Guest Lecture to HKU Department of Architecture
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Energy Efficiency in Buildings

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- Basic Energy Concepts
- Energy Use in Buildings
- Building Energy Efficiency

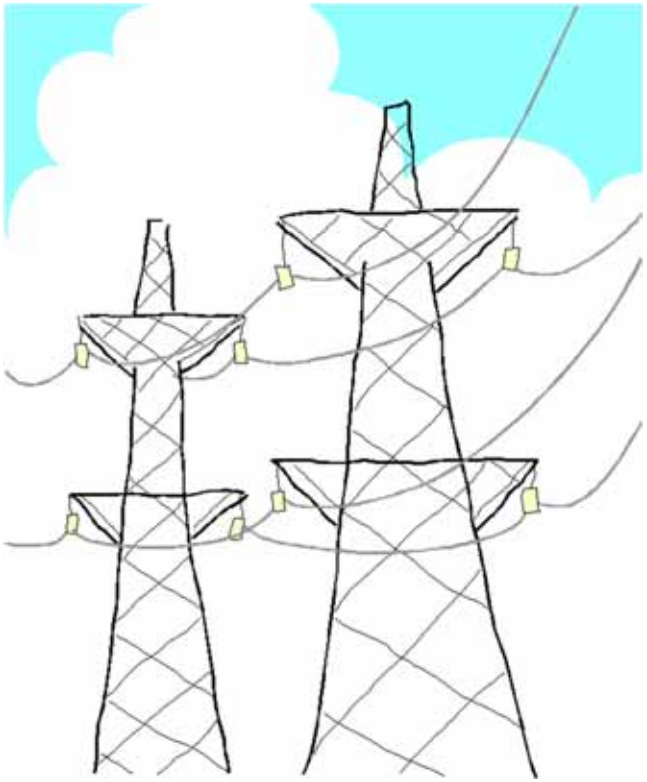
Basic Energy Concepts

Energy Basics

- Units of energy:
  - Kilowatt-hour (kWh), often for electricity use
    - 1 kWh = 3.6 x 10^6 Joule = 860 kcal = 3412 Btu
  - Calorie (卡路里), 1 calorie = 4.2 x 10^3 J
  - British thermal unit (Btu), 1 Btu = 1.055 x 10^3 J
  - Tonne of oil equivalent (toe), 1 toe = 4.2 x 10^{10} J
    - From oil industry http://en.wikipedia.org/wiki/Tonne_of_oil_equivalent
- Power unit:
  - 1 W = 1 J/s = 0.86 kcal/h = 3.41 Btu/h

Different forms of energy

能源

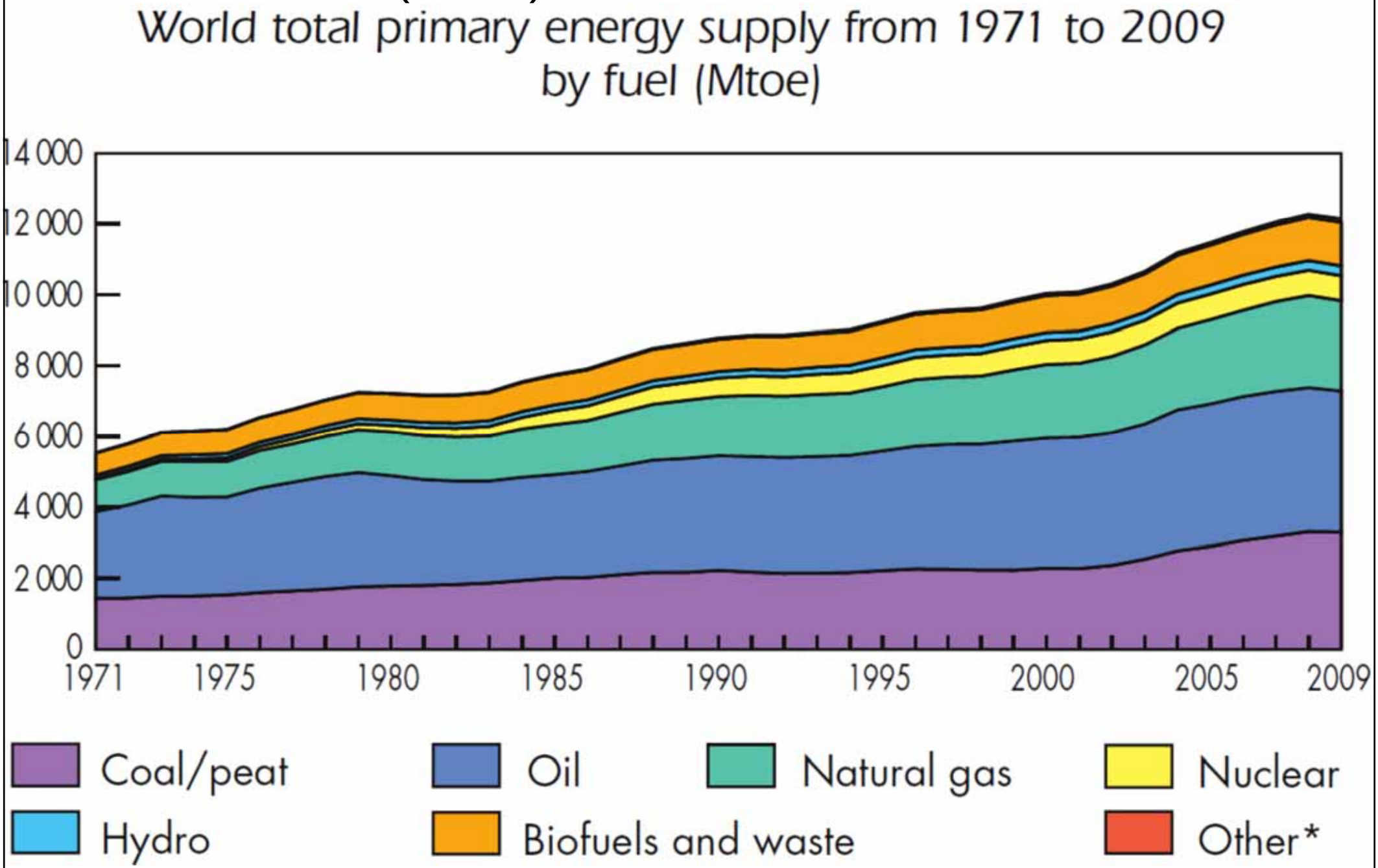


Which one(s) is/are most important nowadays?

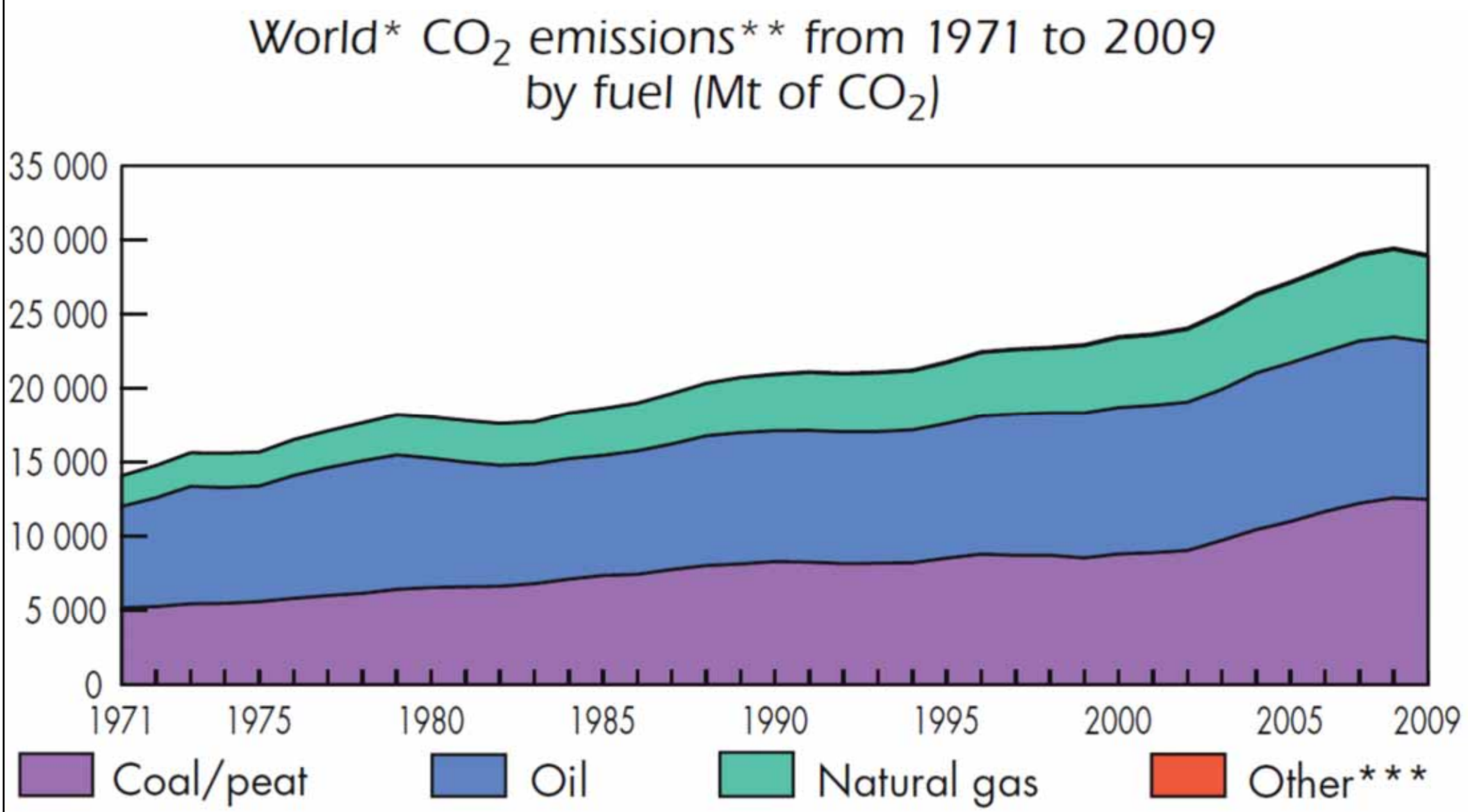
Energy Basics

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

(TPES)



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



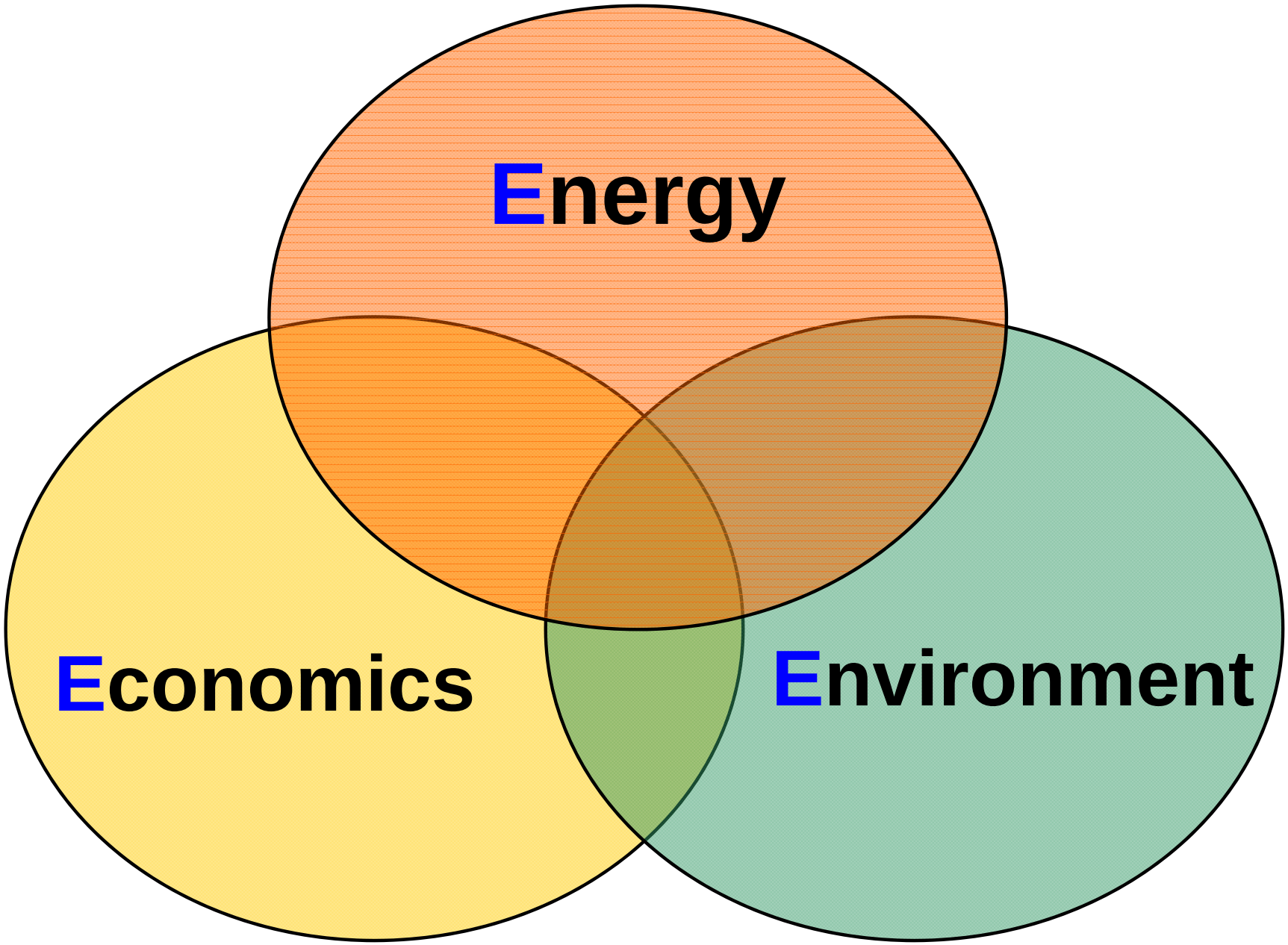
***Other includes industrial waste and non-renewable municipal waste

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

Energy Basics

- **Energy and environment**
  - Driving force for energy efficiency
  - Global warming & climate change- *CO_2 emissions*
    - Electricity 0.832 kg/kWh
    - Natural gas 0.198 kg/kWh
    - Coal 0.331 kg/kWh
  - Need to reduce energy demands and to shift towards environmental-friendly energy sources (e.g. renewable energy)

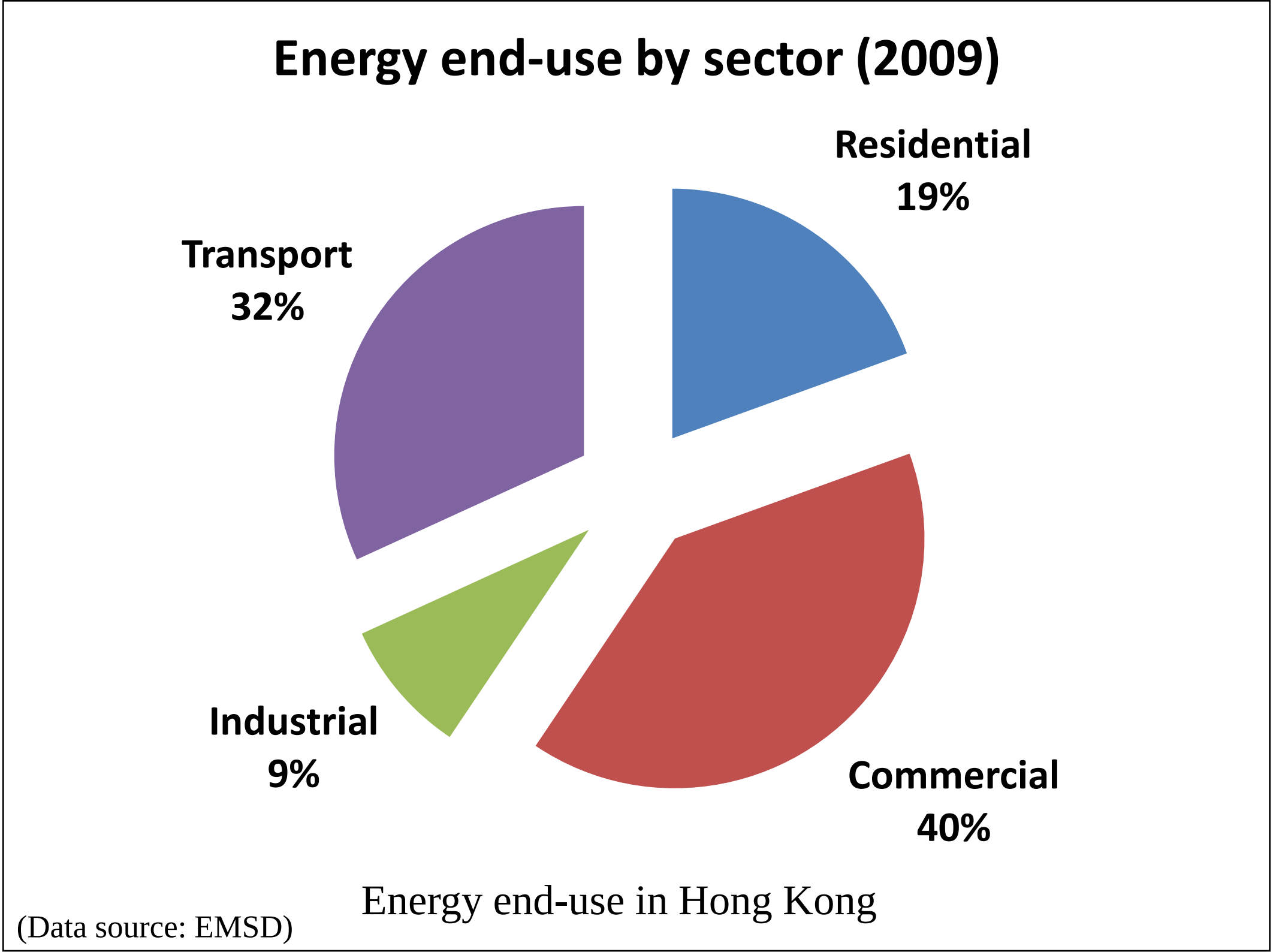
3 ‘E’ Relationships



Energy Use in Buildings

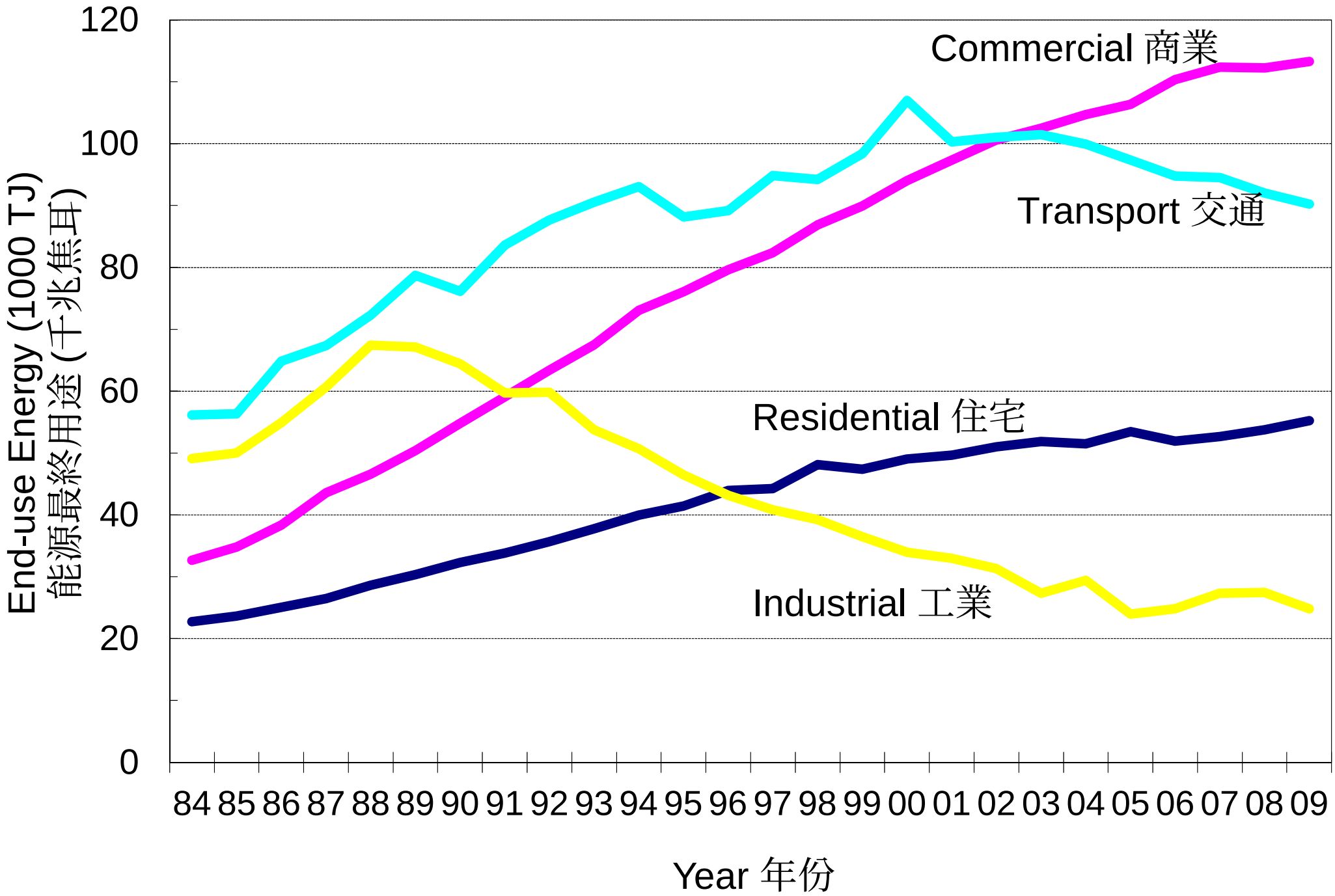
Hong Kong Situation

- In Hong Kong, buildings constitute 60-70% of total energy end-use and 60% of final energy requirements
  - Residential + commercial + industrial
- The potential for energy saving is large
- But the barriers to promoting energy efficiency are yet to overcome
  - Financial barriers
  - Administrative issues



