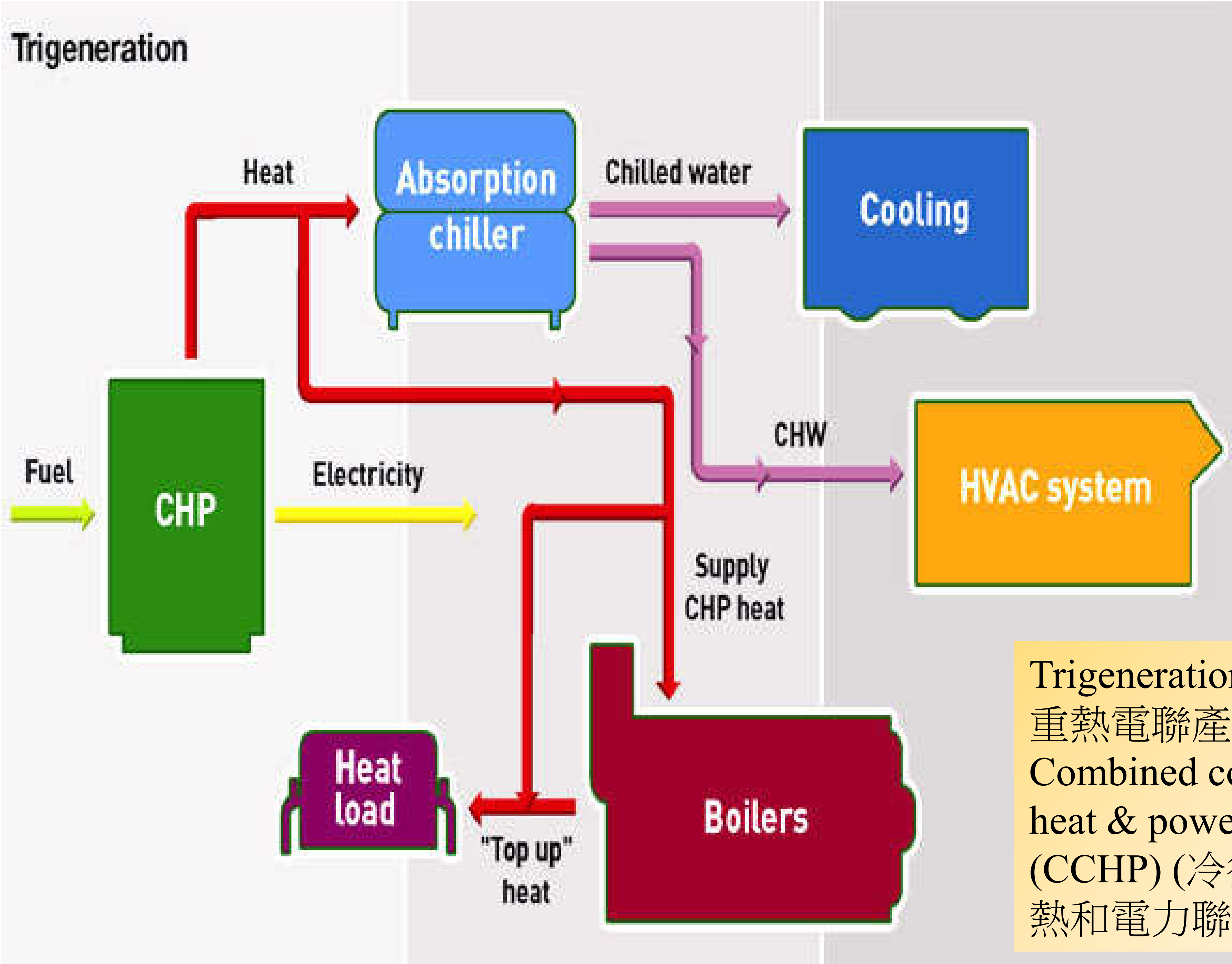
Comparative fuel requirements & losses from energy generation systems

Do you know why combined heat & power or cogeneration (熱電聯產) is more efficient?



(See also: http://en.wikipedia.org/wiki/Cogeneration)

A typical trigeneration system (cool + heat + electricity)

