MEBS6016 Energy Performance of Buildings

http://www.hku.hk/bse/MEBS6016/

Introduction

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- Course Overview
- Energy Basics
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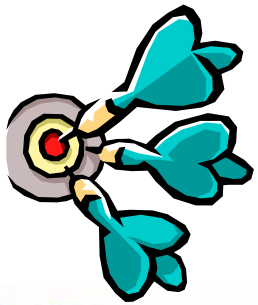
Course Overview



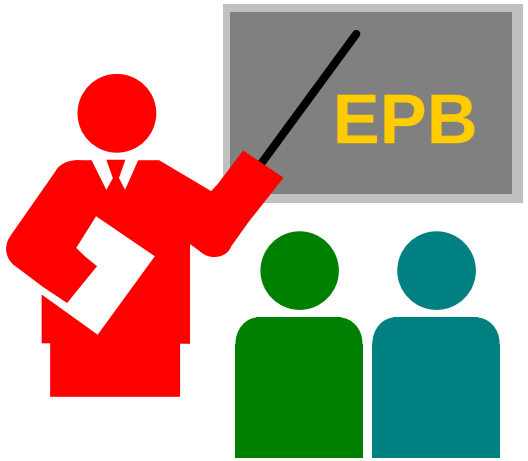
- MEBS6016 Energy Performance of Buildings
- Lecturers:

Dr. Sam C. M. Hui

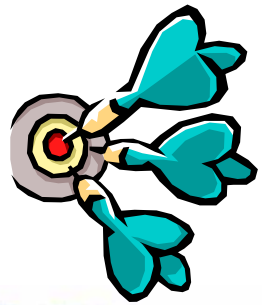
- Email: cmhui@hku.hk
- Office: Room 7-22, Haking Wong Bldg.

- ***Ir Prof. K. K. Lam***

- Email: lam_kam_kuen@yahoo.com.hk
- Adjunct Professor, HKU
- Previously Chief Engineer at EMSD's Energy Efficiency Office

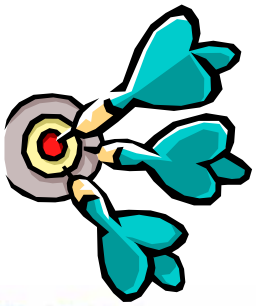


Course Overview



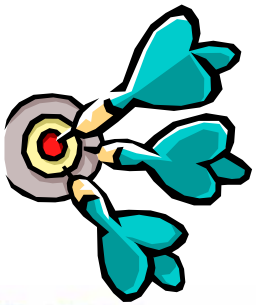
- ***Dr. Sam C. M. Hui***
  - PhD, BEng(Hons), CEng, CEM, MASHRAE, MCIBSE, MHKIE, MIESNA, LifeMAEE, AssocAIA
  - ASHRAE Distinguished Lecturer (2009-11)
  - CEng = Chartered Engineer
  - CEM = Certified Energy Manager
  - LifeMAEE = Life Member, Associatn of Energy Engineers
  - Worked in 1998 as a visiting researcher in the Asia Pacific Energy Research Centre, Japan
  - Research interests: energy efficiency in buildings and sustainable building technologies

Course Overview



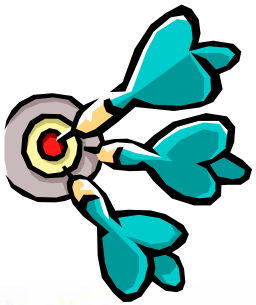
- Educational Objectives:
  - To understand the important issues associated with energy performance of buildings.
  - To develop the essential skills for theoretical analysis and practical study of building energy use
- Duration:
  - About 12 weeks
  - 2.5 hours per week

Course Overview



- Learning Outcomes: After completing the course, students will be able to:
  - Describe the important issues and considerations of building energy performance
  - Explain the technologies, codes and policies for energy conservation in buildings
  - Develop the skills for theoretical analysis and practical study of building energy performance

Course Overview



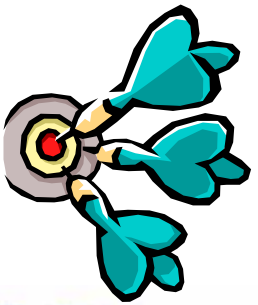
- Study Topics:
  - 1) Introduction
  - 2) Energy efficiency in buildings
  - 3) Building energy analysis techniques
  - 4) Economic and financial analysis

Dr. Sam Hui

  - 5) Energy efficient technologies
  - 6) Building energy standards & codes
  - 7) Energy auditing of buildings

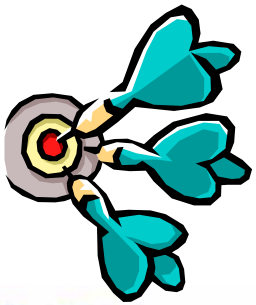
Ir Prof K K Lam

Course Overview

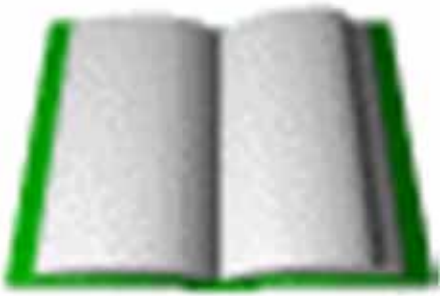


- Learning Methods:
  - Lectures
  - Assigned Reading
  - Assignment
- Learning Resources:
  - References
  - Web Links
  - Course Website
  - WebCT

Course Overview



- Assessment Method
  - Written Examination (100%)
    - 2-hour written exam
- References
  - No required textbook
  - See reference list for some selected useful books
  - Useful info can also be found on the web links



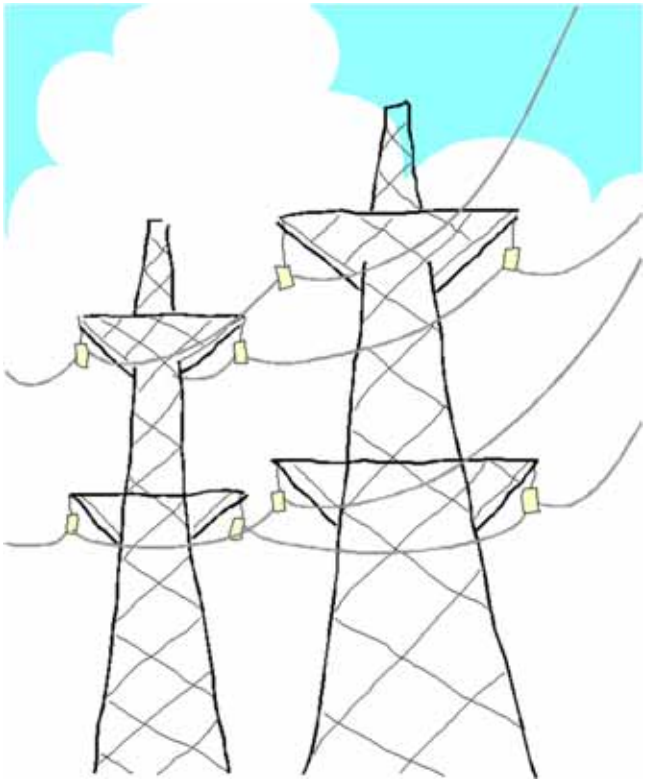
Energy Basics

- Units of energy
  - Kilowatt-hour (kWh), 1 kWh = 3.6×10^6 joule
    - 1 kWh = 3.6 MJ = 860 kcal = 3412 Btu
  - Calorie (卡路里), 1 calorie (cal) = 4.2×10^3 J
  - British thermal unit (Btu), 1 Btu = 1.055×10^3 J
  - Therme (gas supply), 1 therme = 100 000 Btu
  - Tonne of oil equivalent (toe) (from oil industry)
    - 1 toe = 4.2×10^{10} J = 42 GJ or 11.63 MWh or 10^7 cal
- Power unit:
  - 1 W = 1 J/s = 0.86 kcal/h = 3.41 Btu/h

Energy Basics

- Forms of energy: (*Supply side, primary energy*)
  - **Electricity** (most important)
  - Natural gas, town gas, liquified petroleum gas (LPG)
  - Oil products
  - Coal
  - Hydropower
  - Renewable energy (e.g. solar, wind)
  - Nuclear energy

能源



Energy Basics

- Energy end-use: (*Demand side, final energy*)
  - Air-conditioning and ventilation
  - Lighting
  - Equipment
  - Hot water
  - Cooking
  - Industrial processes
  - Transportation

Energy Basics

- Energy use from a historical viewpoint
  - Early human societies
    - Simple gatherers; lived off wild fruit, nuts & vegetables
  - Hunting societies
    - Learn to use fire for cooking & heating
  - Agricultural societies
    - Work with tools; trading of goods & materials
  - Industrial societies
    - Increased energy consumption for cooking, heating, manufacturing, transport, etc.

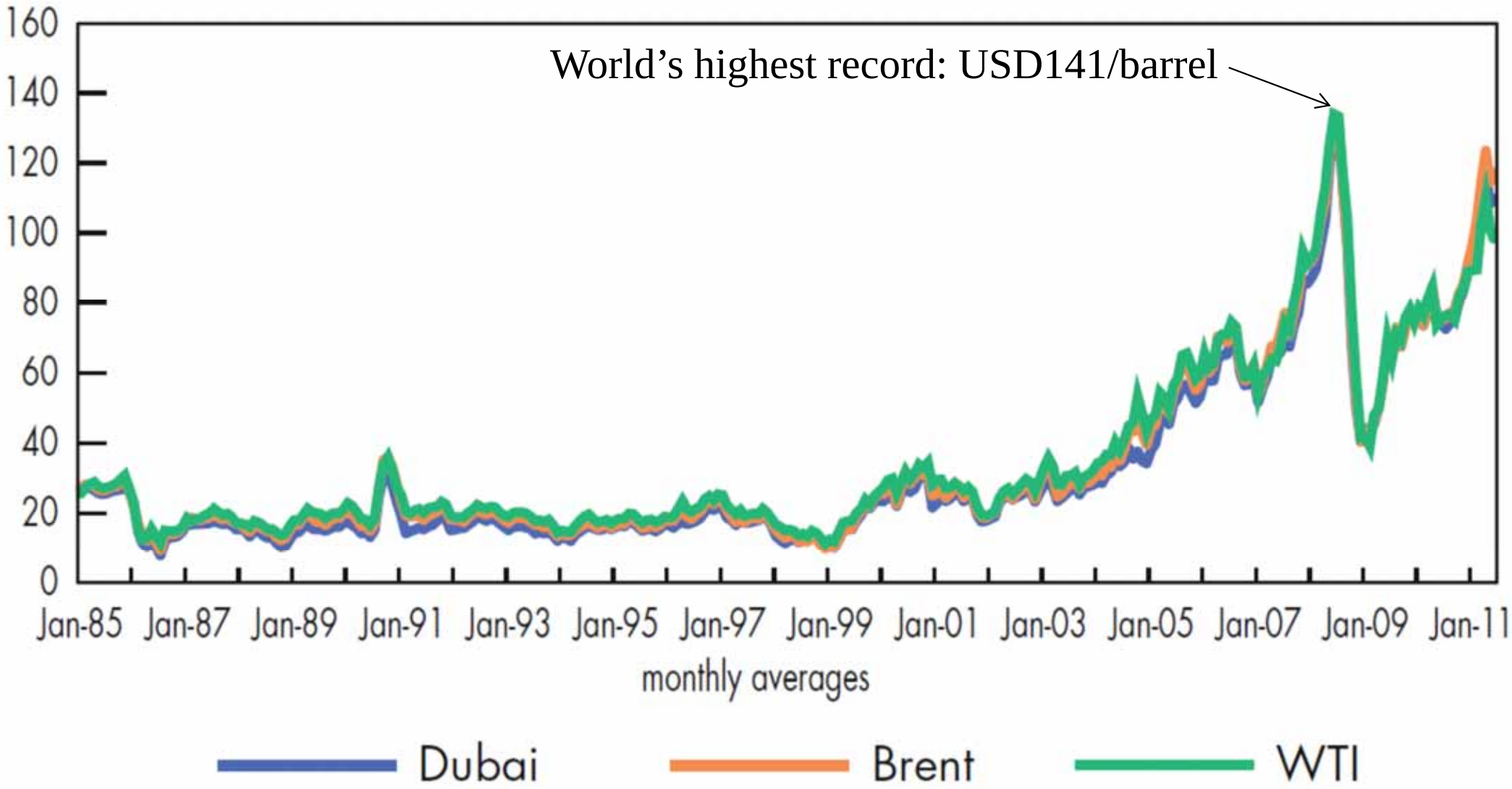
Energy Basics

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

Energy Basics

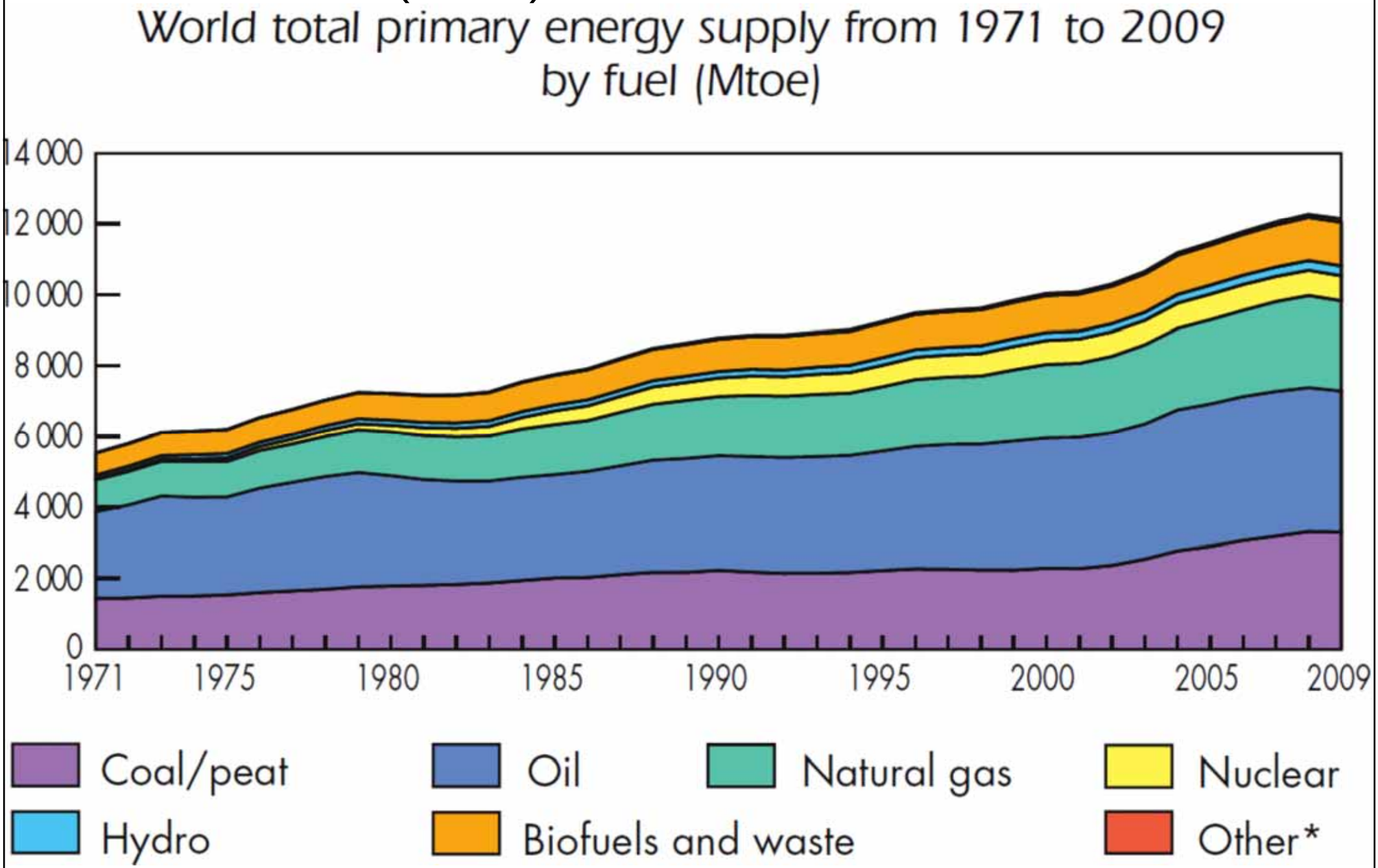
- History of energy issues in the modern world
  - **1970s** (oil crises): to preserve supplies of what were thought to be scarce fuels
  - **1980s**: emphasize on cost effectiveness of energy efficiency (drop in oil price)
  - **1990s**: to reduce the impact of energy use on the environment (esp. control greenhouse gases)
  - **2000s**: to achieve sustainable energy future

Key crude oil spot prices in USD/barrel



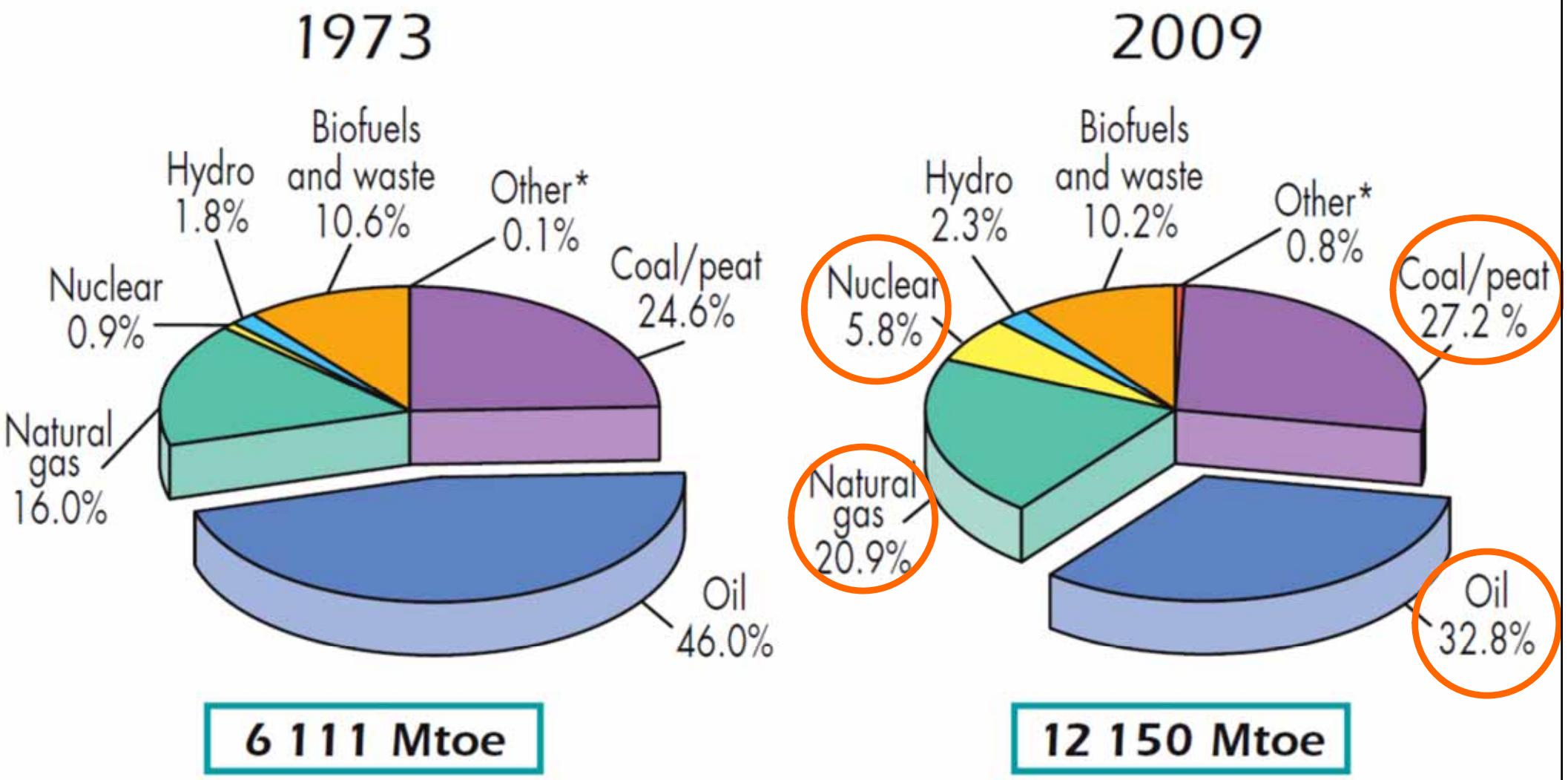
(* Source: IEA, 2011. *Key World Energy Statistics 2011*, International Energy Agency, Paris. Available at www.iea.org)

