MEBS6020 Sustainable Building Design

http://www.hku.hk/bse/MEBS6020/

Energy and Environmental Design (I)

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Feb 2012

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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 convection, 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

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
- Design decisions during the design process

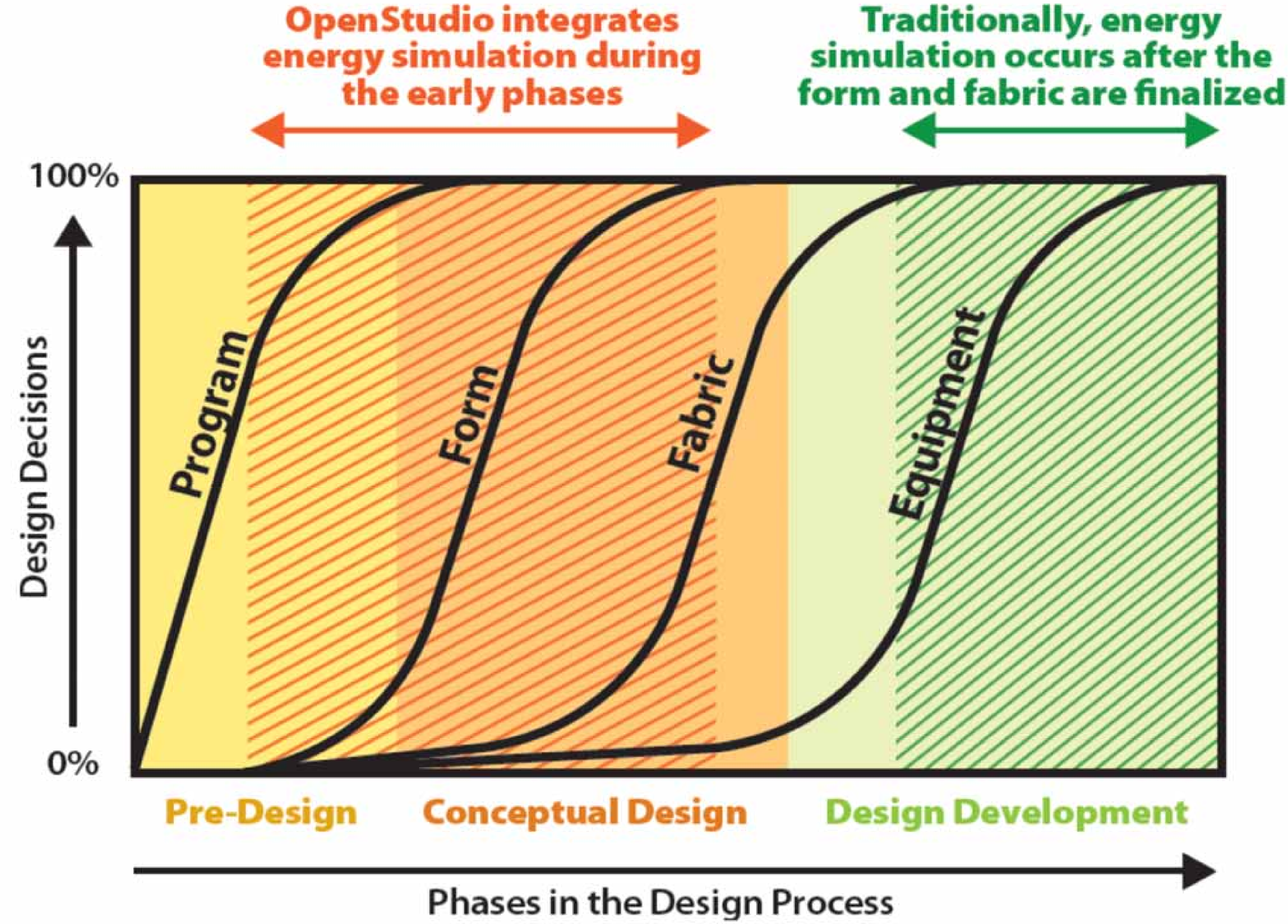
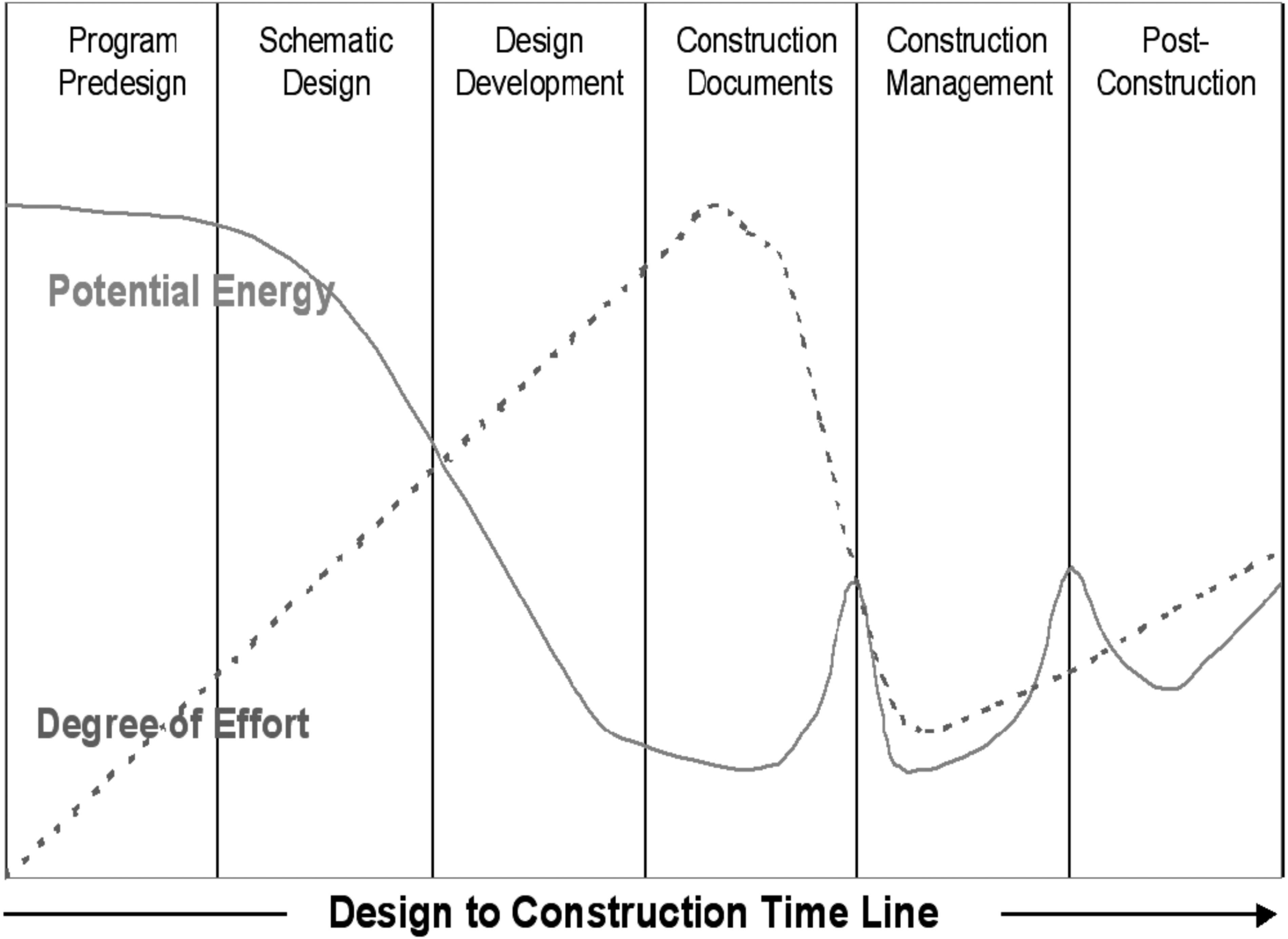


Figure 1. Design Decisions During the Design Process

(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

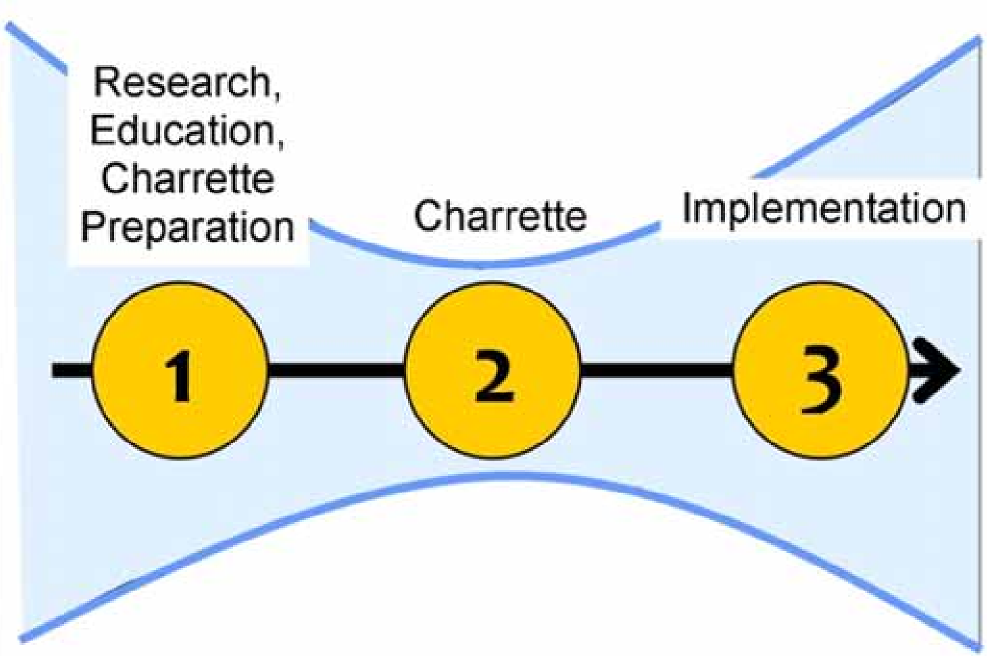


(Source: ASHRAE, 2006. *ASHRAE GreenGuide*)

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

The Charrette process



Sustainable design process

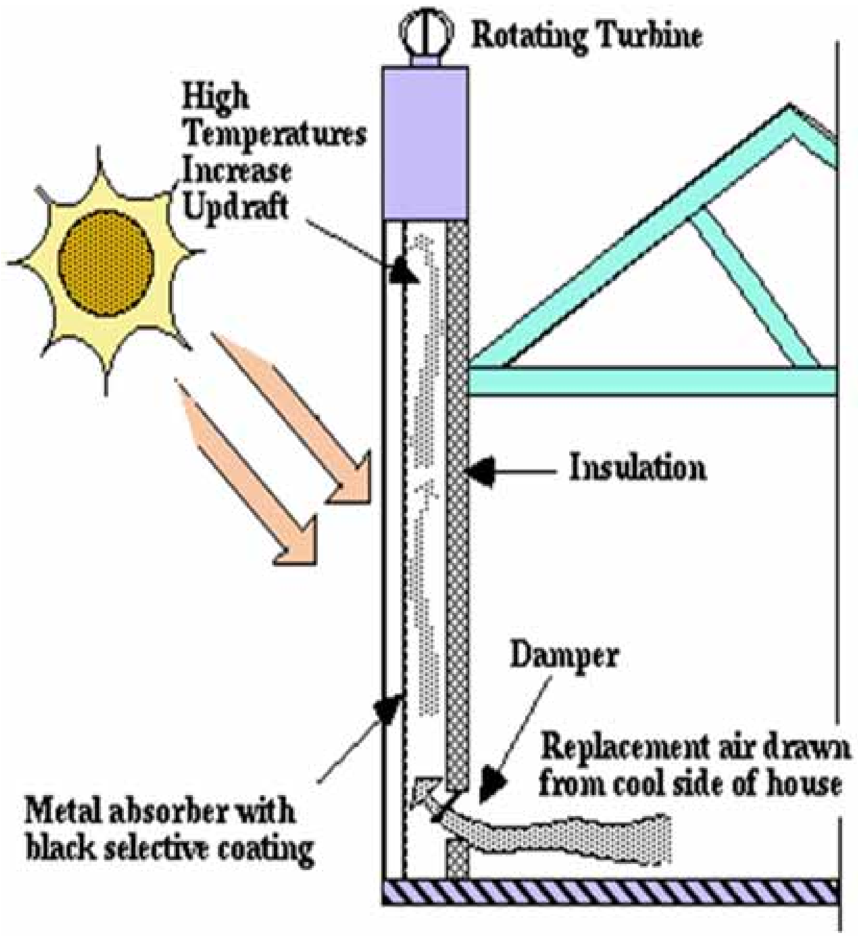
- The Charrette (cont'd)
  - Benefits
    - Promote enthusiasm for a project
    - Set and agree about common project goals
    - Develop early consensus about project design priorities
    - Set performance goals for energy, emissions (carbon and others), water, site, materials, and other topics
  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

Sustainable design process

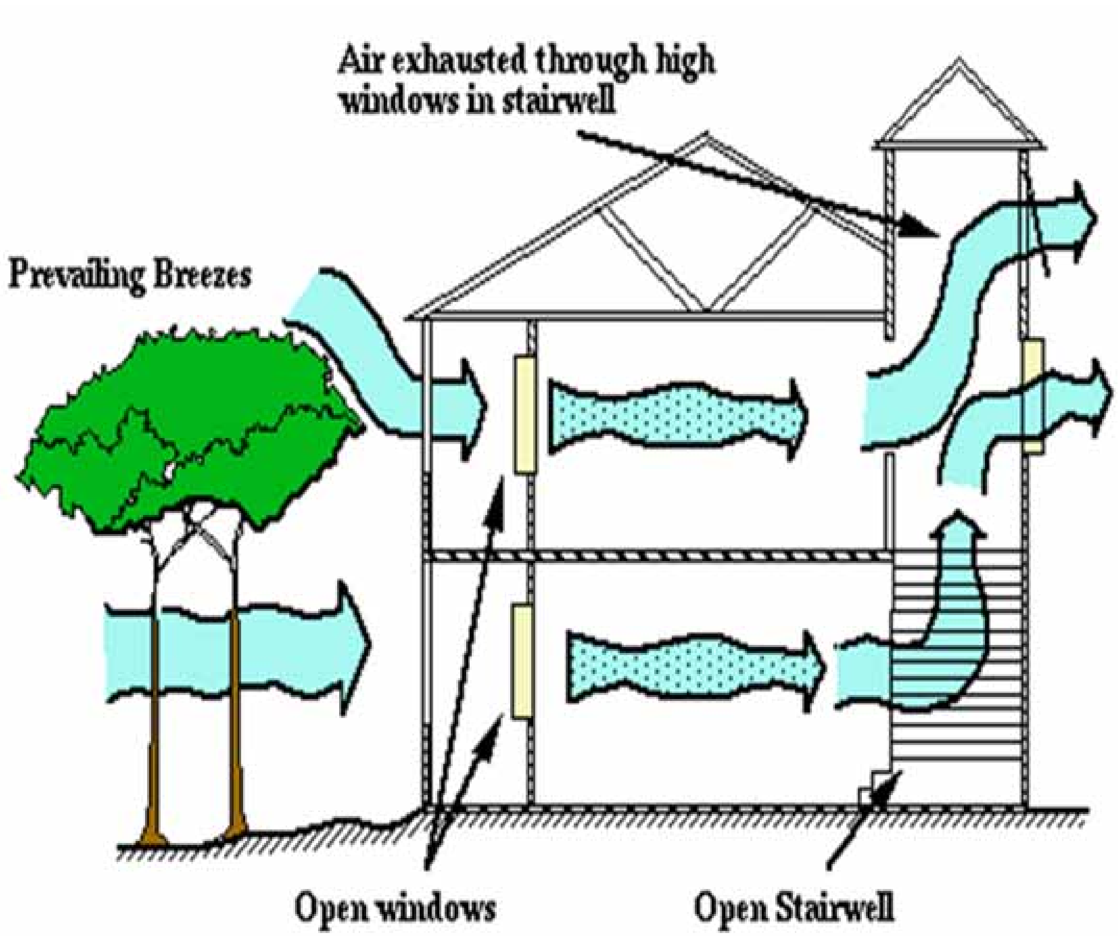
- Key areas for green specialist advices
  - Building structure
  - Envelope design
  - Lighting services
  - Electrical power
  - Cooling and heating engineering
  - Water services
  - Ventilation
  - Cost estimating
  - Landscaping