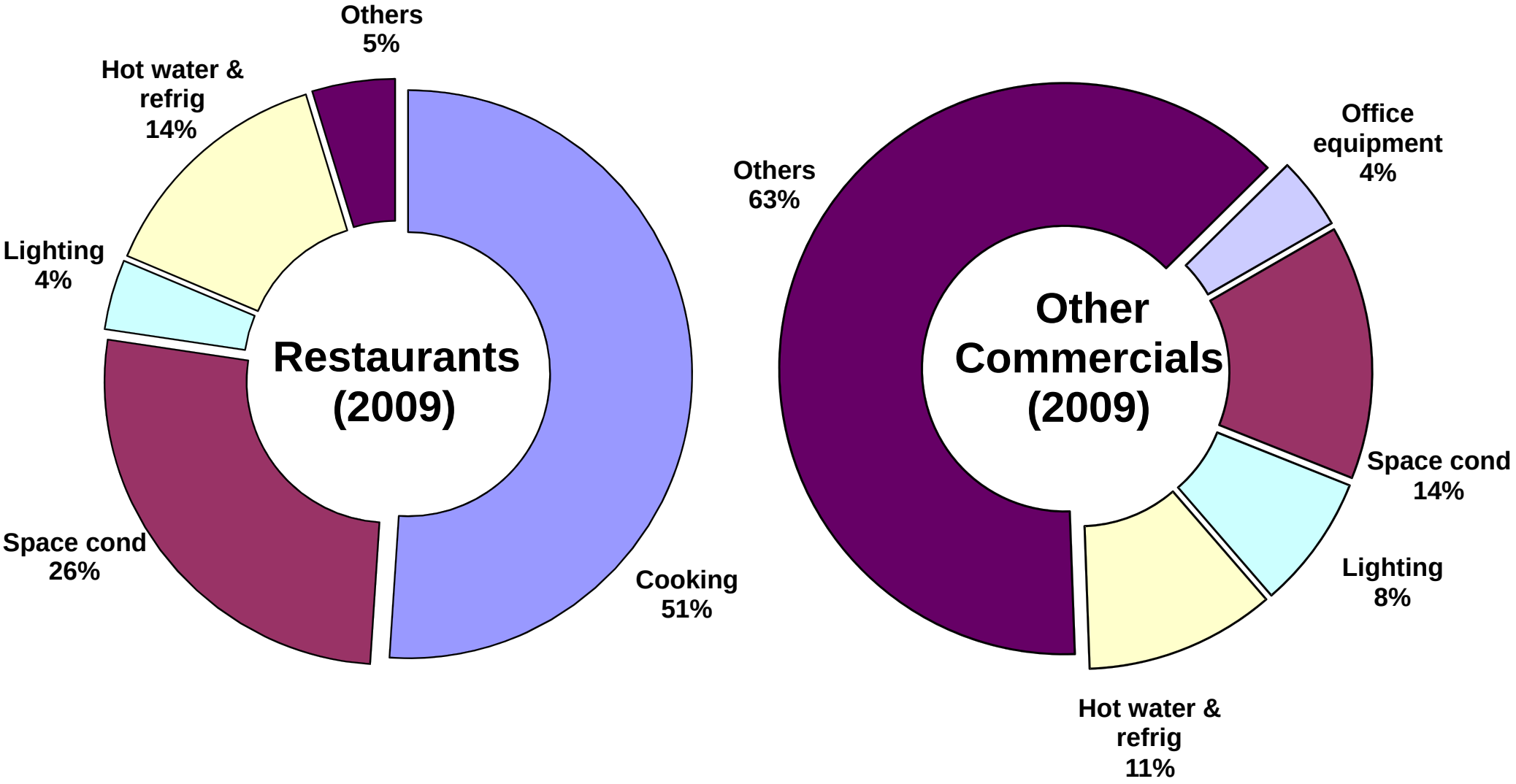
Energy end-use in Hong Kong

(Data source: EMSD)



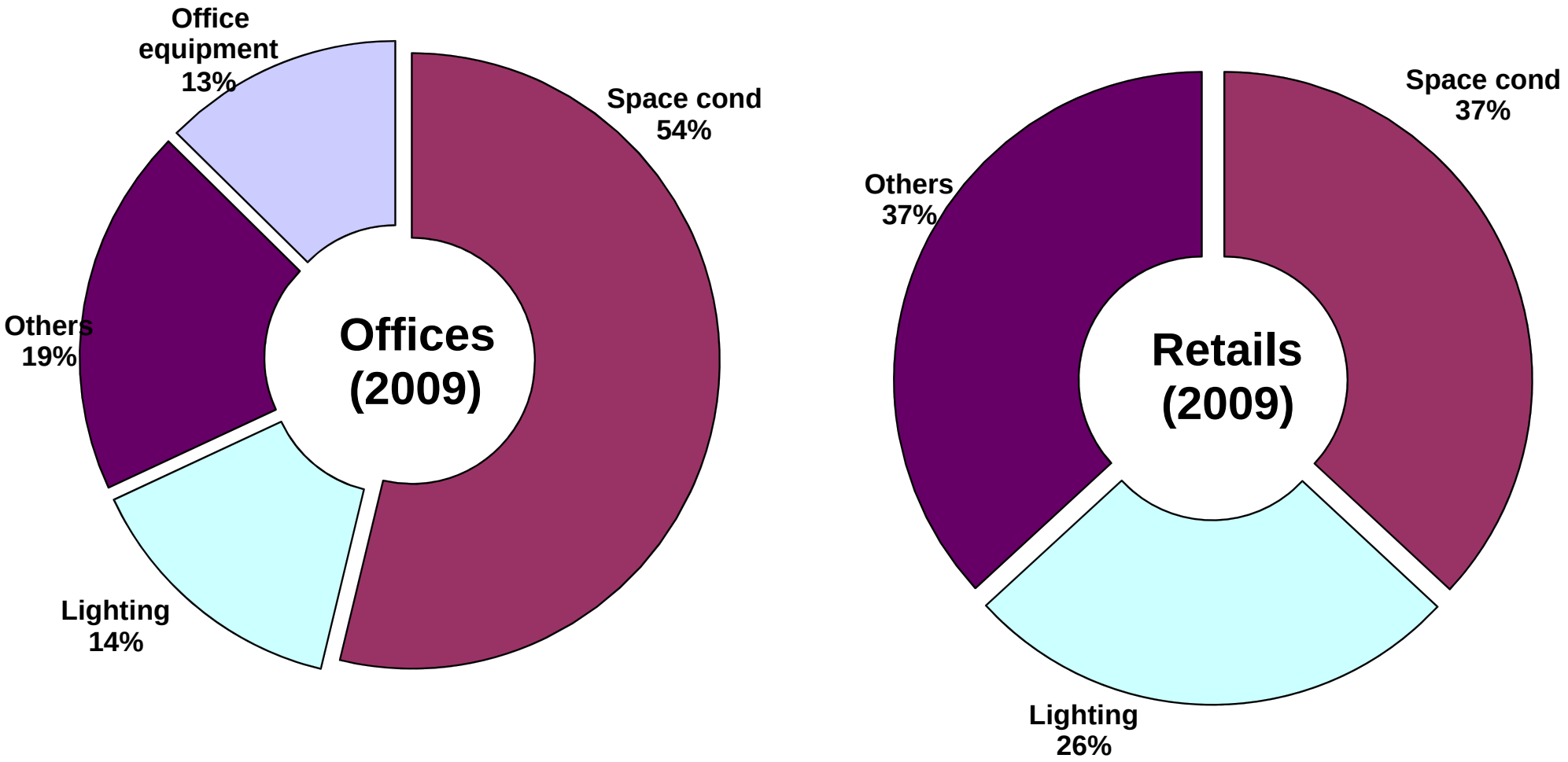
(Data source: EMSD) Energy end-use in Hong Kong by sectors, 1984-2009

What are the major energy usages?



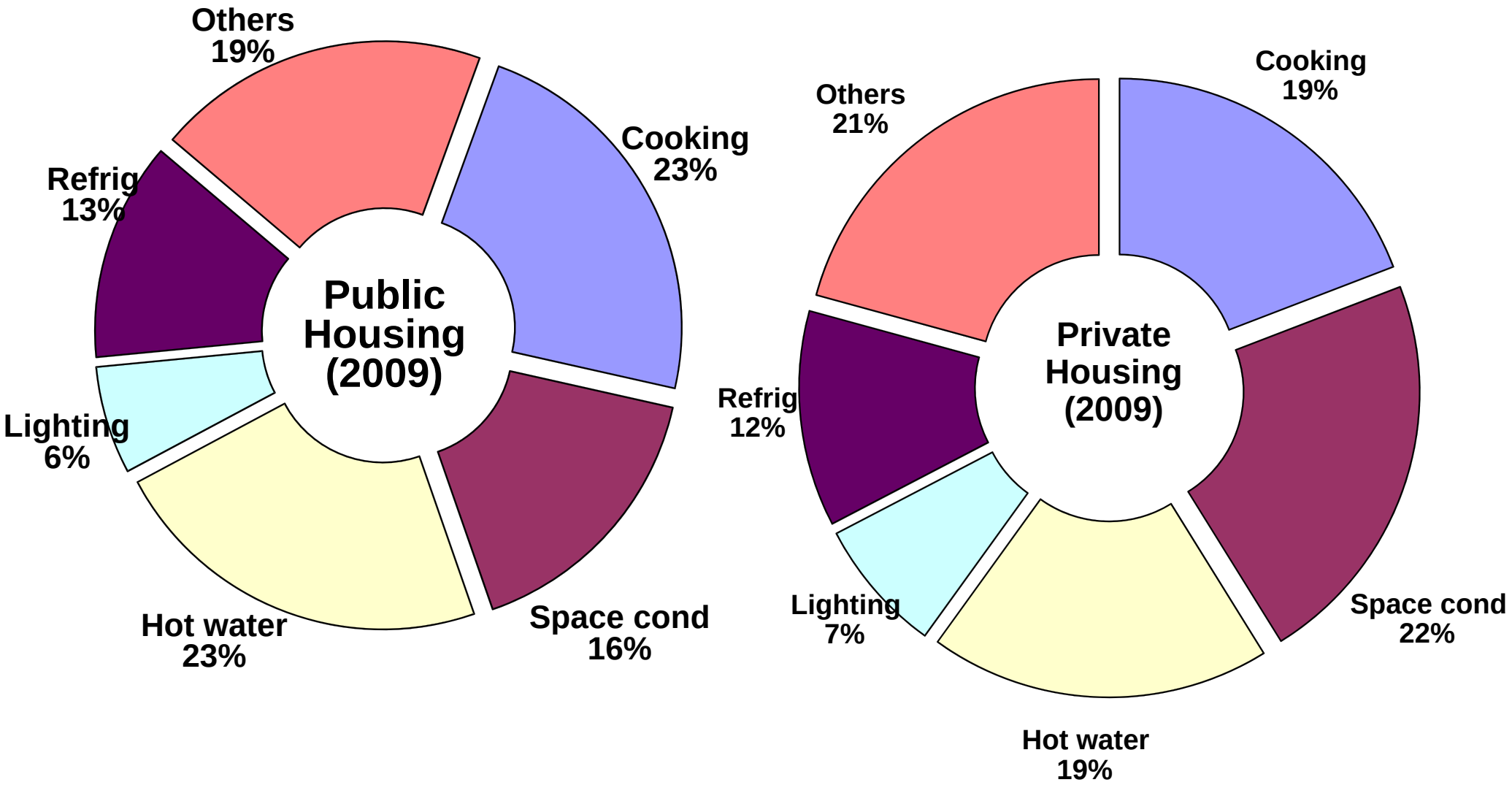
Energy consumption patterns in other commercial buildings
(Data source: Energy Efficiency Office, HK)

What are the major energy usages?



Energy consumption patterns in offices and retails
(Data source: Energy Efficiency Office, HK)

What are the major energy usages?

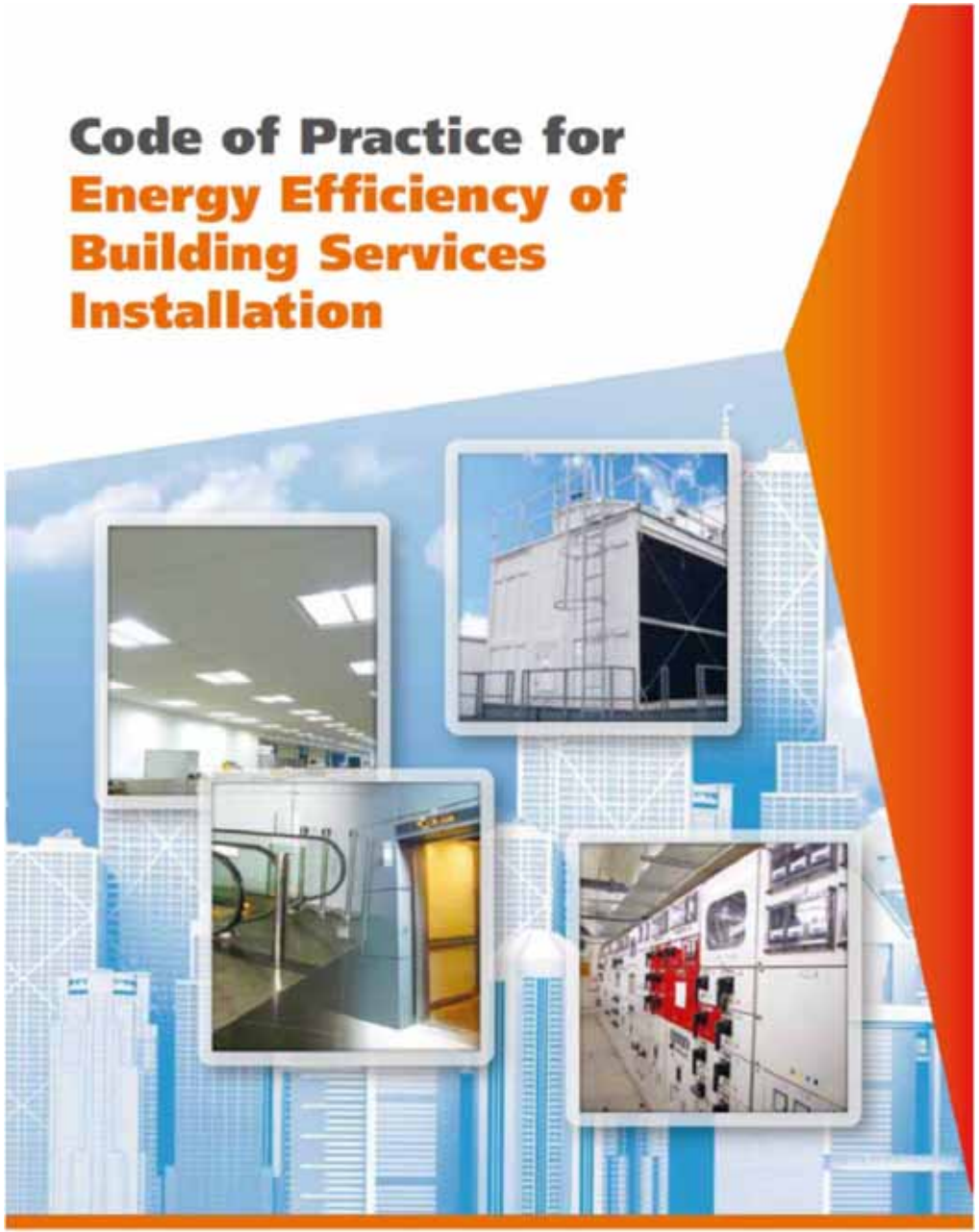


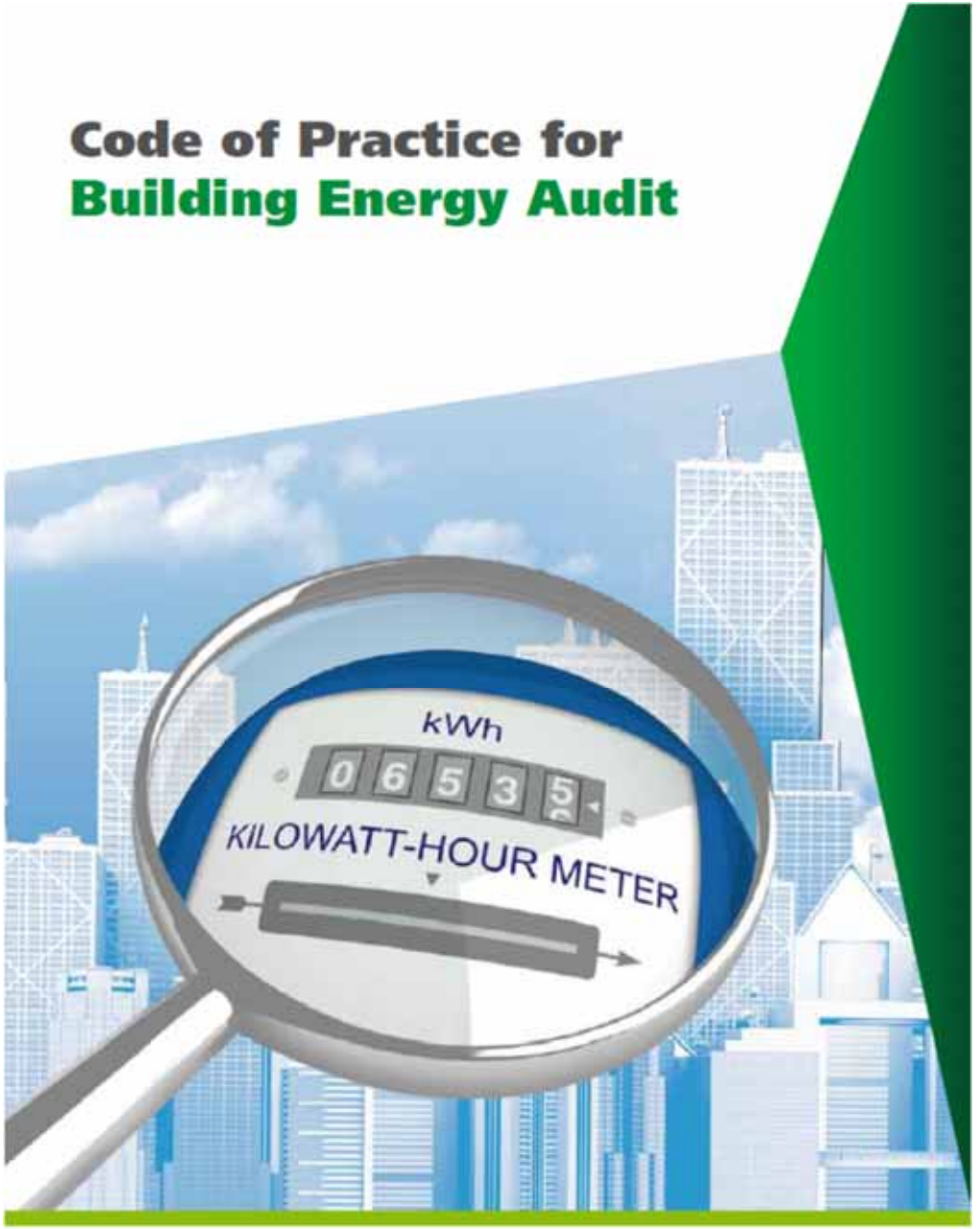
Energy consumption patterns in residential buildings
(Data source: Energy Efficiency Office, HK)

Hong Kong Situation

- The Buildings Energy Efficiency Ordinance (BEEO) (Cap. 610) had been enacted in November 2010 and had come into full operation on 21 September 2012*
  - Mandatory implementation of Building Energy Code (BEC) in prescribed buildings
  - Mandatory implementation of energy audit according to the Energy Audit Code (EAC) in commercial buildings and portions of composite buildings that are for commercial use

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


Code of Practice for
Energy Efficiency of
Building Services
Installation
2012
EMSD


Code of Practice for
Building Energy Audit
kWh
0 6 5 3 5
KILOWATT-HOUR METER
2012
EMSD