(TPES)



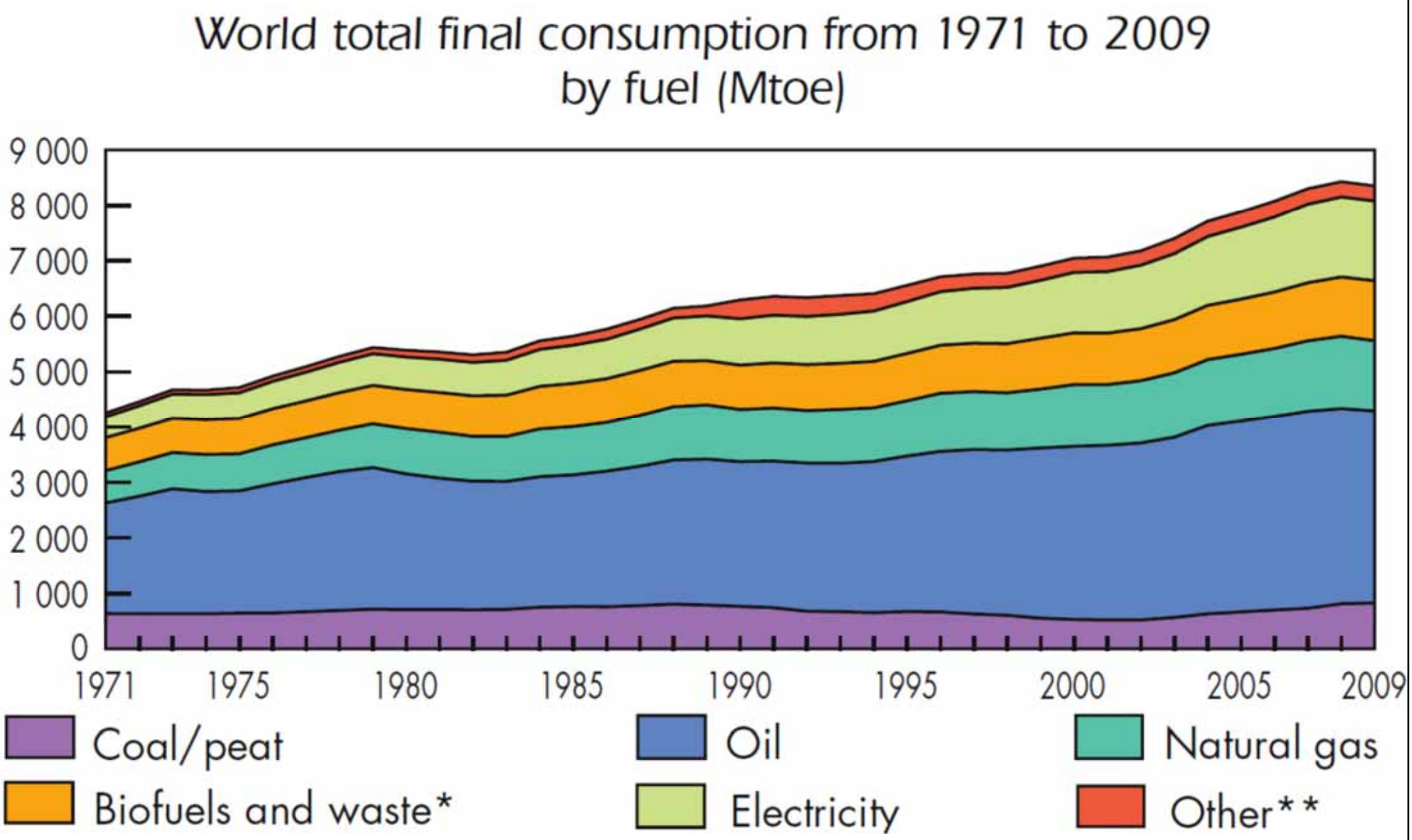
(* Source: IEA, 2011. *Key World Energy Statistics 2011*, International Energy Agency, Paris. Available at www.iea.org)

1973 and 2009 fuel shares of TPES



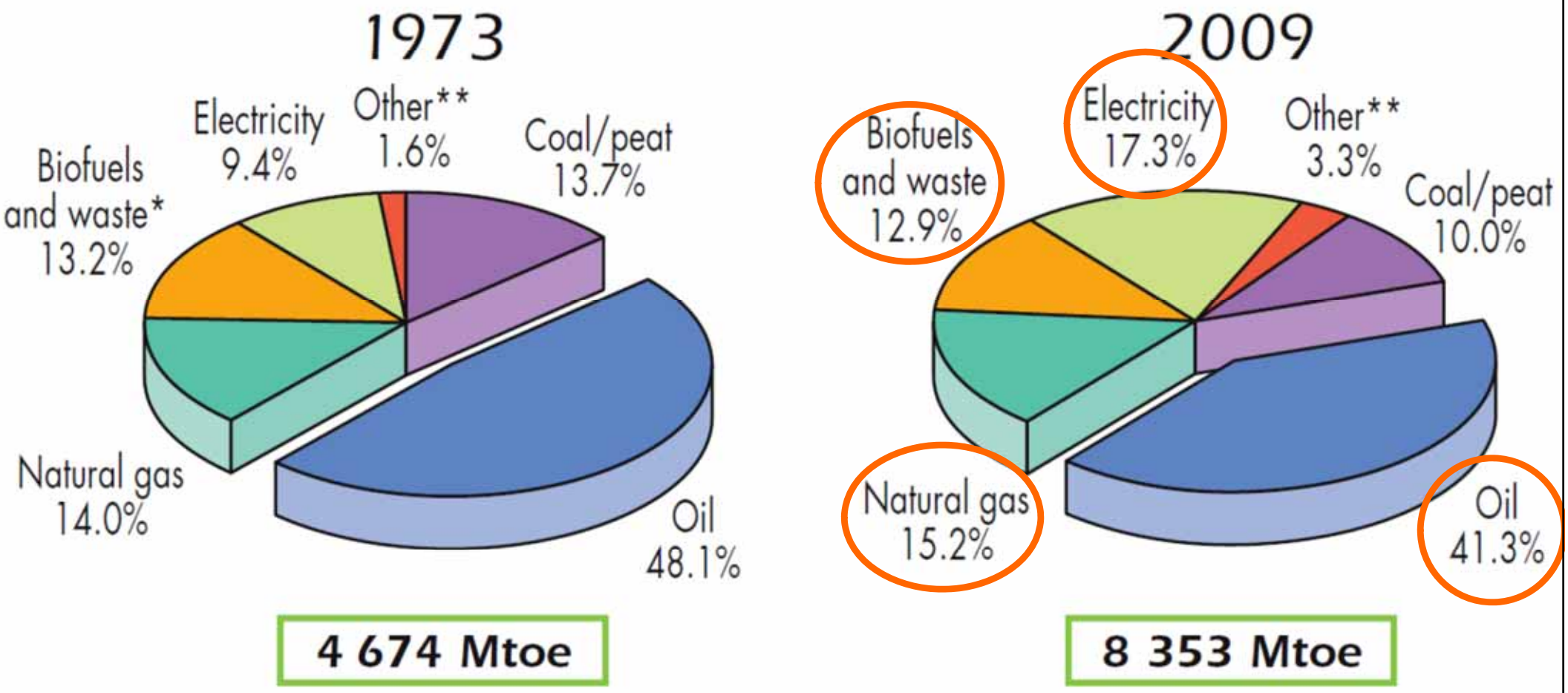
*Other includes geothermal, solar, wind, heat, etc.

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



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

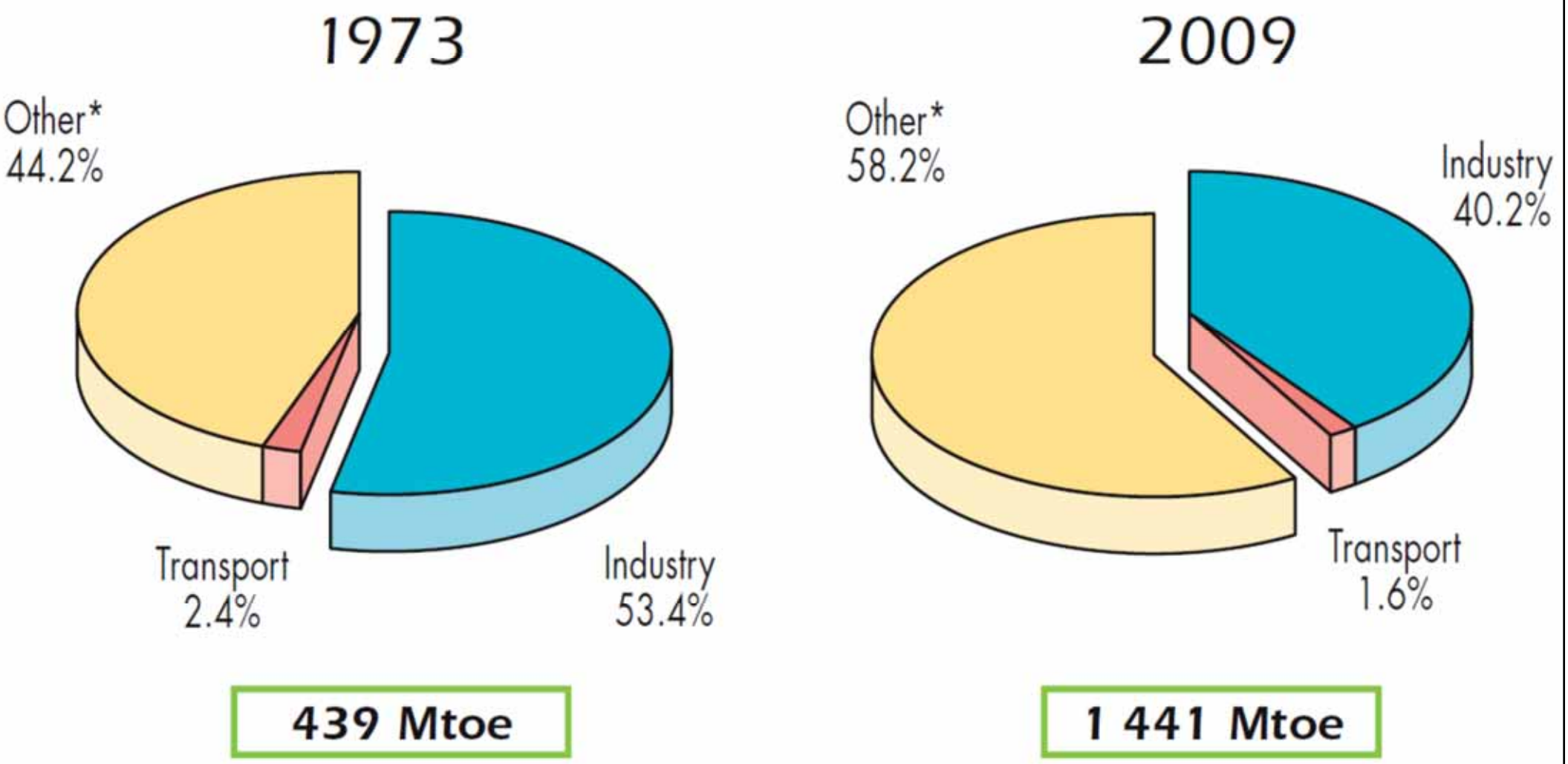
1973 and 2009 fuel shares of total final consumption



*Data prior to 1994 for biofuels and waste final consumption have been estimated.
**Other includes geothermal, solar, wind, heat, etc.

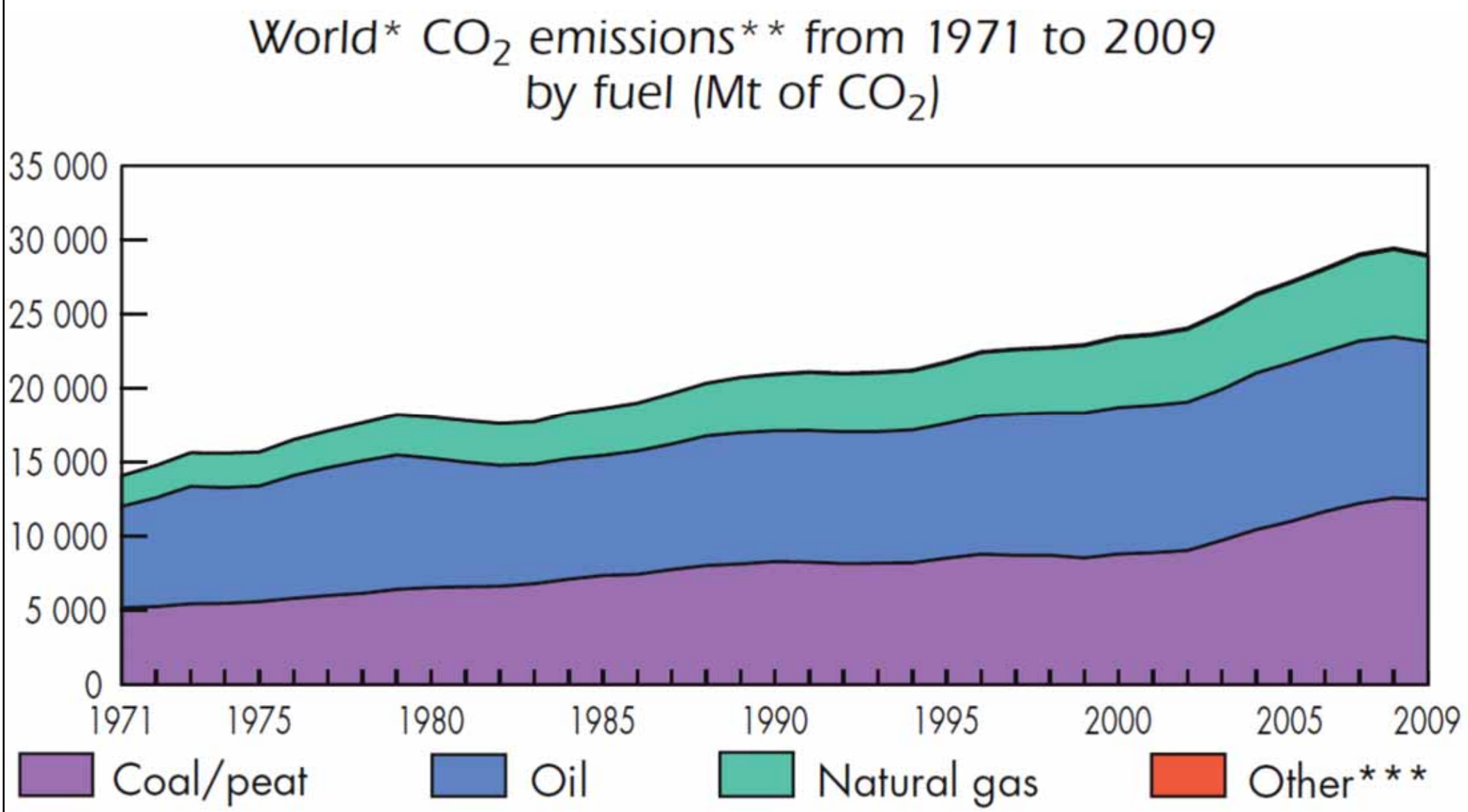
(* Source: IEA, 2011. *Key World Energy Statistics 2011*, International Energy Agency, Paris. Available at www.iea.org)

1973 and 2009 shares of world electricity consumption



*Includes agriculture, commercial and public services, residential, and non-specified other.

(* 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 indicators for 2009

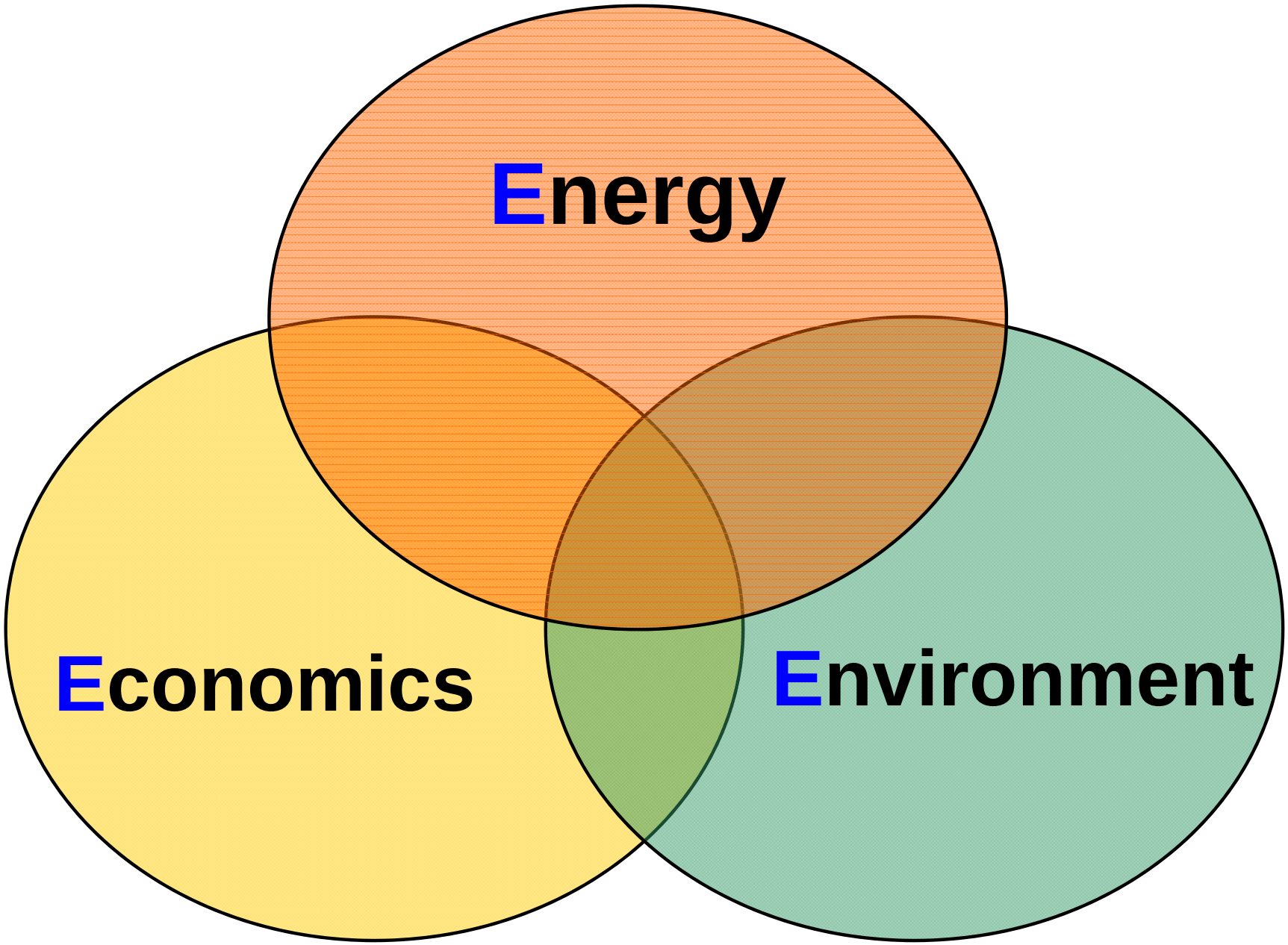
Economy	**Population** (million)	**GDP/pop** (yr2000 USD)	**TPES/pop** (toe/ capita)	**TPES/GDP** (toe/yr2000 USD)	**CO_2/pop** (t CO_2/ capita)	**CO_2/GDP** (kg CO_2/ yr2000 USD)
World	6761	5.87	1.80	0.31	4.29	0.73
China	1331	2.21	1.70	0.77	5.13	2.33
India	1155	0.76	0.58	0.77	1.37	1.81
USA	307	36.94	7.03	0.19	16.9	0.46
Japan	127	38.26	3.71	0.10	8.58	0.22
Germany	82	24.41	3.89	0.16	9.16	0.38
Hong Kong	7	33.05	2.13	0.06	6.51	0.2
Singapore	5	28.75	3.70	0.13	8.99	0.31