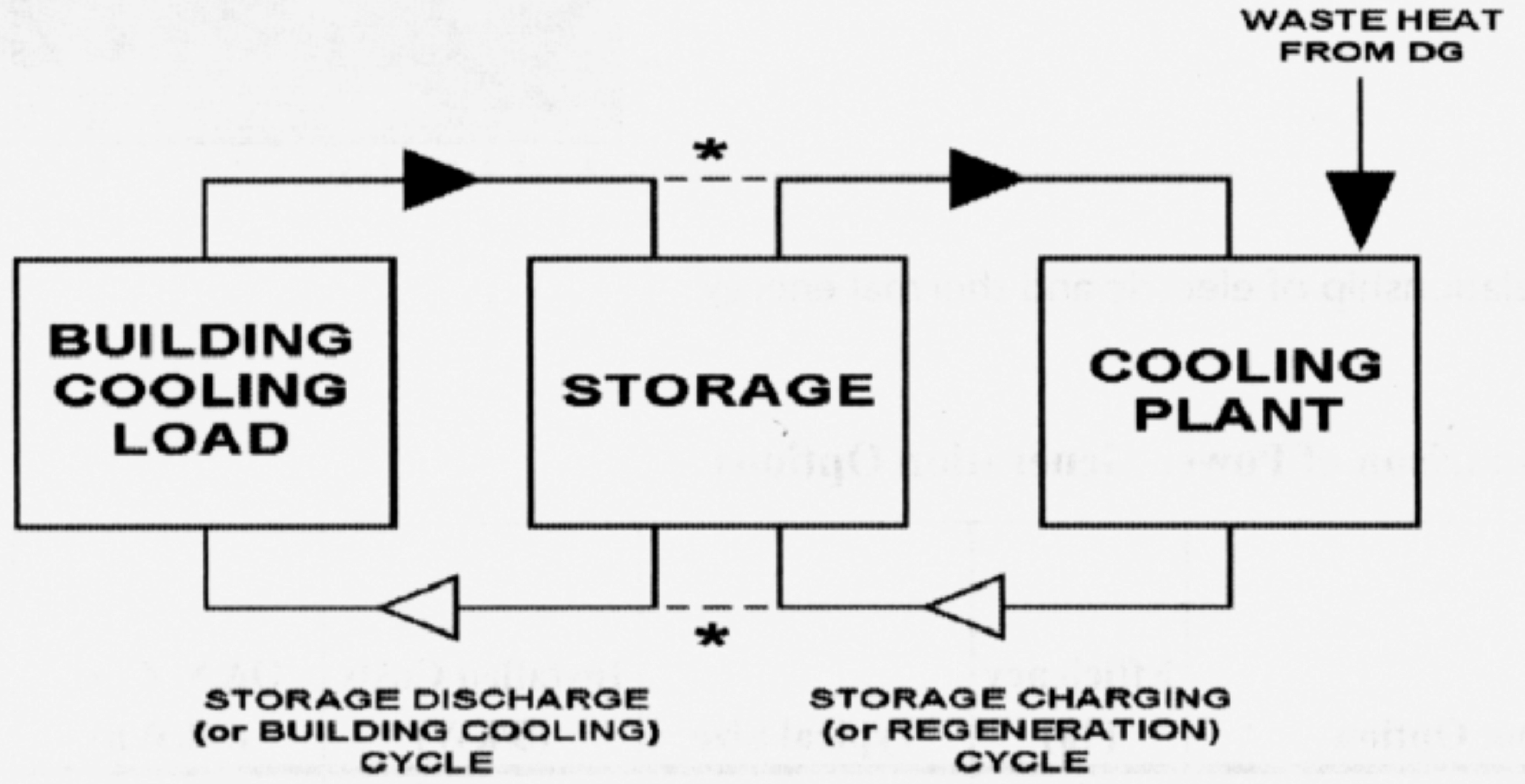


Trigeneration (三重熱電聯產) or Combined cool, heat & power (CCHP) (冷卻，熱和電力聯產)

(Source: http://en.wikipedia.org/wiki/Cogeneration)

Thermal uses of waste heat by energy storage

* DG = distributed generation (electricity)

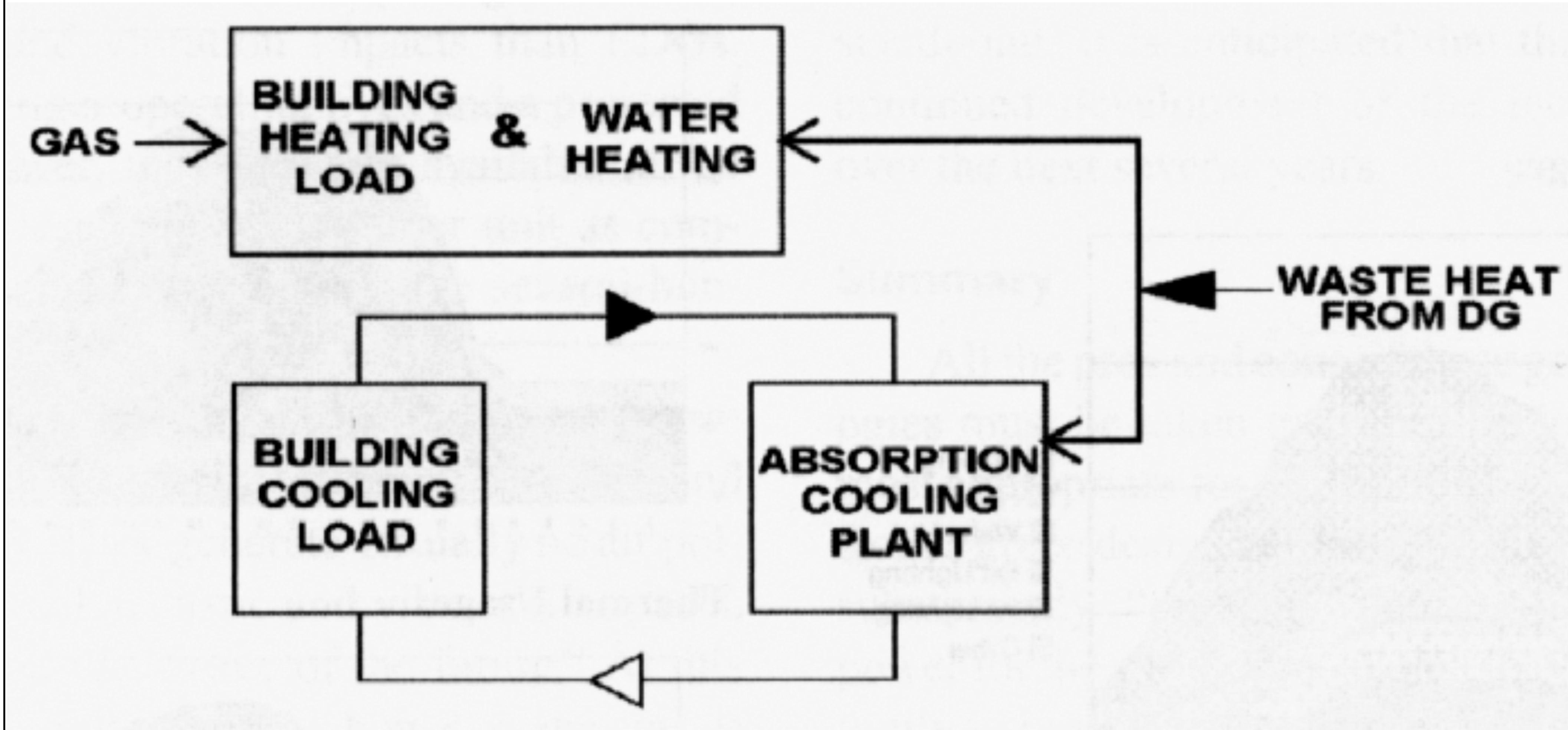


Thermal energy storage (熱能儲存)

(Source: ASHRAE, 2006. *ASHRAE GreenGuide*)

Thermal energy storage and waste heat usage

* DG = distributed generation (electricity)



Waste heat recovery (廢熱回收)

(Source: ASHRAE, 2006. *ASHRAE GreenGuide*)

HVAC design considerations

- **ASHRAE GreenTips**
  - http://ibse.hk/MEBS6020/greentips_2006.pdf
  - Building-type green tips #1 to #5
  - Technology green tips #6 to #39
    - General description
    - When/where it is applicable
    - Pros and cons
    - Key elements of cost
    - Source of further information

HVAC design considerations

- **ASHRAE GreenTips: Examples**
  - GreenTip #4: Student Residence Halls
  - GreenTips #7-9: Air-to-Air Energy Recovery
    - #7: Heat Exchange Enthalpy Wheels
    - #8: Heat Pipe Systems
    - #9: Run-Around Systems
  - GreenTip #12: Ventil. Demand Control Using CO_2
  - GreenTip #27: Indirect Evaporative Cooling
  - GreenTip #37: Rainwater Harvesting

Predesign energy analysis

- Use general information about the building & site to estimate energy performance, characterize energy uses, and identify potential energy savings opportunities
- The objective is to use results to develop design concepts that minimize energy loads and costs from the outset
- Results also provide important guidance for setting energy performance goals

Predesign energy analysis

- Energy performance of a building depends on:
  - Complex interactions between the outdoor environment, indoor conditions, building envelope, and building services systems
- Computer simulation software is the best tool to perform building energy analyses
  - A whole-building simulation tool that calculates hourly or sub-hourly loads for the building
  - >> May require professional energy consultant