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



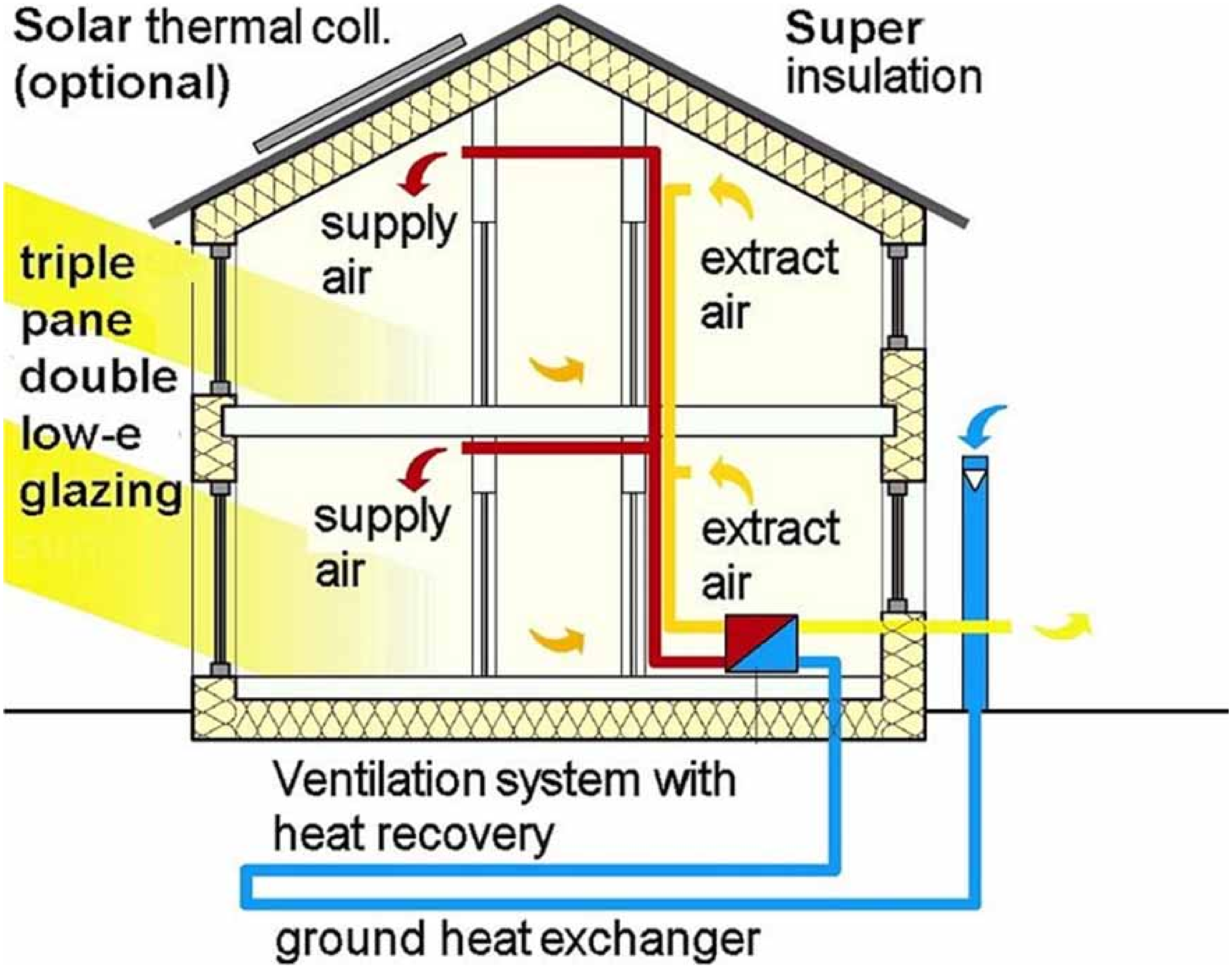
Thermal chimney

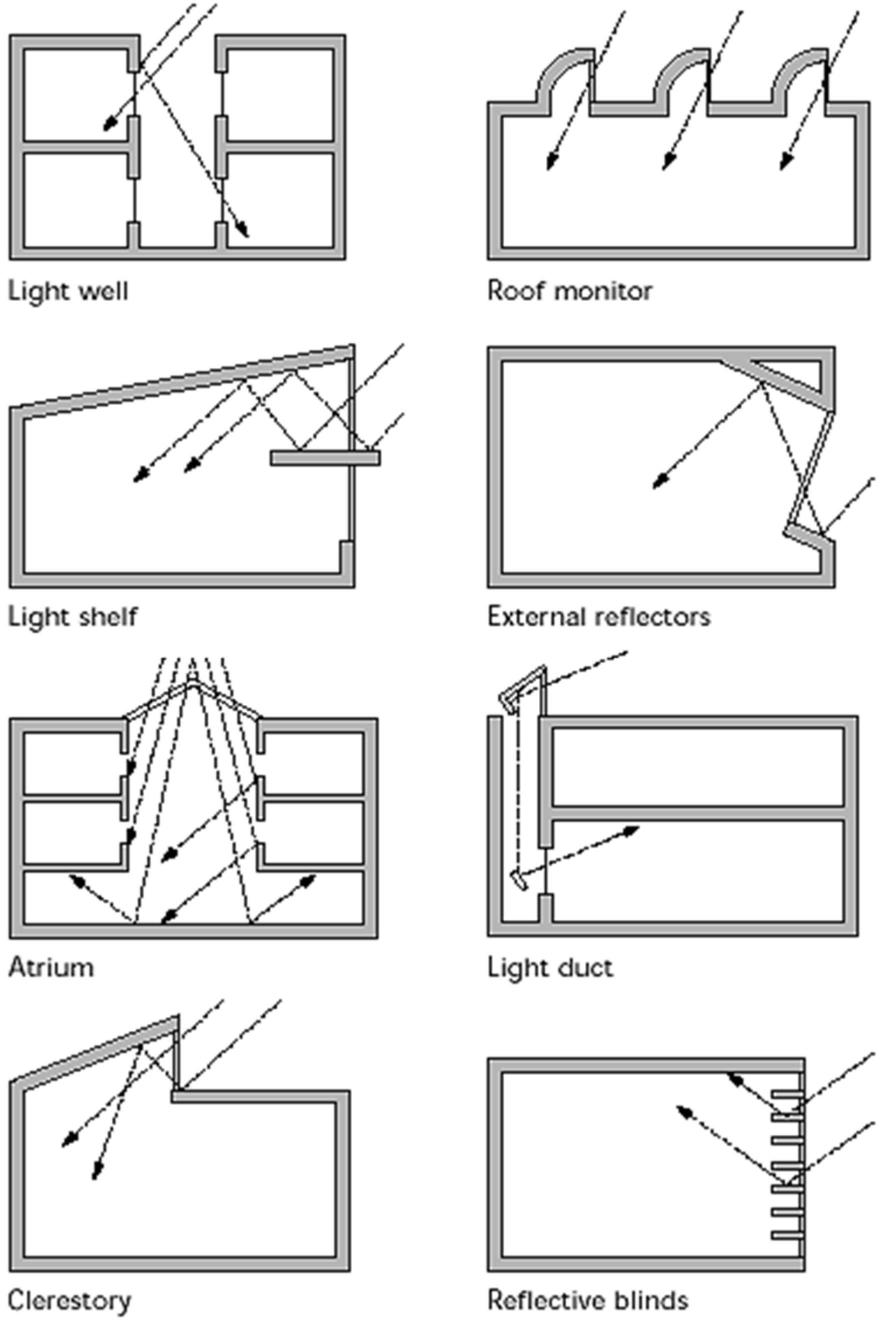


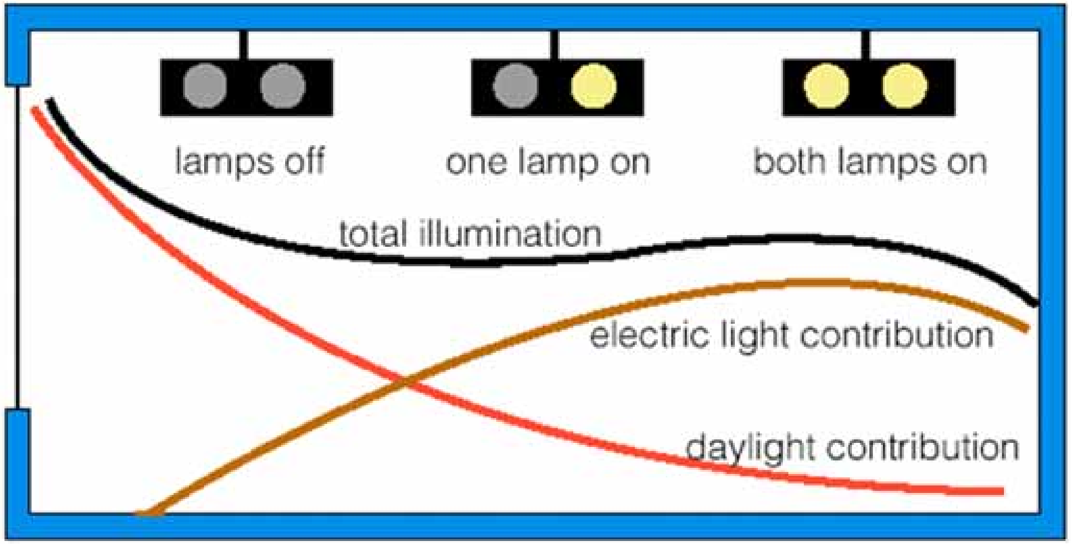
Natural ventilation

Examples of passive cooling designs

Typical techniques for passive house



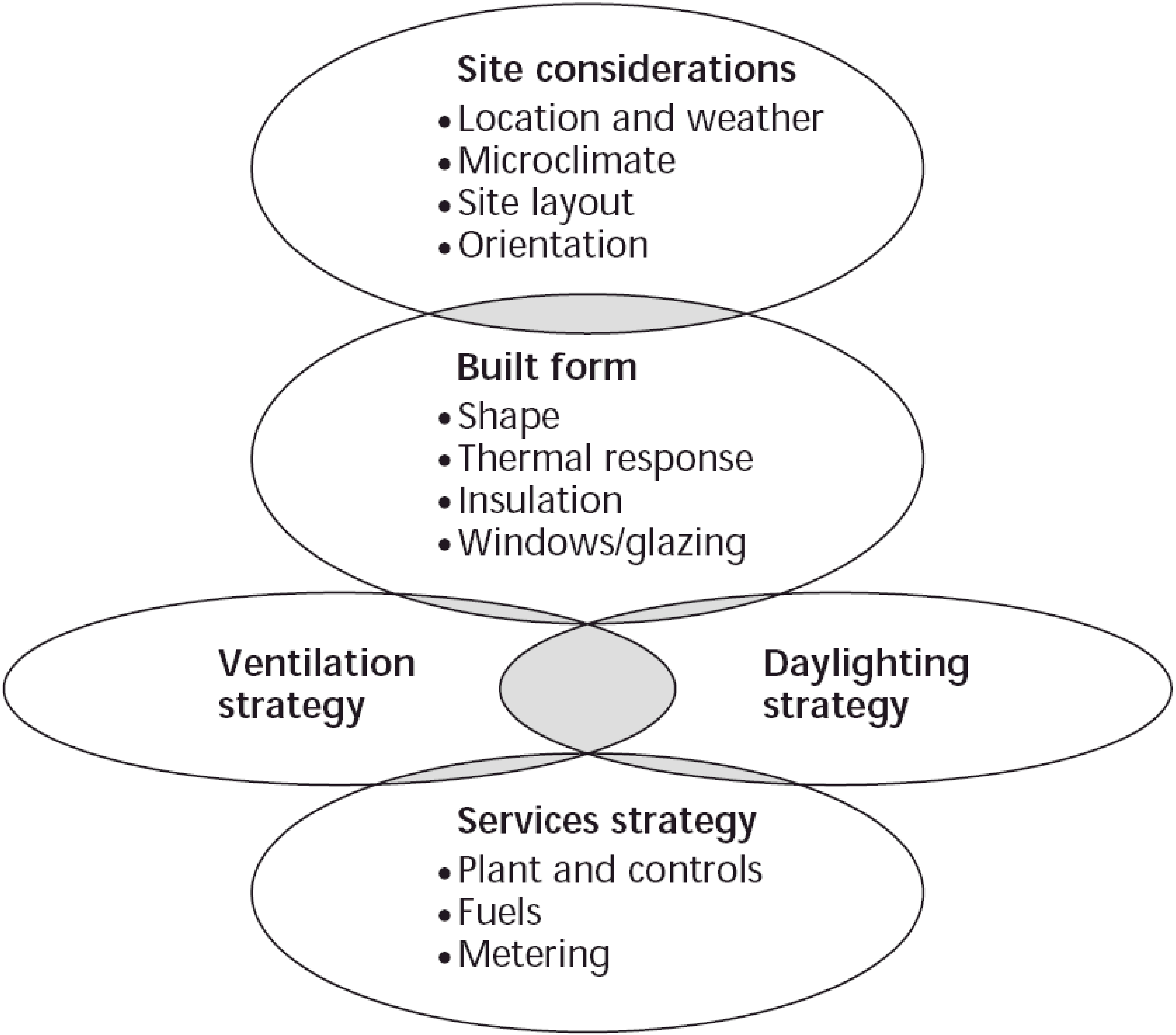




Daylighting design and control

Examples of green building design features/issues

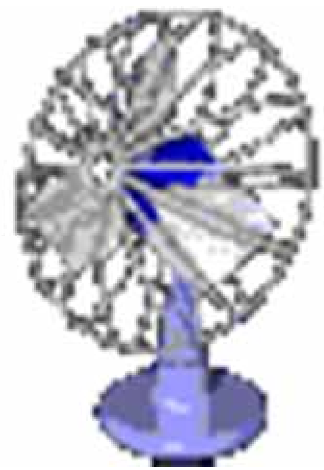
(Source: www.susdev.org.hk)