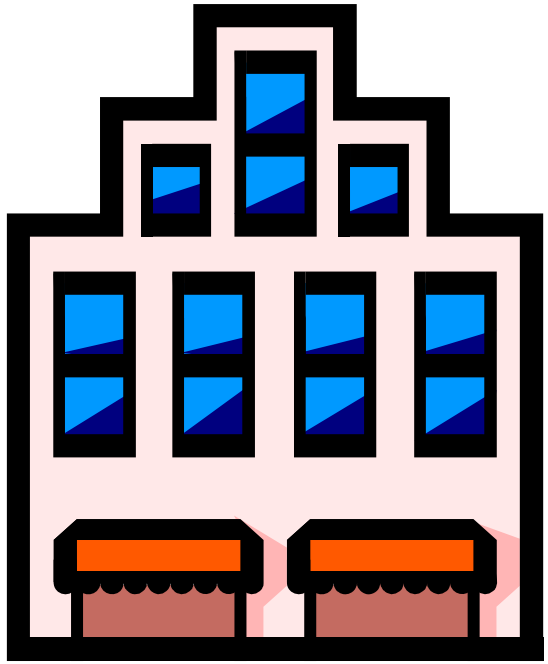
(Source: EMSD)

Comparison of energy label methods

Energy label for appliance

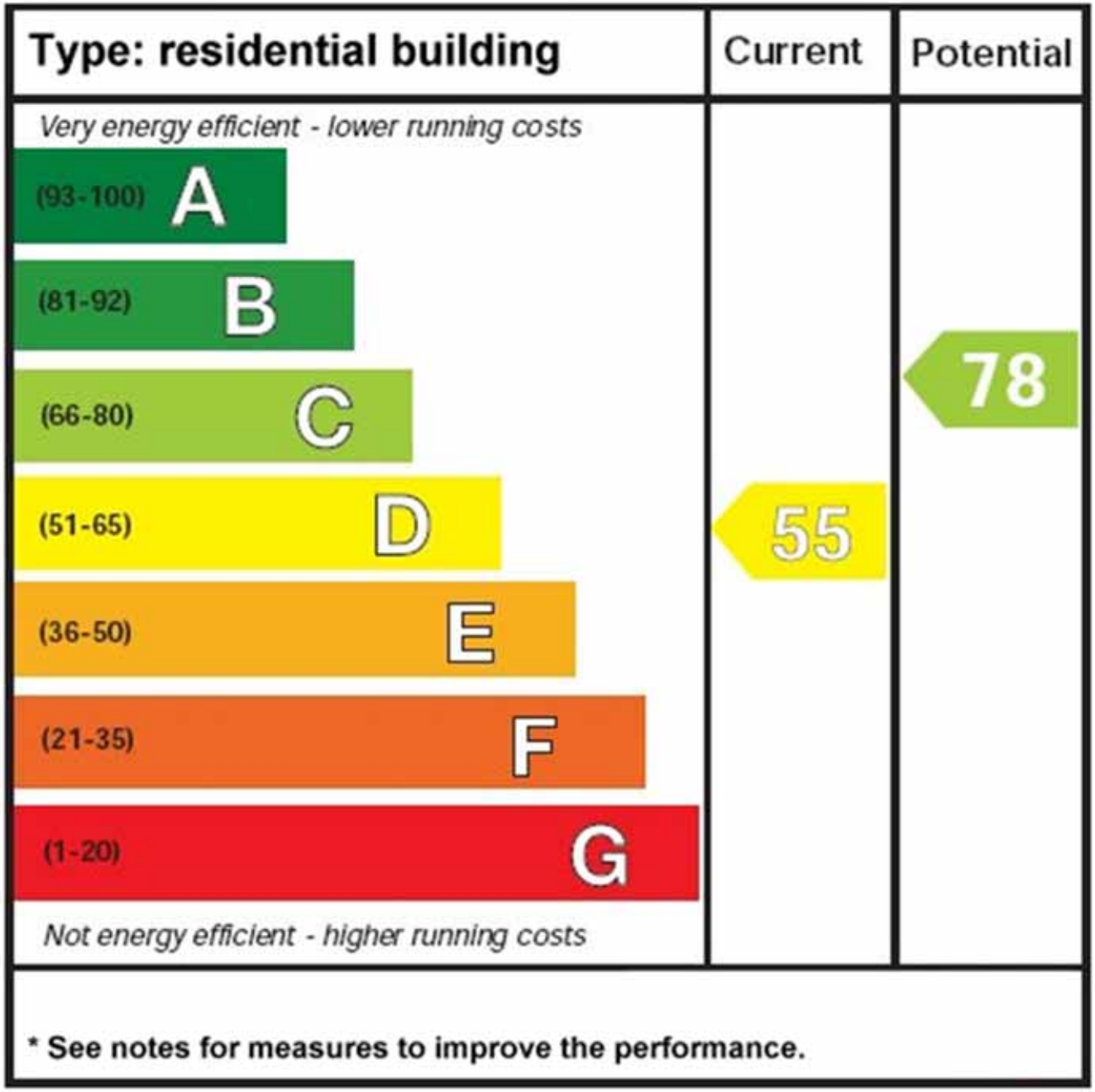
Energy label for passenger car

Energy label for buildings??



In Hong Kong, we pay a lot of money for housing and workplace. But we do not receive any info about their energy performance.

Hong Kong Building Energy Label

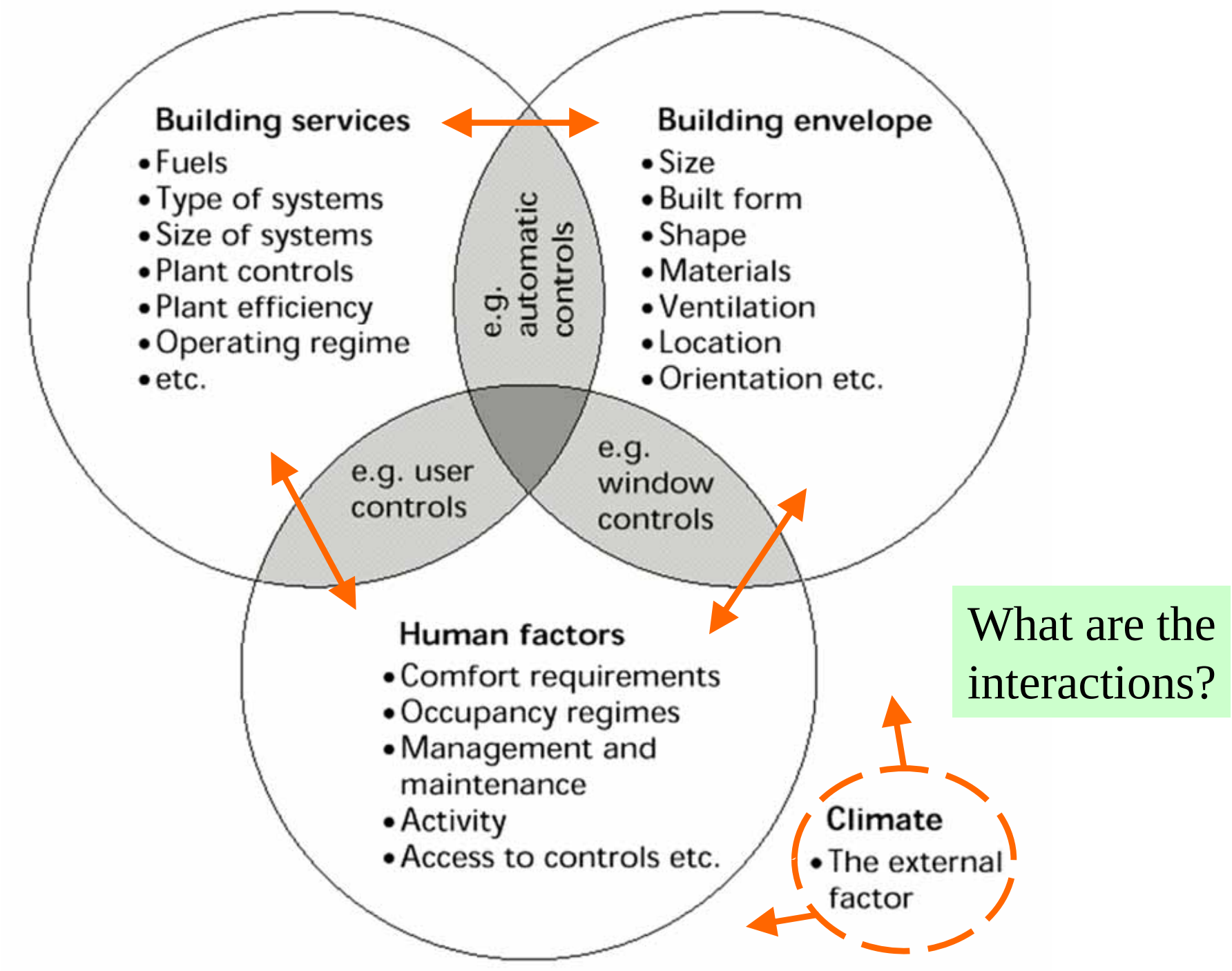


Imagine what effect if we have this when buying or renting a flat?

Would you like to have this?

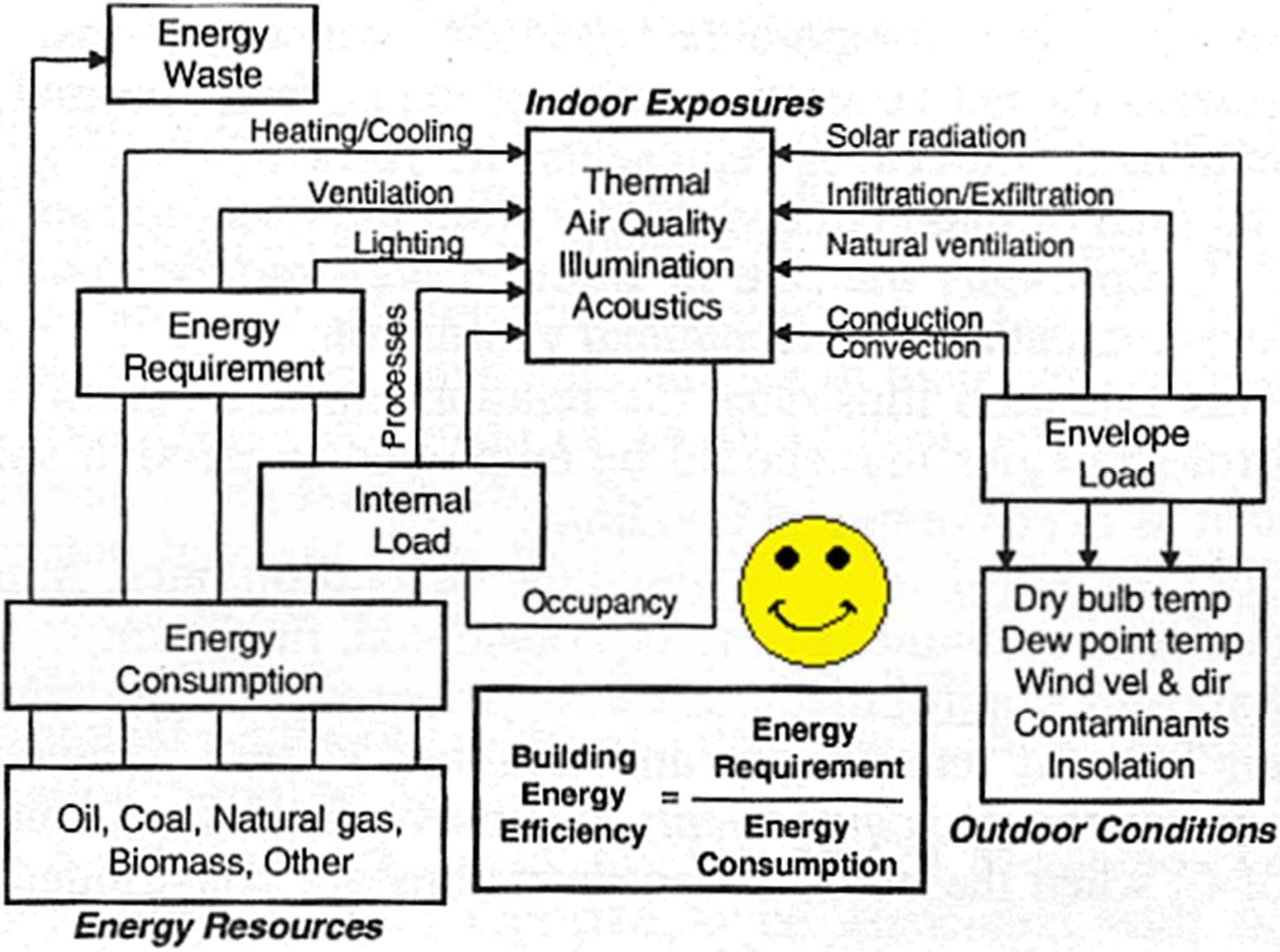
Energy use in buildings

- Possible benefits from energy efficiency:
  - Improved building design and operation
  - Better working environments
  - Life-cycle cost savings
  - Added market value of buildings
  - Reduced CO_2 emissions and consumption of finite fossil fuels
  - Reduced capital cost by better integration of building fabric and systems



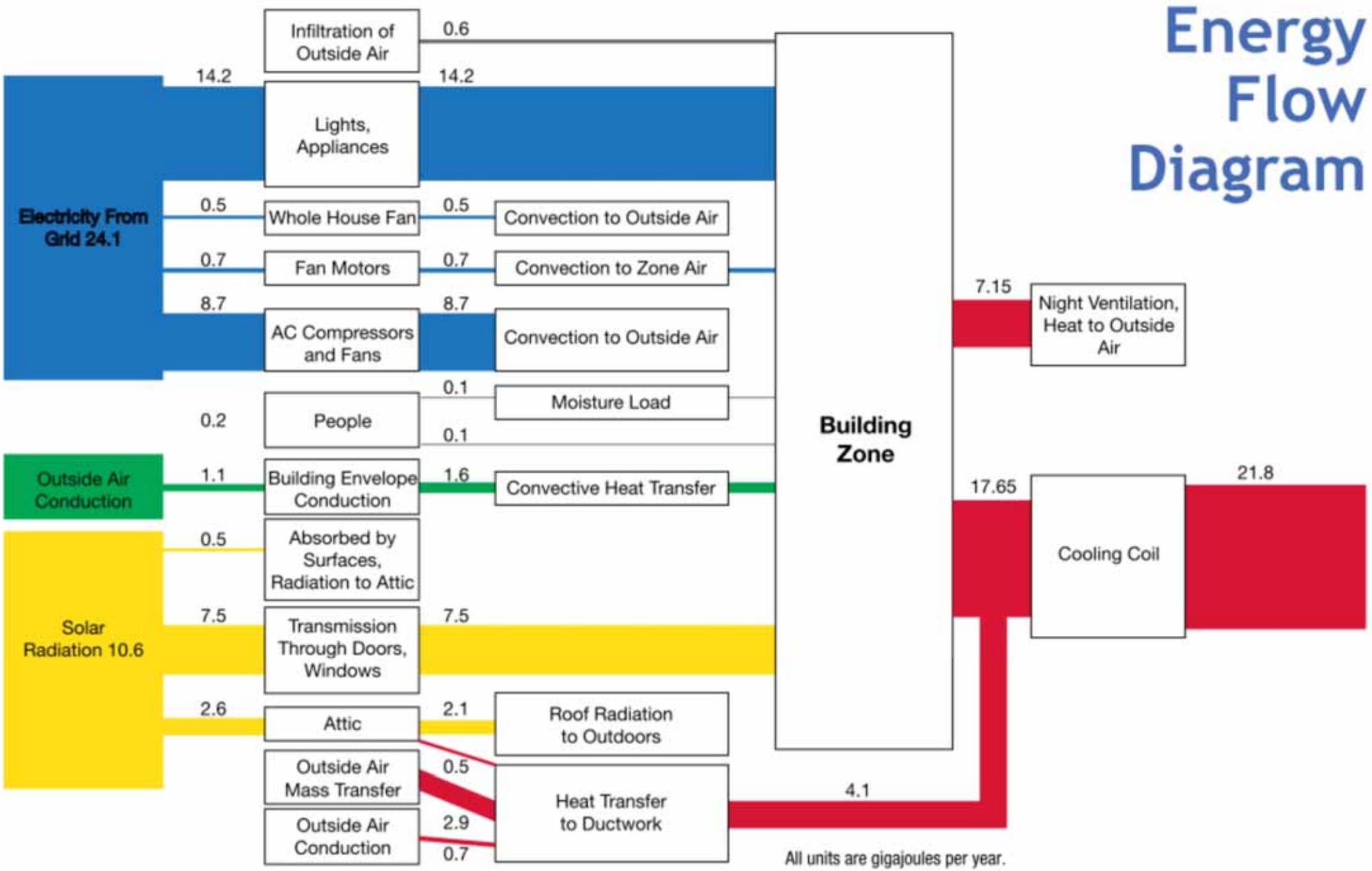
Key factors influencing energy consumption

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



Energy flow and concept in buildings

Energy flow in building



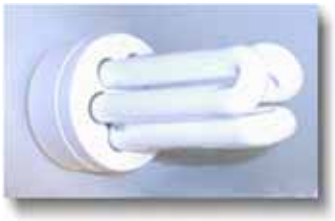
(Source: www.hompower.com)

Building Energy Efficiency

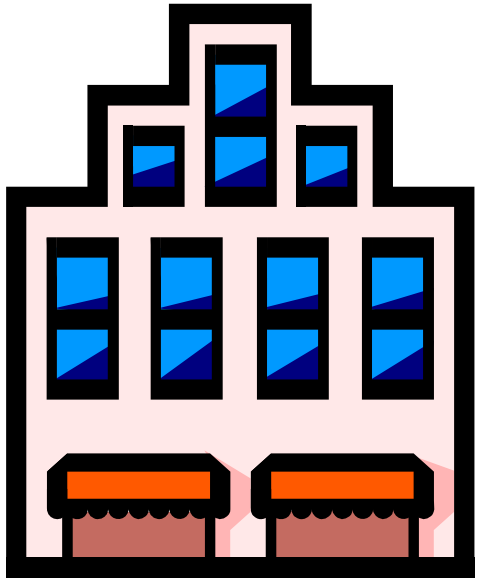
Building Energy Efficiency

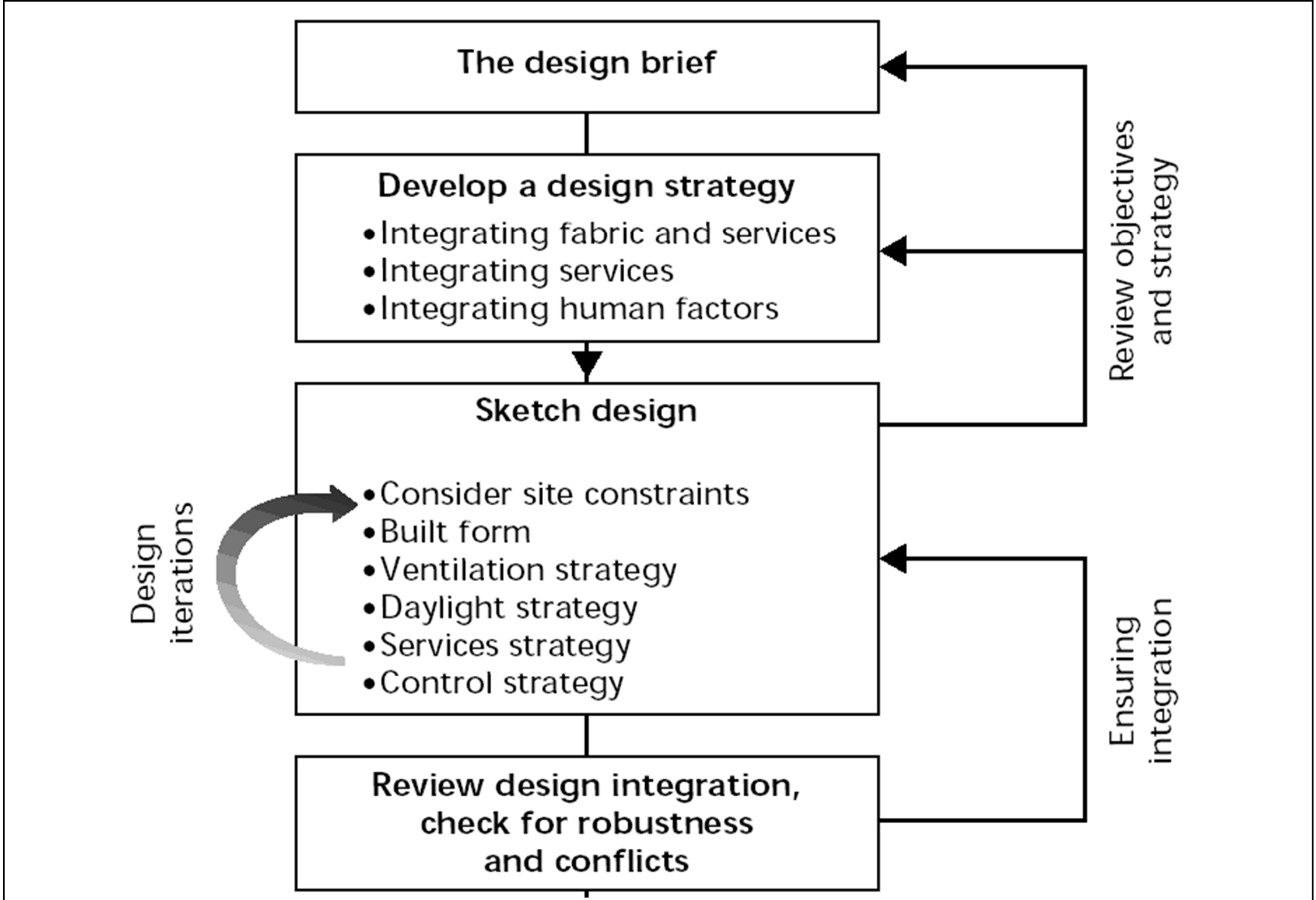
- "An energy efficient building provides the required internal environment and services with minimum energy use in a cost effective and environmentally sensitive manner." – *CIBSE Guide F: Energy Efficiency in Building*
  - Design energy efficient new buildings and refurbishment of existing buildings
  - Manage and operate buildings in an energy efficient way; Upgrade buildings to improve ongoing energy efficiency