Building Energy Simulation Software

ENERGY-10

blast

EnergyPlus

DOE-2

Solar-5

ESP-r

ENER-WIN©

Hourly Energy Simulation Program for Buildings

TRNSYS

Carrier

E-20-II & HAP

HOT2000

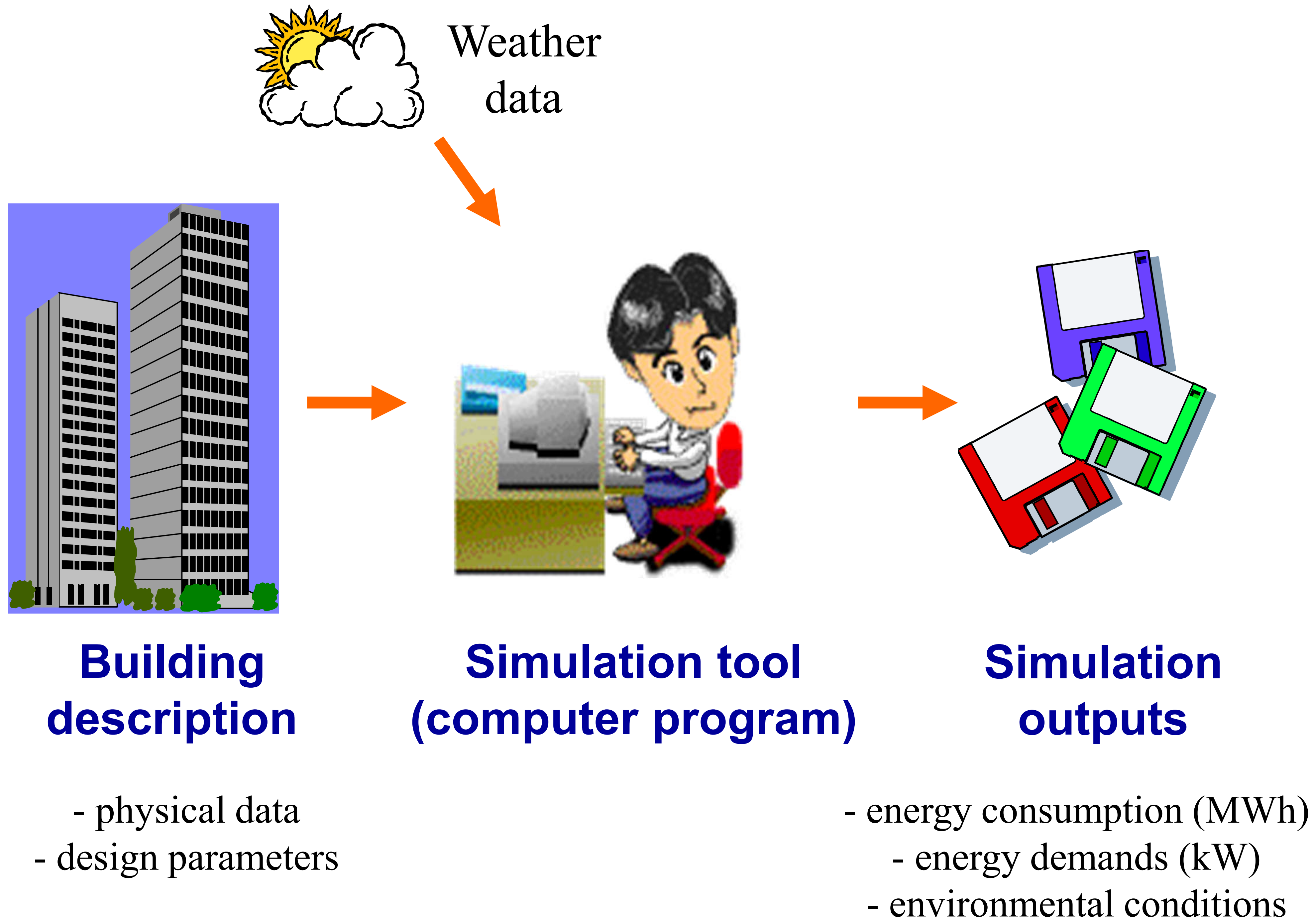
TRANE

TRACE 700

ADELINE

Tas

EE4

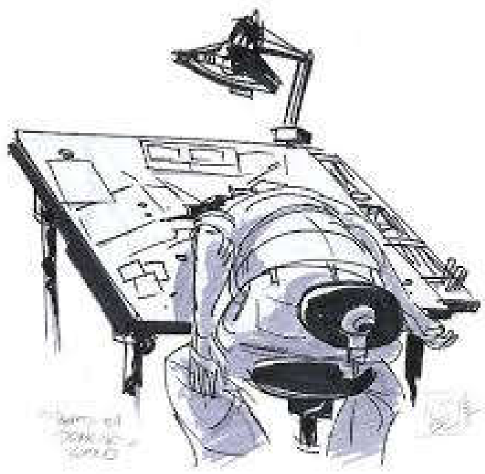

Weather data
Building description
Simulation tool (computer program)
Simulation outputs
- physical data
- design parameters
- energy consumption (MWh)
- energy demands (kW)
- environmental conditions

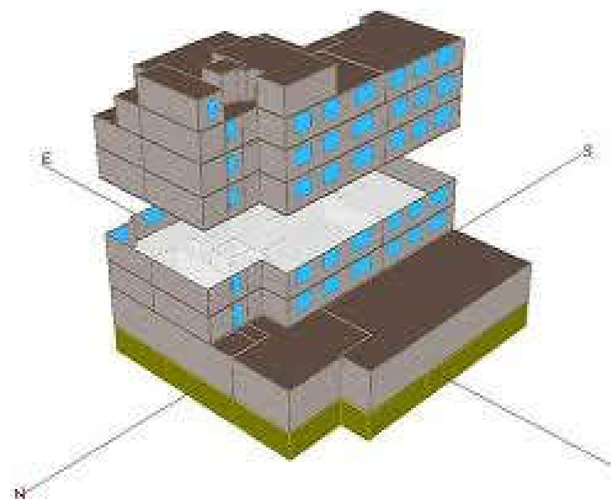
Predesign energy analysis

- Five basic types of predesign energy analyses:
  - 1. Baseline analysis
  - 2. Load elimination parametric analysis
  - 3. Sensitivity analysis
  - 4. Energy conservation measure (ECM) analysis
  - 5. Utility bill analysis (if applicable)
- The first four types: for any building projects
- Utility bill analysis: mainly for renovation projects & existing building

Predesign energy analysis

- Predesign energy model is a simplified sketch of a potential building
- Results are best used to compare and explore alternatives and will not necessarily be representative of the actual performance