(* Extracted from: 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 - *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 Basics

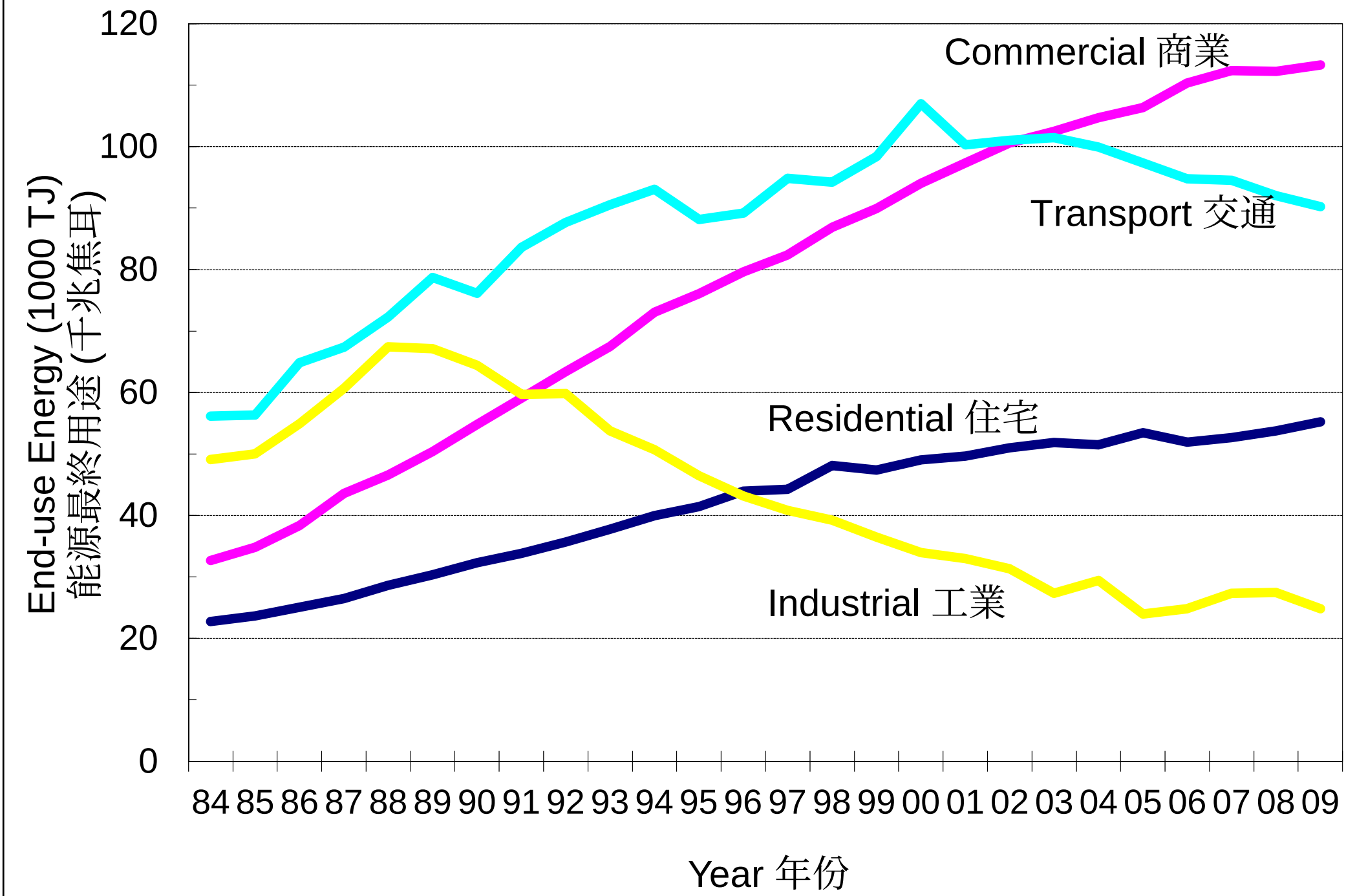
- Significance of energy management
  - Economics
    - Energy costs and operating costs
  - Energy security
    - Energy supply (political and economic reasons)
  - Environment
    - Climate change, global warming, air pollution
  - Resources depletion
    - Oil, gas and coal will be used up

Energy Use in Buildings

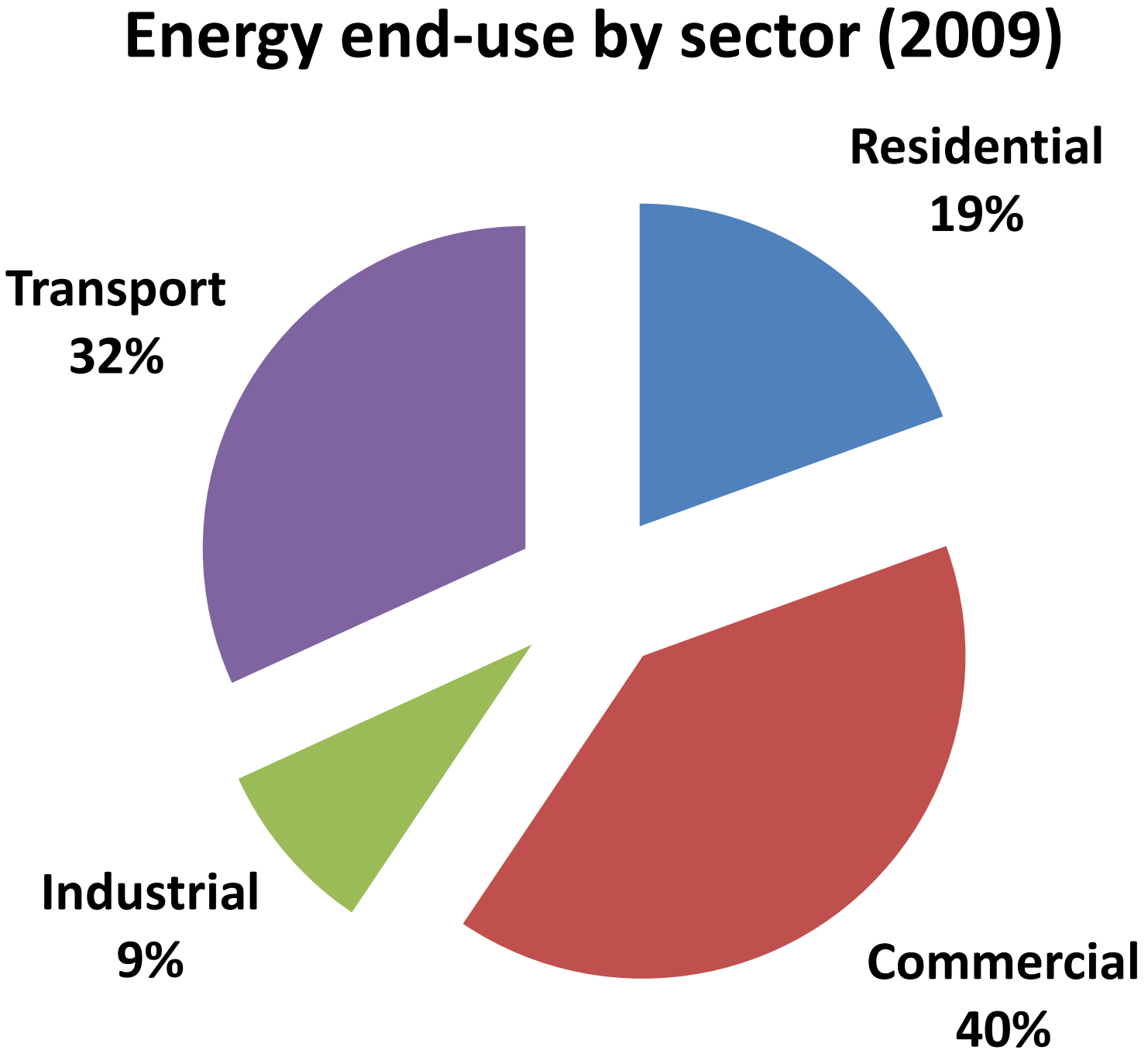
- Buildings constitute 30-50% of energy needs
  - Residential + commercial + industrial
  - The potential for energy saving is large
- The real cost of energy
  - Energy price
  - Environmental costs or externalities
    - e.g. $$ for pollution control & “repairing” of environmental damages
  - Need to internalise the externalities

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



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



Energy end-use in Hong Kong

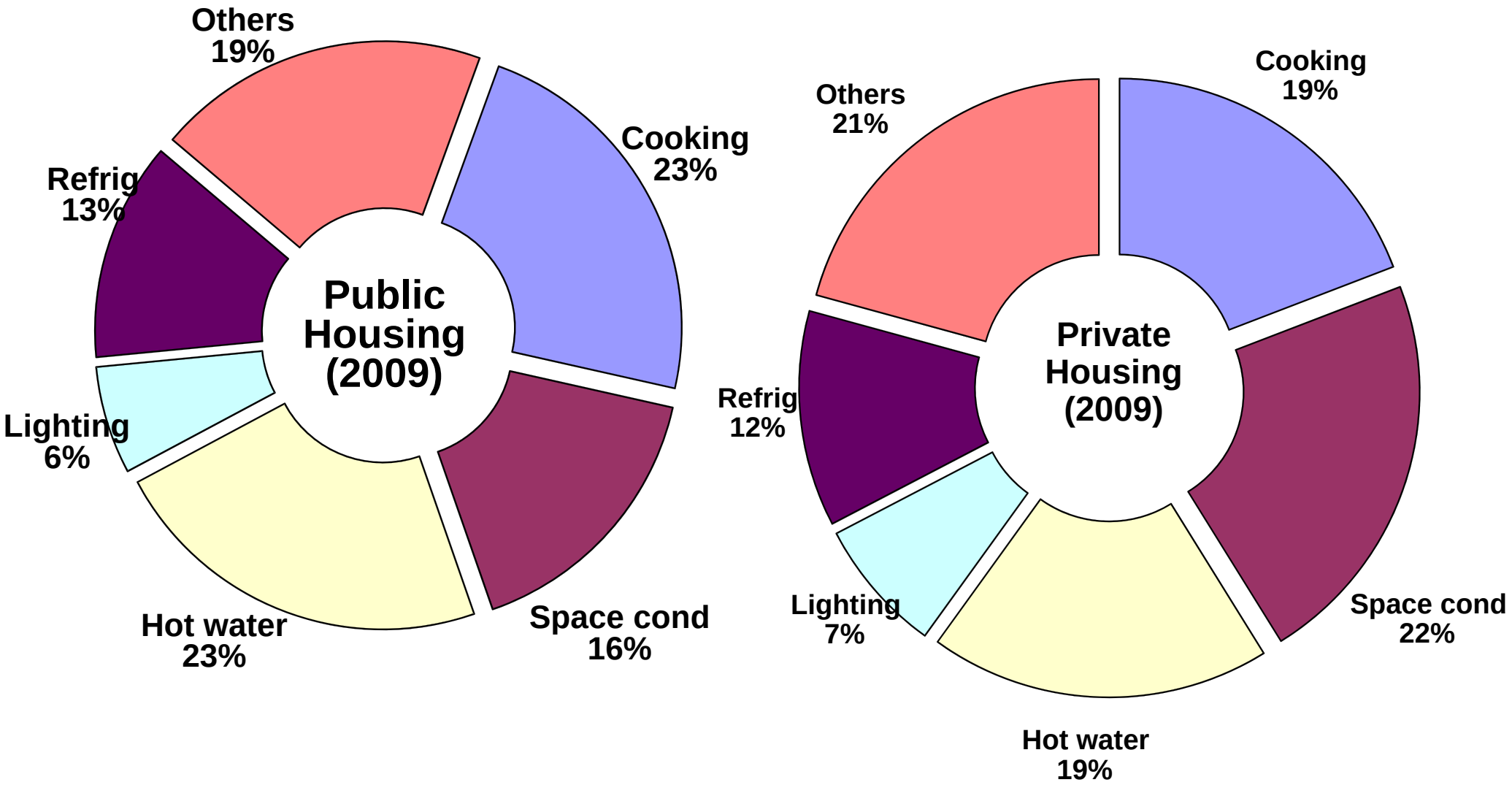
(Data source: EMSD)

Table 1 - Final energy requirements (FER) in Hong Kong (year 2010)

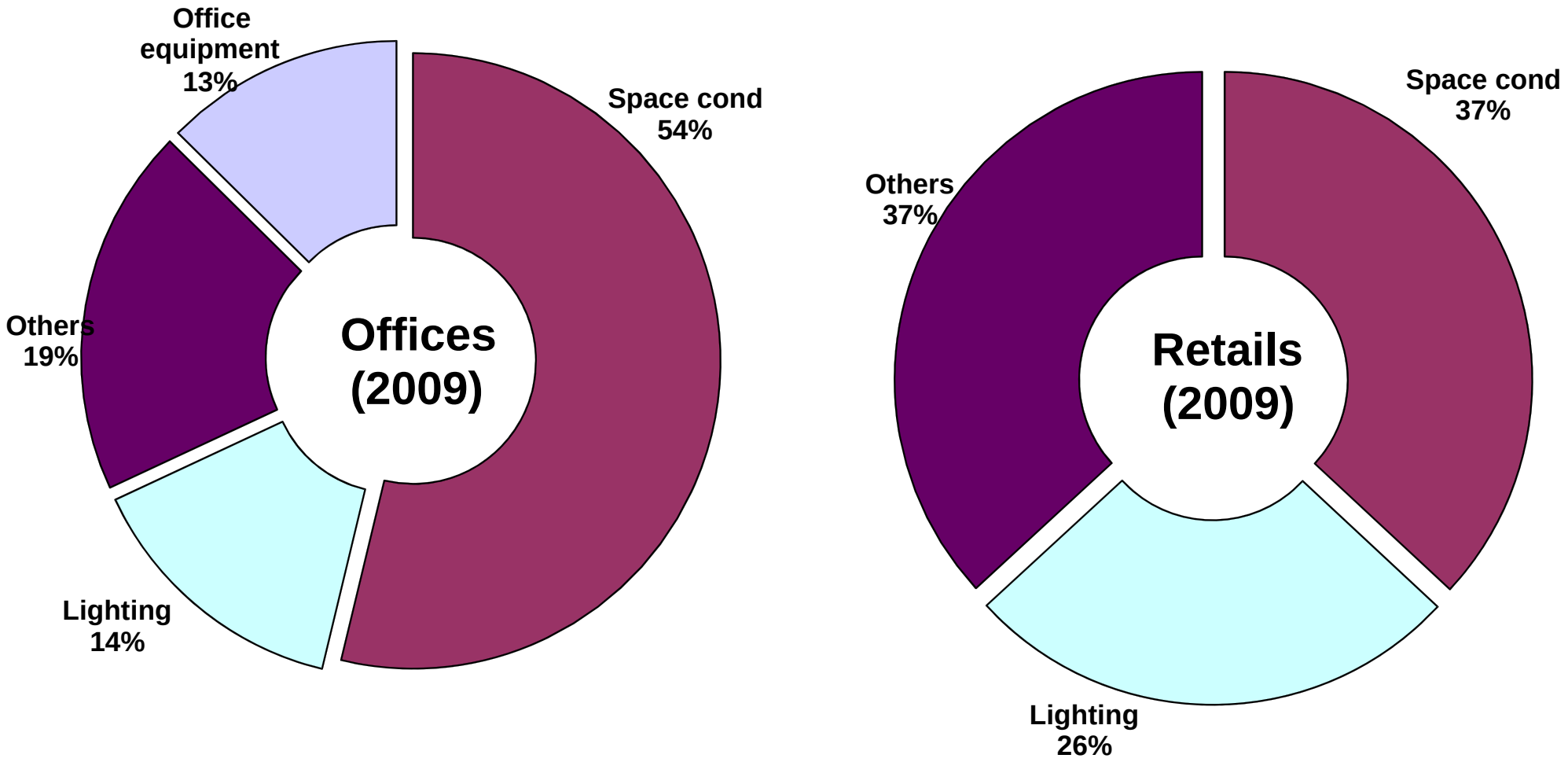
Unit: MJ	**Commercial**	**Residential**	**Industrial**	**Total**
Electricity	100 280 (67%)	39 344 (26%)	11 080 (7%)	150 705 (100%)
Town gas	11 389 (41%)	15 272 (55%)	917 (3%)	27 578 (100%)
Elec. + town gas	111 669	54 616	11 997	178 283
% in total FER	37.5%	18.4%	4.0%	59.9%

Total FER for 2010 = 297 488 TJ

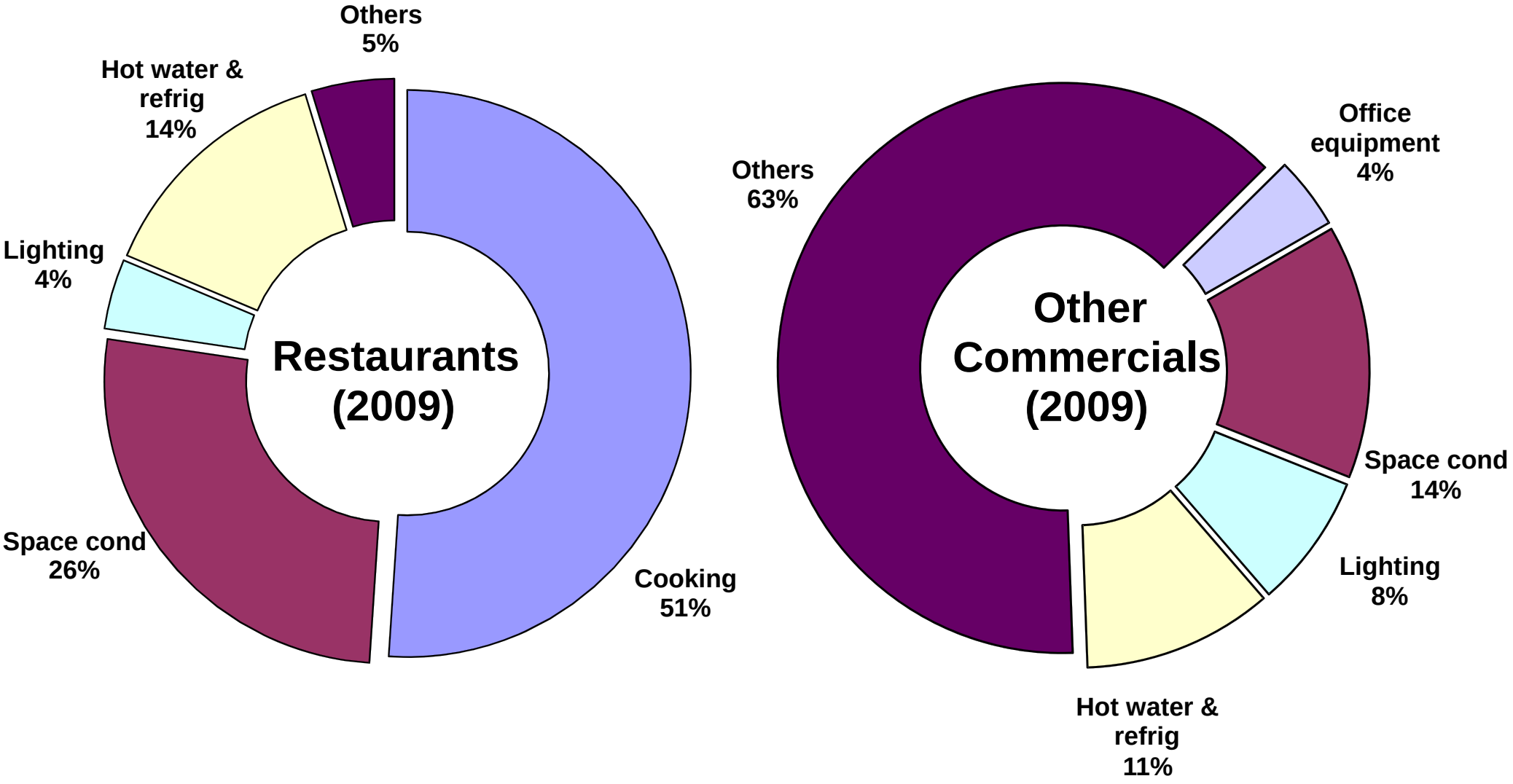
(* Data Source: *Hong Kong Energy Statistics 2010 Annual Report*)