Building Energy Efficiency

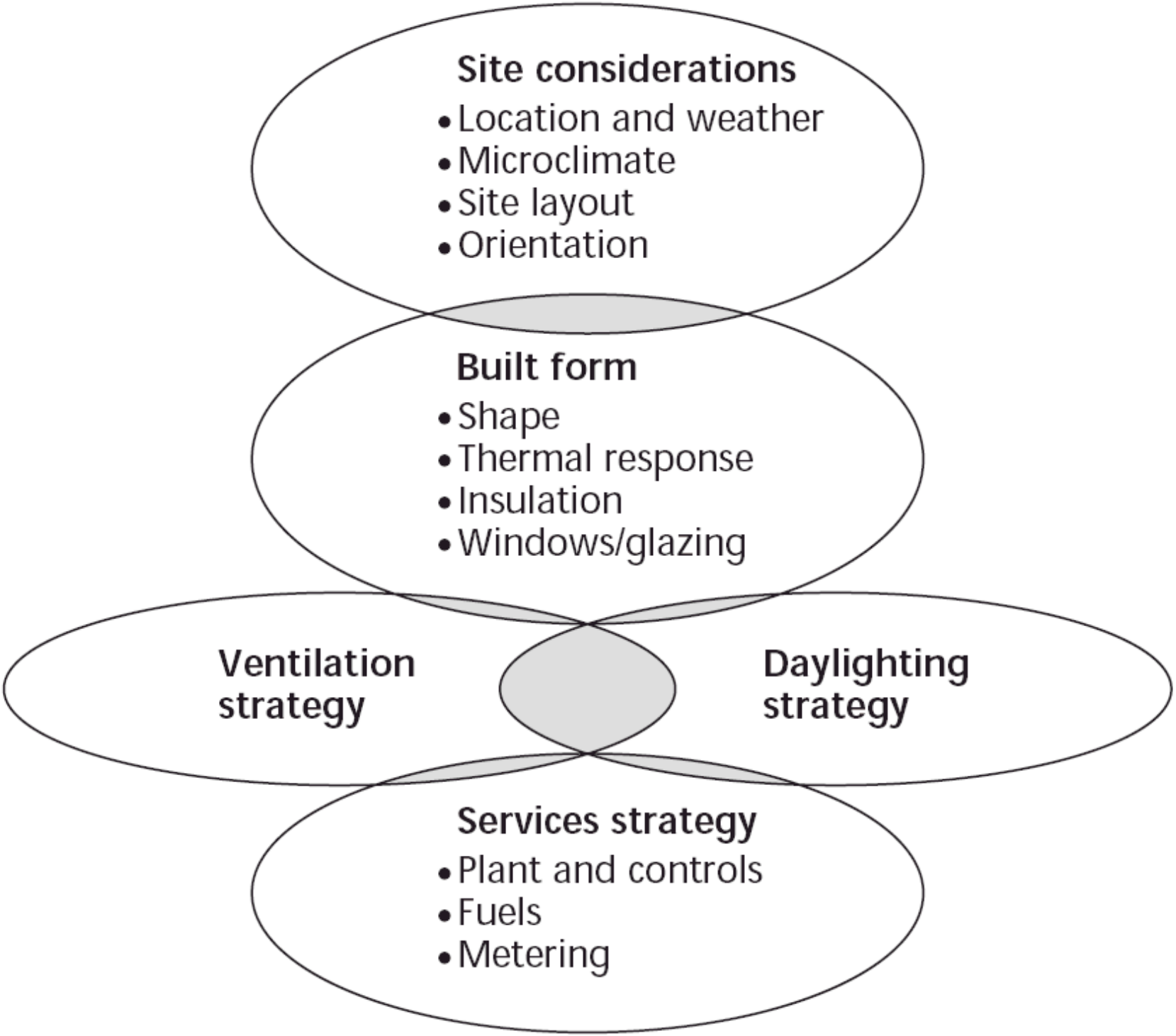


- For new buildings
  - Designing the building
    - Design strategy
    - Control strategies
    - Commissioning
- For existing buildings
  - Operating and upgrading the building
    - Building management
    - Refurbishment/renovation/retrofitting
    - Maintenance and monitoring



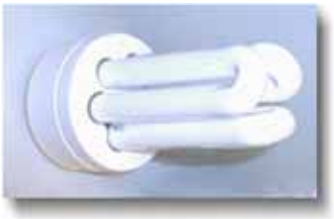


(Source: Energy Efficiency in Buildings: CIBSE Guide F)

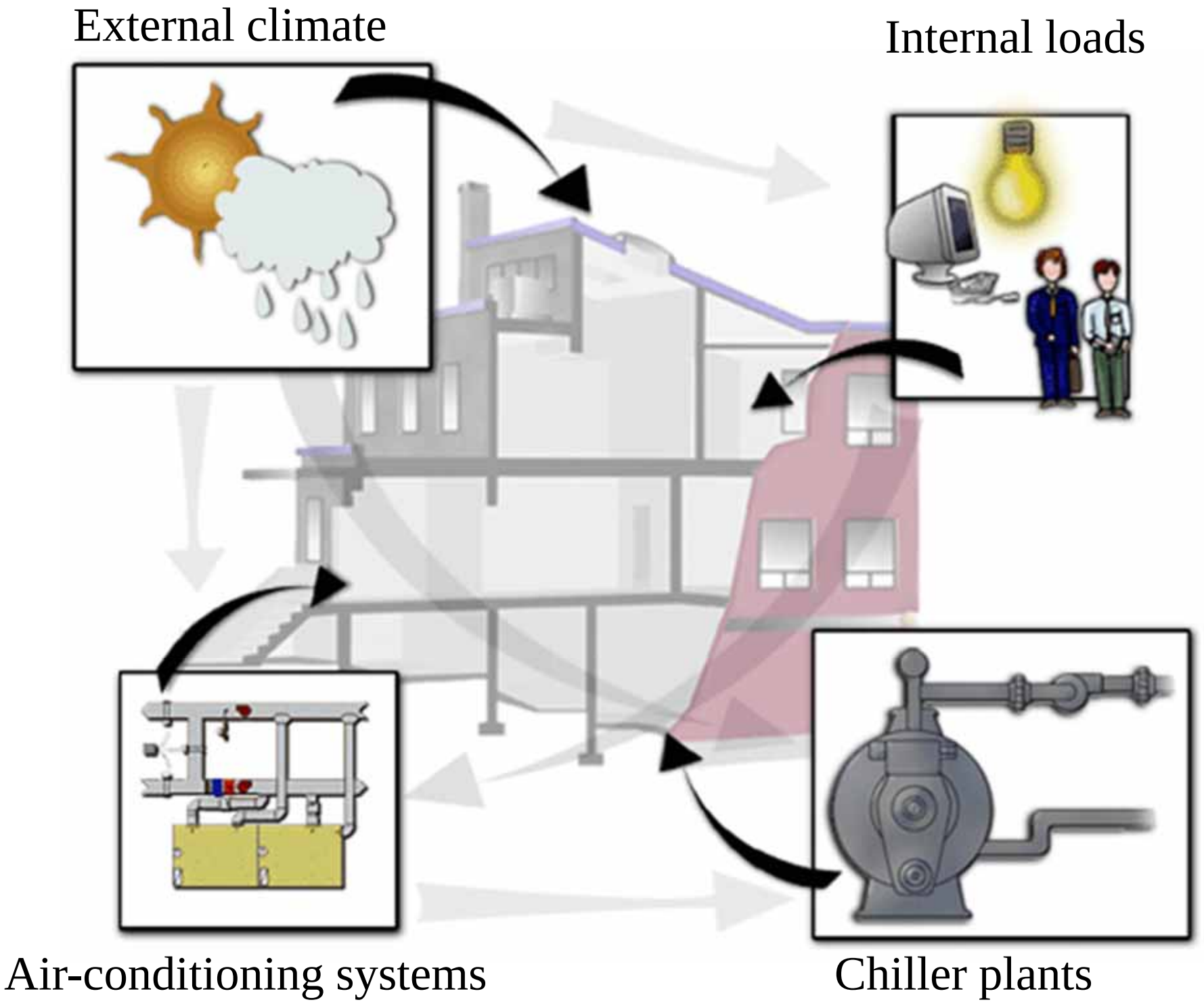


(Source: Energy Efficiency in Buildings: CIBSE Guide F)

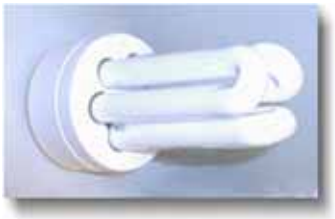
Building Energy Efficiency



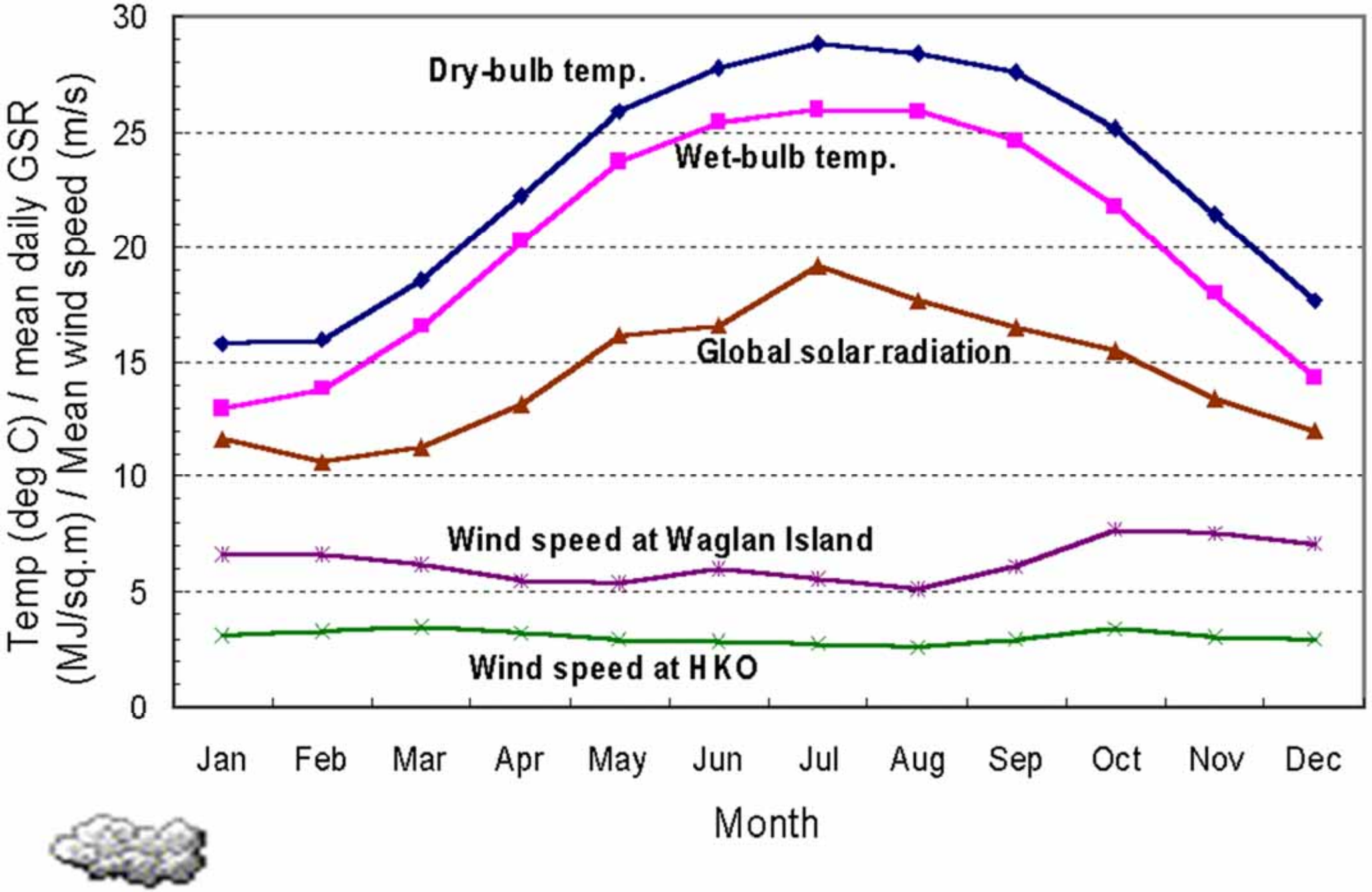
- Efficient use of energy
  - Reduce energy consumption
  - Optimise building's performance
- Major factors
  - Response to local climate (temp., humidity, solar)
  - Building envelope (skin) design
  - Building services systems
  - Human factors & building operation


External climate
Internal loads
Air-conditioning systems
Chiller plants

Building Energy Efficiency



- Climate
  - It has a major effect on building thermal and energy performance
- Response of a building to climate:
  - Thermal response of building structure
  - Response of HVAC and lighting systems
- Building design must “fit” its climate
  - Human comfort and bioclimatic design

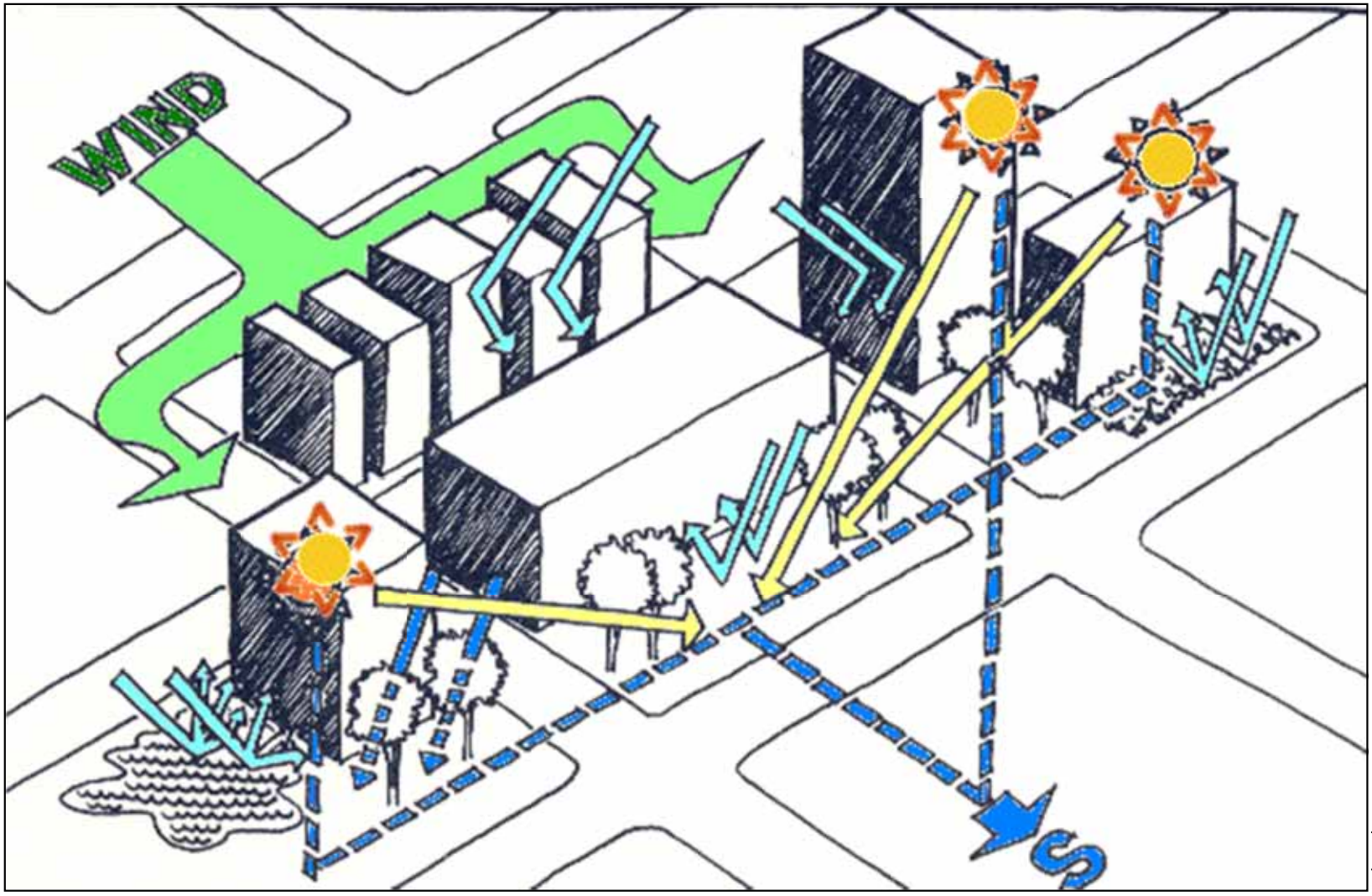


Major climatic elements of Hong Kong

Building designer is like a “Feng Shui” master.