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

HVAC design considerations

- Design intent
  - Set goals for performance
    - Energy performance
    - Environmental performance
    - Comfort
    - Operating cost
    - Determine how to achieve the goals
  - System by system
    - Integrated design



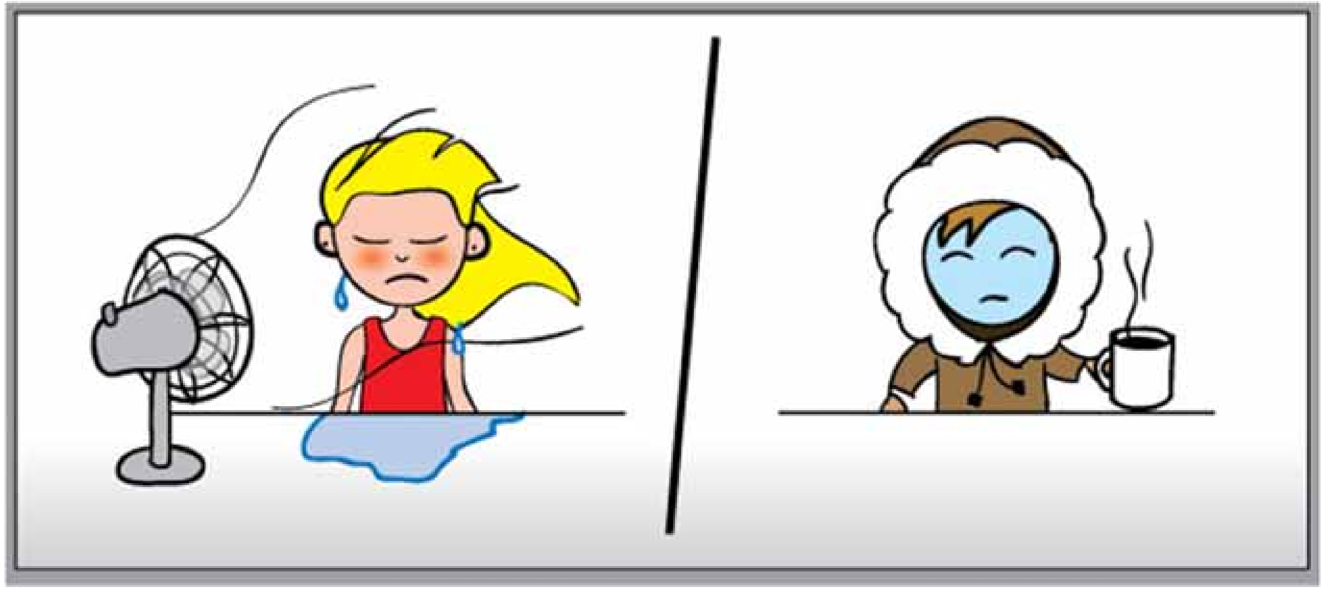
(Source: ASHRE, 2006. *ASHRAE GreenGuide*)

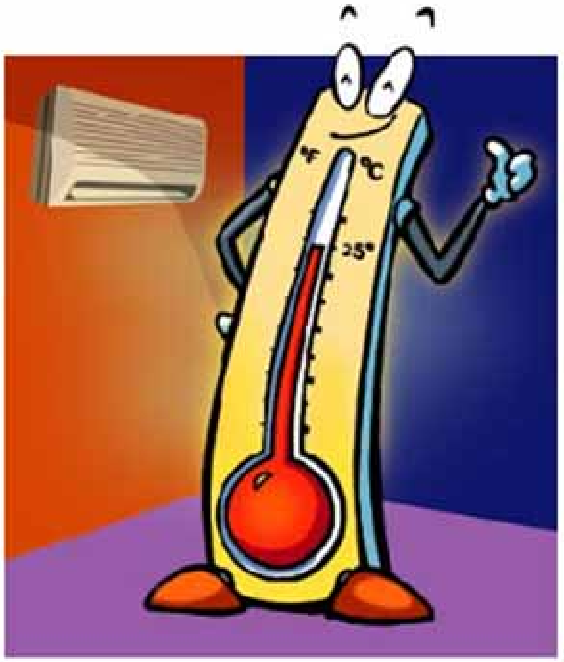
HVAC design considerations

- 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" design
  - Increased emphasis on HVAC performance
    - Thermal comfort
    - Indoor air quality (IAQ)
    - Energy efficiency



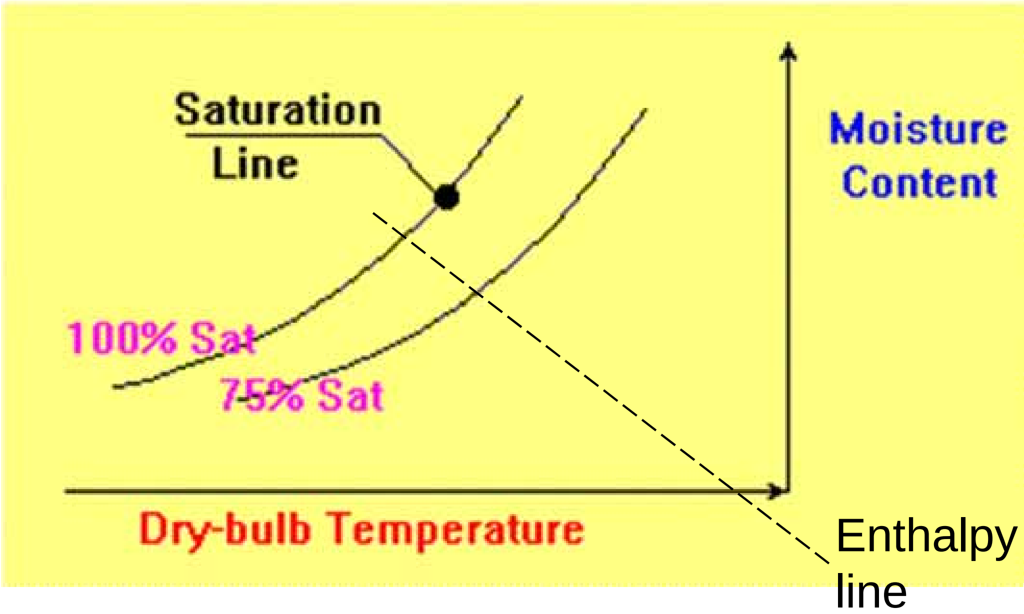


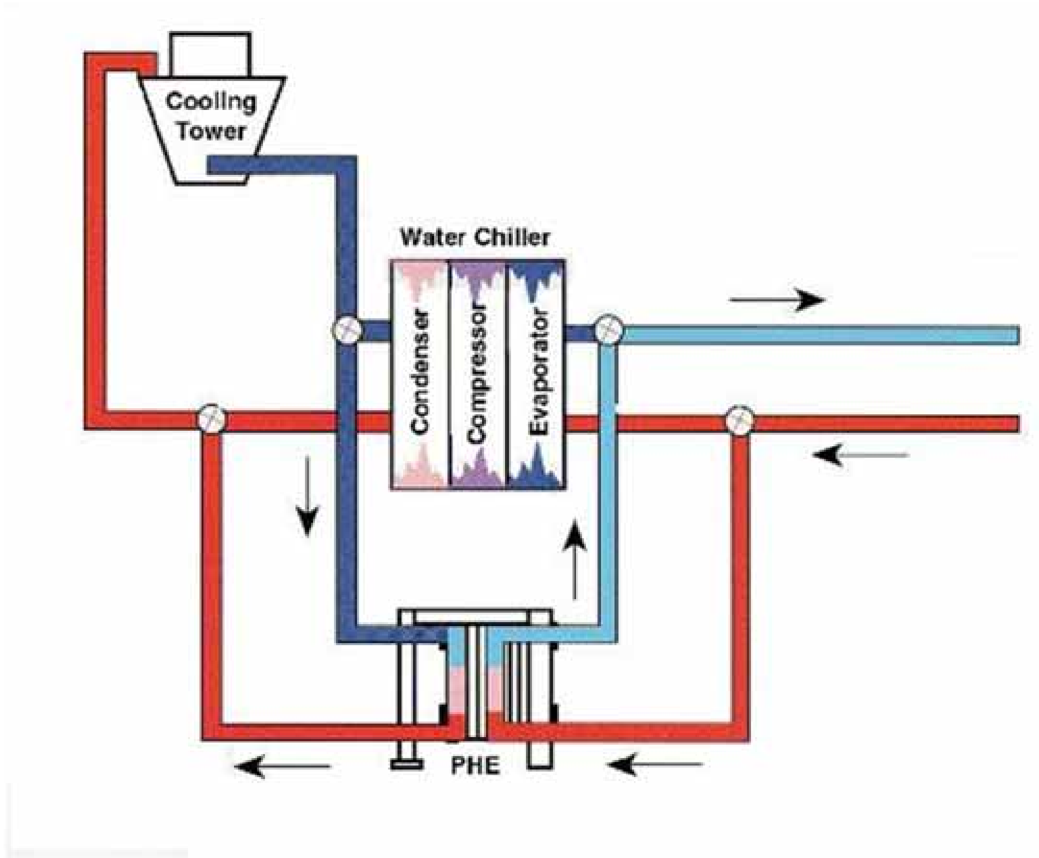
Just nice at 25°C
Electricity Efficiency Centre

Cleaner filter filters better.
Electricity Efficiency 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