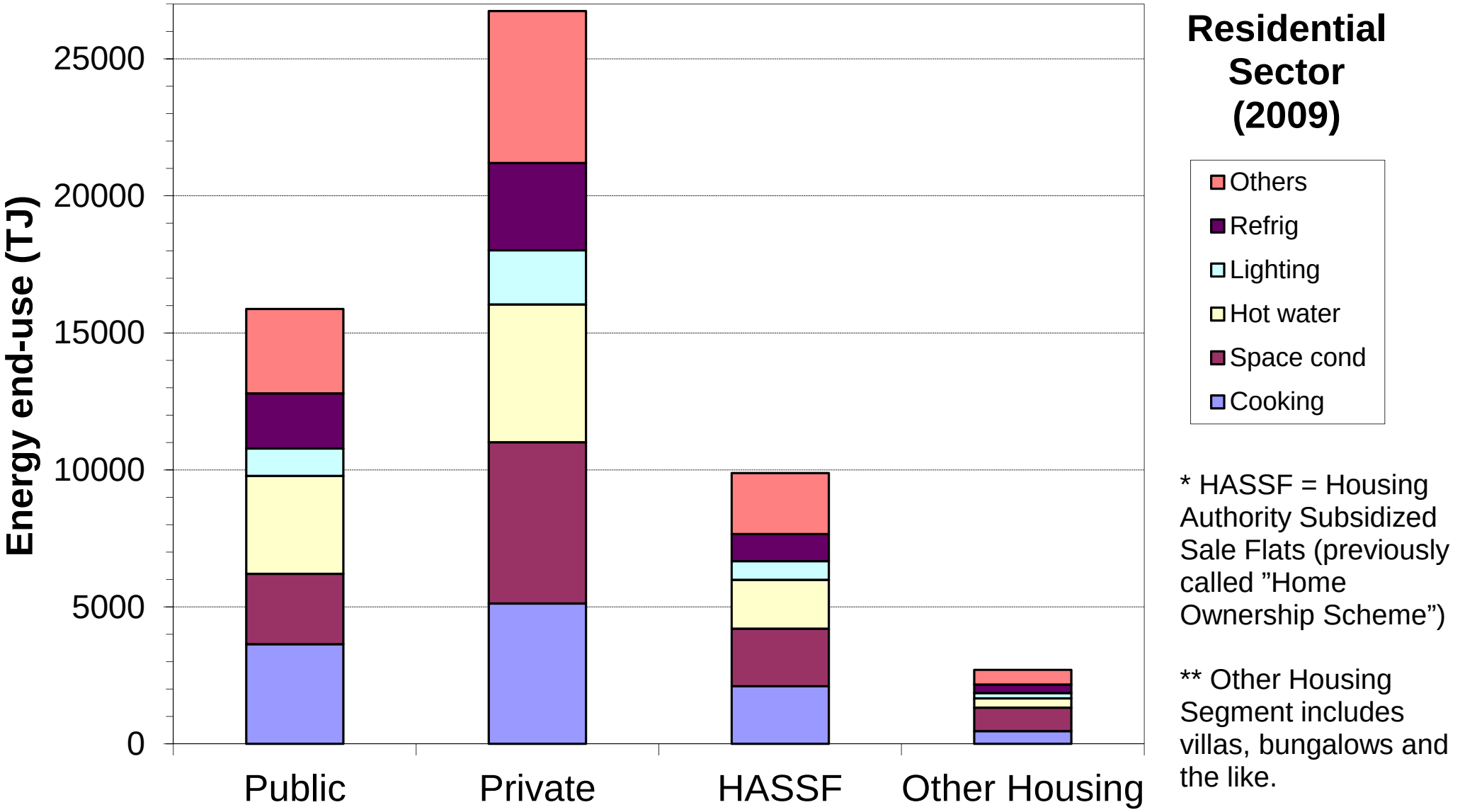
Energy consumption patterns in residential buildings
(Data source: Energy Efficiency Office, HK)



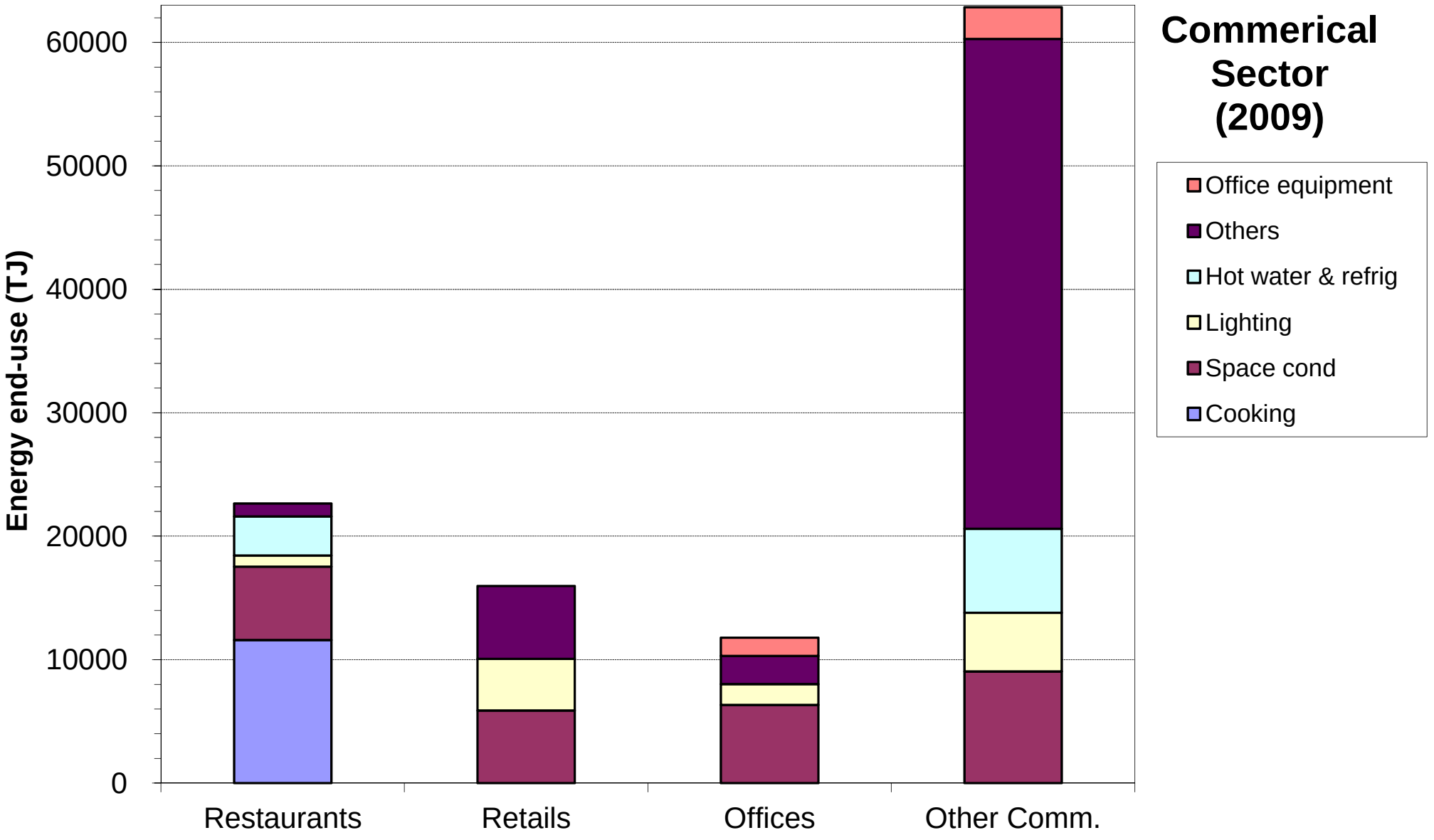
Energy consumption patterns in offices and retails
(Data source: Energy Efficiency Office, HK)



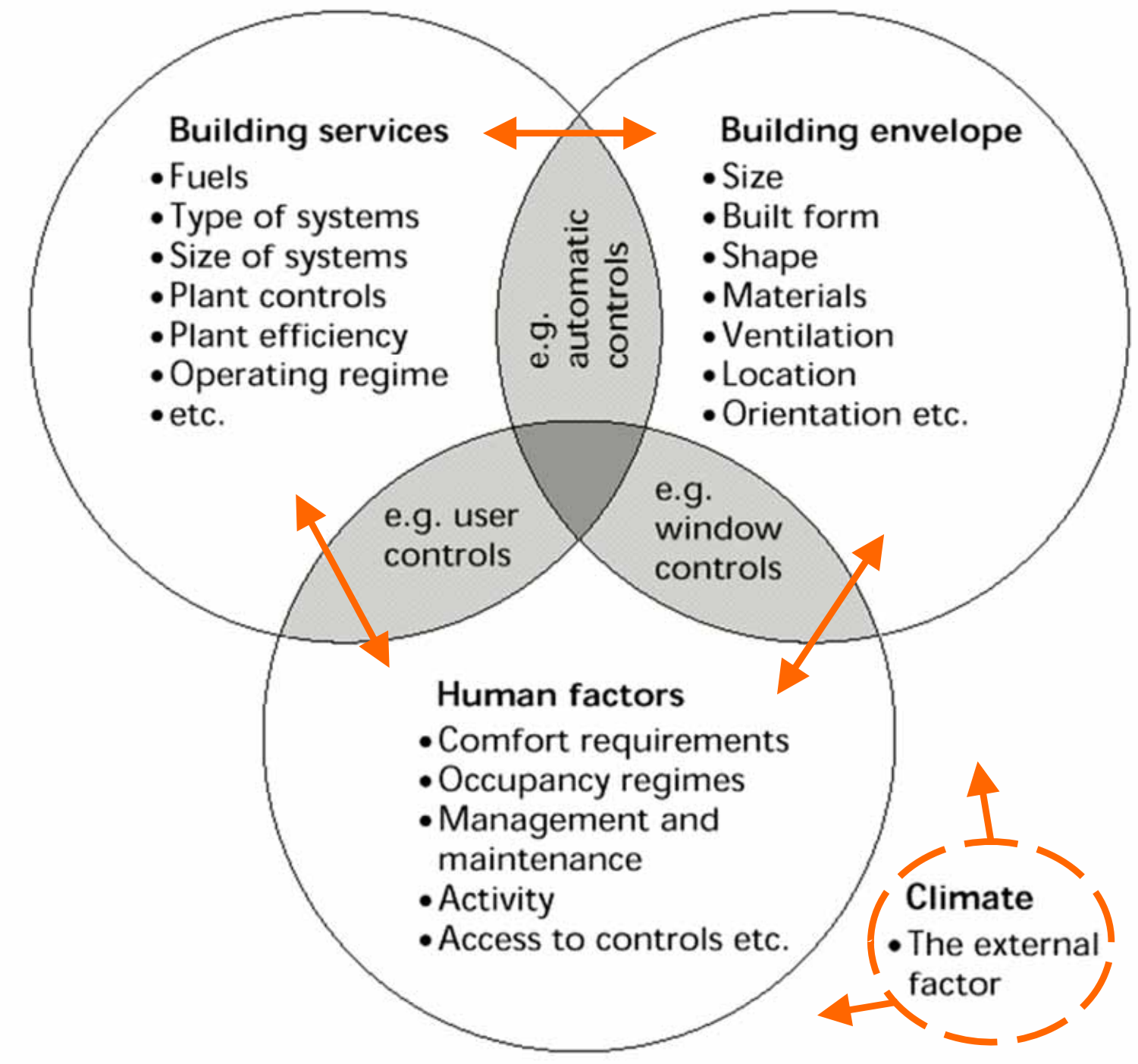
Energy consumption patterns in other commercial buildings
(Data source: Energy Efficiency Office, HK)



Energy end-use in residential sector, 2009
(Data source: Energy Efficiency Office, HK)

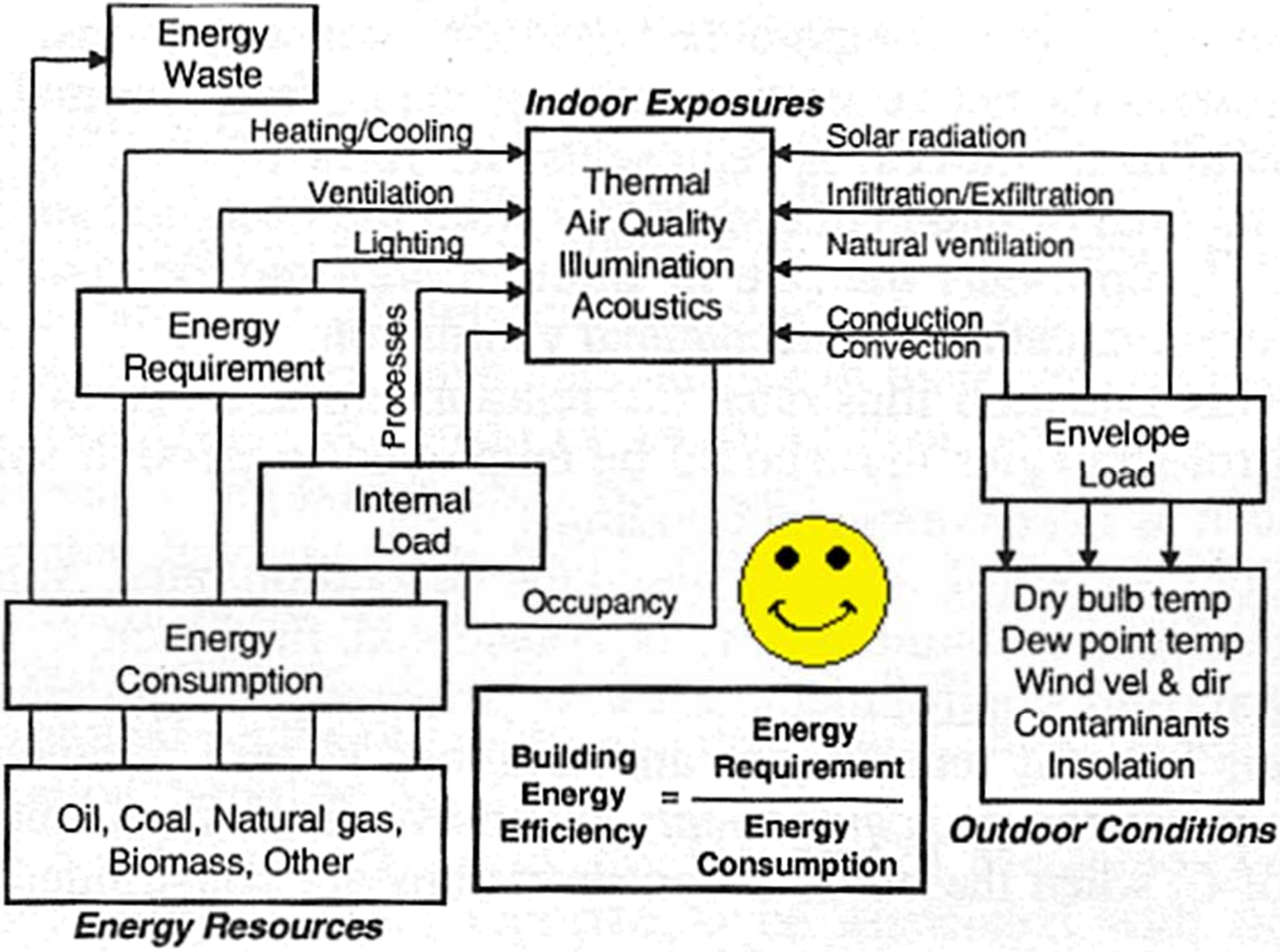


Energy end-use in commercial sector, 2009
(Data source: Energy Efficiency Office, HK)



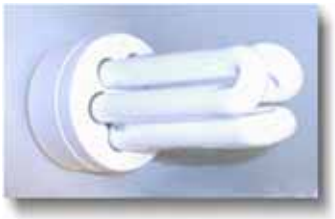
Key factors influencing energy consumption

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



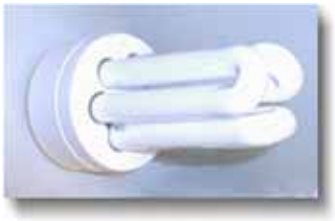
Energy flow and concept in buildings

Energy Efficiency

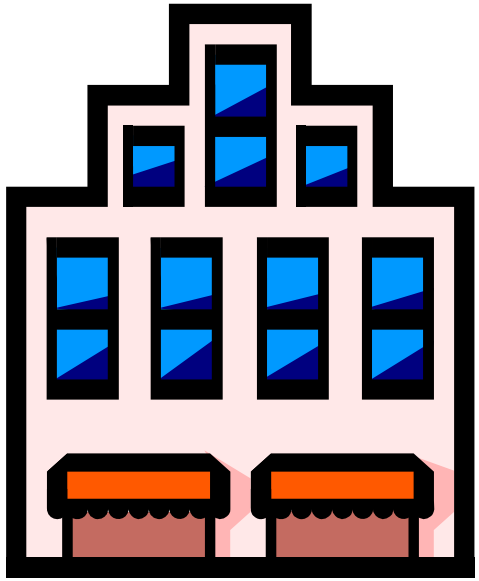


- Key persons in building energy efficiency
  - Building Developer or Owner (Client)
  - Architect
  - Building Services Engineer
  - Building/Facility Manager
  - End-Users