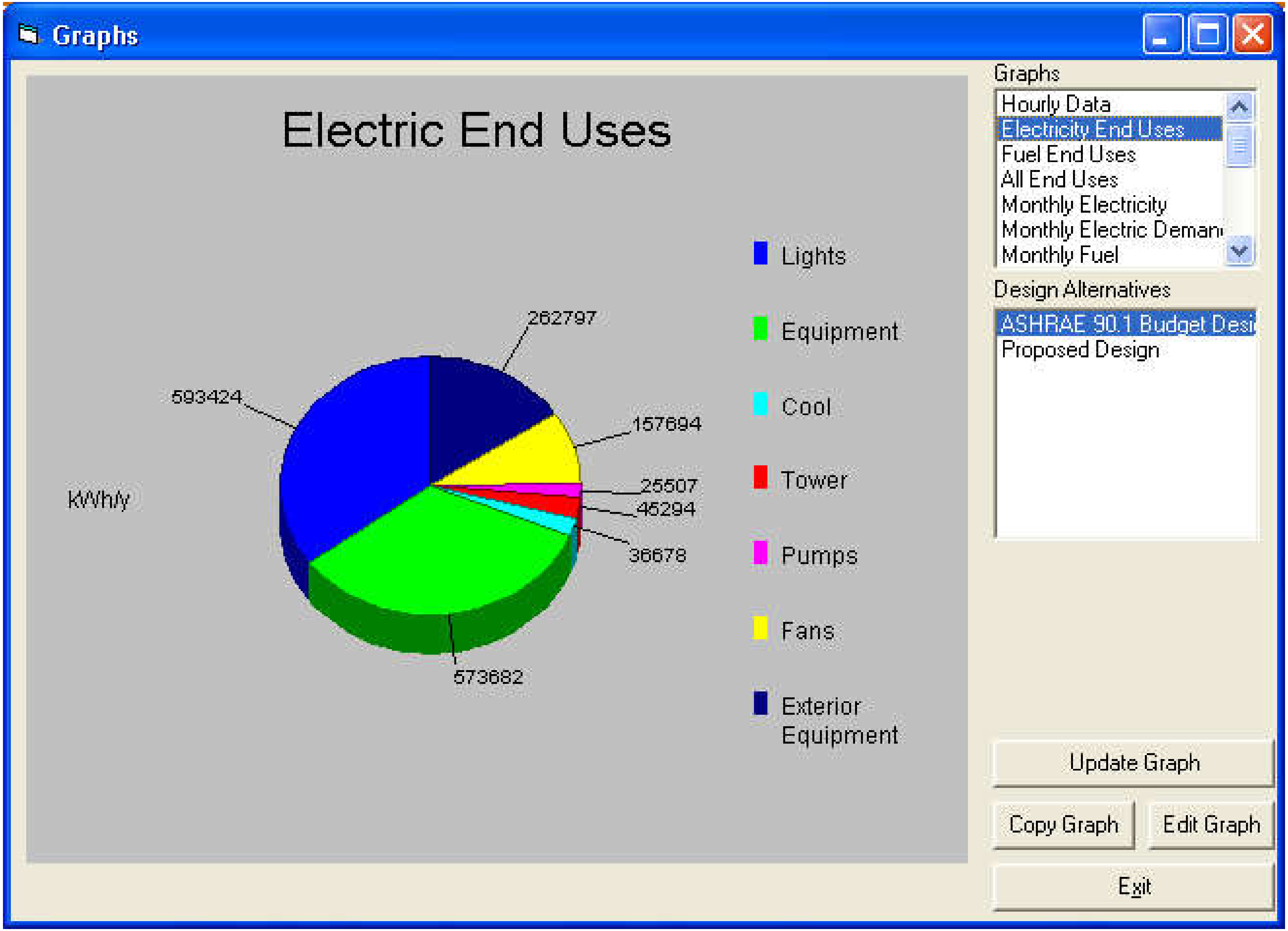




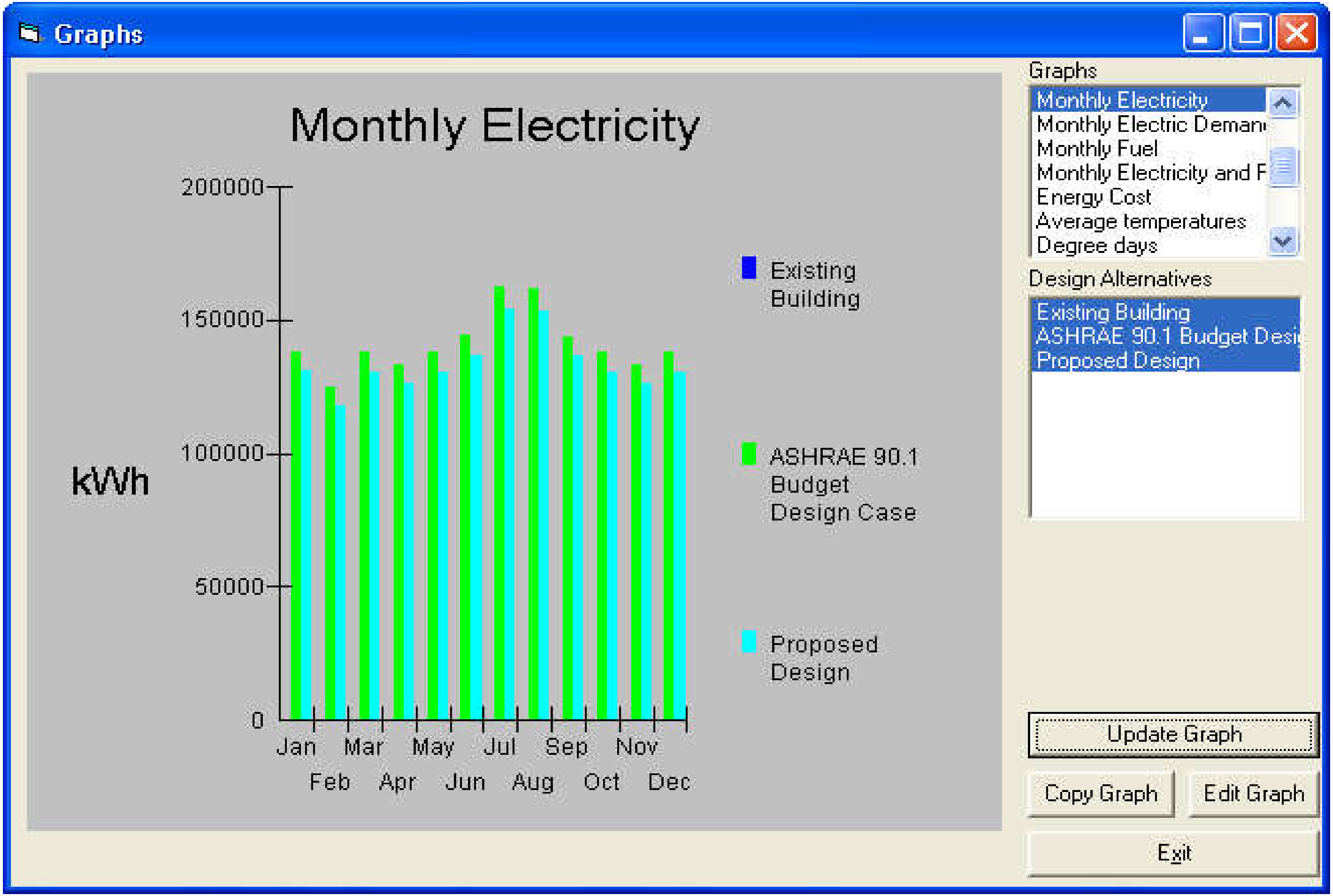
Predesign energy analysis

- Baseline analysis
  - Also known as base case/building analysis
  - Characterize the energy uses and costs that would be expected if the building were built to code with no green or high performance features
  - Typical results: estimated total annual energy use, total annual energy cost, and peak demand
  - Breakdown of end-use energy consumption
  - Energy use profiles