風
Wind

光
Light

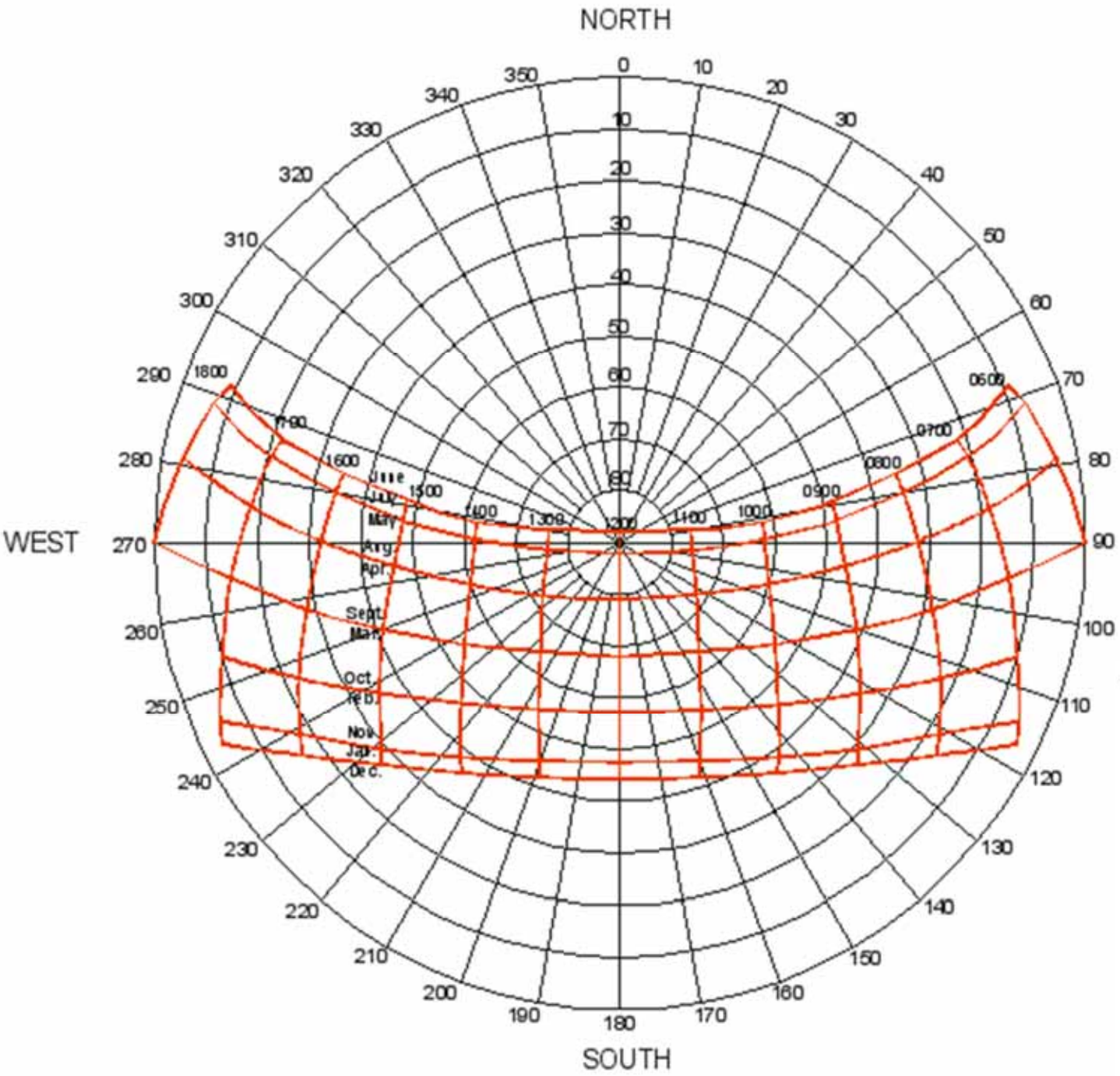


水
Water

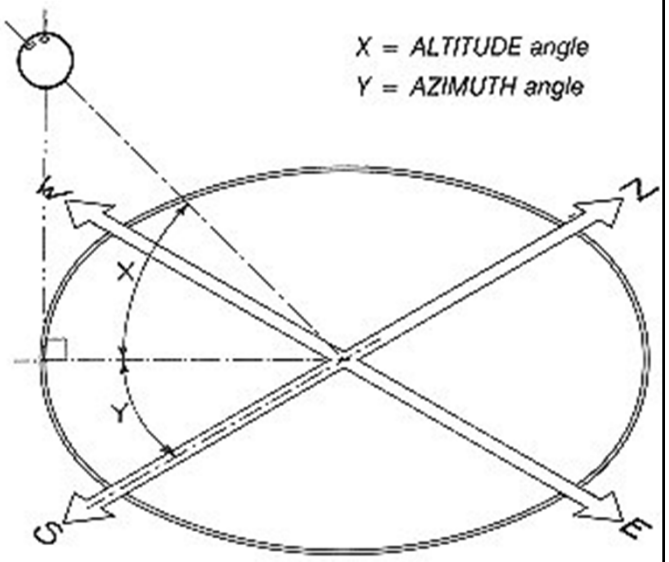
物
Matter

Major site factors

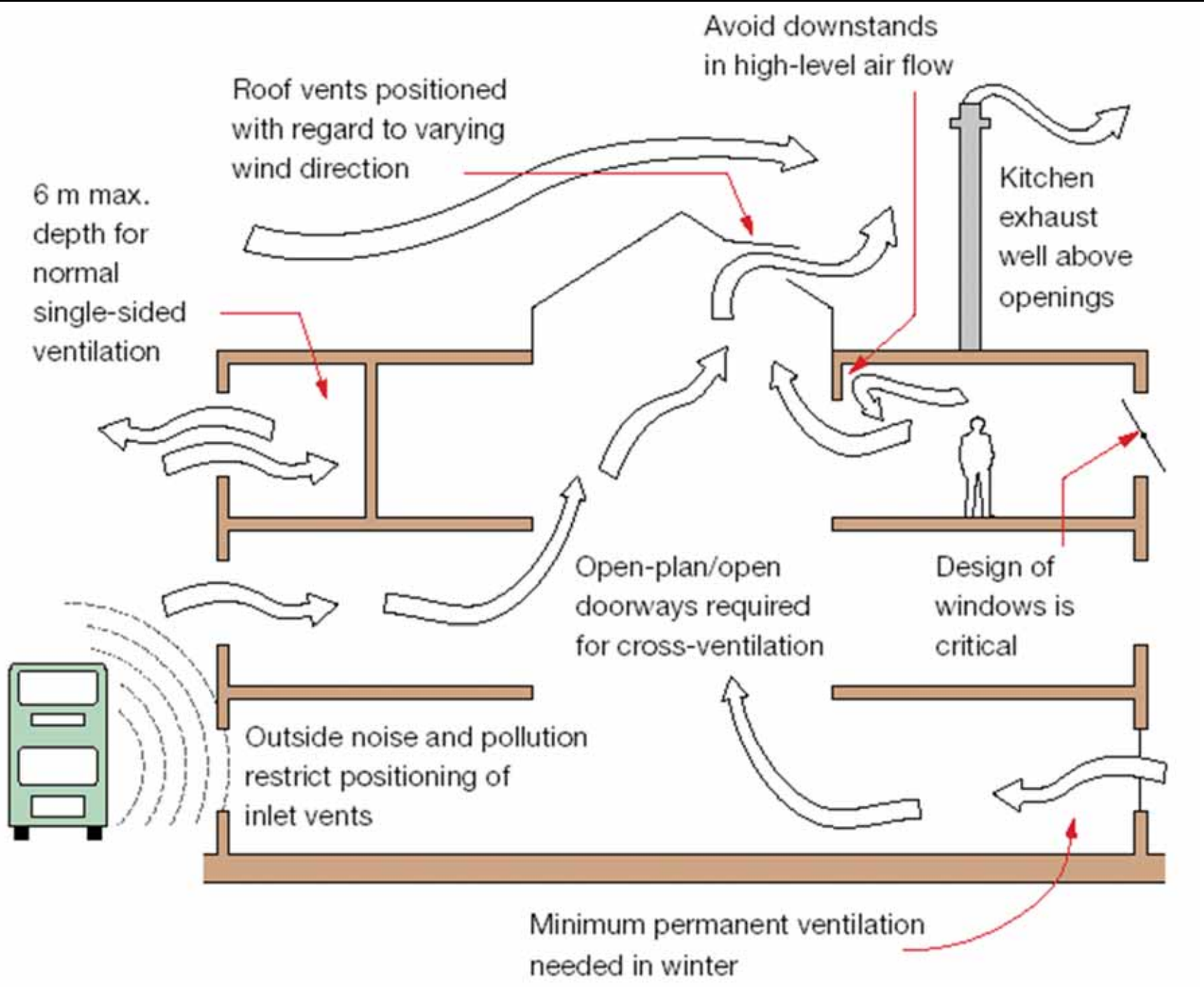
Sun path diagram for Hong Kong (latitude 22.3º)



How to find the sun's position?

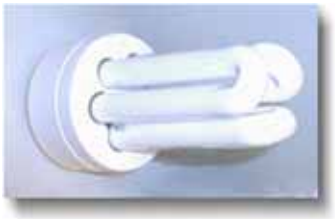


Solar Geometry

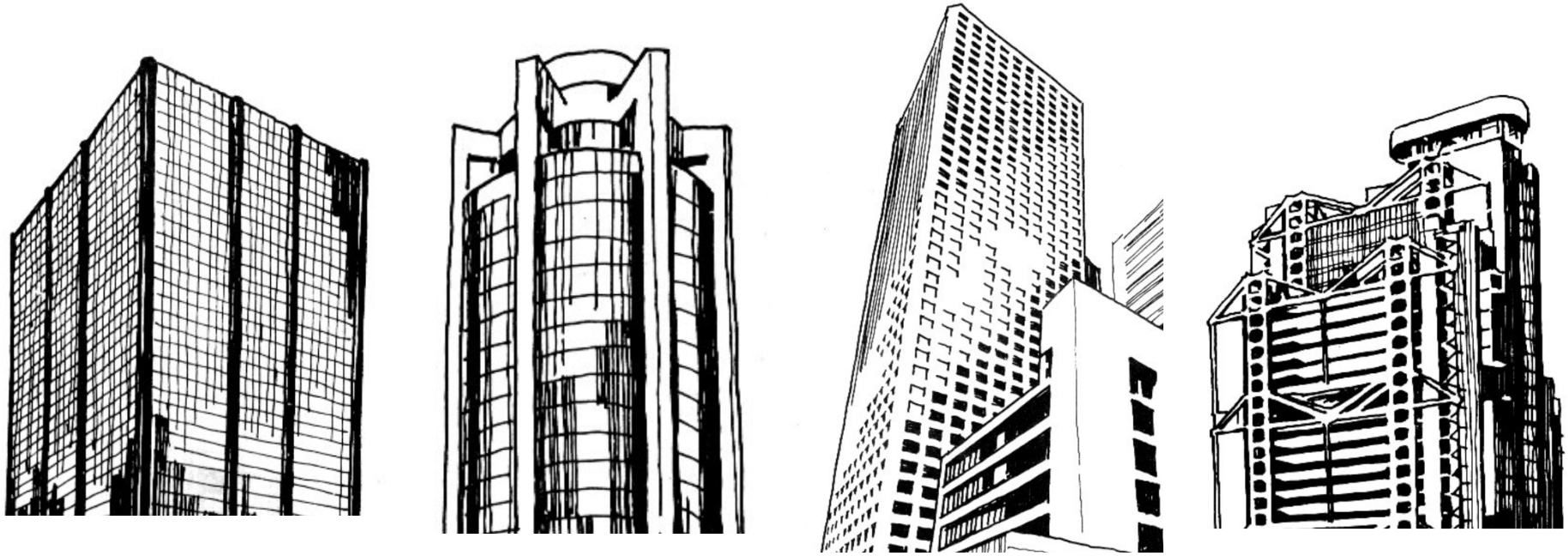


Modes of natural ventilation

Building Energy Efficiency



- Building envelope (or skin)
  - Walls, roofs, windows, skylights, etc.
    - Area, thermal properties, mass, shading
  - Good design
    - Consider & respond to local climate
    - Good thermal performance
    - Appropriate window areas
    - Proper solar control
  - Need to balance with other requirements e.g. aesthetics and view (connect to outside)



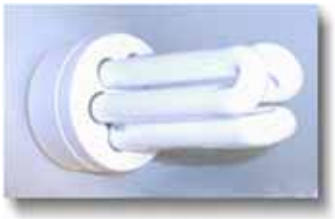
Building envelope designs of commercial buildings
in Hong Kong
(Which one is more energy efficient?)

Look at me.
Is my face (building envelope) energy efficient?

Main criteria:
- wall area
- window area
- thermal properties
- orientations
- thermal mass
- shading device

* Face House, Kyoto, Japan

Building Energy Efficiency

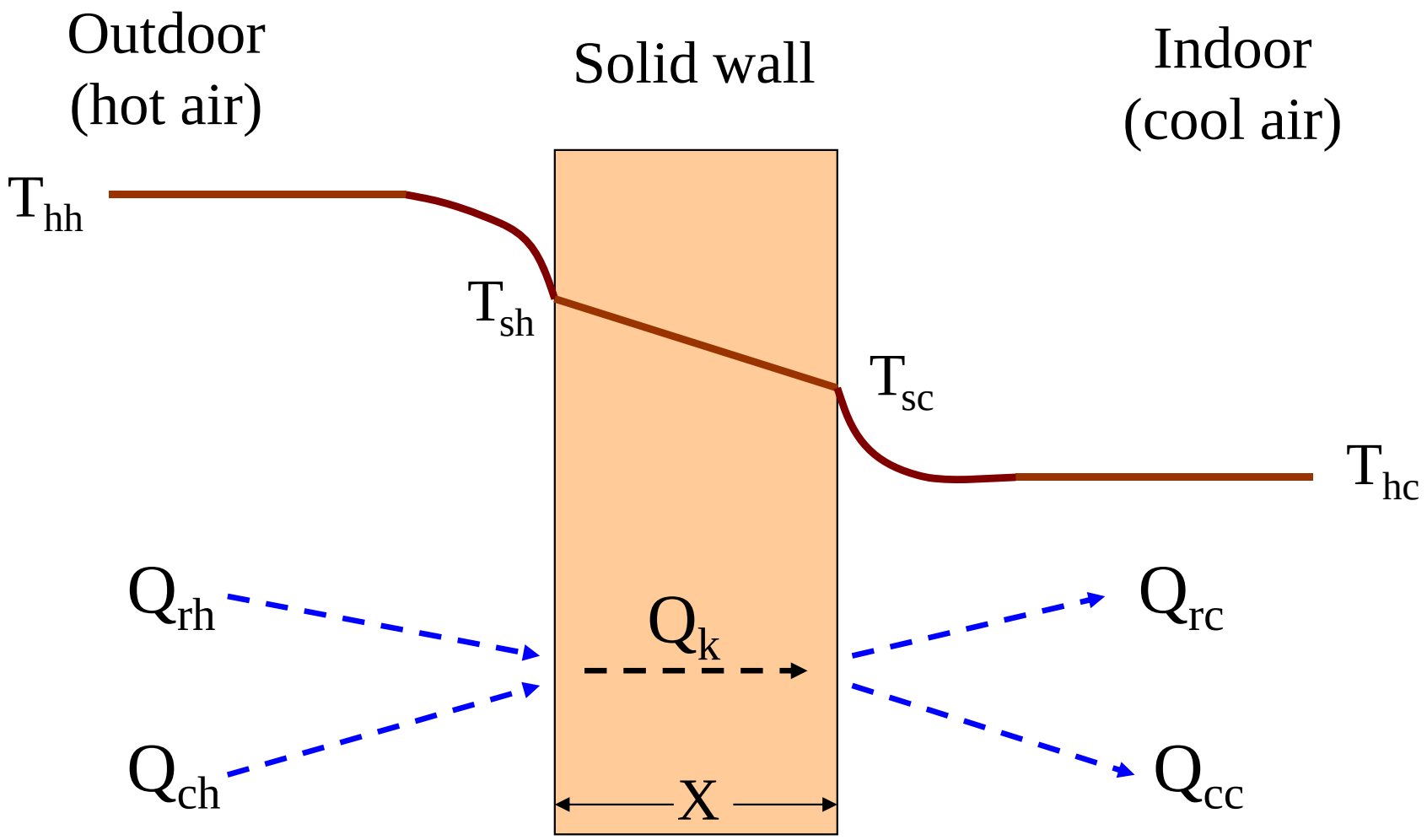


- Major factors determining envelope heat flow:
  - Temperature differential, ΔT
  - Area of exposed building surfaces, A
  - Heat transmission properties, like U-value
  - Thermal storage capacity

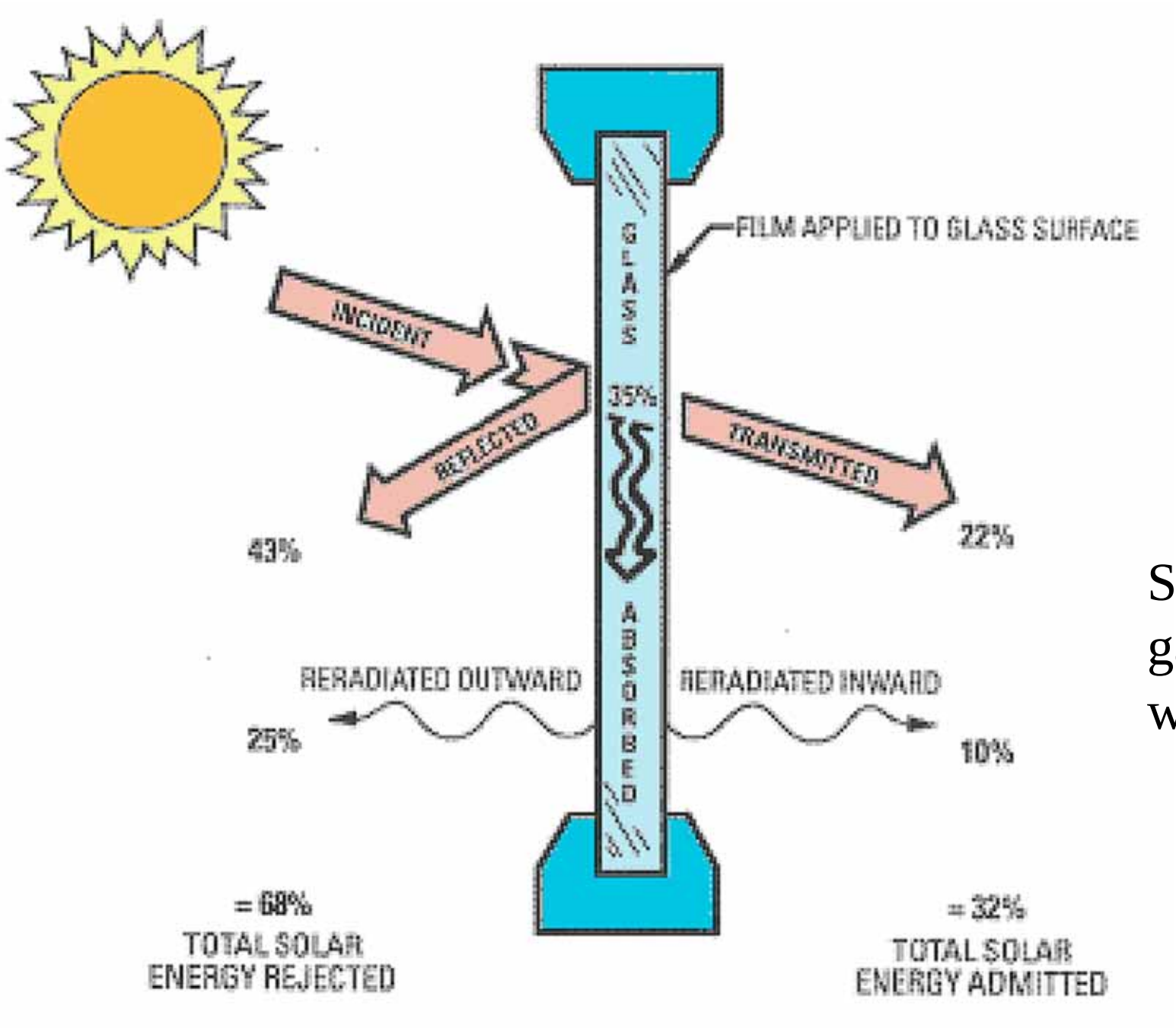
$$Q = U A \Delta T$$

- Effect of thermal mass
  - Delay heat transfer or act as a cooling source
  - Important for intermittently cooled spaces

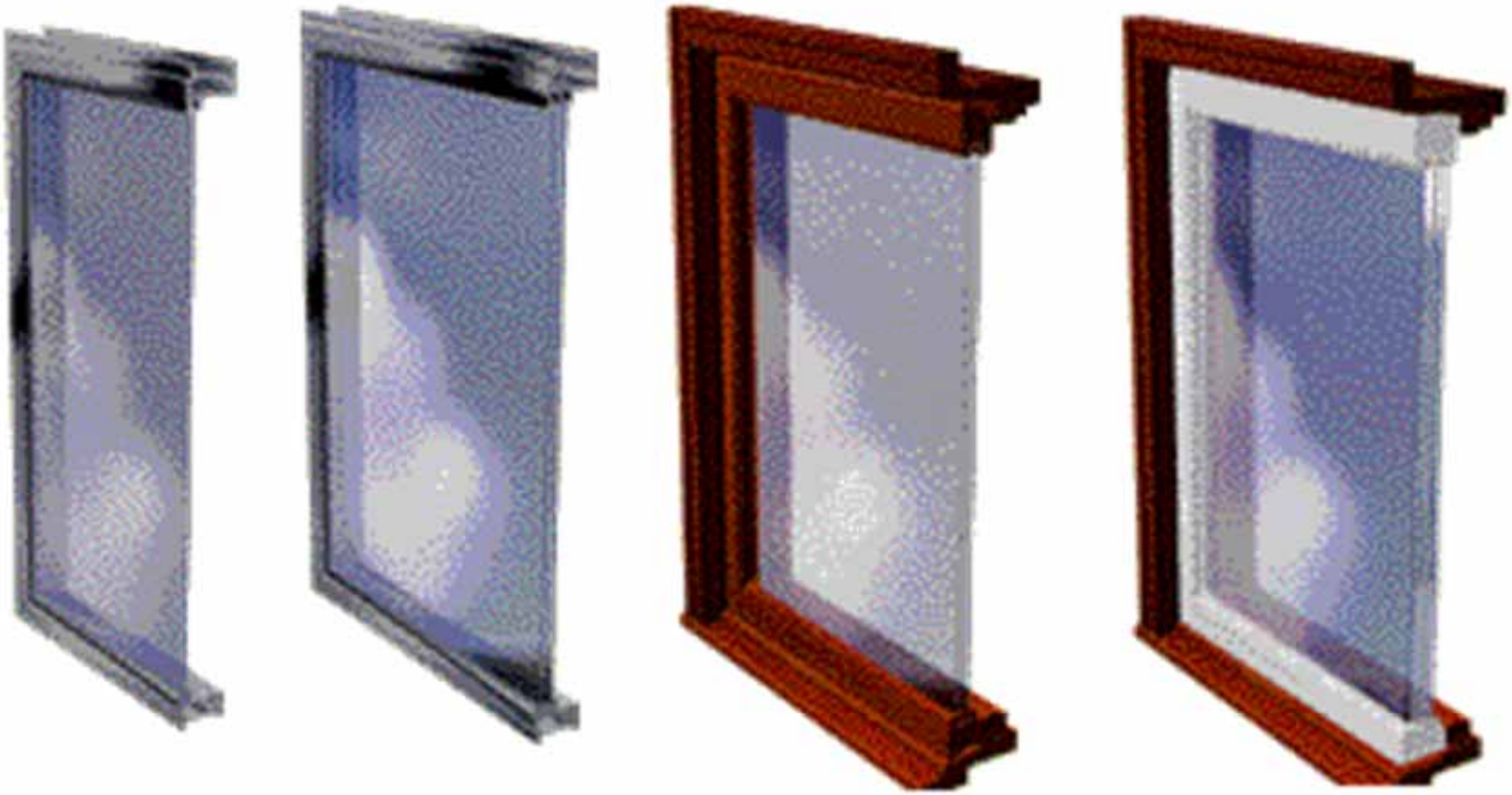
Thermal properties of building materials