(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

'Free' cooling methods in HVAC system

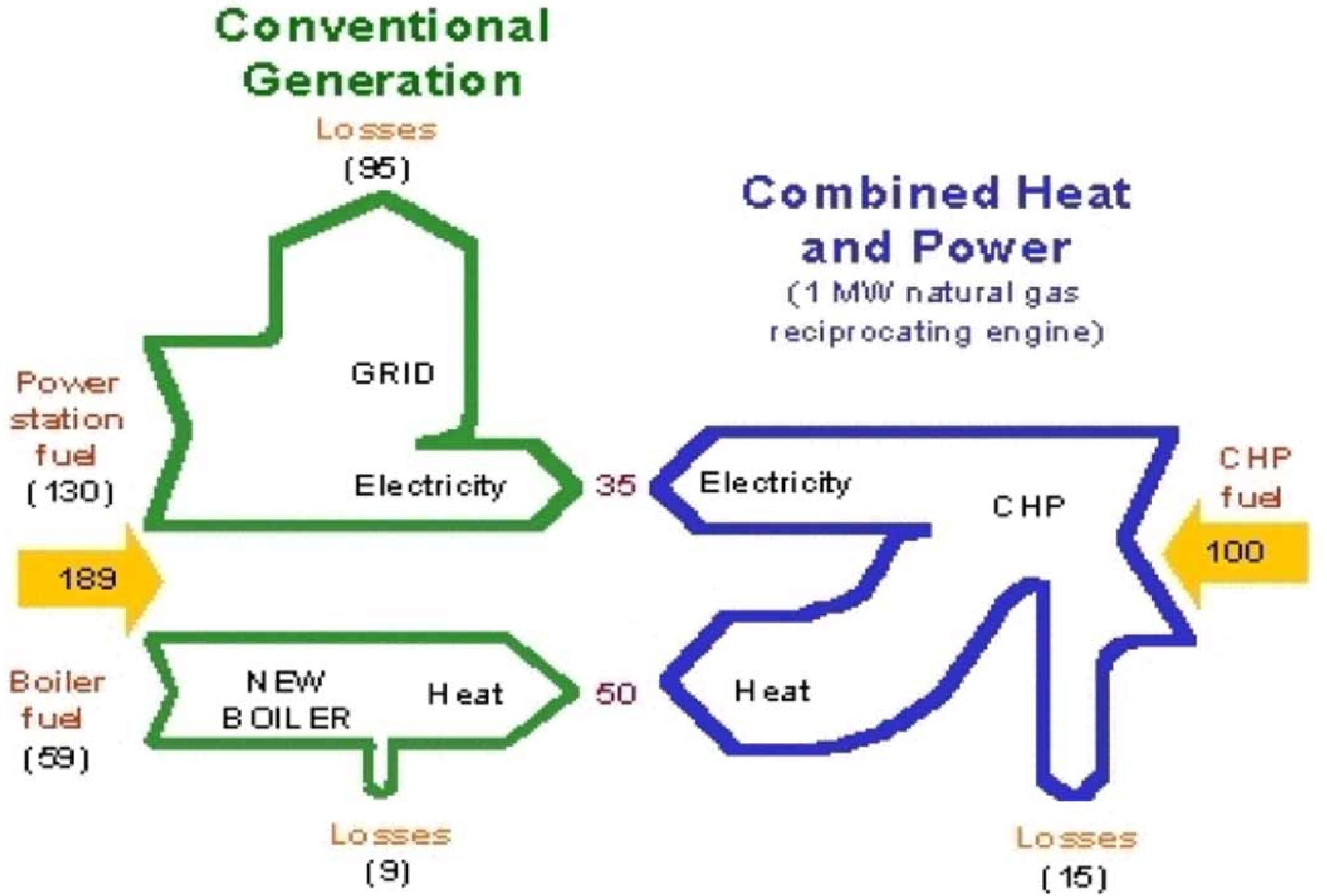
HVAC design considerations

- 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

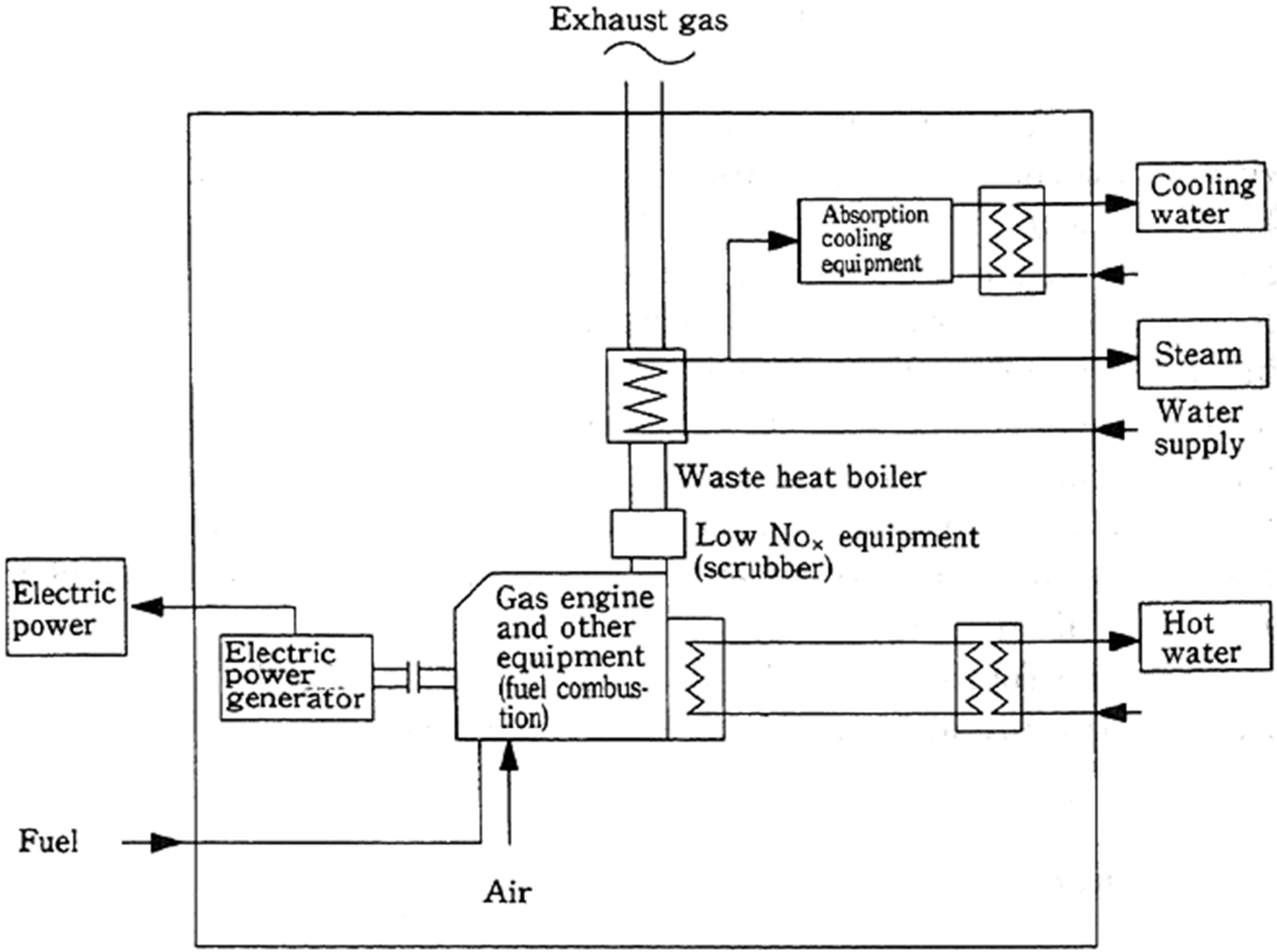
HVAC design considerations

- 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



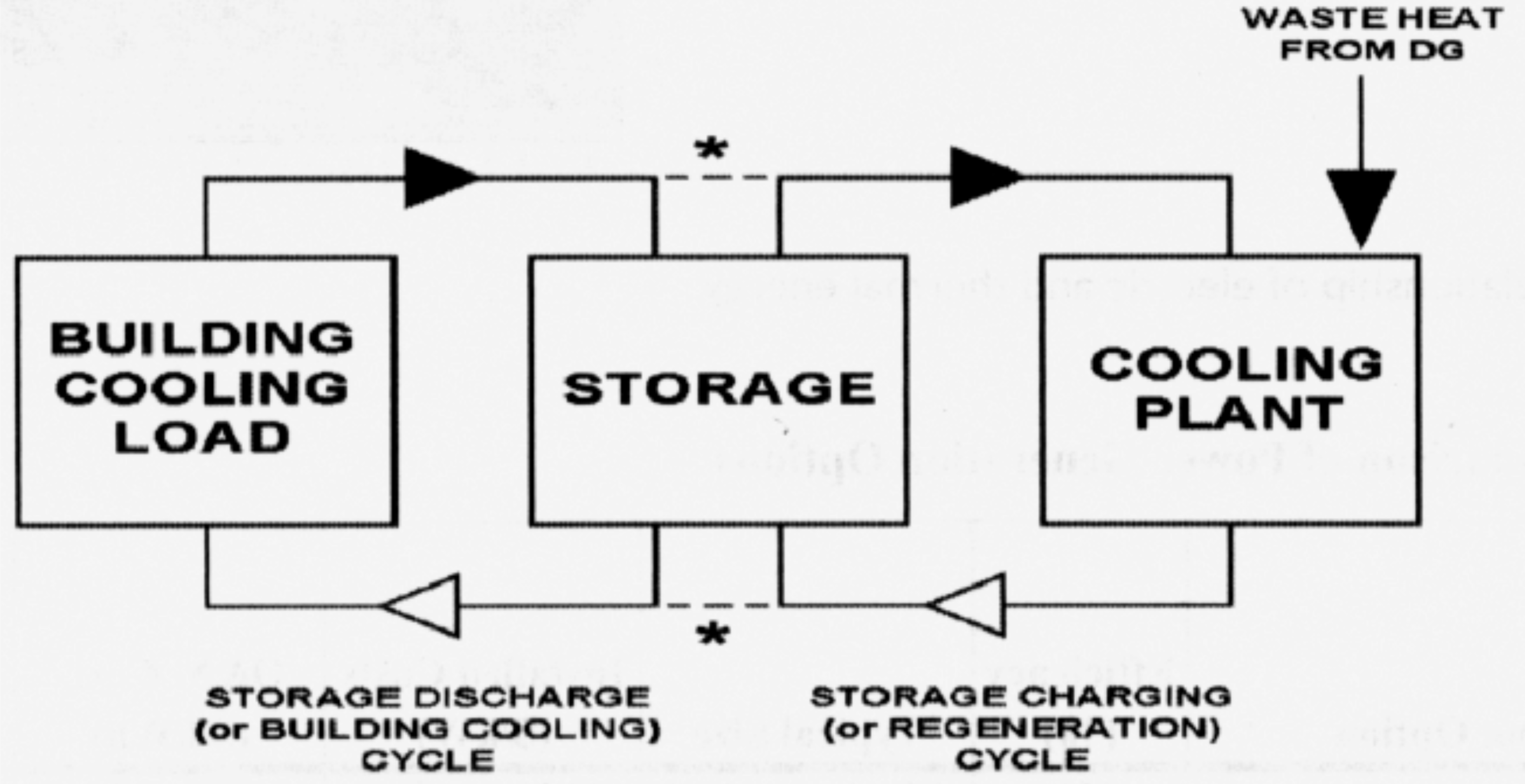
A typical cogeneration system



(Source: www.env.go.jp)

Thermal uses of waste heat by energy storage

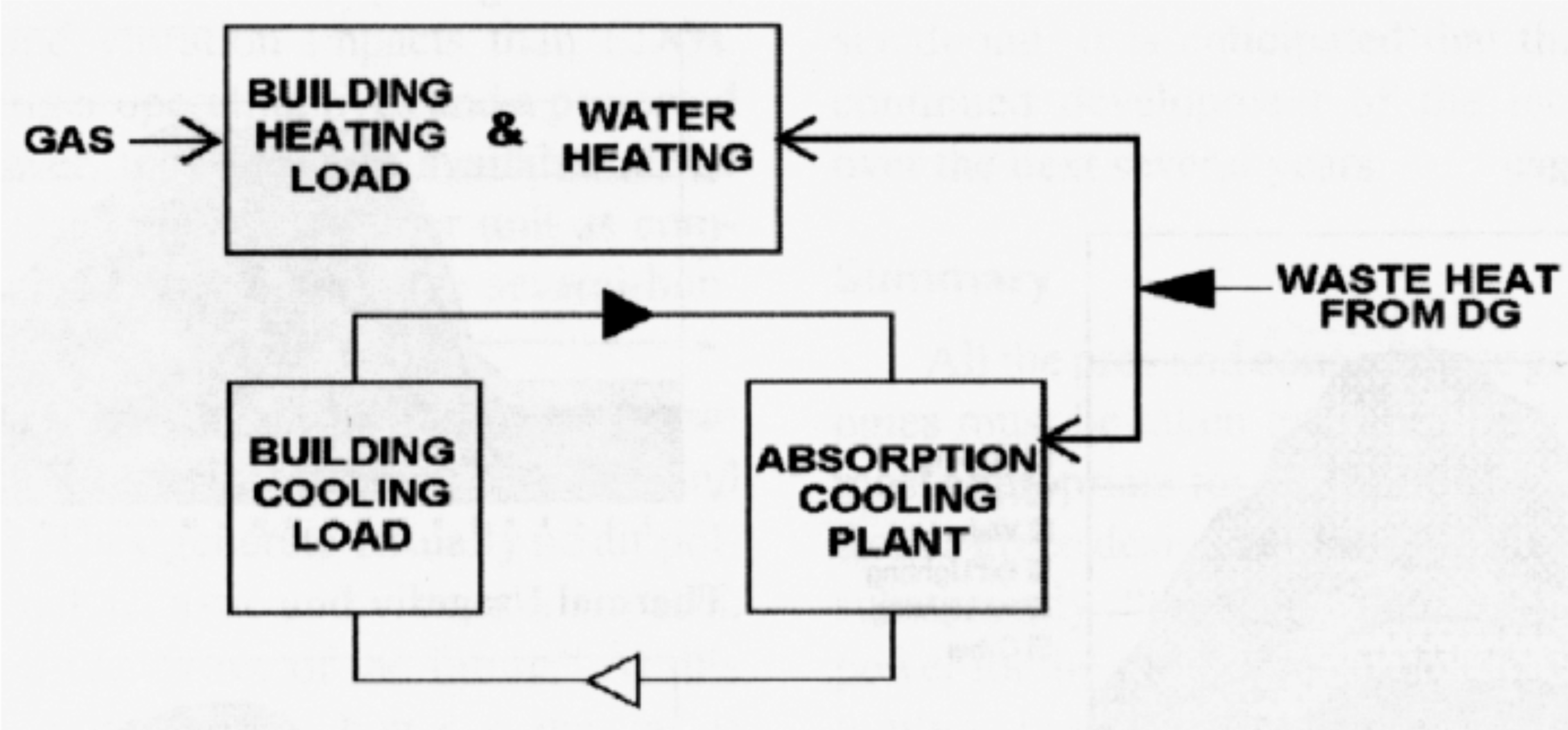
* DG = distributed generation (electricity)



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

Thermal energy storage and waste heat usage

* DG = distributed generation (electricity)



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

HVAC design considerations

- **ASHRAE GreenTips**
  - www.engineeringforsustainability.org/docs/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 and 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