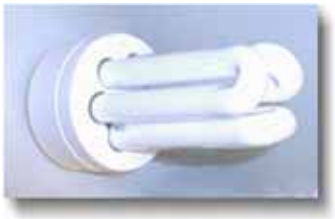
Energy Efficiency



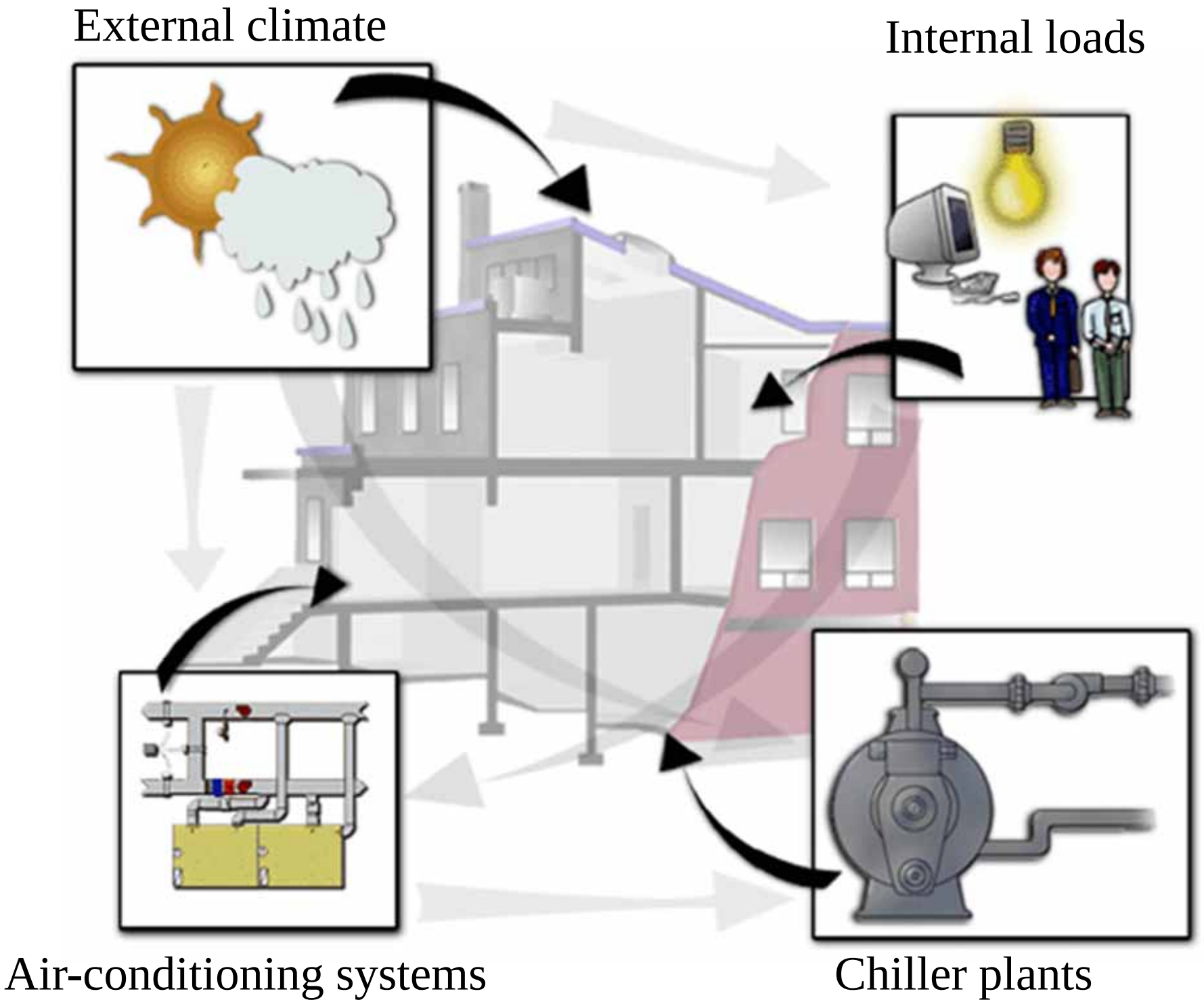
- For new buildings
  - Designing the building
    - Design strategy
    - Control strategies
    - Commissioning
- For existing buildings
  - Operating and upgrading the building
    - Building management
    - Refurbishment/renovation/retrofitting
    - Maintenance and monitoring



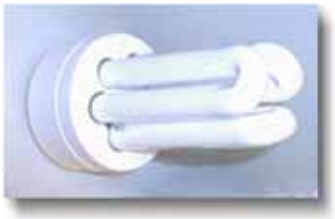
Energy Efficiency



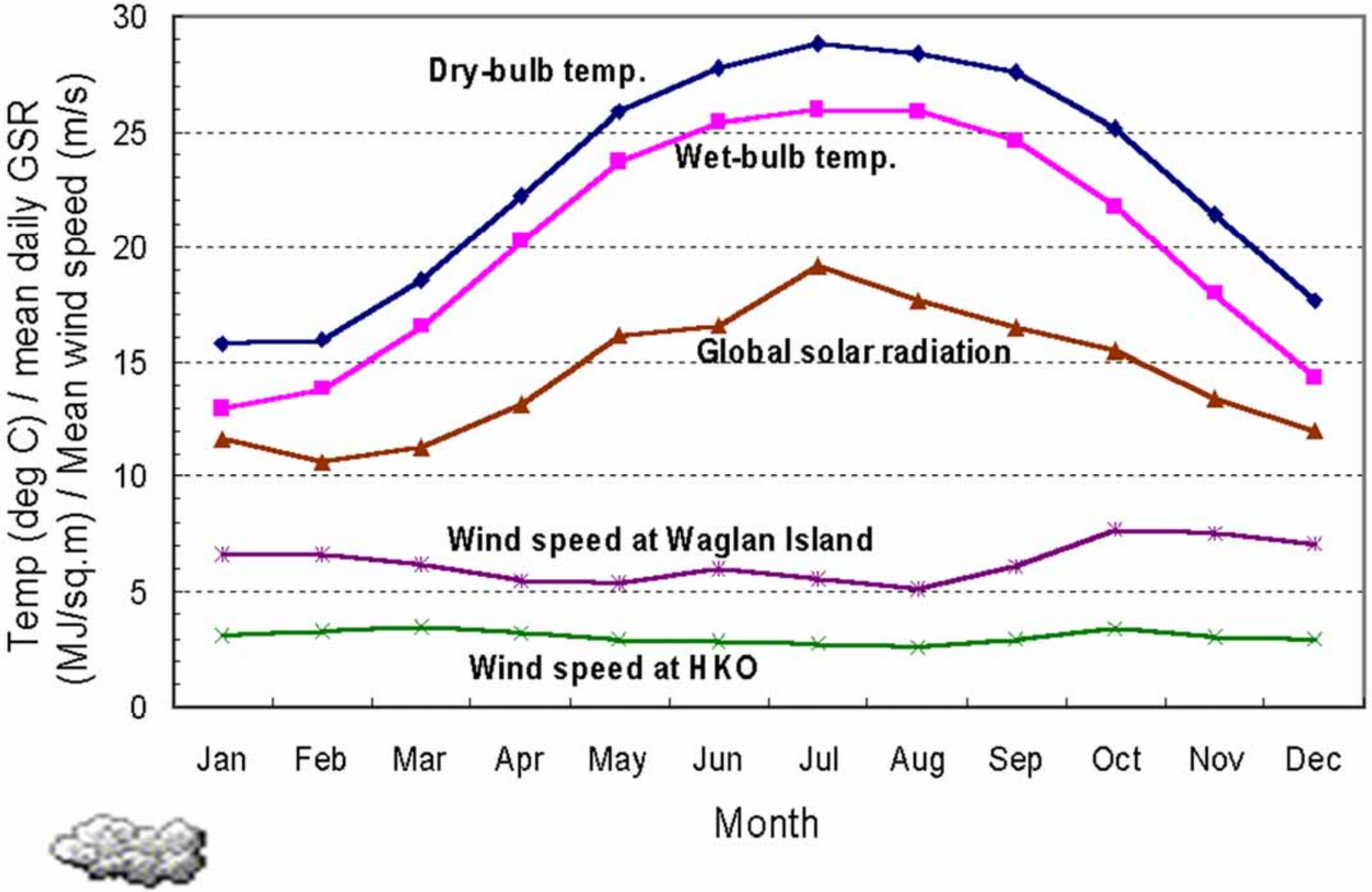
- Efficient use of energy
  - Reduce energy consumption
  - Optimise building's performance
- Major factors to consider
  - Response to local climate (temp., humidity, solar)
  - Building envelope (skin) design
  - Building services systems
  - Human factors & building operation


External climate
Internal loads
Air-conditioning systems
Chiller plants

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

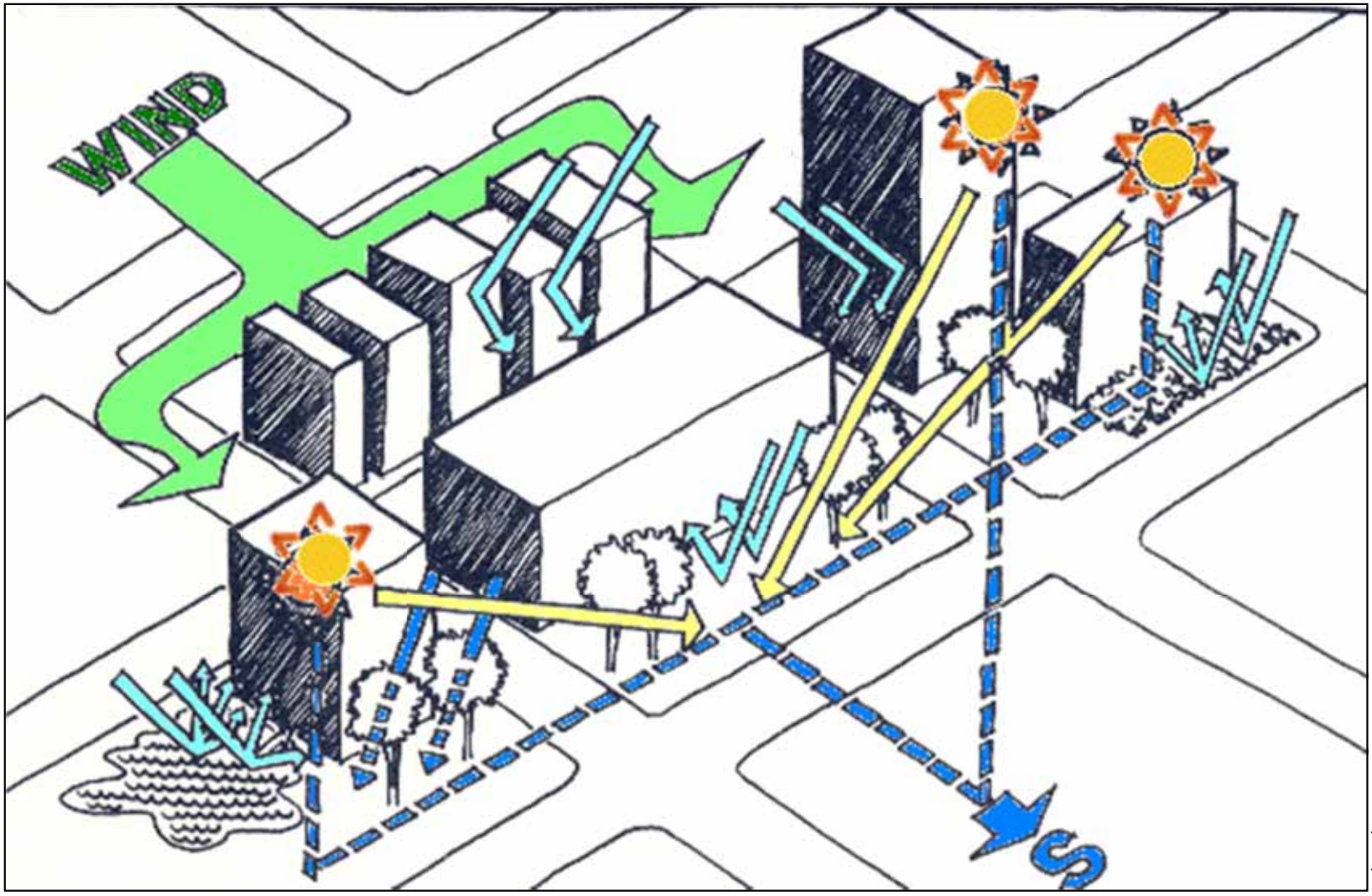


Major climatic elements of Hong Kong

Building designer is like a “Feng Shui” master.

風
Wind

光
Light

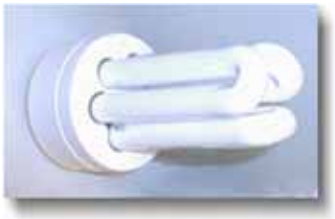


水
Water

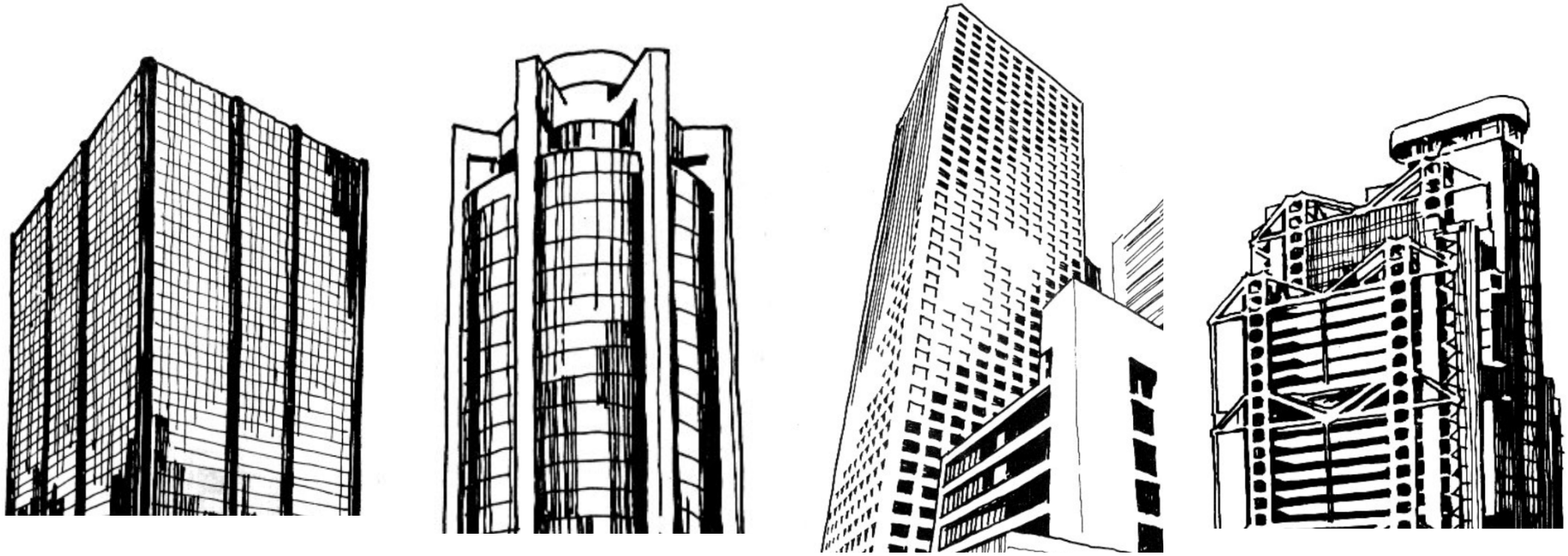
物
Matter

Major site factors

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)



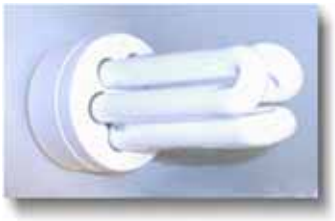
Building envelope designs of commercial buildings
in Hong Kong
(Which one is more energy efficient?)

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

Energy Efficiency

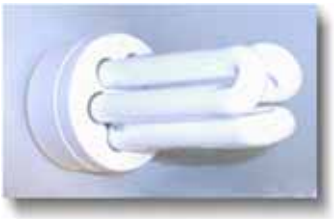


- Major factors determining envelope heat flow:
  - Temperature differential, ΔT
  - Area of exposed building surfaces, A
  - Heat transmission properties, like U-value
  - Thermal storage capacity