Breakdown of end-use energy consumption

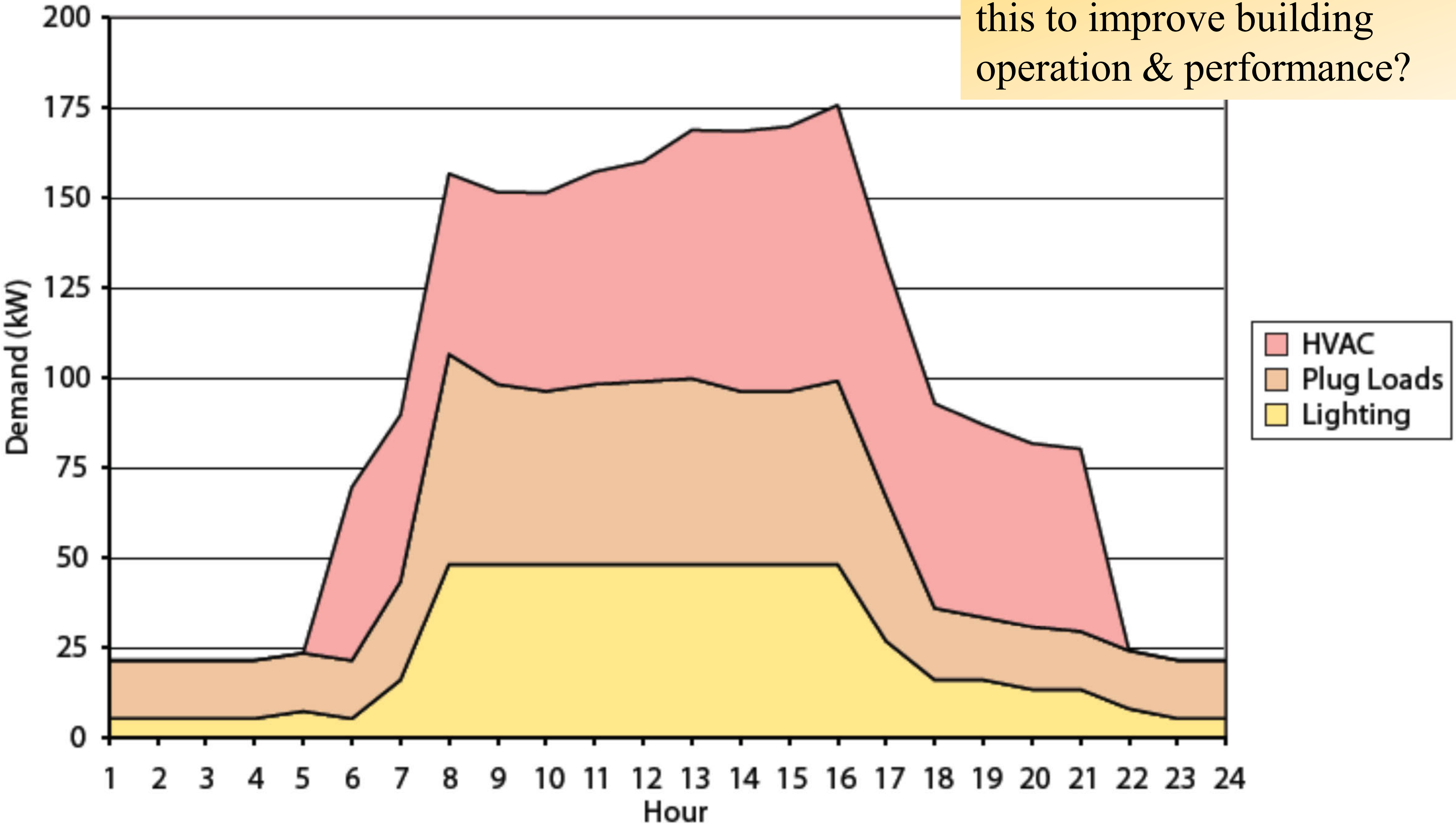


Monthly electricity profile



Peak day demand profile

Do you know how to assess this to improve building operation & performance?