$$Q = A \cdot U \cdot \Delta T$$



Solar heat gain through window glass

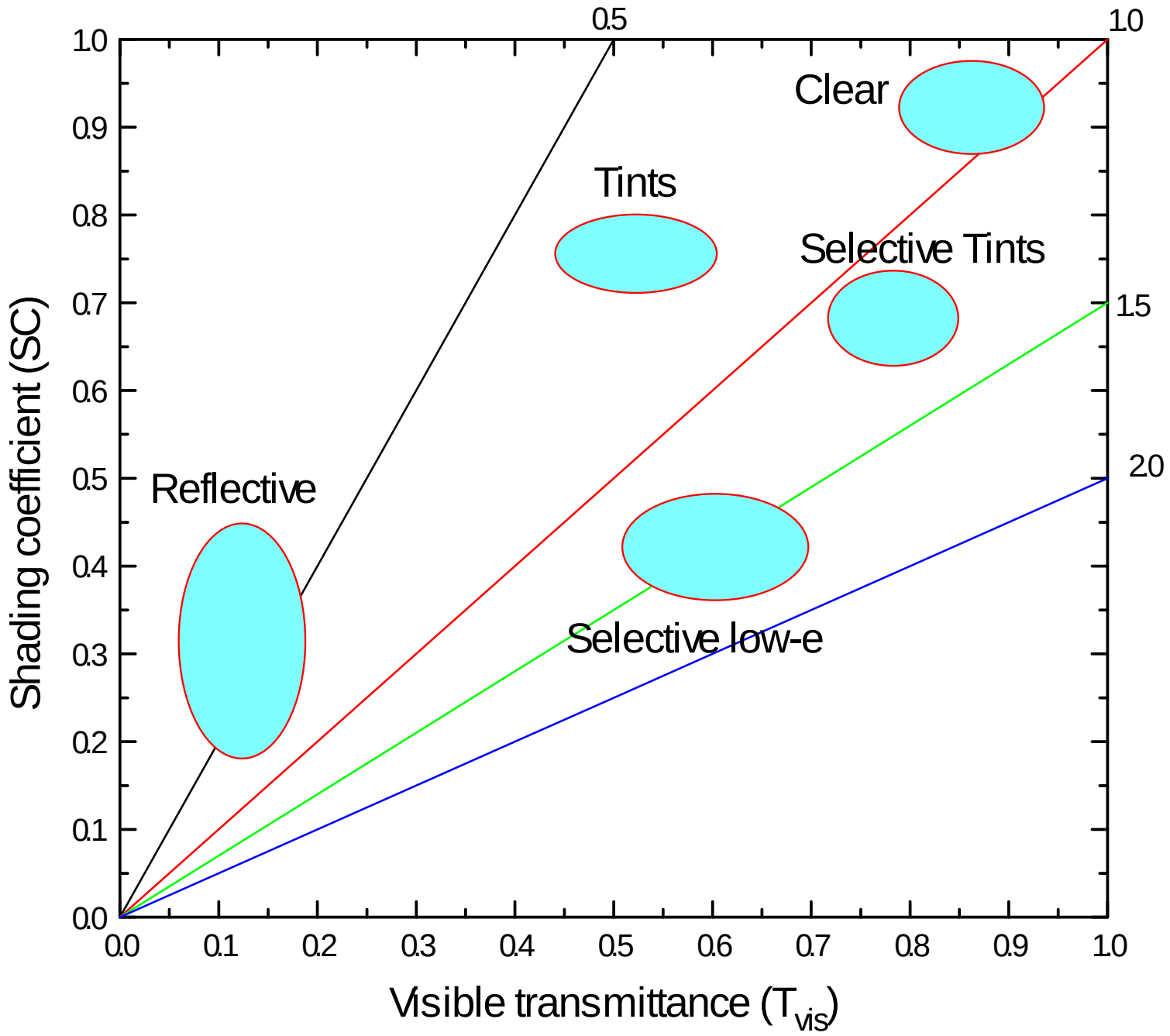


Single Glazed, Clear

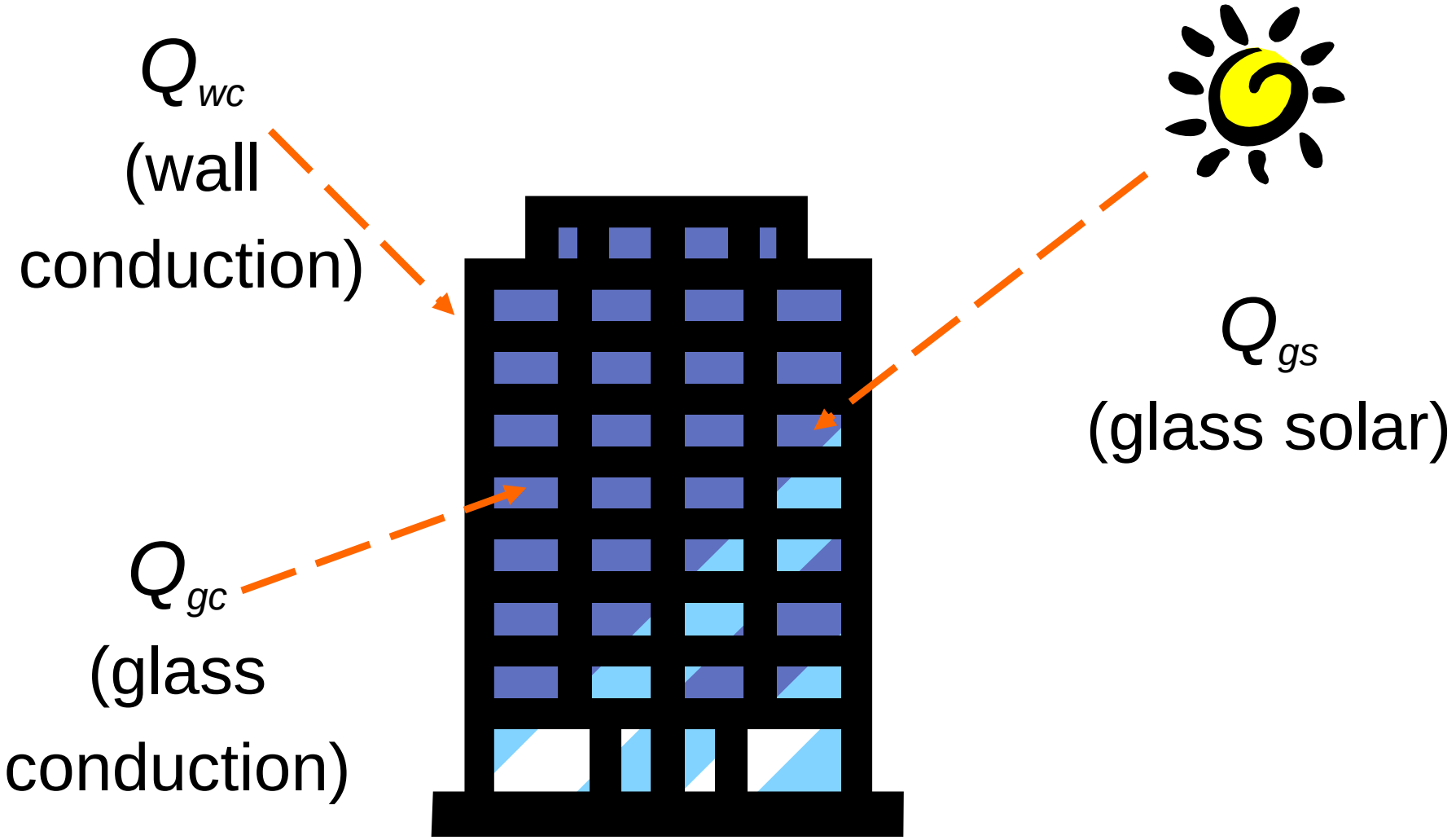
Double Glazed, Clear

Double Glazed, low-e

Triple Glazed, low-e



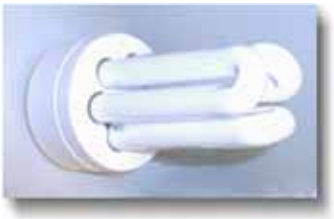
Properties of window glasses



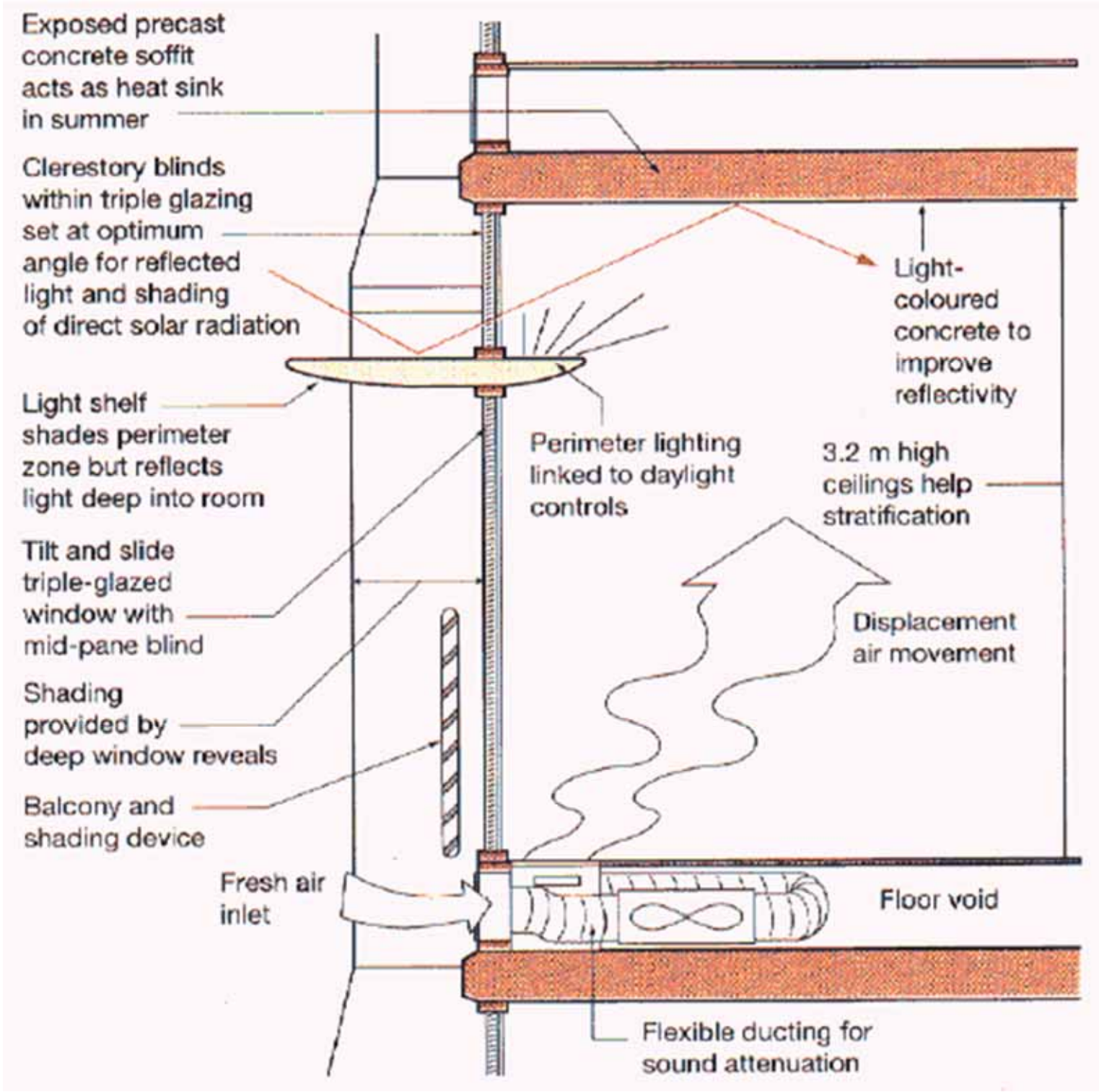
$$OTTV_i = \frac{Q_{wc} + Q_{gc} + Q_{gs}}{A_i}$$

$$= \frac{(A_w \cdot U_w \cdot TD_{eq}) + (A_f \cdot U_f \cdot DT) + (A_f \cdot SC \cdot SF)}{A_i}$$

Building Energy Efficiency

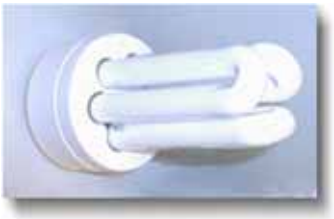


- Architects and Engineers work together to
  - Evaluate envelope performance at early stage
  - Select appropriate window design and materials
  - Design thermal insulation and building fabric
- Complicated issues with building envelope:
  - Dynamic behaviour of climate and building
  - Interaction of light and heat
  - Use of daylighting and solar energy systems

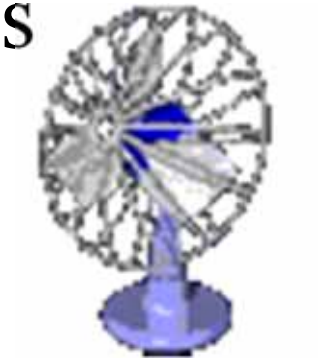


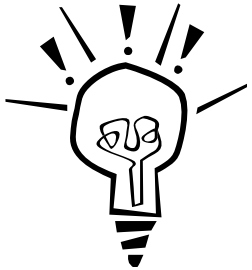
Integrated façade design

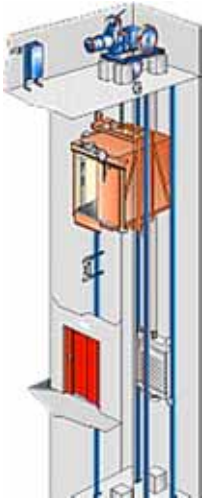
Building Energy Efficiency

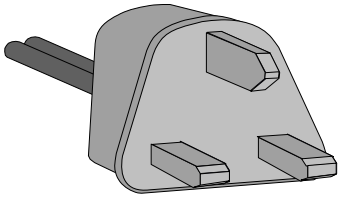


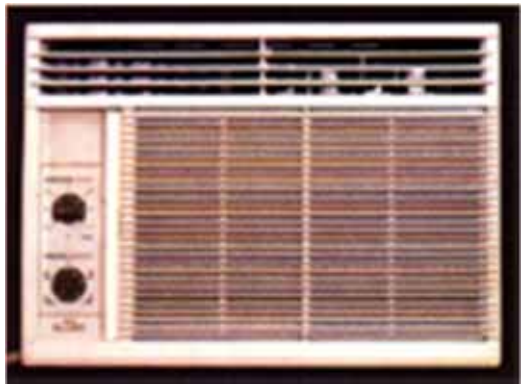
- Building services systems
  - Air-conditioning
  - Lighting
  - Electrical services
  - Lifts & escalators
  - Plumbing & drainage
  - Town gas supply
  - Building management





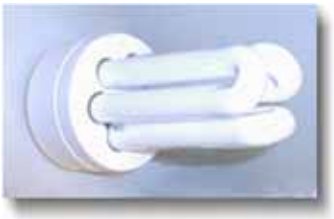




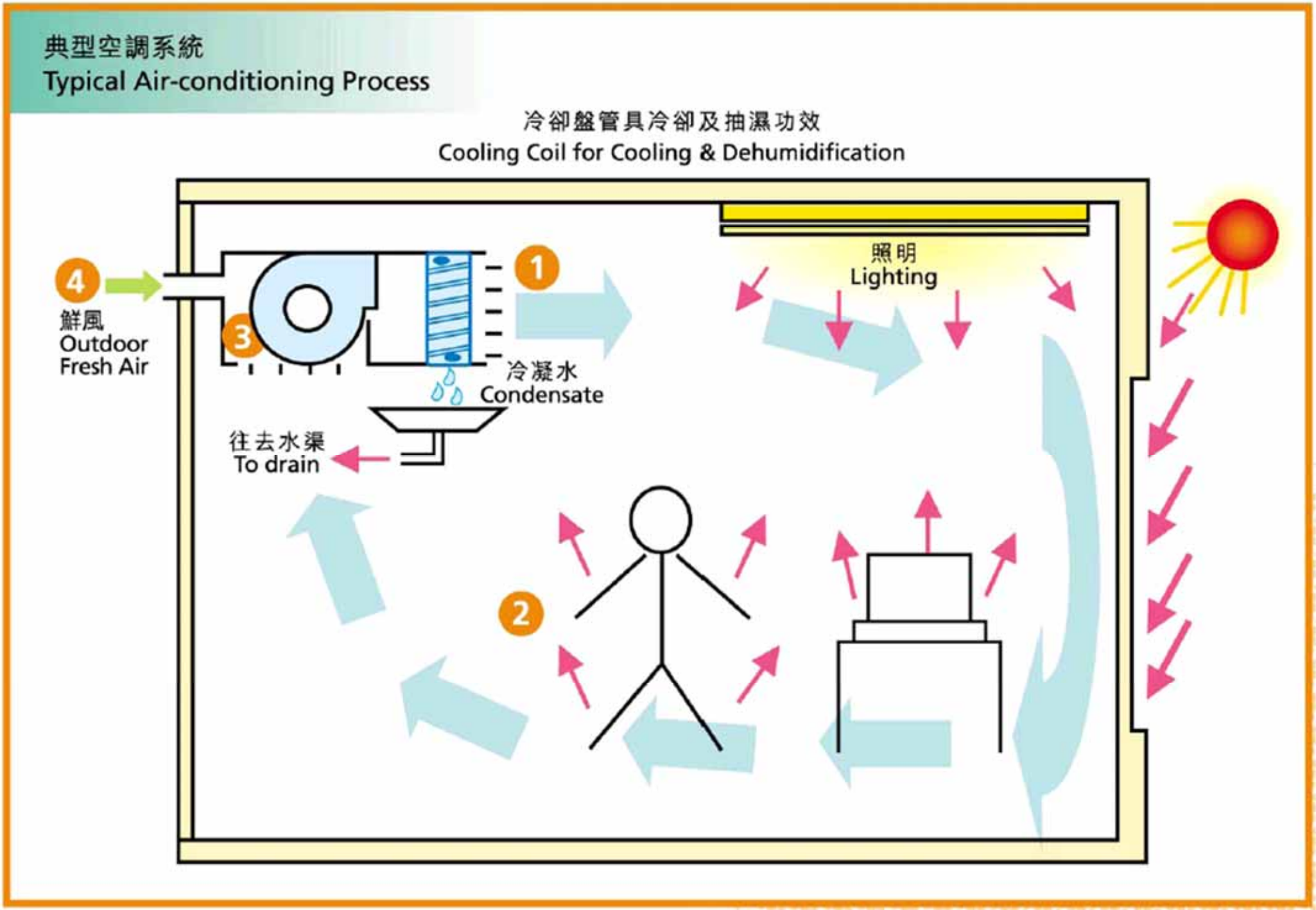


Energy label for appliances and equipment

Building Energy Efficiency

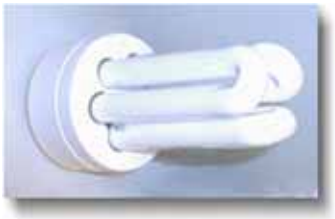


- Heating, ventilating & air-conditioning (HVAC) systems
  - Usually the most important energy users
  - Provide for occupant comfort, health and safety
  - HVAC design is affected by architectural features and occupant needs
- In Hong Kong, heating load is small and main focus is on air-conditioning or cooling energy use