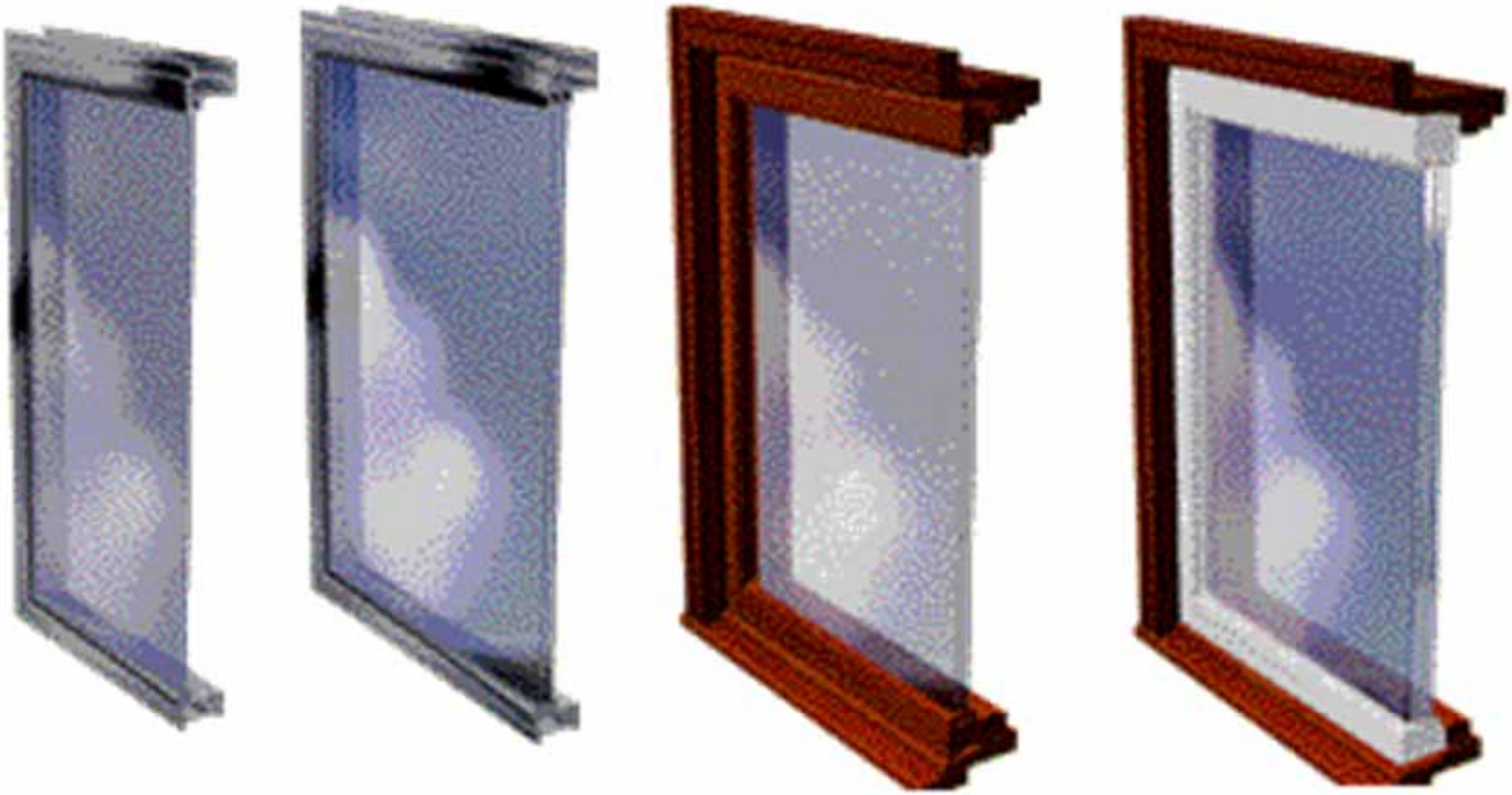
$$Q = U\,A\,\Delta T$$

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

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

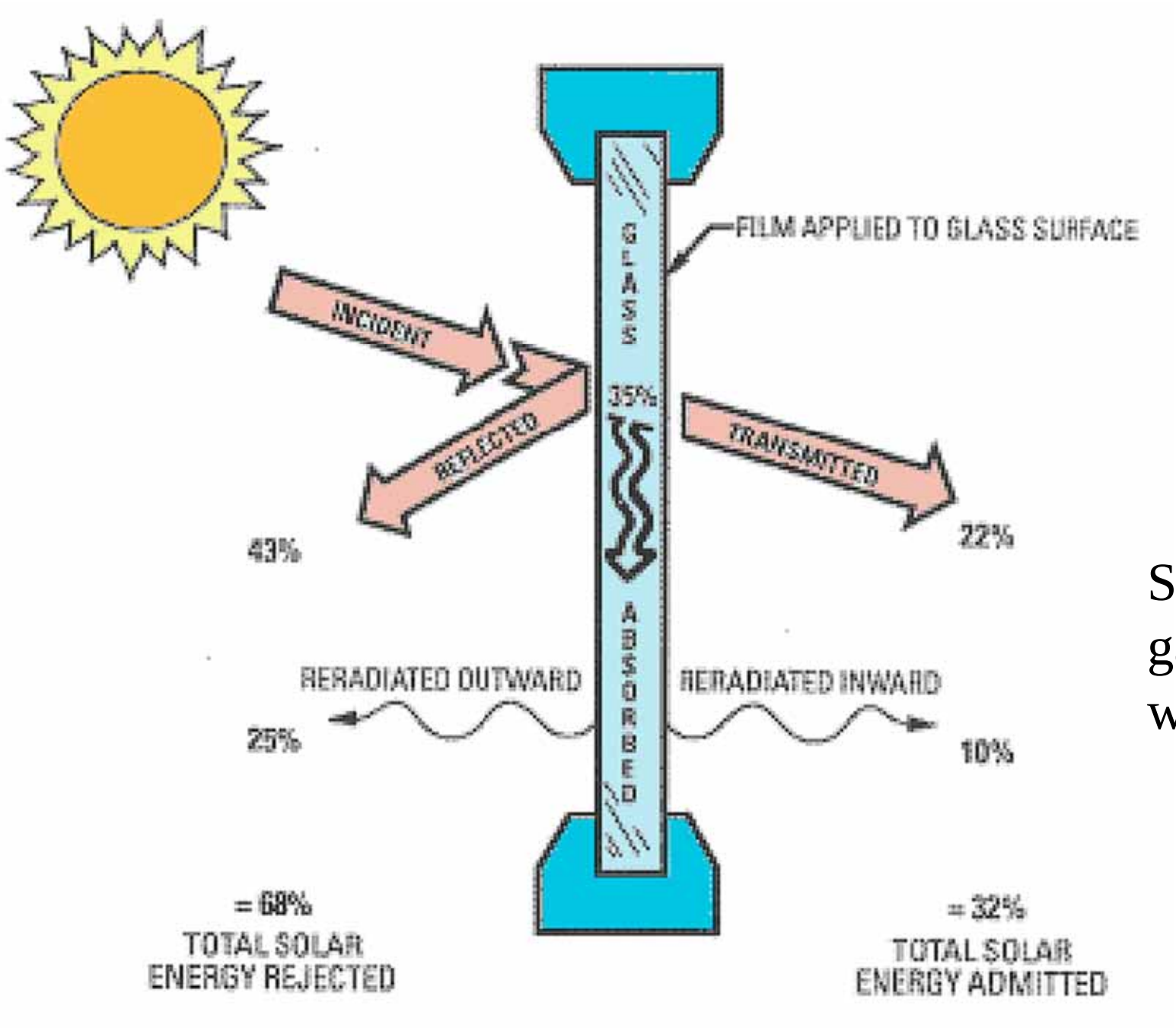


Single Glazed, Clear

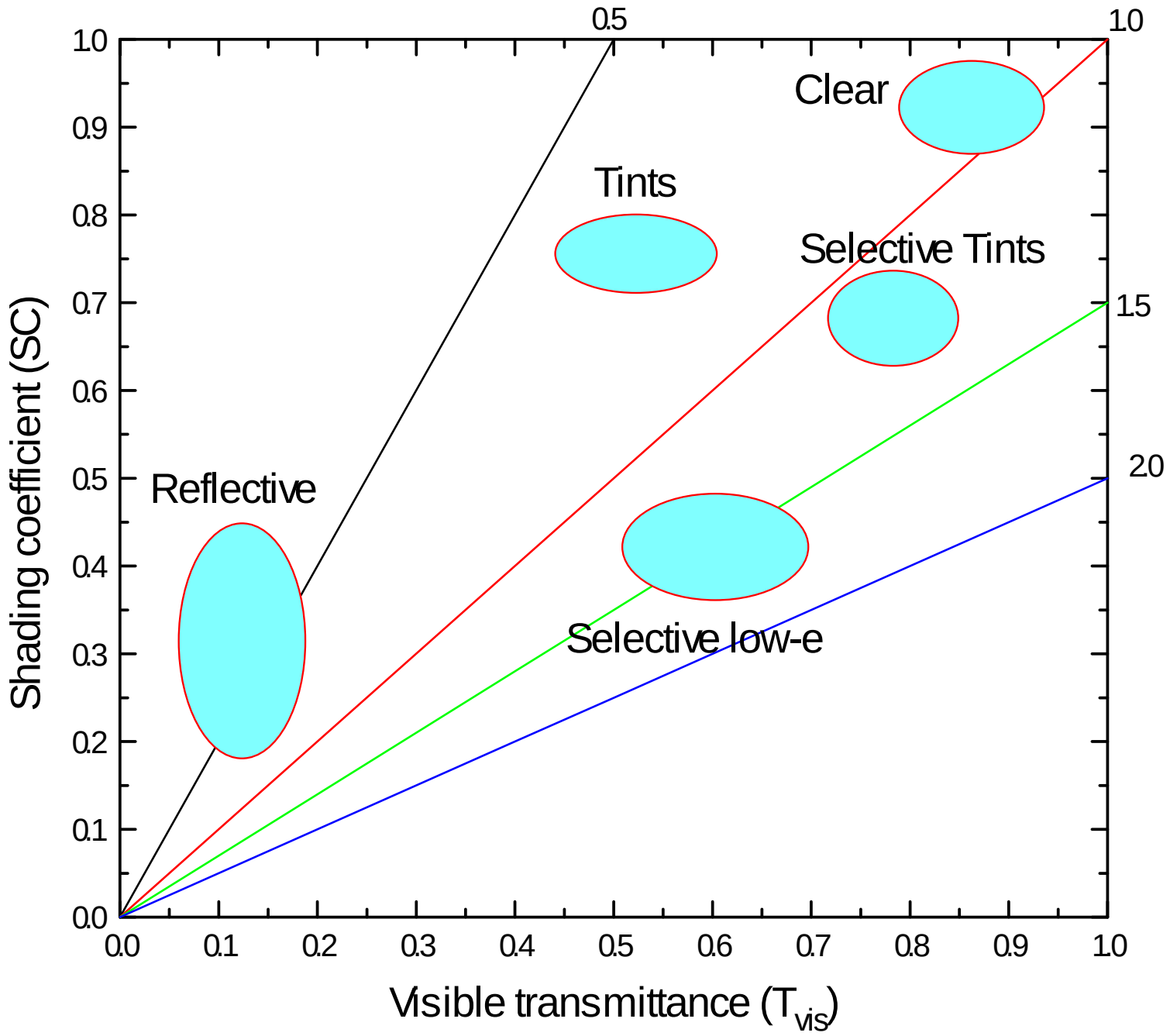
Double Glazed, Clear

Double Glazed, low-e

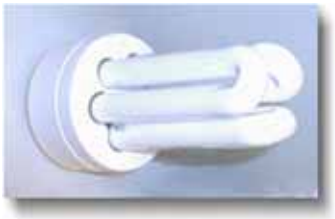
Triple Glazed, low-e



Solar heat gain through window glass

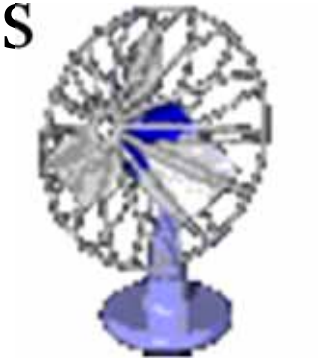
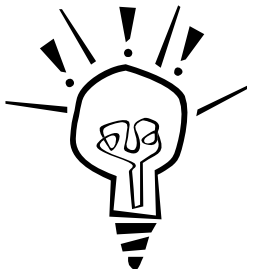
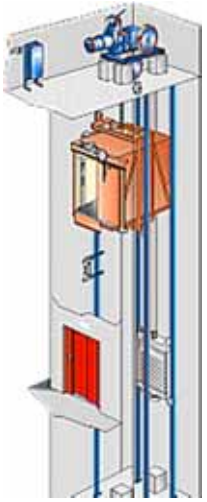
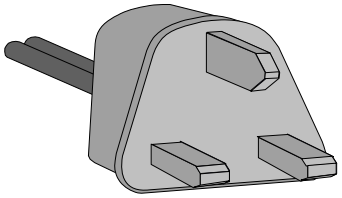


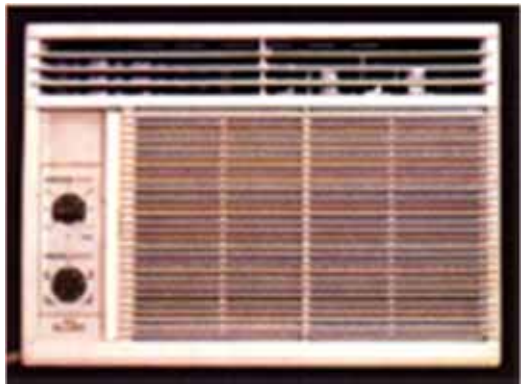
Properties of window glasses



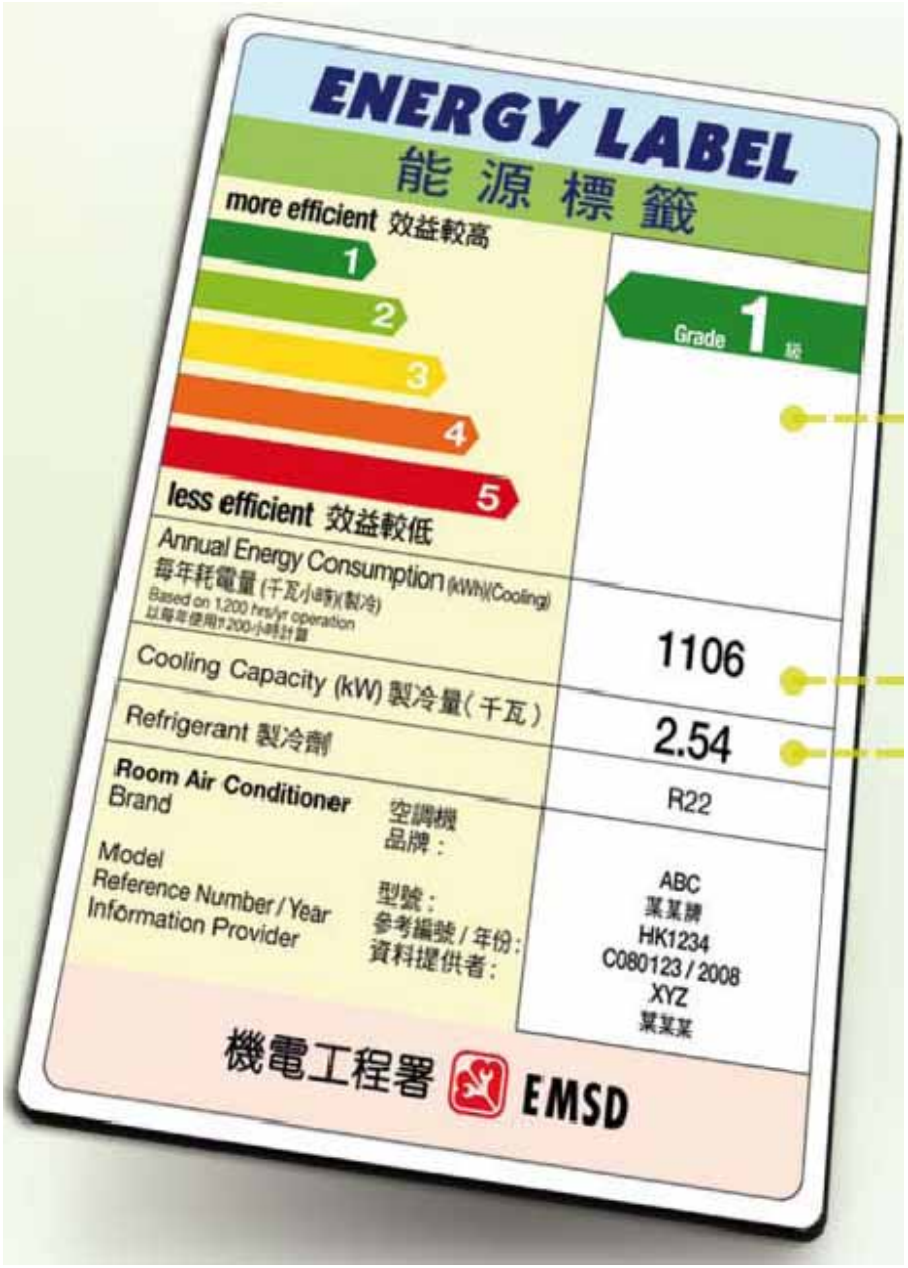
Energy Efficiency

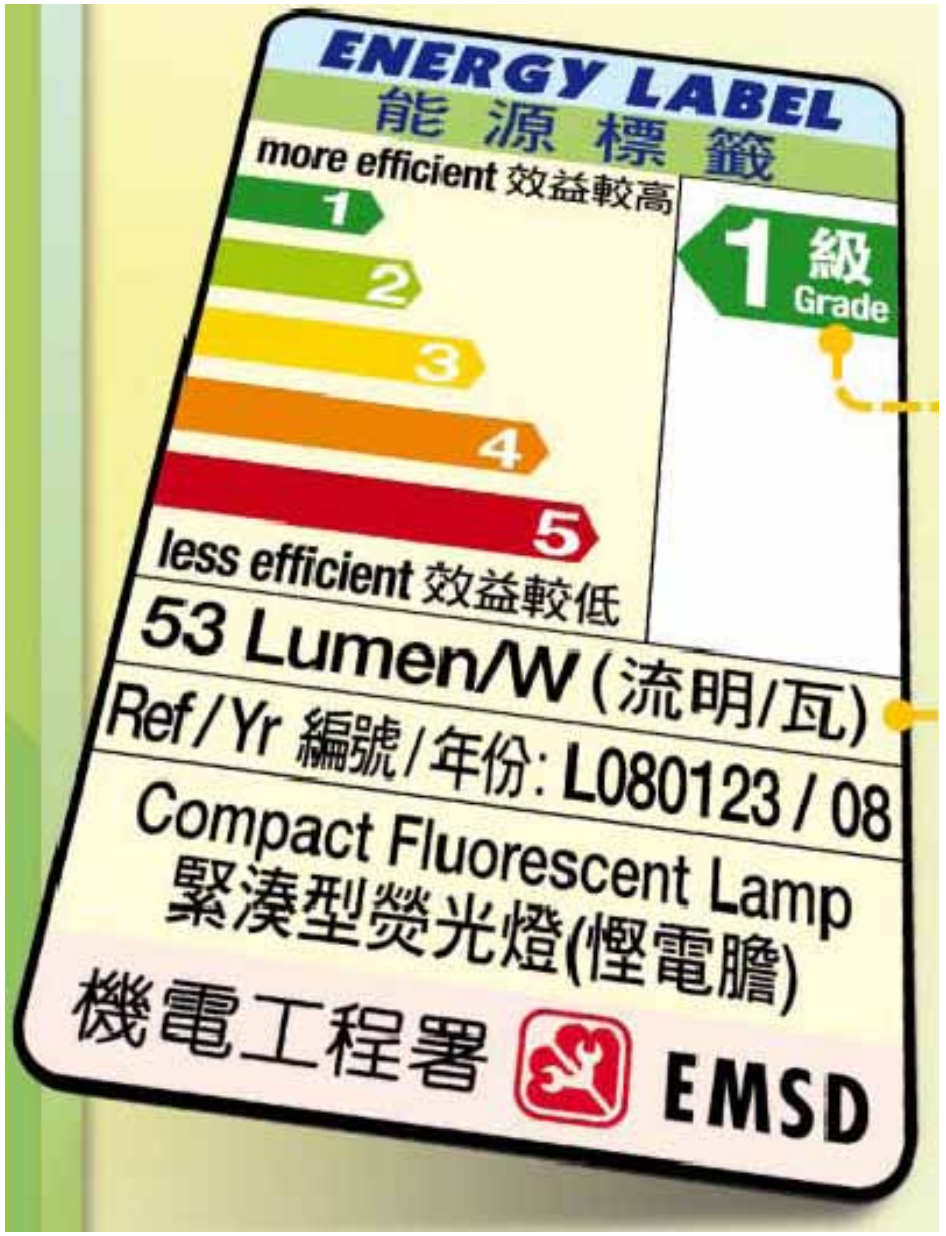
- Building services systems
  - Air-conditioning
  - Lighting
  - Electrical services
  - Lifts & escalators
  - Plumbing & drainage
  - Town gas supply
  - Building management

Energy label for appliances and equipment





Mandatory appliance energy labels in Hong Kong

(Source: EMSD)

能源效益標籤計劃
Energy Efficiency Labelling Scheme

1級能源標籤的電器相比其他級別的同類電器大約可節省電力的百分比如下:
"Grade 1" energy labelled electrical appliances may approximately save the following percentages of electricity as compared to those with a lower grading:

節省電力 Electricity Saving

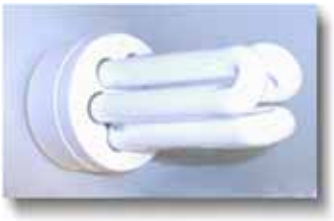
能源標籤的級別 Grading Level of Energy Label	1級 比 3級 Grade 1 vs. 3	1級 比 5級 Grade 1 vs. 5
冷氣機 Room Cooler	15%	30%
雪櫃 Refrigerator	35%	45%
洗衣機 Washing Machine	25%	40%
儲水式電熱水爐 (備用) Electric Storage Type Water Heater (standby)	25%	40%
電乾衣機 Electric Clothes Dryer	20%	40%

Please browse http://www.emsd.gov.hk/emsd/eng/pee/eels_reg.shtml to see the "Energy Label Registration Records".