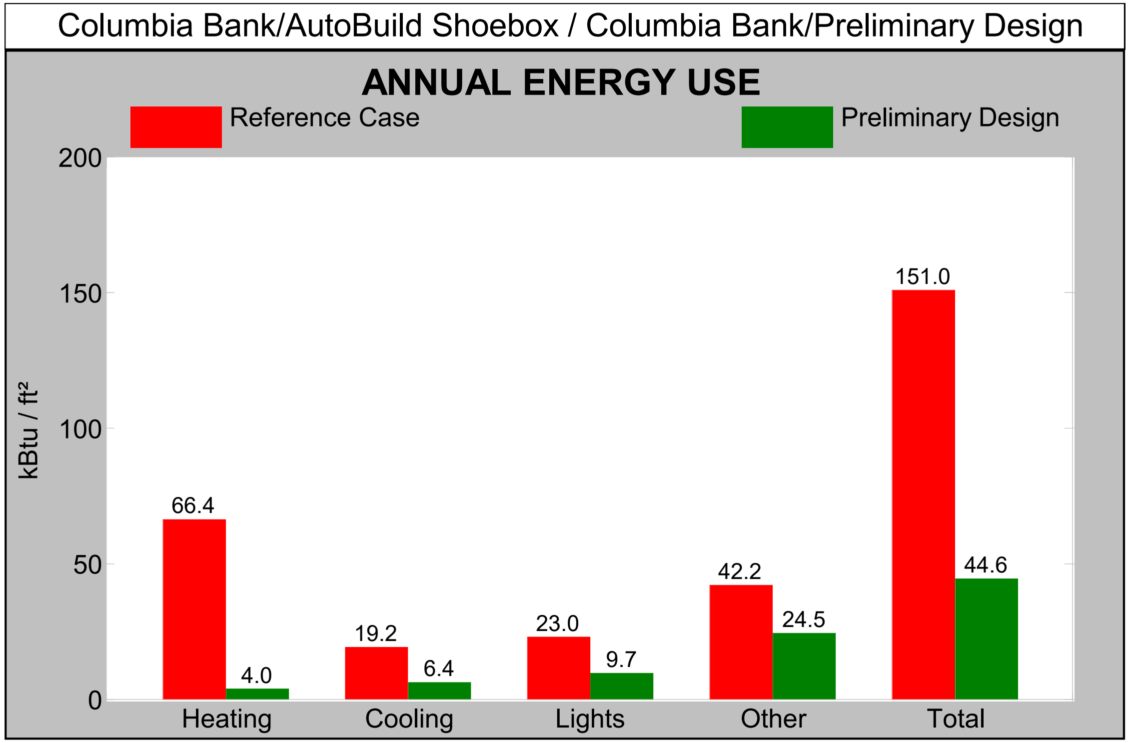


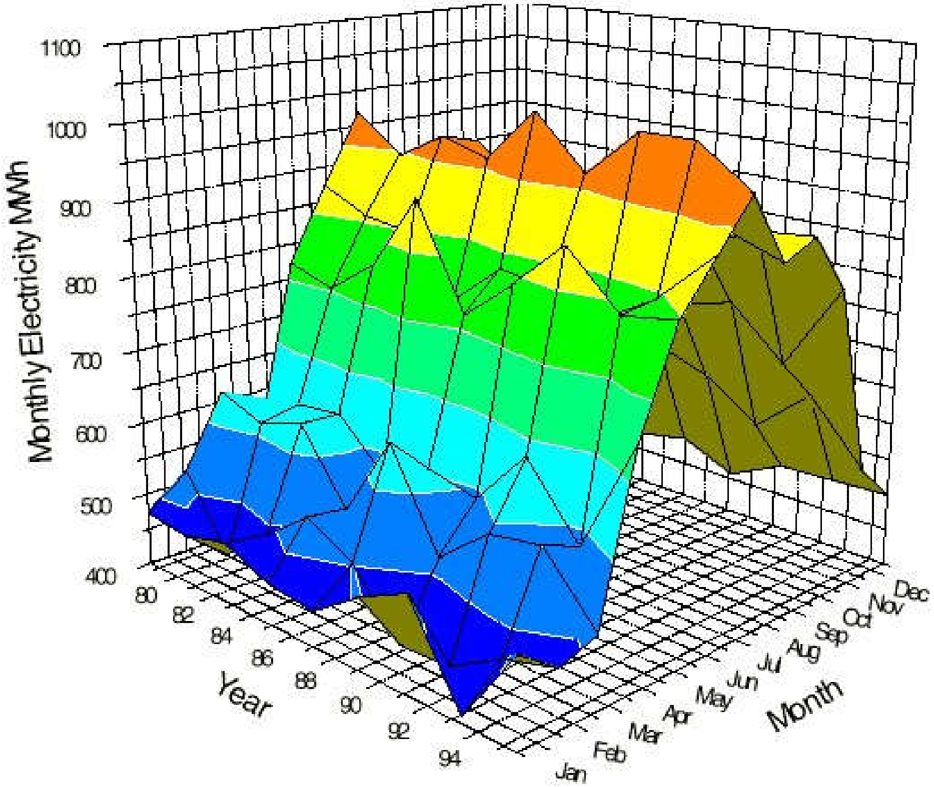
(Source: Lindsey, G., et al., 2009. *A Handbook for Planning and Conducting Charrettes for High-Performance Projects*)

Predesign energy analysis

- Load elimination parametric analysis
  - Shows the impact of individual loads on overall energy use
    - The analysis is performed by sequentially "eliminating" each load in a separate simulation (e.g., the windows, lights, or infiltration) to measure its energy impact
  - Provide a crude means of ranking the relative importance of individual loads or components
  - Can also reveal coupling between different loads (e.g. lighting and cooling)

Presentation of results from building energy simulation

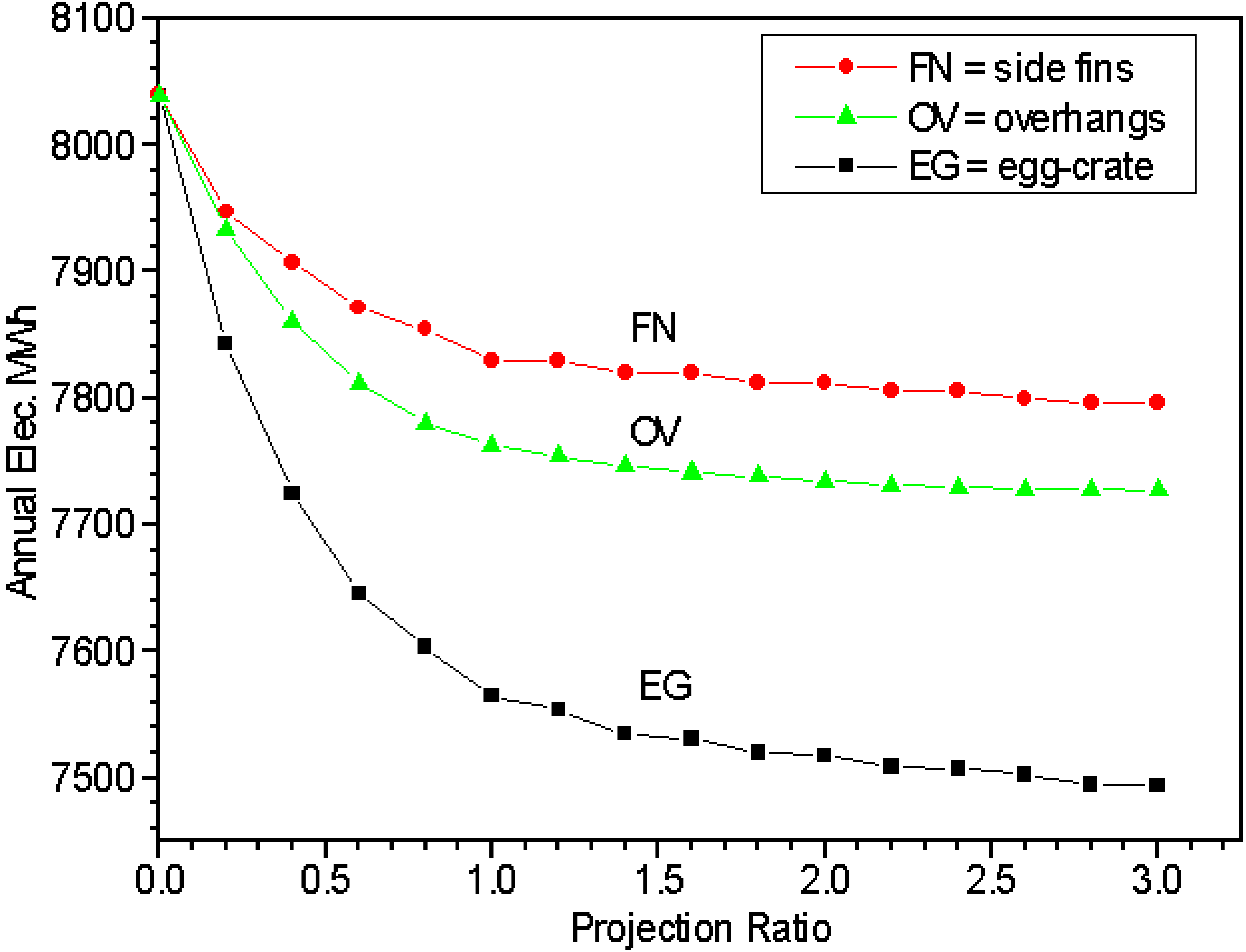




Predesign energy analysis

- Sensitivity analysis
  - Measures the sensitivity of whole-building energy use to changes in key design parameters
    - Such as window area, shading devices, lighting power density, equipment and system efficiency
  - Parameters that show significant impact on overall performance should be considered carefully
  - Further analysis can be used to optimize the parameter and reduce energy use