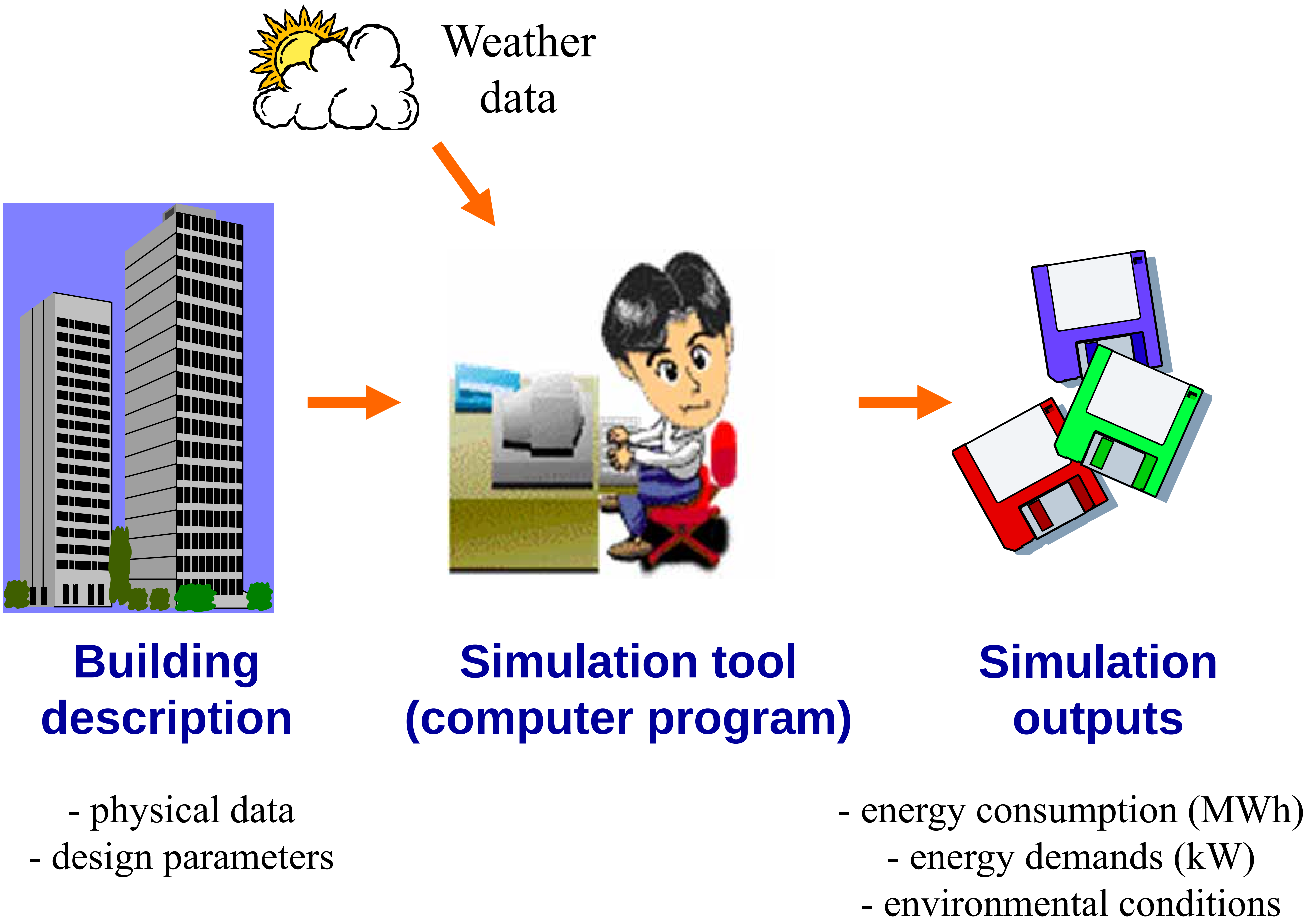
TRANE

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 and existing building

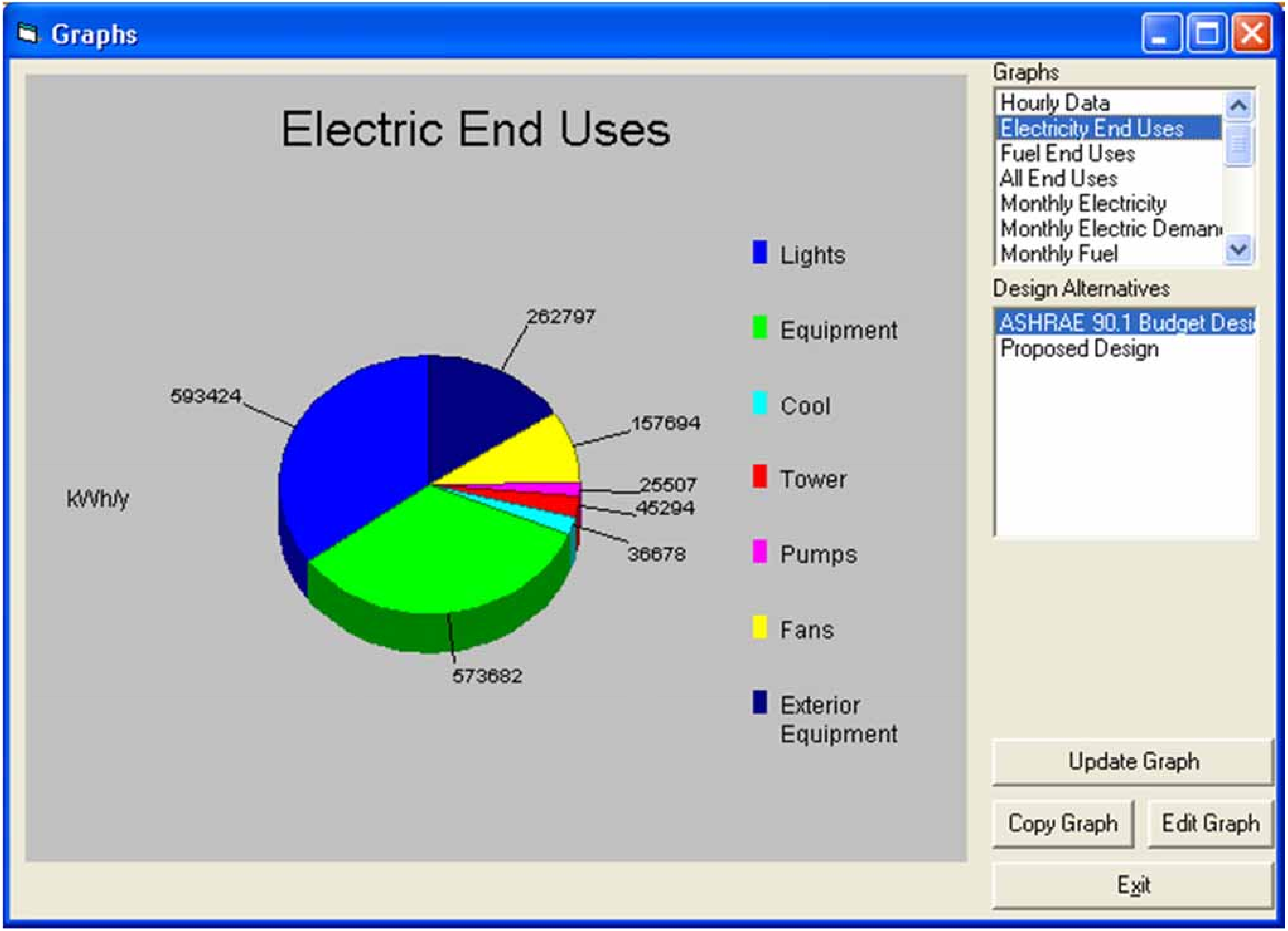
Predesign energy analysis

- 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

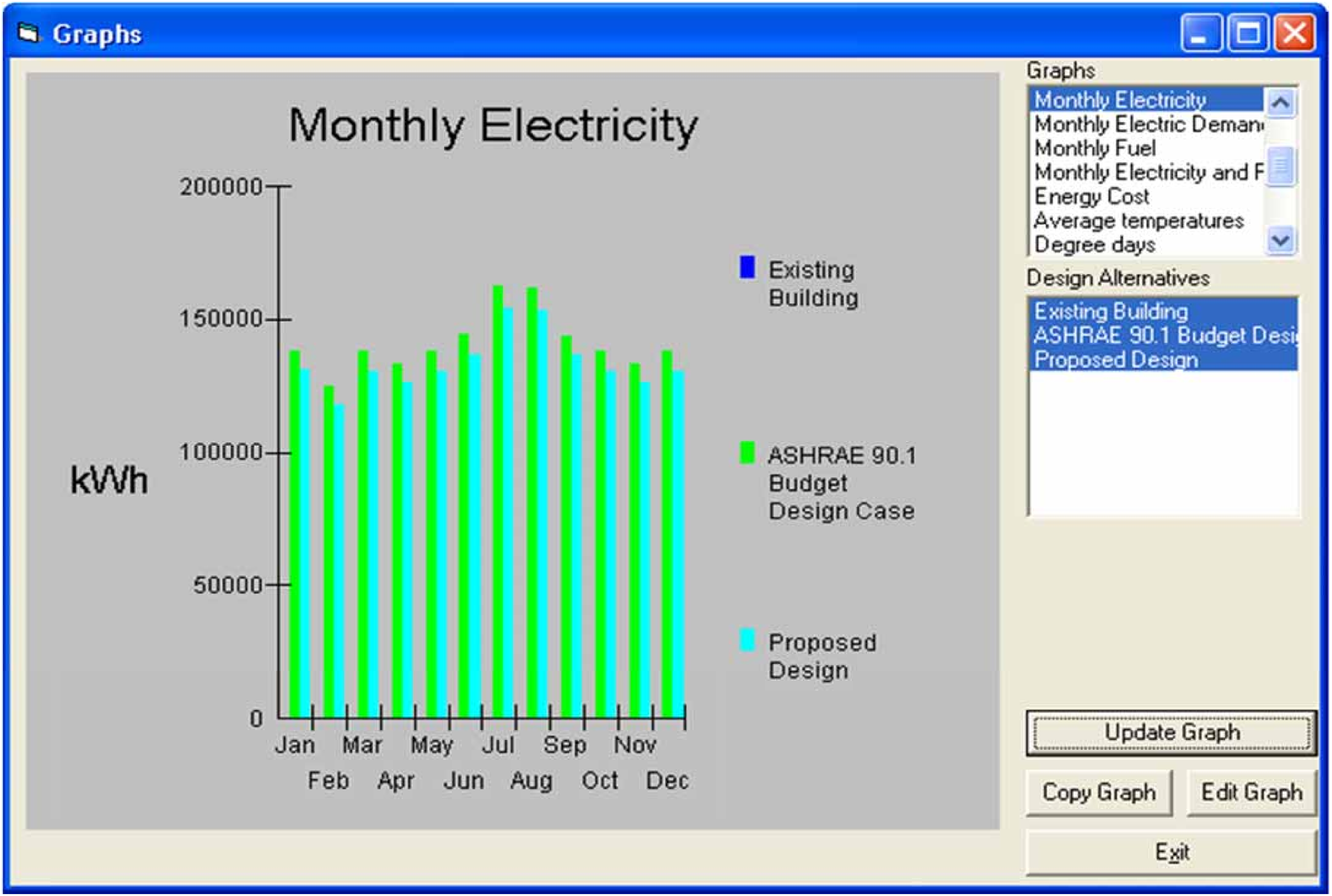
Predesign energy analysis

- 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

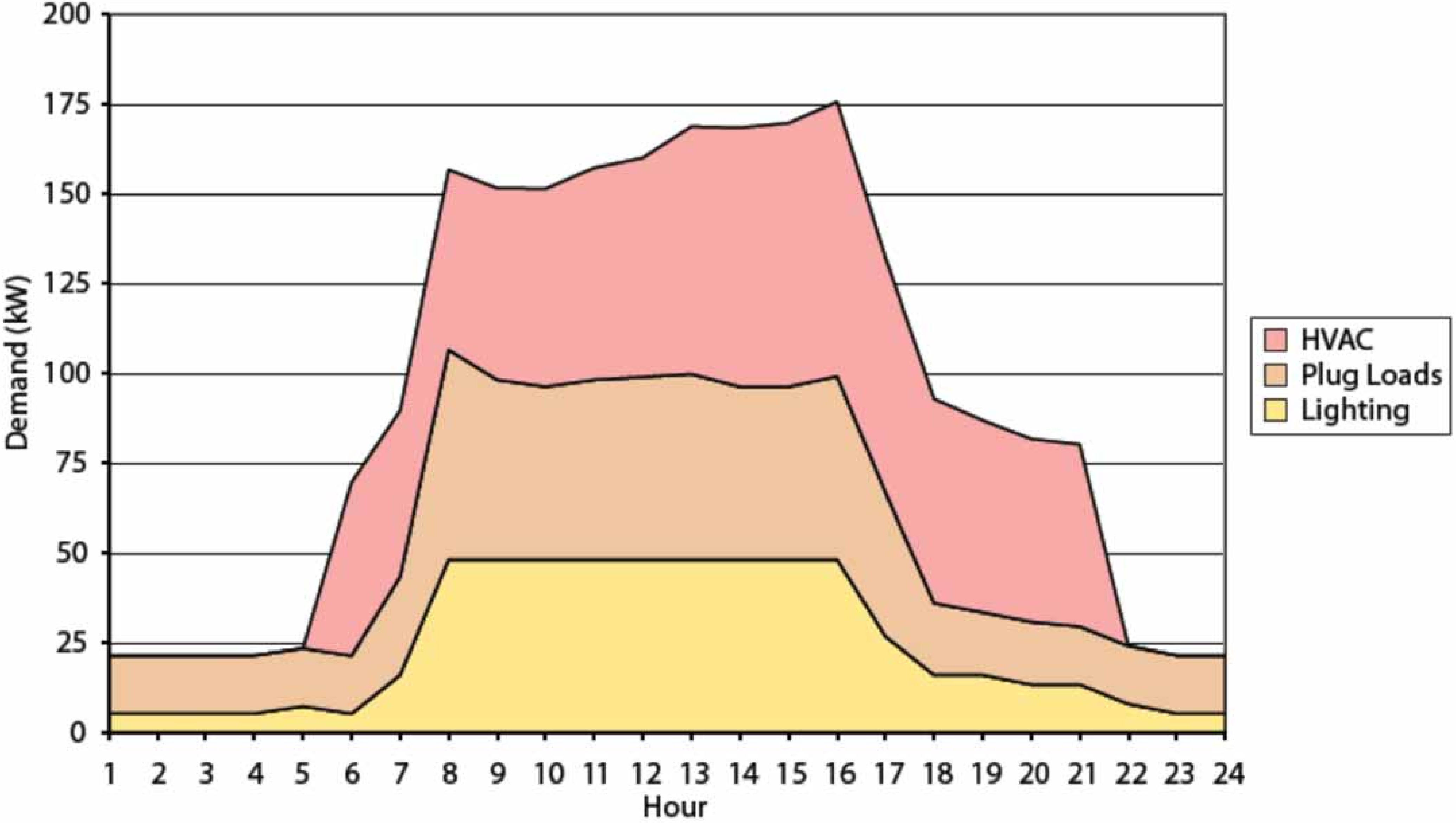
Breakdown of end-use energy consumption



Monthly electricity profile



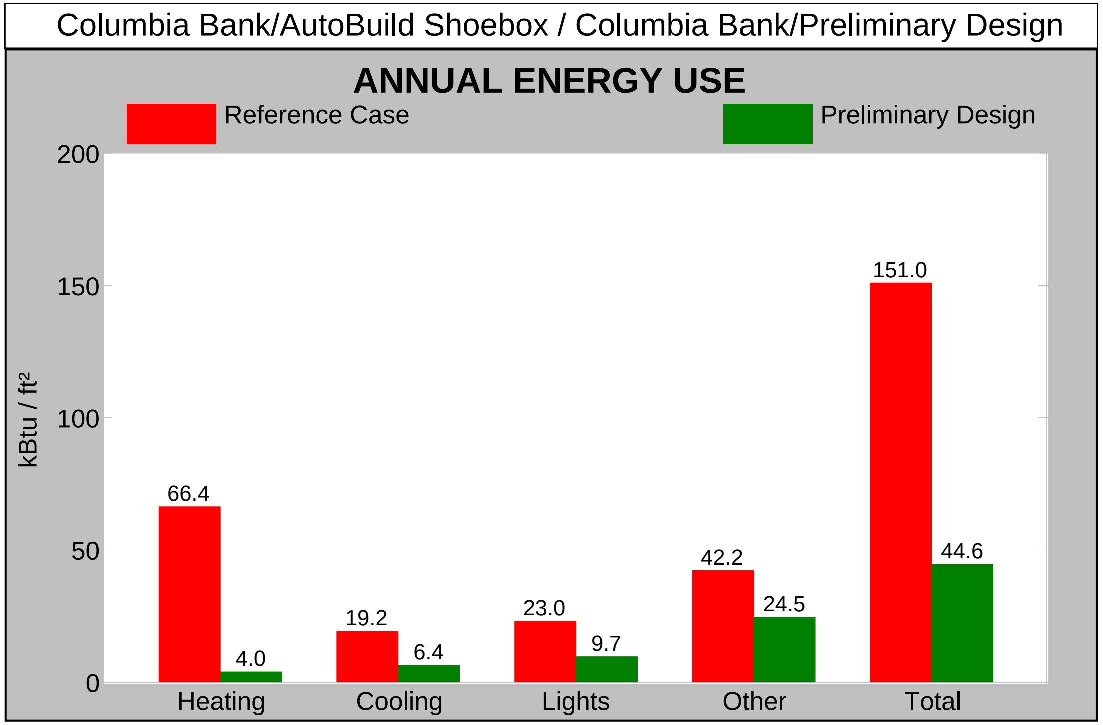
Peak day demand profile

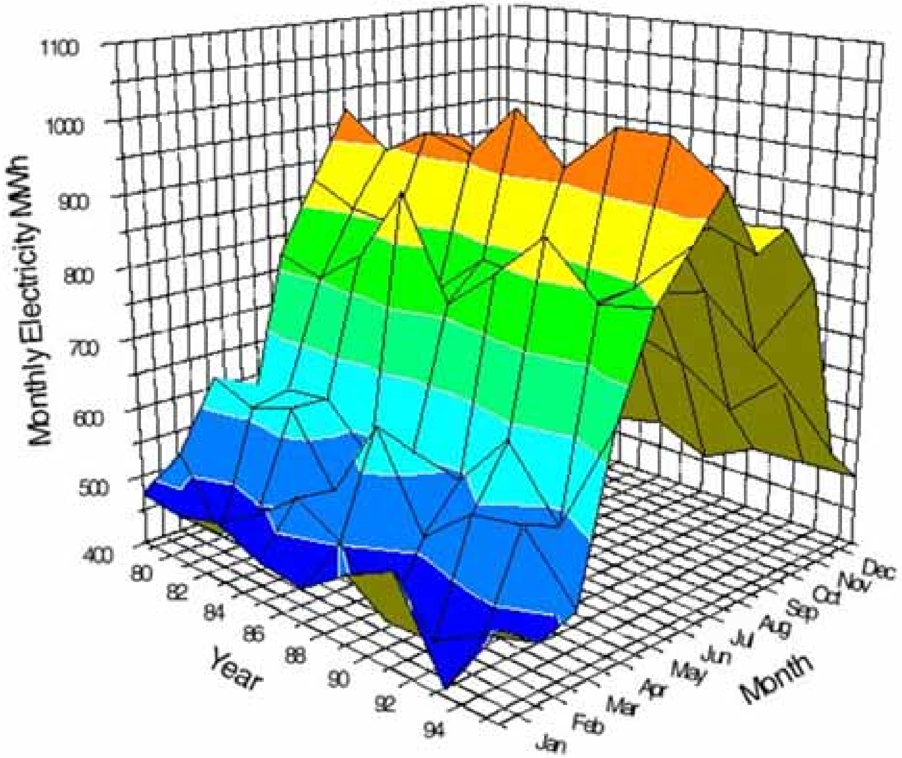


(Source: Lindsey, G., et al., 2009. *A Handbook for Planning and Conducting Charrettes for High-Performance Projects*)