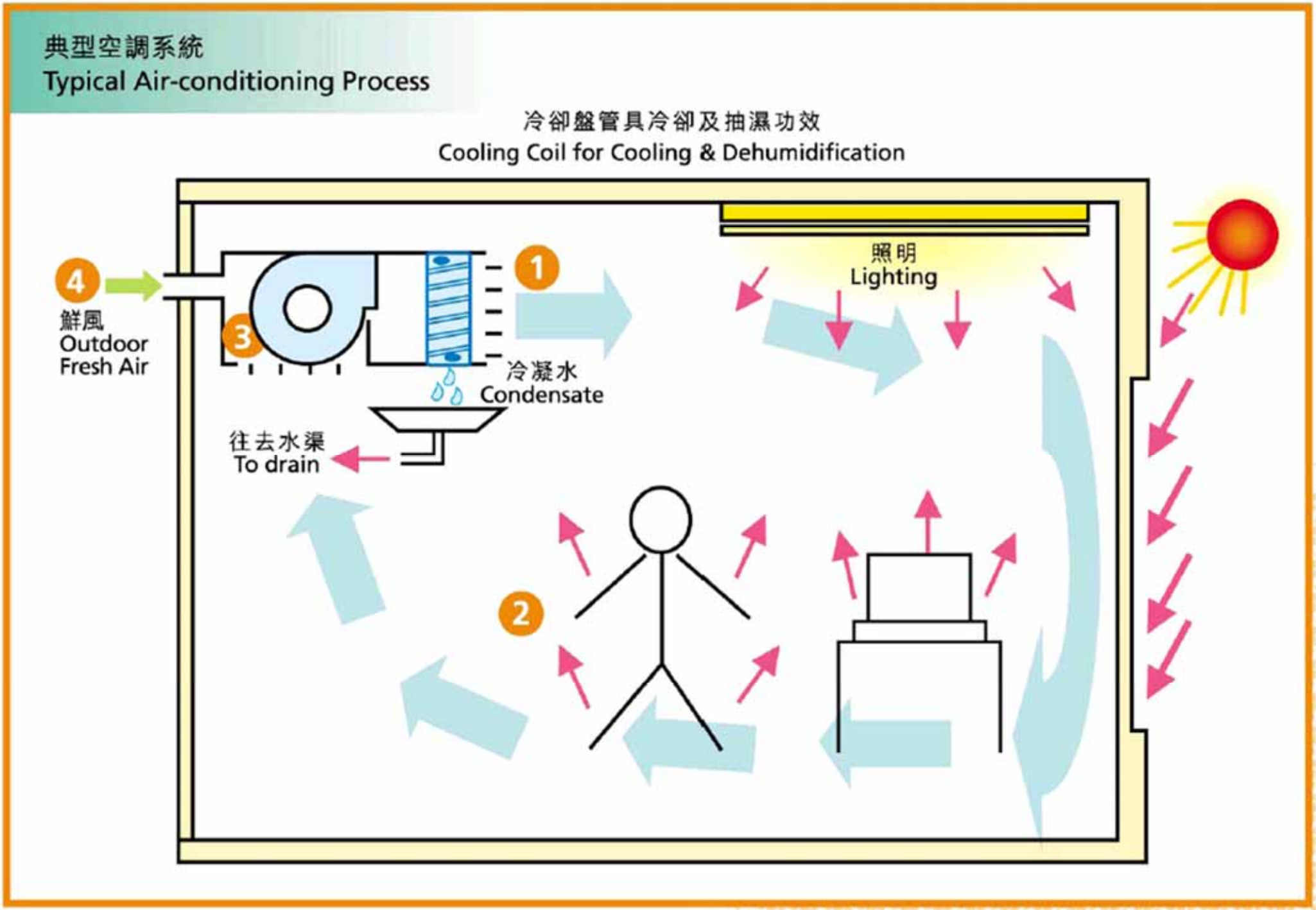
請在 http://www.emsd.gov.hk/emsd/chi/pee/eels_reg.shtml 查閱"能源效益標籤計劃的登記名冊"。

(Source: www.emsd.gov.hk)

Energy Efficiency

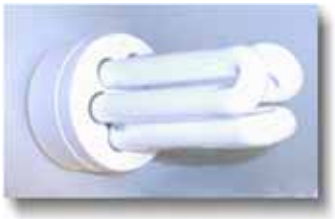


- Heating, ventilating & air-conditioning (HVAC) systems
  - Usually the most important energy users
  - Provide for occupant comfort, health and safety
  - HVAC design is affected by architectural features and occupant needs
- In Hong Kong, heating load is small and main focus is on air-conditioning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

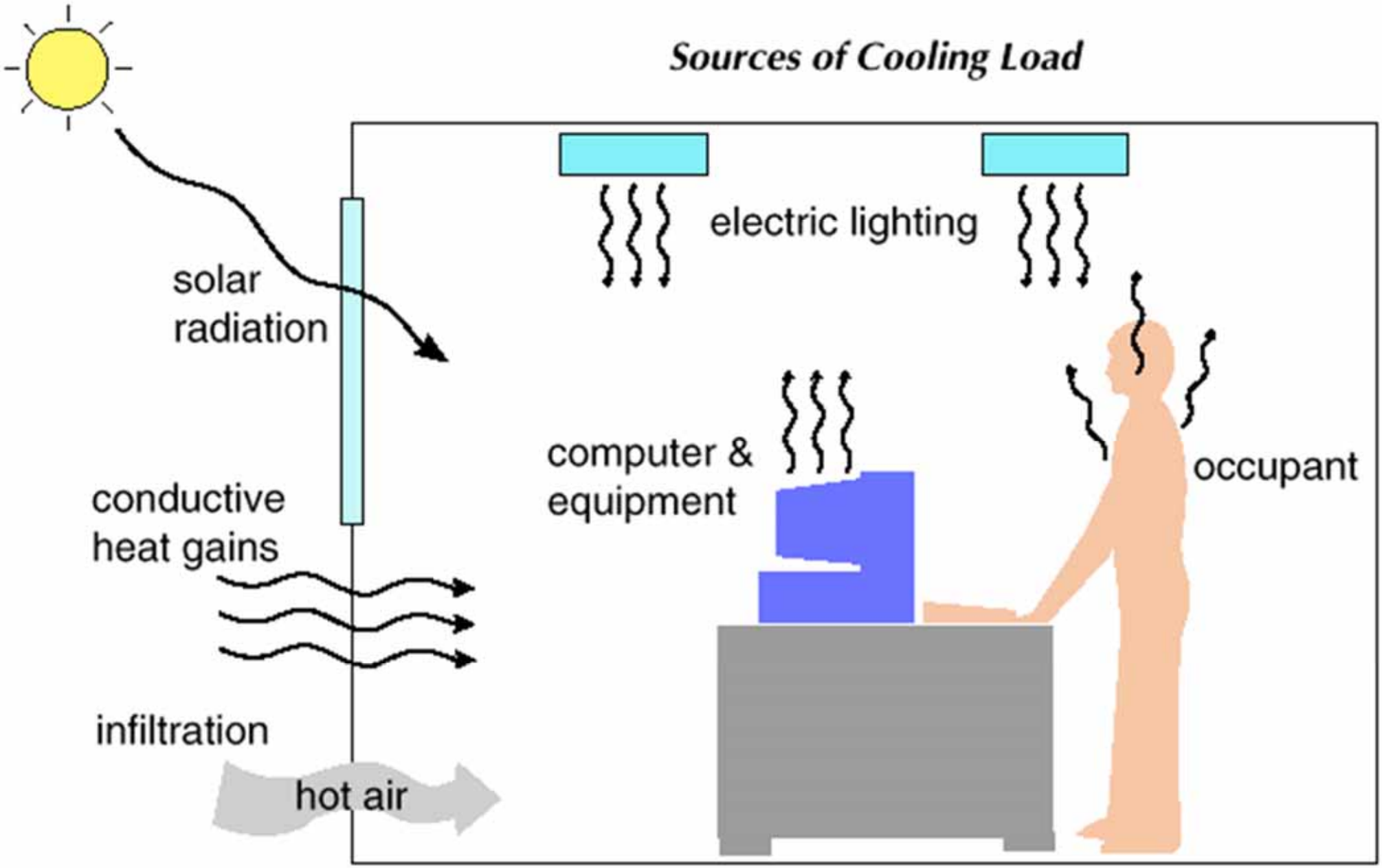


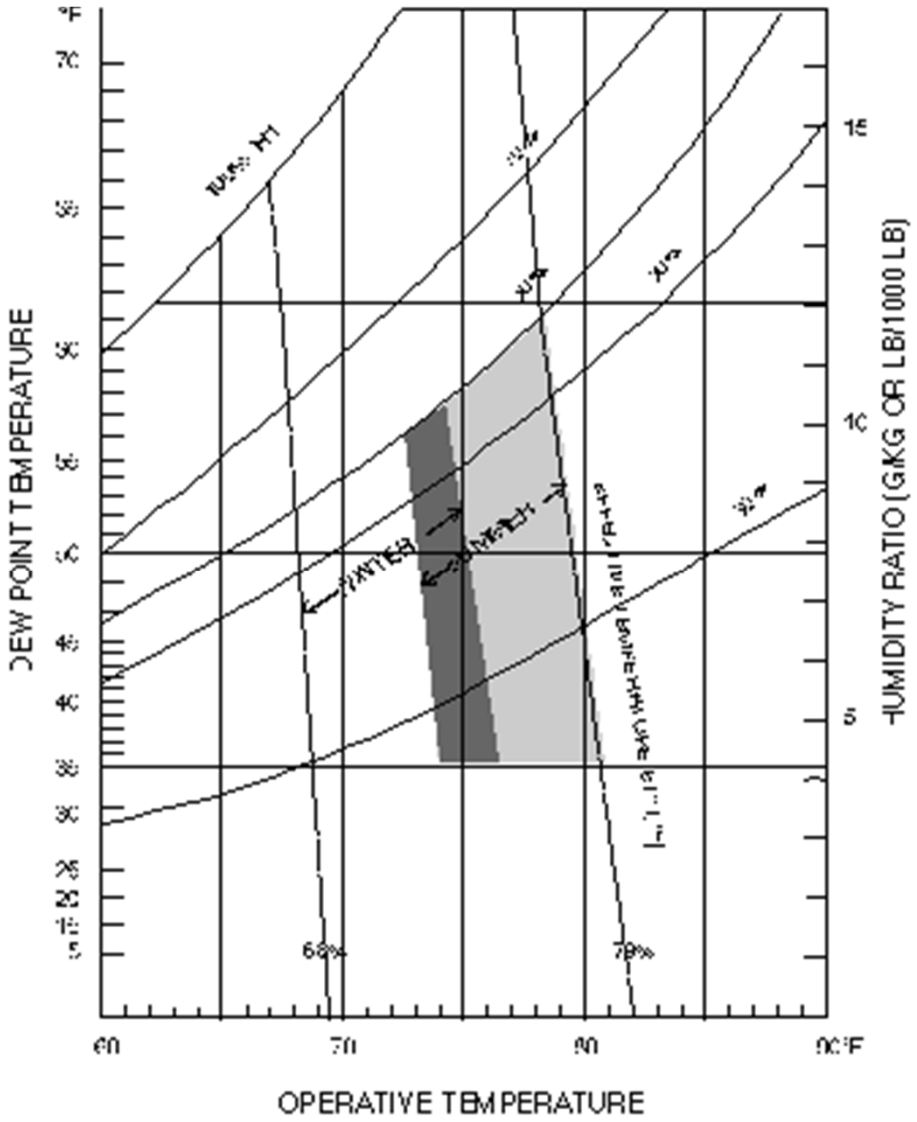
(Source: EnergyWitts newsletter, EMSD)

Energy Efficiency



- Strategies for energy efficiency of HVAC
  - 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

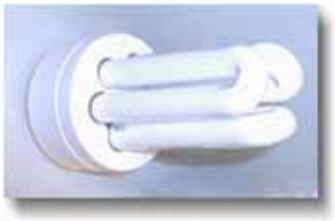

Sources of Cooling Load
electric lighting
solar
radiation
computer &
equipment
occupant
conductive
heat gains
infiltration
hot air



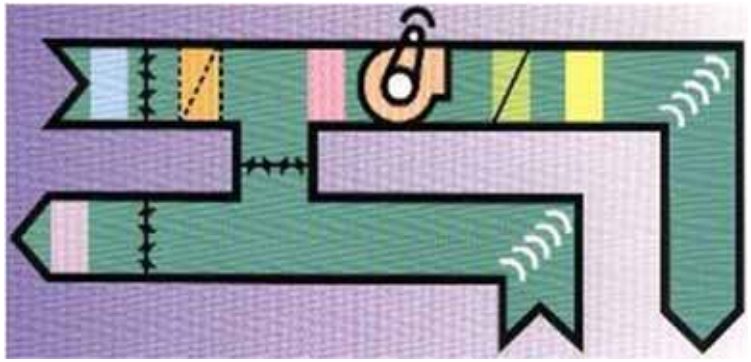
ASHRAE comfort envelope

Thermal comfort & design conditions

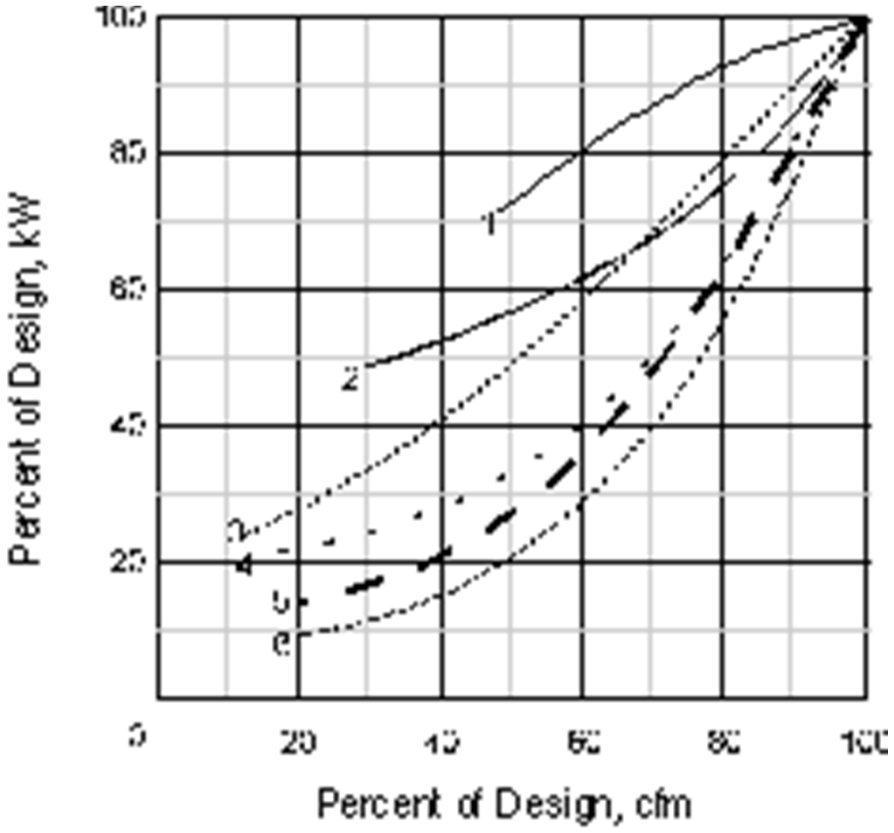
Energy Efficiency



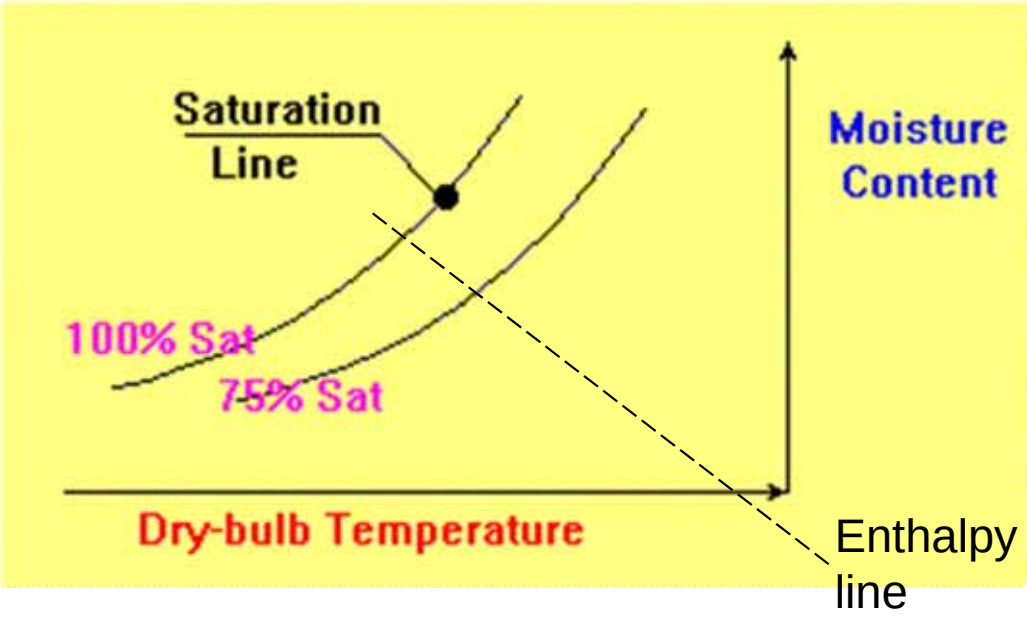
- HVAC system design and operation
  - System characteristics
    - Type of systems
    - Energy efficiency ratios
    - Coefficient of performance
    - System operation & control
  - Equipment and plant operation
    - Especially during partload conditions
    - Opportunity for heat recovery
    - District cooling or energy system