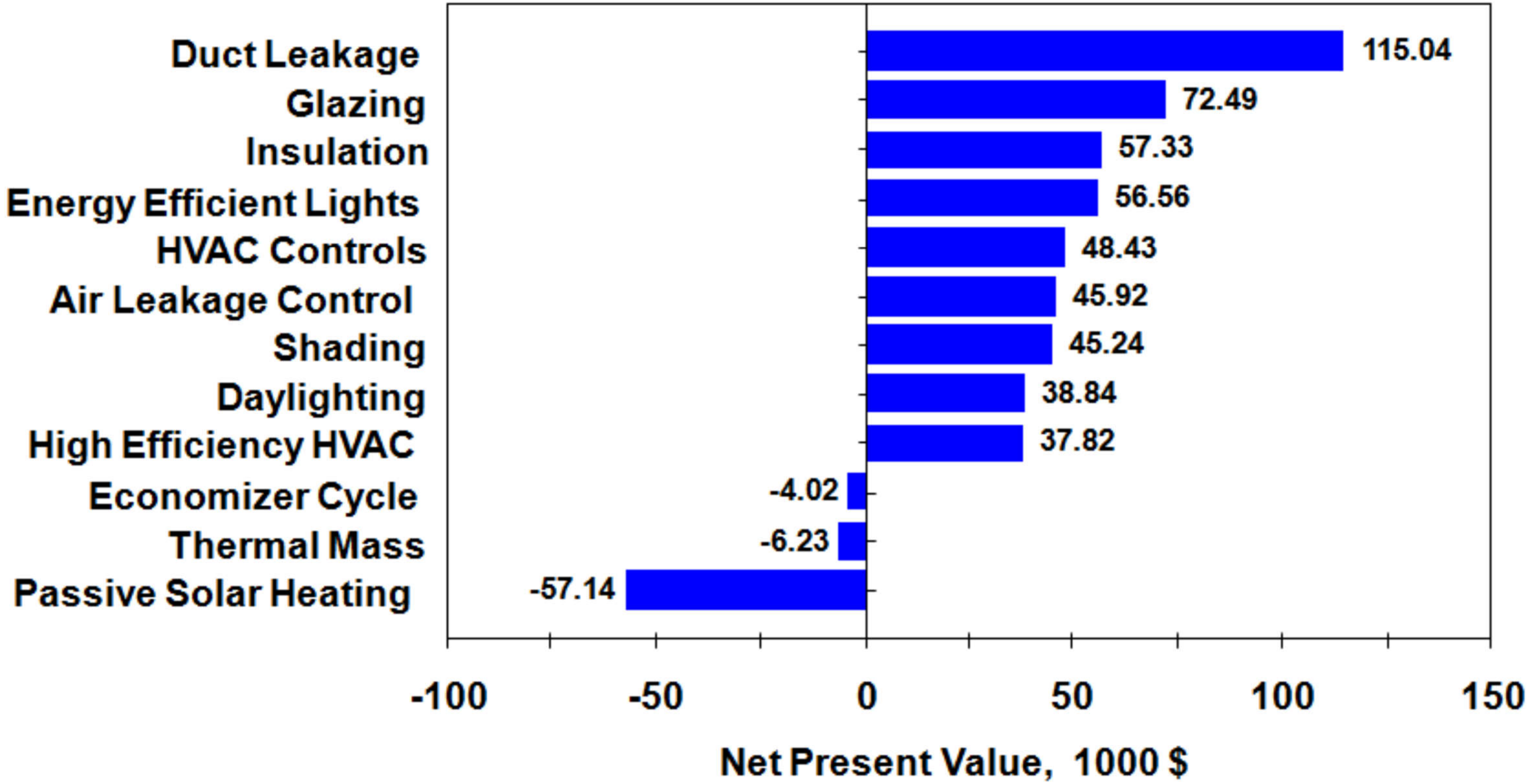
Example: Effects of external shading on energy consumption



Predesign energy analysis

- Energy conservation measure (ECM) analysis
  - Estimates the potential savings in energy consumption, energy cost, and peak energy demand for an individual ECM or combination of ECMs
  - Allows different ECMs to be compared and determine whether an ECM may be cost effective
  - May require additional model development
  - Need to identify promising ECMs

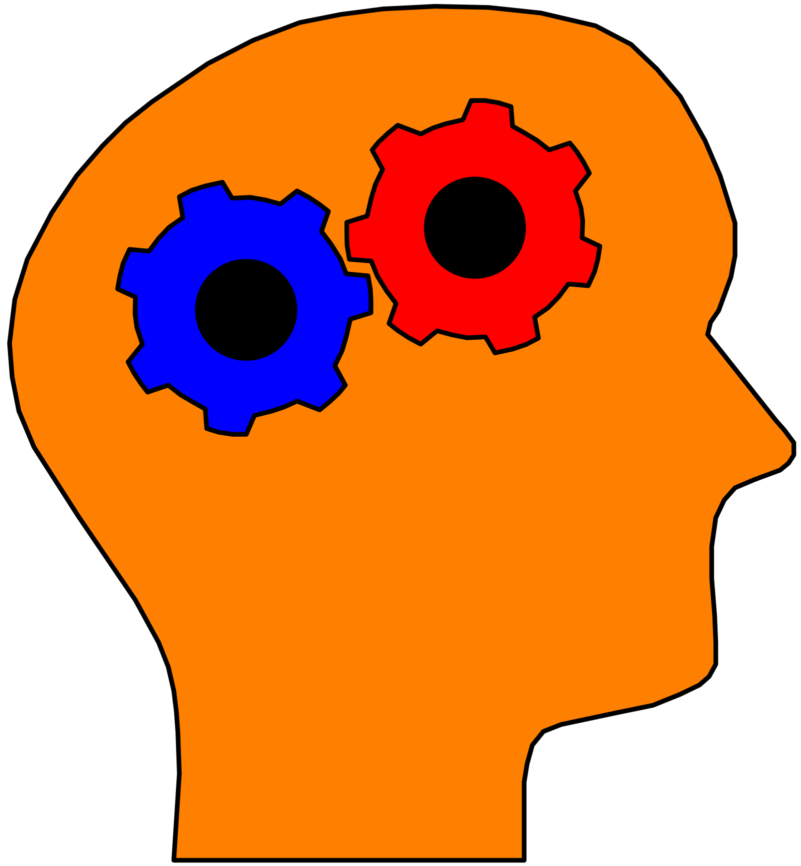
Ranking of energy conservation measures



Predesign energy analysis

- Utility bill analysis
  - Use the utility billing history from an existing building to characterize energy use and help set performance goals
  - Can be used to illustrate monthly trends or to calibrate a baseline model
  - Useful for renovation or remodel projects
  - Also useful for new construction if the new building is similar to another building in size, use, orientation, and climate type