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)



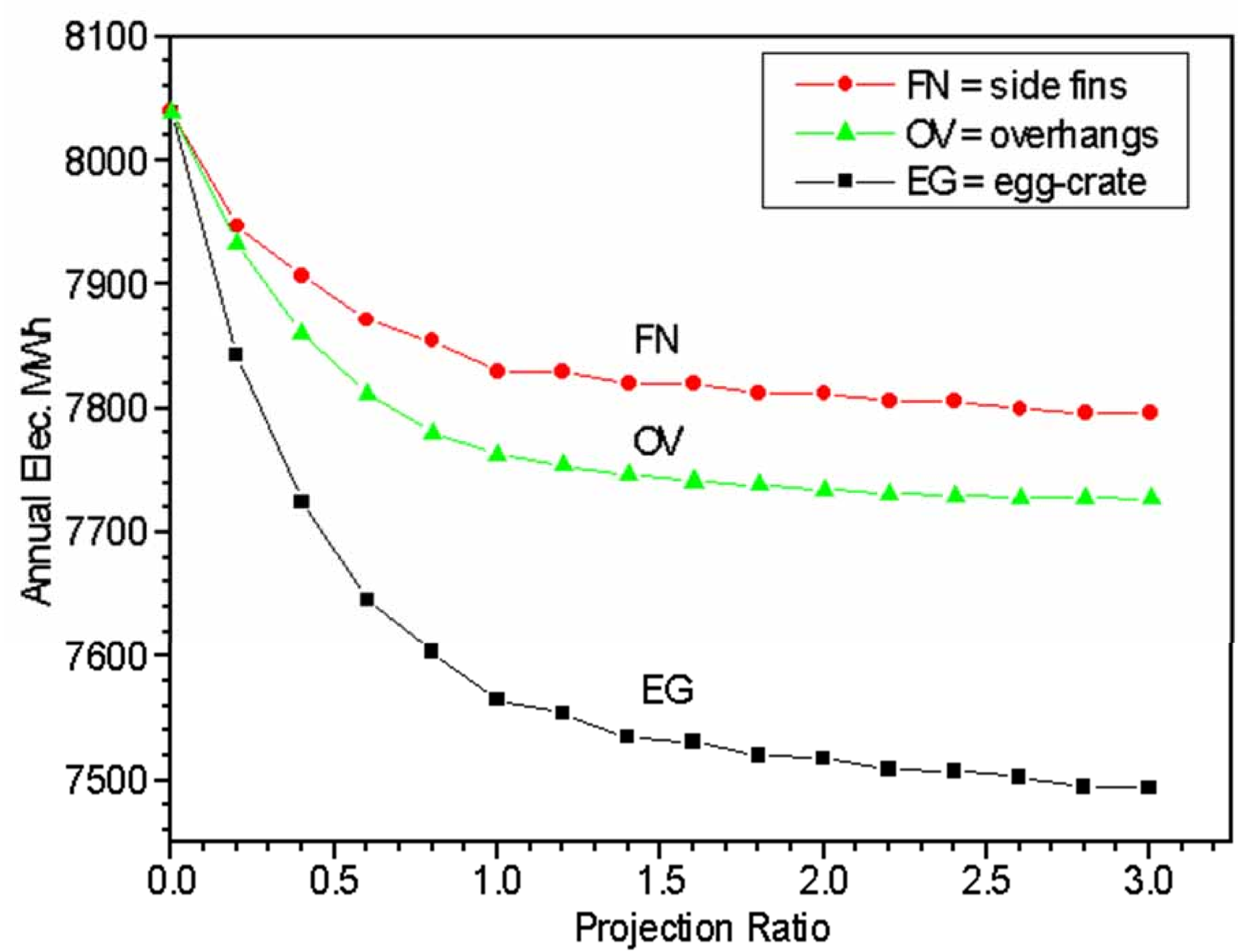


Presentation of results from building energy simulation

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

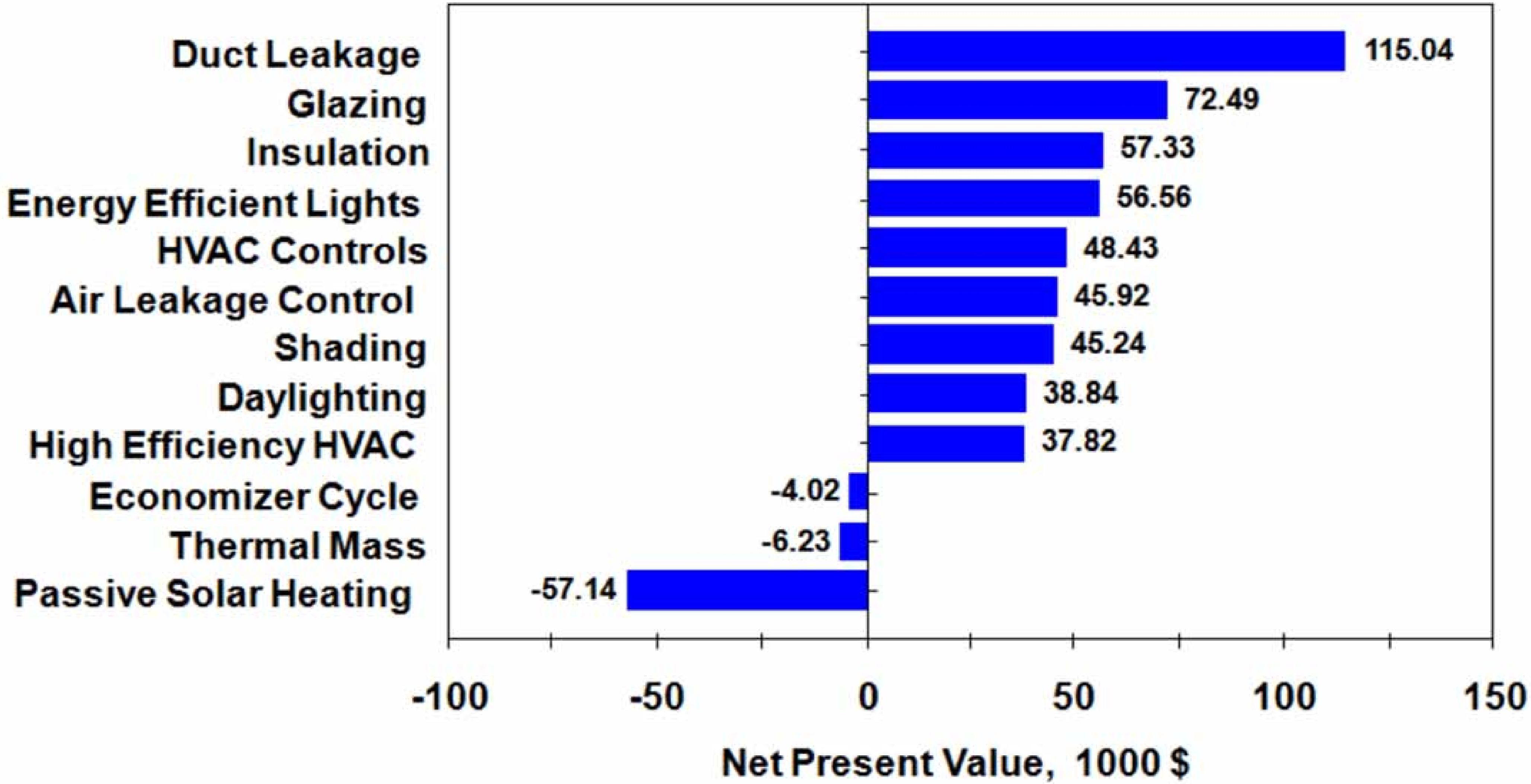
Example: Effects of external shading on energy consumption



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

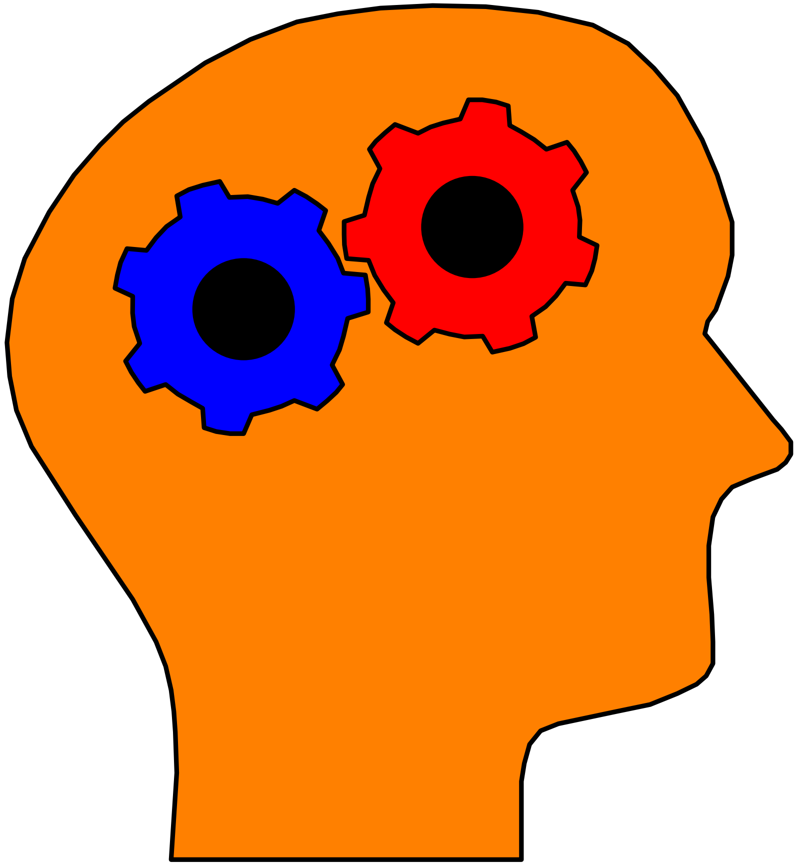
Ranking of energy conservation measures



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



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

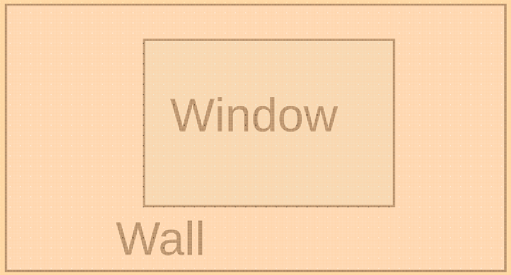
A. 2.8 $W/m^2.K$ SC = 0.95	B. 1.8 $W/m^2.K$ SC = 0.71
C. 3.8 $W/m^2.K$ SC = 0.82	D. 0.8 $W/m^2.K$ SC = 0.51

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)

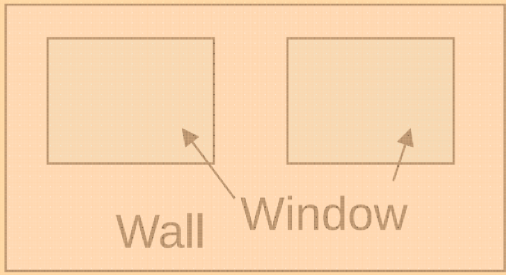
A.

B.

C.



D.



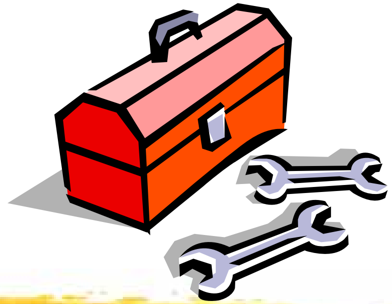
Which of the following strategies of HVAC systems is NOT primarily for energy efficiency?

A. Waste heat recovery	B. Variable speed pump/ fan controls
C. Ice thermal storage	D. Free cooling mode

'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) (Excel file)
  - http://www.wbdg.org/tools/gbt.php?c=1
  - Sorted by 14 categories/topics
  - Divided into 5 types
    - Software
    - Checklist/matrix
    - Publication
    - Database
    - Website

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*)

Zero energy building

"0"

- Zero energy building (ZEB)
  - A building that produces as much energy on-site as it consumes on an annual basis
  - "Net" zero energy building
- Advantages of ZEB:
  - Reduce energy consumption and costs
  - Reduce carbon emissions
  - Reduce dependence on fossil fuels

Zero energy building

"0"

- Net zero site energy (site ZEB)
  - Amount of energy provided by on-site renewable energy sources is equal to the amount of energy used by the building
- Net off-site zero energy (off-site ZEB)
  - Similar to previous one, but consider purchasing of energy off-site from 100% renewable energy sources

Zero energy building "0"

- Net zero source/primary energy (source ZEB)
  - It produces as much energy as it uses in a year, when accounted for the source
  - For electricity, only around 35% of the energy used in a fossil fuel power plant is converted to useful electricity and delivered
  - Site-to-source conversion multipliers are used to calculate a building’s total source energy

Zero energy building

"0"

- Net zero energy costs (cost ZEB)
  - The cost of purchasing energy is balanced by income from sales of electricity to the grid of electricity generated on-site
- Net zero energy emissions
  - Zero carbon building or zero emission building
  - The carbon emissions generated from the on-site or off-site fossil fuel use are balanced by the amount of on-site renewable energy production

Comparison of low energy, zero energy/carbon and green buildings [adapted from ECEEE (2009)]

	Pros	**Cons**
Low energy building (LEB) (e.g. passive house)	Cost optimal; well established principles with thousands of buildings constructed	Does not achieve greatest energy/carbon saving potential
Zero energy building (ZEB)/ Zero carbon building (ZCB)	Greatest energy/carbon saving	More expensive; limited practical experience
Green Building (GB)	Takes account of wider sustainability and resource use issues	May not be realistic across all new buildings

Examples of zero energy/carbon building projects in the world

Pearl River Tower, Guangdong, China [2010]

Self-sufficient solar house, Freiburg, Germany [1992]

Pusat Tenaga Malaysia's ZEO Building, Malaysia [2007]

BCA Academy, Singapore [2009]

Beddington Zero Energy Development (BedZED), London [2002]

The Barratt Green House in Watford, UK [2008]

Zero energy office building in Guangdong, China (Pearl River Tower, for Guangdong Tobacco Company)

(completed in 2011)

Main features:

- Orientation of the building
- Low-E-glass
- Double-layer curtain-wall
- Chilled slab concrete ceilings
- Lighting efficiency
- Geothermal heat sink
- Energy storage
- Wind
- Integrated photovoltaics
- Microturbines

(Source: sustainabledesignupdate.com)

Self-sufficient solar house in Freiburg, Germany [1992]