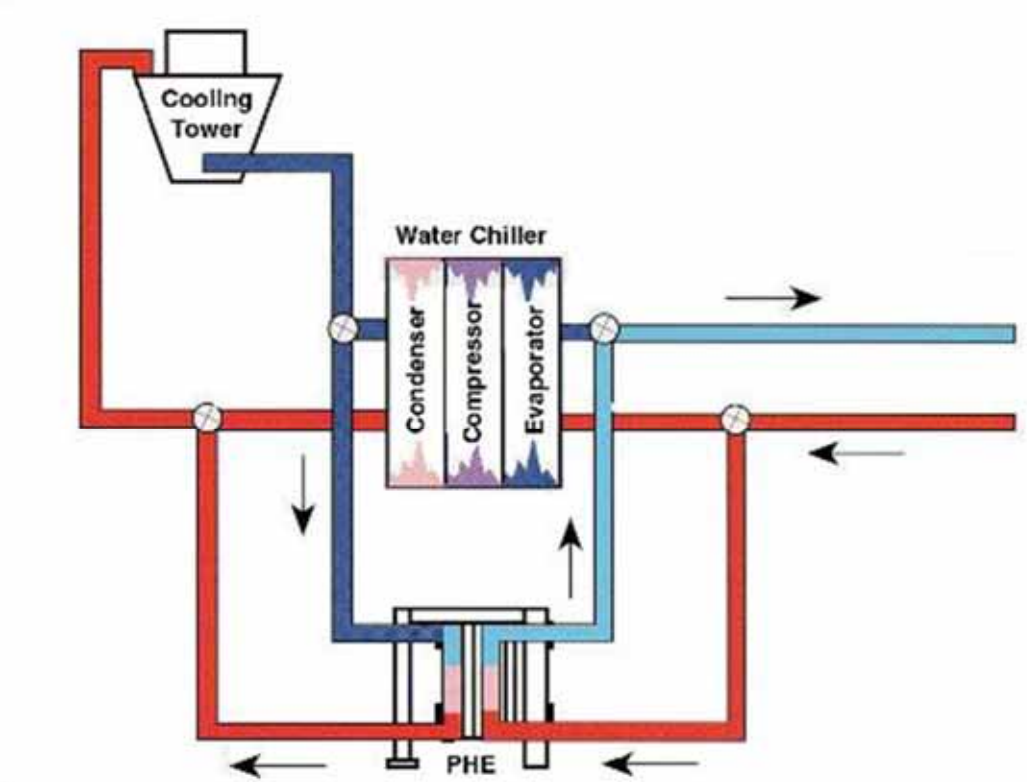


HVAC system and plant



Partload curves for fans

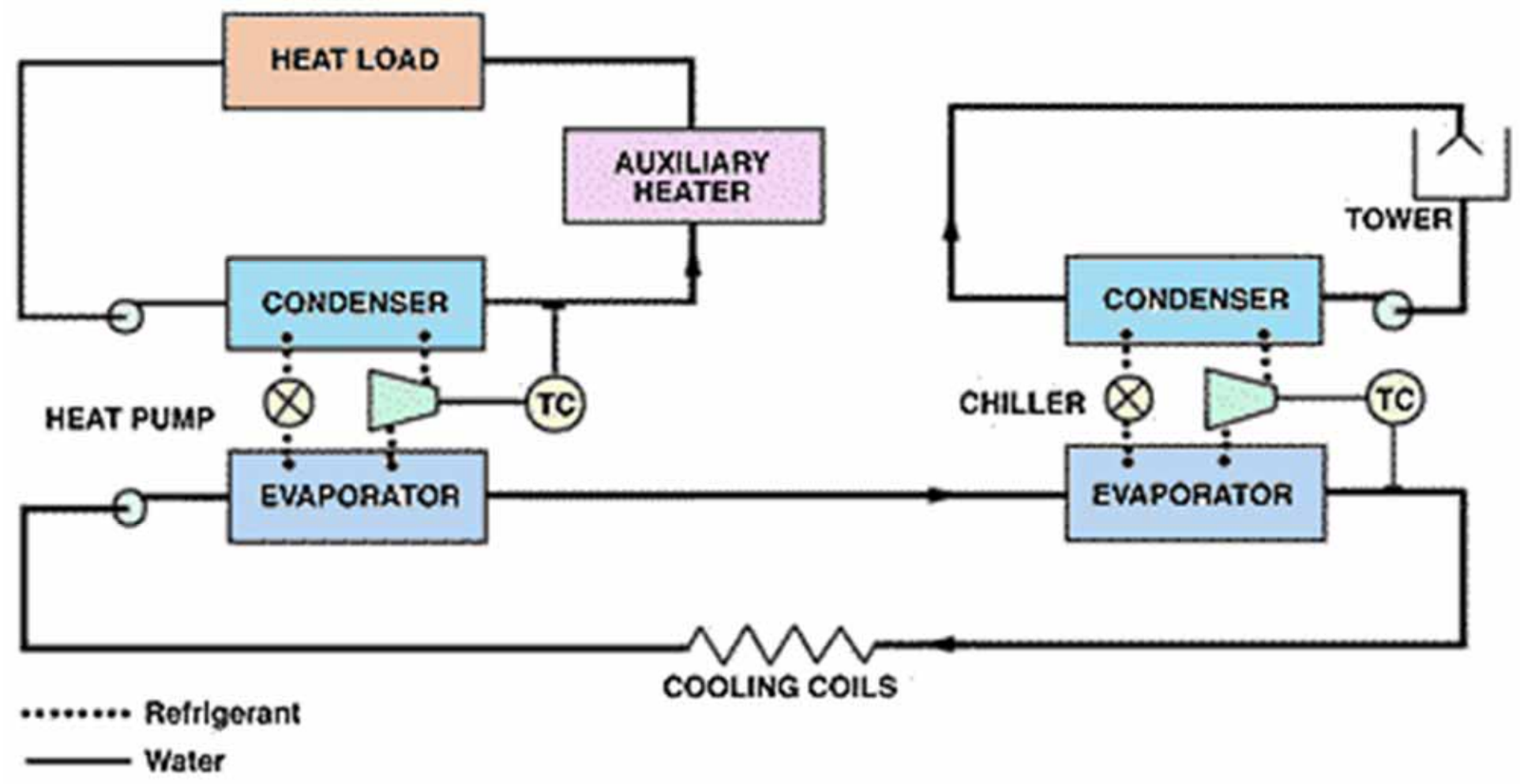




(a) Air-side economiser cycle
- intake more outdoor air when its enthalpy (energy content) is lower than indoor air

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

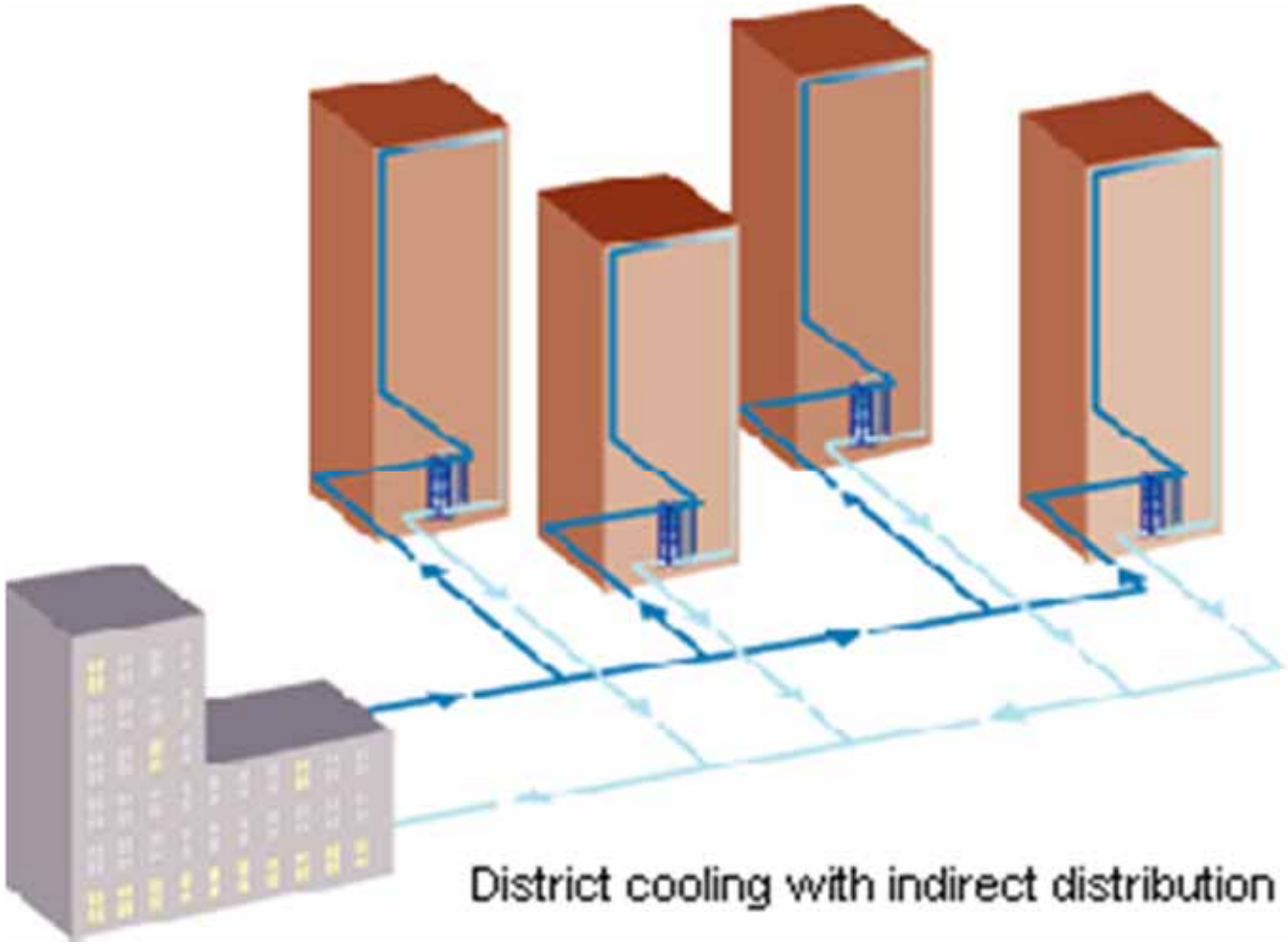
'Free' cooling methods in HVAC system



Waste heat recovery - heat pump + chiller

Individual buildings

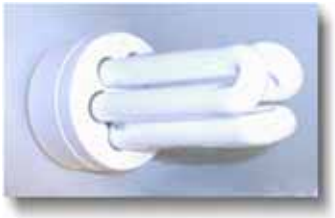
Centralised refrigeration plant



District cooling system

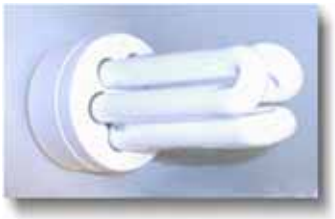
(Question: Do you know what are the advantages?)

Energy Efficiency

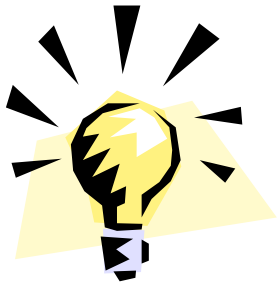


- HVAC energy efficiency can be improved by:
  - Effective zoning and space design
  - Correct sizing and selection of equipment
  - Proper operation and maintenance
  - Better control and monitoring
  - Energy awareness of occupants/building managers
- Good house-keeping and education
  - A very important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

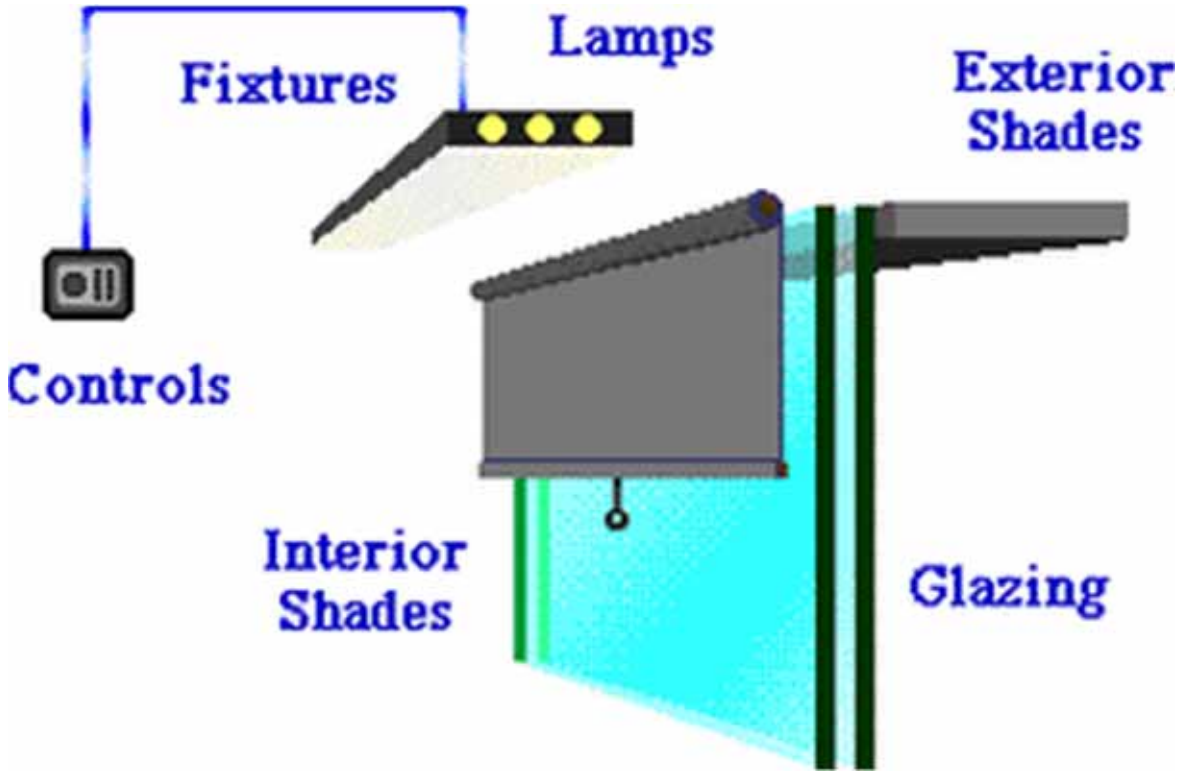
Energy Efficiency



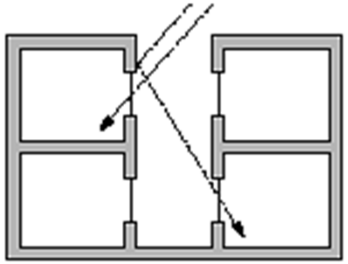
- Lighting systems
  - Have good potential for conserving electricity
  - Also contribute to HVAC load reduction
- General principles of energy efficient lighting
  - Illumination is not excessive
  - Switching arrangements are designed
  - Provide illumination in an efficient manner



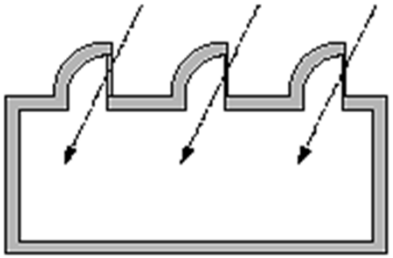
Energy efficient fittings (e.g. compact fluorescent lamps)



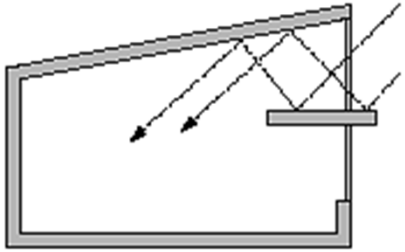
Lighting controls and interactions with windows



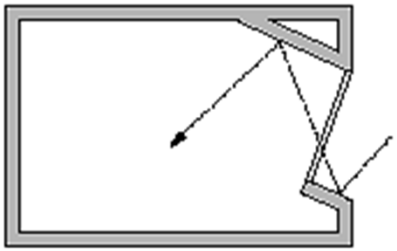
Light well



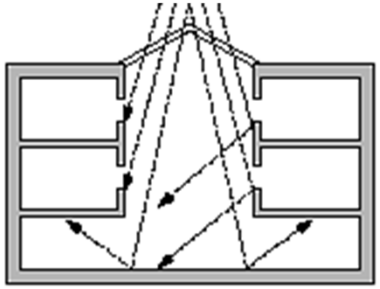
Roof monitor



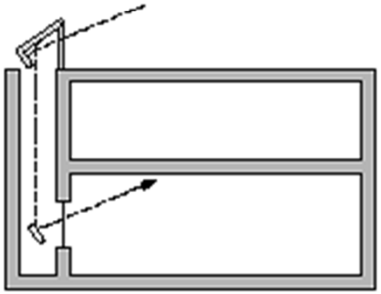
Light shelf



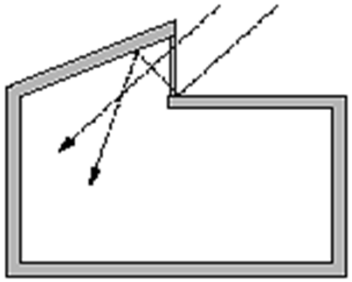
External reflectors



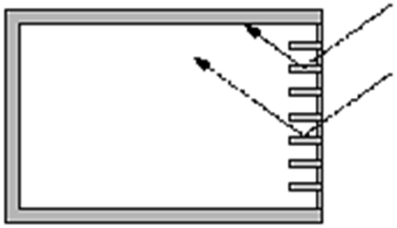
Atrium



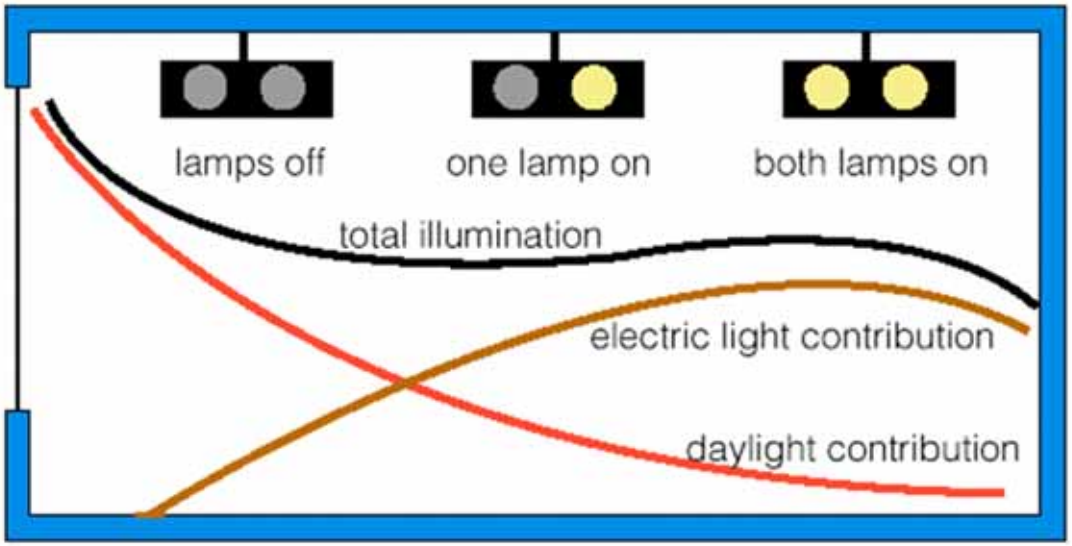
Light duct



Clerestory

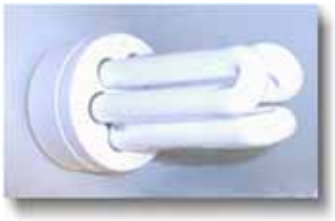


Reflective blinds



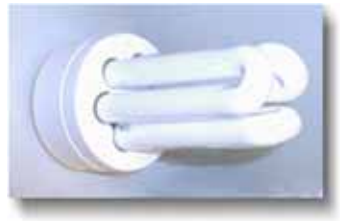
Daylighting design and control

Energy Efficiency



- 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

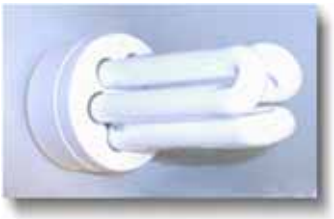
Energy Efficiency



- 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 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

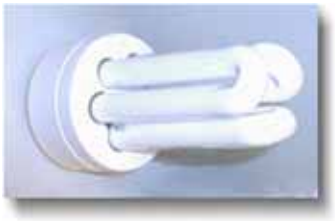
Efficient systems

Good house-keeping

User education & awareness

Efficient operation

Energy Efficiency

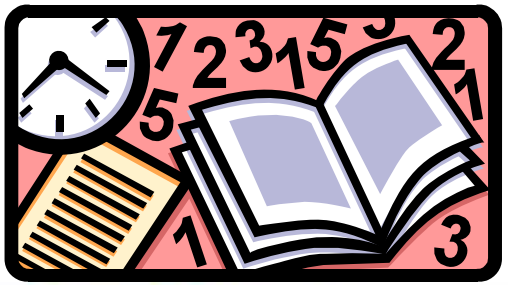


- Checklist for Energy Efficiency
  - http://www.hku.hk/bse/check.pdf
    - Architecture
    - HVAC
    - Electrical services
    - Lighting installations
    - Lifts and escalators
    - Plumbing and drainage
    - Building management

Energy saving in lift system

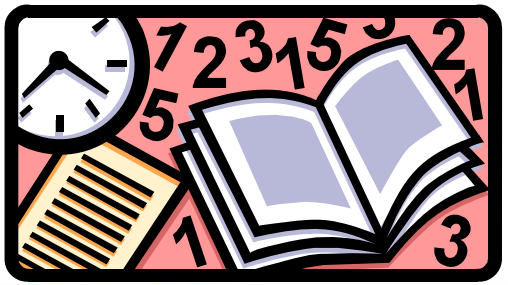
http://www.hku.hk/bse/save.exe

Further Reading



- Public Education: Education Kit [EMSD]
  - www.emsd.gov.hk/emsd/eng/about/pe_ek.shtml
  - Energy Efficiency
  - Energy Efficient Building
- EMSD, 2005. *Energy Efficiency and Conservation for Buildings*, Energy Efficiency Office, Electrical and Mechanical Services Department, Hong Kong.
  - http://www.emsd.gov.hk/emsd/e_download/pee/emsd100dpi.pdf

Useful References



- Beggs, C., 2002. *Energy: Management, Supply and Conservation*, Butterworth-Heinemann, Oxford. [696 B41]
- CIBSE, 2004. *Energy Efficiency in Buildings: CIBSE Guide F*, 2nd edition, Chartered Institution of Building Services Engineers, London. [LB 696 E56 C4g]

- Website: EnergyLand
  - http://www.energyland.emsd.gov.hk/
  - Interesting website on related info and issues