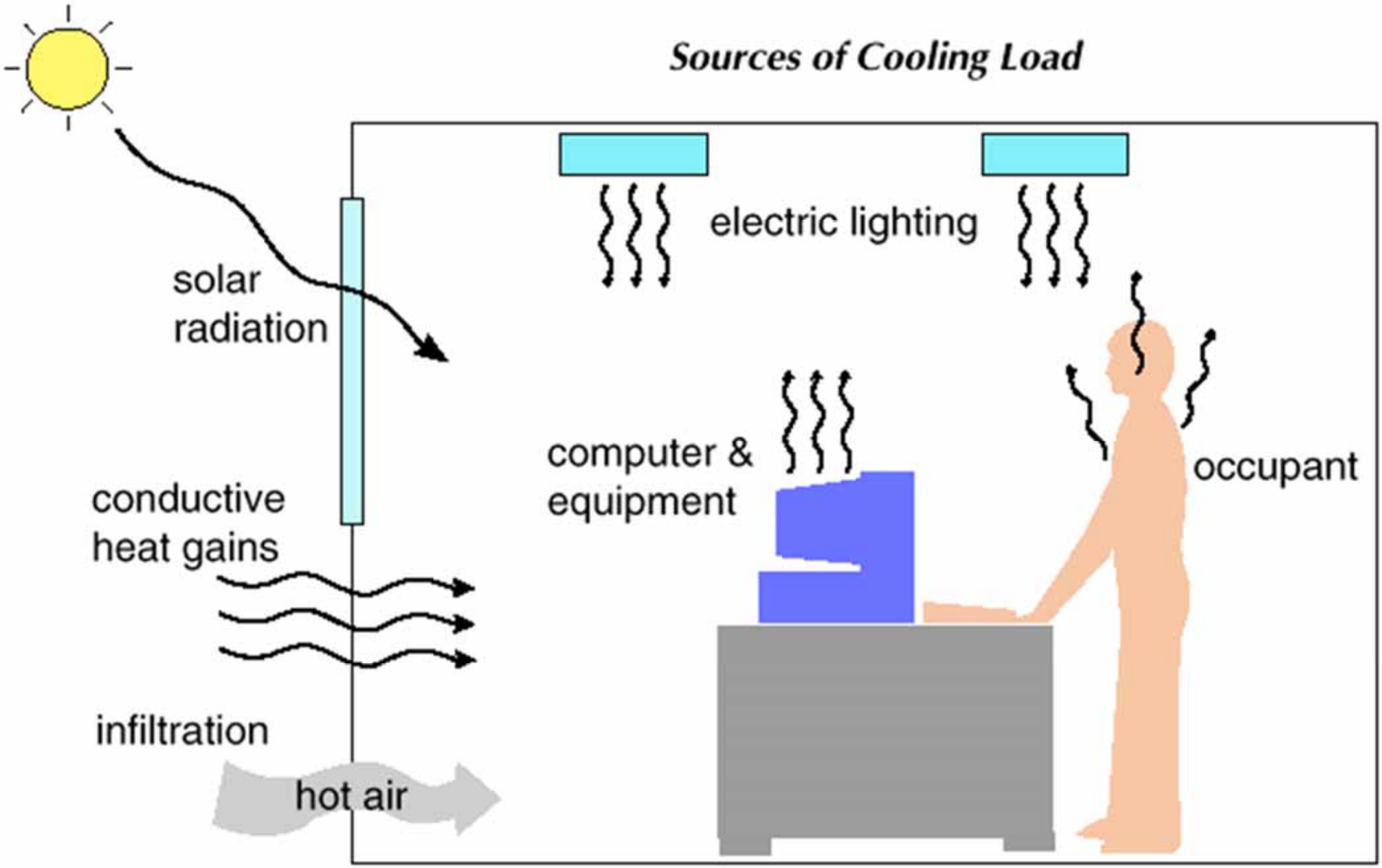


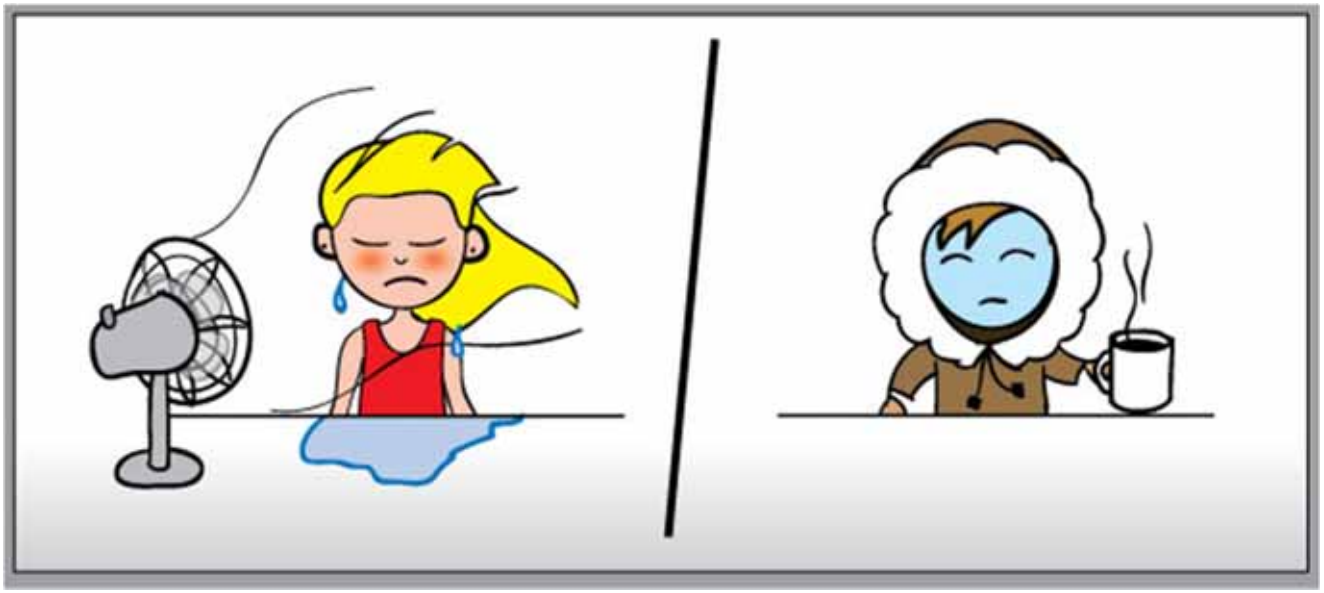
(Source: EnergyWitts newsletter, EMSD)

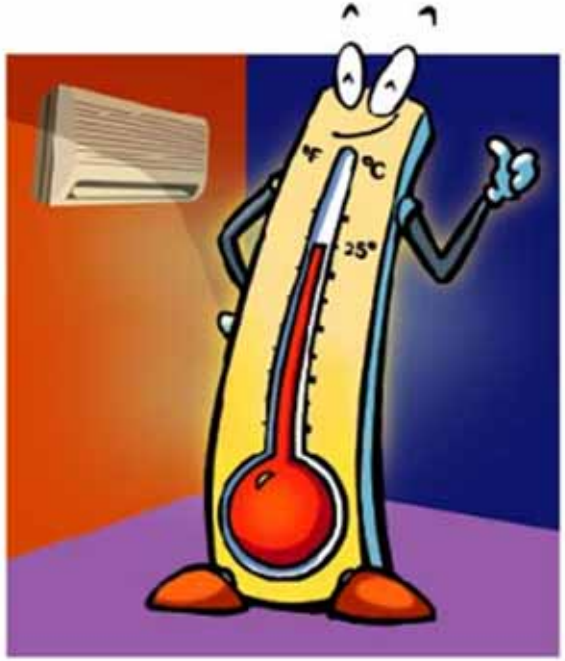
Building Energy Efficiency



- Strategies for achieving energy efficiency
  - Reduce heat load in the air-conditioned spaces
  - Promote natural cooling or ceiling fans, prior to using mechanical cooling
  - Adopt “relaxed dress code” and flexible work schedule, wherever possible
  - Ensure good house-keeping and user education
- Avoid wastage of energy by proper use of air-conditioning and suitable temperature setpoint


Sources of Cooling Load
electric lighting
solar
radiation
computer &
equipment
occupant
conductive
heat gains
infiltration
hot air





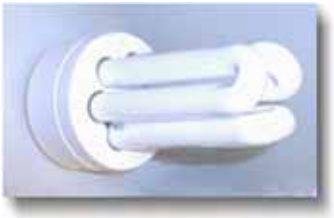
Just nice at 25°C

Electricity Efficiency Centre

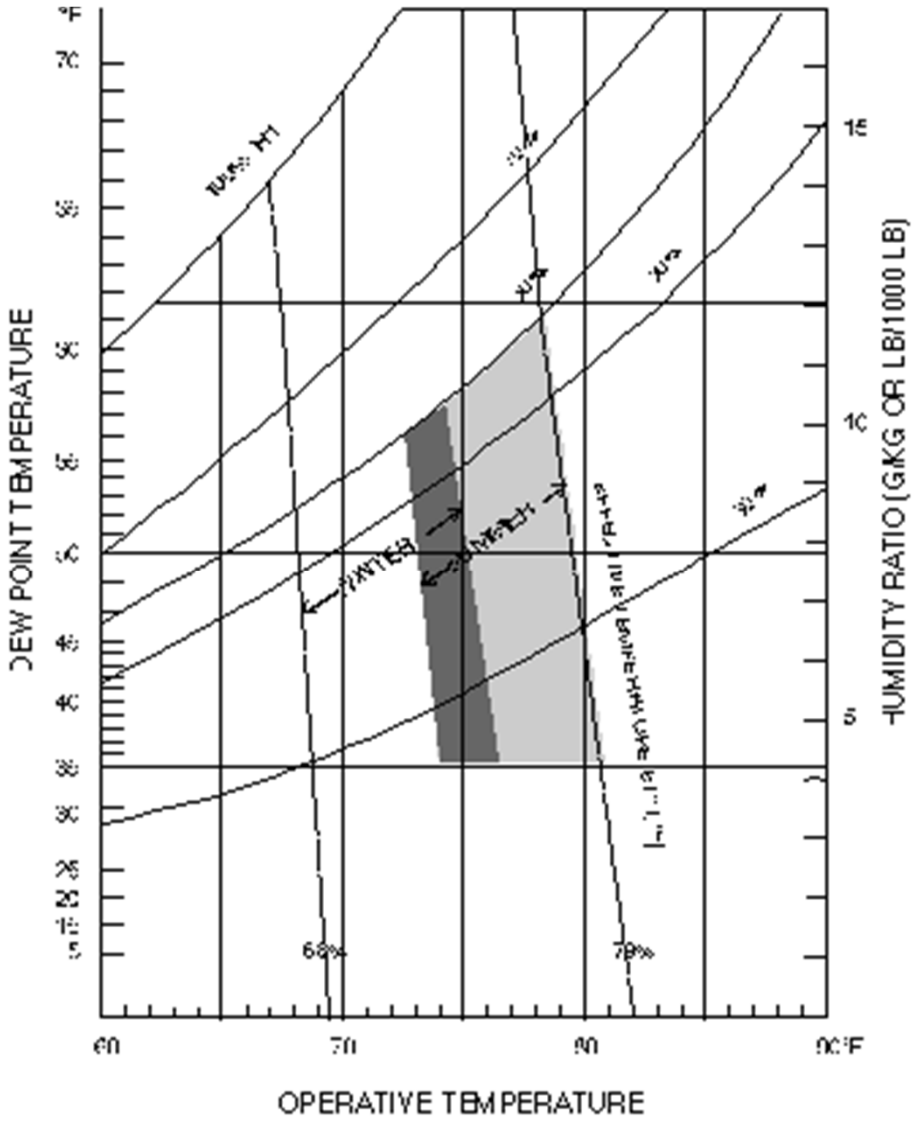
Cleaner filter filters better.

Electricity Efficiency Centre

Building Energy Efficiency

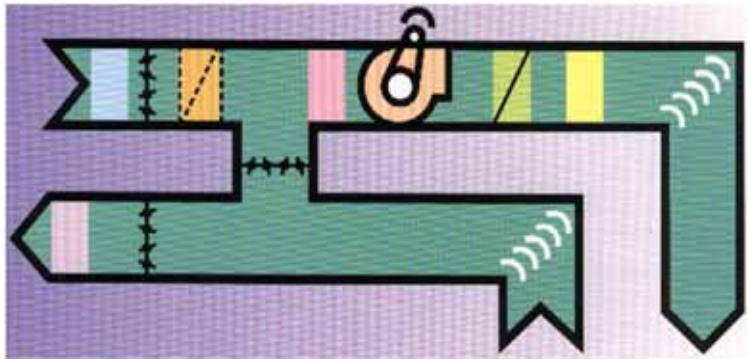


- Key issues for energy efficient HVAC:
  - Thermal comfort criteria
    - Proper design temperature, humidity
  - System characteristics
    - Types, energy efficiency ratios, operation & control
  - Equipment and plant operation
    - Especially during partload conditions

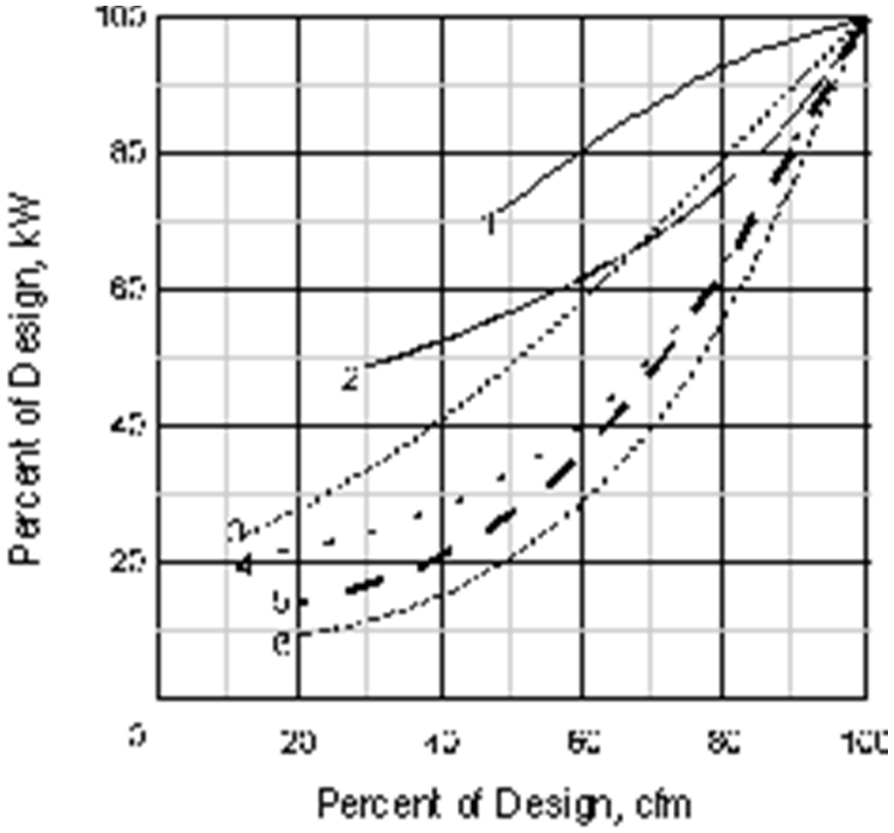


ASHRAE comfort envelope

Thermal comfort & design conditions

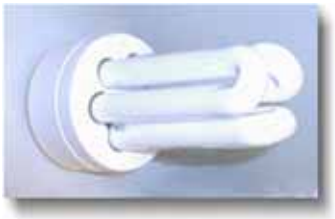


HVAC system and plant

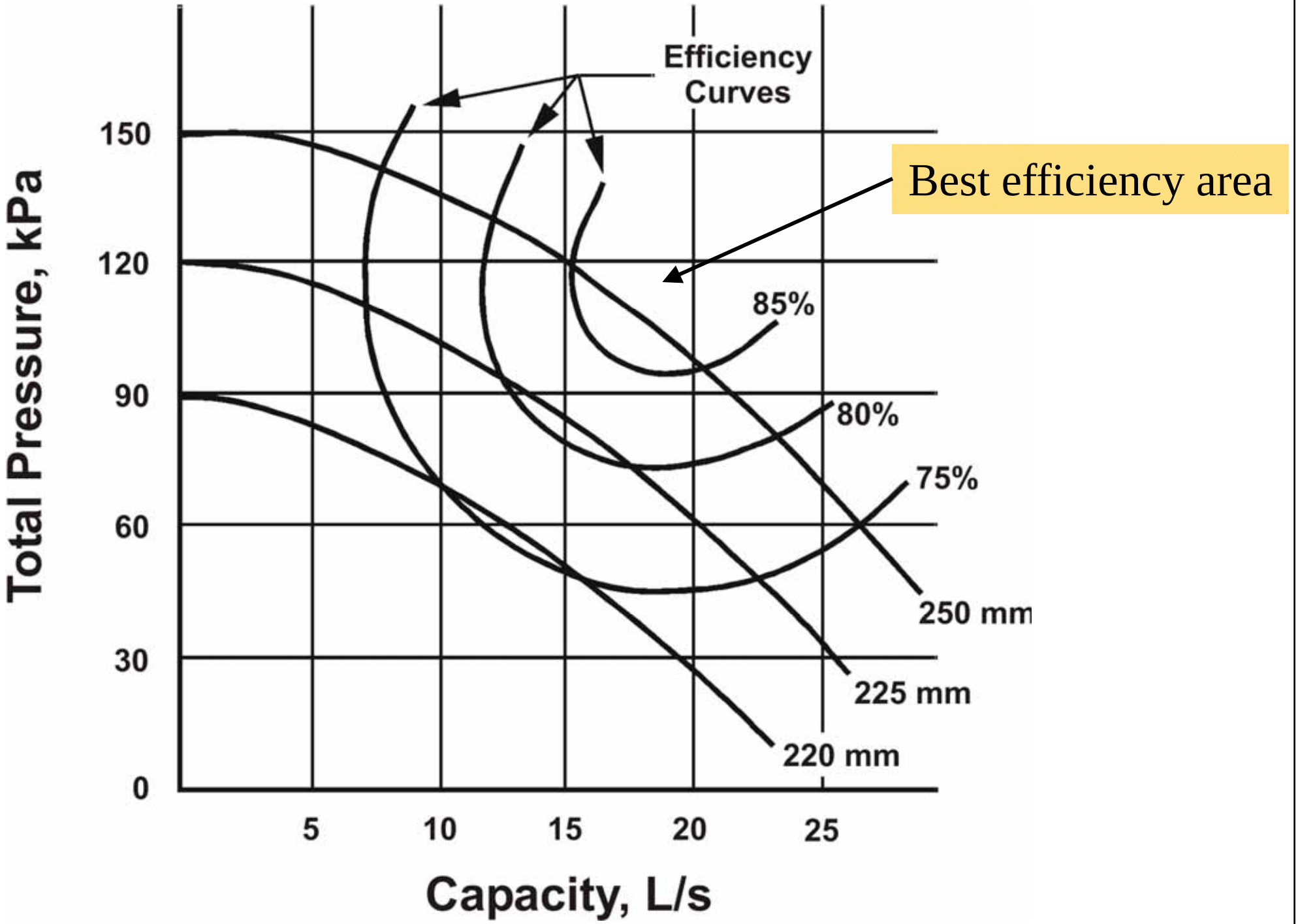


Partload curves for fans

Building Energy Efficiency

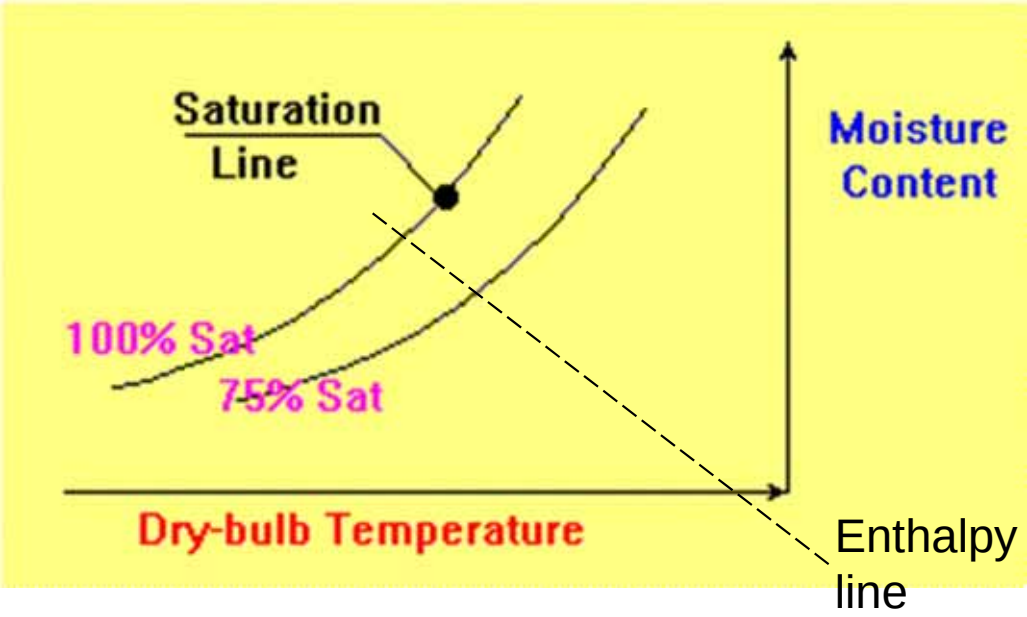


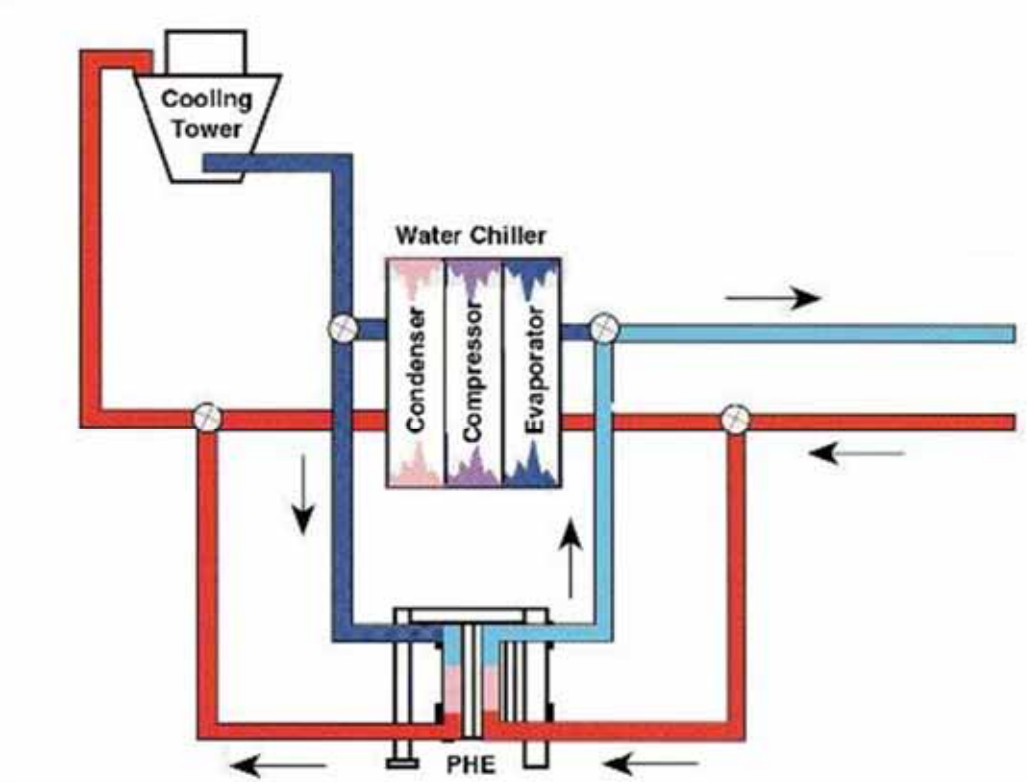
- HVAC energy efficiency can be improved by:
  - Effective zoning and space design
  - Correct sizing and selection of equipment
  - Proper operation and maintenance
  - Better control and monitoring
  - Energy awareness of occupants/building managers
- Good house-keeping and education
  - A very important factor which is often overlooked