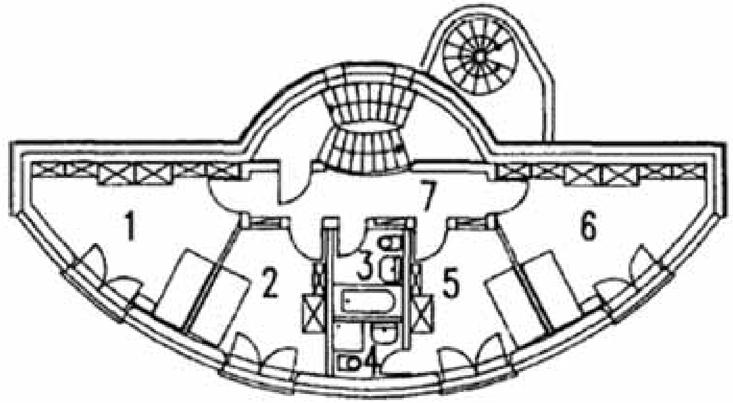
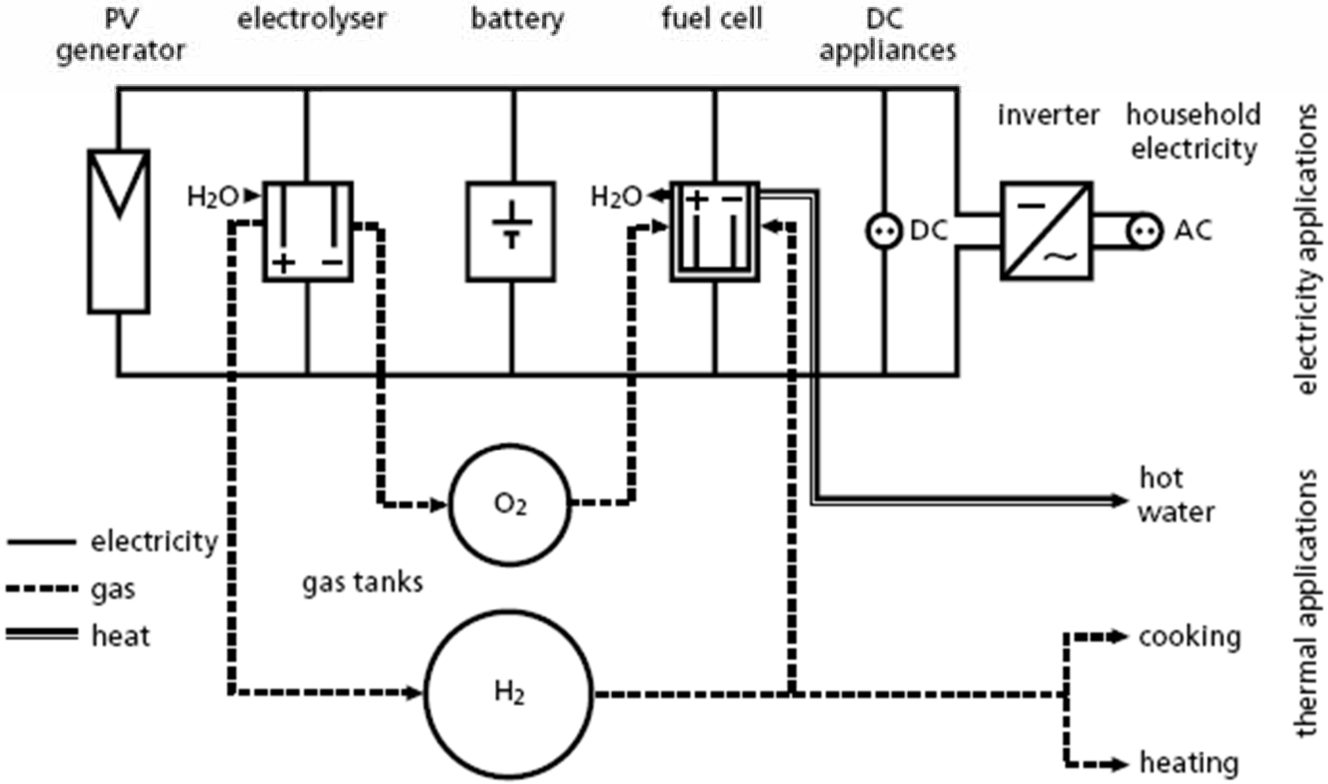


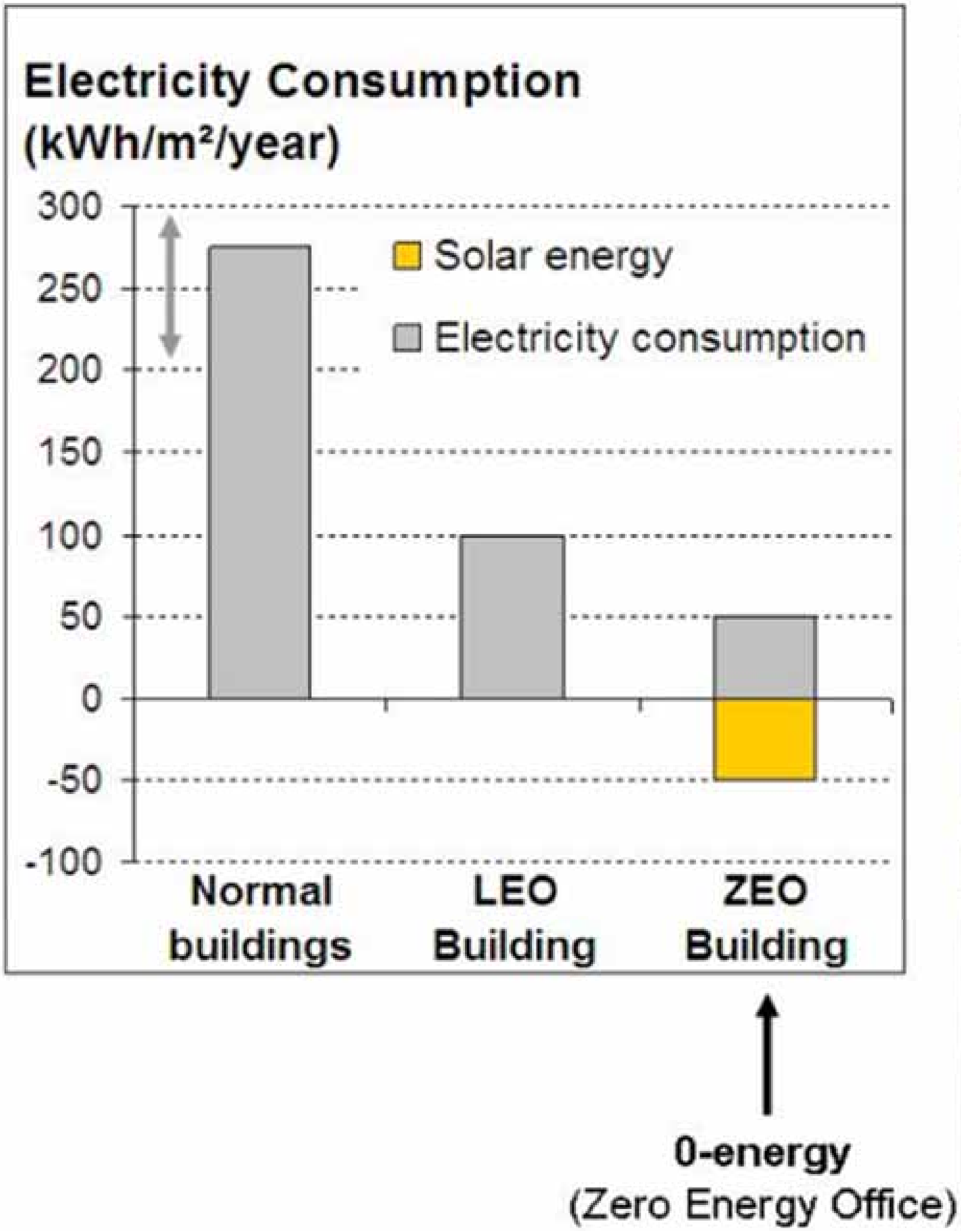
Fig. 3. The first floor of the SSSH

1: room 1, 2: room 2, 3: bath/toilet, 4: shower/toilet, 5: room 3, 6: room 4, 7: dor.



(Source: www.ise.fhg.de)

Malaysia low energy building and zero energy building



(Source: www.ptm.org.my/PTM_Building)

Beddington Zero Energy Development (BedZED), UK

Energy design features:
- Triple glazed
- High thermal insulation
- 777 m² of solar panels
- Co-generation
- District heating & electricity

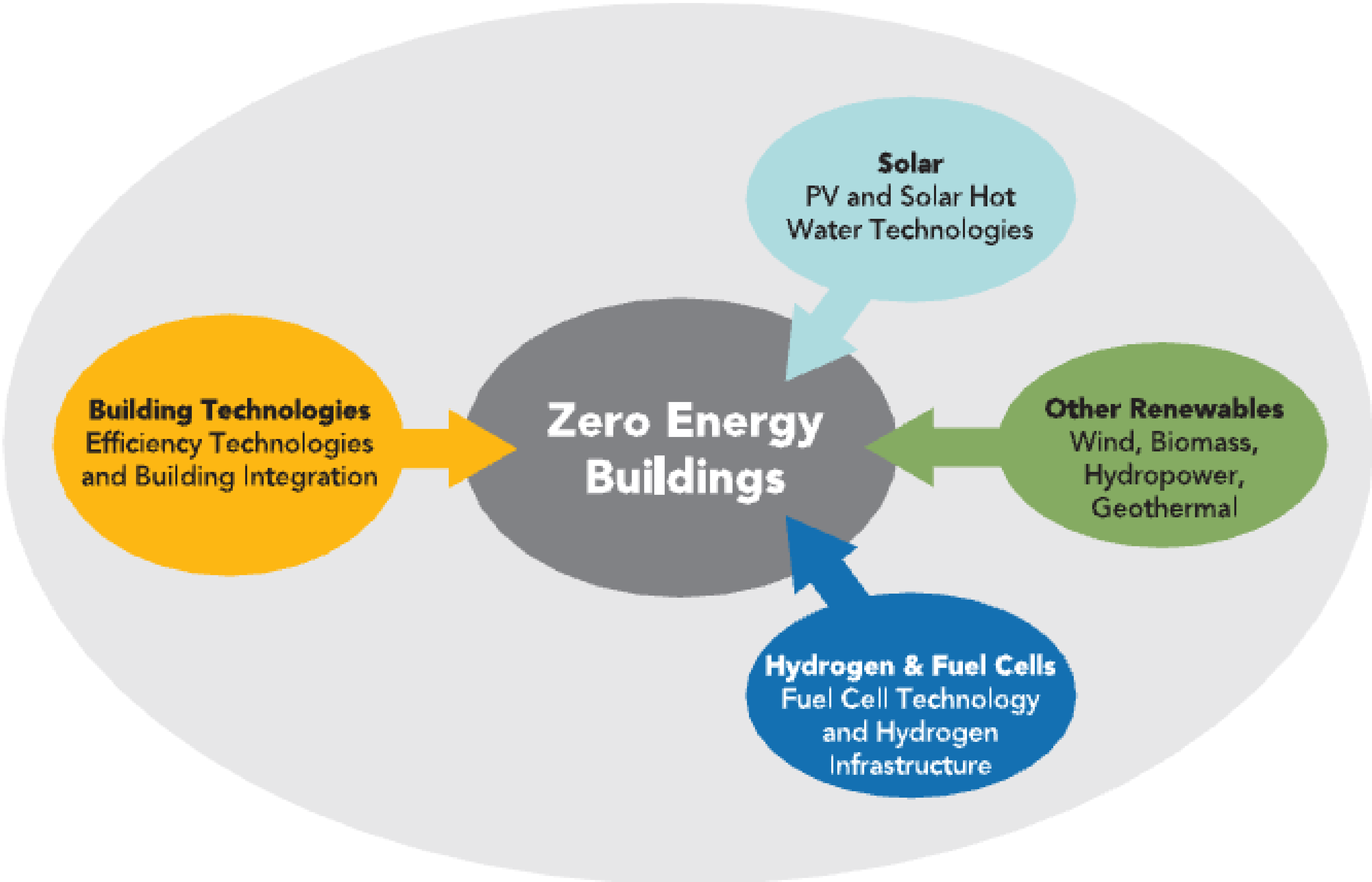
Wind catcher

Zero energy building

"0"

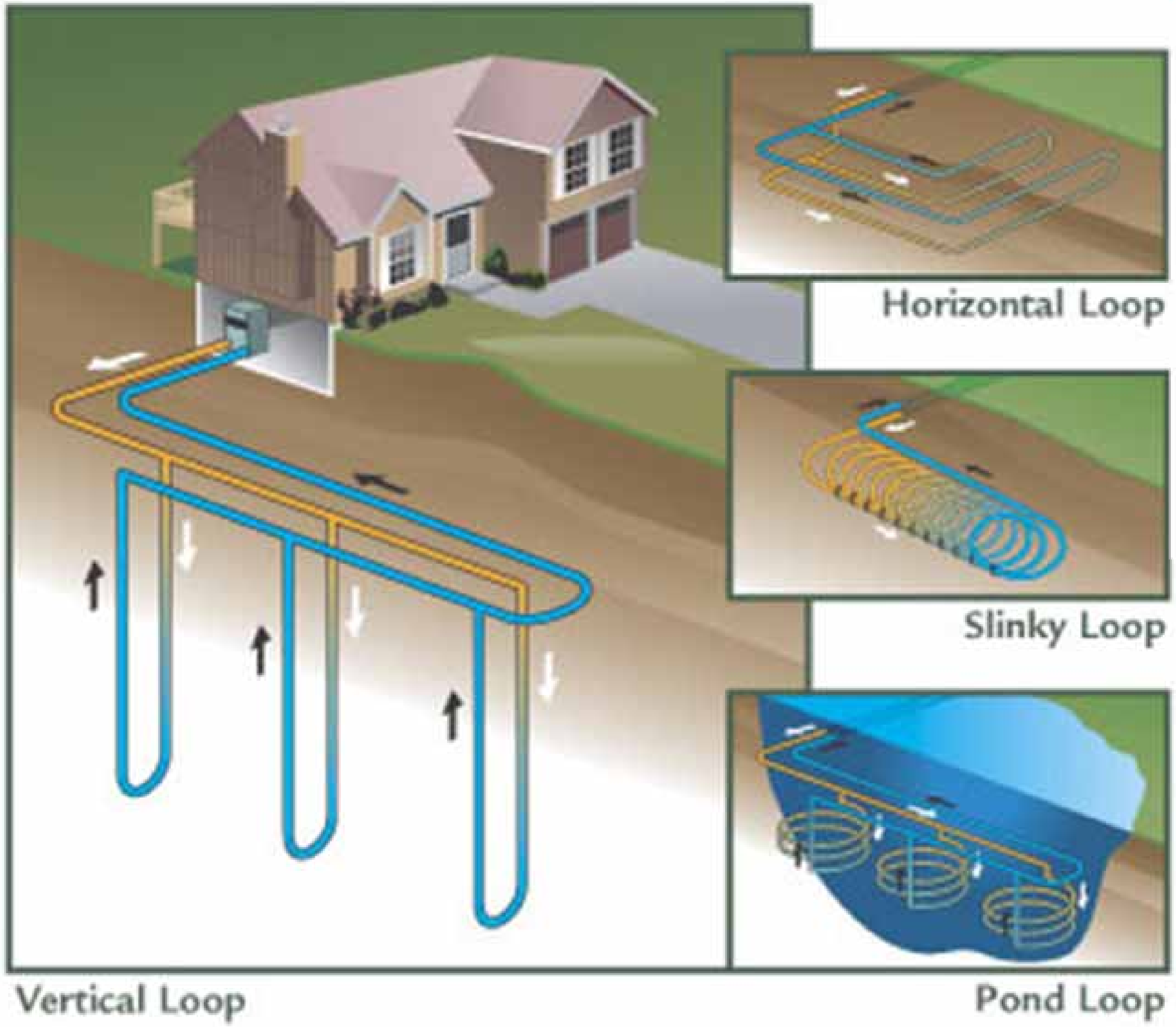
- How to achieve zero energy/carbon building?
  - High energy efficiency
  - On-site carbon reduction measures
    - Such as renewable energy systems, water efficiency
  - Methods to offset the remaining emissions, e.g.
    - Large scale off-site renewable energy facilities (unconnected)
    - Investment in local energy efficiency measures
    - Energy efficient appliances