Quiz for students

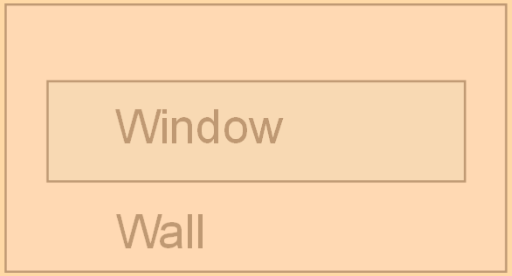


The U-value and shading coefficient (SC) of double-glazed windows (6 mm clear glass; 12 mm air space) are:

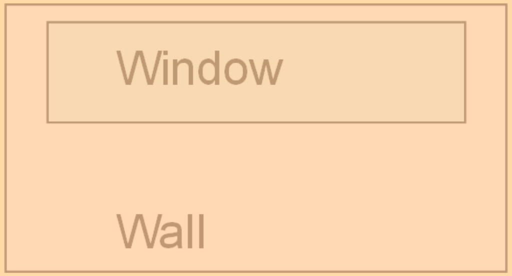
A. 2.8 W/m^2.K SC = 0.95	B. 1.8 W/m^2.K SC = 0.71
C. 3.8 W/m^2.K SC = 0.82	D. 0.8 W/m^2.K SC = 0.51

Which of the following window patterns will give better daylighting in a room? (the total area of window glazing is the same in each case)

A.

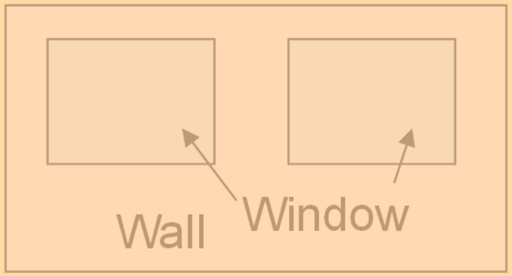


B.



C.

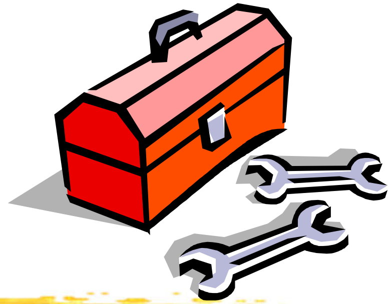
D.



'Free cooling' mode for saving energy can be used in air-conditioning systems when which the following condition occurs?

A. Temperature of air outdoor < indoor	B. Humidity of air outdoor < indoor
C. Dew point of air outdoor < indoor	D. Energy content of air outdoor < indoor

Design and analysis tools



- Decision support tools for green building (Whole Building Design Guide)
  - https://www.wbdg.org/additional-resources/tools?c=1
  - Desktop or Web-based software tools
  - Evaluation methods & purposes:
    - Drawing, manual calculation, computer calculation, scale model, computer simulation
    - For scoping, system design, energy/cost analysis & monitoring

Design tools and environmental evaluation

	Drawing	Manual calculation	Computer calculation	Scale model	Computer simulation
Insulation		E	I		D
Overshading	E			E	I / D
Thermal performance		E	I		D
Daylighting		E	I	E	D
Ventilation		E	I		D
Infiltration		E	I		D
Comfort			E		D
Building fabric		E			D
Services systems		E	I / D		D
Energy consumption		I		D	
Total performance					D

Note: E = Early; I = Intermediate; D = Detailed

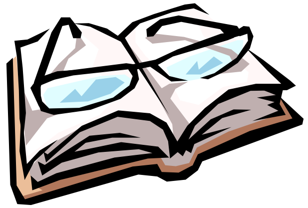
(Source: *A Green Vitruvius: Principles and Practice of Sustainable Architectural Design*)

Summary of analysis/modelling tools

Stage	Requirements	Tools	Checks
Scoping	-Quick analysis -Comparative results -Reduce alternatives -Control strategy modelling (simple)	-Ecotect -Energy-10 -eQUEST	-kWh/m^2 -Energy cost -Payback or other financial measure
System design	-Accurate output -Industry-accepted methods	-Carrier HAP -TRACE 700	-design flow -Load intensity
Energy/cost analysis	-Accurate -Industry-accepted methods -Flexible -Modelling of complex control strategies -Energy code compliance -For existing buildings too	-DOE-2 -EnergyPlus -Carrier HAP -TRACE 700	-Detailed kWh/m^2 -Detailed energy cost -Economic indexes
Monitoring	-Simplicity -Intuitive interface -Interoperable	-BACnet -Building automation	-Trended operating characteristics -Benchmark comparison

(Adapted from ASHRAE, 2006. *ASHRAE GreenGuide*)

Further Reading



- Building Science Concepts (WBDG)
  https://www.wbdg.org/resources/building-science-concepts
- Key areas for green specialist advices
  http://ibse.hk/MEBS6020/Key_Areas_For_Green_Specialist_Advice.pdf
- Lindsey G., *et al.*, 2009. *A Handbook for Planning and Conducting Charrettes for High-Performance Projects*, Second Edition, National Renewable Energy Laboratory (NREL), U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Washington, DC.
  https://www.nrel.gov/docs/fy09osti/44051.pdf

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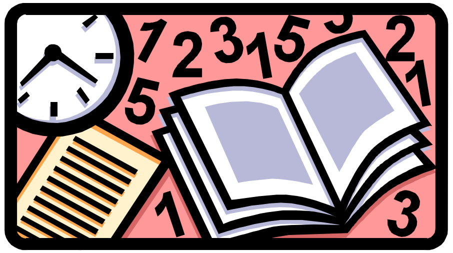

- ASHRAE Green Tips (2006) http://ibse.hk/MEBS6020/greentips_2006.pdf
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- European Commission, Directorate General XVII for Energy, 1999. *A Green Vitruvius: Principles and Practice of Sustainable Architectural Design*, James & James, London. [720.47 G79 E]
- PTI, 1996. *Sustainable Building Technical Manual: Green Building Design, Construction and Operations*, Public Technology, Inc. (PTI), Washington, D.C. [721.0467 S964][https://pdhonline.com/courses/g240/Buiilding_%20Systems_%20and_IAQ-Sustainabledesignmanual.pdf]