Pump efficiency curve

(Source: *Fundamentals of Water System Design*)

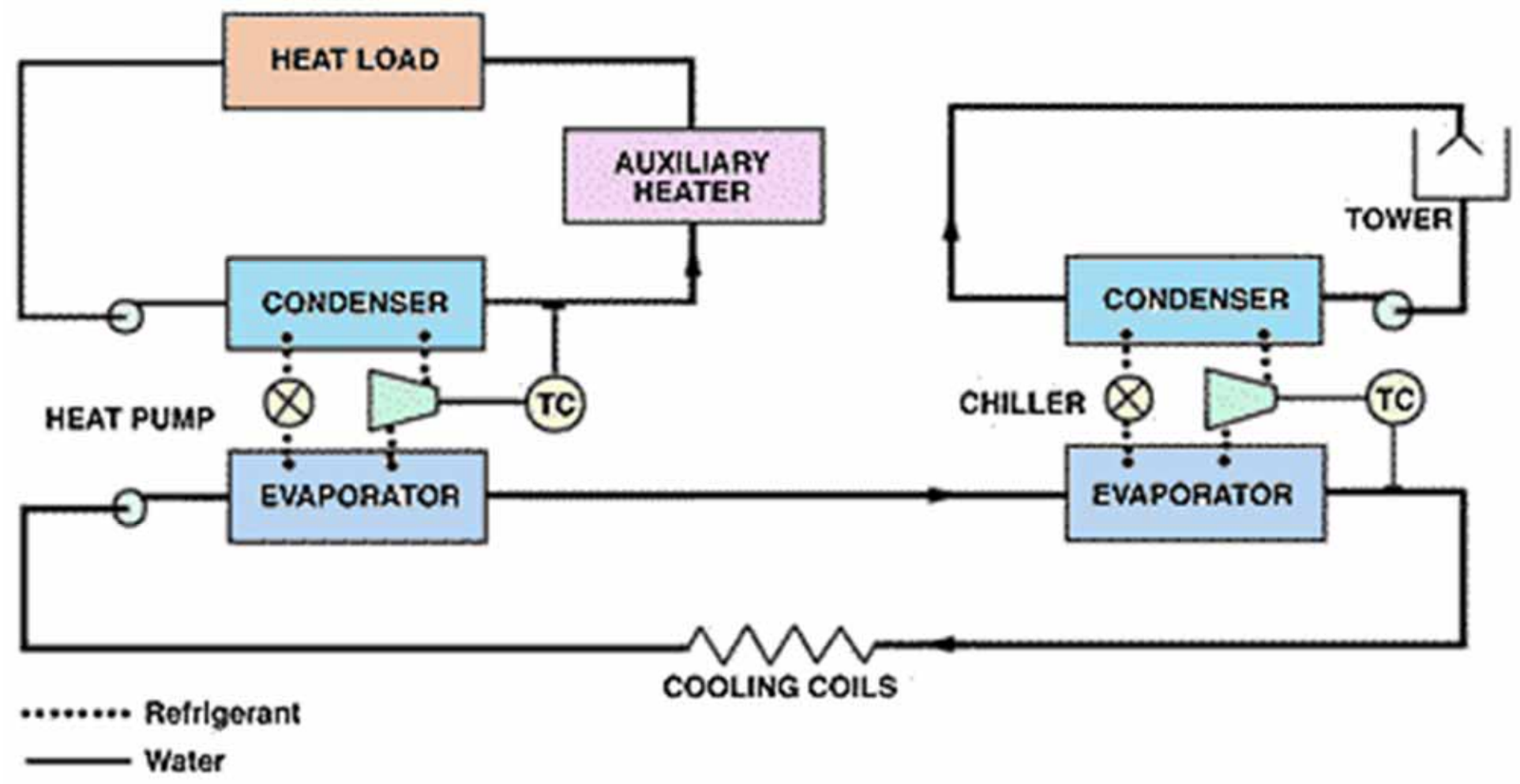




(a) Air-side economiser cycle
- intake more outdoor air when its enthalpy (energy content) is lower than indoor air

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

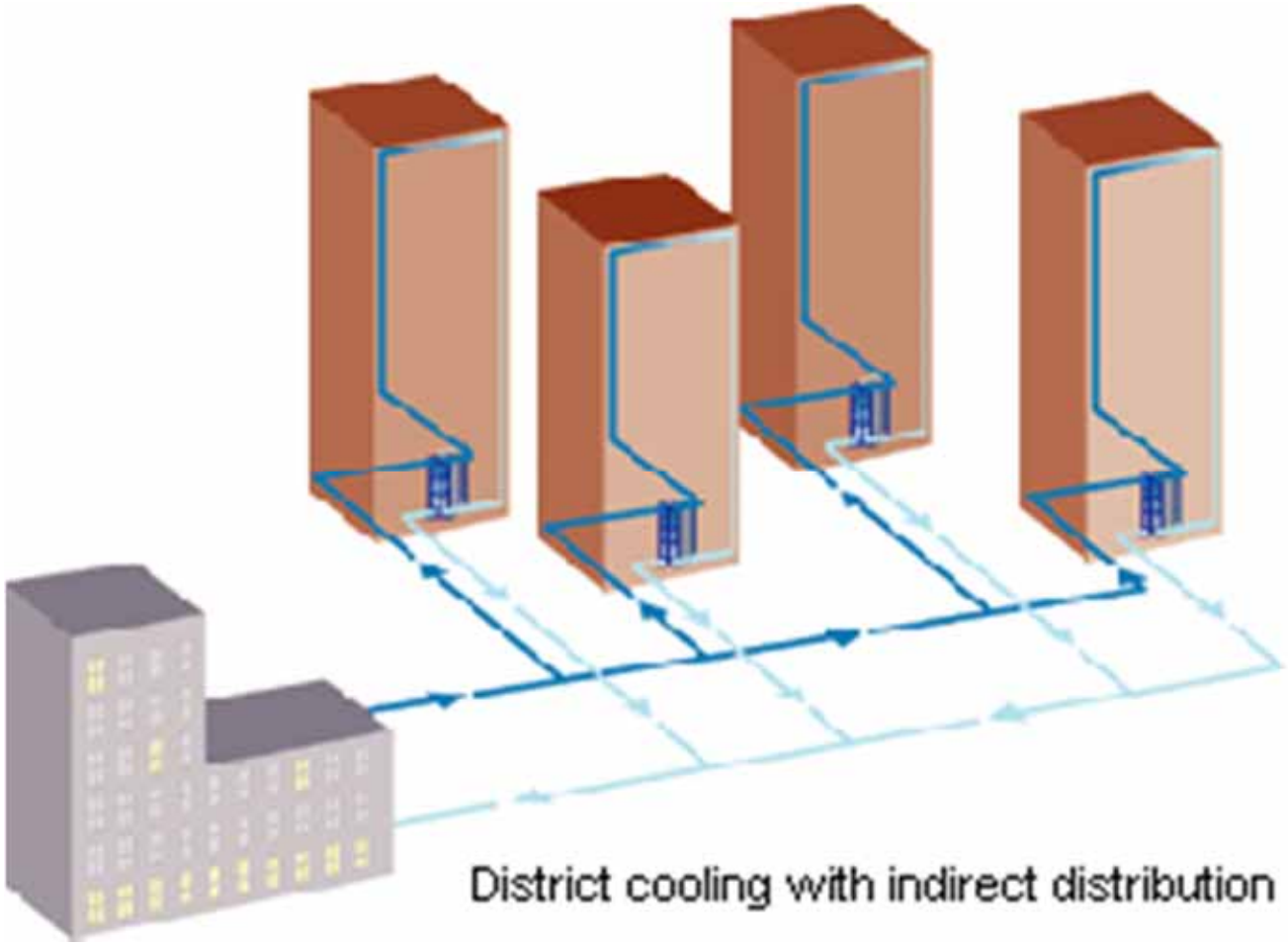
'Free' cooling methods in HVAC system



Waste heat recovery - heat pump + chiller

Individual buildings

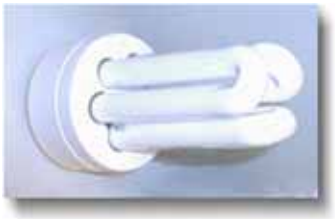
Centralised refrigeration plant



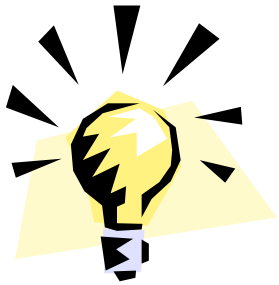
District cooling system

(Question: Do you know what are the advantages?)

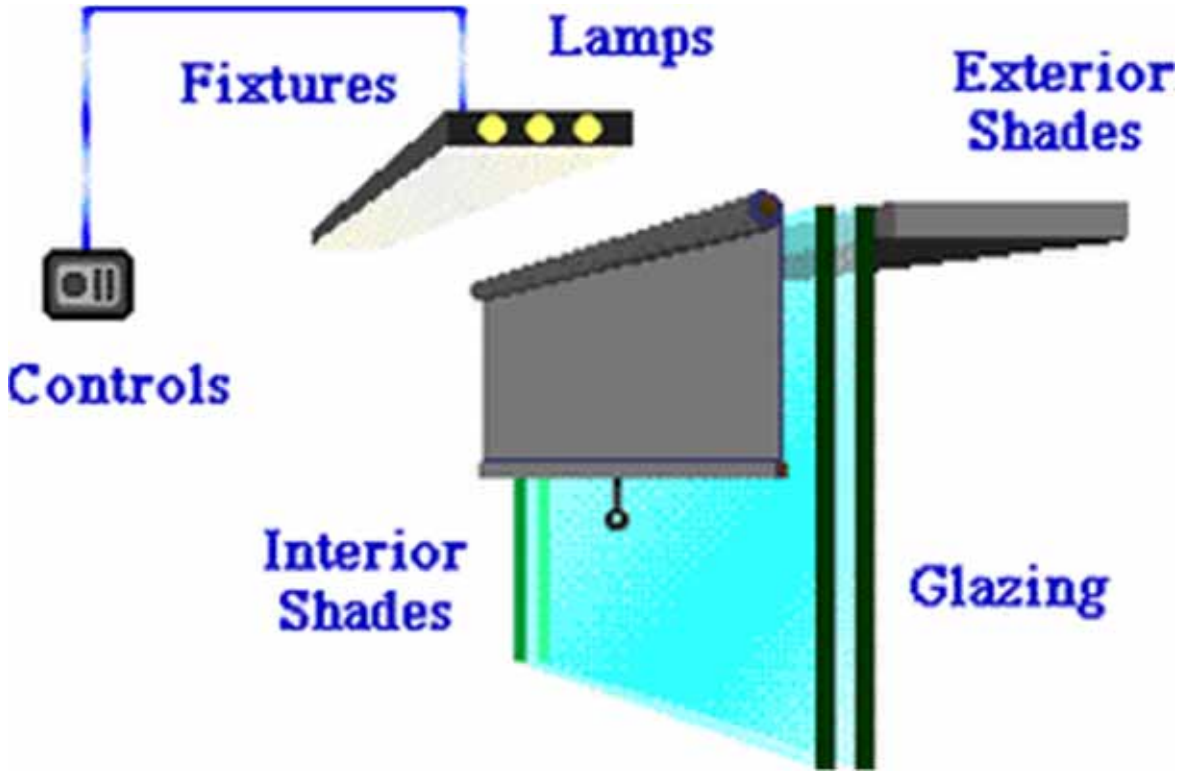
Building Energy Efficiency



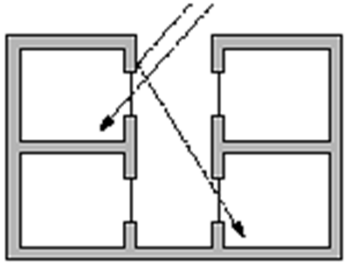
- Lighting systems
  - Have good potential for conserving electricity
  - Also contribute to HVAC load reduction
- General principles of energy efficient lighting
  - Illumination is not excessive
  - Switching arrangements are designed
  - Provide illumination in an efficient manner



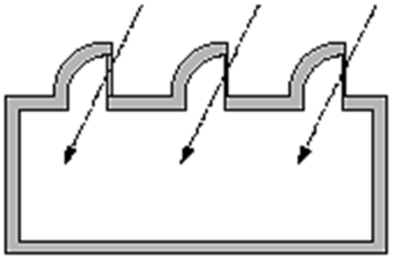
Energy efficient fittings (e.g. compact fluorescent lamps)



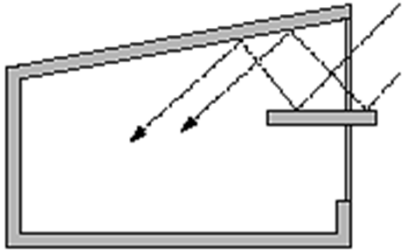
Lighting controls and interactions with windows



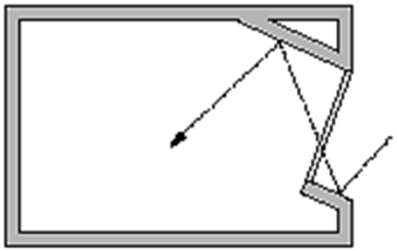
Light well



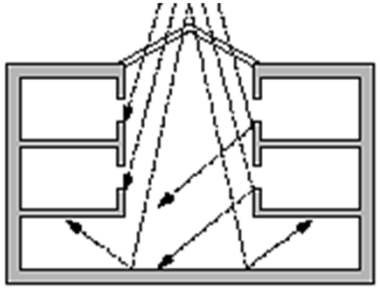
Roof monitor



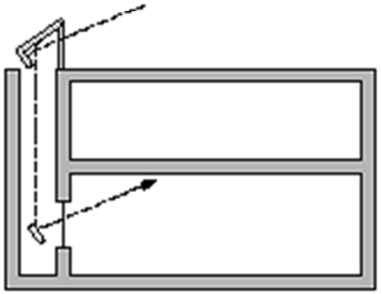
Light shelf



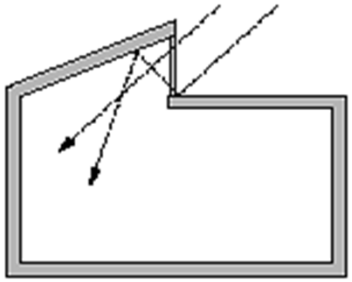
External reflectors



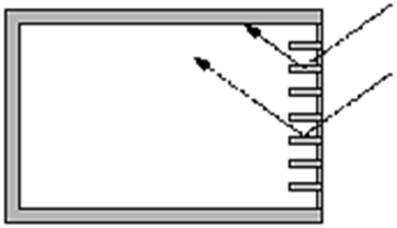
Atrium



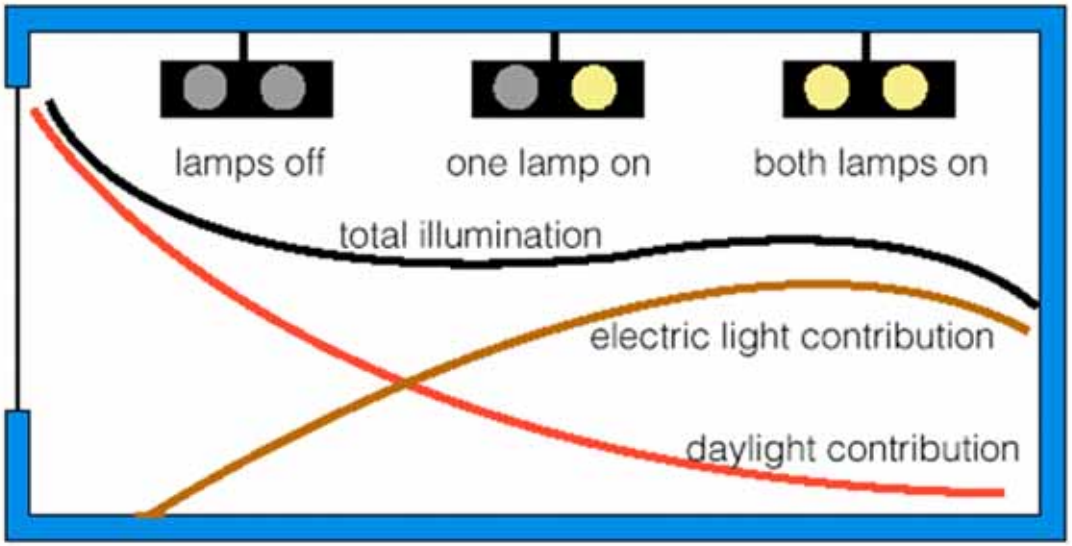
Light duct



Clerestory



Reflective blinds



Daylighting design and control

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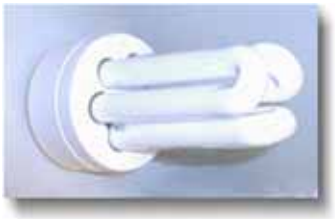
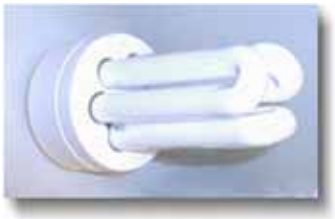


- Conserve lighting energy by:
  - (a) Reduce power input
    - Illumination level required, lamp types, ballast, room layouts and colours
  - (b) Reduce hours of use
    - Optimised switching
    - Automatic controls
    - Use of daylight
    - Education and propaganda

Building Energy Efficiency



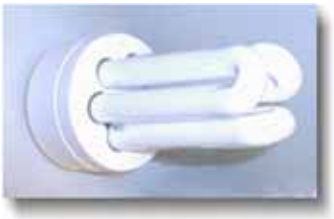
- Other building services systems
  - Electrical installation
  - Lifts and escalators
  - Water supply systems
  - Town gas supply system (cooking)

- Basic principle for energy efficiency:
  - Energy efficient appliances, correct sizing, design and operation, effective distribution network and proper maintenance

Energy saving in lift system

http://www.hku.hk/bse/save.exe

Building Energy Efficiency



- Human factors
  - Comfort requirements
    - Thermal comfort
    - Visual comfort
    - Noise control
  - Occupant behaviours
    - Patterns of use
    - Periods of occupation
- Management issues
  - Building use, operation & maintenance

Good design practices

Integrated & total energy approach

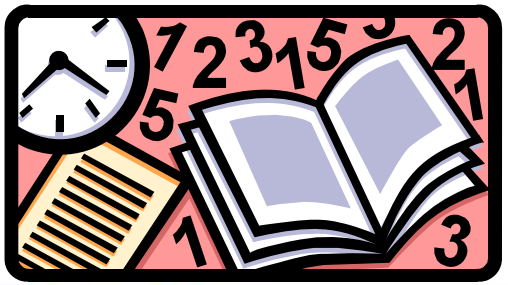
Efficient systems

Good house-keeping

User education & awareness

Efficient operation

Further Reading



- Public Education: Education Kit [EMSD] -- Energy Efficient Building
  - www.emsd.gov.hk/emsd/eng/about/pe_ek.shtml
- Checklist for Energy Efficiency
  - http://www.hku.hk/bse/check.pdf
    - Architecture, HVAC, electrical services, lighting installations, lifts and escalators, plumbing and drainage, building management