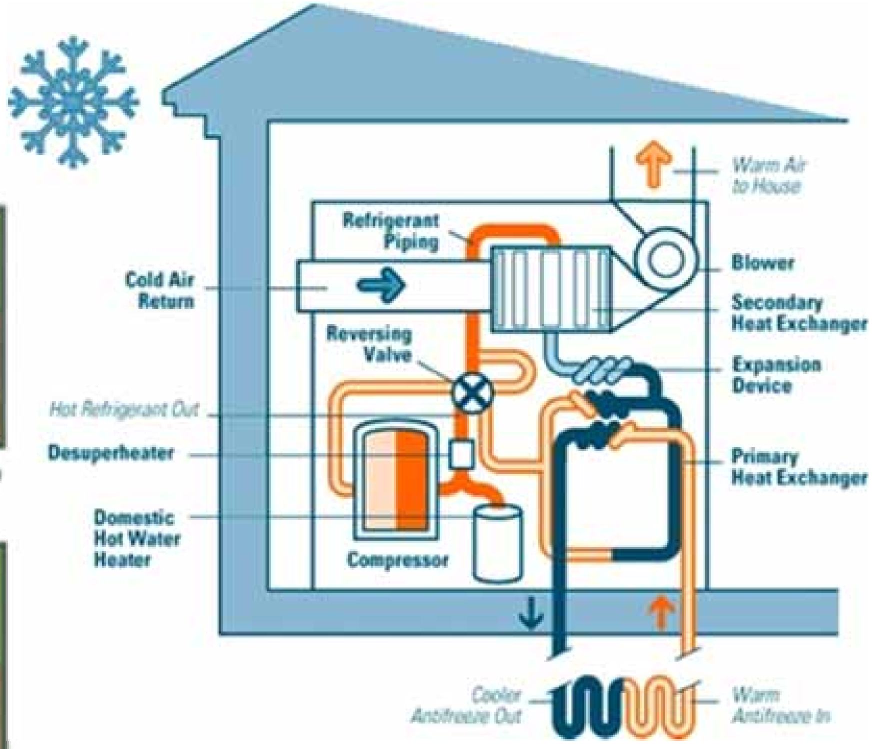
Strategies for net zero energy building [Source: NSTC (2008)]

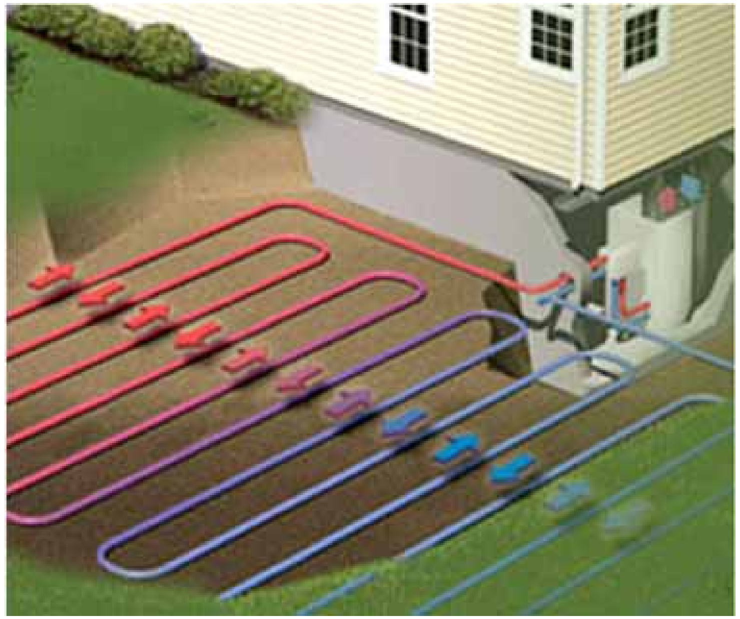


PV-wind lamp pole (installed at HKU Faculty of Medicine Building)

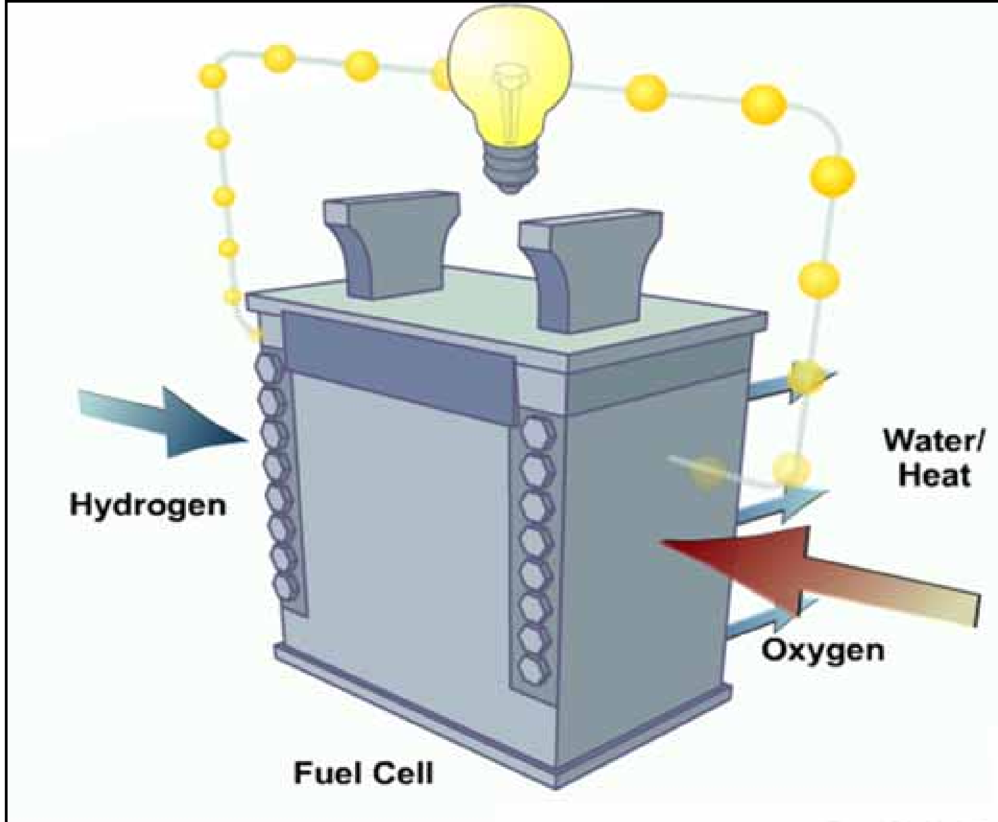
1.5 kW vertical wind turbine (installed at EMSD Headquarters)



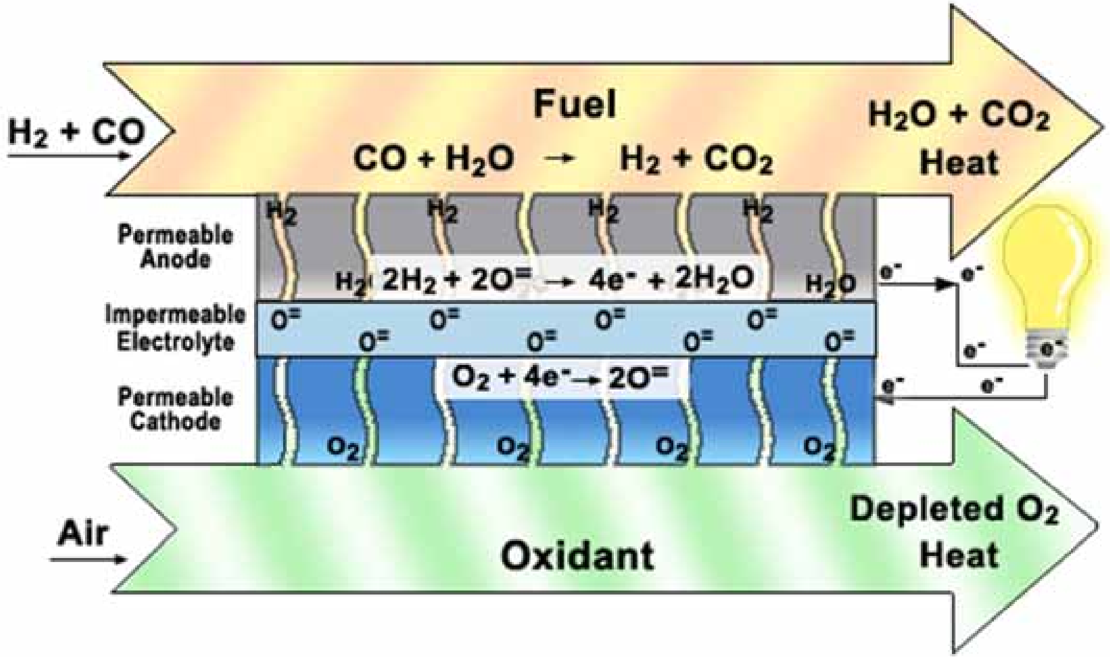


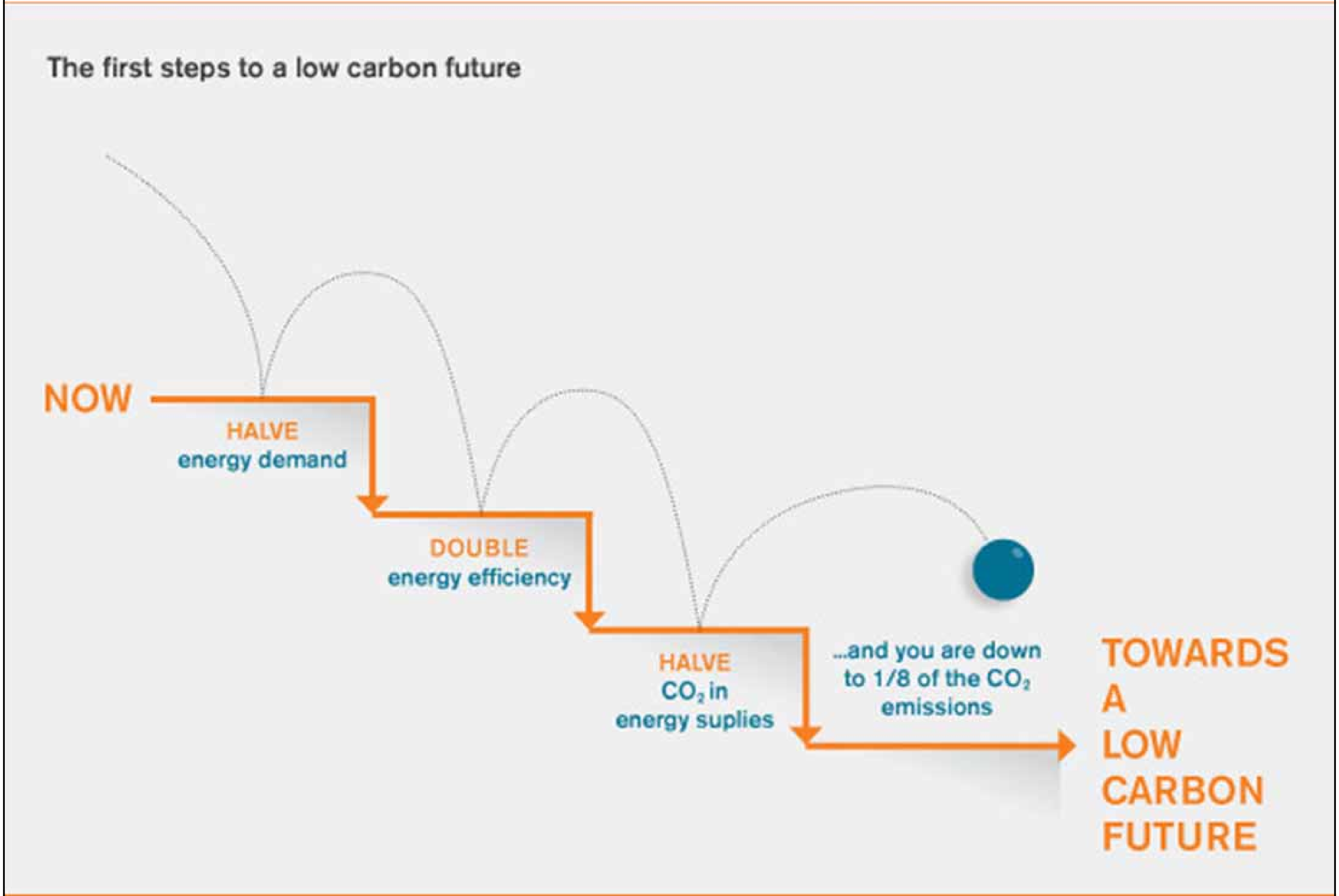


Geothermal heat pumps



Solid Oxide Fuel Cell

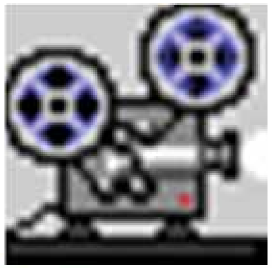




(Source: www.cabe.org.uk/buildings)

(Source: www.cabe.org.uk/buildings)

Video Presentation



- Achieving Net-Zero-Energy Design - ASHRAE (2:05)
  - http://youtu.be/pQFJr5E7_R0
- PTM Zero Energy Office (ZEO) Building Video (7:36) (Malaysia)
  - http://youtu.be/kDdvL2N7LUI
  - More information: (now called Green Energy Office (GEO) Building)
    - www.futurarc.com/previous_edition/zeroenergy.cfm